MEDITERRANEAN ACTION PLAN (MAP)
REGIONAL MARINE POLLUTION EMERGENCY RESPONSE CENTRE FOR THE MEDITERRANEAN SEA (REMPEC)

Sixteenth Meeting of the Focal Points of the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC)

REMPEC/WG.61/INF.9
24 January 2025
Original: English only

Sliema, Malta, 13-15 May 2025

Agenda Item 7: Air Pollution from ships

Study on the Readiness of the Mediterranean Region to Respond to Marine Pollution Incidents Involving Low-Sulphur Fuels and Alternative Fuels

REMPEC
Malta, 2025

Note by the Secretariat

This document presents the Study on the Readiness of the Mediterranean Region to Respond to Marine Pollution Incidents Involving Low-Sulphur Fuels and Alternative Fuels.

Background

1 The entry into effective implementation of the Mediterranean Sea Emission Control Area for Sulphur Oxides and Particulate Matter (Med SOx ECA), on 1 May 2025, will bring along a transformative regulatory milestone. This regulation limits Sulphur content in marine fuels to 0.10%, aligning with global efforts to reduce emissions. While this transition supports environmental sustainability, it also brings challenges due to the adoption of alternative fuels like LNG, ammonia, hydrogen, and methanol. These fuels introduce unique environmental and safety risks that current frameworks, designed for conventional oil spills, are ill-equipped to handle.

2 In this context, the Secretariat commissioned the IMO World Maritime University (WMU) and the Centre of Documentation, Research and Experimentation on Accidental Water Pollution (CEDRE), to prepare a Study on the Readiness of the Mediterranean Region to Respond to Marine Pollution Incidents Involving Low-Sulphur Fuels and Alternative Fuels, hereinafter referred to as the Study, in order to assesses the region's readiness for these changes, identifying critical gaps and proposing actionable recommendations. The findings aim to establish a comprehensive framework for addressing pollution risks associated with low Sulphur and alternative fuels, ensuring harmonized, effective, and sustainable responses. legal challenges to Mediterranean coastal States.

3 The Study was carried out, pursuant to the Programme of Work and Budget for 2024-2025 of the Mediterranean Action Plan (MAP) of the United Nations Environment Programme (UNEP), adopted by the Twenty-third Ordinary Meeting of the Contracting Parties to the Barcelona Convention and its Protocols (Portorož, Slovenia, 5-8 December 2023).

4 This activity was financed by the Integrated Technical Cooperation Programme (ITCP) of the International Maritime Organization (IMO) and the voluntary contribution from the Italian Ministry for Environment and Energy Security.

5 The Study is presented in the **Appendix** to the present document.

Action requested by the Meeting

6 **The Meeting is invited to take note** of the information provided in the present document.

******

Appendix

Study on the Readiness of the Mediterranean Region to Respond to Marine Pollution Incidents Involving Low-Sulphur Fuels and Alternative Fuels

STUDY ON THE READINESS OF THE MEDITERRANEAN REGION TO RESPOND TO MARINE POLLUTION INCIDENTS INVOLVING LOW-SULPHUR FUELS AND ALTERNATIVE FUELS

13 DECEMBER 2024

This activity is financed by the voluntary contribution from the IMO Integrated Technical Cooperation Programme (ITCP) and the Italian Ministry for Environment and Energy Security and is implemented by the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC), in cooperation with the International Maritime Organization (IMO).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Full Form
ACPs	Area Contingency Plans
AMSA	Australian Maritime Safety Authority
CEDRE	Centre of Documentation, Research and Experimentation on Accidental Water Pollution
CLC 1992	The International Convention on Civil Liability for Oil Pollution Damage, 1992
CP	Contracting Party
DME	Dimethyl Ether
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EMSA	European Maritime Safety Agency
EU	European Union
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GHG	Greenhouse Gas
HELCOM	Helsinki Commission – The Baltic Marine Environment Protection Commission
HFO	Heavy Fuel Oil
HNS	Hazardous and Noxious Substances
IGF Code	International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels
IMAROS	Improved Marine Oil Spill Response Through Technology
IMO	International Maritime Organization
IMSAS	IMO Member State Audit Scheme
ISM Code	International Safety Management Code
ISO	International Organization for Standardization
ITCP	IMO's Integrated Technical Cooperation Program
ITOPF	International Tanker Owners Pollution Federation
KPI	Key Performance Indicator
LLMC	Limitation of Liability for Maritime Claims
LNG	Liquefied Natural Gas
LSFO	Low Sulphur Fuel Oil
MAP	Mediterranean Action Plan
MARPOL	The International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978
MCA	The UK's Maritime and Coastguard Agency
MDO	Marine Diesel Oil
MEDGIS-MAR	Mediterranean Integrated Geographical Information System on Marine Pollution Risk Assessment and Response
MEMAC	Marine Emergency Mutual Aid Centre
MEPC	Marine Environment Protection Committee
MERCU	Mediterranean Emergency Response Coordination Unit
MIDSIS-TROCS	Maritime Integrated Decision Support Information System on Transport of Chemical Substances
NCP	National Contingency Plan

NGO	Non-Governmental Organization
OPRC	Oil Pollution Preparedness, Response, and Cooperation
OPRC HNS	Oil Pollution Preparedness, Response, and Cooperation – Hazardous and Noxious Substances
OSR	Oil Spill Response
PPE	Personal Protective Equipment
R&D	Research and Development
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea
RETOS	Readiness Evaluation Tool for Oil Spills
RPT	Rapid Phase Transition
SAR	Search and Rescue
SDR	Special Drawing Rights
SERTC	The Security and Emergency Response Training Center
SMS	Safety Management System
SO	Strategic Objective
SOLAS	International Convention for the Safety of Life at Sea
TEN-T	Trans-European Transport Network
ULSFO	Ultra-Low Sulphur Fuel Oil
UN	United Nations
UNEP	United Nations Environment Programme
VLSFO	Very-Low Sulphur Fuel Oil
VOO	Mediterranean network for Vessels of Opportunity
VSR	Vessel Speed Reduction
West MOPoCo	Western Mediterranean Region Marine Oil and HNS Pollution Cooperation Project
WMU	World Maritime University
WRC	Nairobi International Convention on the Removal of Wrecks

EXECUTIVE SUMMARY

The Mediterranean region, a critical global maritime corridor, faces a transformative regulatory milestone with the Med SOx Emission Control Area (ECA) taking effect in May 2025. This regulation limits Sulphur content in marine fuels to 0.10%, aligning with global efforts to reduce emissions. While this transition supports environmental sustainability, it also brings challenges due to the adoption of alternative fuels like LNG, ammonia, hydrogen, and methanol. These fuels introduce unique environmental and safety risks that current frameworks, designed for conventional oil spills, are ill-equipped to handle.

This Study, commissioned by REMPEC, assesses the region's readiness for these changes, identifying critical gaps and proposing actionable recommendations. The findings aim to establish a comprehensive framework for addressing pollution risks associated with low Sulphur and alternative fuels, ensuring harmonized, effective, and sustainable responses.

Key findings

Regulatory gaps: While international instruments such as MARPOL, SOLAS, the IGF Code, the ISM Code and the OPRC Convention provide the essential foundational framework, several Contracting Parties (CPs) to the Barcelona Convention are yet to ratify key instruments critical for pollution prevention, preparedness and response, most notably MARPOL Annex VI. This lack of ratification undermines regional efforts to address air pollution and Sulphur emissions effectively. Additionally, other critical instruments such as the OPRC-HNS Protocol, the LLMC Protocol, and the Fund 2003 Protocol remain unratified by several CPs, further weakening the regulatory landscape. National regulations also frequently lack tailored provisions to address the unique risks posed by low Sulphur and alternative fuels. The absence of standardized enforcement mechanisms across the region exacerbates these challenges, significantly limiting the readiness and capacity to manage pollution incidents comprehensively.

Preparedness challenges: This Study, based on the review of the assessments of the level of preparedness to Oil Spill Response in 18 Contracting Parties to the Barcelona Convention (CPs) (2019–2023) and insights gathered through a survey questionnaire administrated to relevant stakeholders in the CPs through REMPEC, highlights several gaps in the preparedness of CPs to respond to oil spill incidents. Outdated or incomplete contingency plans, with limited provisions for addressing risks posed by low Sulphur and alternative fuels, remains a critical concern. The shortage of specialized equipment and inadequately trained personnel further compounds the challenges, particularly in responding to alternative fuel spills. Furthermore, challenges in cross-border coordination frameworks weaken regional collaboration, potentially resulting in several CPs dependence on external assistance during large-scale pollution incidents.

Fuel-specific risks: Low Sulphur fuels, while compliant with emissions regulations, pose challenges due to their persistence and high viscosity, complicating recovery and cleanup efforts. Alternative fuels each present distinct risks that demand specialized responses: LNG, with its explosiveness upon evaporation, requires cryogenic handling protocols. Ammonia, highly toxic and corrosive, necessitates advanced containment systems to protect both the environment and human health. Hydrogen’s extreme flammability and low ignition energy call for robust monitoring and safety measures, while methanol, though biodegradable, presents significant fire hazards due to its low flash point and invisible flames.

Key recommendations

This Study proposes a set of 72 implementation actions organized under 31 recommendations to achieve four Strategic Objectives (SOs), addressing policy and regulatory gaps (SO1), enhancing capacity building (SO2), strengthening response mechanisms (SO3), and promoting stakeholder engagement and collaboration (SO4).

Policy and regulatory improvements (SO1): To mitigate risks associated with low Sulphur and alternative fuels, CPs should update national frameworks to align with IMO instruments, particularly MARPOL Annex VI and OPRC-HNS Protocol. Tailored regional guidelines are essential to address the specific challenges of alternative fuels within the Mediterranean context. Enforcement mechanisms must be strengthened through satellite monitoring and tiered penalties considered for regionally harmonized implementation, while expanded liability frameworks should incorporate provisions for alternative fuels.

Capacity building and training (SO2): Specialized training programs are critical to equip responders with the knowledge of alternative fuel behaviors and associated risks. An added emphasis may be desirable in the specialized training programs on the safety risks associated with response to spill involving alternative fuels. These programs should include novel methods such as simulation-based drills leveraging virtual reality (VR) to prepare responders for complex scenarios. Furthermore, REMPEC and CPs should establish certification standards to ensure consistent competency across the region, complemented by knowledge-sharing platforms for disseminating best practices and lessons learned.

Enhancing response mechanisms (SO3): Fuel-specific response protocols should be developed to guide response strategies, including containment, recovery, and mitigation efforts effectively. Investments in specialized equipment, such as cryogenic booms and new generation bioremediations agents, are essential, alongside the establishment of strategically located stockpiles in high-risk areas. Such rapid response hubs should be prioritized near ecologically sensitive zones so as to minimize environmental damage during incidents. Further, real-time monitoring technologies, such as satellites and drones, and regionally coordinated aircraft operations, can significantly improve detection and response times.

Strengthening stakeholder engagement and collaboration (SO4): An expanded regional stakeholder forum, led by REMPEC, is essential to align strategies and pool resources for enhancing coordinated responses. Public-private partnerships can play a pivotal role in funding innovations and enhancing response capabilities, while involving local communities in preparedness campaigns and drills fosters grassroots resilience. Collaboration with scientific institutions is essential to advance research on alternative fuel behaviors and refine response strategies, ensuring a scientifically informed and unified approach to spill management.

These recommendations collectively aim to strengthen the individual CPs and the entire Mediterranean region's readiness for low Sulphur and alternative fuel-related incidents.

Strategic roadmap

To ensure effective operational response readiness for the CPs and the entire Mediterranean region’s transition to low Sulphur and alternative fuel future, this Study proposes a phased strategic roadmap, adopting a philosophy to ***build, strengthen and sustain*** via short (0-2 years), mid (2-5 years) and longer term (over 5 years) implementation. The roadmap addresses immediate regulatory gaps, builds capacity, and establishes a long-term framework for sustainability and resilience, leveraging innovation and regional collaboration.

Building the foundation: In the initial short-term phase, the focus of REMPEC and the CPs should be on addressing key policy and regulatory gaps, initiating foundational training programs, and establishing basic response readiness. Key actions include updating national frameworks to align with IMO instruments and initiating stakeholder engagement. Foundational pollution response hubs should be established in high-risk areas and accompanied by simulation-based drills and communication exercises to enhance responder capacity and raise awareness of alternative fuel risks.

Strengthening preparedness: The mid-term phase emphasizes scaling up efforts through advanced regional collaboration and infrastructure expansion. This includes the development of regional certification standards, conducting joint cross-border exercises, and deploying real-time monitoring technologies like drones and satellites. Specialized response hubs will be enhanced with cutting-edge equipment, ensuring readiness for complex spill scenarios. Collaborative research initiatives will promote innovation and sharing of knowledge.

Sustaining full operational readiness: In the final long-term phase, the roadmap aims to institutionalize best practices, integrate more advanced technologies and monitoring systems, and foster a culture of continuous improvement. Harmonized regional frameworks will ensure consistency, while permanent training centers will sustain high responder competence. Long-term multi-stakeholder partnerships and adaptive management strategies will serve to consolidate the region’s capacity to address future challenges, ensuring preparedness for emerging risks and protecting the regions unique marine environment.

Monitoring and evaluation

A robust monitoring and evaluation framework is critical to track progress, ensure accountability, and adapt strategies to new emerging challenges in managing spills of low Sulphur and alternative fuels. This framework should be integrated into each phase of the strategic roadmap to provide measurable outcomes, refine actions, and sustain readiness of the CPs and across the entire Mediterranean region.

Key Performance Indicators (KPIs) will ensure measurable success. Therefore, a set of specific KPIs are proposed in the study across focus areas such as regulatory frameworks, capacity building, infrastructure development, response mechanisms, and stakeholder collaboration. Annual reporting by CPs to REMPEC will provide for a comprehensive and updated regional overview. Periodic reviews and assessments will be required to evaluate the effectiveness of the action plan against established KPIs. A continuous feedback mechanism will ensure dynamic adjustments to strategies and protocols.

Funding mechanisms

The successful implementation of the Action Plan relies on diverse and sustainable funding mechanisms. National budgets of CPs are pivotal, enabling investments in training programs, infrastructure development, and the procurement of specialized equipment essential for effective spill response at the national level. Regional funds at the UNEP/MAP level will facilitate collaborative initiatives, including joint training exercises, resource sharing, and regional preparedness programs. Furthermore, international grants from potential lenders and technical assistance from organizations like IMO, UNEP, and the EU would provide critical support, enabling the adoption of advanced technologies and innovative response strategies. Not least, private-sector partnerships play an equally vital role, offering cost-sharing opportunities and advancing next-generation spill response tools, ensuring access to cutting-edge solutions and long-term financial sustainability.

Conclusion

The Mediterranean region stands at a pivotal juncture in addressing the dual challenges and opportunities posed by the transition to low Sulphur and alternative fuels. This Study underscores the need for a robust, harmonized, and adaptive framework for safeguarding the region's unique marine ecosystem and socio-economic interests. By systematically addressing regulatory gaps, enhancing capacity, strengthening response mechanisms, and fostering stakeholder collaboration, the proposed roadmap offers a clear path forward. Strategic investment in innovative solutions, capacity building, and coordinated regional efforts will be instrumental in achieving and sustaining operational readiness. Through collaborative action and the support of diverse funding mechanisms, REMPEC and the CPs can lead the way in setting a global benchmark for pollution response preparedness in a multi-fuel future, ensuring a sustainable, resilient and environmentally secure Mediterranean for generations to come.

1. INTRODUCTION

1.1. Background and rationale

The maritime industry, a vital driver of global trade and economic growth, faces growing pressure to mitigate its environmental footprint, particularly concerning air pollution. Among the most pressing environmental concerns is the emission of Sulphur Oxides (SOx) from ships, which are harmful to both the environment and human health[1]. Recognizing this, the International Maritime Organization (IMO) introduced amendments to MARPOL[2] Annex VI Prevention of Air Pollution from ships, which sets strict standards for the permissible Sulphur content in marine fuels to significantly curb SOx emissions[3].

The IMO's Marine Environment Protection Committee (MEPC 79) adopted amendments to MARPOL Annex VI in December 2022, establishing the Med SOX Emission Control Area (ECA) with an effective date of 1 May 2025. In alignment, the 22nd meeting of the Contracting Parties to the Barcelona Convention[4] urged Contracting Parties[5] to ratify MARPOL Annex VI by this date and requested the support of the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC) in facilitating implementation. Consequently, the Mediterranean region is preparing to enforce the Med SOX ECA, introducing a Sulphur cap of 0.10% in marine fuels, effective from May 2025. This designation is a key component of the "Mediterranean Strategy for the Prevention, Preparedness and Response to Marine Pollution from Ships 2022-2031" adopted in 2021, by the Contracting Parties to the Barcelona Convention. The implementation of the Med SOX ECA is expected to result in significant reductions in Sulphur dioxide (SO_2) emissions.[6] Studies show that the introduction of a 0.10% Sulphur cap in marine fuels can reduce SO_2 emissions by up to 77% compared to the 3.50% global Sulphur cap previously in place[7]. Additionally, this shift is anticipated to improve air quality, leading to public health benefits and reducing the risk of acid rain, which contributes to ocean acidification and damage to marine ecosystems[8]. The shift is essential to improve air quality and environmental sustainability in one of the busiest maritime regions globally[9]. However, while this transition to low-Sulphur fuel oils represents a positive shift toward cleaner shipping, it also brings forth significant challenges, particularly regarding the region's preparedness to manage marine pollution incidents involving low Sulphur and alternative fuels.

---

[1] IMO. (2019, December 20). IMO 2020 - cleaner shipping for cleaner air.

[2] International Convention on the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978

[3] REMPEC (2021). Mediterranean Strategy (2022-2031). https://Contracting.rempec.org/en/our-work/strategies-and-actions-plans/regional-strategy

[4] The Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean, originally the Convention for Protection of the Mediterranean Sea against Pollution, adopted in 1976, and often simply referred to as the Barcelona Convention

[5] The twenty-two Contracting Parties to the Barcelona Convention are: Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, the Syrian Arab Republic, Tunisia, Turkey, and the European Union.

6 For benefits of the Med SOx ECA see: https://Contracting.rempec.org/en/our-work/pollution-prevention/hop-topics/med-eca/med-eca

[7] IMO (2019). IMO 2020-cleaned shipping for cleaner air. https://Contracting.imo.org/en/MediaCentre/PressBriefings/pages/34-IMO-2020-Sulphur-limit-.aspx

[8] European Environment Agency (EEA). (2020). Air Quality in Europe – 2020 Report. https://Contracting.eea.europa.eu/publications/air-quality-in-europe-2020-report

[9] 25% of global maritime traffic and 30% of the world's oil traffic are concentrated in the Mediterranean. Source: UNEP (2021). The blue economy in the Mediterranean https://Contracting.unep.org/unepmap/resources/factsheets/blue-economy

Contracting Parties to the Barcelona Convention (in grey) and proposed area of the Med SOX ECA (in dark blue). Source: (REMPEC 2021)

The shipping industry is rapidly adapting to these changes, not only by adopting low Sulphur fuel oils (LSFO) but also by exploring alternative energy sources such as biofuels, ammonia, hydrogen, and liquefied natural gas (LNG). Each of these fuels has distinct marine pollution hazards based on their chemical properties, influencing their behaviour in the event of an accidental spill at sea. LSFOs generally pose a lower environmental threat compared to conventional fuels due to their reduced Sulphur content. Biofuels, with high biodegradation rates, may degrade more readily than traditional hydrocarbons. In contrast, alternative fuels like ammonia and hydrogen raise more significant safety concerns due to their toxicity and flammability, respectively[10]. These varying properties emphasize the need for a robust, well-prepared emergency response framework.

Oil Spill Response (OSR) at sea currently focuses on mechanical and chemical methods to prevent oil from reaching coastal areas. Given the shift to alternative fuels, the response framework may need to address specific hazards associated with these fuels under Article 10.2 of the 2002 Prevention and Emergency Protocol to the Barcelona Convention. This article emphasizes that, when combating pollution from ships, measures should prioritize the protection of human life and the vessel itself, while minimizing or preventing environmental damage. This emphasis may guide the development of tailored response measures that address the distinct risks posed by emerging fuel types.

In the Mediterranean, similar to many other ECAs, the established frameworks for marine pollution response are predominantly designed for traditional marine fuels, leaving a significant gap in the region's ability to respond effectively to incidents involving low Sulphur and alternative fuels. The unique environmental hazards presented by these new fuel types—ranging from their chemical reactivity to their potential for rapid dissipation or accumulation in marine environments—necessitate a rethinking of emergency preparedness and response strategies.

To address this gap, the Mediterranean Action Plan (MAP), through REMPEC, has commissioned a comprehensive study titled *"Readiness of the Mediterranean Region to Respond to Marine Pollution Incidents Involving low-Sulphur Fuels and Alternative Fuels."* This Study aims to evaluate the current state of readiness among Contracting Parties, identifying strengths and weaknesses in their emergency response capabilities. More importantly, the Study seeks to provide actionable recommendations for enhancing

[10] ITOPF. (2024). Fate, behaviour and potential damage & liabilities arising from spills of alternative fuels into the marine environment: overview Report for the International Group of P&I Clubs Alternative Fuels Working Group.

preparedness, ensuring that the region is better equipped to manage the complexities of pollution incidents involving both low Sulphur and alternative fuels.

By focusing on the critical issue of response readiness for pollution incidents involving low-Sulphur fuels and alternative fuels, the Study aims to contribute not only to the safety and environmental sustainability of the Mediterranean region but also to global maritime resilience, as shipping continues its transition to cleaner, yet more complex, energy sources.

1.2. Purpose and objectives of the study

The overarching purpose of this Study is to provide an assessment of the Mediterranean region's capacity to respond to marine pollution incidents associated with low-Sulphur and alternative fuels. The Study aims to identify the strengths, weaknesses, and gaps in current emergency response mechanisms and offer strategic recommendations for improvement.

The specific objectives of the Study are:

1. to identify and analyse the strengths, weaknesses, and gaps in existing emergency response mechanisms and protocols specific to low-Sulphur and alternative fuels;
2. to assess the risks and environmental behaviour of low-Sulphur and alternative fuels in marine environments, considering their potential impact in the event of accidental release;
3. to review best practices, policies, and lessons learned from other ECAs globally and explore their applicability to the Mediterranean context; and
4. to propose strategic recommendations and a potential roadmap for enhancing regional response mechanisms, regulatory frameworks, and policy interventions.

1.3. Scope of the Study

The scope of the Study encompasses a thorough analysis of the capacity of Contracting Parties to manage pollution incidents involving both low-Sulphur and alternative fuels. The Study includes:

1. a review of existing emergency response frameworks and protocols at both regional and national levels within the Mediterranean;
2. an assessment of preparedness levels across Contracting Parties, focusing on the ability to effectively respond to incidents involving new fuel types;
3. an examination of the environmental behaviour of low-Sulphur fuels and alternative fuels—such as ammonia, biofuel, LNG, and hydrogen—addressing their potential fate in marine ecosystems and associated risks; and
4. the formulation of a set of recommendations aimed at strengthening regional response strategies, policies, and capacity-building efforts, ensuring robust mechanisms to address incidents involving low-Sulphur and alternative fuels.

Overall, this Study aims to provide a strategic and evidence-based approach to enhancing the Mediterranean region's preparedness and response capabilities for potential marine pollution incidents involving low-Sulphur and alternative fuels. The research methodology employed in this Study is provided at **Annex I**.

2. REGULATORY LANDSCAPE FOR LOW-SULPHUR AND MARINE FUELS

This chapter presents an overview of the regulatory frameworks relevant to the management of marine fuels, with a particular attention on the applicability on low Sulphur and alternative marine fuels. The analysis includes key international conventions, IMO instruments, and industry standards that influence the environmental and safety dimensions of these fuels, with a focus on identifying gaps in current regulatory mechanisms. The chapter also provides insights into ongoing discussions at IMO and other industry bodies to address the challenges posed by the adoption of these fuels.

2.1. Regulatory status of alternative fuels in maritime

The maritime industry is undergoing a significant transition toward alternative fuels as part of global efforts to reduce greenhouse gas emissions (GHG) and address environmental concerns. This transition, accompanied by revisions of existing regulatory frameworks such as MARPOL Annex VI, aims to curb emissions from conventional marine fuels. However, the adoption of alternative fuels—such as methanol, ethanol, hydrogen, ammonia, biofuels, and LNG—introduces new challenges that are not fully addressed by existing safety and environmental regulations. While progress has been made by, among others, relevant regulatory bodies such as IMO and classification societies in developing guidelines for some alternative fuels, critical gaps remain, particularly concerning the safe handling and accidental spill response protocols for such fuel types with distinct proprieties, including low-flashpoint and toxic fuels.

Alike Hazardous and Noxious Substances (HNS), alternative fuels such as ammonia and hydrogen, characterized by distinct chemical properties, present unique safety and environmental hazards in terms of toxicity, flammability, and environmental behaviour in case of spills at sea. While major IMO conventions like SOLAS[11] and MARPOL, effectively regulate conventional fuels such as Heavy Fuel Oil (HFO) and Marine Diesel Oil (MDO), the adoption of alternative fuels requires additional regulatory efforts to ensure that safety and environmental protection in maritime sector remain on par with conventional fuel standards.

IMO's GreenVoyage2050[12] regulatory mapping exercise offers an assessment of the current regulatory framework governing alternative marine fuels. It identifies several significant gaps in IMO safety and environmental protection instruments, particularly for fuels such as ammonia, hydrogen, and Dimethyl Ether (DME). In fact, these are not fully addressed by existing conventions like MARPOL Annex I and II. Notably, the mapping exercise categorizes regulatory readiness into Low, Medium, and High levels, highlighting areas where further regulatory development is needed. Summary of the finding of the mapping exercise is provided in **Table 1 in Section 2.3**. This initiative aims to offer IMO member States and the maritime industry with a clearer understanding of these gaps and to support prioritization of future regulatory efforts, particularly in important areas such as fuel safety, environmental standards, and spill management.

As preparations for the implementation of the Med SO_X ECA in the Mediterranean region advance towards the May 2025 deadline, a thorough regulatory assessment becomes essential. The Mediterranean region's transition to low-Sulphur and alternative fuels will demand updates to existing preparedness and response frameworks at the national, sub-

[11] The International Conventional for the Safety of Life at Sea, 1974 as amended

[12] The IMO's Greenvoyage2050 exercise was conducted by the members of the Alternative Fuels workstream of the Global Industry Alliance to Support Low Carbon Shipping (Low Carbon GIA), with significant contributions from ICS and the IMO Marine Environment and Maritime Safety Divisions. For more details, see IMO GreenVoyage2050, Alternative Marine Fuels Regulatory Mapping, available at: https://greenvoyage2050.imo.org/alternative-marine-fuels-regulatory-mapping/."

regional, and regional levels to manage potential marine pollution incidents involving low Sulphur and alternative fuel effectively.

In this context, integrating the principles of the International Safety Management (ISM) Code can enhance safety and environmental protection in handling these emerging risks. The ISM Code emphasizes a structured and standardized approach to managing operational safety and environmental risks in the maritime sector, providing a foundation for robust incident management protocols. By embedding ISM Code principles, response frameworks can be strengthened to address the unique challenges posed by low-Sulphur and alternative fuels, thereby ensuring safer and more efficient management of pollution incidents.

This Study uses the regulatory mapping conducted under GreenVoyage2050 as a key reference for assessing the Mediterranean region's regulatory readiness.

2.1.1. Main IMO Instruments governing marine fuels usage

2.1.1.1. IMO safety standards for marine fuels

The International Convention for the Safety of Life at Sea (SOLAS**)** sets foundational safety standards for ship construction, equipment, and operations. A critical aspect of these standards, particularly concerning marine fuels, is outlined in SOLAS Chapter II-1. This chapter describes, particularly in part G, requirements for the use of low-flashpoint fuels[13] onboard merchant ships. These types of fuels present more hazards due to their higher risk of fire and explosion compared to fuels with higher flashpoints, necessitating specialized safety measures in their design, storage, and handling.

At the IMO level, the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code)[14] was introduced to address these safety concerns. The IGF Code provides detailed regulations on the arrangement, installation, control, and monitoring of machinery, equipment, and systems using low-flashpoint fuels, focusing primarily on LNG, which has been in use for some time. The code mandates provisions on fuel storage, machinery spaces, fire safety measures, and training requirements for the crew to safely manage LNG-powered ships.

Whereas ammonia and hydrogen are seen as promising fuel options for reducing GHG emissions they present unique safety challenges that require continuous regulatory work. Ammonia is toxic and poses significant environmental and health hazards if spilled, while hydrogen is highly flammable and requires specific handling protocols due to its properties, including its potential for creating explosive mixtures with air. The IGF Code for these fuels is progressively addressing the attendant safety challenges through the development of interim

[13] According to SOLAS and the IGF Code, a "low-flashpoint fuel" is defined as follows:

- SOLAS Chapter II-1, Regulation 2.29 defines "low-flashpoint fuel" as gaseous or liquid fuel having a flashpoint lower than otherwise permitted under regulation II-2/4.2.1.1. This regulation specifies that no oil fuel with a flashpoint lower than 60°C shall be used, except in certain cases such as emergency generators (with a minimum of 43°C) or specific provisions for low-flashpoint fuels.
- The IGF Code, Part A, Paragraph 2.2.28, defines "low-flashpoint fuel" as gaseous or liquid fuel having a flashpoint lower than otherwise permitted under SOLAS regulation II-2/4.2.1.1. This includes fuels like liquefied natural gas (LNG) and other low-flashpoint fuels that require special safety measures for their use.

[14] The International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) provides mandatory provisions for the arrangement, installation, control, and monitoring of machinery, equipment, and systems using low-flashpoint fuels. It aims to ensure the safe use of such fuels, which present particular risks due to their properties, such as a lower flashpoint. The IGF Code was adopted by the International Maritime Organization (IMO) and entered into force on 1 January 2017

guidelines by the IMO[15] and amendments to the Code which accommodate rapidly evolving fuel technology and take into account both experience and technical developments.[16, 17]

SOLAS Chapter II-1, Part G specifically regulates the use of low-flashpoint fuels on board merchant ships, while Part F allows for alternative design arrangements, supporting the use of fuels not yet fully regulated under the IGF Code. The alternative design approach permits ship designers to propose innovative solutions to meet safety standards, provided they can demonstrate equivalent or higher safety levels. In this respect, MSC.1/Circ.1455 provides guidelines on alternative design and arrangements for fire safety and MSC.1/Circ.1212/Rev.1 deals with low-flashpoint fuel use under special conditions. These alternative arrangements are crucial in the maritime sector for accommodating the rapid technological changes in marine fuels while ensuring safety.

The International Safety Management (ISM) Code, implemented under the SOLAS Convention, establishes a framework for the safe management and operation of ships, including provisions that cover fuel-related risks. The ISM Code outlines the obligations of ship operators to identify, assess, and manage risks to the safety of life at sea, including the risks associated with the handling, storage, and use of marine fuels.

The ISM Code is highly relevant to the safe adoption of alternative fuels, as these new fuels introduce operational risks that differ from those posed by traditional oil-based fuels. For example, alternative fuels such as LNG, methanol, ammonia, and hydrogen require special considerations regarding fuel storage, handling systems, and spill response protocols. As the adoption of these fuels' increases, the ISM Code will need to evolve to address the specific safety risks associated with these new fuel types, such as:

- **Fuel Handling:** The ISM Code lays down the principles for ensuring the safe management and operation of ships, which includes the handling of fuels. However, with the introduction of low-flashpoint fuels like LNG and hydrogen, additional best practices and specific protocols will be required. While the ISM Code provides the overarching framework, ship-specific Safety Management Systems (SMS) will need to be adapted to account for the heightened risks of fire and explosion associated with these alternative fuels. This may include establishing new procedures for fuel transfer operations, managing ventilation systems, and implementing emergency shutdown mechanisms, among other matters. Not least, bunkering procedures—both onboard and ashore—must be adapted to reflect the unique requirements of these fuel types, ensuring safety during refuelling operations and compliance with international standards.

- **Fuel Storage:** The storage of alternative fuels also requires special considerations. For instance, LNG must be stored in cryogenic tanks to maintain its low temperature, while ammonia and methanol require tanks that prevent corrosion and contain leaks. The ISM Code will need to incorporate guidelines on the design and inspection of fuel storage systems to ensure they meet the highest safety standards.

- **Spill Response:** The ISM Code includes provisions for responding to fuel spills, but these are primarily focused on oil-based fuels. With the shift to alternative fuels, new contingency plans and response protocols must be developed to address the environmental hazards posed by biofuels, LNG, and other alternative fuels. For

[15] Interim guidelines for ammonia and hydrogen are under discussion. Resolution MSC.420(97), adopted in 2017, provides interim recommendations for the carriage of liquid hydrogen in bulk.

16 Resolution MSC.458(101) (adopted on 13 June 2019) Amendments to the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code)

17 Resolution MSC.475(102) (adopted on 11 November 2020) Amendments to the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code)

example, an LNG leak behaves differently from an oil spill, requiring different response strategies such as gas dispersion modelling and fire suppression techniques.

- **Training:** One of the central tenets of the ISM Code is ensuring that seafarers and crew members are properly trained to handle fuel-related risks. As alternative fuels become more common, the ISM Code will need to ensure that training programs are updated to cover the unique risks associated with these new fuels. This includes training on the use of specialized equipment, emergency procedures, and risk mitigation strategies.

The evolution of the ISM Code in line with the growing use of alternative fuels is critical to ensuring that safety standards and practices aboard ships remains robust, even as the industry transitions to low-carbon energy sources.

The development of safety regulations for alternative fuels is an ongoing process. While significant progress has been made, particularly for methanol and ethanol as marine fuels[18], substantial work is still needed for low-flashpoint and toxic fuels such as ammonia and hydrogen. Although the IGF Code provides a framework for LNG and is evolving to cover other alternative fuels, considerable regulatory work remains to fully integrate ammonia, hydrogen, and other low-flashpoint fuels into SOLAS and related IMO conventions.

2.1.1.2. IMO environmental standards for marine fuels

The International Convention for the Prevention of Pollution from Ships (MARPOL) is one of the key IMO instruments governing marine environmental protection. MARPOL Annex VI specifically addresses the prevention of air pollution from ships. Among other matters, it regulates emissions of Sulphur Oxides (SOx), Nitrogen Oxides (NOx), and Particulate Matter (PM), setting limits for these pollutants to reduce the harmful effects on both the environment and human health.

The global Sulphur cap, introduced under MARPOL Annex VI, in Regulation 14, limits the Sulphur content in marine fuels to 0.50% by mass for ships operating outside designated ECAs[19] and 0.10% for ships operating within ECAs. This has driven the adoption of low-Sulphur fuels, such as marine gas oil (MGO) and ultra-low Sulphur fuel oil (ULSFO), in compliance with these regulations.

Annex VI also plays a critical role in managing NOx emissions, with the NOx Technical Code setting specific emission standards (referred to as Tier I, II, and III standards) depending on the engine's power output and the ship's area of operation.

While MARPOL Annex VI provides a strong framework for regulating conventional marine fuels, there are gaps concerning marine alternative fuels, especially regarding their specific environmental impacts. One significant example is methane (CH_4), used in liquefied natural gas (LNG)-powered ships. Methane is the second most important GHG contributor to climate change following carbon dioxide, with a global warming potential over 20 times that of CO_2

---

[18] For methanol, for instance, the IMO has issued MSC.1/Circ.1621 which provides interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel. Additionally, standards for methanol are under development, with references to the IMPCA Methanol Reference Specification and ASTM D1152 for quality specifications. These interim measures allow for the controlled use of methanol and ethanol in the maritime sector, but further regulatory updates are anticipated for full integration into the IGF Code.

[19] According to MARPOL Annex VI, Regulation 2.13, ‘Emission Control Area (ECA)’ means an area where the adoption of special mandatory measures for emissions from ships is required to prevent, reduce and control air pollution from NOx or SOx and particulate matter or all three types of emissions and their attendant adverse impacts on human health and the environment. Emission Control Areas shall include those listed in, or designated under, regulations 13 and 14 of MARPOL Annex VI.

over a 100-year period[20]. Despite its cleaner combustion properties compared to heavy fuel oil, fugitive methane emissions, particularly from LNG-powered engines, are not yet fully regulated under MARPOL Annex VI. This highlights a regulatory gap, as methane slip during engine operation or bunkering can significantly contribute to global warming.

Another emerging issue involves Nitrous Oxide (N_2O) emissions. While there are comprehensive regulations for NOx emissions through the certification and survey requirements under Regulation 13 of Annex VI, N_2O—a GHG that can be produced during combustion in certain engine types—requires further scrutiny. The current NOx Technical Code (2008) does not specifically regulate N_2O emissions, but it is anticipated that future revisions will include provisions to address this, particularly as the use of alternative fuels such as ammonia or hydrogen is growing. These fuels, while promising in reducing carbon emissions, present potential risks of N_2O emissions if not properly managed during the combustion process.

The need to extend regulatory frameworks to cover methane and N_2O emissions has been acknowledged by IMO, and efforts are ongoing to ensure that the next iterations of MARPOL Annex VI and the NOx Technical Code address these issues[21]. This will likely include requirements for certification of GHG emissions from alternative fuels, as well as stricter monitoring and reporting mechanisms for methane slip and other fugitive emissions.

Importantly, in connection with MARPOL Annex VI, the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)[22] hazard profiles, which assess the marine environmental risks associated with different substances, must to be updated to cover hazard profiles of alternative fuels such as LNG, ammonia, and hydrogen. These profiles will offer maritime industry a better understanding on how these fuels behave in the marine environment, especially in cases of accidental spills.

The IMO's Sub-Committee on Pollution Prevention and Response (PPR) Product Data Reporting Form[23] plays a crucial role in documenting the characteristics and handling requirements of these low-Sulphur fuels, providing essential data on fuel composition and potential hazards. This data is particularly important as the industry transitions to alternative fuels.

Additionally, as the industry adopts new fuels, attention must also be given to the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code), established by the IMO. This code governs the safe transport of dangerous chemicals in bulk, ensuring that appropriate safety measures are in place to mitigate risks associated with handling and carriage.

In summary, MARPOL Annex VI provides a solid regulatory structure for traditional fuels but must evolve to fully address the environmental impacts of alternative fuels. Ensuring that regulations keep pace with new technologies is critical for achieving the maritime industry's decarbonization goals while mitigating any unintended environmental consequences.

---

[20] European Commission. (2022). Methane emissions. Energy - European Commission. https://energy.ec.europa.eu/topics/carbon-management-and-fossil-fuels/methane-emissions_en

[21] IMO. (2023). 2023 IMO Strategy on Reduction of GHG Emissions from Ships. https://Contracting.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx

[22] The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) is an advisory body, established in 1969, that advises the United Nations (UN) system on the scientific aspects of marine environmental protection.

[23] The PPR Product Data Reporting Form is used by the IMO's Pollution Prevention and Response (PPR) Sub-Committee to gather and document essential information about the characteristics of marine fuels, including low-Sulphur fuels and alternative fuels. This form is a key tool for assessing the composition, handling requirements, and potential environmental hazards of these fuels, supporting compliance with MARPOL Annex VI and enabling safer fuel handling practices.

2.1.1.3. IMO pollution preparedness and response standards

The International Convention on Oil Pollution Preparedness, Response, and Cooperation (OPRC Convention), adopted by the IMO in 1990, established a global framework for responding to marine pollution incidents, with an emphasis on oil spills. The OPRC Convention requires signatory States to establish a national system for responding promptly and effectively to oil pollution incidents including development of national capabilities for handling oil pollution emergencies through contingency planning, regular training exercises, and fostering cooperation between countries and the shipping industry. It also encourages the creation of regional response strategies to manage the environmental impacts of oil spills.

Although the OPRC Convention initially focused on oil spills, its scope was extended to cover Hazardous and Noxious Substances (HNS) through the Protocol on Preparedness, Response, and Cooperation to Pollution Incidents by Hazardous and Noxious Substances, 2000 (OPRC-HNS Protocol). This Protocol addresses pollution incidents involving chemicals, liquefied gases, and other hazardous substances transported by sea, which pose risks to both the marine environment and human health. The Protocol mandates similar response measures to those for oil spills, including contingency planning, cooperation, and specialized strategies for managing HNS spills.

Alternative fuels like low-Sulphur fuels, biofuels, and liquefied natural gas (LNG) would be categorized as contributing cargo under the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea, 2010 (HNS Convention). However, the HNS Convention does not cover hazardous substances used as bunkers, introducing a distinction in legislative terminology. While existing regulations and guidance under the OPRC Convention and the OPRC-HNS Protocol help manage spills involving these substances, the focus remains largely on bulk cargo. Consequently, the current frameworks, although adaptable, do not fully address the risks posed by alternative fuels when used as bunkers.

When used as marine bunkers, these fuels present new environmental risks that require additional response measures beyond what the current OPRC and OPRC-HNS Protocol frameworks cover. These measures may include adapting spill containment techniques for cryogenic fuels like LNG, developing toxicity protocols for biofuels, enhancing training for handling flammable and reactive fuels like hydrogen and ammonia, and integrating advanced monitoring systems for real-time spill detection and impact assessment. Therefore, while these frameworks provide a solid foundation for managing spills, they need to be adapted to account for the specific risks associated with alternative fuels, particularly regarding their toxicity, spill behaviour, and environmental impact. For example, the environmental hazards posed by biofuels and LNG differ significantly from traditional petroleum-based fuels. Biofuels, though more biodegradable, can still have toxic effects on marine ecosystems. Similarly, LNG, while it evaporates quickly and leaves minimal residue, can lead to oxygen depletion in water, and its methane content is a potent GHG.

The existing response techniques for oil spills, such as booms, skimmers, and dispersants, may not be suitable for alternative fuel spills. For instance, LNG spills evaporate on contact with air, so traditional containment methods are ineffective. Instead, response efforts should focus on managing the gas cloud, preventing fire hazards, and mitigating the effects of rapid gas evaporation on marine life. For biofuels, response measures must address both their potential biodegradability and toxicity, which can vary depending on the fuel type.

The OPRC-HNS Protocol's provisions for hazardous substances can be crucial in shaping response strategies for emerging fuels such as ammonia and hydrogen, which are both toxic and hazardous. The complexity and diverse risks posed by these substances highlight the need for international cooperation in sharing resources, expertise, and technology to ensure effective spill management. This aligns with the OPRC Convention's emphasis on collaboration among nations and the shipping industry in responding to large-scale marine pollution incidents.

In a nutshell, while the OPRC Convention and its HNS Protocol provide a robust framework for oil and hazardous substance spills, evolving response protocols are necessary to address the environmental risks associated with biofuels, LNG, and other alternative fuels. By updating and expanding the OPRC and HNS response strategies, the maritime industry can ensure effective preparedness for the unique challenges posed by emerging low- or zero-emission fuels. Collaboration between the IMO, industry stakeholders, and member States will be vital to adapting the OPRC framework to the future landscape of marine fuels.

2.1.1.4. IMO liability and compensation regime for marine fuel-related pollution

The International Maritime Organization (IMO) has developed a comprehensive liability and compensation regime to address pollution incidents arising from the use of marine fuels. At the core of this regime is the Convention on Limitation of Liability for Maritime Claims (LLMC 1976), which allows shipowners to limit their liability for a wide range of maritime claims, including those related to pollution. The liability limits under the LLMC are based on the ship's tonnage, offering shipowners a predictable framework for financial risk management. This Convention was amended by the 1996 LLMC Protocol, which significantly increased the liability limits to reflect the increasing costs associated with pollution incidents.

In addition to the LLMC, the International Convention on Civil Liability for Oil Pollution Damage (CLC 1992) is a key instrument for addressing oil pollution specifically. CLC 1992 makes shipowners strictly liable for pollution damage caused by oil spills, including spills of bunker oil, without requiring proof of fault or negligence. This ensures that victims of pollution are compensated, while shipowners have the ability to limit their liability based on the ship's tonnage, as set out in the convention. The convention provides exceptions to liability only in cases of war, natural disasters, or deliberate actions by third parties.

The limit of liability under CLC 1992 is 89.77 million SDR for ships over 140,000 gross tonnages. To further supplement this regime, the 1992 Fund Convention was established the International Oil Pollution Compensation (IOPC) Fund, and provides additional compensation up to 750 million SDR when the shipowner's liability under the CLC 1992 is insufficient to fully cover the damage caused by an oil spill. Whereas CLC 1992 is covered by the shipowner's insurance, the Fund is financed by contributions from entities in contracting states that receive oil in bulk by sea, and it plays a crucial role in large-scale pollution incidents, particularly where shipowner liability is inadequate.

Further, Protocol of 2003 to the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage, 1992, established a Supplementary Fund, adding another layer of compensation for extreme cases where the total liability and compensation from earlier funds were insufficient. The 2003 Protocol raised the total compensation available to 750 million Special Drawing Rights (SDR)[24].

The International Convention on Civil Liability for Bunker Oil Pollution Damage (Bunker Convention), adopted in 2001, complements the CLC 1992 by specifically addressing pollution from bunker oil spills from non-tanker vessels. The convention establishes a strict liability regime, holding the registered shipowner accountable for pollution damage within a

[24] Special Drawing Rights (SDR) is an international reserve asset created by the International Monetary Fund (IMF) that can be exchanged among governments for freely usable currencies. Its value is based on a basket of major international currencies (US dollar, euro, Japanese yen, British pound, and Chinese renminbi). SDR is commonly used in international conventions to standardize monetary values across countries

contracting state's territory, territorial sea, and exclusive economic zone. This ensures that compensation is available to victims of bunker oil pollution incidents, even if the spill is accidental and without requiring proof of fault. Additionally, the convention mandates that shipowners maintain insurance or other financial security to cover potential liabilities, providing a reliable mechanism for compensation.

Although the current liability and compensation framework has been highly effective for managing oil spills, the maritime industry's shift toward alternative fuels—such as liquefied natural gas (LNG), hydrogen, and ammonia—introduces new risks that are not fully covered by existing conventions. For instance, the environmental impact of methane slips from LNG or the toxicity of ammonia pose challenges that the current framework does not adequately address.

Another instrument relevant to liability and compensation for marine pollution is the 2010 Protocol to the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea (HNS Convention), referred to as the 2010 HNS Convention. Although not yet in force, the 2010 HNS Convention provides a comprehensive framework for addressing pollution and damage caused by hazardous and noxious substances (HNS), including liquefied natural gas (LNG) and other alternative fuels. The convention establishes a two-tier system of compensation: first, the shipowner's liability, insured through mandatory financial security, and second, a compensation fund financed by contributions from cargo receivers. This framework is crucial for addressing the unique risks associated with the transport of HNS, ensuring adequate compensation for victims while holding the responsible parties accountable. Once operational, the HNS Convention is expected to fill existing gaps in the liability and compensation regime for incidents involving hazardous and noxious substances, complementing the existing conventions like CLC 1992 and the Bunker Convention.

2.1.1.5. Other IMO instruments indirectly contributing to pollution prevention

Several other IMO conventions indirectly support pollution prevention, particularly concerning low-Sulphur and alternative fuels.

The International Convention on Maritime Search and Rescue (SAR 1979) plays a critical role by coordinating the rescue of ships in distress, helping to prevent potential fuel spills that could lead to environmental damage. Timely interventions through SAR can prevent incidents involving vessels carrying low-Sulphur or alternative fuels, such as liquefied natural gas (LNG), from escalating into pollution events.

Similarly, the Nairobi International Convention on the Removal of Wrecks (WRC 2007) ensures the removal of wrecks that may pose significant pollution risks, such as the release of bunker fuel or alternative fuels like ammonia or hydrogen, which present unique hazards.

The International Convention on Salvage (1989) promotes effective salvage operations and includes provisions that reward salvors for actions that prevent environmental harm, encouraging rapid responses to avoid pollution from hazardous fuels.

These conventions, while not primarily focused on pollution, provide critical support in preventing environmental damage during maritime emergencies and are essential for ensuring preparedness for low-Sulphur and alternative fuel spill incidents.

2.1.2. EU instruments

The European Union has implemented several key Directives and Regulations that support pollution prevention and sustainable fuel use in maritime transport. These legislative acts complement international conventions by establishing stricter regional standards within EU waters, especially concerning the Sulphur content of marine fuels, the deployment of alternative fuel infrastructure, and the reduction of GHG emissions from maritime transport.

Each legislative act outlined below addresses critical aspects of pollution control, such as setting Sulphur limits, monitoring CO_2 emissions, and promoting the use of alternative fuels and shore-side electricity, thereby contributing to the EU's broader goals of environmental protection and air quality improvement in the maritime sector.

- Directive 2012/33/EU, also known as the Sulphur Directive, specifies the maximum Sulphur content of marine fuel oils and also specifies the methods to be used to measure the Sulphur levels in both marine and motor fuels.
- Directive 2014/94/EU sets a common framework of measures for the deployment of alternative fuels infrastructure in the European Union to minimize dependence on oil and to mitigate the environmental impact of transport. Minimum requirements for the building-up of alternative fuels infrastructure include refuelling points for natural gas (LNG and CNG) and hydrogen.
- Directive (EU) 2016/802 relating to a reduction in the Sulphur content of certain liquid fuels is a codification of the original Directive 1999/32/EC, and the five substantial amendments (in particular by Directives 2005/33/EC and 2012/33/EU).
- Regulation (EU) 2015/757, also known as the EU MRV Directive, lays down rules for the accurate monitoring, reporting, and verification of carbon dioxide (CO_2) emissions and of other relevant information from ships arriving at, within, or departing from ports under the jurisdiction of a Member State, to promote the reduction of CO_2 emissions from maritime transport in a cost-effective manner.
- European Commission Recommendation 2006/339/EC recommends the Member States, inter alia, to "consider the installation of shore-side electricity for use by ships at berth in ports; particularly in ports where air quality limit values are exceeded or where public concern is expressed about high levels of noise nuisance, and especially in berths situated near residential areas."

In addition, the recent FuelEU Maritime Regulation (Regulation (EU) 2023/1805), as part of the Fit for 55 package[25], mandates that starting in 2030, container and passenger ships connect to onshore power supplies (OPS) while at berth in Trans-European Network (TEN-T) ports, provided their port stays exceed two hours. This requirement is intended to reduce emissions from auxiliary engines while docked, thereby improving air quality in port cities. Ports across the EU are investing in shore-to-ship power infrastructure to meet this deadline, a critical step toward reducing pollutant emissions, including Sulphur Dioxide, Nitrogen Oxides, and Particulate Matter, in port areas. By supporting ships in drawing electricity from shore while docked, the FuelEU Maritime Regulation strengthens EU goals for reducing maritime emissions and aligns with broader climate objectives.

[25] For further information on the Fit for 55 Package see: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal/fit-55-delivering-proposals_en

2.1.3. Barcelona Convention

The Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention) was adopted on 16 February 1976 in Barcelona and entered into force in 1978. The Barcelona Convention was amended in 1995 and renamed as the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean. The amendments to the Barcelona Convention entered into force in 2004. , is a key legal framework for protecting the Mediterranean Sea from pollution, including oil and hazardous substance spills. The Barcelona Convention and its Protocols address marine pollution prevention and response, making it central to alternative and low-Sulphur fuel spill management in the region.

Key Protocols relevant to fuel spill response include:

- Protocol Concerning Cooperation in Combating Pollution of the Mediterranean Sea by Oil and Other Harmful Substances in Cases of Emergency (1976): This Protocol, also known as the *Emergency Protocol*, is central to the Barcelona Convention's spill response framework. It establishes cooperation mechanisms among Contracting Parties for responding to oil spills and other hazardous substances. The Protocol outlines how Contracting Parties must notify each other and assist in response operations.

- Protocol for the Protection of the Mediterranean Sea Against Pollution from Land-Based Sources and Activities (1980): This Protocol addresses pollution originating from land-based sources, which could include fuel storage facilities, refineries, or bunkering stations. Low-Sulphur and alternative fuel handling at ports, particularly in Contracting Parties with busy shipping lanes, falls under this protocol's jurisdiction. The Protocol's relevance extends to the prevention of spills from fuel processing and storage facilities, which are a potential source of marine pollution.

- Protocol on Preparedness, Response and Cooperation to Pollution Incidents by Hazardous and Noxious Substances (HNS Protocol) (2002): This Protocol, based on the OPRC-HNS Protocol of the International Maritime Organization (IMO), aims to strengthen the capacity of Contracting Parties to prepare for and respond to pollution incidents involving hazardous substances. It establishes guidelines for response strategies, technical assistance, and regional cooperation for pollution incidents involving non-oil substances, which directly applies to alternative fuels.

The Mediterranean Action Plan (MAP): The MAP was established in 1975 as a multilateral environmental agreement in the context of the Regional Seas Programme of the United Nations Environment Programme (UNEP). Under the auspices of UNEP/MAP, the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) was adopted in 1995. It provides the overarching framework for the protection of the Mediterranean marine environment, including measures against pollution from ships, land-based sources, and exploration activities. Within this framework, specific action plans address the development of strategies for managing pollution from maritime transport, which includes the handling of alternative fuels. The MAP supports integrated regional efforts to enhance low-Sulphur fuel spill preparedness by encouraging cooperation among Contracting Parties.

REMPEC was established as part of the Barcelona Convention to help Contracting Parties strengthen their capacities to prevent and combat pollution from ships and ensure cooperation in pollution incidents. It provides technical assistance, conducts training programs, and coordinates regional spill response efforts. REMPEC's role is particularly crucial for alternative and low-Sulphur fuel spills, as it facilitates the exchange of information and best practices, supports the implementation of contingency plans, and assists in national response preparedness assessments.

The Barcelona Convention and its Protocols offer a strong foundation for coordinated spill response across the Mediterranean. However, the increasing use of alternative fuels highlights the need for ongoing updates and regional cooperation to manage the evolving risks posed by cleaner but more complex energy sources in the maritime sector.

2.2. Industry standards for marine fuels

In addition to the IMO conventions, the maritime industry has implemented various standards and best practices that can be instrumental in managing the risks associated with the adoption of low Sulphur and alternative fuels. These standards not only complement regulatory frameworks but also play a crucial role in ensuring the operational safety of vessels transitioning to alternative energy sources. Industry standards, such as those developed by the International Organization for Standardization (ISO) [26] and guidelines within the International Safety Management (ISM) Code[27], provide essential tools for managing fuel-related risks in this evolving landscape.

ISO has set key standards that define the quality and safety requirements for marine fuels. These standards are instrumental in regulating both conventional marine fuels and the emerging alternative fuels that will power vessels as the maritime industry transitions towards decarbonization. Relevant ISO standards, among others, include:

- ISO 8217:2017 defines the specifications for conventional marine fuels, including diesel and heavy fuel oil (HFO), covering key parameters such as Sulphur content, viscosity, and water content. Adherence to this standard ensures fuel quality, reducing risks of engine failure or environmental pollution. ISO is revising the standard to include Hydrotreated Vegetable Oil (HVO) and Fatty Acid Methyl Esters (FAME), addressing stability, cold flow, and oxidation resistance. The update aims to ensure biofuels meet the same quality standards as conventional fuels, minimizing operational risks.

- ISO PAS 23263:2019 was introduced to guide fuel suppliers and users in managing marine fuel quality under the global Sulphur cap (0.50% Sulphur content). Although this standard focuses on conventional fuels, it also provides valuable insights into how alternative fuels can be integrated into the existing regulatory framework, particularly in terms of ensuring their safety and compatibility with ship engines.

Industry standards, such as ISO standards, not only promote fuel quality but also ensure that the adoption of new fuel types does not compromise the safety or operational performance of vessels. As alternative fuels become more prevalent, further revisions to the Industry Standards, including ISO standards, will be necessary to address their unique chemical compositions, storage conditions, and handling procedures.

[26] The International Organization for Standardization (ISO) is a global body that develops and publishes international standards to ensure quality, safety, and efficiency across various industries. Established in 1947, ISO has released over 23,000 standards, including ISO 9001 for quality management systems, ISO 14001 for environmental management, and ISO 45001 for occupational health and safety, which are widely used in sectors like manufacturing, technology, and services to enhance operational efficiency and safety practices.

[27] The ISM Code was adopted through IMO Resolution A.741(18) and became mandatory under SOLAS Chapter IX on 1 July 1998, establishing a standard for safe ship management. It emphasizes safety at sea, human protection, and environmental preservation

2.3. Regulatory readiness for alternative marine fuels

The regulatory readiness for alternative marine fuels varies significantly depending on the fuel type. Based on the GreenVoyage2050 regulatory mapping exercise and supporting literature, the readiness levels for each fuel type in terms of safety and environmental protection are categorized as low, medium, or high. This assessment highlights existing regulations, areas under development, and gaps that need to be addressed to ensure safe and environmentally responsible use of these fuels.

The following **Table 1** provides an overview of the regulatory readiness for different marine fuels, covering external standards, IMO safety regulations under SOLAS, and environmental standards under MARPOL.

***Table 1**. Regulatory readiness of alternative marine fuels (adopted from Greenvoyage2050)*

Fuel Type	ISO Standards	IMO Safety Standards (SOLAS)	IMO Environmental Standards (MARPOL)
Conventional Fuels (Diesel/ Gas Oil/ Fuel Oil)	ISO 8217:2017 ISO PAS 23263:2019	SOLAS Chapter II (Flashpoint >60°C) SOLAS Chapter II-1 Part F and G (low-flashpoint fuels)	MARPOL Annex I (oil spills and discharges) MARPOL Annex VI (SOx, NOx, PM)
Low Sulphur Fuels (LSFO)	ISO 8217:2017 ISO PAS 23263:2019 (0.50% Sulphur)	SOLAS Chapter II-1 Part F and G IGF Code (for low-flashpoint fuels)	MARPOL Annex VI (SOx)
Bio/Synthetic Liquid Fuels (HVO, FAME)	EN 14214:2012 EN 15940:2016 ISO in progress (revision of ISO 8217 for HVO/FAME)	SOLAS Chapter II-1 Part G (low-flashpoint fuels) IGF Code MSC.1/Circ.1212/Rev.1	MARPOL Annex VI (SOx reduction, biofuel blends)
Methanol	ISO/AWI 6583 (in progress) IMPCA Methanol Reference	SOLAS Chapter II-1 Part G (low-flashpoint fuels) MSC.1/Circ.1621	MARPOL Annex VI (CO_2 and NOx) MARPOL Annex II (no specific provisions for spills)
Ethanol	No marine standards available	SOLAS Chapter II-1 Part G MSC.1/Circ.1621	MARPOL Annex II (minor hazard classification, no spill guidelines) MARPOL Annex VI (CO_2, NOx)
Dimethyl Ether (DME)	No marine standards available	SOLAS Chapter II-1 Part G MSC.1/Circ.1212/Rev.1	MARPOL Annex VI (CO_2, NOx) IGC Code prohibits toxic cargo as fuel
Liquefied Natural Gas (LNG)	ISO 23306:2020	SOLAS Chapter II-1 Part G IGF Code	MARPOL Annex VI (CO_2, NOx) Methane-slip not regulated
Ammonia	No marine standards available	SOLAS Chapter II-1 Part G (in development) Draft IGF interim guidelines	MARPOL Annex VI (NOx) MARPOL Annex II (ammonia as category CONTRACTING substance)
Hydrogen	ISO 14687:2019	SOLAS Chapter II-1 Part G MSC.420(97) for bulk carriage Draft IGF interim guidelines	MARPOL Annex VI (NOx)
Propane/ Butane (LPG)	No marine standards available	SOLAS Chapter II-1 Part G IGF Code (draft guidelines expected 2023)	MARPOL Annex VI (CO_2, NOx)

From the regulatory framework standpoint, a significant gap prevails in existing instruments in terms of inconsistency in fuel definitions across various IMO conventions. These discrepancies, particularly with the term “fuel oil,” complicate the uniform application of safety and environmental regulations as the industry shifts to alternative fuels. This lack of standardization creates ambiguities in regulatory enforcement and hinders the effective implementation of alternative fuel regulations.

For example:

- SOLAS Chapter II-2 defines "fuel oil" based on its flashpoint, restricting the use of fuel oil with a flashpoint lower than 60°C, except in special cases. SOLAS Chapter II-1, Part G, also refers to "low-flashpoint fuels" and covers gases like LNG under the IGF Code, but does not fully address newer fuels like ammonia and hydrogen.

- MARPOL Annex I focus on "fuel oil" primarily in terms of its oil content for pollution prevention, not its flashpoint, creating a differing definition.

- IGF Code mentions "fuel oil" alongside distillates and residual fuels, but primarily in the context of dual-fuel engines, without providing a comprehensive definition for alternative fuels.

These inconsistencies cause confusion in implementing safety protocols and environmental measures for alternative fuels like biofuels, LNG, methanol, ammonia, and hydrogen. These fuels differ in risk and behaviour from conventional fuels, and existing regulations do not fully address these challenges. For instance, methanol is classified as hazardous in the IBC Code, yet its use as fuel is treated differently under the IGF Code. Similarly, ammonia’s classification as toxic under the IGC Code is still being addressed in fuel-use regulations.

Moreover, regulatory guidelines for spills of alternative fuels under MARPOL Annexes I and II are limited, despite the distinct spill response techniques required for biofuels, LNG leaks, or other non-oil substances.

IMO is working on aligning definitions across conventions like SOLAS, MARPOL, the IGF Code, and the IBC Code to harmonize fuel terminology[28]. This uniform approach is crucial for streamlining regulations and ensuring the consistent application of safety and environmental standards, especially as the industry moves toward decarbonization and explores low-carbon, zero-emission fuels.

2.4. Ongoing IMO discussions on alternative fuels

IMO is actively working to address the unique challenges posed by alternative marine fuels through updates to its regulatory frameworks. As the shipping industry accelerates the transition towards decarbonization and alternative energy sources, the IMO’s Marine Environment Protection Committee (MEPC) and other key bodies, like the Sub-Committee on Carriage of Cargoes and Containers (CCC), are leading discussions and initiatives aimed at ensuring safety, environmental protection, and emissions reduction. These initiatives are critical to achieving the IMO’s goal of net-zero GHG emissions from international shipping.

[28] IMO GreenVoyage2050, Alternative Marine Fuels Regulatory Mapping. https://greenvoyage2050.imo.org/alternative-marine-fuels-regulatory-mapping/."

IMO MEPC 82 discussions on alternative fuels.
Source: (IMO, 2024)

2.4.1. Amendments to MARPOL and the IGF Code

A central aspect of IMO's ongoing work is updating MARPOL and the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) to accommodate alternative fuels like biofuels, ammonia, and hydrogen. These amendments are crucial for ensuring that the safety risks associated with these new fuels are properly addressed, and that spill response mechanisms and emissions controls are robust enough to mitigate potential environmental impacts.

At MEPC 82[29], held in October 2024, the Committee took significant steps in this direction by advancing discussions on GHG emissions and finalizing important amendments to MARPOL Annex VI. These amendments focus on creating ECAs in regions such as the Norwegian Sea and the Canadian Arctic, where stringent controls on NOx, SOx, and particulate matter (PM) emissions will take effect starting in March 2026. Specifically, the Sulphur content of marine fuels will be limited to 0.10% in these regions starting from 1 March 2027, while Tier III NOx requirements will apply to ships constructed (or keel-laid) from 2025 onward for the Canadian Arctic and from 2026 for the Norwegian Sea.

The Committee also progressed with ongoing efforts to amend the NOx Technical Code to allow for the use of multiple engine operational profiles (MEOPs), which will enable more flexible and efficient engine operation. These revisions are part of a broader effort to manage emissions from alternative fuels more effectively, particularly as the IMO continues to develop guidelines for certifying methane and nitrous oxide (N_2O) emissions from fuels like LNG and biofuels, which are not yet comprehensively covered under the existing MARPOL Annex VI framework. The regulation of fugitive methane emissions from LNG engines remains an urgent area of focus, as methane is a potent GHG, contributing significantly to climate change.

2.4.2. Future developments

Looking ahead, the IMO is actively working towards establishing a net-zero GHG emissions framework for shipping, as outlined during the MEPC 82 discussions. The Committee continued to develop a strategy to reduce GHG fuel intensity, with the potential inclusion of a GHG pricing mechanism. This effort aligns with the broader goal of achieving net-zero

[29] IMO. (2024). Marine Environment Protection Committee (MEPC 82), 30 September – 4 October 2024. https://Contracting.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-82nd-session.aspx

emissions by mid-century. A comprehensive regulatory package, consisting of both technical and economic measures, is set to be adopted in late 2025[30].

One of the key elements of this package will be a marine fuel standard that phases in reductions in GHG intensity, particularly for alternative fuels like ammonia and hydrogen. Additionally, the IMO is exploring the possibility of a GHG emissions pricing mechanism, which would provide economic incentives to reduce emissions and adopt cleaner technologies. Although consensus on these measures has not yet been fully reached, the intersessional work leading up to MEPC 83 in 2025 will continue to refine these proposals, ensuring that the regulatory framework keeps pace with advancements in alternative fuel technologies.

In addition to these developments, the IMO also continued its work on refining the Carbon Intensity Indicator (CII) and improving the Ship Energy Efficiency Management Plan (SEEMP), as part of its overall strategy to reduce the carbon footprint of the global maritime fleet.

The ongoing discussions and negotiations at MEPC 82 illustrate the IMO's proactive approach to ensuring that alternative fuels can be safely and sustainably integrated into global shipping.

As the transition to alternative fuels accelerates, continuous collaboration between the IMO and the maritime industry will be essential for addressing regulatory gaps and ensuring that GHG emissions reductions can be achieved in a manner that supports both operational safety and environmental sustainability (DNV, 2024; GreenVoyage2050, 2023).

Overall, the regulatory landscape for low-Sulphur and alternative fuels is evolving, with significant gaps remaining in safety and environmental management.

[30] IMO. (2024). Marine Environment Protection Committee (MEPC 82), 30 September – 4 October 2024. https://Contracting.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-82nd-session.aspx

3. REVIEW OF LITERATURE AND DATA ON FUEL PROPERTIES

3.1. Introduction

This chapter, supplemented by **Annex II**, provides a comprehensive review of the properties of low-Sulphur and alternative fuels, with a particular focus on their behaviour in the marine environment and their implications for spill management. The chapter examines key characteristics such as toxicity, dispersal, persistence, and biodegradability, which are essential to understanding the environmental and operational challenges associated with these fuels. Special attention is given to the Mediterranean context, where unique environmental conditions such as warmer water temperatures, higher salinity, and specific ecosystem sensitivities influence the behaviour and impact of fuel spills.

The analysis includes a discussion of the refining methods, physical-chemical properties, and environmental risks of low-Sulphur fuels (e.g., VLSFO) and alternative fuels (e.g., hydrogen, ammonia, LNG, and methanol). By exploring their behaviour upon release into the sea and their interactions with environmental factors, this chapter aims to inform effective spill response strategies tailored to the Mediterranean region and CPs' specific needs.

3.2. Properties of low-Sulphur fuels

3.2.1. Refining methods for LSFO

LSFO for marine use are produced through specific refining methods designed to meet the MARPOL Annex VI Sulphur cap regulations, which aim to reduce Sulphur emissions from marine fuels. These methods focus on either directly sourcing low-Sulphur crude oil or removing Sulphur from high-Sulphur crude oil using advanced technologies. The primary methods for refining LSFO are presented **Figure 1** and an elaborated summary is provided in **Annex II.**

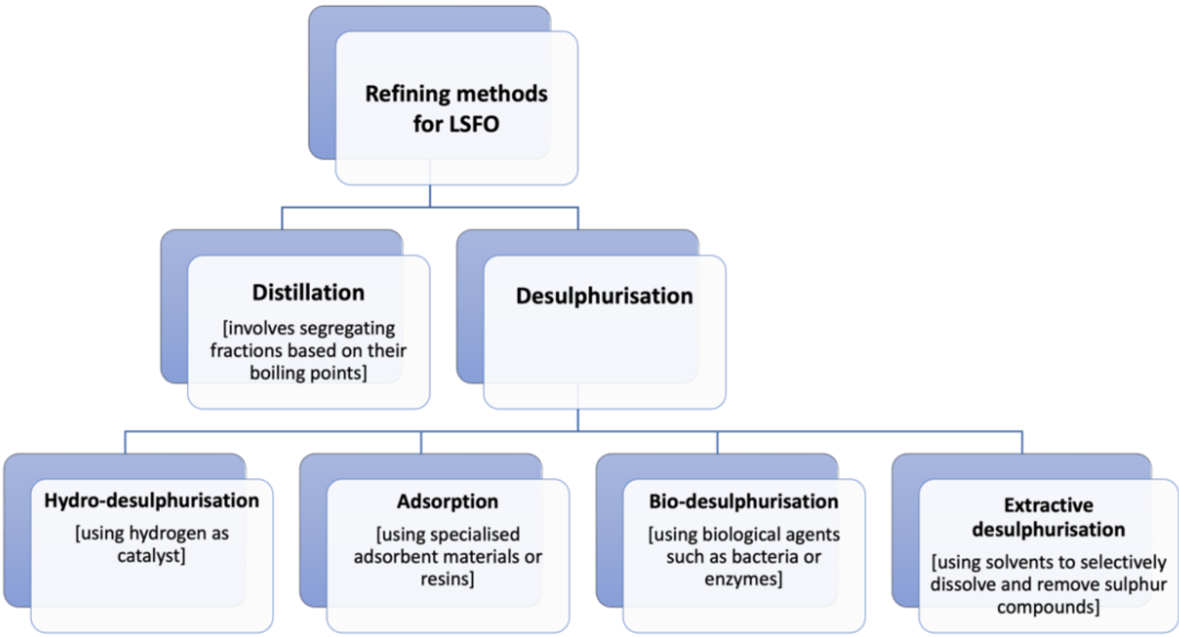


***Figure 1**. Primary methods for refining LSFO*

3.2.2. Chemical composition, density, pour point, viscosity, flash point, and evaporation rate

The chemical and physical properties of LSFO vary significantly due to differences in refining methods and crude oil sources. LSFO for use in ECAs are divided into two categories, very low-Sulphur fuel oils (VLSFO) and ultra-low-Sulphur fuel oil (ULSFO). LSFOs comprise hydrocarbons of various chemical compositions and physical properties, and have Sulphur content as the common characteristic, even though those oils still have to comply with regulations (ISO 8217:2024).

Table 2 consolidates findings on key properties from several research projects conducted with the aim of providing better knowledge of LSFO in order to prepare for oil spills response.

***Table 2**. Core chemical and physical properties of LSFO*

Property	Range (Min - Max)	Average	Key Observations
Asphaltenes (% wt)	0.14 - 12.5	Varies by study	High variability, influencing viscosity and pour point.
Wax Content (% wt)	4.4 - 21.6	Varies by study	High wax content correlates with higher pour points and potential for solidification.
Density (g/mL)	0.867 - 0.990	Varies by study	All densities are below 1, suggesting LSFO will generally float on seawater.
Pour Point (°C)	-36 to +30	Highly variable	Affects solidification and behaviour in colder waters.
Viscosity (mPa.s)	24.8 - 800,000 (depending on temperature)	Increases with weathering	Viscosity significantly affects spreading and recovery techniques.
Flash Point (°C)	75 - 174.5	Above safety threshold	High flash points ensure safe handling during storage and transport.
Evaporation Rate (%)	<5 - 28.2	Varies by oil type	Low evaporation rates reduce risks of volatile hydrocarbon plumes but increase persistence.

Details from specific studies (e.g., Sørheim, IMAROS, Gilbert) are presented in **Annex II**. These studies provide valuable insights into LSFO variability and their implications for spill response.

3.3. Properties of alternative fuels

3.3.1. Hydrogen

Hydrogen is a clean energy alternative with significant potential for maritime applications. It can both be used to fuel a combustion engine or a fuel cell, even if only combustion engines have been developed for the maritime sector. Its core properties, along with associated risks, are summarized in **Table 3**. Hydrogen is characterized by its low density, wide flammability range, and highly reactive nature, which present unique challenges for storage, handling, and spill response. Further discussion on risks related to cryogenic storage, leaks, and hydrogen embrittlement can be found in **Annex II**.

Table 3. Core chemical and physical properties and associated risks for hydrogen

Property	Value/Behaviour	Risk/Impact
Boiling Point	-253°C	Stored as a cryogenic liquid; significant risks of frostbite and structural brittleness at low temperatures.
Vapour Pressure	Very high	High risk of leaks through joints and cracks; requires advanced containment.
Flammability Range	4.0 – 75.0% (v/v in air)	Extremely wide flammability range increases explosion risk.
Minimum Ignition Energy	0.017 mJ	Highly sensitive to ignition, even from static electricity or mechanical sparks.
Specific Gravity	0.071 (liquid); 1.338 (gas at -253°C)	Liquid hydrogen floats; cryogenic vapour clouds can linger and pose explosion hazards.
Marine Pollution Risk	Minimal	Non-toxic and non-bio-accumulative.

3.3.2. Ammonia

Ammonia is an emerging alternative fuel for maritime applications at an early stage of technological maturity. Like hydrogen, it could be used in combustion engines, typically in dual-fuel engines, or fuel cells. Its high solubility in water, significant toxicity to marine life, and potential for rapid evaporation in warmer waters require specific attention in spill scenarios. **Table 4** summarises the core chemical and physical properties of ammonia and the associated risks with its use as a marine fuel. Ammonia's behaviour in various spill scenarios, including leak dynamics and environmental interactions and other information are elaborated in **Annex II**.

Table 4. Core chemical and physical properties and associated risks for ammonia

Property	Value/Behaviour	Risk/Impact
Boiling Point	-33.3°C	Stored as a liquid under pressure; rapid evaporation upon release.
Flammability Range	15.5 – 27.0% (v/v in air)	Flammable only within a narrower range compared to hydrogen.
Toxicity	Acute toxicity for humans (skin and respiratory)	Causes burns and respiratory damage; toxic even at low concentrations. According to the GORSAP scale, ammonia is a very dangerous chemical for human health as it can cause irreversible damage
Solubility	529 kg/m³	Highly soluble in water; forms ammonium hydroxide (NH_4OH) with exothermic reaction.
Marine Pollution Risk	Toxic to aquatic organisms	Non-bio-accumulative but highly toxic to marine life due to alkalinity and ammonium formation.

3.3.3. Liquefied Natural Gas (LNG)

LNG primarily composed of methane (85% methane content), is a well-established alternative fuel with extensive use in maritime operations. This technology is already installed in a few hundreds of ships. Its low density and non-persistent nature in the environment make LNG less impactful in spill scenarios compared to traditional fuels. **Table 5** summarizes the core chemical and physical properties and associated risks for LNG. More detailed analysis of the proprieties, the associated risks, among others fire/explosion risks and structural issues are presented in **Annex II**.

Table 5. *Core chemical and physical properties and associated risks for LNG*

Property	Value/Behaviour	Risk/Impact
Boiling Point	-162°C	Stored cryogenically; rapid evaporation upon release.
Flammability Range	5 – 15% (v/v in air)	Highly explosive under favourable conditions.
Specific Gravity	0.415 – 0.45 (liquid); 1.5 (vapour at -162°C)	Floats on water as liquid; cold vapour clouds can linger and pose ignition hazards.
Marine Pollution Risk	Minimal	Non-persistent and non-bio-accumulative; low environmental toxicity, according to the GORSAP scale

3.3.4. Methanol

Methanol is a highly flammable alternative fuel with the advantage of being compatible with existing engines with minimal modification. While methanol poses significant risks due to its toxicity and low flash point, it is less persistent in the marine environment due to its miscibility and biodegradability. **Table 6** summarises the core chemical and physical properties and the associated risks with the use for methanol as a marine alternative fuel. Further discussion on methanol proprieties, and associated risk can be found in **Annex II**.

Table 6. *Core chemical and physical properties and associated risks for methanol*

Property	Value/Behaviour	Risk/Impact
Boiling Point	64.5°C	Stays liquid at ambient conditions; vaporizes upon heating.
Flammability Range	6.0 – 36.5% (v/v in air)	Highly flammable; risk of invisible flames complicates fire management.
Toxicity	Toxic via ingestion, inhalation, and skin contact	Environmental risks are comparatively lower due to biodegradability. According to the GORSAP scale, methanol is a slightly dangerous chemical for human health that can cause reversible damage.
Marine Pollution Risk	Low	Fully miscible and biodegradable in water; less impactful than traditional fuels.

3.4. Behaviour of low-Sulphur and alternative fuels in the marine environment

Understanding the behaviour of low-Sulphur and alternative fuels in the marine environment is essential for effective spill response planning. This section summarizes the general behaviour of these substances based on key properties such as solubility, density, vapour pressure, and viscosity. Critical environmental factors influencing these behaviours, including temperature, salinity, and agitation, are also highlighted.

3.4.1. General behaviour of substances

Table 7 below summarises the general behaviour of low-Sulphur and alternative fuels in the marine environment, focusing on properties that determine their interaction with water, air, and the ecosystem. More detailed and case-specific behaviour of the studied substances are presented in **Annex II**.

Table 7. *Overview of general behaviour of substances in the marine environment*

Property	Definition	Impact on Behaviour
Solubility	Ability of a substance to dissolve in water.	Determines the extent to which the fuel mixes with the water column, affecting dispersion and dilution.
Density	Ratio of fuel density to water density (1.025 for seawater).	Fuels with density <1.025 float, while those >1.025 tend to sink or suspend in the water column.
Vapour Pressure	Pressure at which fuel evaporates at a given temperature.	High vapour pressure fuels evaporate quickly, releasing vapours into the atmosphere.
Viscosity	Measure of a fuel's resistance to flow.	Low-viscosity fuels spread quickly; high-viscosity fuels form thick slicks, complicating recovery efforts.

3.4.2. Weathering processes for low-Sulphur fuels

Low-Sulphur fuels undergo several weathering processes when spilled in the marine environment, including evaporation, emulsification, dispersion, and biodegradation of their lighter fractions. The behaviour of these fuels is heavily influenced by their physical and chemical properties, as well as environmental conditions. **Table 8** below highlights how specific environmental parameters impact the weathering processes of spilled fuels. Detailed discussion and breakdown of specific weathering behaviours are presented in **Annex II**.

Table 8. *Key environmental factors influencing weathering processes*

Environmental Parameter	Evaporation	Spreading	Emulsification	Dispersion	Sedimentation	Biodegradation
Temperature	+	+	-	+		+
Salinity				-	-	
Water Agitation	+	+	+	+	+	
Sunlight (UV)	+	+				
Wind	+	+				

Legend: (+) sign indicates a condition favouring weathering; (-) sign indicates a condition opposing weathering

3.4.3. Behaviour of alternative fuels in the marine environment

Alternative fuels such as hydrogen, ammonia, LNG, and methanol exhibit unique behaviours in the marine environment due to their distinct physicochemical properties.

Alternative propulsion energies, employed in the form of cryogenic liquids such as LNG (-162°C) and hydrogen (-253°C), or cold liquids like ammonia (-33°C), may react violently when accidentally released into the sea, a phenomenon referred to as rapid phase transition (RPT). RPT denotes an explosive vaporization (a physical explosion, without flame). Energetic RPTs are more likely to occur in areas where a cryogenic liquid and water are disturbed, either by wave action or the impact of a jet entering the water. These physical explosions can be likened to localized detonations, generating a shockwave that propagates through the surrounding environment. However, the energy released remains limited in comparison to typical chemical explosions. The likelihood of the phenomenon appears to increase when the volume spilled is substantial and the duration of the release is prolonged (Melhem et al., 2006).

In addition to the pressure effects, RPTs lead to the ejection and dispersion of bursts of cryogenic liquid and gas (likely mixed with fragmented water), which is distinct from the usual dispersion of a vapor cloud resulting from regular heat transfer. This phenomenon increases the average evaporation rate and represents a significant risk.

Table 9 summarises the different behaviours of these fuels once released into the marine environment. Additional details on case-specific scenarios for each alternative fuel are provided in **Annex II**.

Table 9. *Overview of behaviour of hydrogen, ammonia, LNG and methanol in the event of spill to marine environment and key considerations for spill response*

Fuel	Behaviour in Marine Environment	Key Considerations for Spill Response
Hydrogen	Light gas that disperses rapidly in open air; cryogenic hydrogen forms cold vapour clouds.	Monitor for explosive vapours; avoid leaks in confined or poorly ventilated spaces.
Ammonia	Rapid evaporation with highly toxic vapours; forms ammonium hydroxide in water.	Focus on minimizing human exposure and monitoring ammonium and nitrates in the water column.
LNG	Floats on water, evaporates rapidly; cryogenic vapours initially heavier than air.	Prioritize containment and monitoring for fire/explosion risks from vapour clouds.
Methanol	Miscible with water, quickly biodegrades; partially evaporates depending on environmental factors.	Manage fire risks from low flash point; rapid dilution limits long-term environmental impact.

3.5. Environmental risk assessment

The environmental risk assessment evaluates the potential impacts of low Sulphur and alternative fuels on marine ecosystems and human health. It focuses on ecotoxicity, persistence, and hazards associated with spills or releases of these fuel types.

3.5.1. Low Sulphur fuels

Ecotoxicity studies of low-Sulphur fuels (LSFO) indicate variable toxicity levels across different marine species, influenced by the chemical composition of the fuels. The key findings from ecotoxicity tests conducted during the IMAROS study are summarized in **Table 10**.

Table 10. *Key findings from ecotoxicity tests conducted during the IMAROS study for LSFO*

Ecotoxicity Parameter	LSFO 1	LSFO 2	LSFO 3	Key Observations
Algae (LC_{50})	No toxicity observed (> WAF max)	No toxicity observed (> WAF max)	No toxicity observed (> WAF max)	LSFO shows limited toxicity to algae, similar to traditional fuels.
Copepods (LC_{50}, g/L WAF)	0.11	3.04	0.81	Significant variability; LSFO 1 exhibited higher toxicity to copepods compared to LSFO 2 and LSFO 3.
Amphipods (LC_{50}, mg/kg)	542	2,124	266	Amphipods are relatively sensitive to LSFO, particularly LSFO 3, due to its higher hydrocarbon content.

Key Insights:

- LSFO toxicity generally falls within the range observed for traditional heavy fuel oils.
- Variability in ecotoxicity depends on specific chemical characteristics like asphaltene and wax content.

3.5.2. Alternative fuels

Alternative fuels exhibit distinct risks to human health and the environment based on their chemical and physical properties. The comparative **Table 11** below summarizes the key environmental and health risks associated with hydrogen, ammonia, LNG, and methanol. Additionally, further details on specific ecotoxicity tests for individual alternative fuel types and additional context, are presented in **Annex II**.

Table 11*. Key environmental and health risks associated with hydrogen, ammonia, LNG, and methanol*

Fuel Type	State in Marine Environment	Toxicity to Humans	Toxicity to Marine Life	Key Risks
Hydrogen	Non-toxic, buoyant gas; dissipates quickly in open air.	Minimal (asphyxiation risk only)	Non-toxic, non-bio-accumulative.	Explosivity, cryogenic burns, and asphyxiation risks from vapour clouds in confined areas.
Ammonia	Soluble; forms ammonium hydroxide with water.	Acutely toxic (skin, respiratory).	Highly toxic; harms aquatic life.	Risks from toxic vapours, burns, and water contamination with ammonium hydroxide.
LNG	Floats; evaporates rapidly; cryogenic vapours linger.	Minimal (asphyxiation risk only).	Non-toxic, non-persistent.	Explosivity, cryogenic injuries, and vapour ignition risks.
Methanol	Miscible; biodegrades rapidly in water.	Toxic (inhalation, ingestion).	Low toxicity; non-persistent.	Fire risk from low flash point; minimal long-term impact due to rapid dilution and biodegradation.

Key Insights:

- Hydrogen and LNG present minimal toxicity but pose significant physical hazards due to flammability and cryogenics.
- Ammonia's acute toxicity to humans makes it a high-risk fuel. However, its ecotoxicity to marine life decreases quickly as it is converted into nitrate ions, which can be assimilated by algae.
- Methanol has lower environmental risks but higher flammability concerns compared to other alternative fuels.

3.6. Discussion: Preparedness for spills from low Sulphur and alternative fuels

The Mediterranean region's distinctive environmental, ecological, and operational characteristics present both opportunities and challenges in managing spills of low-Sulphur and alternative fuels. This discussion explores the implications of the fuel properties for spill response, examines the gaps in existing preparedness, and highlights how conventional response frameworks may fall short in addressing the unique challenges posed by these emerging fuels.

	State		Longevity in the environment	Flammability	Toxicity to humans	Health & Safety: Main Concerns	Protracted Response to recover pollutant
	Under Ambient conditions	During transport					
Biofuels	Liquid	Liquid	Weeks to months	<5% flammable range	Toxic (direct contact)	Low risk from initial exposure. Toxicity poses a risk if exposed for extended periods	Likely
Liquefied Natural Gas (LNG)	Gas	Liquid (cryogenic)	Hours to days	5 - 20% flammable range	Non-toxic	Significant risks linked to flammability, explosivity, asphyxiation, and cryogenic temperatures	Unlikely
Liquefied Petroleum Gas (LPG)	Gas	Liquid (pressurised and refrigerated)	Hours to days	5 - 20% flammable range	Non-toxic	Significant risks linked to flammability, explosivity, asphyxiation, and extreme low temperatures	Unlikely
Hydrogen	Gas	Liquid (cryogenic), or pressurised gas	Hours to days	>20% flammable range	Non-toxic	Significant risks linked to flammability & explosivity	Unlikely
Ammonia	Gas	Liquid (pressurised and refrigerated)	Hours to days	5 - 20% flammable range	Acutely toxic (vapours and upon direct contact)	Immediate risk in vicinity of substance, high toxicity with particular risk from vapours	Unlikely
Methanol	Liquid	Liquid	Hours to days	>20% flammable range	Toxic (direct contact & inhalation of vapours)	Significant risks linked to toxicity & flammability	Unlikely

Source: (ITOPF, 2024)

Implications of fuel properties for spill response

LSFO presents significant challenges due to its physical and chemical characteristics. Its persistence in the marine environment, driven by low evaporation rates and high viscosity, could complicate clean-up efforts and require extended recovery operations. The rapid emulsification of LSFO in the Mediterranean's warm waters may exacerbate the problem, creating stable water-in-oil emulsions that are difficult to manage. The effectiveness of chemical dispersants would be further limited by LSFO's variable viscosity, often necessitating mechanical recovery methods that are resource-intensive and time-consuming.

Alternative fuels introduce an entirely new set of challenges. Hydrogen, for example, poses minimal environmental risks but presents considerable safety concerns for responders due to its wide flammability range and low ignition energy, especially in confined spaces. Ammonia, while emerging as a potential maritime fuel, is highly toxic to both humans and marine ecosystems. Rapid containment of ammonia spills is crucial to prevent severe ecological impact and health impacts to responders and local communities. LNG, on the other hand, evaporates quickly and does not persist in the environment, but its cryogenic properties and the risk of asphyxiation or explosion from cold vapour clouds make it uniquely hazardous for responders and local communities. Methanol, while less persistent and less ecologically damaging, presents challenges due to its low flash point and invisible flames, complicating fire response operations.

Gaps in preparedness for alternative fuel spills

Preparedness frameworks for marine fuel spills have traditionally focused on conventional heavy and light fuel oils. These frameworks, however, are inadequate for managing the complexities associated with low-Sulphur and alternative fuels.

The persistence of LSFO and its weathering behaviours requires modifications to existing mechanical recovery techniques and dispersant application strategies. Moreover, the lack of specialized equipment for handling high-viscosity emulsions may delay effective response, increasing the potential for environmental damage.

The challenges posed by alternative fuels further expose critical gaps in the current spill response infrastructure. Most response frameworks lack the necessary detection systems, containment technologies, and safety protocols to address the risks associated with alternative fuels like hydrogen, ammonia, and LNG. For instance, ammonia spills require specialized gas detection systems and protective equipment that are not commonly available in many CPs' ports. Similarly, the cryogenic risks associated with LNG spills demand advanced handling tools and training that are absent in conventional response setups.

Regional environmental and operational constraints

The Mediterranean region's unique environmental and operational conditions compound the challenges of spill response. Warmer sea surface temperatures accelerate evaporation rates for light fuels (i.e., ammonia and methanol), but they also increase emulsification rates for fuel oils (i.e., LSFO), complicating recovery operations. High salinity levels in the Mediterranean region further alter the behaviour of spilled fuels, potentially driving denser fractions into the water column and complicating recovery efforts. Limited wave action in calmer areas of the Mediterranean region restricts natural dispersion, necessitating active intervention and advanced containment strategies. **Annex II** provides an overview of how environmental conditions influence the behaviour of LSFO and alternative fuel spills, drawing on data from various sources such as Safety Data Sheets (SDS), the MIDISIS-TROCS database[31], and findings from research initiatives like IMAROS and AMSA.

Ecological sensitivity adds another layer of complexity. The Mediterranean region hosts a wide array of vulnerable ecosystems, including seagrass meadows, coral reefs, and wetlands. Spills of toxic fuels, such as ammonia, pose significant threats to these habitats, while the proximity of spills to coastal areas heightens risks to fisheries, tourism, and human health. Current response systems are not adequately equipped to mitigate these ecological and socio-economic impacts, especially when dealing with alternative fuels.

Operational constraints also reveal systemic gaps in preparedness. Many CPs' ports lack the infrastructure and equipment required to handle spills of alternative fuels. Hydrogen and ammonia, for example, require specific containment and recovery technologies that are rarely available at the regional level. The region and CPs fragmented regulatory environment and geopolitical complexities further hinder coordinated spill response efforts. High maritime traffic in the region exacerbates these challenges, increasing the probability of spills and underscoring the need for robust and adaptive response frameworks.

[31] "The Maritime Integrated Decision Support Information System on Transport of Chemical Substances (MIDSIS-TROCS) was developed by REMPEC, with the support of IMO, HELCOM, Bonn Agreement, CEDRE, Royal Belgian Institute of Natural Sciences, Transport Canada (CANUTEC), and ITOPF. Financial support for its development was provided by the European Union under the West MOPoCo project and Mediterranean Technical Working Group (MTWG). MIDSIS-TROCS integrates chemical spill behavior classification systems, emergency guides, and databases like CAMEO and WISER, offering both offline and online tools to assist responders. Updated regularly since its inception in 2001, the tool reflects state-of-the-art practices for addressing marine chemical emergencies. Access MIDSIS-TROCS here.

Concluding remarks

Similar to other ECAs, the transition to low-Sulphur and alternative fuels in the maritime sector introduces unprecedented challenges for spill response in the Mediterranean region. Existing preparedness frameworks within the CPs, designed primarily for conventional fuels, are ill-equipped to address the unique hazards and behaviours of these new fuel types. The gaps within the CPs in equipment, training, and regional coordination underscore the urgent need to rethink spill response strategies, particularly in light of the Mediterranean region's ecological sensitivities and operational constraints. Addressing these gaps will require targeted interventions to ensure the safety of responders and the protection of marine and coastal environments.

To support CPs in overcoming these challenges, **Annex III** serves as a dedicated guide to enhance national preparedness for accidental releases of low-Sulphur fuels and select alternative fuels, including ammonia, LNG, and methanol.

4. BEST PRACTICES AND INNOVATIVE SOLUTIONS

This chapter presents a compilation of best practices in other ECAs and the innovative solutions for the implementation of response measures to address accidental releases of low-Sulphur and alternative fuels into the marine environment. Additionally, the best practices, strategies, and innovative solutions from selected ECAs outside the Mediterranean region are summarized. The chapter further evaluates the effectiveness of these practices and solutions in dealing with fuel spills.

4.1. Best practices

4.1.1. Monitoring systems

CleanSeaNet (North Sea and Baltic Sea ECA)

In the North Sea and Baltic Sea ECAs, real-time monitoring systems track ship emissions and detect accidental spills promptly. A critical component is CleanSeaNet, a satellite-based system managed by EMSA. CleanSeaNet[32] uses Synthetic Aperture Radar (SAR) images, which offer night-and-day coverage, unaffected by fog or clouds, to detect oil spills and vessel movements. The satellite data provides actionable intelligence for emergency responses, helping authorities trace pollution sources efficiently.

Additionally, vessels above 5,000 GT are equipped with onboard emission monitoring systems that notify authorities of any fuel leakages or deviations from permitted emission levels. This reduces response times to fuel spills, preventing further environmental damage.

This service is soon expected to be available to countries bordering the Mediterranean Sea.

Satellite surveillance coupled with sail drone technology (North American ECA)

In the North-American ECA, the U.S. Coast Guard (USCG) employs satellite surveillance and sail drone technology (low-cost unmanned surface system) to detect and monitor spills, enabling rapid response[33].

The benefit from CleanSeaNet can be enhanced by integrating its satellite data with sail-drone data and AI-powered predictive models to forecast spill drift and potential impact zones.

Post-incident monitoring teams (UK's National Contingency Plan)

The UK's National Contingency Plan (NCP) also provides for post-incident monitoring teams to conduct environmental assessments, ensuring long-term recovery efforts align with ecological needs[34].

4.1.2. Stakeholder Integration and Training Programs

Cross-border cooperation for coordinated pollution control flights (HELCOM)

[32] CleanSeaNet is a European satellite-based oil spill and vessel detection service which offers assistance to participating States for the following activities: Identifying and tracing oil pollution on the sea surface; Monitoring accidental pollution during emergencies; Contributing to the identification of polluters. https://Contracting.emsa.europa.eu/csn-menu.html

[33] Congress tasked USCG with examining the feasibility, costs, and benefits of improving maritime domain awareness in the remote Pacific Ocean using a low-cost unmanned surface system https://Contracting.saildrone.com/news/uscg-test-maritime-domain-awareness-solution

[34] UK National Contingency Plan for responding to marine pollution incidents https://assets.publishing.service.gov.uk/media/668d41974a94d44125d9cf9c/National_Contingency_Plan_-_June_2024.pdf

The Baltic Sea, under the HELCOM framework, emphasizes cross-border cooperation and preparedness through regular simulated spill drills and emergency response exercises. HELCOM's collaborative framework ensures coordinated responses to marine pollution incidents. These joint operations include Coordinated Extended Pollution Control Operation (CEPCO) flights and the exchange of real-time surveillance data, enhancing situational awareness across participating states[35].

The Mediterranean region could benefit from adopting a contingency plan based on the UK model, with cross-border coordination facilitated by REMPEC to align national strategies and pool resources effectively.

Periodical simulation exercises (UK's National Contingency Plan)

The UK's Maritime and Coastguard Agency (MCA) oversees marine pollution management and conducts National Contingency Plan (NCP) simulation exercises every 18 months to assess preparedness. Public communication plays a critical role in their framework, ensuring transparency and real-time updates during incidents.

National plan coordination (Australian Maritime Safety Authority)

For pollution response, AMSA cooperates with state and territory agencies, and industry stakeholders to respond to pollution incidents. Their capabilities include the use of specialized equipment, oil spill remediation and prosecution of the perpetrators[36].

AMSA also actively collaborates with universities and industry to improve biodegradation techniques for alternative fuels, based on the latest research.

4.1.3. Pre-Positioned inventories of Specialized Equipment

Regional Stockpiles (ROPME Sea Area)

In the ROPME Sea Area, the *Regional Contingency Plan to Combat Pollution of the Sea (ChemPlan)* is supported by four regional stockpiles of tier 2/3 equipment are operated through the Marine Emergency Mutual Aid Centre (MEMAC) and MERCU.

Pre-positioned inventories (North American ECA)

Specialized pollution control equipment, such as lightweight skimmers and high-efficiency booms, is pre-positioned in high-risk areas across the North American ECA which ensures quick response. The network of Area Contingency Plans (ACPs) in the U.S. integrates government, industry and environmental organizations in regular training exercises to improve response capabilities[37].

Vessel of Opportunity Programs (North American ECA)

Vessel of Opportunity (VOO) programs, which involve private-sector partnerships with local fishing vessels, have proven effective in mobilizing resources for large-scale spill incidents. Establishing a Mediterranean VOO network could significantly enhance spill response capacity in remote or politically sensitive areas[38].

---

[35] HELCOM manual on cooperation in response to marine pollution https://helcom.fi/wp-content/uploads/2021/03/HELCOM-Manual-on-Co-operation-in-Response-to-Marine-Pollution.pdf

[36] Pollution response in Australia https://Contracting.amsa.gov.au/marine-environment/pollution-response

[37] Environmental response equipment divided into containment, collection, storage, command and support https://Contracting.ccg-gcc.gc.ca/environmental-environnementale/environmentalresponse-eng.html

[38] VOO established after 2020 BP Deepwater Horizon oil spill https://Contracting.fws.gov/media/voo-vessels-opportunity-boat-charter-after-2010-bp-deepwater-horizon-oil-spill

4.1.4. Coordinated regional response frameworks

Sulphur Inspectors as shared expertise (North Sea and Baltic Sea)

The Bonn Agreement in the North Sea and HELCOM in the Baltic Sea facilitate joint training exercises and the sharing of expertise (Sulphur inspectors) to improve regional coordination. These frameworks demonstrate that real-time communication and resource-sharing mechanisms can reduce response times which minimises environmental damage. Such coordinated regional response frameworks are essential for addressing cross-border incidents effectively, as they enable Contracting Parties to pool resources, harmonize operational procedures, and ensure a consistent approach to enforcement and response measures. For example, shared expertise from Sulphur experts and inspectors not only strengthens compliance monitoring but also provides valuable data to refine response strategies and enhance preparedness for future incidents. These frameworks furthermore foster trust and collaboration among CPs, contributing to long-term regional resilience.

Given the Mediterranean region's unique and complex dynamics, a regional coordination framework aligned with the Barcelona Convention is essential to manage cross-border spill responses effectively. REMPEC could play a central role in fostering collaboration among Contracting Parties, enabling rapid deployment of resources and expertise.

Fuel-specific protocols (Australian Maritime Safety Authority)

Australia's National Plan for Maritime Environmental Emergencies outlines protocols for alternative fuels like LNG and methanol. LNG presents unique risks, such as cryogenic burns and explosions, requiring specialized Personal Protective Equipment (PPE) and response tools.

Developing fuel-specific protocols for LNG, methanol, and biofuels in the Mediterranean would enhance the region's readiness to manage future incidents.

ChemPlan (ROPME Sea Area)

In the ROPME Sea Area, the *Regional Contingency Plan to Combat Pollution of the Sea (ChemPlan)* resources include an interactive chemical spill trajectory computer mode (CHEMMAP)[39], Contingency Plan Decision Support Software, computer-Aided Model for Emergency Operations, Aerial Locations of Hazardous Atmosphere, Chemical Hazard Response Information System, Computerized IMG Code, Milbros Chemical Information system, Marine Oil spill Information System, Oil Spill Response Atlas, ChemAlert and ChemData.

Designation of authorities for pollution preparedness and response (NOWPAP)

Each NOWPAP Member, under the *Regional Oil and HNS spill contingency plan* should designate national authorities and points of contact[40] as obliged by OPRC 1990 and OPRC-HNS Protocol 2000.

Table 12 summarizes the best practices, strategies, and innovative solutions from selected ECAs outside the Mediterranean region.

---

[39] Regional contingency plan to combat pollution of the sea by hazardous and noxious substances https://memac-rsa.org/assets/fileManager/12_1_HNS_Plan-1st_Draft-10_sep_2011Ahd.pdf

[40] NOWPAP regional oil HNS spill contingency plan for the Northwest pacific region https://wedocs.unep.org/handle/20.500.11822/26368

Table 12. *Best Practices and Innovative Solutions in Existing ECAs*

Emission Control Area (ECA)	Existing Strategies	Best Practices/ Innovations	Applicability to Low-Sulphur and Alternative Fuels
North Sea ECA[41]	Real-time monitoring of ship emissions and spills Advanced onboard emission monitoring for ships >5,000 GT SAR satellite monitoring (via EMSA CleanSeaNet) Aerial surveillance exercises Centralized spill data collection	EMSA satellite surveillance for oil spills Network of Vessels of Opportunity (VOO) Joint training drills	Coordinated protocols for spills from alternative fuels Scrubbers and LSF systems monitored for wash-water impacts
Baltic Sea ECA[42]	HELCOM response plans for oil and chemical spills with recovery vessels Use of oil spill recovery vessels Real-time chemical spill modelling collaboration LNG bunkering infrastructure development	Predictive spill modelling tools Specialised training for Sulphur inspectors LNG bunkering infrastructure development	Ensures readiness for alternative fuel and LSF spills Jointly addresses chemical and biofuel risks LSF bunkering infrastructure development
North American ECA[43]	Synthetic Aperture Radar (SAR) and multispectral satellite imagery analysis Partnerships with private sector oil spill response organisations through use of a vessel of opportunity program Cryogenic booms for LNG spills	Use of unmanned Sail drones for oil spill detection Partnership with private response organizations (VOO network)	Use of drones Use of VOO
UK[44]	National Contingency Plan (NCP) for marine pollution response Regular simulation exercises every 18 months UK Response and Salvage Team trained for multi-fuel spills Multilateral agreements to share expertise and resources	Public communication integrated into contingency plans	Proper and well-coordinated preparation for a variety of fuel types
Chinese ECAs and Hong Kong ECA[45]	the master and owner of any vessel using non-compliant fuel within the waters of Hong Kong will be liable to a fine of up to HKD 200,000 (USD 25,000) and/or imprisonment for six months. Masters and shipowners who fail to record and keep the aforementioned records and particulars will, in addition, be liable	LNG bunkering trials Air quality monitoring at critical ports Strong punishment	Fuel-specific spill drills conducted Integrated LNG and chemical response measures Introduce penalties

[41] Bonn Agreement: UK, Norway, Germany, Netherlands, Belgium, Denmark, Sweden
[42] HELCOM Agreement (Helsinki Convention): Finland, Sweden, Poland, Estonia, Latvia, Lithuania, Germany, Denmark
[43] Canada-U.S. Joint Marine Pollution Contingency Plan
[44] UK: National Contingency Plan
[45] Hong Kong, China: Local Maritime Regulations

	to a fine of up to HKD 50,000 and/or imprisonment for three months[46].		
Korean ECA[47]	Released a special Act on improvement of air quality in port areas Sulphur restriction: From 1 September 2020 it is mandatory to use fuel with max. 0.1% Sulphur content while berthing. Vessels required to use max 0.1% Sulphur fuel when berthing/anchoring for the times set out below: Berthing: 1 hour after completion of berthing until 1 hour before unberthing Anchoring: 1 hour after completion of anchoring until 1 hour before weighing anchor From 1 January 2022: It is mandatory to use fuel with max. 0.1% Sulphur content while navigating ECAs. Ships should navigate no faster than a maximum speed of 12 knots for container ships and car-carriers, 10 knots for other ship types, when moving from starting point to an end point within defined Sea Area. Lower speed pays off: Under the **Vessel Speed Reduction** (VSR) Programme, ships will have their port facilities fees lowered when they enter defined port areas[48] at specified speed levels. For affected ships, port entry/leave fee (currently 111 KRW per ton), will be discounted. The discount ceiling will differ between the ports. Container ships, for example, which traditionally enters port at relatively high speeds, will enjoy up to a 30% discount, while other ships will be granted a 15% discount.	Phased Sulphur limit enforcement Vessel Speed Reduction (VSR) incentivises lower speeds with discounts	Fuel transition readiness ensures LNG and LSF spill management “Lower speed pays off” principle ensures smooth compliance

4.2. Innovative solutions for pollution response in the Mediterranean

4.2.1. AI-powered predictive models

AI and machine learning enable predictive spill models that analyse shipping traffic, weather patterns, and environmental data to forecast high-risk zones. In the Baltic Sea, AI has reduced response times by optimising the allocation of resources. Implementing AI-based models

[46] China’s MSA introduced their ECA 0.5% Sulphur content restriction obligation by a gradual process https://maritime-mutual.com/risk-bulletins/china-ecas-hong-kong-waters-outpace-the-imos-2020-0-5-Sulphur-cap/
[47] South Korea
[48] A new ECA and speed reduction limits in South Korean ports. https://Contracting.dnv.com/news/a-new-eca-and-speed-reduction-limits-in-south-korean-ports-173622/

tailored to Mediterranean currents would improve the region's ability to anticipate spill drift and minimise environmental impact.

4.2.2. Next-Generation dispersants

Next-generation eco-friendly dispersants are designed to address, among others, the unique challenges posed by low-Sulphur fuels (LSF) and biofuels, which, while less persistent than heavy fuel oils in some cases, can still exhibit significant ecological impacts in marine environments. These dispersants prioritize rapid biodegradability, reduced toxicity, and targeted efficacy without compromising environmental safety. Unlike dispersants formulated for heavy fuel oils, these formulations are specifically engineered to break down alternative fuels and bio-fuels while minimizing long-term ecological harm and residue accumulation in marine ecosystems.

The Mediterranean region, characterized by higher salinity levels and seasonal temperature variations, would benefit from deploying biodegradable dispersants specifically adapted to these local conditions. particularly in marine protected areas. Deploying these dispersants in the Mediterranean would enhance pollution response, especially in sensitive habitats in the Marine Protected Areas (MPAs), if the chemical dispersion be authorized by the relevant authorities in charge of the response.

Any such authorisation would require adoption of national standards in accordance with international frameworks, such as the IMO guidelines for dispersant use, as well as regional protocols, and rigorous qualification tests to ensure they meet the required standards and can be applied under the local conditions.

4.2.3. Bioremediation techniques

Bioremediation employs microbial organisms to degrade fuel spills, leveraging natural processes to minimize environmental harm. This technique has proven effective in regions such as Canada and the Gulf of Mexico, where targeted microbial consortia have been used to accelerate the breakdown of hydrocarbons. Advances in research are focusing on developing fuel-specific microbial strains and enzyme-based solutions that optimize degradation under specific environmental conditions.

However, the effectiveness of bioremediation can vary significantly depending on factors such as the type and quantity of the spilled fuel, the environmental conditions, and the availability of nutrients necessary for microbial activity. For instance, while bioremediation is highly effective for lighter hydrocarbons, its efficiency diminishes with heavier, more complex compounds, which are slower to degrade.

In the Mediterranean's warmer climate, bioremediation holds significant potential, as elevated temperatures can enhance microbial activity and accelerate degradation processes. Nevertheless, its application should be carefully evaluated on a case-by-case basis, considering factors such as the spill's location, the extent of contamination, and the vulnerability of the affected ecosystem.

Moreover, bioremediation is not a rapid-response technique; it requires time to achieve measurable results and is best suited for managing the long-term aftermath of spills rather than addressing immediate acute impacts. Complementary methods, such as dispersants or mechanical recovery, may be necessary to mitigate initial damage before bioremediation can be effectively deployed. Bioremediation should be considered as a supplementary technique to be employed towards the end of a clean-up operation

Tailored microbial solutions, potentially enriched with bio-stimulants or bio-augmentation techniques, could further enhance bioremediation in the Mediterranean. These strategies would be particularly valuable in addressing localized contamination in ecologically sensitive areas, such as MPAs, where minimizing chemical interventions is critical. While bioremediation offers a sustainable and eco-friendly approach to pollution management, its use must be integrated within a broader spill response strategy to ensure both immediate and long-term environmental protection.

4.2.4. Drone and satellite surveillance for spill detection

The North Sea uses drones equipped with infrared cameras and chemical sensors for real-time spill monitoring.

Similarly, Synthetic Aperture Radar (SAR) satellites provide data even in adverse weather conditions.

Implementing a Mediterranean-wide drone network in conjunction with impending CleanSeaNet implementation for all Mediterranean Sea States would enhance spill detection and improve response times across the region, especially in remote areas.

4.2.5. Containment and recovery

The priority in maritime response to an oil spill is its containment and subsequent pumping. Containment serves to reduce the surface area of the spill, thereby increasing its thickness, which, in turn, enhances the efficiency of recovery devices. This approach should be favoured in the case of low-sulphur oil spills, which are often high-viscosity petroleum products.

The selection of the recovery equipment (skimmer) is determined by various environmental factors (sea state, depth, presence of ice or debris, etc.), technical considerations (selectivity, efficiency, flow rate, support vessel, etc.), but most critically, the viscosity of the spilled product and its pour point. Few devices are suitable for the recovery of viscous oils, and particular attention must be given to the choice of pump used in conjunction with the skimmer. Even if the recovery device proves effective on highly viscous hydrocarbons, the challenge of facilitating the flow of such oil towards the recovery and pumping system must also be taken into account (IMAROS, 2022)[49]. Oleophilic skimmers generally exhibit greater selectivity due to their operational principles (Cedre, 2015). Currently, new developments are underway, and equipment such as the Giant Octopus, by DESMI[50], appears to demonstrate promising performance. It is therefore crucial that responders are equipped with appropriate tools and have the capacity to seek assistance from other countries when needed.

4.3. Evaluation of effectiveness in Mediterranean's specific incidents

4.3.1. Geopolitical coordination challenges

The unique and complex dynamics of the Mediterranean with over 20 bordering countries, presents significant coordination challenges. Unlike the seamless collaboration seen in North American ECAs, Contracting Parties must navigate jurisdictional complexities. Enhanced cooperation through REMPEC will be essential to harmonise response efforts and align protocols.

[49] IMAROS 2022: Impacts and response options regarding low-sulphur marine fuel oil spills. https://civil-protection-knowledge-network.europa.eu/projects/imaros-2
[50] https://desmi.com

4.3.2. Environmental sensitivities

The semi-enclosed nature of the Mediterranean means pollutant's stay longer than in open oceans which increases the risk to biodiversity regardless of the substantial volume of water (~3.75 million km^3). This sensitivity requires the recovery of all the pollution whenever possible, particularly when low-Sulphur oil is spilled. Should the dispersion option be selected, it will be imperative to make a judicious choice of the products to be employed.

Customized dispersants and bioremediation techniques could be well adapted for the Mediterranean conditions. Customized dispersants for the Mediterranean should account for the region's unique water characteristics—such as higher salinity, temperature variations, and specific circulation patterns—to maximize pollutant breakdown without causing ecological harm. Additionally, advanced bioremediation approaches could include microbial treatments and enzyme-based solutions tailored to Mediterranean habitats, which would enhance the natural degradation process of pollutants. Such tailored methods offer a targeted and sustainable approach to pollution control, especially critical in ecologically sensitive areas like marine protected areas, where preserving biodiversity is paramount.

4.3.3. Infrastructure and resource gaps

Not all Contracting Parties possess the infrastructure required for rapid spill response. Investments in training programs and pre-positioning of equipment will be necessary to ensure uniform response capabilities across the region.

This point is crucial, as the recovery of the pollutants should be prioritized, particularly when the contaminant is oil (ULSFO, VLSFO and biofuels). If the spilled product involves cryogenic fuels (LNG and hydrogen) or colds (ammonia), the focus will be on equipment suited for combating gas clouds. For methanol, the equipment to be deployed will primarily consist of analytical tools to monitor the dissolution and diffusion of the product in the water column.

4.3.4. Bioremediation potential

The Mediterranean's warm climate may accelerate microbial degradation, making bioremediation techniques particularly effective for biofuel spills. Bioremediation - using natural microbial processes to break down contaminants - holds particular promise in this region due to the climate's positive impact on microbial activity, which can accelerate degradation rates.

A regionally-focused bioremediation program could capitalize on native microbial species, which are already adapted to the Mediterranean's specific environmental conditions, such as its higher salinity, unique nutrient cycles, and warmer water temperatures. By leveraging these local microbial communities, bioremediation strategies can be made more effective and sustainable, offering a solution that minimizes ecological disruption. For instance, local microbes can be optimized to target biofuel components, reducing toxic residues and promoting quicker environmental recovery.

The development of a bioremediation program in the Mediterranean could involve selecting and cultivating specific microbial strains known for breaking down biofuels efficiently under local conditions. This approach would not only provide a targeted response for spills but also align with broader ecological preservation goals, as native species are less likely to disrupt local biodiversity. Additionally, deploying such bioremediation techniques in protected areas would allow for rapid spill response that respects the delicate balance of marine ecosystems, ultimately offering a resilient, sustainable model for pollution management across the Mediterranean region.[51]

4.4. Conclusion

The transition to low-Sulphur and alternative fuels presents both challenges and opportunities for the Mediterranean. By adopting best practices from other ECAs and implementing innovative solutions, the region can strengthen its ability to respond effectively to future pollution risks.

However, geopolitical coordination and infrastructure investments will be critical to ensuring the success of these measures. REMPEC will play a key role in aligning national efforts and promoting cross-border collaboration. With a combination of preparedness, innovation and cooperation, the Mediterranean can protect its marine environment and ensure sustainable maritime operations.

[51] However, its selection may be subject to a net environmental benefit analysis (NEBA), which would demonstrate that the impact of traditional response techniques is more significant.

5. RESPONSE PREPAREDNESS OF THE CONTRACTING PARTIES

This chapter evaluates the regulatory alignment and overall preparedness of Contracting Parties to the Barcelona Convention. It begins with an overview of the ratification status of key IMO conventions related to marine pollution prevention and response, followed by an analysis of the current state of preparedness in each Contracting Party based on recent assessments between 2019-2023 conducted by REMPEC. The chapter identifies gaps and limitations in national response systems, particularly regarding readiness for low-Sulphur and alternative fuel spills, exploring data collected via desktop research regarding:

- Country profiles maintained by REMPEC and ITOPF;
- IMO GISIS regarding the status of ratification of IMO Instruments; and
- A survey questionnaire administered to the 21 Contracting Parties.

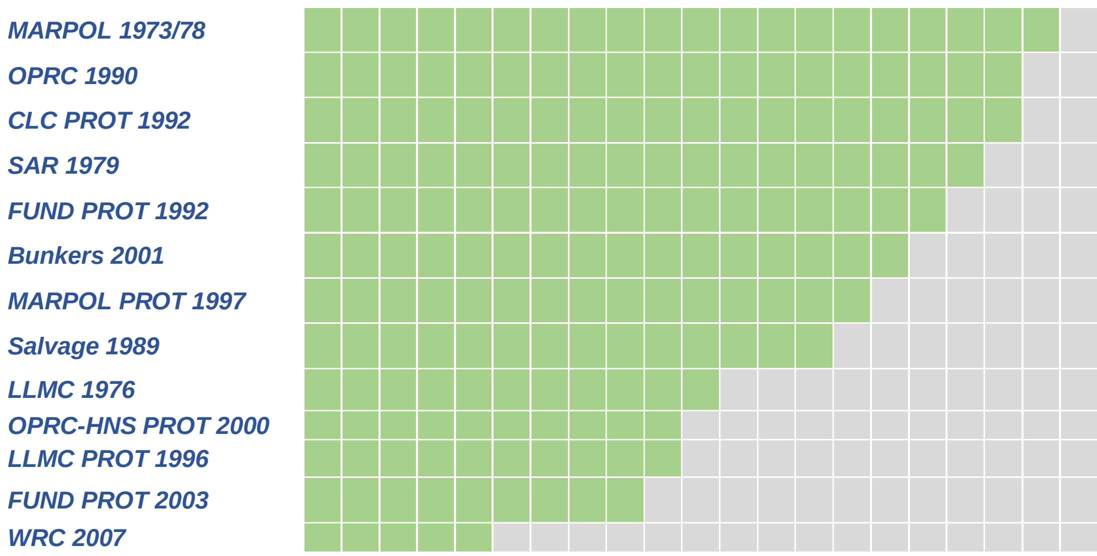
5.1. Regulatory overview and current state of preparedness

5.1.1. Regulatory overview of ratification status of key IMO conventions

This section offers a regulatory overview of the ratification status of key IMO Instruments related to pollution prevention, preparedness and response, and compensation among the Contracting Parties, that are Contracting Parties to the Barcelona Convention. The IMO instruments include — OPRC 1990, OPRC-HNS PROT 2000, MARPOL 1973/78, MARPOL Annex VI, LLMC, CLC 1992, FUND 1971, FUND 1992, FUND PROT 2003, Bunkers 2001, SAR 1979, WRC 2007, and Salvage 1989. Collectively, the instruments address a broad spectrum of pollution-related issues, from oil spill prevention and hazardous substances management (MARPOL Convention, OPRC 1990 and OPRC HNS 2000) to providing liability and compensation mechanisms for pollution incidents (LLMC, CLC, FUND and Supplementary FUND). The SAR 1979, WRC 2007, and Salvage 1989 conventions play a complementary role by ensuring that emergency responses, wreck removals, and salvage operations are conducted in a way that minimizes environmental risks.

Table 13 presents the ratification status of the aforementioned IMO instruments for the Contracting Parties, offering a regulatory snapshot that highlights how well the Contracting Parties' regulatory status aligns with international standards supporting further their readiness for low-Sulphur and alternative fuel spill response.

Table 13. *Ratification Status of Key IMO Instruments for Pollution Prevention, Response and Compensation among Contracting Parties to the Barcelona Convention*



5.1.2. Overview of the current state of preparedness of Contracting Parties.

The RETOS™ tool [52], developed by ARPEL, has been instrumental in assessing the preparedness levels of the Contracting Parties to handle marine pollution incidents. REMPEC facilitated the deployment of this tool in several national workshops, enabling Contracting Parties to the Barcelona Convention to evaluate their oil spill response frameworks comprehensively.

The assessments, conducted between 2019 and 2023, using RETOS™ tool highlighted significant variability in preparedness across the Mediterranean region. Some Contracting Parties demonstrated strong preparedness systems, with well-structured contingency plans, effective response coordination, and up-to-date training programs. In contrast, other Contracting Parties faced notable challenges, with preparedness hindered by outdated contingency plans and insufficient coordination between national agencies. Equipment shortages and limited training further exacerbate their vulnerability to large-scale pollution incidents, especially those involving low Sulphur and alternative fuels. Some Contracting Parties are still in the early stages of developing their oil spill response frameworks.

The RETOS™ assessments for the Contracting Parties identified gaps in operational response and technical capacity, leaving them particularly exposed to environmental risks from significant spills. **Table 14** and **Figure 2** summarize the outcomes of the RETOS™ assessments (2022-2023), comparing the levels of preparedness among the 10 Contracting Parties across various critical areas, including Legislation, Regulations, and Agreements (LRA), Oil Spill Contingency Planning (OSCP), Response Coordination (RC), Health, Safety & Security (HS&S), Operational Response (OR), Tracking, Assessment & Information Management (TA&IM), Logistics (L), Financial & Administrative Considerations (F&AC), Training & Exercises (T&E), and Sustainability & Improvements (S&I).

***Table 14**. Overview of National Preparedness Scores of 10 Contracting Parties to the Barcelona Convention using RETOS™ Tool* (Adapted from REMPEC, 2023)

Indicator/ CPs	***LRA***	***OSCP***	***RC***	***HS&S***	***OR***	***TA&IM***	***L***	***F&AC***	***T&E***	***S&I***	***Total***
CP 1	100%	91%	100%	100%	94%	100%	100%	83%	94%	92%	**95%**
CP 2	100%	88%	100%	83%	100%	83%	100%	83%	100%	100%	**95%**
CP 3	88%	97%	94%	100%	100%	100%	100%	67%	69%	92%	**91%**
CP 4	75%	79%	100%	100%	88%	100%	92%	100%	100%	83%	**90%**
CP 5	88%	82%	95%	100%	88%	100%	100%	67%	100%	92%	**90%**
CP 6	100%	91%	100%	100%	88%	67%	83%	100%	75%	67%	**88%**
CP 7	88%	94%	90%	17%	63%	67%	58%	83%	81%	83%	**79%**
CP 8	88%	82%	90%	50%	81%	83%	75%	50%	63%	17%	**72%**
CP 9	88%	76%	80%	100%	63%	83%	67%	17%	56%	42%	**68%**
CP 10	100%	63%	75%	50%	56%	67%	17%	67%	56%	17%	**57%**
Region	**92%**	**84%**	**92%**	**80%**	**82%**	**85%**	**79%**	**72%**	**79%**	**69%**	**83%**

LEGEND:
CP: Contracting Party; LRA: Legislation, Regulations, Agreements; OSCP: Oil Spill Contingency Planning; RC: Response Coordination; HS&S: Health, Safety & Security; OR: Operational Response; TA&IM: Tracking, Assessment & Information Management; L: Logistics; F&AC: Financial & Administrative Considerations; T&E: Training & Exercises; S&I: Sustainability & Improvement

[52] The RETOS™ tool, developed by ARPEL (Regional Association of Oil, Gas, and Biofuels Sector Companies in Latin America and the Caribbean), is a self-assessment instrument designed to evaluate national oil spill response capabilities. It enables governments, agencies, and stakeholders to measure their preparedness in key areas such as legislation, contingency planning, and response coordination, providing a clear picture of strengths and areas needing improvement.

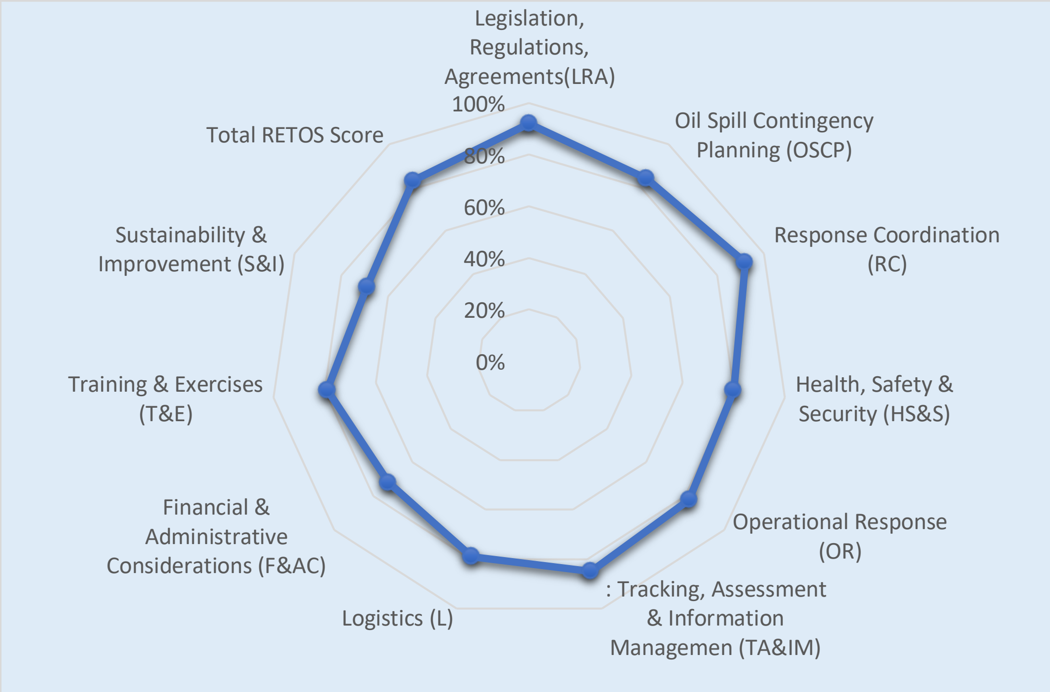


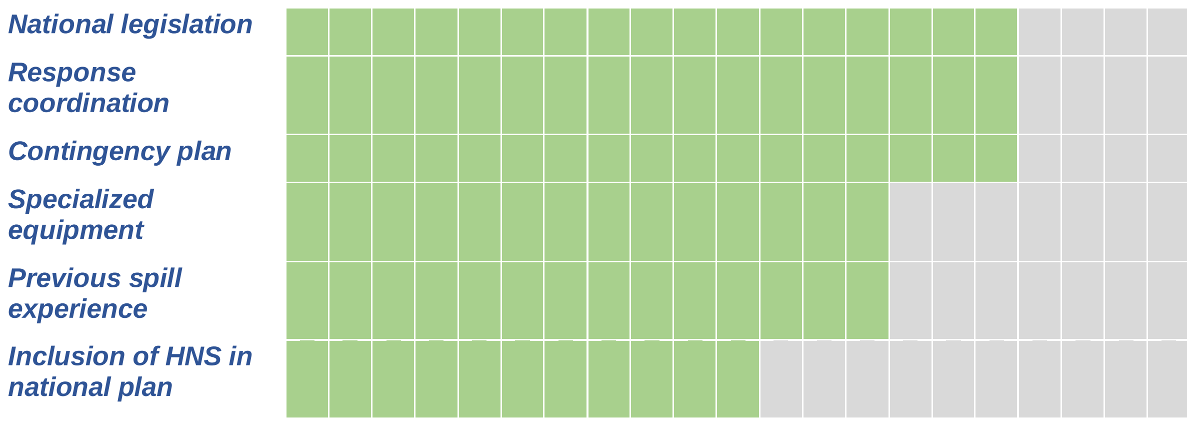
Figure 2. *Collective regional preparedness scores based on assessment of 10 Contracting Parties to the Barcelona Convention using RETOS™ tool (Adapted from REMPEC, 2023)*

5.2. Key observations on national coordination and gaps

All Contracting Parties to the Barcelona Convention, except one, have established national agencies responsible for coordinating oil spill response efforts. These agencies work in collaboration with regional bodies such as REMPEC to ensure preparedness and response capabilities. The presence of National Contingency Plans (NCPs) varies across Contracting Parties, with some plans outdated or in need of revision, while others lack designated authorities or provisions for Hazardous and Noxious Substances (HNS).

Table 15 outlines the key indicators for the 21 Contracting Parties in terms of their legislative frameworks, contingency plans, inclusion of HNS, response coordination, specialized equipment, and previous spill experiences. The RETOS Assessment (2019-2023) provides an additional layer of evaluation, offering insight into the overall readiness of each Contracting Party.

Table 15*. Key indicators of preparedness and response of the CPs to the Barcelona Convention*



The RETOS™ assessments, supported by REMPEC's technical guidance, and this study desktop research, have revealed that several Contracting Parties face critical gaps in their national oil spill response systems, including:

- National Contingency Plans: One Contracting Party has no finalized plan. Two Contracting Parties have contingency plans that are outdated, dating back to the mid-1990s, which hinders their ability to handle contemporary challenges, including alternative fuel and HNS spills. These plans are currently under review, but their present state may delay effective response measures.

- Planning for Hazardous and Noxious Substances (HNS): Two Contracting Parties are updating their contingency plans to incorporate HNS, which poses a particular challenge due to the complexities of responding to such incidents. In contrast, two other Contracting Parties are still in the process of developing comprehensive plans that include HNS response strategies.

- Coordination between national and local authorities: Two Contracting Parties have well-defined response frameworks that delegate responsibilities across national and local levels, including specific roles for harbourmasters, local mayors, and maritime authorities. These frameworks enhance coordination during both at-sea and onshore response efforts.

- Equipment and resources: While Contracting Parties three EUMSs maintain extensive stockpiles of response equipment and resources, others three third Contracting Parties have limited or no specialized equipment for oil spill response, relying heavily on international support or private contractors. The availability of resources such as booms, skimmers, dispersant systems, and helicopters is a crucial factor in determining the effectiveness of a national response.

- Regional cooperation frameworks: Contracting Parties like Israel, Cyprus, and Greece – Algeria, Morocco and Tunisia – the six Adriatic Contracting Parties – France, Monaco and Italy have established sub-regional agreements to coordinate cross-border spill responses. These frameworks ensure that even when national capabilities are limited, regional cooperation can fill critical gaps. Contracting Parties like Spain and France have further strengthened their response through bilateral agreements and participation in European task forces, such as the European Community Task Force. Accordingly, 15 of the 21 Contracting Parties to the Barcelona Convention are supported by other sub-regional and/or bilateral cooperation frameworks whereas 6 others, which are also among the resource deficient Contracting Parties rely solely on REMPEC.

Table 16 summarises the frequent gaps identified in the 21 Contracting Parties, offering insights into where improvements are most needed. This information has been gathered through REMPEC's RETOS™ assessments (2019-2023), along with supplementary data from desktop research and survey responses from the 21 Contracting Parties.

The Global Improvement Programs (GIP) generated from the RETOS application were developed as the foundation for the National Implementation Plans (NIP) for improvements to national and regional systems for preparedness and response

Regional opportunities for REMPEC assistance were defined and common key suggested areas for regional cooperation and support: Training and exercises, National emergency preparedness and response fund, ratification of international conventions.

Country-specific areas of interest were defined as summarized below: training and exercises, funding national emergency preparedness and response, enhancing and fostering communication between the various stakeholders their role and responsibilities, matching stockpile and location of equipment to the risks, training of trainers and updates on new topics, challenges, innovations etc. (for instance information regarding responding to VLSFO spills), managing of information, sharing knowledge and experience with other Contracting Parties, ratifying of international conventions and agreements , health and safety.

***Table 16**. Overview of gaps in national spill response plans*

Gaps Identified
No specialized equipment for pollution control
No specific policy for dispersants
No dedicated or outdated contingency plan
Limited equipment for HNS spills, relying on oil spill resources.
No significant national oil spill response mechanism
Limited response equipment.
Lack of clarity on dispersant policy in the newly redrafted NCP.
Limited Tier 2/3 response capabilities
Lack of coordination, particularly in stockpile maintenance
Updated National Contingency Plan needed
Relies heavily on private resources
Gaps in Tier 2/3 capabilities
No risk analysis.
Limited human resources and financial commitment
Lack of coordination among stakeholders
Relies on neighbouring countries for equipment
No significant incidents in the past: so, no previous learning experience from incidents
Prohibition on dispersants.
Coordination between regional response centres need improvement
Lack of knowledge of communication plans among stakeholders
No dispersant-testing procedure

5.3. Mediterranean regional cooperation

A part of the Mediterranean region cooperation efforts, REMPEC plays a critical role in strengthening coordination among Contracting Parties through initiatives like the RETOS workshops and the WestMOPoCo project. These programs aim to improve national preparedness by offering training, technical support, and assessments of national oil spill response programs. Contracting Parties like Tunisia and Malta have benefited from these workshops, which help harmonize response capacities across the region. In addition to the Barcelona Convention, which unites 21 Contracting Parties, several other multilaterals, bilateral, and trilateral agreements exist across the region. **Table 17** provides a mapping of these coordination agreements, further illustrating the framework for regional cooperation.

***Table 17.** Regional/Bilateral Agreements*

Contracting Party	Sub-regional agreements
Six Adriatic countries	• Multilateral Agreement on the Adriatic Plan
Algeria	• Trilateral agreement with Morocco & Tunisia
Cyprus	• Trilateral agreement with Egypt and Israel
Egypt	• Jeddah Convention • Trilateral agreement with Israel & Cyprus

	• Gulf of Aqaba plan with Israel and Jordan
France	• Bonn Agreement • Lisbon Agreement • RAMOGE Agreement with Italy and Monaco • Lion Plan with Spain
Greece	• Bilateral agreement with Italy • Trilateral agreement with Cyprus and Israel
Israel	• Sub-regional plan with Egypt and Cyprus • Gulf of Aqaba plan with Egypt and Jordan • Trilateral agreement with Cyprus and Greece
Italy	• RAMOGE Agreement with France and Monaco • Bilateral agreement with Greece
Malta	• Drafting bilateral agreement with Sicilian Coast Guard
Monaco	• RAMOGE Agreement with France and Italy
Morocco	• Lisbon Agreement • Trilateral Agreement with Algeria and Tunisia
Spain	• European Community Task Force; • observer in Bonn Agreement • Lion Plan with France
Tunisia	• Trilateral agreement with Algeria and Morocco
Turkiye	• Bucharest Convention

5.4. Results of the survey questionnaire

The results of the survey questionnaire aided in drawing conclusions on the response preparedness of Contracting Parties. These initial findings provide insights into current capabilities, gaps, and readiness levels, offering a valuable basis for further analysis and recommendations. A tabular overview is provided in **Figure 3** and the full set of graphs related to each survey question is presented at **Annex IV**.

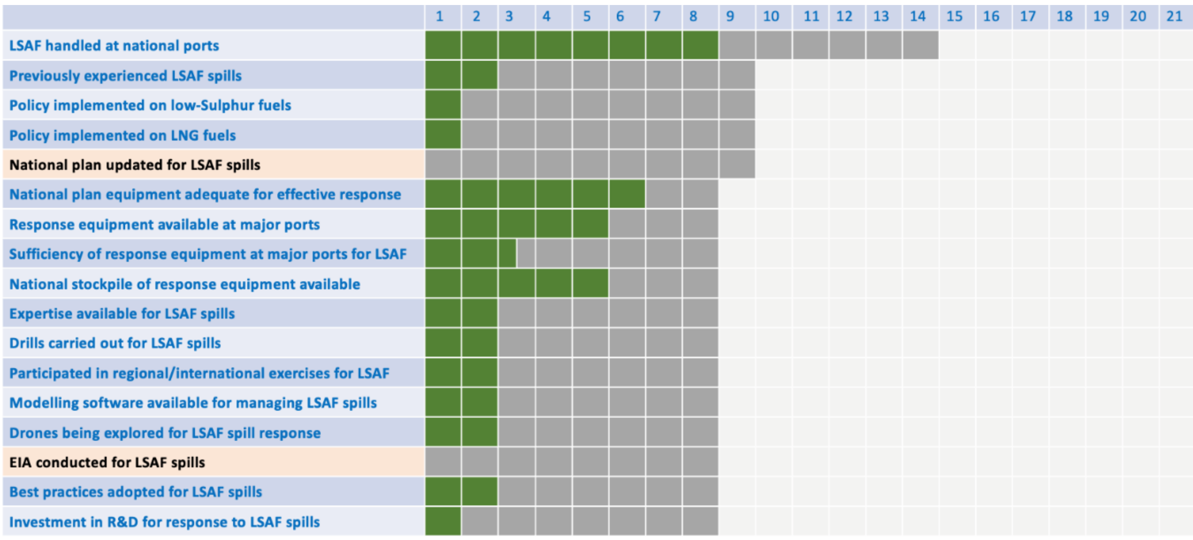


Figure 3. Results of questionnaire survey on low-Sulphur and alternate fuels (LSAF)

Participation in the survey: The survey received 28 total responses from 14 CPs, with 50% completion rate (14 completed responses).

Fuel handling and incident history*:* 44% of respondents indicated that ports in their country handle low-Sulphur or alternative fuels, such as LNG, LPG, and methanol. 22% reported past incidents involving low-Sulphur or alternative fuels, showing limited experience with such incidents in the region.

Policy and response plans: 87% of Contracting Parties lack specific national policies to address pollution from alternative fuels. Only one Contracting Party reported having policies, highlighting a substantial gap in regulatory preparedness. None of the surveyed Contracting Parties updated their National Oil Spill Response Plans in the last five years to account for low-Sulphur or alternative fuels, signalling an absence of recent adaptation efforts.

Response equipment and stockpiles: 62% rated their equipment as "Not sufficient" for handling potential major spills involving alternative fuels, indicating a significant capacity gap. 37% confirmed that major ports maintain response equipment stockpiles. 37% participant CPs maintain national stockpiles. 62% noted the insufficiency of these stockpiles for major incidents, emphasizing a need for enhancement in both availability and quantity of response equipment.

Personnel expertise and training: 50% rated the expertise of their personnel as "Not sufficient," reflecting a critical need for training and skill development for low-Sulphur and alternative fuel spill response. Only 25% of participating CPs are actively conducting drills focused on spills of low-Sulphur and alternative fuels, indicating limited preparedness exercises across the region.

Use of technology and best practices: 75% of participating CPs do not utilize decision support systems for managing such incidents. Only one Contracting party employs modelling software, showing limited adoption of advanced response tools. 2 CPs reported exploring new technologies, specifically drones, for pollution response. This suggests an interest in innovative methods, but broader adoption is lacking.

Research and Development (R&D) investment: 88% respondents rated their R&D investment as "Not sufficient," underscoring a need for more robust financial and research commitments to improve response capabilities.

Regional and international cooperation: 75% had not participated in regional or international exercises for low-Sulphur and alternative fuel spills. Similarly, adoption of best practices from other nations or international bodies remains limited, with only one Contracting Party referencing the WestMOPoCo HNS manual as a best practice.

Recommendations from participants: Key recommendations offered include:

- urgent technological and infrastructural support for developing CPs;
- enhanced capacity-building efforts for experts to enable robust support for regional decision-making;
- increased international cooperation; and
- more frequent, realistic training exercises to improve readiness for major incidents.

6. OVERVIEW AND ASSESSMENT OF ACTIONS, REGULATORY FRAMEWORKS, INCENTIVE SCHEMES, AND OTHER MECHANISMS

This chapter provides an overview and assessment of the regulatory frameworks, incentive schemes, and regional cooperation mechanisms that could be implemented in the Mediterranean region to handle low-Sulphur and alternative fuels. It evaluates current frameworks in alignment with international standards and explores potential enhancements, aiming to strengthen the region's response to marine pollution incidents involving these fuel types.

6.1. Strengthening regulatory frameworks for enhancing preparedness

The implementation of the Med SO_X ECA requires significant regulatory adaptations. Key international conventions guiding this transition, as outlined in Chapter II, include MARPOL Annex VI and other related frameworks. To ensure effective compliance, each Contracting Party must ratify, transpose, and enforce these instruments within their national legal systems. Additionally, the consistent and uniform application of these standards across the region is crucial for mitigating risks associated with low-Sulphur and alternative fuel spills. This will also ensure that the region's maritime industry remains aligned with global best practices, enhancing environmental protection and pollution response capabilities*.*

6.1.1. Key regulatory requirements for effective implementation

Ratification and transposition: Each Contracting Party must ensure the ratification of key international maritime conventions, followed by their transposition into national legislation. These efforts should be supported by clear policies and guidelines for monitoring and enforcement.

National policy: Contracting Parties must develop jointly policies and procedures that support specialised national regulatory frameworks, including detailed guidelines for enforcement, at the national level, agencies, training for personnel involved in spill response, and coordination mechanisms for cross-border incidents.

*Regulatory updates for new fuel types***:** As the Mediterranean region transitions to alternative fuels such as LNG, hydrogen, and ammonia, existing regulations must be updated to align with the deliverables provided by competent international institutions and organization. This involves revising port regulations, safety standards, and pollution response protocols to ensure they adequately cover the unique properties of low-Sulphur and alternative fuels. These updates should consider guidelines and recommendations from bodies such as IMO, UNEP, and the European Commission to ensure harmonized and effective implementation across the region.

6.1.2. Key potential actions for effective implementation of regulatory frameworks

*Developing regional guidelines for alternative fuels***:** A set of regional guidelines tailored to alternative fuels should be created in collaboration with REMPEC and IMO. These guidelines should focus on risk mitigation strategies, spill containment, and recovery protocols specific to alternative fuel spills. This initiative could be jointly envisaged with other regions, similar to the approach taken in the Marine HNS Manual developed as a multi-regional document between Bonn Agreement (BA), HELCOM, and REMPEC in 2021. This approach will ensure harmonization of practices and knowledge-sharing across regions

Monitoring and enforcement mechanisms: Regional and national authorities should strengthen monitoring systems to ensure compliance with environmental standards, with particular emphasis on low-Sulphur and alternative fuels. Ports must be equipped with real-time monitoring systems for emissions, spills, and other risks associated with these new fuel types.

Incentives for compliance: To encourage widespread compliance, Governments and ports should introduce financial incentives, such as reduced fees, tax breaks, or subsidies for operators that adopt environmentally friendly technologies and fuels.

6.2. Enhancing regional cooperation and strengthening REMPEC's role

REMPEC has played a pivotal role in coordinating pollution response efforts across Contracting Parties. the Center's role should continue to focus on enhancing preparedness, response coordination, and knowledge sharing. Within its current mandate, REMPEC is well-positioned to address the distinct challenges posed by these fuels. By collaborating with competent international and regional organizations, such as the European Maritime Safety Agency (EMSA), REMPEC can integrate emerging best practices, guidelines, and technical solutions into its framework. This collaboration would allow REMPEC to benefit from EMSA's experience in supporting the safe use of alternative fuels and addressing decarbonization challenges, ensuring harmonized efforts across the region.

6.2.1. Key areas for strengthening regional cooperation through REMPEC

Alternative fuel spill preparedness: REMPEC should ensure that protocols for managing spills involving alternative fuels are aligned with international guidelines and frameworks. These protocols must be integrated into existing regional contingency plans to ensure a uniform and comprehensive approach to managing pollution incidents across the region.

Standardizing response strategies across Contracting Parties: To ensure a consistent and effective response, REMPEC should work with CPs to establish a unified set of standards for alternative fuel spill management. These standards would form the basis of a Mediterranean-wide spill response framework[53]. This framework encompasses a collaborative mechanism involving the pooling of resources (e.g., equipment, expertise, and personnel), a structured communication system, and a network of stakeholders, including governments, industry representatives, and scientific experts. The aim is to facilitate the rapid deployment of resources and ensure that all CPs adhere to best practices in spill management. The framework would build upon and integrate with existing regional frameworks and procedures for oil and HNS spills, such as those established under the OPRC Convention and OPRC-HNS Protocol, maintaining continuity and alignment with recognized international standards. By leveraging these existing mechanisms, the proposed approach would enhance coordination without duplicating efforts.

Conducting regular, targeted spill response exercises: REMPEC should organize spill response exercises specifically designed to simulate incidents involving alternative fuels at regional and Sub-regional level. These exercises will strengthen regional preparedness by testing response strategies under real-world conditions. To ensure comprehensive readiness, these exercises should involve both public-sector agencies and private industry stakeholders, including shipping companies and port authorities.

---

[53] For further information on the Mediterranean regional spill response framework, refer Box on the following page.

The Mediterranean regional spill response framework

In the context of the Mediterranean regional spill response framework, the term "network" refers to the core and existing collaborative system established and coordinated by REMPEC to enhance regional preparedness and response to marine pollution incidents. This network is particularly crucial for strengthening the region's capacity to respond effectively to spills involving low-sulphur and alternative fuels. The network encompasses a range of mechanisms and partnerships, including, among others:

- **Mediterranean Assistance Unit (MAU):** This consortium of specialized institutions provides technical expertise, equipment, and support during pollution emergencies. Members including Sea Alarm, CEDRE, the Adriatic Training and Research Centre for Accidental Marine Pollution Preparedness and Response (ATRAC), the Italian National Institute for Environmental Protection and Research (ISPRA), and the Mediterranean Oceanography Network for Global Ocean Observing System (MONGOOS) offer services ranging from wildlife response to oceanographic monitoring, ensuring a comprehensive response capability.

- **Mediterranean Technical Working Group (MTWG)**: This correspondence-based group established to support the work of REMPEC's Focal Points facilitates the consideration of specific issues through consolidated reports prepared by the Secretariat. The MTWG also serves as a regional forum for Contracting Parties to contribute to and align with global initiatives, such as the IMO OPRC-HNS Technical Group, ensuring regional actions are consistent with international standards.

- **Mediterranean Network of Law Enforcement Officials relating to MARPOL (MENELAS):** This dedicated platform facilitates cooperation among Mediterranean coastal States for the enforcement of MARPOL regulations. It supports uniform implementation of international pollution prevention standards, a critical factor in managing incidents involving alternative fuels.

- **Sub-Regional Contingency Plans:** Formal agreements such as the RAMOGE Agreement between France, Monaco, and Italy provide coordinated response frameworks for marine pollution incidents. These plans promote resource sharing, mutual support, and streamlined decision-making during emergencies.

- **Partnerships with International and Non-Governmental Organizations:** REMPEC collaborates with global and regional entities such as EMSA, Bonn Agreement, HELCOM IMO, IOPC Funds, and ITOPF. These partnerships enhance technical expertise, mobilize resources, and align regional efforts with international best practices.

- **Other resources accessed online**: REMPEC provides several decision-support tools to enhance responses to oil and HNS spills. These include MEDGIS-MAR for data on response equipment, environmental and socio-economic layers, and maritime traffic; MIDSIS-TROCS to aid decision-making for hazardous material spill management; and Waste Management Decision Support Tool, to support countries in developing or updating national strategies for managing oily waste from marine pollution. These tools, alongside REMPEC's guidelines on preparedness, response, and mutual assistance, ensure effective and timely decisions during pollution incidents.

These components collectively form a robust network that facilitates resource sharing, expertise exchange, and coordinated action to effectively address marine pollution challenges in the Mediterranean region. Not least, this network not only builds on existing structures but also offers opportunities for further adaptation to meet the unique challenges posed by low-Sulphur and alternative fuels, ensuring the Mediterranean region remains prepared for emerging risks while protecting its marine environment.

6.2.2. Key potential actions for REMPEC to expand regional cooperation

Updating national contingency plans: REMPEC must work with Contracting Parties to ensure that national contingency plans are updated to reflect the risks and response strategies associated with alternative fuels. This includes addressing the specific properties and spill management techniques required for fuels like LNG, hydrogen, and ammonia.

Establishing a Mediterranean knowledge-sharing platform: REMPEC should lead the creation of a platform that facilitates the exchange of best practices, technological innovations, and case studies related to alternative fuel management. This platform would serve as a repository of cutting-edge knowledge, accessible to all signatories of the Barcelona Convention, and would help Contracting Parties stay informed of the latest developments in spill response technologies and methodologies.

Fostering public-private partnerships (PPPs): To strengthen the region's spill response infrastructure, REMPEC should encourage collaboration between Governments, port authorities, and private-sector entities. These partnerships can be leveraged to co-invest in the development of critical infrastructure, such as specialized spill response equipment and technologies for alternative fuels. For example, CPs could consider partnerships similar to those in the North Sea, where private companies provide rapid-response vessels and containment booms, or in the Baltic Sea, where industry partners contribute to joint training exercises and real-time spill monitoring systems. CPs could also explore investment models where private firms help fund and maintain emergency response depots equipped with alternative fuel spill kits.

Monitoring and enforcement of regional cooperation: In order to ensure that the enhanced roles and protocols are effectively implemented, REMPEC and regional/national authorities must establish monitoring mechanisms that track compliance with alternative fuel spill response guidelines and ensure coordination between all Contracting Parties. Regular audits, training programs, and the establishment of compliance metrics will be essential for the successful application of these regional cooperation efforts.

6.3. Enhancing sub-regional cooperation and synergy among CPs for environmental challenges

Sub-regional cooperation and synergy are crucial for Contracting Parties to address shared maritime challenges, particularly as they transition to low-Sulphur and alternative fuels. Building on synergy principles and activities already facilitated by REMPEC in 2023, CPs can form smaller, sub-regional partnerships based on geographic proximity and similar environmental risks. These partnerships would complement existing regional cooperation frameworks, such as sub-regional contingency plans and agreements coordinated by REMPEC, while ensuring alignment with established procedures for oil and HNS spill management. By leveraging shared resources, expertise, and knowledge, this approach would strengthen preparedness and response capabilities without duplicating existing mechanisms.

6.3.1. Key areas for strengthening sub-regional cooperation

Shared infrastructure development: Contracting Parties within sub-regions should collaborate on developing essential infrastructure for alternative fuels, such as LNG bunkering facilities and spill response equipment. By pooling resources, nations with less capacity can benefit from shared investments, ensuring broader access to the necessary infrastructure for fuel management.

Standardized spill response protocols: Sub-regions can work together to create joint spill response protocols for low-Sulphur and alternative fuels. These standardized protocols would facilitate faster, more coordinated responses to pollution incidents, ensuring consistency across Contracting Parties. REMPEC should guide these efforts to align with broader regional and international standards.

Harmonized incentives for green ports: Aligning incentives such as reduced port fees and environmental certifications across sub-regions would promote the use of alternative fuels. By creating uniform green port initiatives, Contracting Parties can encourage cleaner maritime practices while simplifying compliance for shipping companies operating across multiple Contracting Parties.

6.3.2. Key potential actions for strengthening sub-regional cooperation within CPs

Joint training programs: Sub-regions should focus on capacity-building through joint training in spill response and alternative fuel management, ensuring that technical expertise is evenly distributed across the region.

Sub-regional enforcement agreements: Establishing shared enforcement mechanisms will help ensure consistent application of MARPOL Annex VI and other key regulations, particularly as the Med SOX ECA comes into effect.

Public-private partnerships (PPPs): Sub-regional cooperation can foster PPPs to co-invest in alternative fuel infrastructure, helping to bridge resource gaps and encourage innovation.

6.4. Tailoring national policies to country-specific challenges

In the Mediterranean region, several Contracting Parties face significant challenges in transitioning to alternative fuels due to limited financial, technical, and infrastructural capacity. These nations require targeted national initiatives that address their specific needs, focusing on building regulatory frameworks, developing infrastructure, and fostering adoption of clean fuels.

6.4.1. Key areas of focus for resource-constrained Contracting Parties

Technical assistance for regulatory implementation: Contracting Parties with limited resources often struggle to adopt and enforce international regulations, such as MARPOL Annex VI. Regional organizations like REMPEC and international bodies such as the IMO should provide direct technical assistance to help these Contracting Parties develop, implement, and enforce the necessary regulatory frameworks. This support would ensure that they comply with international standards for managing alternative fuels.

Infrastructure development support: The lack of adequate infrastructure, particularly for fuel bunkering and handling, presents a significant challenge for several Contracting Parties. To address this, Governments should seek international financial assistance, such as grants, to support infrastructure development. These resources should be used to upgrade port facilities, ensuring they are equipped to manage a variety of cleaner fuels safely and efficiently.

Capacity-building and training programs: National initiatives must focus on developing local expertise in handling and responding to fuel spills. Training programs, supported by regional bodies such as REMPEC, should be established to equip personnel with the skills needed to manage the risks associated with alternative fuels.

6.5. Incentivizing green maritime practices via regional mechanisms

Incentive schemes are crucial for promoting the adoption of environmentally friendly fuels and technologies in the maritime sector, and they play a vital role in enhancing preparedness for managing spills of these alternative fuels. By offering financial and operational rewards for sustainable practices, Governments and ports can drive the transition toward cleaner maritime operations while also ensuring the region is better equipped to prevent and respond to fuel-related pollution incidents. Existing initiatives have already proven effective, but there is potential to expand these efforts and introduce new mechanisms that not only promote sustainability but also strengthen spill preparedness.

6.5.1. Key potential incentive schemes

Green Ports Initiatives: Several Mediterranean ports, including Malaga, Barcelona**,** and Marseille, have implemented green initiatives offering reduced fees to vessels that meet environmental criteria, such as using low-emission or alternative fuels. These initiatives encourage the adoption of cleaner fuels while supporting the development of infrastructure and operational protocols that reduce the risk of spills. Expanding these programs regionally and standardizing them across Mediterranean ports would provide a unified framework, fostering greener maritime practices while improving overall spill preparedness.

*Environmental certification programs***:** Ports could introduce certification programs like the Energy Efficiency Design Index (EEDI)**,** which offer financial incentives and expedited services for vessels that demonstrate high environmental performance. By promoting cleaner technologies and practices, such as energy-efficient designs and alternative fuel use, these certifications also indirectly prepare ports for handling potential fuel spills, as they encourage better fuel management and risk mitigation.

Technology grants and subsidies: Introducing grants and subsidies to encourage investments in advanced spill detection and management technologies can significantly improve preparedness for fuel spills. These incentives would enable shipping companies and ports to invest in cutting-edge tools such as AI-based pollution management systems**,** real-time spill detection technologies, and high-efficiency containment equipment. Such investments not only promote environmental protection but also enhance the region's ability to prevent and respond to potential spills from alternative fuels, such as LNG, hydrogen, and biofuels.

Training and certification support: Governments and ports should introduce financial incentives, such as tax breaks, to support companies investing in specialized training programs for handling alternative fuels and responding to spills. Comprehensive training is critical for developing the skills needed to manage the specific risks associated with alternative fuels. By incentivizing workforce development in this area, the maritime sector will be better prepared to prevent and respond to incidents, minimizing the environmental impact of spills.

7. STATEGIC OBJECTIVES AND RECOMMENDATIONS

The Mediterranean region is set to witness a significant regulatory shift as it prepares to enforce the Med SO_X ECA, which will introduce a sulphur cap of 0.10% in marine fuels, effective from May 2025. This regulation aims to align the region with the global efforts to reduce sulphur emissions and improve air quality, yet it also highlights new challenges specific to the Mediterranean, particularly as the region increasingly adopts low-sulphur and alternative fuels. These emerging fuels, such as LNG, biofuels, methanol, ammonia, and hydrogen, bring unique environmental and safety hazards that existing response frameworks - primarily designed for conventional fuel oil spills - are not fully prepared to manage.

The present study, aligned with recent assessments by REMPEC utilizing the RETOS tool, has identified critical gaps in the region's preparedness. These findings reveal that current regulatory frameworks and response strategies lack essential provisions to manage the unique behaviours and hazards associated with new fuel types, including low-Sulphur and alternative fuels. While international standards such as MARPOL Annex VI and the IGF Code provide foundational guidance, they do not fully address the complexities associated with these new fuels. This gap in regulatory and response frameworks highlights the need for a coordinated and harmonized approach to effectively manage pollution incidents and protect the Mediterranean's marine environment.

This chapter offers a set of targeted recommendations aimed at strengthening the Mediterranean region's ability to respond to pollution incidents, with a specific focus on those involving low Sulphur and alternative fuels. These recommendations emphasize enhancing regulatory alignment, improving response mechanisms, and fostering cross-border collaboration. The recommendations are organized into four key Strategic Objectives (SOs) (**Figure 4** refers):

- Policy and regulatory improvements (SO1)
- Capacity building and training (SO2)
- Enhancing response mechanisms (SO3)
- Strengthening stakeholder engagement and collaboration (SO4)

Figure 4. *The four key Strategic Objectives (SOs)*

By implementing these strategic objectives, CPs and the entire Mediterranean region could work towards building a more resilient and coordinated framework for response and infrastructure, potentially improving the management of pollution risks associated with the transition to low-Sulphur and alternative fuels.

7.1. Strategic Objective 1 (SO1) — Policy and Regulatory Improvements

To address the unique challenges and opportunities presented by a transition to low Sulphur and alternative fuels in the Mediterranean region, a set of targeted policy and regulatory improvements is recommended. This area of recommendations is intended to enhance national and regional frameworks, strengthen and harmonise enforcement, and develop regional guidelines to manage the specific risks associated with low Sulphur and alternative fuels.

7.1.1. Updating and aligning national regulatory frameworks (RC1.1)

Contracting Parties to the Barcelona Convention should prioritize updating their national regulatory frameworks to address the distinct risks and behaviours of low Sulphur and alternative fuels. These updates should align with international standards, such as MARPOL Annex VI, the OPRC Convention, and the IGF Code, as well as regional frameworks like the Mediterranean SOX Emission Control Area (Med SO_X ECA). Specific actions to achieve this recommendation include:

- *Ratification and transposition of key IMO instruments:* CPs should ratify and integrate key IMO instruments, such as the OPRC 1990, OPRC-HNS Protocol 2000, CLC 1992, and the Bunker Convention, into national legislation. These conventions are critical for ensuring comprehensive regulatory coverage for incidents involving alternative fuels. As initial step, CPs should conduct a thorough gap analysis of IMO instruments relevant to spill response to assess national compliance with international frameworks. Additionally, CPs should utilize the IMO Member State Audit Scheme (IMSAS) to identify gaps in compliance and implement corrective measures to address these regulatory shortcomings effectively. Following the initial gap analysis, CPs should ratify missing IMO instruments and transpose them into their national legislation to ensure a cohesive response framework. Focus should also be placed on revisiting previously ratified instruments to ensure full compliance and consistency with global best practices.
- *Review and update national contingency plans and regulatory frameworks for incorporation of alternative fuel spill response strategies:* Each CP should update its national contingency plan to integrate specific strategies for low-Sulphur and alternative fuel spills, ensuring a seamless response mechanism. This involves engaging relevant stakeholders, such as industry leaders, environmental agencies, and port authorities, in a collaborative review process.

  National regulations and response plans must include specific guidance for handling alternative fuels, considering their unique environmental behaviour, containment, and recovery challenges. Tailored protocols should be developed for fuels such as LNG, ammonia, and hydrogen, which exhibit distinct physical and chemical properties compared to conventional fuels. These protocols should address:

  - the environmental behaviour of each alternative fuel.
  - specific containment techniques suitable for spills; and
  - effective recovery methods to mitigate environmental impact.

  Additionally, regulatory frameworks should incorporate provisions for training responders and equipping them with the necessary tools and knowledge to manage incidents involving alternative fuels.
- *Establishing prosecution mechanisms for non-compliance;* CPs should ensure that national frameworks support robust mechanisms for prosecuting violations related to the use and handling of alternative fuels. These mechanisms must align with MARPOL

Annex VI standards to address non-compliance effectively and include detailed procedures for identifying and addressing infractions. Utilizing resources such as the Marine Environment Network of Legal and Administrative Structures (MENELAS) for technical assistance and capacity building offers significant benefits.

- *Ensuring consistent enforcement and compliance:* Harmonized enforcement across CPs is essential to ensure effective implementation. CPs should establish mechanisms for monitoring compliance with fuel standards and spill preparedness. Both flag states and port states should ensure that ships and facilities are prepared to handle low-Sulphur and alternative fuel spills. Advanced tools like the EMSA CleanSeaNet for satellite monitoring and the THETIS-MED database for compliance tracking should be leveraged to enhance oversight and enforcement capabilities.

To ensure continuous adaption of regulatory frameworks to emerging fuel technologies, REMPEC and the CPs should keep updating national and regional regulations to reflect advancements in alternative fuel technologies, ensuring that policies remain relevant, effective, and aligned with international standards

7.1.2. Developing regional guidelines for low Sulphur and alternative fuel spills (RC1.2)

To strengthen response mechanisms and ensure cohesive practices across the Mediterranean, it is necessary to build on the existing regional guidelines and adapt them to the specific challenges posed by low-sulphur and alternative fuels. In collaboration with REMPEC and other regional stakeholders, efforts should focus on revising and developing targeted provisions to complement the current frameworks, such as those referenced in the GloMEEP Ship and Port Emissions Toolkit guides and MARPOL Annex VI-related standards. Key recommendations include:

- *Standardized spill response protocols:* REMPEC and CPs in collaboration with other regions should collaborate to develop and adopt standardized regional guidelines for low-Sulphur and alternative fuel spill management. These guidelines should include, among other matters, specific procedures for response, inter-agency communication, and regional coordination to foster unified practices across borders. Existing guidelines should also be expanded to include specific procedures tailored to the risks associated with alternative fuels. These protocols must address containment, mitigation, and recovery strategies, considering the distinct chemical and physical behaviours of fuels like LNG, ammonia, and hydrogen. Fuel-specific protocols (e.g., LNG, methanol) from the Australian Maritime Safety Authority and ChemPlan in the ROPME region offer tailored approaches.

- *Cross-border coordination mechanisms:* Current frameworks should enhance cross-border collaboration through improved coordination systems. These mechanisms must ensure synchronized responses among CPs and simplify provisions for providing and receiving assistance. Importantly, CPs should establish pathways for assistance from or to countries beyond the Mediterranean ECA, fostering broader international cooperation in managing large-scale incidents.

- *Integration of innovative techniques:* Regional guidelines should incorporate lessons learned and innovative practices, such as cryogenic booms for LNG spills and pre-positioned regional stockpiles in high-risk areas. These additions will ensure the region's readiness to handle the unique challenges posed by alternative fuels.

- *Continuous review and dissemination:* Leveraging REMPEC's role, guidelines should undergo regular reviews to incorporate emerging technologies, best practices, and insights from real-world incidents. Dissemination efforts should focus on ensuring accessibility and awareness among relevant stakeholders, from policymakers to on-field responders.

7.1.3. Strengthening enforcement mechanisms (RC1.3)

Ensuring effective enforcement of environmental regulations is essential for achieving compliance among ships and port facilities in the Mediterranean. To address current challenges and improve enforcement, CPs should adopt the following actions:

- *Enhancing inspection procedures:* Conduct regular and more rigorous inspections of ships and port facilities to verify adherence to fuel-use regulations, emissions standards, and spill response preparedness. Inspections should align with MARPOL Annex VI and regional frameworks like Med SO_X ECA requirements.
- *Establishing a robust legal framework:* Develop a comprehensive national legal framework to prosecute offenders for non-compliance with MARPOL Annex VI. This framework should clearly outline enforcement mechanisms, penalties, and legal processes, supported by the Marine Environment Network of Legal and Administrative Structures (MENELAS) for technical assistance and capacity building.
- *Leveraging advanced monitoring technologies:* Utilize state-of-the-art surveillance tools such as EMSA's CleanSeaNet, AIS-based monitoring, and Remotely Piloted Aircraft Systems (RPAS) for real-time compliance tracking. These technologies enhance monitoring capabilities and ensure swift detection of violations related to emissions and alternative fuel use.
- *Applying tiered deterrent penalties:* Introduce a tiered penalty system, similar to those implemented in Chinese ECAs, to discourage non-compliance. Higher penalties for severe violations can act as a deterrent while encouraging adherence to environmental standards.
- *Providing technical assistance and capacity building:* Collaborate with MENELAS to define and deliver technical assistance, guidance, and training for national authorities to implement and enforce these regulations effectively. This includes capacity building to address gaps identified through the IMO Member State Audit Scheme (IMSAS) and ensuring corrective actions are applied.

7.1.4. Establishing a clear liability and compensation framework for alternative fuels (RC1.4)

The transition to alternative fuels introduces distinct risks that existing liability frameworks may not fully address. To enhance legal preparedness for incidents involving these fuels, CPs are encouraged to update their national liability and compensation mechanisms and make specific provision designed for alternative fuels. Key actions for CPs to consider include:

- *Defining responsibilities of key stakeholders:* Liability frameworks should clearly outline the roles and responsibilities of shipowners, fuel providers, and port authorities in the event of a spill or accident involving alternative fuels. This clarity is essential to ensure that each party is aware of their obligations and liabilities, promoting coordinated response efforts and effective risk management.
- *Ratifying and effectively implementing existing conventions on liability and compensation:* CPs should prioritize the ratification of foundational conventions such as the CLC 1992, FUND 1992, HNS Convention 2010 and Bunker Convention. These conventions provide a structured framework for liability and compensation, ensuring that those affected by pollution incidents receive adequate compensation and that environmental damage is addressed effectively. While originally developed for

traditional fuels, these conventions could be adapted or expanded to cover incidents involving alternative fuels. By ratifying these conventions and potentially advocating for amendments to include alternative fuels, CPs can create a more inclusive liability regime that addresses emerging risks associated with fuels like LNG, ammonia, and hydrogen. In addition, Blue Fund for the Mediterranean should be progressed concurrently.

- *Developing national and regional guidelines on liability and compensation:* Beyond ratifying international conventions, CPs should collaborate with REMPEC on regional guidelines that address the specific risks associated with alternative fuels. These guidelines would serve as a supplement to international frameworks, offering region-specific recommendations on liability and compensation. By working with REMPEC, CPs can ensure that these guidelines align with international best practices and address the unique challenges posed by alternative fuels in the Mediterranean context.

7.2. Strategic Objective 2 (SO2) — Capacity Building and Training Recommendations

To address the complexities of responding to marine pollution incidents involving low-Sulphur and alternative fuels, the Mediterranean region must prioritize targeted capacity-building efforts and specialized training programs. These measures are essential to equip responders with the skills and resources needed for rapid, effective, and coordinated responses to incidents. Unlike conventional fuels, alternative fuels may pose unique risks to responder safety due to their distinct chemical and physical properties, making enhanced preparedness across Contracting Parties (CPs) critical to minimizing environmental, socio-economic, and safety impacts. Recommendations to strengthen capacity building and training include:

7.2.1. Developing specialized training programs for alternative fuels (RC2.1)

With the introduction of low-Sulphur and alternative fuels such as LNG, hydrogen, ammonia, and biofuels, spill response teams must be equipped to address the unique properties and risks associated with each type. To achieve this, tailored training programs should be developed to cater to a diverse range of stakeholders, including policymakers, port authorities, and field responders. These programs should emphasize the chemical and physical characteristics of alternative fuels, effective containment methods, and advanced spill response techniques. Training efforts could include high-level awareness sessions for decision-makers, operational courses for on-site responders, and technical workshops for port authorities and regulatory bodies. Partnerships with maritime academies, research institutions, and the chemical industry will ensure comprehensive and practical knowledge transfer.

Priority should be given to high-risk ports and major maritime hubs, where specialized training can be conducted with support from local institutions. Programs should also incorporate elements from IMO OPRC and HNS Model Courses, while leveraging the expertise of organizations such as REMPEC and EMSA to provide a robust and practical foundation for spill response preparedness.

REMPEC could organize Regional-level training for marine pollution response at a dedicated training center, leading to certification in alternative fuel spill response should be organized periodically under the auspices of REMPEC. This training should be complemented with virtual reality (VR) simulations, and regular drills. Funding can be sought from international donors like IMO's Integrated Technical Cooperation Program (ITCP).

7.2.2. Implementing simulation-based training for spill response (RC2.2)

To prepare responders for real-life scenarios, CPs should invest in simulation-based training for spill response such as multi-nation drills integrating AI-powered monitoring. Best practices for simulation exercises can be found in HELCOM's CEPCO flights and the UK's NCP periodic drills focus on cross-border collaboration. Using virtual reality (VR) or advanced simulator technologies, responders can be trained to manage incidents involving alternative fuels in a controlled, risk-free environment. Simulated scenarios can replicate the behaviour of various fuel types upon release, testing response techniques under different environmental conditions. This immersive approach can significantly improve the preparedness and confidence of response teams. VR platforms should align with training standards from already established programs like POSOW Model Courses to cover shoreline cleanup, wildlife response, and waste management.

7.2.3. Establishing certification standards for responders (RC2.3)

Certification programs specific to handling spills of alternative fuels should be developed. Such certifications would ensure that responders meet a standard level of knowledge and proficiency in managing the risks associated with alternative fuels. The certification could cover topics such as chemical hazards, containment methods, environmental impact mitigation, and the use of specialized equipment. Having certified personnel across the region can raise the quality of response capabilities and ensure consistent standards are applied in the field. Certification should align with international standards, such as the IMO's OPRC Model Training Courses, which provide structured training for oil spill response at various levels[54]. While these training programs have primarily focused on traditional fuels, they present a foundational framework that could be expanded to include alternative fuels. Similarly, specialized training initiatives like the AFFIRM course offered by the Security and Emergency Response Training Center (SERTC) demonstrate the potential for region-specific programs tailored to alternative fuels[55]. By leveraging such existing models and incorporating regionally relevant elements, consistent competency and enhanced preparedness can be achieved.

7.2.4. Conducting regional training workshops and exercises (RC2.4)

Regular regional training workshops and collaborative exercises are crucial for enhancing cross-border coordination and knowledge-sharing among CPs . These activities should include annual or biennial national and sub-regional exercises facilitated by REMPEC and EMSA, involving the REMPEC Mediterranean Assistance Unit (MAU) and private sector stakeholders. Scenario-based drills should be conducted to test and refine protocols for alternative fuels, with a particular focus on rapid response in sensitive ecological areas. Cross-sector workshops can evaluate lessons learned from real incidents and integrate them into training modules to improve preparedness. Additionally, regional spill response drills involving multiple CPs should be organized to assess the effectiveness of communication channels, deployment strategies, and resource allocation. Lessons learned from all these activities should inform continuous improvements to national and regional frameworks, ensuring they remain robust and adaptive to emerging challenges. HELCOM and AMSA cross-border cooperation and university-industry partnerships in the region are best practices from which the Mediterranean region can learn about collaborative training programs.

---

[54] Oil Spill Response. (n.d.). IMO Equivalent Courses. https://www.oilspillresponse.com/training/training-standards/imo-equivalent-courses

[55] Security and Emergency Response Training Center (SERTC). (n.d.). Alternative Fuels and Flammable Incident Response and Management (AFFIRM) Course. https://sertc.org/course/new-course-coming-fall-2024-per-327-alternative-fuels-and-flammable-incident-response-and-management

7.2.5. Building a pool of regional experts (RC2.5)

The complexity of alternative fuels necessitates having a network of regional experts who can provide guidance and support during a pollution incident. CPs should work together to build a roster of experts in fields such as hazardous materials, marine chemistry, spill response, and environmental protection. This pool of experts could be mobilized quickly in the event of an incident, offering technical support and ensuring that best practices are applied. Moreover, an expert network would enable knowledge exchange, allowing CPs with more experience to mentor others and raise the overall competency level across the entire region. More importantly, Expanding the network of REMPEC Mediterranean Assistance Units (MAUs) to support capacity building at a regional level offers high benefits.

7.2.6. Enhancing knowledge-sharing platforms (RC2.6)

REMPEC in collaboration with CPs, should create e-learning platforms and online repositories for training materials, case studies, and response protocols. These platforms should:

- host forums for responders, policymakers, and environmental agencies to exchange ideas and discuss challenges;
- provide access to Earth Observation tools, RPAS services, and incident reports for continuous learning and innovation; and
- serve as a bridge for connecting response teams with resources like the Mediterranean OSCAR-MED surveillance system.

7.2.7. Investing in research and development for response innovations (RC2.7)

Continuous research and development (R&D) is necessary to keep pace with the evolving fuel landscape and improve response methods. CPs must allocate resources for R&D to address evolving challenges in spill response. This may include, among others:

- developing new containment methods and environmentally friendly dispersants tailored to alternative fuels;
- collaborating with universities and industry stakeholders to advance spill response technologies;
- enhancing surveillance and monitoring capabilities through tools like the EMSA THETIS-MED database and satellite surveillance systems; and
- expanding multi-sectoral contingency planning to include chemical pollution scenarios, as proposed under existing REMPEC frameworks.

7.3. Strategic Objective 3 (SO3) — Improving Response Mechanisms

Traditional response mechanisms for marine pollution incidents must evolve to meet the unique challenges posed by alternative fuels. The following recommendations aim to enhance response mechanisms to ensure swift, effective, and environmentally sensitive management of pollution incidents involving alternative fuels.

7.3.1. Developing fuel-specific response protocols (RC3.1)

Alternative fuels like LNG, ammonia, hydrogen, and biofuels each have unique properties that influence their behaviour in marine environments in spill situations. It is essential to develop specific response protocols tailored to the characteristics of each fuel type. These protocols should outline fuel-specific containment, recovery, and mitigation techniques. It should be developed collaboratively with environmental scientists, chemical experts, and response professionals to ensure comprehensiveness and efficiency.

Leveraging existing guidelines, such as the Guide for Combating Accidental Marine Pollution in the Mediterranean Sea and other REMPEC resources can be a starting point. Additionally, REMPEC should work in collaboration with Contracting Parties and other regional agreements to ensure a harmonized approach to these protocols, incorporating lessons learned from global best practices and scientific advancements.

7.3.2. Investing in specialized response equipment (RC3.2)

The region's current inventory of spill response equipment, primarily designed for oil spills, is, in most CPs, inadequate for handling spills of alternative fuels. CPs should invest in specialized equipment that can effectively address the risks posed by these alternative fuels. For example:

- gas detectors and dispersal models for LNG and hydrogen, which can quickly evaporate and pose asphyxiation and explosion risks;
- ammonia containment booms and neutralizing agents to mitigate ammonia's toxic and corrosive effects; and
- cryogenic protective gear and gas-tight containment for responders dealing with extremely low-temperature or high-pressure fuels.

Therefore CPs, given the inadequacy of current spill response equipment for alternative fuels, must upgrade inventory to enhance the safety and efficiency of response operations. Importantly, establishing regional equipment stockpiles for high-risk zones, with specialized equipment like cryogenic gear and lightweight skimmers for LNG and ammonia with EMSA's pollution response services to supplement national resources are of high benefits for the region. Also, North American ECA's pre-positioned inventories and ChemPlan's equipment are good examples.

7.3.3. Implementing real-time monitoring and detection systems (RC3.3)

Real-time monitoring systems are critical for timely detection and response to alternative fuel spills. Advanced detection technologies, including satellite-based monitoring, drones, and remote sensing, should be implemented in the region, to identify spills and track the movement of fuel plumes. Real-time data collection, combined with predictive modelling, can provide valuable insights into how a spill is likely to spread, allowing responders to pre-position resources and take preventive actions. Integrate data with existing decision-support tools, such as THETIS-MED and MEDGIS-MAR will enhance monitoring capabilities. Real-time monitoring capabilities should be integrated into regional maritime traffic control centres to ensure prompt and coordinated response actions. CleanSeaNet and RPAS are good examples in using real-time monitoring and predictive models for spill detection and movement.

7.3.4. Developing fuel dispersion and impact models (RC3.4)

To understand the environmental behaviour of alternative fuels in marine settings, REMPEC and the CPs must:

- invest in scientific research and development of dispersion models for different types of alternative fuels;

- use these models to predict the spread, impact, and interaction of spills with marine ecosystems, considering variables such as water salinity, temperature, and currents; and
- collaborate with academic and research institutions to ensure accuracy and applicability of these models.

7.3.5. Establishing rapid response units (hubs) for high-risk areas (RC3.5)

Certain areas in the Mediterranean are particularly vulnerable to pollution incidents due to high traffic density and sensitive ecosystems. To address this, REMPEC and the CPs should establish rapid response hubs strategically located in high-risk zones. These hubs should be equipped with fuel-specific response kits and staffed with trained personnel to ensure prompt and effective responses that minimize environmental impact. For instance, placing response units near ecologically sensitive areas, such as marine protected areas (MPAs) or heavily trafficked straits, can significantly reduce response times for incidents involving alternative fuels.

These hubs can be integrated into the Subregional Contingency Plans (SCP) framework, aligning with regional preparedness strategies. Initial efforts should focus on creating a resource network and stockpiles of specialized equipment for alternative fuels at strategic locations. Early investment in these hubs will not only enable rapid response in critical areas but also serve as prototypes for a broader regional network.

The hubs could be supported by a Mediterranean Emergency Operational Center, established on a cost-sharing model and integrating satellite surveillance, drone technology, AI tools, and a shared platform to enhance spill monitoring and enable rapid resource deployment.

7.3.6. Enhancing cross-border response coordination (RC3.6)

Given the interconnected nature of the Mediterranean, pollution incidents can easily affect multiple countries. Strengthening cross-border coordination and establishing clear protocols for joint response efforts are essential. CPs should formalize agreements for mutual aid, shared resources, and coordinated action during spills involving alternative fuels. These agreements should include pre-defined roles, shared communication channels, and joint training exercises to ensure seamless collaboration in actual spill events. REMPEC could play a central role in facilitating this coordination. CPs also should facilitate the procedures for sending and reception of international assistance in case of spill incidents to ensure quick response time, ensuring alignment with the Host Nation Support Guidelines. Using networks such as MENELAS are of prime importance to strengthen cooperation and enforcement across borders.

7.3.7. Utilizing data from past incidents and drills (RC3.7)

Continuous improvement of response mechanisms requires learning from past incidents and simulation exercises. CPs should maintain a shared database of incident reports and lessons learned from previous spills involving alternative fuels, leveraging tools like the Barcelona Convention Reporting System (BCRS). Regular analyses of this data will allow to identify gaps and improve protocols. Analysis findings could be incorporated into regional training and exercises to continuously refine response strategies.

7.3.8. Integrating Environmental Sensitivity Indexes (ESIs) into response planning (RC3.8)

Alternative fuel spills have varied impacts on different types of ecosystems. Integrating Environmental Sensitivity Indexes (ESIs) into contingency response planning can help prioritize resources and focus on protecting the most sensitive areas. ESIs rank habitats and shoreline types by their sensitivity to pollution, allowing response teams to deploy resources strategically. For instance, areas with high ESI rankings, such as coral reefs, marshlands, or seagrass beds, should be given priority in spill containment and clean-up efforts. ESIs could be integrated into decision support tools adopted in the region such as the Mediterranean Integrated Geographical Information System on Marine Pollution Risk Assessment and Response (MEDGIS-MAR), Maritime Integrated Decision Support Information System on Transport of Chemical Substances (MIDSIS-TROCS) and Mediterranean Oil Spill Waste Management Decision Support Tool (Waste Management).

7.3.9. Enhancing communication and public awareness protocols (RC3.9)

Transparency and effective communication are crucial during pollution incidents, especially those involving potentially hazardous fuels. CPs should establish clear communication protocols for informing the public about spills, associated risks, and ongoing response actions. Utilizing social media, local news outlets, and dedicated websites can help keep the public informed, reduce misinformation, and ensure that affected communities are aware of safety measures. Public awareness campaigns about the risks associated with alternative fuels can also promote understanding and support for safety regulations, aligned with REMPEC's existing awareness-raising efforts under its capacity-building initiatives.

7.3.10. Evaluating and updating response mechanisms regularly (RC3.10)

The rapidly evolving marine fuel landscape and associated technologies require regular evaluation and updates to ensure response mechanisms remain effective and relevant over time. REMPEC and CPs should establish a system for periodic reviews, such as annual assessments, to evaluate the effectiveness of response protocols, training programs, and equipment stockpiles. This process should incorporate continuous monitoring and feedback from recent pollution incidents, lessons learned, and regulatory or technological advancements. This approach allows CPs to track performance, identify areas needing improvement, and adapt to evolving risks, ensuring their response mechanisms remain robust, agile, and capable of addressing emerging challenges in marine pollution response.

7.4. Strategic Objective 4 (SO4) — Enhancing Stakeholder Engagement and Collaboration

Effectively managing marine pollution incidents involving low-sulphur and alternative fuels demands a multi-stakeholder approach. Active engagement of national authorities, regional organizations, industry players, non-governmental organizations (NGOs), scientific institutions, and local communities is essential to foster trust, build capacity, and align resources for a coordinated response. These efforts will not only strengthen regional preparedness but also ensure the development of a resilient and sustainable framework for managing pollution incidents across the Mediterranean. The following recommendations focus on enhancing stakeholder engagement and collaboration:

7.4.1. Establishing a regional stakeholder forum on pollution response (RC4.1)

A dedicated regional stakeholder forum established by REMPEC is necessary to facilitate regular discussions on pollution response strategies, foster collaboration, and ensure the alignment of efforts. This forum should bring together representatives from government agencies, REMPEC, shipping companies, fuel suppliers, environmental NGOs, academic institutions, and local communities. Regular meetings and workshops within the forum will enable the exchange of best practices, the review of recent incidents, and the identification of emerging challenges. To ensure the forum's effectiveness:

- *Coordination by REMPEC:* The forum could be coordinated by REMPEC, leveraging its regional expertise and resources.
- *Cross-sector integration:* Engage stakeholders from diverse sectors, including maritime and environmental organizations, to ensure comprehensive representation.
- *Outcome-driven agenda*: Focus discussions on actionable outcomes, such as the development of joint response protocols, funding mechanisms, and stakeholder training programs.

7.4.2. Strengthening partnerships with the private sector (RC4.2)

Private sector entities, including shipping companies, fuel providers, and port operators, are pivotal in preventing and responding to pollution incidents. CPs should establish formal partnerships with these stakeholders to foster collaboration, resource sharing, and joint preparedness efforts. The North American VOO program showcases private-sector integration with local fishing vessels for large-scale incidents.

These partnerships can significantly enhance the effectiveness of pollution prevention and response strategies through the following key actions:

- *Joint training programs:* These programs should focus on fuel-specific risks, containment strategies, and response protocols, ensuring a coordinated and informed response to incidents. Training can be tailored to include practical drills, tabletop exercises, and workshops to enhance readiness across all levels of operations.
- *Incentives for compliance*: CPs should offer incentives to encourage their private-sector compliance with stringent environmental standards. These incentives could include reduced port fees, recognition programs for environmentally responsible practices, and financial benefits for companies that contribute to preparedness funds or invest in pollution prevention measures. Such initiatives create a win-win scenario, promoting environmental stewardship while reducing operational risks.
- *Collaboration on innovation*: CPs should actively engage their private entities in research and development initiatives that would advance spill response technologies and promote eco-friendly fuel solutions. Collaborative initiatives can focus on developing next-generation spill containment systems, bioremediation techniques, and advanced monitoring tools such as drones and AI-powered surveillance systems. Joint funding mechanisms would accelerate the adoption of innovative solutions.
- *Resource sharing and technology investments*: CPs should encourage private-sector investment in spill prevention and response technologies, leveraging shared resources to improve regional preparedness. This could include co-financing response equipment stockpiles, contributing to regional response hubs, and participating in pilot projects that test new technologies and operational frameworks.

By formalizing partnerships, REMPEC and the CPs can integrate private-sector expertise, resources, and innovations into the national and regional pollution response frameworks. This approach will ensure that the response efforts are not only robust and resource-efficient but also aligned with the latest industry standards and technological advancements.

7.4.3. Engaging local communities in response preparedness (RC4.3)

Local communities, often the first affected by pollution incidents, can play an important role in response efforts. Their engagement ensures preparedness at the grassroots level while fostering trust and cooperation. Proposed measures to engage local communities include:

- *Community awareness campaigns:* Conducting educational programs will help raising awareness of pollution risks associated with alternative fuels and train community members in basic spill response techniques.
- Involvement in drills: Including local communities in simulation exercises, particularly those focused on shoreline clean-up and habitat restoration ensures preparedness at the grassroots level while fostering trust and cooperation.
- *Public consultations:* Holding regular consultations with local communities will ensure that their concerns and suggestions are integrated into response planning.

7.4.4. Enhancing collaboration with scientific and research institutions (RC4.4)

Scientific institution's role is crucial for advancing understanding of alternative fuel behaviours and developing innovative response mechanisms. CPs should actively collaborate with universities, research centres, and environmental agencies to support these efforts. Key steps include:

- *Collaborative research initiatives:* Partner with scientific institutions to study the environmental impacts of alternative fuels and develop predictive models for spill behaviour.
- *Integration of research into practice:* Using findings from academic studies will assist in updating response protocols, improving monitoring systems, and designing specialized equipment.
- *Expert advisory panels:* Establishing panels of scientific experts will provide guidance during pollution incidents and inform policy decisions.

7.4.5. Facilitating cross-border resource sharing (RC4.5)

Given the transboundary nature of pollution incidents, cross-border collaboration is critical for efficient resource utilization. CPs should formalize agreements for sharing resources such as equipment, trained personnel, and expertise. Actions to support this include:

- *Regional resource networks:* Establishing centralized inventories of available equipment and personnel across CPs will enable rapid mobilization during incidents and enhance the region's collective response capabilities.
- *Clear response protocols:* Developing standardized procedures for requesting and providing cross-border assistance, aligned with REMPEC's guidelines and the Host Nation Support Framework will ensure a coordinated and efficient response during emergencies
- *Joint resource pools:* Creating regional stockpiles of specialized equipment for alternative fuels, stationed in high-risk zones will strengthen the region's preparedness for incidents involving low-Sulphur and alternative fuels.

7.4.6. Supporting regional training programs and joint drills (RC4.6)

Joint training programs and drills are crucial for building cohesion and familiarity among stakeholders who will need to collaborate in a crisis. These activities should focus on fuel-specific risks, cross-border collaboration, and rapid deployment strategies. Proposed initiatives include:

- *Regular joint drills:* Conducting annual or biennial drills simulating alternative fuel spills, with participation from public, private, and NGO stakeholders.
- *Regional training workshops:* Organizing workshops led by REMPEC to share lessons learned and refine response strategies.
- *Capacity-building partnerships:* Collaborating with maritime academies and research institutions to design and deliver advanced training modules.

7.4.7. Mediterranean database of pollution response resources (RC4.7)

A centralized database managed by REMPEC will serve as a critical tool for streamlining coordination during pollution incidents. This database would catalogue equipment inventories, trained personnel, and expert contacts across the region. Key features of the database include:

- *Real-time updates:* Ensuring that the centralized database is regularly updated with the latest resource availability and response capabilities.
- *Accessible platform:* Providing easy access for authorized stakeholders, enabling quick mobilization of resources.
- *Integration with decision-support tools:* Linking the database to regional systems such as MEDGIS-MAR, MIDSIS-TROCS and Mediterranean Waste Management Decision Support Tool for enhanced response planning.

7.4.8. Encouraging transparent communication and information sharing (RC4.8)

Transparent communication builds trust among stakeholders and ensures accountability during pollution incidents. CPs should establish clear protocols for sharing information on incidents, response efforts, and outcomes to public. Recommended measures include:

- *Public updates:* Regularly informing the public about ongoing response actions and environmental impacts through social media, news outlets, and dedicated websites.
- *Incident debriefings:* Conducting transparent reviews of response operations, sharing findings with stakeholders to promote learning and improvement.
- *Open data platforms:* Developing platforms for sharing incident data, lessons learned, and research findings to encourage collaboration and innovation.

7.4.9. Promoting Public-Private-NGO partnerships for environmental stewardship (RC4.9)

NGOs bring valuable expertise in environmental monitoring, public engagement, and habitat restoration. CPs should foster partnerships between government agencies, private companies, and NGOs to enhance stewardship efforts. Key actions include:

- *Joint initiatives:* Collaborating on projects such as fuel spill monitoring, habitat restoration, and public education campaigns.

- *Community trust-building:* Leveraging NGOs as intermediaries to address public concerns and ensure transparent communication during incidents.
- *NGO involvement in drills:* Including NGOs in training exercises and simulation drills to align their efforts with national and regional strategies.

7.4.10. Leveraging REMPEC's role for enhanced regional coordination (RC4.10)

REMPEC plays a central role in coordinating pollution response efforts across the Mediterranean. To strengthen regional response, CPs should leverage REMPEC's expertise and resources, such as by supporting its initiatives, actively participating in its programs, and collaborating on research and capacity-building projects. By supporting REMPEC's role, CPs can ensure a unified approach to pollution response involving low-Sulphur and alternative fuels, benefiting from the centre's experience and strategic oversight.

Further, REMPEC's coordination efforts can be expanded to include regular assessments of regional response capabilities and recommendations for improvement.

REMPEC could establish specialized sub-committees on alternative fuels, spill response, and technology development. These sub-committees could be supported by seconded junior and senior officers funded by CPs. This approach would enhance technical expertise, foster collaboration among CPs, and ensure the consistent implementation of best practices while addressing REMPEC's staffing constraints effectively.

7.5. Conclusion

This chapter presented a set of strategic objectives and respective detailed 31 recommendations designed to prepare the Mediterranean region for the challenges posed by the transition to low Sulphur and alternative fuels. The recommendations are organized into four Strategic Objectives (SOs) that emphasize policy and regulatory improvements (SO1), capacity building and training (SO2), enhancing response mechanisms (SO3), and fostering stakeholder engagement and collaboration (SO4). These objectives provide a clear pathway to addressing the critical gaps identified in the region's existing preparedness and response frameworks.

The outlined 31 recommendations serve as a foundation for building a harmonized, efficient, and resilient system capable of managing pollution incidents involving these emerging fuels. By focusing on aligning national regulations, enhancing cross-border collaboration, advancing technologies, and involving a diverse range of stakeholders, the Mediterranean region can better safeguard its marine environment while adapting to evolving global energy demands.

The next chapter will translate these four strategic objectives and the related 31 recommendations into a structured roadmap and action plan for implementation. It will outline the practical steps, timelines, and milestones required to operationalize these strategies and ensure their sustained impact across the Mediterranean region.

8. STRATEGIC ROADMAP AND ACTION PLAN

8.1. Strategic roadmap: A phased approach

Similar to other ECAs, the Mediterranean region is at a critical time as it transitions to low Sulphur and alternative fuels, requiring a structured and phased approach to ensure effective preparedness and response mechanisms. The strategic roadmap provides a vision and high-level guidance for addressing the unique challenges posed by these marine fuels. It is organized into three distinct phases, each targeting specific milestones to achieve a resilient and harmonized regional response framework. This roadmap establishes the foundation for the subsequent action plan, which operationalizes the recommendations presented in the preceding Chapter 7.

8.1.1. Objectives of the strategic roadmap

The roadmap suggested in this study aims to:

- **Lay the foundation** for preparedness by addressing regulatory and operational gaps in the short term.
- **Strengthen regional coordination and capacity** through mid-term actions that enhance infrastructure, technology, and collaboration.
- **Achieve long-term sustainability and resilience** by fully integrating innovation, harmonizing frameworks, and institutionalizing best practices.

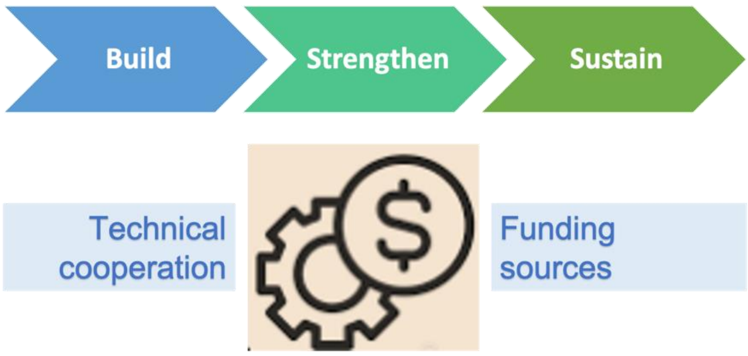


***Figure 5.** Action plan for implementation of recommendation*

8.1.2. Phases of the strategic roadmap

The roadmap organizes efforts into three time-bound phases. **Short-term (0–2 Years)** phase consists of **laying the foundation**. This phase prioritizes immediate actions to address critical gaps in regulatory frameworks, initial capacity building, and stakeholder engagement. Key objectives include updating national legislation, initiating training programs, and forming foundational partnerships.

The key focus areas in the short-term phase consist of:

- Regulatory alignment and enforcement;
- Initial training and awareness programs;
- Establishing foundational response readiness; and
- Stakeholder collaboration and knowledge-sharing mechanisms.

Medium-term (2–5 Years) phase aims at **strengthening preparedness**. This phase builds on the foundational work, emphasizing capacity building, cross-border collaboration, and infrastructure expansion. It also introduces advanced technologies and fosters regional partnerships to enhance overall preparedness. The key focus areas in this phase consist of:

- Expanding regional coordination mechanisms;
- Scaling up training and certification standards;
- Developing specialized response hubs and tools; and
- Promoting research and technology adoption.

Long-term (+5 Years) phase aims at **achieving sustainable and full operational readiness**. This phase focuses on institutionalizing resilience through the harmonization of regional frameworks, integration of cutting-edge technologies, and fostering a culture of continuous improvement. Sustained collaboration and innovation will ensure the Mediterranean remains prepared for emerging challenges. Key focus areas in this phase consist of:

- Full harmonization of regulatory and operational frameworks;
- Deployment of AI-powered and predictive monitoring technologies;
- Establishing permanent training centres and multi-stakeholder partnerships; and
- Promoting continuous research, development, and adaptation.

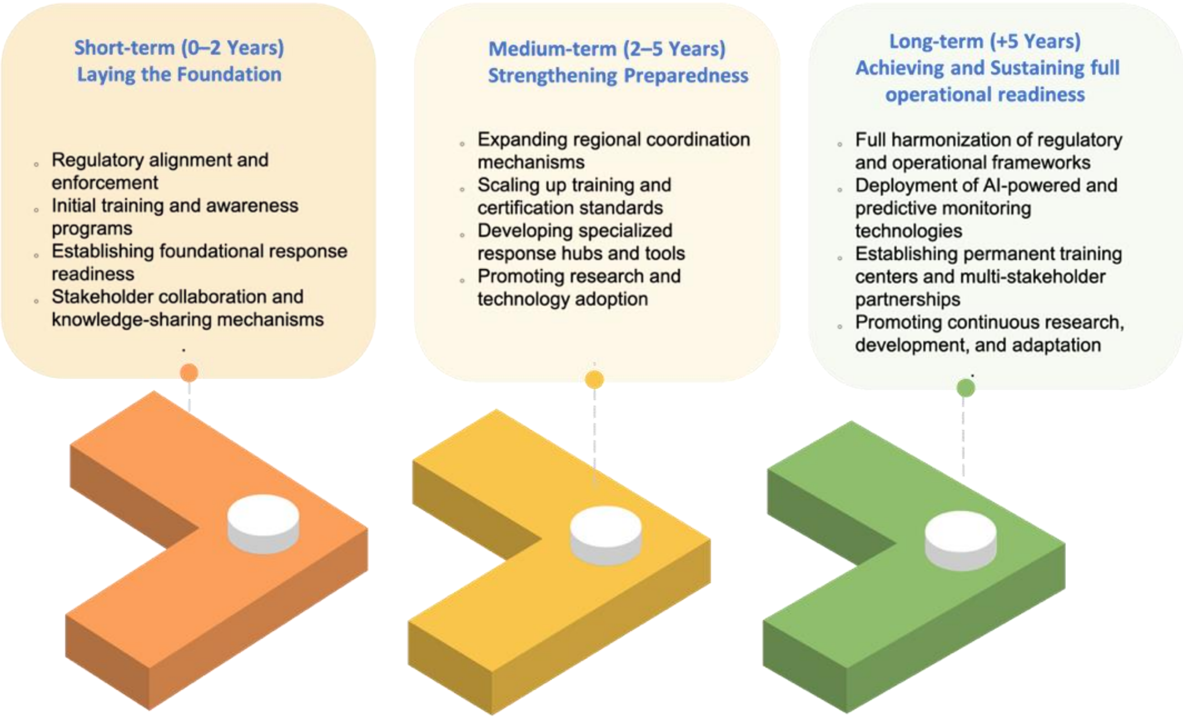


Figure 6. *Phases of the strategic road map*

8.1.3. Integration with the action plan

While the roadmap provides the strategic direction, the action plan (outlined in subsequent sections) translates this vision into actionable steps for implementation. Each phase of the roadmap corresponds to specific actions, mapped to the strategic objectives and responsible stakeholders, ensuring coherence and accountability in execution.

This phased approach is critical for achieving the Mediterranean region's transition to LSFO and alternative fuels. By prioritizing actions based on urgency and feasibility, the roadmap ensures a balanced progression toward a harmonized, resilient, and adaptive pollution response framework across the Mediterranean. This systematic progression allows for efficient allocation of resources, integration of innovative technologies, and strengthening of regional cooperation.

8.2. Action plan: Operationalizing the roadmap

Building on the strategic roadmap presented in **Section 8.1**, this action plan details the operational steps required to implement the recommendations outlined in Chapter VIII. The plan focuses on ensuring that the transition to low-Sulphur and alternative fuels and the preparedness and response to any spill involving these types of fuels is managed effectively through coordinated, measurable, and actionable initiatives. Organized into the three phases of the roadmap, the action plan identifies the specific steps, and maps the recommendations to their strategic objectives, and responsible stakeholders for implementation.

8.2.1. Short-term (0–2 Years): Laying the foundation and building preparedness

The short-term phase emphasizes addressing immediate gaps in the Mediterranean region's capacity to manage pollution incidents involving low-sulphur and alternative fuels. The focus is on creating a robust regulatory and operational foundation, initiating training programs, and fostering basic stakeholder engagement. Key milestones in this phase include updated regulatory frameworks, basic capacity-building initiatives, and the establishment of foundational response mechanisms.

Table 18 outlines the specific short-term recommendations, actions to implement them, their mapping to strategic objectives, and the responsible stakeholders.

Table 18. *Short-term recommendations and implementation actions*

Recommendation	Actions to Implement	Strategic Objective	Responsible Stakeholders
Updating and aligning national regulatory frameworks (RC1.1)	S1. Establish national implementation committees S2. Ratify and transpose key IMO conventions S3. Review and update national contingency plans to incorporate alternative fuel response strategies S4. Provide incentives to promote compliance and deterrent penalties for violations/infractions S5. Establish prosecution mechanisms for non-compliance S6. Ensure consistent enfoncement and compliance	SO1	CPs
Developing regional guidelines for low-sulphur and alternative fuel spills (RC1.2)	S7. Standardize spill response protocols S8. Establish cross-border coordination mechanisms S9. Integrate innovative response techniques S10. Implement a system for continuous review and dissemination	SO1	REMPEC, CPs

Strengthening enforcement mechanisms (RC1.3)	S11. Enhance inspection procedures for alternative fuels S12. Establish robust legal frameworks S13. Leverage advanced monitoring technologies S14. Provide technical assistance and capacity building for enforcement	SO1	CPs, REMPEC
Establishing initial response hubs in high-risk areas (RC3.5)	S15. Identify high-risk zones for pollution incidents S16. Allocate basic equipment stockpiles S17. Train personnel in spill response	SO3	REMPEC, CPs, Local Authorities
Conducting regional training workshops and exercises (RC2.4)	S18. Facilitate annual or biennial workshops focusing on alternative fuel spill protocols S19. Conduct scenario-based drills in collaboration with REMPEC, EMSA, and private sector stakeholders	SO2	REMPEC, EMSA, CPs
Building a pool of regional experts (RC2.5)	S20. Develop a roster of experts in hazardous materials, marine chemistry, and environmental protection S21. Expand the network of REMPEC Mediterranean Assistance Units (MAUs)	SO2, SO4	REMPEC, CPs
Enhancing communication and public awareness protocols (RC3.9)	S22. Develop clear communication plans for informing the public about pollution incidents and safety measures S23. Launch awareness campaigns on alternative fuel risks	SO4	CPs, NGOs, Local Governments
Engaging local communities in response preparedness (RC4.3)	S24. Conduct community awareness campaigns S25. Involve communities in drills and simulation exercises S26. Hold public consultations to integrate local concerns into response planning	SO4	NGOs, Local Governments

8.2.2. Medium-term (2–5 Years): Strengthening preparedness through capacity building and regional cooperation

The medium-term phase builds on the foundation laid in the short term. This phase is dedicated to scaling up efforts, enhancing regional collaboration, and integrating advanced technologies to improve response mechanisms. Actions include expanding response hubs, conducting joint cross-border drills, implementing real-time monitoring systems, and developing standardized training certifications.

Table 19 highlights the medium-term recommendations, the actions required for implementation, the corresponding strategic objectives, and the roles of stakeholders in achieving them.

Table 19. *Medium-term recommendations and implementation actions*

Recommendation	Steps to Implement	Strategic Objective	Responsible Stakeholders
Standardizing regional spill response protocols (RC1.2)	M1. Finalize regional guidelines for alternative fuel spill management, focusing on containment, mitigation, and recovery	SO1	REMPEC, CPs

	M2. Coordinate between REMPEC and CPs to ensure harmonization of protocols across the Mediterranean M3. Integrate best practices and lessons learned into updated guidelines		
Expanding response hubs in high-risk areas (RC3.5)	M4. Upgrade existing response hubs with specialized equipment for alternative fuel spills M5. Train and certify additional personnel to operate response hubs effectively	SO3	REMPEC, CPs, Local Authorities
Conducting joint regional drills (RC2.4, RC3.6)	M6. Organize biennial cross-border exercises involving multiple CPs, REMPEC, and EMSA M7. Test communication channels, resource-sharing frameworks, and response coordination M8. Include drills for handling large-scale incidents involving alternative fuels	SO2, SO3	REMPEC, EMSA, CPs
Establishing certification standards for responders (RC2.3)	M9. Develop certification programs to ensure responders meet standardized proficiency levels in managing alternative fuel spills M10. Align certifications with international standards such as EUROWA model courses	SO2	REMPEC, Maritime Academies
Enhancing real-time monitoring and detection systems (RC3.3)	M11. Implement advanced spill detection technologies, such as satellite monitoring, drones, and predictive modelling tools M12. Integrate real-time data with decision-support systems like THETIS-MED and MEDGIS-MAR	SO3	EMSA, CPs, Private Sector
Building a Mediterranean database of response resources (RC4.7)	M13. Develop a centralized inventory of equipment, personnel, and expertise available across CPs M14. Ensure the database is regularly updated and accessible to all stakeholders M15. Link the database with decision-support tools for efficient resource allocation	SO4	REMPEC, CPs
Facilitating cross-border resource sharing (RC4.5)	M16. Establish regional resource networks for rapid deployment of equipment and personnel during incidents M17. Develop standardized protocols for requesting and providing cross-border assistance	SO4	REMPEC, CPs
Collaborating on research and development (RC2.7, RC4.4)	M18. Partner with universities and industries to advance spill response technologies, predictive models, and monitoring tools M19. Conduct collaborative research on the environmental impacts of alternative fuels	SO2, SO4	CPs, Scientific Institutions
Integrating Environmental Sensitivity Indexes (ESIs) into response planning (RC3.8)	M20. Use ESIs to prioritize resources for protecting sensitive ecosystems, such as coral reefs and marshlands M21. Incorporate ESIs into decision-support tools for strategic response planning	SO3	REMPEC, CPs, Scientific Institutions
Promoting transparent communication	M22. Develop platforms for sharing incident data, lessons learned, and response protocols among CPs	SO4	REMPEC, CPs

and information sharing (RC4.8)	M23. Regularly update stakeholders and the public on response efforts and environmental impacts		

8.2.3. Long-term (+5 Years): Achieving and sustaining full operational readiness

The long-term phase focuses on achieving a harmonized and resilient regional framework capable of managing pollution incidents involving alternative fuels. By institutionalizing best practices, integrating advanced technologies, and fostering sustained collaboration, this phase ensures the CPs and the entire Mediterranean region remains equipped for future challenges. Milestones include harmonized regulatory frameworks, permanent training centres, AI-powered monitoring systems, and long-term multi-stakeholder partnerships.

Table 20 provides the long-term recommendations, actionable steps, their alignment with strategic objectives, and the stakeholders responsible for implementation.

Table 20. *Long-term recommendations and implementation actions*

Recommendation	Steps to Implement	Strategic Objective	Responsible Stakeholders
Harmonizing regional frameworks (RC1.1, RC1.2)	L1. Finalize the alignment of national and regional regulatory frameworks with international standards L2. Conduct periodic reviews to ensure frameworks remain up-to-date with emerging technologies and global best practices L3. Ensure consistent enforcement across the region	SO1	CPs, REMPEC, IMO
Maintaining advanced regional training programs (RC2.4, RC2.3)	L4. Establish permanent training centres to provide continuous professional development for responders L5. Update training modules regularly to reflect advancements in spill response technologies and alternative fuel management L6. Ensure regional certifications for responders are maintained and aligned with international standards.	SO2	REMPEC, Maritime Academies
Integrating innovative technologies (RC3.3, RC3.4)	L7. Fully deploy AI-powered tools, real-time monitoring systems, and predictive models for spill response L8. Use advanced fuel dispersion models to simulate and predict the behaviour of alternative fuel spills L9. Integrate these tools with regional traffic control centres for better coordination	SO3	EMSA, CPs, Private Sector
Establishing long-term multi-stakeholder partnerships (RC4.2, RC4.9)	L10. Strengthen partnerships between governments, NGOs, private sector entities, and research institutions L11. Collaborate on joint initiatives such as habitat restoration, environmental monitoring, and fuel spill mitigation projects L12. Leverage NGOs to enhance public trust and support during pollution incidents	SO4	REMPEC, NGOs, Private Sector
Expanding expert advisory panels (RC4.4, RC2.5)	L13. Create permanent regional panels of scientific and technical experts to guide	SO4	REMPEC, Scientific Institutions

	policy development and support incident response L14. Ensure the advisory panels regularly review and update response protocols based on new findings		
Creating a centralized resource database (RC4.7)	L15. Develop a Mediterranean-wide inventory of response resources, including personnel, equipment, and expertise L16. Ensure the inventory database is fully integrated with decision-support tools and accessible to all stakeholders	SO4	REMPEC, CPs
Fostering a culture of continuous improvement (RC3.7, RC3.10)	L17. Implement regular drills, incident reviews, and simulation exercises to test and refine response mechanisms L18. Use feedback from drills and incidents to continuously improve regional frameworks and protocols	SO3	REMPEC, CPs
Promoting public-private partnerships for innovation (RC4.9)	L19. Collaborate with the private sector to develop next-generation spill response tools and eco-friendly technologies L20. Co-finance projects that address alternative fuel risks and improve response readiness	SO4	CPs, Private Sector Stakeholders
Developing advanced compensation and liability frameworks (RC1.4)	L21. Finalize liability frameworks that address the unique risks associated with alternative fuels L22. Advocate for the inclusion of alternative fuels under existing international compensation regimes L23. Regularly update these frameworks to align with evolving fuel technologies L24. Establish a regional fund under REMPEC (Blue Fund) for compensating pollution damages by inter alia alternative fuels	SO1	CPs, REMPEC, IMO

8.3. Monitoring and evaluation

The successful implementation of the action plan necessitates a robust monitoring and evaluation framework. This would ensure that progress is systematically tracked, challenges are identified early, and actions are continuously refined to align with emerging needs and lessons learned. monitoring and evaluation mechanisms should be integrated into each phase of the roadmap to assess progress and ensure accountability among stakeholders.

8.3.1. Key Performance Indicators (KPIs)

Key Performance Indicators (KPIs) should be developed for each recommendation to provide measurable benchmarks for implementation success. These indicators should be Specific, Measurable, Achievable, Relevant, and Time-bound (SMART). Examples of KPIs are presented in **Table 21.**

***Table 21.** Examples of Key Performance Indicators (KPIs) for monitoring the implementation of the action plan*

Focus Area	Key Performance Indicators (KPIs)
Regulatory Frameworks	○ Percentage of CPs updating national legislation to align with IMO instruments. ○ Number of national contingency plans revised to include alternative fuel spill response strategies
Capacity Building	○ Number of responders trained in alternative fuel spill management ○ Percentage of CPs with certified spill response personnel meeting international standards
Infrastructure Development	○ Number of response hubs established or upgraded with specialized equipment for alternative fuels ○ Quantity of spill response equipment procured and deployed in high-risk areas
Response Mechanisms	○ Average time taken to detect and respond to spills involving alternative fuels during drills or incidents ○ % of CPs integrating real-time monitoring systems into decision-support tools
Stakeholder Collaboration	○ Number of formalized cross-border agreements for resource sharing and mutual aid ○ Frequency of regional stakeholder meetings and joint drills conducted
Knowledge Sharing and Innovation	○ Number of research initiatives completed or ongoing related to alternative fuels and spill response technologies ○ Volume of data or case studies shared on regional knowledge platforms

8.3.2. Regular reporting

Annual progress reports will be a critical component of the monitoring and enforcement framework, submitted by CPs to REMPEC. These reports should include:

- updates on completed activities for each phase (short, medium-term, long-term);
- challenges encountered and proposed solutions;
- progress on meeting KPIs, with quantitative and qualitative data; and
- resource allocation and utilization details, including funding sources and expenditures.

REMPEC will consolidate these reports into a regional overview, highlighting key trends, gaps, and areas requiring further attention. This will ensure transparency and allow stakeholders to stay informed about overall progress.

8.3.3. Periodic Reviews

Periodic reviews, conducted every 1-2 years, will provide an opportunity to evaluate the Action Plan’s effectiveness and make necessary adjustments. These reviews should:

- analyse progress against KPIs to determine whether milestones are being achieved;
- incorporate lessons learned from drills, exercises, and real-world incidents;
- assess the relevance of ongoing actions in light of emerging technologies, regulatory developments, or environmental changes; and

- recommend adjustments to the roadmap or action plan to address new challenges or optimize resource allocation.

8.3.4. Feedback loops and adaptive management

For continuous improvement, a feedback mechanism should be established. This will ensure that:

- insights from monitoring and periodic reviews are shared with all stakeholders;
- adjustments to the action plan are communicated effectively and implemented collaboratively; and
- best practices and innovations are disseminated regionally to improve overall readiness.

By systematically applying monitoring and enforcement principles, the Action Plan will remain dynamic and adaptable, ensuring that the CPs and the entire Mediterranean region achieves and sustains full operational readiness for low-sulphur and alternative fuel spill response.

8.4. Funding and support mechanisms

Funding mechanisms and support structures form the backbone of the proposed action plan's success, enabling effective training, acquisition of critical equipment, development of necessary infrastructure, and execution of collaborative initiatives. Below is an overview of key funding and support avenues:

- **National budgets**: CPs play a pivotal role in ensuring the success of the action plan by allocating dedicated portions of their national budgets. These allocations are vital for:
  - training personnel;
  - procuring equipment for monitoring and rapid response to incidents; and
  - building and maintaining infrastructure that supports implementation efforts.
- **Regional funds**: Regional initiatives, such as those coordinated by REMPEC, rely on pooled resources to address shared priorities. These funds support activities such as joint training exercises, shared response mechanisms, and capacity-building programs. The MedFund[56] serves as a leading example of such regional collaboration, targeting enhanced management and financial autonomy for MPAs across the Mediterranean region. Consideration is required for establishing a regional fund under the auspices of REMPEC (Blue Fund) for compensating pollution damages by inter alia alternative fuels.
- REMPEC could also seek access to the EU's environmental funding schemes (e.g., LIFE program, Horizon Europe) for advanced technologies like AI spill detection or bioremediation trials.

[56] The MedFund aims to mobilize public and private stakeholders to promote the development and effectiveness of Mediterranean MPAs.

- **International support**: Grants and technical assistance from international organizations like IMO, UNEP, and the EU provide critical resources to implement the propose recommendations and action plan in this study effectively.

  For instance, The MedFund, launched in 2015, receives substantial backing from international stakeholders, including:

  - the Global Environment Facility (GEF);
  - the French Facility for Global Environment (FFEM); and
  - the French Development Agency (AFD) This support strengthens efforts to protect biological diversity and implement co-management practices in MPAs.

  Additionally, EU-funded projects play a significant role in supporting marine environmental protection in the Mediterranean region. For example, the "EFFECTIVE" project aims to enhance the effectiveness of protection and restoration management in Mediterranean MPAs, helping to preserve their natural capital57. Another initiative, the "MPA Europe" project, systematically maps an optimal network of MPAs across European seas, including the Mediterranean, to maximize biodiversity conservation and blue carbon storage[58]. These projects, among others, exemplify the EU's commitment to fostering sustainable and inclusive economic growth within the Mediterranean region through targeted environmental initiatives.

- **Private sector engagement**: Public-private partnerships (PPPs) and cost-sharing mechanisms with industry stakeholders drive innovation and sustainability in implementing the proposed recommendations and action plan. The MedFund exemplifies this approach by leveraging support from the Prince Albert II of Monaco Foundation, aquariums led by the Oceanographic Institute of Monaco, and private sector partners. Such partnerships provide funding for:

  - activities essential to preserving marine ecosystems; and
  - support for local communities dependent on marine resources.

These efforts reflect a broader commitment to sustainable and inclusive economic growth within the Mediterranean region.

Through these funding and support mechanisms, the recommendations and the proposed action plan in this study could address critical gaps in management, preparedness, and collaboration. Initiatives like the MedFund showcase how innovative, multi-stakeholder financing models can strengthen long-term environmental resilience and enhance the capacity of CPs to fulfil obligations under international instruments.

8.5. Conclusion

The action plan outlined in this chapter provides a comprehensive framework to operationalize the strategic roadmap, ensuring a coordinated and phased approach to address the Mediterranean region's transition to low Sulphur and alternative fuels. By organizing actions

[57] European Commission. (2023). EFFECTIVE: EU-funded projects for enhanced MPA management. Retrieved from https://oceans-and-fisheries.ec.europa.eu/system/files/2023-06/2023-06-29-List-of-projects-eu-mission-call_en.pdf

[58] European Commission. (2023). MPA Europe: Systematic mapping for biodiversity and carbon storage. https://cordis.europa.eu/project/id/101059988

into short-term, medium-term, and long-term phases, the plan offers a structured path toward enhancing preparedness, capacity, and resilience.

Key to the success of this plan is the alignment of national, regional, and international efforts, supported by robust monitoring and evaluation mechanisms. KPIs, regular progress reporting, and periodic reviews will ensure accountability and track the effectiveness of implemented measures. Additionally, adaptive management strategies and feedback loops will allow for continuous refinement of the plan, enabling it to respond to emerging challenges and integrate new technologies.

The action plan proposed in this study is closely aligned with the **Mediterranean Strategy 2022-2031**, as detailed in **Annex V**, ensuring that its objectives and priorities are integrated into broader regional efforts to promote sustainable development and environmental protection.

Funding and resource mobilization play a critical role in realizing the objectives of the action plan. By leveraging diverse funding sources, including national budgets, regional cooperation funds, international grants, and private-sector partnerships, the CPs and the region can ensure the sustainability of their initiatives. Collaborative efforts, such as multi-stakeholder partnerships and shared resources, will further enhance the CPs' collective response capabilities.

Furthermore, by fostering collaboration, advancing capacity-building efforts, and integrating cutting-edge technologies, the Mediterranean region will be well-equipped to mitigate the risks of low-sulphur and alternative fuel spills, safeguarding its marine environment and contributing to global environmental protection efforts.

9. CONCLUSION

The Mediterranean region, as a critical global maritime corridor, faces both challenges and opportunities with the imminent implementation of the Med SOx ECA in May 2025. This transformative regulatory milestone signals a commitment to environmental progress but also demands a proactive response to the risks posed by low-Sulphur and alternative fuels. The findings of this study emphasize the pressing need for a harmonized and adaptive approach to address regulatory, capacity, and preparedness gaps within the region.

By identifying critical weaknesses, such as the lack of ratification of essential international instruments like MARPOL Annex VI and the absence of tailored national provisions for alternative fuels, this study highlights the urgency of updating and standardizing the regulatory landscape. Similarly, deficiencies in specialized equipment, training, and cross-border coordination underscore the necessity for enhanced preparedness and response frameworks.

The proposed roadmap outlines a phased strategy for achieving operational readiness in the short, mid, and long term. Its focus on building foundational capabilities, strengthening regional collaboration, and sustaining continuous improvement ensures a comprehensive approach to managing the unique risks of low-Sulphur and alternative fuels. Innovative solutions such as simulation-based training, real-time monitoring technologies, and advanced response hubs are pivotal in enhancing the region's capacity to address complex spill scenarios effectively.

To ensure the Mediterranean region's readiness for marine pollution incidents involving low-Sulphur and alternative fuels, the success of the initiatives proposed in this study relies on the collective efforts of all stakeholders, particularly Contracting Parties and their public and private sectors. Providing human resource support, such as seconded experts, are essential to strengthening REMPEC's operational capacity and enabling it to effectively fulfill its critical role in the region. Funding mechanisms, including national investments, regional funds, and private-sector partnerships, provide the financial backbone for implementing these critical initiatives.

In conclusion, this study charts a clear path forward for the Mediterranean region to navigate the transition to a multi-fuel future with resilience and foresight. By addressing identified gaps and leveraging innovative practices, REMPEC and the Contracting Parties can establish a global benchmark for pollution response preparedness, ensuring the protection of the region's unique marine environment and socio-economic interests for generations to come.

LIST OF ANNEXES

BIBLIOGRAPHY

Aarhus University, DCE – Danish Centre for Environment and Energy. (2022). *Assessment of the potential environmental impacts of a major ammonia spill from a Power-to-X plant and from shipping of ammonia in Greenland*. Aarhus University. Retrieved from: https://dce2.au.dk/pub/SR487.pdf

AFHYPAC. (2020). *Memo on hydrogen.* With contributions from INERIS.

Alcaro, L., Brandt, J., Giraud, M., Mannozzi, M., & Nicolas-Kopec, A. (2021). *Marine HNS Response Manual: Multi-regional Bonn Agreement, HELCOM, REMPEC.* Project WestMopoco.

American Bureau of Shipping (ABS). (2021). *Sustainability whitepaper: Methanol as marine fuel*. American Bureau of Shipping. Retrieved from: https://absinfo.eagle.org/acton/media/16130/sustainability-whitepaper-methanol-as-marine-fuel

American Bureau of Shipping (ABS). (2024). *Methanol bunkering: Technical and operational advisory*. American Bureau of Shipping. Retrieved from: https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/methanol-bunkering-advisory.pdf

Arctic Council PAME*. (2024). Low Sulphur- and Ultra-Low Sulphur Fuel Oils Used by Ships in Arctic Waters. Report from Work Package 1, Approved February 2024. https://oaarchive.arctic-council.org/items/3b0c727c-b2d7-4140-b2d9-99dea76b58d*

ARIA. (2008). *Accidents involving hydrogen.*

Australian Maritime Safety Authority (AMSA). (2021). *Study on responding to Very Low Sulphur Fuel Oil (VLSFO) spills*. Reef Ecologic Pty Ltd. Retrieved from: http://www.amsa.gov.au/marine-environment/pollution-response/very-low-sulphur-fuel-oil-study

Baltic Marine Environment Protection Commission (HELCOM). (2019). *Alternative fuels for shipping in the Baltic Sea region*. Retrieved from: https://www.helcom.fi/wp-content/uploads/2019/10/HELCOM-EnviSUM-Alternative-fuels-for-shipping.pdf

Bureau Veritas. (2021a). *NR971 Ammonia-Fueled Ships - Tentative Rules - Rule Note.*

Bureau Veritas. (2021b). *NR670 - Methyl/Ethyl Alcohol-Fueled Ships - Rule Note.*

Cedre & Transport Canada. (2012). *Understanding chemical pollution at sea: Learning guide.* Brest: Cedre.

Centre of Documentation, Research, and Experimentation on Accidental Water Pollution *(Cedre)*. (2015). *Les récupérateurs, Guide opérationnel. Brest: Cedre. 93 p*

Centre of Documentation, Research, and Experimentation on Accidental Water Pollution *(Cedre)*. (2012). *Chemical intervention guide: Methanol.*

Centre of Documentation, Research, and Experimentation on Accidental Water Pollution *(Cedre)*. (2006). *Chemical intervention guide: Ammonia. https://wwz.cedre.fr/en/content/download/2779/140112/file/Extract-ammonia.pdf*

Chever, F. (2022). *IMAROS Deliverable D3.2: Physical-chemical characterization of 13 LSFO.* Brest: Cedre.

ClearSeas. (2019). *LNG and maritime transport.*

European Maritime Safety Agency (EMSA). (2015). *Study on the use of ethyl and methyl alcohol as alternative fuels in shipping.* With contributions from Ellis, J., & Tanneberger, K.

European Maritime Safety Agency (EMSA). (2018). *Guidance on LNG bunkering for port authorities and administrations.*

European Maritime Safety Agency (EMSA). (2023). CleanSeaNet Service. Retrieved from: https://www.emsa.europa.eu/csn-menu.html

European Maritime Safety Agency (EMSA). (2023). Potential of Ammonia as Fuel in Shipping. Retrieved from: https://emsa.europa.eu/csn-menu/items.html?cid=14&id=4833

European Maritime Safety Agency (EMSA). *(2024). Safety of Ammonia for Use in Ships: Properties, Regulations, and Accidents Review. Rev. 1.1, EMSA, Lisbo.* https://www.emsa.europa.eu/about/financial-regulations/items.html?cid=14&id=5264

European Renewable Ethanol Producers Association (ePURE). *(2023). Overview of Biofuels Policies and Markets Across the EU. Updated February 2023. ePURE - Rue de la Loi 223, Brussels.* https://www.epure.org/wp-content/uploads/2023/02/230227-DEF-REP-Overview-of-biofuels-policies-and-markets-across-the-EU-February-2023-1.pdf

Faksness, L. G., Røyset, J. A., Altin, D., Sørheim, K. R., Berger, S., & Daling, P. S. (2024, July). Chemical characteristics and acute toxicity of low sulphur fuel oils and their fate and behaviour in cold water and Arctic conditions. In International Oil Spill Conference Proceedings (Vol. 2024, No. 1). Allen Press. Retrieved from: https://meridian.allenpress.com/iosc/article/2024/1/243/501973

Favier, J., Amanzholova, D., & Lee, N. M. (2020). *The domestication of international regulation as a fundamental step to developing a preparedness and response framework.* 2020 International Oil Spill Conference. Retrieved from: https://meridian.allenpress.com/iosc/article/2021/1/687628/473301/Domestication-of-International-Regulation-as-a

Federal Railroad Administration. (2012). *Emergency responder guidance: Liquefied natural gas (LNG)*. U.S. Department of Transportation. Retrieved from: https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/18510/Emergency%20Responder%20Guidance%20LNG%20brochure.pdf

García-Monteiro, S., Sobrino, J. A., Julien, Y., Sòria, G., & Skokovic, D. (2022). Surface Temperature trends in the Mediterranean Sea from MODIS data during years 2003–2019. Regional Studies in Marine Science, 49, 102086. Retrieved from: https://www.sciencedirect.com/science/article/pii/S2352485521004692

Gilbert, T. (2022). *Response to very low sulfur marine fuel oil spills: Final report.* Australian Maritime Safety Authority.

Global Centre for Maritime Decarbonisation (GCMD). (2024). *How do we respond to an ammonia release at sea? Retrieved from:* https://www.gcformd.org/how-do-we-respond-to-an-ammonia-release-at-sea/

Global Centre for Maritime Decarbonisation (GCMD). *(2024). How Do We Respond to an Ammonia Release at Sea? https://www.gcformd.org/how-do-we-respond-to-an-ammonia-release-at-sea/*

GORSAP. (2016). *Orange guide for firefighters in Geneva - 5th edition.*

HELCOM. (2002). *HELCOM manual on cooperation in response to marine pollution within the framework of the Helsinki Convention, Volume 2: Response to accidents at sea involving spills of hazardous substances and loss of packaged dangerous goods*. Helsinki Commission. Retrieved from: https://helcom.fi/wp-content/uploads/2019/08/HELCOM-Manual-on-Co-operation-in-Response-to-Marine-Pollution-Volume-2.pdf

Helsinki Commission (*HELCO) (2002). Manual on Co-operation in Response to Marine Pollution Within the Framework of the Helsinki Convention. Volume 2, 1. https://helcom.fi/wp-content/uploads/2021/03/HELCOM-Manual-on-Co-operation-in-Response-to-Marine-Pollution.pdf*

INERIS. (1999). *Ammonia: Large-scale atmospheric dispersion tests.* With contributions from Bouet, R., Gaston, D., & Faucher, B.

INERIS. (2012). *Toxicological and environmental data sheet for chemical substances: Ammonia.* With contributions from Barneaud, A., Bisson, M., Del Grata, F., Ghillebaert, F., Guillard, D., & Tack, K.

INERIS. (2015). *Proposed semi-quantitative method for evaluating ignition probabilities.* With contributions from De Dianous, V., Flauw, M., Janes, A., Kribi, S., & Leprette, E.

INRS. (2018). *About toxicological data sheets.*

International Maritime Organization (IMO). (1973/1978). *International Convention for the Prevention of Pollution from Ships (MARPOL).* London publication

International Maritime Organization (IMO). (1974). *International Convention for the Safety of Life at Sea (SOLAS).* London publication

International Maritime Organization (IMO). (1990). *International Convention on Oil Pollution. Preparedness, Response and Co-operation (OPRC Convention).* London publication

International Maritime Organization (IMO). (1998). *International Safety Management Code (ISM Code): For the Safe Operation of Ships and for Pollution Prevention.* London publication

International Maritime Organization (IMO). (2000). *Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances (OPRC-HNS Protocol).* London publication

International Maritime Organization (IMO). (2015). *International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code).* London publication.

International Maritime Organization (IMO). (2019). *2019 Guidelines for consistent implementation of the 0.50% sulphur limit under MARPOL Annex VI (Resolution MEPC.320(74))*. International Maritime Organization. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Resolution%20MEPC.320%2874%29.pdf

International Maritime Organization (IMO). (2022). *Amendments to MARPOL Annex VI: Prevention of Air Pollution from Ships*.

International Maritime Organization (IMO). (2022). *Proposal to designate the Mediterranean Sea as an Emission Control Area for Sulphur Oxides* (MEPC 78/11). https://cleanarctic.org/wp-content/uploads/2022/06/MEPC-78-11-Proposal-to-Designate-the-Mediterranean-Sea-as-a-whole-as-an-Emission-ControlArea-for-Su...-Albania-Algeria-Austria....pdf

International Maritime Organization (IMO). (2023). *GreenVoyage2050 Regulatory Mapping Exercise on Alternative Fuels*. Retrieved from: https://www.imo.org/en/ourwork/partnershipsprojects/pages/greenvoyage2050.aspx

International Maritime Organization (IMO). (2024). *Draft report of the 30th session of the Technical Group on the Evaluation of Safety and Pollution Hazards of Chemicals*. ESPH 30/WP.1.

International Maritime Organization (IMO). (2024). *Global Integrated Shipping Information System – Status of Treaties.* Retrieved from https://gisis.imo.org/Public/ST/Treaties.aspx

International Tanker Owners Pollution Federation (ITOPF). (2024). *Fate, behaviour, and potential damage & liabilities arising from a spill of liquefied natural gas into the marine environment*. Report for the International Group of P&I Clubs Alternative Fuels Working Group. https://www.itopf.org/fileadmin/uploads/itopf/data/Documents/Papers/ITOPF_LNG_-_Fate__Behaviour__Damage_and_Liability_Report.pdf

International Tanker Owners Pollution Federation (ITOPF). (2024). *Fate, behaviour, and potential damage & liabilities arising from a spill of methanol into the marine environment*. Report for the International Group of P&I Clubs Alternative Fuels Working Group. https://www.itopf.org/knowledge-resources/documents-guides/fate-behaviour-potential-damage-liabilities-arising-from-a-spill-of-methanol-in-the-marine-environment/

International Tanker Owners Pollution Federation (ITOPF). (2024). *Country profiles for spill preparedness and response.* Retrieved from https://www.itopf.org

International Tanker Owners Pollution Federation (ITOPF).. (2014). *Response to marine chemical incidents*. Technical Information Paper. Retrieved from https://www.itopf.org/fileadmin/uploads/itopf/data/Documents/TIPS_TAPS_new/TIP_17_Response_to_Marine_Chemical_Incidents.pdf

International Tanker Owners Pollution Federation (ITOPF).. (2024). *Fate, behaviour and potential damages & liabilities arising from a spill of hydrogen into the marine environment.* Report for the International Group of P&I Clubs Alternative Fuels Working Group. Retrieved from https://www.itopf.org/fileadmin/uploads/itopf/data/Documents/Papers/ITOPF_Hydrogen_-_Fate__Behaviour__Damage_and_Liability_Report.pdf

International Tanker Owners Pollution Federation (ITOPF).. (2024). *Fate, behaviour and potential damages & liabilities arising from a spill of ammonia into the marine environment.* Report for the International Group of P&I Clubs Alternative Fuels Working Group. Retrieved from https://www.itopf.org/fileadmin/uploads/itopf/data/Documents/Papers/ITOPF_LNG_-_Fate__Behaviour__Damage_and_Liability_Report.pdf

International Tanker Owners Pollution Federation (ITOPF).. (2024). *Fate, behaviour and potential damages & liabilities arising from a spill of biofuels into the marine environment.* Report for the International Group of P&I Clubs Alternative Fuels Working Group. Retrieved from: https://www.itopf.org/knowledge-resources/documents-guides/fate-behaviour-potential-damage-liabilities-arising-from-a-spill-of-biofuels-in-the-marine-environment/

IOPC Funds (International Oil Pollution Compensation Funds). (2024). Compensation and Claims Management. Retrieved from: https://iopcfunds.org/compensation/

IPIECA (2024). *Response to Spills of Alternative Fuels and Energy Products: Very Low and Ultra Low Sulphur Fuel Oils. https://www.ipieca.org/resources/alternative-fuels-response-fact-sheets/very-low-and-ultra-low-sulphur-fuel-oils*

IPIECA (2024). *Response to Spills of Alternative Fuels and Energy Products: Non-floating Oils. https://www.ipieca.org/resources/alternative-fuels-response-fact-sheets*

IPIECA. (2020). *Lower-sulphur fuels, road transport strategies, and air quality improvements: Guidance document for the management of road transport emissions*. Partnership for Clean Fuels and Vehicles. Retrieved from: https://www.ipieca.org/resources/lower-sulphur-fuels-road-transport-strategies-and-air-quality-improvements

Kass, M. D., Sluder, C. S., & Kaul, B. C. (2021). Spill behaviour, detection, and mitigation for emerging nontraditional marine fuels (No. DTMA91X20A65). United States. Department of Transportation. Maritime Administration. Retrieved from :https://rosap.ntl.bts.gov/view/dot/56542

Kim, B. K., Ruiz, R., Zhang, B., Nayak, S., Mentzer, R. A., & Mannan, M. S. (2012). Recent Progress in LNG Safety and Spill Emergency Response Research. Texas A&M University system, College Station, Texas, 77843-3122. Retrieved from: https://www.icheme.org/media/9159/paper07-hazards-23.pdf

Kirk, B., & Thompson, S. (2021, May). Identifying local oil spill risk factors: an application of hazard identification within the international maritime organization formal safety assessment framework in Washington State. In International Oil Spill Conference (Vol. 2021, No. 1, p. 677002). Retrieved from: https://meridian.allenpress.com/iosc/article-abstract/2021/1/677002/473228

Melhem, G., & Ozog, M. (2006). *Understanding LNG rapid phase transitions (RPT).*

NISHIMURO, M. (2020). Roadmap to Zero Emission from International Shipping. ClassNK technical journal, 2020(1), 13-20. Retrieved from: https://cir.nii.ac.jp/crid/1522262181152662144

O'Driscoll, D. (2021, May). Responder Safety-Evolving Safety Systems, Processes, and Behaviours in an International Oil Spill Response Cooperative. In International Oil Spill Conference (Vol. 2021, No. 1, p. 688791). Retrieved from: https://meridian.allenpress.com/iosc/article-abstract/2021/1/688791/473214

OPECST. (2013). *Hydrogen: A vector for the energy transition?* With contributions from Kalinowski, L., & Pastor, J.-M.

Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC). (2024). *REMPEC online country profiles.* Retrieved from https://www.rempec.org

Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC). (2024). *Overview of National Preparedness for Spill Response in the Mediterranean*.

Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC. (2019). *Technical and feasibility study to examine the possibility of designating the Mediterranean Sea, or parts thereof, as SOx ECA(s) under MARPOL Annex VI*.

Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC. (2021). *Final report on the carrying out of the further study related to the additional analyses of fuel supply and alternative compliance methods*.

Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC. (2021). *Guidance document for the identification and designation of Particularly Sensitive Sea Areas in relation to Specially Protected Areas of Mediterranean Importance*.

Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC. (2021). *Marine HNS Response Manual: Multi-regional Bonn Agreement, HELCOM, REMPEC*.

Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC. (2021). *Report of the regional meeting of national experts on the Mediterranean Strategy for the Prevention of, and Response to, Marine Pollution from Ships (2022-2031)*.

Sørheim, K. R., Daling, P. S., Cooper, D., Buist, I., Faksness, L.-G., Altin, D., Pettersen, T.-A., & Bakken, O. M. (2020). Characterization of Low Sulfur Fuel Oils (LSFO) – A New Generation of Marine Fuel Oils: Weathering, Dispersibility, WAF and Toxicity, and Ignitability / In-Situ Burning. SINTEF Ocean AS, Report No. OC2020 A-050. https://www.itopf.org/fileadmin/uploads/itopf/data/Documents/RDaward/Summary_Report_Sintef_Low_sulphur_fuel_oils.pdf

Sørheim, K. R., Daling, P. S., Cooper, D., Bust, I., Faksness, L. G., Altin, D., ... & Bakken, O. M. (2020). Characterization of Low Sulfur Fuel Oils (LSFO)–A new generation of marine fuel oils-OC2020 A-050. Retrieved from: https://sintef.brage.unit.no/sintef-xmlui/handle/11250/2655946

Sundaravadivelu, D., Alloy, M., Barron, M., Conmy, R., & Lech, K. (2024, July). Physico-Chemical Properties and Dispersibility of Low Sulphur Fuel Oils (LSFO) and Conventional Crude Oils (CCO). In International Oil Spill Conference Proceedings (Vol. 2024, No. 1). Allen Press. Retrieved from: https://meridian.allenpress.com/iosc/article/2024/1/164/501967

United Nations Environment Programme (UNEP). (1976). *Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention).*

United Nations Environment Programme (UNEP). (2009). *HNS Guide: Response to hazardous and noxious substances at sea*. Retrieved from: https://wedocs.unep.org/handle/20.500.11822/26155

United States Coast Guard. (1999). *Chemical hazard response information system (CHRIS).*

Van Hoecke, L., Laffineur, L., Campe, R., Perreault, P., Verbruggen, S. W., & Lenaerts, S. (2021). Challenges in the use of hydrogen for maritime applications. Energy & Environmental Science, 14(2), 815-843. Retrieved from: https://pubs.rsc.org/en/content/articlehtml/2020/ee/d0ee01545h

ANNEX I. RESEARCH DESIGN

This Annex outlines the research approach, including how data was collected and the specific methods used to analyse data in the study.

1 Methodology overview

The primary goal of this Study is to assess the readiness of the Mediterranean region to respond effectively to marine pollution incidents involving low Sulphur fuels or alternative fuels. Given the upcoming enforcement of the Med SO_X Emission Control Area (ECA), understanding current preparedness levels is critical. To achieve this objective, a comprehensive research approach was adopted, integrating both qualitative and quantitative data collection and analysis.

The methodology involved an extensive desktop review of relevant data and the administration of structured questionnaires to gather insights from Contracting Parties to the Barcelona Convention. This combined approach facilitated a thorough analysis of the strengths, weaknesses, gaps, and best practices related to marine pollution preparedness in the context of low Sulphur and alternative fuels.

2 Data sources and collection methods

Desktop research

A key component of this Study's methodology was the extensive desktop research carried out to compile and analyse existing information on the region's response capabilities for marine pollution incidents. This involved reviewing a variety of sources, including:

- **Academic studies and published reports**: A detailed examination of the latest research on spills of low-Sulphur and alternative fuels, their environmental impacts, and associated response measures was undertaken. Peer-reviewed journals and scientific databases such as Scopus, Web of Science, and Elsevier were key sources of up-to-date information. Proceedings from international conferences, such as the Arctic Marine Oil Spill Program (AMOSP) and the International Oil Spill Conference (IOSC), were also reviewed, along with scientific papers from CEDRE and deliverables from international projects like EU DG ECHO/WestMoPoCo and EU-DG ECHO/Manifests.
- **Regulatory guidelines and frameworks**: A thorough review of international, regional, and national guidelines governing marine pollution response was conducted. This included key regulatory frameworks such as MARPOL, the OPRC Convention, EU Directives on pollution response, and guidelines issued by EMSA. Relevant documents were accessed via platforms like IMO Docs, GISIS, and the EMSA website, providing insights into current standards, policies, and operational procedures for managing spills of low-Sulphur and alternative fuels.
- **Pollution response agreements**: The Study examined the Barcelona Convention's provisions concerning low-Sulphur and alternative fuel spills within the Mediterranean. Agreements like HELCOM and the Bonn Agreement were reviewed to draw lessons and identify best practices for cross-regional cooperation in pollution response.

- **Pollution response resources and tools**: Resources from various organizations, including IMO, REMPEC, CEDRE, and ITOPF, were reviewed to understand available technologies and tools for oil spill response. The adaptability of these resources to incidents involving low-Sulphur and alternative fuels was a key focus.
- **Statistical data and past incidents**: Historical data on alternative fuel spills and related incidents were gathered to assess risks and environmental behaviour. Databases such as the International Oil Pollution Compensation (IOPC) Funds, IMO GISIS, and other official reports were utilized to provide a contextual understanding of past pollution events and response outcomes.

Structured Questionnaire

To complement the desktop research, structured questionnaires were distributed to the REMPEC OPRC Focal Points of the 21 Contracting Parties to the Barcelona Convention. Additionally, Contracting Parties outside the Mediterranean region, particularly those within other ECAs, were included to gather insights on best practices and preparedness strategies.

The questionnaires consisted of both closed and open-ended questions, aiming to collect data on national policies, emergency response mechanisms, and resources available for marine pollution incidents involving low-Sulphur and alternative fuels. Key areas covered included:

- national oil spill response plans and frameworks;
- stakeholder engagement in pollution response;
- regional and national cooperation mechanisms;
- existing policies, emergency response protocols, and resource availability for managing low-Sulphur and alternative fuel spills; and
- best practices and lessons learned from past incidents.

The questionnaires were distributed electronically, leveraging the networks and contacts of WMU, CEDRE and REMPEC to ensure high response rates and the relevance of collected data. Follow-ups were conducted as necessary to maximize participation and gather comprehensive insights from respondents.

3 Data analysis

The collected data underwent both quantitative and qualitative analysis to ensure a holistic understanding of the region's preparedness. The Study analysed key aspects of response readiness, such as the existence and robustness of national frameworks, the availability and readiness of response resources, and past experiences in managing pollution incidents involving low-Sulphur and alternative fuels.

The analysis included:

- **Quantitative analysis**: Data on existing plans, frameworks, resources, and historical incidents were analysed to provide measurable insights into the region's preparedness. This included assessing the distribution and quantity of response resources and identifying response times and recovery efforts in past incidents.

- **Qualitative analysis**: Open-ended responses from the questionnaires were analysed to identify collaborative approaches, stakeholder involvement, and best practices in pollution response. Insights were also drawn on the effectiveness of shared equipment, joint planning exercises, and national and regional cooperation efforts.

The results of the data analysis provided a comprehensive picture of the current state of marine pollution preparedness across the Mediterranean, highlighting areas of strength, gaps, and opportunities for improvement.

4. Online validation webinar on policy recommendations and strategic roadmap

Stakeholders to the Barcelona Convention were invited to participate in an online validation webinar, organized by WMU and CEDRE, on behalf of REMPEC. This webinar reviewed and discussed the findings and draft policy recommendations from the study. The online validation webinar was held on Monday, 18 November 2024, from 10:00 to 12:00 CEST.

The webinar which brought together thirty-seven (37) representatives from maritime administrations from different Contracting Parties and key stakeholders:

- reviewed key insights from the comprehensive assessment of the region's capacity and preparedness to respond to marine pollution incidents;
- examined the strategic roadmap and policy recommendations designed to enhance response mechanisms and strengthen regional frameworks for managing low-Sulphur and alternative fuel spills; and
- engaged in a dialogue to validate, refine, and ensure that the recommendations align with the region's operational needs and strategic objectives.

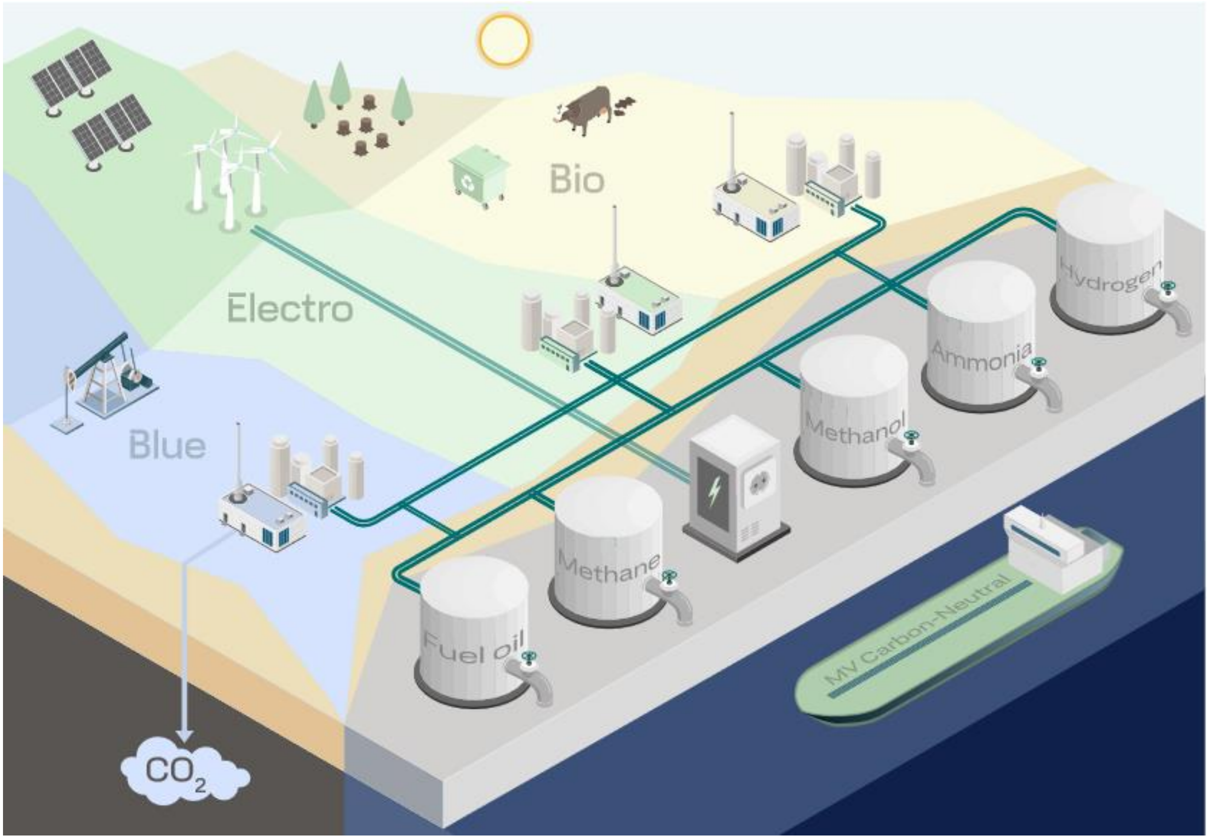
5 Limitations and challenges

While the Study aimed to gather comprehensive data on preparedness for marine pollution incidents, several limitations and challenges were encountered:

- **Data availability and quality**: Access to updated and detailed data varied across Contracting Parties, leading to potential gaps in the comprehensiveness of information obtained.
- **response rate for questionnaires**: Although efforts were made to ensure high participation, the response rate for questionnaires was not uniform across all Contracting Parties, which may have affected the depth of some comparative analyses.
- **Rapidly evolving landscape**: The landscape of low-Sulphur and alternative fuel usage in the maritime sector is rapidly evolving, which posed a challenge in ensuring that the findings remained current with the latest developments in fuel technology, regulatory standards, and best practices.

ANNEX II. REVIEW OF EXISTING LITERATURE AND DATA ON FUEL PROPERTIES

The diversity of fuel development for maritime transport reflects the industry's efforts to reduce its environmental impact and transition to more sustainable energy sources. These fuels include options such as hydrogen, ammonia, LNG, and methanol, each with its own set of advantages and challenges. Hydrogen, for example, offers zero emissions when produced from renewable sources but faces storage and cost barriers. Ammonia, with its higher energy density, holds promise for deep-sea shipping but remains expensive and lacks infrastructure. LNG provides a lower-emission alternative to traditional marine fuels but still generates CO_2, while methanol offers flexibility in engine design and cleaner combustion, though its energy density is lower. The broad range of options highlights the need for a multi-fuel approach as the maritime sector works towards decarbonization, with ongoing research and development required to overcome the technical, economic, and infrastructure challenges of each fuel type.



Production pathways for carbon-neutral fuels, source: DNV[1]

[1] DNV (2023). Maritime Forecast to 2025, Energy Transition Outlook 2023. DNV AS

The ensuing Table illustrates the diversity of fuels under development and highlights their respective emission benefits.

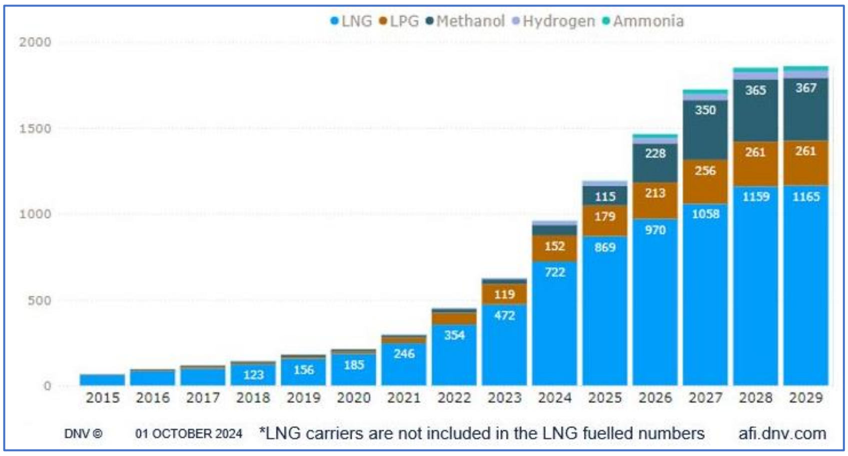
Comparison of LSFO and alternative fuels (source: MESD[2])

Fuel	TRL[(a)]	Calorific value (MJ/kg)	SFOC[(b)] (g/kWh)	Operational Fuel Emission (g/kWh)					
				CO_2	CH_4	N_2O	SO_X	NO_X	PM
LSFO	9	40.5	179	541	0.01	0.027	3.23	15.8	0.72
MDO	9	42.6	170	524	0.01	0.026	0.32	14.8	0.16
LNG	9	48.6	150	412	3	0.016	0.003	1.17	0.027
LH_2	3-4	120	57	0	0	0	0	0	0
Methanol	8-9	20	381	522	0	0	0	3.05	0
Ammonia	6	18.9	381	0	0	N. A.	0	N. A.	0

(a) TRL: Technology Readiness Level; (b) SFOC: Specific Fuel Oil Consumption

According to DNV's *Alternative Fuels Insight 2023*[3], the global ship fleet is still primarily powered by conventional fuels, with a significant reliance on heavy fuel oil (HFO) and marine gas oil (MGO). However, the shift toward alternative fuels is accelerating, with LNG, ammonia, methanol, and biofuels being explored as viable options for future vessels. As of 2023, around 20% of ships on order are being designed to run on alternative fuels, reflecting a growing trend toward decarbonization in the industry. In 2023, DNV lists 298 alternative fuelled vessels orders (+8% from the previous year), either new build or retrofit, with in particular 138 methanol-fuelled ships and 130 LNG-fuelled ships. 2023 marks the start of ammonia uptake as a marine fuel with 11 orders on the books. The graph below illustrates the past and expected number of ships running on various alternative fuels. As of 2024, 590 vessels in operation are powered with LNG (LNG carriers excluded) and 29 vessels operate on methanol.

Growth of alternative fuel uptake by number of ships (new build or retrofit) (source: DNV)



This Annex, therefore, provides a review of existing literature, technical reports, and data on the properties of low-Sulphur and alternative fuels, with particular focus on their behaviour when released into the sea. It will also cover, among others, toxicity, dispersal, persistence, and biodegradability, particularly in the Mediterranean context.

[2] MESD (2021). Methanol as a Marine Fuel – Availability and Sea Trial Considerations. MESD Centre of Excellence.
[3] DNV (2023). *Alternative Fuels Insight (AFI)*

1. Properties of low-Sulphur fuels (e.g., VLSFO)

1.1. LSFO refinery methods

Several methods of obtaining compliant LSFO exist, among them:

- Distillation of a low-Sulphur crude oil;
- Distillation of a high-Sulphur crude oil, followed by desulphurization process.

The desulphurization technologies include diverse biological, physical, and chemical techniques for oil treatments: hydrodesulphurization (HDS), adsorption of S-compounds, bio-desulphurization (BDS), extractive desulphurization (EDS), etc.

1.2. Properties of low-Sulphur fuels

With the change in OMI regulations (MARPOL Convention, Annex VI), ships now have to use fuels that comply with the Sulphur Cap. Those low-Sulphur fuel oils (LSFO) are divided into two categories, very low-Sulphur fuel oils (VLSFO) and ultra-low-Sulphur fuel oil (ULSFO) for use in emission control areas (ECAs). LSFOs gather hydrocarbons of various chemical compositions and physical properties, and have Sulphur content as the common characteristic, even though those oils still have to comply with regulations (ISO 8217:2024).

Several research projects aimed at providing better knowledge of LSFO in order to prepare for oil spills response.

- In 2020, the multi-client project “Characterization of Low Sulphur Fuel Oils (LSFO)” (Sørheim, et al., 2020) [4] carried out a study on the properties of four LSFO (two VLSFO and two ULSFO)
- In 2022, European project IMAROS (Chever, 2022)[5] tested the physical-chemical properties of 13 LSFO (11 VLSFO and 2 ULSFO).
- In 2022, Gilbert (2022)[6] studied 49 VLSFO in the RMG380 category for the Australian Maritime Safety Authority (AMSA)

The main conclusions from these studies are given below.

1.2.1. Chemical composition

The results of LSFO chemical analysis from the 2020 multi-client project show high variation: the LSFO tested contains 0.14 to 5.2% asphaltenes and 4.4 to 21.6% wax.

Regarding the LSFO from the IMAROS project, asphaltenes contents vary from 0.3% to 3.7%. The average value for the 13 oils is 1.9%. The wax content variation is high, from 4.8% to 20.6% with an average value of 10.5%. For most of the samples exhibiting high wax contents, the pour point is generally high, well above the minimum seawater temperature. This will induce a solidification of those oils when in contact with the seawater.

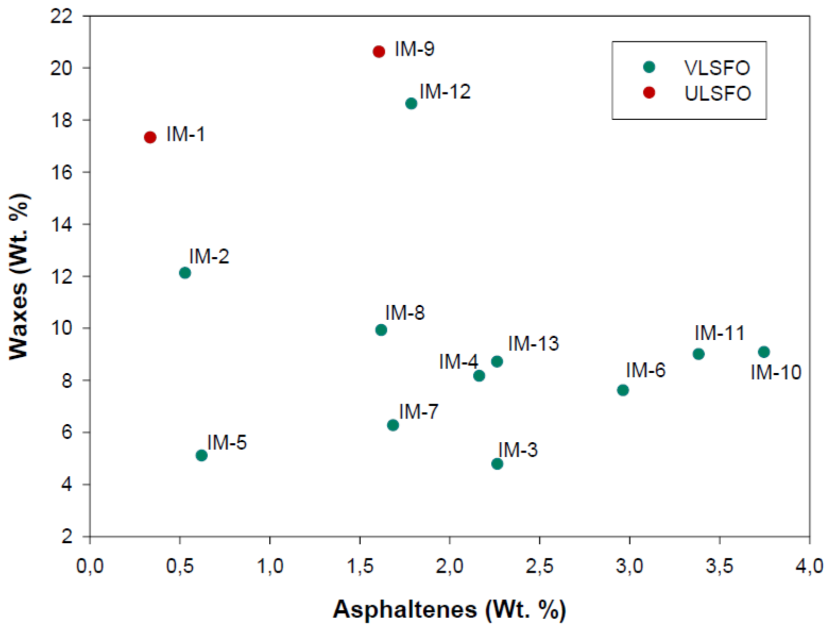
---

[4] Sørheim, K. R., Daling, P. S., Cooper, D., Buist, I., Faksness, L.-G., Altin, D., . . . Bakken, O. M. (2020). Characterization of Low Sulfur Fuel Oils (LSFO) – A new generation of marine fuel oils. Trondheim: SINTEF

[5] Chever, F. (2022). IMAROS Deliverable D3.2 PHYSICAL-CHEMICAL CHARACTERISATION OF 13 LSFO. Brest: Cedre

[6] Gilbert, T. (2022). Response to very low sulphur marine fuel oil spills - Final report Australian Maritime Safety Authority.

Figure 1.Distribution of the 13 LSFO tested at Cedre based on asphaltenes and wax contents (IMAROS, 2022)



Twenty-one samples were tested for chemical composition among those collected for the AMSA study. The VLSFO tested contains 0.2 to 12.5% asphaltenes (5.7% average). Table 1 below shows results from the three listed studies.

This high variability in composition (as varied as crude oil) likely reflects different ways of making VLSFO to comply with the Sulphur limits.

Table 1 - Asphaltenes and wax content from several studies on LSFO

	Asphaltenes %			Wax %		
	Min	Avg.	Max	Min	Avg.	Max
Multi-partner project (4 samples)	0.14	-	5.2	4.4	-	21.6
IMAROS (13 samples)	0.3	1.9	3.7	4.8	10.5	20.6
AMSA (21 samples)	0.2	5.7	12.5	/	/	/

1.2.2. Density

Whether a spilled oil floats or sinks will depend on its density compared to water. Table 2 below shows density results for fresh oils from the three listed studies.

Table 2 - Density values from several studies on LSFO

	Density (g/mL)		
	Min	Avg.	Max
Multi-partner project (4 samples)	0.872	-	0.990
IMAROS (13 samples)	0.900	-	0.980
AMSA (48 samples)	0.8677	0.9413	0.9899

As all samples show densities below 1, all those LSFO should float at the surface. However, depending on the salinity and material concentration, some could be found in the water column.

1.2.3. Pour point

The oil pour point is defined as the temperature at which the oil ceases to flow (temperature at which the oil becomes semi-solid). This data provides information on the behaviour of the oil in case of spill. Table 3 below shows results from the three listed studies.

Table 3 - Pour point values from several studies on LSFO

	Pour point (°C)		
	Min	Avg.	Max
Multi-partner project (4 samples)	3	-	24
IMAROS (13 samples)	-27	13	30
AMSA (35 samples)	-36	7	27

All three studies found high variability in pour points for LSFO. This variability induces different behaviours if spilt at sea and implies the choice of different response options, especially of different recovery techniques. Depending on the water temperature, oil solidification will occur for oils characterized by the highest pour points.

1.2.4. Viscosity

Viscosity is a measure of the resistance of the fuels to flow. The higher the temperature of the oil, the lower the viscosity. The viscosity of a spilled oil increases with evaporation since the heavier, more viscous components remain in the residue.

Table 4 below shows viscosity results for fresh oils from the three listed studies.

Table 4 - Viscosity values from several studies on LSFO

	Viscosity (mPa.s)		
	Min	Avg.	Max
Multi-partner project (3 samples at 13°C)	Fresh[(a)]: 3,948 250°C+[(a)]: 9,903 Emulsion[(b)]: 60,024 (44%)	-	Fresh[(a)]: 16,507 250°C+[(a)]: 68,041 Emulsion[(b)]: 321,340 (50%)
IMAROS (13 samples at 15°C)	Fresh[(a)]: 375 250°C+[(a)]: 938 Emulsion [(b)]: 5,000 (50%)	-	Fresh[(a)]: 6,240 250°C+[(a)]: 272,261 Emulsion[(b)]: 800,000 (50%)
AMSA (9 samples at 20°C)	Fresh: 24.8	-	Fresh: 4522

(a) shear rate of 100 s^{-1}, (b) shear rate of 10 s^{-1}

1.2.5. Flash point

The oil flash point is defined as the temperature at which the oil gives off sufficient vapour to ignite in air. Flash point is a key parameter for safety during storage, transport and use of the fuel. Standard ISO 8217:2024 (ISO, 2024)[7] sets a flash point safety standard at 60 °C. Table 5 below shows flash point results for fresh oils from the three listed studies. All oils present a high flash point, well above ambient temperatures.

[7] ISO (2024). ISO 8217:2024 Products from petroleum, synthetic and renewable sources – Fuels (class F) – Specifications of marine fuels.

Table 5 - Flash point values from several studies on LSFO

	Flash point (°C)		
	Min	Avg.	Max
Multi-partner project (3 samples)	75	-	109
IMAROS (13 samples)	77	-	>100
AMSA (2 samples)	172	-	174.5

1.2.6. Evaporation rate

As the lighter molecules disappear progressively and the quantitative analysis of samples compared to the initial oil can give the evaporation rate. Table 6 below shows final evaporation rate results for fresh oils from the three listed studies.

Table 6 - Evaporation rate values from several studies on LSFO

	Evaporation rate (%)		
	Min	Avg.	Max
Multi-partner project (3 samples)	<5 % mass	-	20 % mass
IMAROS (13 samples)	2.6 % vol	12.9 % vol	28.2 % vol
AMSA	/	/	/

1.2.7. Summary

Table 7 summarize the variety of physico-chemical properties of 13 low sulfur fuel oils, as tested during the IMAROS project.

Table 7 - High variability in the physico-chemical properties of LSFO (IMAROS project)

Sample	Sulfur content (%)	Density 5°C	Density 15°C	Viscosity 5°C (mPa.s) [1] [2]	Viscosity 15°C (mPa.s) [1]	Pour Point (°C)	Flash point (°C)	Asph. (%) [3]	Waxes (%) [3]	Evaporation (vol. %)
IM-1	0.08	0.96	0.95	solid	solid	27	>100	0.3	17.3	3.8
IM-2	0.46	0.94	0.93	solid	solid	27	>100	0.5	12.1	5.2
IM-3	0.46	0.99	0.98	4 858	1 293	0	99.5	2.3	4.8	8.6
IM-4	0.48	0.95	0.95	2 808	703	21	93	2.2	8.1	9.0
IM-5	0.47	0.92	0.91	1 826	375	9	84	0.6	5.1	10.5
IM-6	0.45	0.98	0.97	2 244	892	-27	78	3.0	7.6	28.1
IM-7	0.49	0.95	0.94	4 415	19 117	15	>100	1.7	6.2	6.7
IM-8	0.49	0.97	0.96	15 585	3 348	9	>100	1.6	9.9	15.4
IM-9	0.08	0.90	0.90	solid	solid	30	>100	1.6	20.6	21.6
IM-10	0.47	0.95	0.94	12 443	2 451	0	>100	3.7	9.1	2.9
IM-11	0.49	0.95	0.94	8 171	1 964	0	>100	3.4	9.0	2.6
IM-12	0.48	0.95	0.94	10 679	3 042	-9	83.5	1.8	18.6	21.4
IM-13	0.48	0.96	0.96	24 994	6 240	-6	77	2.3	8.7	16.9

2. Properties of alternative fuels (e.g., LNG, ammonia, hydrogen)

Among alternative fuels

2.1. Hydrogen

2.1.1. Use

Hydrogen can both be used to fuel a combustion engine or a fuel cell, even if only combustion engines have been developed for the maritime sector.

2.1.2. Physicochemical properties

Hydrogen (H) is a naturally occurring compound in water and hydrocarbons. At atmospheric pressure, dihydrogen, commonly known as hydrogen, is a gas of very low density. Table 8 presents the main properties of hydrogen.

Table 8 - Hydrogen properties

Hydrogen	Properties	Behaviour
Boiling Point	-253 °C	At ambient conditions, hydrogen is a gas.
Vapour pressure	Very high	
Liquid Specific Gravity (at -253 °C)	0.071	Hydrogen is approximately 14 times less dense that water; therefore, as a liquid, LH_2 will float if spilled on water.
Gas Specific Gravity (at 253 °C)	1.338	Saturated vapour is heavier than air and will remain close to the ground until the temperature rises.
Vapour Specific Gravity (at ambient temperature)	0.067	Vapours of hydrogen at ambient conditions are significantly lighter than air (buoyant) and will easily disperse in open or well-ventilated areas.
Solubility	Insoluble	Hydrogen will not mix with water or seawater.
Flammability Range	4.0 – 75.0 (v/v) %	Outside of this range, hydrogen/air vapour mixture is not flammable.
Self-ignition temperature	585 °C	
Minimum ignition energy	0.017 mJ	
Viscosity	8.39×10^{-6} Pa.s	
SEBC	G	
Marine pollution classification (MARPOL Annex II)	-	

2.1.3. Associated risks

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) pictogram for hydrogen and its containment are given below:

Table 9 - GHS classification for hydrogen

	Chemical	Storage
Pictogram		
Classification	Flammable gas	Gases under pressure
Hazard statement	H200: Extremely flammable gas	H280: Contains gas under pressure; may explode if heated H281: Contains refrigerated gas; may cause cryogenic burns or injury

The main risks associated with hydrogen are:

- tendency to leak (low viscosity and low molecular mass);
- ability to damage materials and equipment;
- very low minimum ignition energy;
- barely visible flame; and
- wide explosion zone.

2.1.4. Storage

Storage of hydrogen needs to address the low energy density of hydrogen, effectively requiring a significantly larger tank than hydrocarbons for the same energy amount. Therefore, hydrogen is either stored pressurised (gas at 700 bars) or cryogenized (liquid at -253 °C) in order to reduce the required storage volumes.

<u>Cryogenic hydrogen</u>

Cryogenic hydrogen is stored in liquefied form at -253°C. At this temperature, many materials become brittle or friable (ARIA, 2008)[8]. Furthermore, at this temperature, contamination of liquid hydrogen by oxygen can lead to solidification of nitrogen or air gases, resulting in clogged pipes (ARIA, 2008). Finally, in the event of overheating and temperature rise, a BLEVE can occur (GORSAP, 2016)[9].

<u>Hydrogen under pressure</u>

In its liquid or gaseous state, due to its low viscosity and low molecular weight, H_2 is particularly prone to leaks (the leak rate for liquid hydrogen is around 50 times higher than for water, and 10 times higher than for liquid nitrogen) (ARIA, 2008). Hydrogen passes easily through porous walls, leaks very easily through the smallest interstices, and can therefore escape from a device or circuit that would be airtight or sealed against another gas ((ARIA, 2008; OPECST, 2013[10]).

---

[8] ARIA (2008). Accidentologie de l'hydrogène.

[9] GORSAP (2016). GORSAP : Guide orange des sapeurs-pompiers de Genèvre - 5ème édition.

[10] OPECST (2013). L'hydrogène : Vecteur de la transition énergétique ? (Office parlementaire d'évaluation des choix scientifiques et technologiques) with the contribution of Kalinowski L., and Pastor J.-M.

As a result, the weak points in installations that need to be monitored are naturally the isolation valves, connecting devices and associated joints, with particular consideration to be given to how these items of equipment are tightened (ARIA, 2008). Hydrogen releases need to be monitored, to avoid any risk of explosion (Van Hoecke et al., 2021)[11].

<u>Degradation and incompatibility</u>

Degradation of metals and alloys continuously exposed to hydrogen can lead to leakage of substances or outright failure of equipment. Two modes of degradation have been identified for steels: hydrogen embrittlement (HE) and hydrogen attack (ARIA, 2008).

Hydrogen reacts spontaneously with chlorine in the reaction $H_2 + Cl_2 \rightarrow 2\ HCl$. This reaction is slow in the dark, but explosive in the presence of light or heat (ARIA, 2008). In the worst case, the lower explosive limit of hydrogen in chlorine can be as low as 3.1%. This is a parameter to be taken into account in electrolysis plants using both chlorine and hydrogen (ARIA, 2008).

2.2. Ammonia

2.2.1. Use

Ammonia usage as a maritime fuel is at an early stage of technological maturity. Like hydrogen, it could be used in combustion engines or fuel cells, although only combustion engines have been developed for the maritime sector. Research into ammonia as a marine fuel started back in 2018 and the first ammonia-ready ship (*Kriti Future*) was built in 2022. While it is still a conventionally fuelled ship, it is designed to be converted to run on ammonia.

Due to its high auto ignition temperature and low burning rate, ammonia is usually integrated in dual-fuels engines (MGO most likely) with the second fuel acting as a combustion initiator.

2.2.2. Physicochemical properties

Ammonia (NH_3) is a colourless inorganic compound composed of nitrogen(N) and hydrogen (H) molecules. Table 10 presents the main properties of ammonia.

Table 10 - Ammonia properties

Ammonia	Properties	Behaviour
Boilin	-33.3	At ambient conditions, ammonia is a gas.

[11] Van Hoecke, L., Laffineur, L., Campe, R., Perreault, P., Verbruggen, S.W., et Lenaerts, S. (2021). Challenges in the use of hydrogen for maritime applications. Energy Environ. Sci. 14, 815-843.

g Point	°C	
Vapour pressure	211.9 psia	
Liquid Specific Gravity (at -33 °C)	0.682	Ammonia is less dense than water; therefore, as a liquid, ammonia will float if spilled on water.
Vapo	>1.0	When ammonia initially vaporises in the presence of water vapour, it will form a whiteish cloud denser than air above the ground/sea surface.

urSpecificGravity(at-33°C)		
VapourSpecificGravity(atambie	0.597	Vapours of ammonia at ambient conditions are lighter than air (buoyant) and will easily disperse in open or well-ventilated areas.

nttemperature)		
Solubility	529 kg/m³	Ammonia is highly soluble in water.
FlammabilityRange	15.5 – 27 (v/v) %	Outside of this range, the ammonia/air vapour mixture is not flammable.
Self-ignition	651 °C	

temperature		
Minimum ignition energy	14 mJ	
Viscosity	10.225 mPa.s at -33°C / 0.0092 mPa.s at 0°C / 0.0098 mPa.s at 20°C	
SEBC	DE	
Marine pol	P (MARPOL Ann	

lution classification	exIII)	

2.2.3. *Associated risks*

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) pictogram for ammonia and its containment are given below:

Table 11 - GHS classification for ammonia

	Chemical	Storage
Pictogram		
Classification	Skin corrosion/irritation Acute toxicity Hazardous to the aquatic environment, long-term (Chronic)	Gases under pressure
Hazard statement	H314: Causes severe skin burns and eye damage H331: Toxic if inhaled H411: Toxic to aquatic life with long lasting effects EUH071: Corrosive to the respiratory tract	H280: Contains gas under pressure; may explode if heated H281: Contains refrigerated gas; may cause cryogenic burns or injury

According to the GORSAP scale, ammonia is a very dangerous chemical for human health as it can cause irreversible damage. Ammonia is heat stable and has moderate explosion and fire risks.

The main risks associated with ammonia are:

- Its dangers to human health
- Its reactivity to water
- The risk of cold cloud formation

2.2.4. Storage

Ammonia is either stored pressurised (liquid at 8 bars and 20 °C) or refrigerated (-33 °C at atmospheric pressure) in order to reduce the required storage volumes. LNG ships can be used to transport ammonia.

Copper, copper-containing alloys and zinc should not be used in pipes, valves, fittings and other equipment in contact with ammonia (Bureau Veritas, 2021a)[12]. Anhydrous ammonia can also cause stress corrosion cracking in carbon-manganese steel or nickel steel piping and containment systems (Bureau Veritas, 2021a).

2.3. LNG

2.3.1. Use

LNG (85% methane content) is viewed as the most mature alternative fuel to date. By 2021, it was available in about 30 ports in the world. This technology is already installed in a few hundreds of ships.

2.3.2. Physicochemical properties

Natural gas (NG) is mainly composed of methane (CH_4). Its boiling point is around -162°C. In liquid form, natural is called LNG. Table 12 presents the main properties of LNG.

Table 12 - LNG properties

LNG	Properties	Behaviour
Chemical Composition	Usually >85% methane with small quantities of ethane, propane, butane, carbon dioxide and nitrogen	LNG properties vary slightly depending on the exact composition.
Boiling Point	-162 °C	At ambient conditions, LNG is a gas.
Vapour pressure	Very high	
Liquid Specific Gravity (at -162 °C)	0.415 – 0.45	LNG has less than half the density of water; therefore, as a liquid, LNG will float if spilled on water.
Vapour Specific Gravity (at -162 °C)	1.5	Vapours of LNG at ambient conditions are lighter than air (buoyant) and will easily disperse in open or well-ventilated areas.
Vapour Specific Gravity (at ambient temperature)	0.55 – 1.0	Vapours of LNG at ambient conditions are lighter than air (buoyant) and will easily disperse in open or well-ventilated areas.
Solubility	Insoluble	Liquid LNG will not mix with water or seawater.
Flammability Range	5 – 15 (v/v) %	Outside of this range, the LNG/air vapour mixture is not flammable.
Self-ignition temperature	537 °C	
Minimum ignition energy	0.29 mJ at 25 °C	
Viscosity	-	
SEBC	G	

[12] Bureau Veritas (2021a). NR971 Ammonia-fuelled Ships - Tentative Rules - Rule Note.

Marine pollution classification (MARPOL Annex III)	-	

2.3.3. Associated risks

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) pictogram for LNG and its containment are given below:

Table 13 - GHS classification for LNG

	Chemical	Storage
Pictogram		
Classification	Flammable gas	Gases under pressure
Hazard statement	H224: Extremely flammable liquid and vapour	H280: Contains gas under pressure; may explode if heated H281: Contains refrigerated gas; may cause cryogenic burns or injury

According to the GORSAP scale, LNG is a slightly dangerous chemical for human health and is considered an asphyxiating gas. LNG is highly flammable at any temperature and is highly explosive in the air. If refrigerated or cryogenized, BLEVE (Boiling Liquid Expanding Vapor Explosion) occurrence is possible. It is however heat stable and does not react to water.

The main risks associated with LNG are:

- Its asphyxiating suffocating properties (displacement of oxygen)
- Its cryogenic damages to people and equipment
- Its explosion and gas vapours ignition risks

2.3.4. Storage

LNG is liquefied at -161 °C in order to reduce the required storage volumes (600 times less than for its gaseous form).

Rapid phase transitions are of particular concern for LNG ships with low cargo tank pressure ratings. This is because the tank pressure relief system may not activate quickly enough to evacuate the large volumes of vapour that can be generated spontaneously by a rapid LNG phase transition (Melhem and Ozog, 2006)[13].

[13] Melhem, G., et Ozog, H. (2006). Understand LNG Rapid Phase Transitions (RPT).

2.4. Methanol

2.4.1. Use

Methanol is an alternative fuel that can be used in existing engines with only minimal changes. It is available in about 100 ports in the world.

2.4.2. Physicochemical properties

Methanol (CH_3OH) is an organic compound of the alcohol family. Table 14 presents the main properties of methanol.

Table 14 - Methanol properties

Methanol	Properties	Behaviour
Boiling Point	64.5 °C	At ambient conditions, methanol is a liquid.
Vapour pressure	-	
Liquid Specific Gravity (at 20 °C)	0.792	Methanol is less dense than water; therefore, as a liquid, methanol will float if spilled on water.
Vapour Specific Gravity (at 20 °C)	1.1	Vapours of methanol at ambient conditions are denser than air and will spread above the ground/water surface when spilled.
Solubility	Fully miscible	Methanol has no limit to its solubility in water.
Flammability Range	6.0 – 36.5 (v/v) %	Outside of this range, the methanol/air vapour mixture is not flammable.
Flash point	12 °C	Above this temperature, highly flammable methanol vapours are produced.
Self-ignition temperature	455 °C – 464 °C	
Minimum ignition energy	-	
Viscosity	0.6 cSt at 25°C	
SEBC	DE	
IMO category	Y	

2.4.3. Associated risks

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) pictogram for methanol and its containment are given below:

Table 15 - GHS classification for methanol

	Chemical
Pictogram	
Classification	Flammable liquid
Hazard statement	H225: Highly flammable liquid and vapour H301 + H311 + H331: Toxic if swallowed, if in contact with skin, if inhaled

According to the GORSAP scale, methanol is a slightly dangerous chemical for human health that can cause reversible damage. Methanol is flammable at ambient temperature above 11 °C and its vapours are explosive in the air. It is however heat stable and does not react to water.

The main risks associated with methanol are:

- impact on human health;
- low flash point that can lead to fire at ambient temperature; and
- barely visible flame.

3. Behavior of these fuels in marine environments

3.1. General behaviour of substances

Four properties are relevant to predict the behaviour of a substance when spilled: solubility, density, vapour pressure and viscosity. These properties are found on the substance Safety Data Sheet (SDS).

- Solubility, represents the ability of a substance to dissolve in another, this parameter reflects the passage in the water column of a product in case of spill.
- The density, corresponds to the ratio of the density of the liquid in relation to pure water. This value allows to anticipate the buoyancy of the product: if its density is greater than 1 (or 1.025 in sea water), it will tend to sink, if it is lower, it will tend to float.
- Vapour pressure is the pressure at which vapour escapes from a liquid at a given temperature (INRS, 2018)[14]. It increases rapidly with temperature. Vapour pressure is a data related to volatility. The higher the vapour pressure of a liquid, the faster it evaporates and the more it can diffuse into the atmosphere (water with a vapour pressure of 2,300 Pa at 20°C). This parameter allows the prediction of a product's release into the atmosphere in case of a spill by characterizing its evaporative power.
- Viscosity measures the friction force generated by moving two layers of fluid close together. The viscosity allows to characterize the spreading and the kinetics of solubilization of a product.

[14] INRS (2018). À propos des fiches toxicologiques.

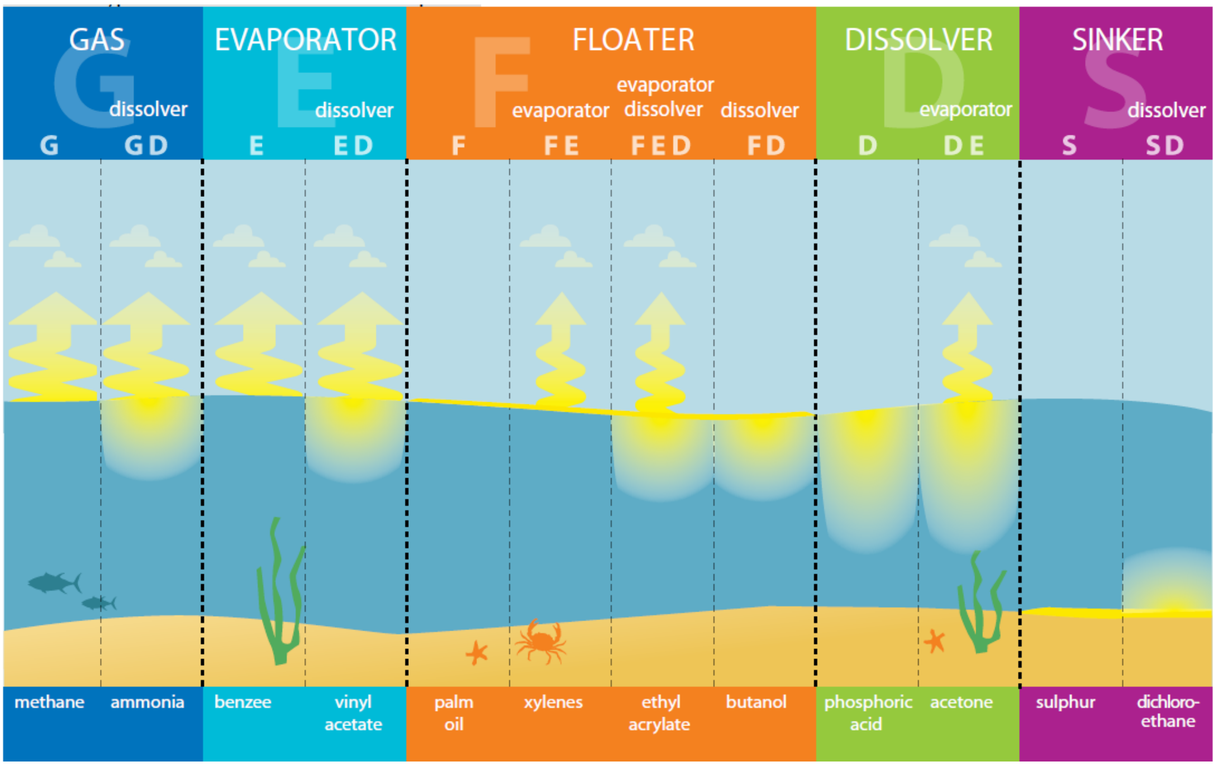


Figure 2 - Theoretical substance behaviour according to SEBC (Cedre and Transport Canada, 2012)

The Standard European Behaviour Classification (SEBC) (Figure 2) classifies substances into one of 5 categories, depending on its physical and chemical properties: gases (G), evaporators (E), floaters (F), dissolvers (D) and sinkers (S).

3.2. Hazards

The physical and chemical properties of a substance also determine its hazards. The main risks are explosivity, flammability, oxidation, corrosion, toxicity, ecotoxicity and reactivity. A short description is given but further information is available in the WESMOPOCO project's Marine HNS Response Manual (Alcaro L *et al*, 2021)[15].

- An explosive substance is a solid or liquid substance (or a mixture of substances) which is in itself capable by chemical reaction of producing gas at such a temperature and pressure and at such a speed as to cause damage to the surroundings.
- Flammability of a substance is defined as the ease with which a combustible substance can be ignited, causing fire or explosion.
- Oxidising materials have the ability to decompose and release oxygen or an oxidising substance.
- A corrosive material is defined as a highly reactive substance that causes damage to or destroys another material by chemical reaction.
- Toxicity is defined as the degree to which a substance can harm a cell, an organ, or a whole organism.
- Reactivity of a substance is its potential for reacting with water, air, other products or itself, potentially producing heat, and or flammable/explosive gases.

[15] Alcaro L., Brandt J., Giraud W., Mannozzi M., Nicolas-Kopec A (2021). MARINE HNS RESPONSE MANUAL Multi-regional Bonn Agreement, HELCOM, REMPEC. Project WestMopoco. 321 p.

3.3. Low-Sulphur fuels

When spilled at the water surface, oils are subjected to weathering processes such as evaporation, emulsification, dispersion, photo-oxidation, and biodegradation. These processes naturally occur due to water agitation generated by currents, wind and/or waves, to the sun exposure (UV oxidation), and to bacteria's and micro-organisms activity. Throughout the weathering processes, the oil continuously changes in terms of chemical composition and physical properties. Oil generally becomes more and more viscous and can turn into a new persistent pollutant in the environment. The behaviour of weathered oil is often different from the one of the oil initially spilled. Understanding these transformations is a key element in evaluating the potential impacts and optimizing the emergency response to spillage.

3.3.1. Spreading

The spreading of an oil slick occurs in the first few moments after the spill. Viscosity is an important parameter for estimating the spread of a slick from a spilled volume. As a general rule, a low viscosity hydrocarbon will spread rapidly and the slick will cover a large surface area. The thickness of the slick will be fairly small and will diminish as it spreads until it forms a sheen. The slick will also tend to fragment, which can complicate recovery operations. On the other hand, a spill of a highly viscous product will tend to fragment and drift on the surface of the water in the form of thick slicks that can be up to several centimetres thick.

In light of LSFO properties (*cf.* studies in section 1), particularly highly varying viscosity and pour point, the oil could spread on the surface, form thick slicks or could solidify due to the water temperature.

3.3.2. Evaporation

Evaporation depends mostly on the composition of the oil. The greater the proportion of light hydrocarbons with a low boiling point in the composition of the oil, the greater the evaporation. Evaporation is increased when there is a large spread and is dependent on meteorological conditions, such as sunshine or wind. Evaporation of a petrol slick can be total, whereas that of a heavy fuel oil is much more limited.

In light of LSFO properties (*cf.* studies in section 1), most of them will be persistent in the aquatic environment, with a maximum of 30% of evaporation. Because of low levels of evaporation, the LSFO are unlikely to form hazardous plumes of light hydrocarbons. Recovery operations should be safe to start immediately once characteristics of the oil are confirmed.

3.3.3. Dispersion

Dispersion can be seen as the opposite of emulsion. This process corresponds to the passage of hydrocarbon droplets through the water column. This phenomenon is observed in a highly agitated environment under the effect of waves for low viscosity hydrocarbons. Due to the strong mixing of waves and surface agitation, slicks can break up and form small droplets of hydrocarbons that penetrate the water column. Droplets smaller than 70 µm in diameter are able to remain in the water column and drift to the subsurface under the influence of marine currents. As a result, the hydrocarbons will gradually dilute in the water column over time. This phenomenon can significantly reduce the volume of oil at the surface. The oil ends up in the water column in dispersed form, making it more susceptible to biodegradation or sedimentation.

Dispersion of the oil in the water column can be forced by the use of dispersants. Dispersibility depends on the viscosity of the oil: dispersant effectiveness will decrease as the viscosity of spilled oil climbs above 2000- 6000 cSt and once it reaches over 10,000 cSt it is highly unlikely to be dispersible. The oils are classified as dispersible, potentially dispersible and not dispersible.

As LSFO have a large viscosity range, studies show that dispersant could be used to treat some LSFO spills when fresh. However, when weathered, the efficiency of this technique is highly reduced. This response option seems to be limited considering spills involving LSFO.

3.3.4. Emulsification

Emulsification is defined as the incorporation of droplets of water into the hydrocarbon. There are two types of emulsion: those that are stable over time and those that tend to separate. An oil may incorporate up to 100% water, with significant consequences in terms of slick drift and an increase in the volume of pollutant by a factor of up to 4. The viscosity of the substance will also be greatly increased, which directly affects the recovery and response techniques that need to be put in place to limit the impact of the pollution.

Weathering test were conducted as part of the multi-partner and IMAROS projects. It was found that the LSFO tested would form stable emulsions rather quickly, with up to 90% water uptake.

3.3.5. Discussion on low-Sulphur fuels in the Mediterranean context

The processes involved in the weathering of petroleum products are not simply dependent on the physical-chemical characteristics of the substances. Environmental conditions must also be taken into account when assessing the fate of a hydrocarbon when spilt in the aquatic environment. Sunshine, water temperature, wind, environmental agitation, salinity and water turbidity are all factors that influence the fate of an oil in the environment by promoting or limiting the various ageing processes of hydrocarbons (Table 16).

Table 16 - Influence of environmental parameters on weathering process of an oil

	Sunshine	Temperature	Wind	Agitation	Salinity	Turbidity
Evaporation	•	•	•	•		
Spreading	•	•	•	•		
Emulsification		•		•		
Dissolution		•		•	•	
Dispersion				•		•
Photo-oxidation	•					
Sedimentation				•	•	•
Biodegradation		•				

In the context of the Mediterranean, it is likely that the behaviour of the oil will be different in terms of emulsification, dissolution, dispersion and sedimentation.

3.4. Alternative fuels

These fuels have different physical and chemical characteristics, which impact their behaviour when poured into the sea and, consequently, how spills of these fuels should be managed.

3.4.1. Hydrogen

Behaviour in the event of a leak

<u>In gaseous storage</u>

Hydrogen can easily escape through joints and cracks in any piping or storage system. This high diffusivity is also one of its main advantages: hydrogen is a light gas that disperses easily if released into the open air in gaseous form (Van Hoecke et al., 2021).

Moreover, in the event of strong expansion, a reverse Joule-Thompson effect can occur: the escaping hydrogen heats up as it expands, which may be sufficient for it to ignite spontaneously.

<u>In cryogenic storage</u>

The release of cryogenic hydrogen can lead to the formation of a cold cloud, limiting its dispersion and rapidly cooling the ground surface (Van Hoecke et al., 2021).

Fire/explosion risk

In the event of a leak, the main risk associated with hydrogen is fire or explosion (84% of accidents recorded (ARIA, 2008)), due to its very wide flammability range (from 4 to 75% in air, and even wider in oxygen- or chlorine-enriched atmospheres), and its very low activation energy (ARIA, 2008).

So, while a low-flow leak in the open air with no nearby obstacles is generally of no consequence, in the event of a gradual accumulation of hydrogen in a confined or poorly ventilated environment, there is a risk of late ignition of the premixture formed (AFHYPAC, 2020)[16].

Furthermore, in the event of a high-flow leak, ignition may occur spontaneously (AFHYPAC, 2020).

Hydrogen is also highly flammable: the energy required to ignite it is ten times lower than that required to burn methane. The ignition sources of flammable clouds formed by hydrogen are multiple: hot spot, lightning, electrical origin, mechanical spark or static electricity (ARIA, 2008). Because of their low dispersibility, cryogenic hydrogen vapor clouds increase the risk of explosion (Van Hoecke et al., 2021).

In the event of fire, the hydrogen combustion flame is extremely dangerous, as it is generally not very visible (colourless except in the presence of impurities (carbon particles...)) (ARIA, 2008; GORSAP, 2016). It is recommended to evacuate the area and extinguish the fire only if the hydrogen leak can be stopped (GORSAP, 2016).

The recommended extinguishing media are powder and water spray (GORSAP, 2016). The use of CO_2 is not recommended (risks associated with static electricity), nor is the use of water jets in the liquid (if the hydrogen is refrigerated) (GORSAP, 2016).

Structural risk associated with cryogenics

When storing hydrogen as a cryogenic liquid, i.e. in the form of liquid hydrogen at -253°C, it is important to use appropriate materials capable of withstanding cold temperatures so that they do not become brittle. For example, cryogenic liquid spills on board ships can be particularly

[16] AFHYPAC (2020). Mémento sur l'hydrogène. With the contribution of INERIS

dangerous: the rapid cooling of the floor surface can cause cold fracture of the steel, which can damage the hull (Van Hoecke et al., 2021).

3.4.2. Ammonia

Behaviour in the event of a leak

<u>Discharge or spill in a closed environment or on land</u>

Under atmospheric conditions, ammonia transforms into gas: in the event of a leak, one litre of liquid transforms into 947 litres of gas (expanded at 15°C, under 1 bar pressure) (INERIS, 1999)[17].

As its density is lower than that of air, ammonia tends to diffuse upwards in the event of a leak. However, in the event of a large-scale leak, ammonia released into the atmosphere generally leads to the formation of a cold cloud, heavier than air, due to ammonia's high latent heat of vaporization (cf. § 5.1.2.2) (INERIS, 1999).

Moreover, its behaviour differs according to the environment into which it is released, the type of storage and the type of release. Different scenarios can therefore be anticipated (INERIS, 1999):

- Ammonia gas jets from a pressurized container (release from the gaseous phase). In this case, if the jet encounters an obstacle, it may lead to the formation of a puddle on the ground, thus reducing the flow of gas passing into the atmosphere.
- Two-phase ammonia jets from a pressurized container (release from the liquid phase). In this case, liquid leaks can cause an aerosol to form on the ground: ammonia's particularly high latent heat of vaporization (1371.2 kJ/kg) means that micro-droplets can only evaporate very slowly. These droplets can be deflected from their trajectory by wind or major obstacles. Aerosol dissipation is complete within a few minutes of emission cessation. In the event of an obstacle (e.g. ground), a puddle of ammonia may form.
- Evaporation of a puddle of liquid ammonia whose temperature is less than or equal to its boiling point. Evaporation is influenced by ground humidity, infiltration, substrate and wind.
- Liquid ammonia leaks from a refrigerated tank (liquid ammonia at a temperature below boiling point and at atmospheric pressure).

Ammonia in the liquid phase, at equilibrium at atmospheric pressure, can be effectively collected and stored in open air in a holding tank; however, the heating of the tank walls is accompanied by gas and aerosol emissions.

<u>Discharge or spill into water</u>

Generally speaking, the evaporation of ammonia (NH_3) from surface waters into the atmosphere is considered a major process. It takes place at the interface and is influenced by pH (for pH > 7), temperature and other parameters such as water flow, wind speed, ammonia nitrogen concentration and salinity (INERIS, 2012)[18].

---

[17] INERIS (1999). Ammoniac : Essais de dispersion atmosphérique à grande échelle. With the contribution Bouet R., Gaston D., and Faucher B.
[18] INERIS (2012). Fiche de données toxicologiques et environnementales des substances chimiques : Ammoniac. With the contribution of Barneaud A., Bisson M., Del Grata F., Ghillebaert F., Guillard D., and Tack K.

When spilled over water, some of the liquid anhydrous ammonia in contact with the water will evaporate, while the rest will dissolve. The behaviour of ammonia vapours depends on the quantity of product spilled (Cedre, 2006):

- In the event of a small spill, ammonia vapours will tend to rise due to the low density of the gas (d < 1).
- On the other hand, in the event of a large spill, a cloud of cold vapours may form and behave like a heavy gas (see § 5.1.2.2) (JSIRA and MLIT, 2020).

The remaining solubilized part may lead to a rise in water temperature. The dissolution of ammonia in water is highly exothermic: 2,000 kJ/ kg of ammonia dissolved in water (i.e., 478.5 kcal.kg-1). As an indication, dissolving one kilogram of ammonia releases enough energy to evaporate almost one and a half kilograms (INERIS, 1999).

Note that the rapid, exothermic dissolution of ammonia leads to the formation of ammonium hydroxide (NH4OH). Dissolved ammonia is rapidly transformed into other nitrogen compounds (INERIS, 2012).

Fire/explosion risk

Since the minimum ignition energy of ammonia is 14 mJ, an air-ammonia mixture has a higher minimum ignition energy (by 1 to 2 orders of magnitude) than most air-hydrocarbon mixtures (INERIS, 1999). Thus, and based on accidentology, ammonia ignition is retained only in confined environments (INERIS, 2015).

Toxic and explosive gases can be generated during a fire (JSIRA and MLIT, 2020)[19]: the dissociation of ammonia into hydrogen and nitrogen is initiated at around 450 - 500°C (INERIS, 1999).

On a liquid ammonia fire, only CO_2 or powders can be used as extinguishing agents (INERIS, 1999). Puddles of ammonia should not be sprayed with water, as the liquid phase vaporizes instantaneously (Bureau Veritas, 2021a). In fact, contact between water and liquid ammonia transfers heat to the latter and promotes vaporization, resulting in significant gas and aerosol emissions (INERIS, 1999).

3.4.3. LNG

Behaviour in the event of a leak

<u>Discharge or spill into water</u>

Methane, which is liquid during storage, will float (density of 0.46), boil (boiling temperature of -161°C) and evaporate if spilt in an aquatic environment at ambient temperature and pressure. Evaporation rates will depend on the size of the slick and the temperature of the receiving water (EMSA, 2015[20]; United States Coast Guard, 1999[21]). In this case, the cold vapours may form a heavier-than-air fog spreading at ground level (EMSA, 2015; GORSAP, 2016).

At the same time, a rapid phase transition (RPT) can occur. The pressure pulse created by small pockets of LNG/methane that evaporate instantaneously when superheated by mixing

---

[19] JSIRA, et MLIT (2020). Roadmap to Zero Emission from International Shipping. (Japon: Japan Ship Technology Research Association (JSTRA) and Ministry of Land, Infrastructure, Transport and Tourism (MLIT)).
[20] EMSA (2015). Study on the use of ethyl and methyl alcohol as alternative fuels in shipping. With the contribution of Ellis J., et Tanneberger K.
[21] United States Coast Guard (1999). Chemical Hazard Response Information System (CHRIS).

in water moves at the speed of sound and decays like any other pressure pulse (EMSA, 2018[22]). LNG composition is a critical parameter for the creation of rapid phase transitions: they are more likely to occur in LNG mixtures containing very high fractions of ethane and propane (Melhem and Ozog, 2006).

Rapid phase changes have not resulted in any known major incidents involving LNG (EMSA, 2018).

<u>Discharge or spill in a closed environment or on land</u>

In the event of a spill in a closed environment or on land, the methane will behave in a similar way to a spill at sea: it will boil and return to its gaseous form, producing cold vapours that are initially heavier than air (see section 5.1.2.2), before rising (vapour density < 1) (GORSAP, 2016).

If the event takes place outdoors, the generation of a white cloud of cold natural gas will lead to the dispersion of a plume depending on the prevailing wind (EMSA, 2018).

If the release leads to pockets of gas becoming trapped, either in the ship's structure or in the port infrastructure, there is a risk of creating an explosive atmosphere (EMSA, 2018).

Fire/explosion risk

While natural gas in its liquid form is not flammable, methane in vapour form forms a highly explosive mixture with air (ClearSeas, 2019[23]; GORSAP, 2016).

In the event of an LNG leak, several phenomena related to fire and explosion can occur (EMSA, 2018):

- A ‘flash’ fire if the concentration of methane in the air is above its lower flammable limit (LFL) and below its upper flammable limit (UFL). The duration of a flash fire is relatively short, but it can stabilise by continuing in the form of a jet fire or slick fire from the origin of the leak.
- An LNG slick fire generates significant thermal radiation with a surface emission power of more than 200 kW/m2 (a person wearing protective clothing can generally withstand 12 kW/m for a short time).
- Jet fires, which generally result from the release of gases or condensates from high-pressure equipment or from the release of high-pressure liquids containing dissolved gas, due to the evaporation of the gas, which transforms the liquid into a spray of small droplets. Typical conditions for this are pressures in excess of 2 bar.

Clouds of cold cryogenic natural gas vapours increase the risk of explosion due to their low dispersibility (ClearSeas, 2019; EMSA, 2015). In the event of a spill, natural gas vapours can catch fire in the presence of various ignition sources such as heat, flames or static electricity (ClearSeas, 2019; EMSA, 2015).

It is recommended that the area be evacuated and the fire extinguished only if the methane leak can be stopped (GORSAP, 2016).

The recommended extinguishing media are powder, CO_2 and water spray (GORSAP, 2016). The equipment used must be of ‘Ex’ type (GORSAP, 2016). It is also recommended that the tank be cooled to limit the risk of BLEVE in the event of storage under pressure (EMSA, 2018;

[22] EMSA (2018). Guidance on LNG Bunkering to Port Authorities and Administration. (EMSA).
[23] ClearSeas (2019). GNL et Transport Maritime.

GORSAP, 2016). The use of water jets in the liquid is also not recommended (GORSAP, 2016).

Structural risk associated with cryogenics

While stainless steel remains flexible, carbon steel and low-alloy steel become brittle and fractures are likely to occur if they are exposed to temperatures as low as those of cryogenic LNG. This embrittlement combined with the high thermal deformations induced can cause normal steel structures to collapse when they come into contact with cryogenic LNG. Standard carbon steel on ships (of all categories) must therefore be protected and insulated from possible exposure to an LNG spill (EMSA, 2018).

3.4.4. Methanol

Behaviour in the event of a leak

Discharge or spill into water

Methanol is completely miscible with water: it mixes rapidly in the water column and biodegrades very quickly, while depending on the temperature a certain fraction evaporates (EMSA, 2015; Van Hoecke et al., 2021). Spills of methanol from ships therefore do not have as great an environmental impact as spills of diesel fuel (Van Hoecke et al., 2021).

Methanol is classified as an 'evaporant to soluble' by the Joint Group of Experts on the Scientific Aspects of Environmental Protection (GESAMP): it will therefore mainly solubilise with less evaporation (Cedre, 2012)[24].

However, as methanol has a low density, it will remain in the subsurface and can evaporate from the water mass.

Discharge or spill in a closed environment or on land

Methanol (65°C) has a lower boiling point than MGO (175 - 650°C), but higher than commonly observed ambient temperatures. It therefore remains in liquid form in the event of a spill at ambient temperature and pressure (EMSA, 2015).

Fire/explosion risk

The flash point of methanol at 12°C is below the range of normal ambient conditions in a ship. Protective measures must therefore be taken to avoid exposure to air or ignition sources (EMSA, 2015). The auto-ignition temperature of methanol (464°C) is significantly higher than that of MGO at 257°C, but slightly lower than that of LNG at 532°C (EMSA, 2015).

Methanol presents a higher risk of fire than diesel oil, given their respective flash points (12°C and 52-96 °C) and boiling point (65 °C and 150-350 °C). Methanol lower calorific value (20 MJ/kg) means that less heat will be released by fuel mass compared to MGO and HFO (respectively 43 and 40 MJ/kg) (EMSA, 2015).

Methyl and ethyl alcohols raise issues for fire detection and firefighting techniques. With a barely visible flame, it is important to have available and ready to use thermal imaging to visualize fires. Detection of fires by infra-red camera is a possible solution, combined with water sprinklers.

[24] Cedre (2012). Guide d'intervention chimique : Méthanol.

Structural risk associated with cryogenics

Its oxygen content makes alcohols behaviour different from other conventional fuels and hinders firefighting methods based on oxygen displacement (EMSA, 2015).

3.4.5. Discussion on alternative fuels in the Mediterranean context

The behaviour of these alternative fuels is expected to be modified on warmer waters like in the Mediterranean where the average sea surface temperature was 19.7 °C during years 2013-2019 (García-Monteiro *et al*, 2022)[25].

For example, ammonia's evaporation rate will be greater in case of spill in warmer waters whereas its solubility will decrease. On the contrary, both methanol's evaporation rate and solubility will increase.

4. Environmental risk assessment

4.1. Low-Sulphur fuels

Ecotoxicity has also been studied during IMAROS study. Three of the LSFO in the study were tested for toxicity on algae, copepods and amphipods. If ecotoxicity was observed, it is in the range of that observed for traditional fuel oils (Table 17).

Table 17 - Ecotoxicity data from IMAROS LSFO study

Ecotoxicity	LSFO 1	LSFO2	LSFO3
Algae (CL50)	No toxicity observed (> WAF max)		
Copepodes (CL50, g.L^{-1} WAF)	0.11	3.04	0.81
Amphipodes (CL50, mg.kg^{-1})	542	2124	266

4.2. Alternative fuels

4.2.1. Hydrogen

Risk and toxicity for humans

In the event of a hydrogen spill, two main risks are considered for humans:

- The risk of asphyxiation, increased by the low dispersibility of cryogenic vapor clouds and the higher density of these clouds (GORSAP, 2016; Van Hoecke et al., 2021) ;
- The risk of very severe frostbite by the cryogenic liquid (GORSAP, 2016).

Note that hydrogen is an odourless, invisible gas (Van Hoecke et al., 2021).

---

[25] García-Monteiro S., Sobrino J.A., Julien Y., Sòria G., Skokovic D. (2022), Surface Temperature trends in the Mediterranean Sea from MODIS data during years 2003–2019, Regional Studies in Marine Science, Volume 49

Environmental risk and toxicity

Hydrogen is considered non-harmful to aquatic life and seabirds and non-bioaccumulative (United States Coast Guard, 1999).

4.2.2. Ammonia

Risk and toxicity for humans

<u>In case of contact</u>

Ammonia solutions are highly alkaline and therefore very irritating to mucous membranes, skin and eyes (INERIS, 1999). In humans, ammonia is a gas that causes severe irritation and even burns to mucous membranes. These irritations are also observed in the eye, causing lacrimation, conjunctival hyperemia, conjunctival and corneal ulcerations, and iritis. Cataracts and glaucoma can appear up to 10 days after exposure (INERIS, 2012).

When ingested, very intense pain with gastric intolerance and shock may occur, sometimes accompanied by erythema4 or purpura5 and a risk of complications with oedema of the glottis (INERIS, 1999).

Contact with boiling liquid can cause the skin to freeze. In liquid form, direct contact with the skin freezes tissues and can cause frostbite or burns (INERIS, 1999).

<u>In case of inhalation</u>

Ammonia is highly irritating to mucous membranes, and inhalation of highly concentrated ammonia gas can severely damage the respiratory tract and lungs in a short space of time (JSIRA and MLIT, 2020).

Inhalation of ammonia vapours causes irritation of the upper respiratory tract, with sneezing, dyspnoea and coughing, the most serious stage being acute lung oedema (ALO). ALO is an accident that occurs after inhalation of vesicant gases (including NH3), as a result of degradation of the walls of the pulmonary alveoli, which are then flooded with blood plasma. Fortunately, the olfactory detection threshold for ammonia (between 5 and 20 ppm) is well below concentrations considered dangerous (INERIS, 1999), and ammonia tends to rise in the atmosphere.

However, since ammonia's latent heat of vaporization is high (1371.2 kJ/kg), if a large quantity of ammonia leaks out, a cold cloud is created, increasing the risk of inhalation (JSIRA and MLIT, 2020). The potential lethal zone of the ammonia cloud can then extend up to a few hundred meters, causing fatalities even at great distances from the point of exposure (Van Hoecke et al., 2021).

At atmospheric pressure and 20°C, ammonia is a colorless alkaline gas with a characteristic pungent, irritating odour (INERIS, 1999; JSIRA and MLIT, 2020). Olfactory perception thresholds vary widely from one individual to another; some people detect it at 5 ppm and above, while most people can smell it at 20 ppm and above (Cedre, 2006[26]; INERIS, 1999). These values are well below the threshold for irreversible damage, which in turn is considerably lower than the threshold for lethal effects.

Environmental risk and toxicity

---

[26] Cedre (2006). Guide d'intervention chimique : Ammoniac

Ammonia occurs naturally in the environment and is produced continuously (either directly by the organisms that emit it (e.g. certain fish) or indirectly by the degradation of proteins excreted by these organisms).

This natural compound is required by most organisms for protein synthesis (Cedre, 2006), and is an intermediate in the nitrogen cycle, rapidly transforming into nitrogen compounds, it is not considered persistent or bio-accumulative (INERIS, 2012).

Its toxicity stems from ammonia's strong affinity for water: on contact with damp surfaces, ammonia forms the ammonium ion (NH_4+), which is highly alkaline and causes burns to the tissues of marine and aquatic vertebrates and invertebrates in general, notably to the respiratory system and eyes (Van Hoecke et al., 2021). This toxicity increases with salinity and temperature (Cedre, 2006).

Although ammonia is not considered persistent or accumulative, free ammonia (NH3) in surface water is toxic to fish and aquatic organisms (INERIS, 1999). It is strongly advised not to allow the chemical to enter the environment.

As previously mentioned, ammonia dissolves rapidly and exothermically in water to produce ammonium hydroxide (NH_4OH).

Ammonium ions (NH_4^+) are of little or no toxicity: in the event of water contamination by ammonia, the ammonium salts (NH_4^+) that form do not present a toxic risk (INERIS, 1999).

Thus, unless otherwise specified, effluents containing liquid or dissolved ammonia must not be discharged into the sea (Bureau Veritas, 2021a).

4.2.3. LNG

Risk and toxicity for humans

<u>In case of contact</u>

The human health risks identified for LNG are the cryogenic nature which can lead to severe burns or very severe frostbite on contact (EMSA, 2015; GORSAP, 2016).

<u>In case of inhalation</u>

Methane/natural gas is considered to be an asphyxiant with narcotic effects (GORSAP, 2016). It is therefore a gas with little or no toxicity, but which, if present in large enough quantities in the air, makes it unfit for breathing and therefore unfit for life, due to a lack of oxygen (GORSAP, 2016).

The main risks to humans are therefore related to asphyxiation (in the event of accumulation) and to their condition (in the event of cryogenics).

Environmental risk and toxicity

In the event of a spill, the LNG is unlikely to contaminate water or land because it returns to its gaseous state before sinking or being absorbed (ClearSeas, 2019; EMSA, 2018). The main environmental impacts are related to the cryogenic aspect of LNG.

4.2.4. Methanol

Risk and toxicity for humans

If methanol is ingested in relatively large quantities, it will be metabolized into formic acid or into formate salts that are toxic for the central nervous system and susceptible to cause blindness, a coma or death. Toxic effects can manifest up to several hours after ingestion, and effective antidotes can often prevent permanent damage (DNV-GL, 2016)[27].

Environmental risk and toxicity

Methanol is highly mobile and biodegradable into soils (Cedre, 2012). In case of a spill into water, as methanol is miscible into water, biodegradable et does not accumulate into organisms, its effects in case of a major spill should be far less than those of conventional fuels (EMSA, 2015).

Even though methanol is toxic for humans, it is not considered as toxic for aquatic organisms under GESAMP classification.

[27] DNV-GL (2016). Methanol as marine fuel: Environmental benefits, technology readiness, and economic feasibility. (IMO).

GUIDELINES
NATIONAL PREPAREDNESS FOR ACCIDENTAL RELEASES OF LOW-SULPHUR FUEL AT SEA

This annex serves as a guideline for Contracting Parties (CPs) to establish effective preparedness and response systems for accidental releases of Low-Sulphur Fuels (LSFO) at sea.

1. Understanding low Sulphur fuel: Properties and risks

1.1. Properties of Low-Sulphur Fuel

Low-Sulphur Fuel Oils (LSFOs), including Very-Low-Sulphur Fuel Oil (VLSFO) and Ultra-Low-Sulphur Fuel Oil (ULSFO), have been used in shipping to meet IMO 2020 regulations, which limit Sulphur content to 0.5% globally and 0.1% within Emission Control Areas (ECAs). While these fuels address regulatory requirements, their unique properties pose new challenges for spill preparedness and response.

Key properties of LSFOs include:

Property	Description
State	Generally liquid but may range from viscous to semi-solid, especially in colder climates due to high wax and paraffin content.
Density	Typically, heavier than marine diesel oil (MDO), but lighter than traditional heavy fuel oil (HFO), affecting buoyancy and spreading behaviour.
Pour Point	Highly variable; some LSFs solidify or become highly viscous at low temperatures, leading to the formation of waxy or stiff layers.
Viscosity	Ranges from fluid to highly viscous depending on composition, influencing its spread and recovery characteristics in spill scenarios.
Wax/Paraffin content	High wax/paraffin content in some LSFs can lead to challenges during mechanical recovery, as these fuels may crack or become brittle on the water.
Persistence	LSFs exhibit slower natural degradation in the marine environment, often forming persistent slicks that are difficult to recover.

Key insights:

- *Viscosity and spread:* LSFOs viscosity can vary widely between type of fuels, affecting how they spread when spilled. In warmer climates, for instance, these fuels may flow more freely, leading to extensive slicks, while in colder climates, they may form thick, sticky layers that adhere to surfaces. This variability in viscosity complicates the selection of skimmers and recovery methods, necessitating pre-positioned, adaptive response equipment.
- *Density and buoyancy:* The density of LSFOs can influence whether the fuel remains on the water's surface or partially submerges, complicating containment and recovery efforts. Heavier fuel oils may pose a higher risk of subsurface contamination and require specialized equipment for detection and removal.
- *Pour point and solidification:* LSFOs often have high pour points, particularly in cold environments, where they can solidify into semi-solid or brittle layers. This behaviour can impede mechanical recovery, as solidified layers may break apart when disturbed, leaving residues that are difficult to collect.

- *Wax/Paraffin content:* Fuels with high wax or paraffin content tend to behave more like grease or semi-solid butter when spilled. These characteristics reduce the efficiency of traditional skimmers, as the oil layer may crack or resist recovery. Enhanced recovery systems, such as those using advanced brushes or specialized skimmers, may be required to handle these challenges.
- *Persistence and environmental behaviour:* Unlike lighter fuels (i.e., MDO and alternative fuels) that evaporate or degrade quickly, LSFOs persist longer in the marine environment. This persistence increases the risk of shoreline contamination, especially in sensitive habitats like mangroves, estuaries, and coral reefs. Persistent oils also pose challenges for dispersant application, as higher viscosities limit the effectiveness of chemical treatments.
- *Challenges in recovery and clean-up:* Solidification and brittleness at low temperatures hinder the effectiveness of mechanical recovery methods. Traditional booms and skimmers may require modifications to handle these characteristics. The potential for oil penetration into rocky shorelines or sediments complicates shoreline clean-up, necessitating specialized high-pressure washing equipment or manual removal techniques.

1.2. Risks of accidental releases

LSFOs may pose significant risks when accidentally released into the marine environment. Understanding these risks is critical for developing effective spill response strategies.

Key risks of LSFO spills include:

Risk	Description
Toxicity	LSFO contain polycyclic aromatic hydrocarbons (PAHs) and other toxic compounds harmful to marine life, causing mortality and long-term bioaccumulation in the food chain. Vapours also pose health risks to responders and nearby populations.
Persistence	LSFO forms slicks that resist natural degradation (i.e., degrade slowly), prolonging their environmental presence and disrupting ecosystems by coating habitats like coral reefs and mangroves, causing long-term ecological damage.
Solidification	LSFs with high pour points solidify in cold waters, forming waxy or thick layers, complicating recovery and reducing the effectiveness of traditional skimmers and dispersants.
Environmental spread	LSFO compared with HFO spills can spread extensively depending on the fuel's viscosity and the environmental conditions (i.e., LSFOs can spread widely in warmer climates), contaminating large areas of open water and shorelines. Variations in viscosity and density may also cause partial submersion, making detection and recovery difficult.
Shoreline contamination	LSFOs adhere to and penetrate sediments and vegetation, requiring intensive clean-up efforts and disrupting activities such as fishing and tourism.

2. Risk assessment framework

A comprehensive risk assessment framework is crucial for CPs in order to manage the consequences of low-Sulphur fuel (LSFO) spills at their coastal areas. This proposed framework consists of a scenario identification, vulnerability mapping, and hazard modelling to enable building effective spill preparedness and response.

2.1. Identifying scenarios

Accidental releases of LSFOs can occur under different circumstances, requiring tailored response measures for effective containment and mitigation. Key scenarios include:

- *Bunkering spills:* Leakages during fuel transfer operations, either at ports or mid-sea, are among the most common incidents. These spills are often caused by equipment failure, human error, or improper coupling of fuel lines, resulting in a fuel discharges into marine environments.
- *Tank breaches:* Structural failures or collisions involving ships transporting or storing LSFO can cause large-scale spills. Such incidents may release significant quantities of fuel.
- *Pipeline ruptures:* Damage to pipelines during the transfer of LSFO to storage facilities or ships can result in a fuel discharges into marine environments. Factors such as corrosion, natural disasters, or accidental impact from vessels or machinery often contribute to these ruptures.

Consideration: Each scenario demands specific protocols, such as immediate containment, deployment of skimmers, and use of specialized recovery systems to address unique LSFO properties like solidification and persistence.

2.2. Vulnerability mapping

Mapping vulnerable areas is critical for prioritizing response resources and protecting ecosystems and communities at risk.

Effective response planning begins with identifying and prioritizing areas most at risk from LSFO spills. Vulnerability mapping highlights critical zones requiring heightened surveillance and preparedness. High-risk zones includes:

- *Ports: s*erve as central points for LSFO transfer such as bunkering and storage, making them highly susceptible to spills. Spill incidents in ports can disrupt economic activities and damage infrastructure.
- *Protected areas:* Mangroves, coral reefs, estuaries, and aquaculture zones are particularly susceptible to hydrocarbon contamination from LSFO spills..
- *Human settlements:* Coastal communities and industries reliant on fishing or tourism face economic and health risks due to spill contamination.

Consideration: Vulnerability mapping should include regular updates to account for changing environmental , new infrastructure conditions or operational activities. Pre-position protective booms and barriers in sensitive ecosystems are of prime importance to prevent contamination.

2.3. Hazard modelling

Hazard modeling provides a scientific basis for predicting the behavior of LSFO spills and determining their potential impacts. Advanced tools and simulations can guide response strategies and resource allocation.

Modelling tool	Purpose
Dispersion models	Simulate the spread of spilled fuel based on wind, currents, and temperature, helping to identify high-risk zones.
Impact assessment tools	Evaluate potential effects on marine biodiversity, water quality, and shoreline contamination to guide response priorities.

Consideration:

- Using real-time dispersion models would inform the deployment of booms and skimmers process.
- Conducting ecological impact assessments would help to estimate recovery timelines and allocate resources efficiently.
- Regular updates to hazard models with real-time data and impact assessment findings would enhance accuracy and effectiveness during actual LSFO spill events.

By integrating scenario planning, vulnerability mapping, and hazard modeling, this framework equips Contracting Parties with the tools necessary to anticipate, prepare for, and mitigate the impacts of LSFO spills effectively. Therefore, key steps for CPs to establish a risk assessment framework includes:

- *Scenario identification:* Conduct risk assessments tailored to specific maritime operations, vessel types, and geographic locations.
- *Vulnerability mapping:* Use GIS tools to integrate environmental, economic, and population data for dynamic risk profiling.
- *Hazard modeling:* Invest in advanced modeling tools and regional collaborations to improve predictive accuracy and preparedness planning.

3. Monitoring and detection systems

Effective monitoring and detection systems are essential for identifying and assessing the extent of LSFO spills. By combining advanced technologies and continuous monitoring tools, CPs can respond more efficiently to mitigate environmental and safety risks.

3.1. Detection technologies

State-of-the-art detection tools provide accurate and timely information on the location and spread of spilled fuel:

Technology	Description	Application
Remote sensing	Drones and satellites equipped with imaging sensors for real-time tracking of oil slicks and their movements.	Remote sensing allows large-scale mapping of spill areas, enabling responders to prioritize high-risk zones
In-situ sensors	Hydrocarbon detectors installed on buoys for localized, continuous monitoring of fuel presence in water.	In-situ sensors provide real-time data to monitor spill dynamics and detect new contamination.

3.2. Air and water quality monitoring

Monitoring air and water quality is essential to assess in real time the environmental and health impacts of LSFO spills.

Parameter	Monitoring purpose
Airborne PAHs	Real-time measurement of airborne toxic compounds to ensure responder safety and evaluate public health risks.
Water sampling	Regular analysis of dissolved hydrocarbons and oil droplet dispersion to determine contamination levels and ecological impact.

Implementation:

- Deploying mobile monitoring units in spill zones would assist the immediate air and water quality analysis.
- Combining automated systems with manual sampling would provide comprehensive assessment of the real time environmental and health impacts of LSFO spills.

3.3. Advanced surveillance

Advanced surveillance technologies enhance situational awareness, particularly in challenging environments, critical for large-scale or remote spill scenarios.

Tool	Capabilities	Applications
Drones	Offer quick deployment and precision, making them ideal for identifying spill patterns and monitoring ongoing mitigation efforts.	Assess hard-to-reach spill zones and guide response teams.
Satellites	Real-time, wide-area monitoring of spills and long-term environmental impacts. Useful for cross-border incidents and prolonged spills, they provide regional impact assessments and support coordinated responses.	Track large-scale spills across maritime zones.
Thermal Imaging	Detects fuel slicks and surface temperature changes in low-visibility conditions, such as night-time or fog. Thermal imaging is particularly useful for spills near sensitive habitats or during extreme weather.	Locate and monitor spills during adverse weather conditions or at night
Acoustic sensors	Identifies subsurface leaks and underwater plumes by monitoring soundwave patterns. Acoustic sensors detect hidden spills, enabling prompt intervention and reducing long-term damage.	Detect underwater contamination and guide response strategies for subsurface spills

Having multiple monitoring technologies in place is of prime importance. Each monitoring system will complement the others to create a comprehensive response network. By integrating detection technologies, air and water quality monitoring, and advanced surveillance systems, CPs can develop a robust response framework to address LSFO spills with precision and efficiency.

4. Response strategies

Developing a comprehensive response strategy is essential for mitigating the environmental and economic impacts of LSFO spills. This section outlines immediate actions, specialized equipment, and decontamination procedures, including the critical role of port reception facilities in LSFO spill management.

4.1. Immediate actions

Swift and effective actions during the initial phase of a spill of LSFO are critical to limiting environmental damage and ensuring responder safety. These steps prioritize safety, containment, and environmental protection.

Action	Description	Purpose
Containment	Deploy floating oil booms around the LSFO spill area to restrict slick spread and protect sensitive zones.	Prevent fuel from contaminating larger marine or coastal ecosystems.
Skimming	Use mechanical skimmers to remove LSFO from the surface of the water.	Recover as much spilled fuel as possible to minimize environmental impact.
Shoreline protection	Install absorbent barriers and booms along beaches and wetlands to reduce contamination risk.	Shield coastal areas, such as mangroves and estuaries, from oil exposure.

Considerations:

- Pre-positioning containment booms in high-risk areas ensures rapid deployment.
- Shoreline protection measures must account for variability in LSF properties, including viscosity and potential solidification.

4.2. Specialized equipment

Proper equipment is vital to the safety of responders and the effectiveness of spill containment and recovery operations.

Equipment	Description	Application
Personal Protective Equipment (PPE)	Chemical-resistant suits, gloves, goggles, and respiratory gear.	Safeguards responders from toxic fumes and skin exposure during clean-up.
Recovery systems	Advanced skimmers, portable pumps, and oil-water separators.	Enables efficient recovery of LSO in various physical states, including viscous or semi-solid forms.
Port reception facilities	Designated onshore facilities for safe storage and disposal of recovered fuel and waste.	Ensures proper handling of waste materials to prevent secondary contamination.

Implementation:

- Port reception facilities must be equipped to handle the unique challenges of LSFO spills, such as semi-solid waste or residues with high paraffin content.

- Specialized skimmers designed for sticky or brittle fuels improve recovery efficiency in cold or temperate environments.

4.3. Decontamination and rehabilitation

Cleaning up after a spill is critical for ecological recovery and restoring affected areas.

Target	Procedure	Purpose
Marine life	Use non-toxic cleaning agents and rehabilitation centres to clean and rehabilitate affected species.	Reduce mortality and promote recovery of fish, seabirds, and marine mammals.
Shorelines	Apply high-pressure washing for rocky coastlines or manual removal techniques for sensitive habitats.	Restore contaminated areas and minimize long-term ecological disruption.
Recovered fuel	Store and process recovered fuel at port reception facilities to ensure safe disposal or recycling.	Prevent secondary contamination and maximize resource recovery.

Key considerations:

- Responders must prioritize minimizing harm to ecosystems during decontamination efforts.
- Collected waste must be categorized and treated following national and international waste management protocols.

4.4. Role of port reception facilities

Port reception facilities play an essential role in managing recovered materials during and after LSF spill response. Key consideration regarding the port reception facilities includes:

- *Capacity:* Adequate storage capacity for recovered fuel, oily waste, and contaminated equipment must be ensured.
- *Infrastructure:* Facilities must be equipped with tools (i.e., or connected to external tools) for waste separation, fuel recycling, and safe disposal.
- *Coordination:* Collaboration with spill response teams is vital to streamline waste transportation and processing.

5. Strengthening governance and policy

Effective governance and robust national policy frameworks are essential to enhance preparedness and response capabilities for LSFO spills. This section outlines regulatory measures, port-specific strategies, and regional collaboration to ensure coordinated and efficient LSFO spill management.

5.1. Regulatory enhancements

Regulatory improvements form the foundation of a systematic and proactive approach to LSFO spill preparedness. Fuel **spill contingency plans** for all vessels and ports handling LSFOs should be revised. These plans must incorporate detailed risk assessments, inventories of spill response equipment, and clear, actionable plans tailored to the specific risks associated with LSFO spills.

Additionally, **standardized reporting protocols** should be established by CPs and their authorities to ensure consistent and efficient communication during spill incidents. Reporting systems should include real-time communication channels and centralized databases to monitor and track spill events effectively, enabling rapid response and coordination among stakeholders. These measures will enhance readiness and minimize the environmental and economic impacts of LSF spills.

5.2. Port-specific measures

Ports play a fundamental role in managing the risks associated with LSFO spills, particularly due to their involvement in bunkering operations and storage. To minimize spill risks, ports should establish designated and controlled zones for fuel transfer operations. These zones must be equipped with containment systems, such as booms and barriers, to reduce the likelihood of contamination and ensure rapid containment in the event of a spill.

Stockpiling spill response kits is another essential measure. These kits should include critical equipment like skimmers, booms, and personal protective equipment (PPE) tested and proved to be effective for LSFO to enable swift and effective response actions. Additionally, ensuring that port staff are adequately trained in spill management and the operation of response equipment is crucial. Regular training sessions and drills should be conducted to maintain a high level of preparedness and ensure personnel are confident in addressing LSFO spill incidents.

To enhance effectiveness, controlled zones should integrate advanced technologies like remote sensing and in-situ monitoring systems to detect spills at the earliest stage, enabling prompt response efforts.

5.3. Regional collaboration

Collaboration among neighbouring CPs is essential for effectively managing cross-border LSFO spill incidents and ensuring the efficient use of shared resources. Scenario-based regional drills should be conducted regularly to test coordination between CPs, improve readiness, and identify any gaps in response capabilities. These drills help build a shared understanding of procedures and foster better communication among stakeholders.

Maintaining an updated inventory of shared response equipment, technical expertise, and facilities under frameworks of the REMPEC is crucial. This ensures that resources can be quickly mobilized during emergencies, enabling a collective response to mitigate environmental and economic impacts.

To support these efforts, bilateral or multilateral agreements are of prime importance in facilitating the rapid sharing of resources and expertise during spill events. Additionally, Regional database of LSFO scientific studies, along with documented case studies of spill responses, will enhance collective knowledge and improve preparedness across the entire region. This collaborative approach strengthens the overall capacity to manage LSFO spills effectively.

6. Training, capacity building, tools, and resources

Training and capacity building are critical to equipping responders with the skills and knowledge needed to manage LSFO spills effectively. Comprehensive training should address the properties and risks of LSFOs and the procedures necessary for effective mitigation. Key training areas, among others, include:

Focus Area	Details
Understanding LSFOs	Physical and chemical properties, behavior during spills, and environmental impacts
Personal safety measures	Proper use of PPE, safe handling practices, and exposure management for responders
Spill response protocols	Steps for containment, skimming, and decontamination of affected areas and resources
Use of equipment	Practical training on operating skimmers, booms, pumps, and advanced monitoring tools.
Coordination	Communication protocols for effective collaboration between local and regional response teams

Capacity building recommendations:

- *Structured training programs:* Conduct annual training sessions that combine theoretical knowledge and hands-on exercises, including scenario-based simulations tailored to LSFO spills.
- *Regional drills:* Collaborate with neighboring countries to practice joint responses for large-scale or cross-border spill incidents.
- *Technology integration:* Utilize VR and AR tools to create immersive and realistic training experiences for responders.
- *Knowledge dissemination:* Build national and local expertise by training a core group of responders who can act as trainers in their respective regions.

GUIDELINES
NATIONAL PREPAREDNESS FOR ACCIDENTAL RELEASES OF METHANOL AT SEA

This annex serves as a guidance for Contracting Parties (CPs) to develop effective preparedness and response systems for accidental releases of methanol at sea, addressing its unique properties, risks, and response requirements.

1. Understanding methanol: Properties and risks

1.1. Properties of methanol

Methanol is gaining traction as a low-carbon marine fuel due to its manageable storage requirements and established handling practices. However, its chemical and physical properties present distinct challenges for spill response and environmental management.

Property	Description
State	Methanol is a liquid at ambient temperature and pressure, simplifying storage and transport compared to cryogenic fuels like LNG or hydrogen.
Density	Slightly less dense than water (~0.792 specific gravity), methanol will float when spilled on water.
Solubility	Fully miscible in water, dissolving rapidly into the water column.
Flammability	Highly flammable with a wide flammability range (6%–36.5% by volume in air).
Flash point	Low flash point of 12°C, producing highly flammable vapours even at moderate temperatures.
Toxicity	Toxic if ingested or absorbed through the skin, with vapors causing respiratory and neurological effects at high concentrations.
Vapor behavior	Heavier-than-air vapors tend to hug the ground or water surface, posing ignition and health risks in confined spaces.
Biodegradability	Readily biodegradable in water, with a half-life of 1–7 days, and relatively low bioaccumulation and aquatic toxicity.

1.2. Risks of accidental releases of methanol

Methanol spills present specific risks to human health, the environment, and maritime operations. Understanding these risks is essential for targeted emergency response and mitigation strategies.

Risk	Description
Flammability	Methanol vapors ignite easily within its wide flammability range, posing risks of flash fires or vapor cloud explosions.
Toxicity	Acute exposure to methanol vapors or skin contact may result in respiratory distress, blindness, or death.
Vapour hazards	Dense vapours remain close to the surface, creating ignition risks and asphyxiation hazards in poorly ventilated or confined areas.
Environmental impact	Dissolves quickly in water, posing minimal long-term ecological damage but potential short-term disruptions due to localized temperature changes.

Fire hazards	Methanol burns with a nearly invisible flame, increasing risks to responders and complicating firefighting efforts.

Key insights:

- *Wide flammability range and low flash point:* Methanol's ease of ignition necessitates strict control of ignition sources during response operations.
- *Rapid solubility and biodegradation:* Methanol's dispersion in water limits physical containment options, requiring emphasis on monitoring and dilution strategies.
- *Toxic and asphyxiant risks:* Methanol vapors can displace oxygen in confined spaces, emphasizing the need for responder safety measures and advanced monitoring systems.
- *Fire suppression challenges:* The low visibility of methanol flames requires specialized detection systems, such as infrared cameras, to identify and manage fires

2. Risk assessment framework for methanol spills

A comprehensive risk assessment framework is crucial for managing the impacts of methanol spills, ensuring the safety of responders, minimizing environmental harm, and protecting critical infrastructure. This framework integrates scenario identification, vulnerability mapping, and hazard modeling to enhance preparedness and response.

2.1. Scenario identification

Identifying potential methanol spill scenarios is essential for designing targeted response strategies. Key scenarios include:

- *Transfer spills:* During bunkering or transfer operations, equipment failure, procedural lapses, or human error can cause methanol spills. These incidents risk fires, vapor inhalation, and toxic exposure, particularly in port areas.
- *Tank breaches:* Structural damage to methanol tanks from collisions, grounding, or severe weather can release large quantities of methanol. Such breaches can cause significant environmental contamination and pose hazards to responders.
- *Pipeline ruptures:* Methanol transfer pipelines, vulnerable to corrosion, mechanical failure, or natural disasters, may release pressurized methanol into the environment, creating risks of ignition and toxic vapor exposure.

Considerations: Emergency protocols should prioritize isolating spill sources, evacuating affected areas, and neutralizing ignition risks. Preparedness plans must account for simultaneous hazards such as fire, toxic exposure, and environmental damage.

2.2. Vulnerability mapping

Mapping vulnerable zones helps prioritize protection for sensitive ecosystems, infrastructure, and responders. Key areas include:

- *Port facilities*: Ports and terminals involved in methanol storage or bunkering face high spill risks. Infrastructure such as pipelines, berths, and storage tanks may sustain structural damage, disrupting operations.
- *Sensitive ecosystems:* Coastal and aquatic ecosystems, including wetlands, coral reefs, and estuaries, may experience localized chemical toxicity or temperature changes from methanol dissolution.
- *Coastal communities:* Populations near spill sites are vulnerable to vapor exposure, fire hazards, and toxic effects. Community infrastructure, such as drinking water supplies and transportation systems, may also face contamination or disruption.

Considerations: Vulnerability mapping should highlight critical infrastructure, such as firefighting systems and evacuation routes, and identify staging areas for responders equipped with cryogenic protective gear.

2.3. Hazard modelling

Hazard modeling provides a scientific basis for predicting methanol spill behavior and impacts, enabling informed response planning. Advanced modeling tools simulate key aspects of methanol spills:

Modeling Tool	Purpose
Dispersion models	Simulate the spread of methanol vapor clouds based on wind speed, humidity, and temperature, aiding containment planning.
Thermal impact models	Assess radiant heat zones from methanol fires, guiding evacuation and exclusion zone establishment.
Impact assessment tools	Evaluate risks to marine biodiversity and port infrastructure, prioritizing response resource allocation.

Considerations:

- Real-time data integration improves the accuracy of hazard models, supporting rapid decision-making.
- Ecological impact assessments guide long-term restoration strategies and resource allocation.
- Scenario-based simulations optimize equipment deployment and enhance regional collaboration during methanol spill incidents

3. Monitoring and detection systems for methanol spills

Effective monitoring and detection systems are critical for identifying and managing the impacts of methanol spills. These systems ensure rapid response, mitigate environmental damage, protect responders, and minimize risks to infrastructure. Leveraging advanced technologies and continuous monitoring enables a precise and integrated approach to methanol spill response.

3.1. Detection technologies

State-of-the-art detection technologies provide accurate, real-time insights into the location, extent, and behavior of methanol spills, enabling targeted response actions.

Technology	Description	Application
Remote sensing	Drones and satellites equipped with thermal imaging and gas sensors to track methanol vapor clouds and detect surface changes.	Enables large-scale mapping of spill areas and monitoring of vapor dispersion in real time.
In-Situ sensors	Methanol-specific detectors installed on buoys or at spill sites to monitor vapor concentration and environmental changes.	Provides localized, continuous data on methanol concentrations and environmental conditions.
Thermal imaging	Detects temperature changes caused by methanol spills, particularly in low-visibility conditions.	Useful for identifying spill extent and areas affected by rapid evaporation.

3.2. Air and water quality monitoring

Monitoring air and water quality is essential for assessing environmental impacts and ensuring the safety of responders and nearby communities.

Parameter	Monitoring purpose
Methanol vapor levels	Real-time measurement of methanol concentrations in the air to evaluate toxicity risks and guide responder safety.
Water temperature	Monitoring rapid temperature drops to detect localized thermal impacts caused by methanol evaporation.
Dissolved methanol	Regular sampling to assess underwater methanol concentrations and potential risks to marine ecosystems.

Implementation:

- Deploy mobile monitoring units in spill zones to provide immediate air and water quality analysis.
- Combine automated systems, such as sensor-equipped buoys, with manual sampling for comprehensive assessments.

3.3. Advanced surveillance technologies

Advanced surveillance systems enhance situational awareness, particularly for large-scale or remote methanol spill scenarios, by providing actionable intelligence in real time.

Tool	Capabilities	Applications
Drones	High-resolution imaging and vapor cloud tracking, particularly in hard-to-reach areas.	Guides response teams in assessing spill zones and monitoring mitigation efforts.
Satellites	Wide-area monitoring of spills and vapor clouds over extended periods.	Ideal for cross-border spills and assessing long-term impacts in regional maritime zones.

Acoustic sensors	Detects underwater leaks and subsurface gas plumes by analyzing soundwave patterns.	Identifies hidden spills and informs response strategies for subsurface contamination.
Infrared cameras	Identifies low-temperature spills and detects methanol flames, which are often difficult to see.	Effective for nighttime operations and low-visibility conditions near sensitive habitats or facilities.

Key considerations for methanol spill monitoring:

- *Integration of technologies:* Combining remote sensing, in-situ sensors, and advanced surveillance ensures a comprehensive, layered monitoring approach.
- *Responder safety:* Continuous monitoring of methanol vapor levels and environmental conditions is essential to protect responders from toxic exposure.
- *Infrastructure protection:* Early detection of vapor clouds and subsurface contamination minimizes risks to port facilities, vessels, and responders.
- *Real-time data utilization:* Leveraging real-time data improves decision-making and accelerates the deployment of mitigation resources.

4. Response strategies for methanol spills

Developing a comprehensive response strategy is essential for mitigating the environmental, economic, and safety impacts of methanol spills. This section outlines immediate actions, specialized equipment, and decontamination procedures, addressing the unique challenges posed by methanol's chemical and flammable properties.

4.1. Immediate actions

Swift and effective actions during the initial phase of a methanol spill are critical for limiting environmental damage, protecting responders, and ensuring safety. These steps prioritize containment, fire prevention, and minimizing vapor dispersion.

Action	Description	Purpose
Containment	Deploy spill barriers and floating booms to prevent the spread of methanol on the water surface.	Minimize contamination of sensitive ecosystems and protect coastal areas.
Vapor suppression	Use water sprays curtains or foam to dilute methanol vapor clouds and reduce their density.	Decrease fire risks and protect nearby populations or infrastructure.
Ignition source elimination	Immediately shut down any potential ignition sources in the vicinity of the spill.	Prevent fires or explosions caused by methanol vapor ignition.
Evacuation plans	Establish exclusion zones and evacuate personnel from downwind areas affected by methanol vapors.	Prevent inhalation risks and injuries from toxic or flammable concentrations.

Considerations:

- Pre-deploy spill containment tools, such as booms and foam systems, in high-risk areas to ensure rapid response.
- Evacuation plans must account for methanol's fast vaporization and its tendency to form flammable clouds.

4.2. Specialized equipment

Effective methanol spill response relies on the availability of proper equipment tailored to its toxic and flammable nature.

Equipment	Description	Application
Personal Protective Equipment (PPE)	Includes chemical-resistant suits, gloves, face shields, and respiratory protection for toxic vapors.	Protect responders from skin burns, inhalation hazards, and toxic exposure.
Foam extinguishing systems	Alcohol-resistant foams designed to suppress methanol fires and vapor clouds.	Ensure fire control and suppression in spill zones.
Vapor detectors	Portable devices to monitor methanol vapor concentrations in real-time.	Guide evacuation and containment efforts by identifying high-risk areas.
Thermal imaging cameras	Detect low-temperature areas caused by methanol vaporization.	Assist in identifying spill boundaries and locating invisible methanol flames.

Implementation:

- Ensure methanol-compatible PPE is available and accessible to all responders.
- Use foam systems alongside water sprays to suppress both flames and vapor clouds effectively.

4.3. Decontamination and rehabilitation

Post-spill cleanup and rehabilitation are essential to restore affected areas and minimize long-term environmental impacts.

Target	Procedure	Purpose
Marine life	Implement controlled aeration and dilution of affected waters to mitigate methanol toxicity.	Reduce harmful impacts on marine ecosystems and restore biodiversity.
Port infrastructure	Inspect and repair methanol handling systems, pipelines, and storage tanks exposed to the spill.	Prevent structural failures and ensure safe resumption of operations.
Toxic residues	Neutralize methanol residues using absorbent materials and chemical neutralizers.	Ensure safe handling of remaining methanol and minimize risks of recontamination.

Key Considerations:

- Engage environmental agencies to oversee the safe handling of affected ecosystems and ensure compliance with regulations.
- Use thermal remediation techniques to address localized cooling effects caused by methanol evaporation.

5. Strengthening governance and policy for methanol spill preparedness

Effective governance and comprehensive policy frameworks are vital for improving the preparedness and response systems for methanol spills. Given methanol’s toxic and flammable nature, tailored policies and collaborative strategies are essential to address its unique challenges.

5.1. Regulatory enhancements

Regulatory frameworks should address the specific risks posed by methanol spills, focusing on fire hazards, toxicity, and environmental impacts.

- *Methanol-specific contingency plans:* shall include risk assessments for methanol storage, handling, and transfer operations. The emergency response protocols must include vapor suppression, ignition source elimination, and spill containment strategies.
- *Standardized reporting and communication systems:* centralized databases for tracking methanol spill incidents and response outcomes shall be established by CPs. Implementing real-time communication channels between stakeholders, including port authorities, environmental agencies, and responders is of prime importance.
- *Emergency shutdown systems:* Methanol transfer and storage facilities must be equipped with automated emergency shutdown systems to minimize spill volumes. These systems should be carefully maintained and inspected regularly.

Considerations: Regulatory measures must align with international frameworks, such as IMO’s Interim Guidelines for Low-Flashpoint Fuels (MSC.1/Circ.1621), to ensure global consistency and effectiveness.

5.2. Safety measures for methanol terminals and vessels

Methanol terminals and vessels play a critical role in minimizing risks. Implementing tailored safety measures can significantly reduce the likelihood and severity of spills.

- *Designated transfer zones:* Establish controlled zones equipped with advanced monitoring systems, such as vapour detectors, infrared sensors to detect spills and potential ignition risks.
- *Stockpiling response kits:* Methanol spill response kits should include gas detectors, cryogenic PPE for responders to prevent frostbite or other cold-related injuries, and water curtains and high-expansion foam systems (i.e., alcohol-resistant) to manage vapor dispersion and suppress fires.

- *Training and drills:* Personnel at terminals and onboard vessels must receive regular training in handling cryogenic materials, vapor management and fire suppression techniques, and training on advanced spill response strategies, such as vapor cloud modelling and containment.

5.3. Regional collaboration

Collaboration among neighbouring CPs is essential for effectively managing cross-border methanol spill incidents and ensuring the efficient use of shared resources. Scenario-based regional drills should be conducted regularly to test coordination between CPs, improve readiness, and identify any gaps in response capabilities. These drills help build a shared understanding of procedures and foster better communication among stakeholders.

Maintaining an updated inventory of shared response equipment, technical expertise, and facilities under frameworks of the REMPEC is crucial. This ensures that resources can be quickly mobilized during emergencies, enabling a collective response to mitigate environmental and economic impacts.

To support these efforts, bilateral or multilateral agreements are of prime importance in facilitating the rapid sharing of resources and expertise during spill events. Additionally, Regional database of methanol scientific studies, along with documented case studies of spill responses, will enhance collective knowledge and improve preparedness across the entire region. This collaborative approach strengthens the overall capacity to manage methanol spills effectively.

6. Training and capacity building for methanol spill preparedness

Comprehensive training and capacity-building initiatives are essential for equipping responders with the necessary skills and knowledge to manage methanol spills effectively. Given methanol's flammable and toxic properties, specialized programs must emphasize both safety and operational efficiency. Training programs for methanol spill response should cover the following focus areas:

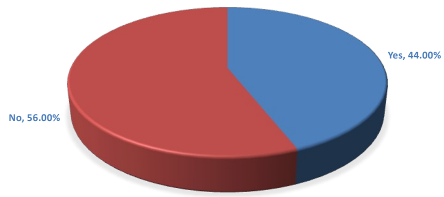
Focus area	Details
Understanding methanol	Methanol’s chemical properties, flammability, toxicity, and environmental impact.
Personal safety measures	Safe handling practices, proper use of PPE, and managing risks such as toxicity , invisible flams and vapor exposure.
Spill response protocols	Procedures for ignition source elimination, containment, and vapor dispersion.
Specialized equipment usage	Practical training on alcohol-resistant foams, vapor suppression systems, and gas detectors.
Coordination and communication	Effective collaboration among response teams, local authorities, and regional stakeholders.

Capacity building recommendations for CPs:

- Conduct annual training sessions combining theoretical knowledge with hands-on exercises.
- Include scenario-based simulations tailored to methanol spill scenarios, such as vapor cloud dispersion and fire suppression.
- Organize collaborative drills with neighbouring CPs to simulate large-scale or cross-border methanol incidents.
- Test coordination frameworks, communication protocols, and shared resource mobilization.
- Employ Virtual Reality (VR) and Augmented Reality (AR) tools to create immersive training experiences for responders.
- Simulate real-world scenarios like cryogenic burns or vapor cloud behavior to improve readiness.
- Develop a core group of methanol spill response experts to act as trainers in their respective regions.
- Establish knowledge-sharing platforms to disseminate best practices and lessons learned from previous incidents.

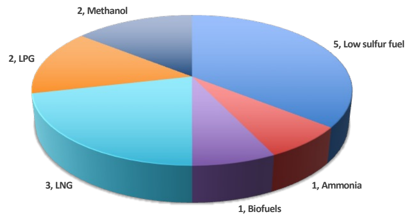
ANNEX IV. QUESTIONNAIRE SURVEY RESULTS

Do ports in your country transport Low Sulphur fuel or alternative fuels (ammonia, hydrogen, biofuels, LNG, LPG, hydrogen, Methanol, etc.)



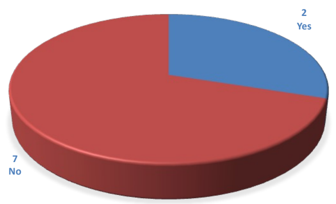
Number of participants: 18 (14 CPs)

Please specify which alternative fuels are handled by ports in your country?



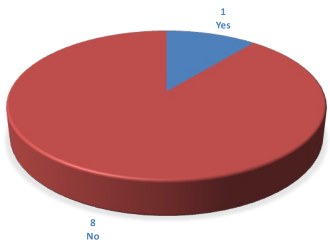
Number of participants: 18 (14 CPs)

Has your country experienced past incidents involving spills of low Sulphur or alternative fuels?



Number of participants: 9 (9 CPs)

Does your country have specific national policies to address marine pollution incidents involving alternative fuels (biofuels, ammonia, hydrogen, LNG)?

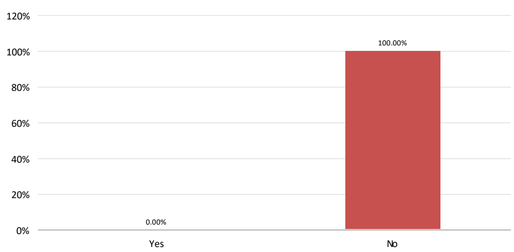


Number of participants: 9 (9 CPs)

Please specify which alternative fuels are specifically covered under these policies?

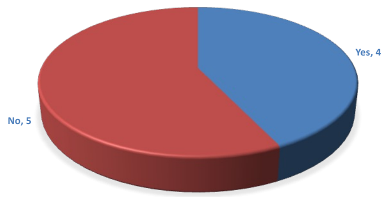
- Low Sulphur fuel
- LNG

Were there any updates of the National Oil Spill Response Plan in your country in the last five years to include provisions for low Sulphur or alternative fuels?



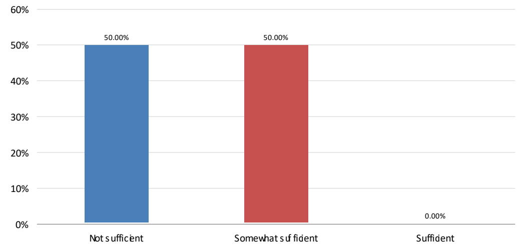
Number of participants: 9 (9 CPs)

Does your country utilize any specific tool for assessment of the effectiveness of the National Oil Spill Response Plan?



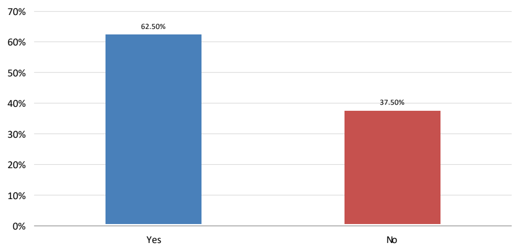
Number of participants: 9 (9 CPs)

How would you rate your country's specialized equipment to respond to potential major spills involving low Sulphur fuels or alternative fuels?



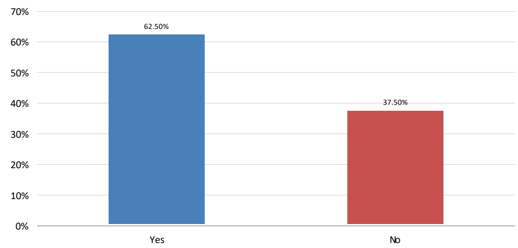
Number of participants:8 (8 CPs)

Do major ports in your country maintain stockpiles of response equipment?



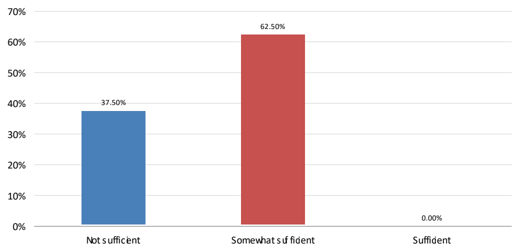
Number of participants: 8 (8 CPs)

Does your country maintain a national stockpile of response equipment in addition to the inventory at ports?



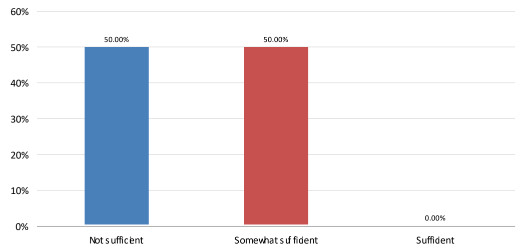
Number of participants: 8 (8 CPs)

How would you rate the sufficiency of the response equipment stockpiles at ports for responding to potential major spills, especially from Sulphur fuel and alternative fuel?



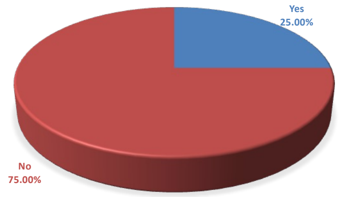
Number of participants: 8 (8 CPs)

How would you rate the overall expertise of your response personnel in handling low Sulphur fuel and alternative fuel spills?



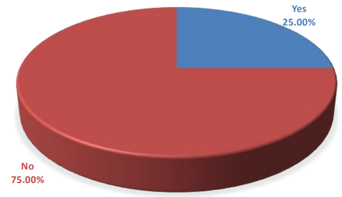
Number of participants: 8 (8 CPs)

Is your country carrying out drills and exercises to test preparedness for marine fuel spills focusing also on spills involving low Sulphur and alternative fuels (e.g., LNG, ammonia, hydrogen)?



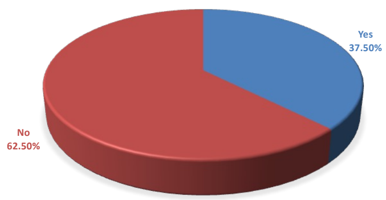
Number of participants: 8 (8 CPs)

Has your country participated in any regional or international oil spill response exercises focusing on low Sulphur or alternative fuels?



Number of participants: 8 (8 CPs)

Does your country use decision support systems for managing oil or alternative fuel spill incidents?

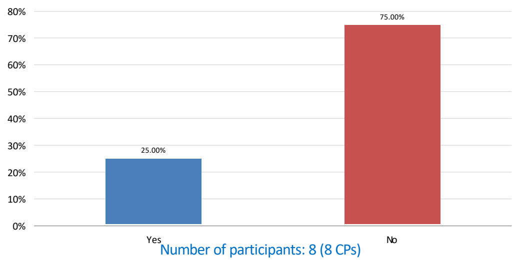


Number of participants: 8 (8 CPs)

Please specify the types of decision support systems used in your country for managing oil or alternative fuel spill incidents?

2 CPs reported using Modelling software.

Are new technologies being explored by your country for pollution response involving spills of low Sulphur or alternative fuels?

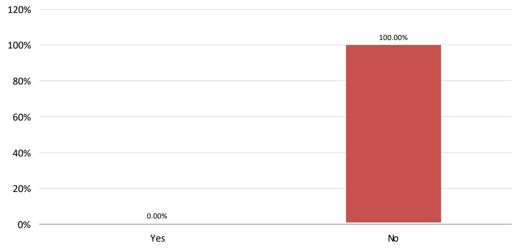


Number of participants: 8 (8 CPs)

Please specify the types of technologies being explored by your country for pollution response involving spills of low Sulphur or alternative fuels?

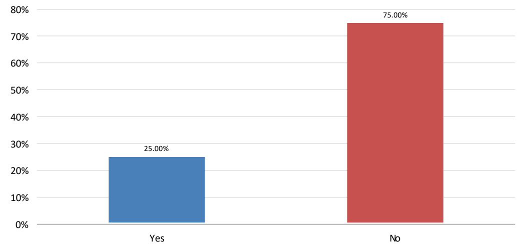
2 CPs reported exploring the use of Drones.

Has your country conducted environmental impact studies on the risks posed by low Sulphur or alternative fuels for waters under jurisdiction?



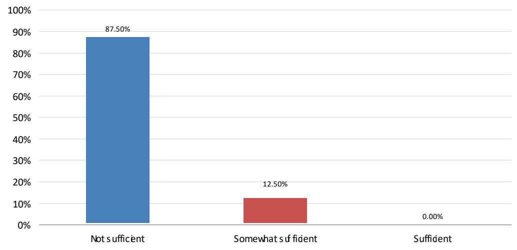
Number of participants: 8 (8 CPs)

Has your country adopted any best practices from other nations or international bodies for responding to alternative fuel spills?



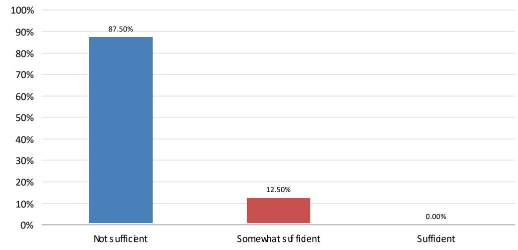
Number of participants: 8 (8 CPs)

How would you rate your country investment in research and development (R&D) to enhance marine pollution response capabilities specific to alternative fuels?



Number of participants: 8 (8 CPs)

How would you rate your country investment in research and development (R&D) to enhance marine pollution response capabilities specific to alternative fuels?



Number of participants: 8 (8 CPs)

GUIDELINES
NATIONAL PREPAREDNESS FOR ACCIDENTAL RELEASES OF AMMONIA AT SEA

This annex serves as a guideline for Contracting Parties to establish effective initial response systems for accidental ammonia spills at sea. In addition to regulatory frameworks, by incorporating technical preparedness, and operational strategies, it aims to minimize environmental damage while safeguarding the health of both affected communities and emergency responders.

1. Understanding ammonia: Properties and risks

Ammonia, an alternative fuel and industrial chemical, plays a critical role in the maritime sector. However, its unique properties, and associated risks necessitate careful handling to ensure safety at sea and in coastal regions.

1.1. Properties of ammonia

Property	Description
State	A colorless gas with a strong, pungent odor, stored and transported as a liquefied gas under pressure
Reactivity	Reacts with water to form ammonium hydroxide, a highly corrosive and alkaline solution
Volatility	Exhibits high vapor pressure, leading to rapid evaporation and the formation of toxic gas clouds upon release
Toxicity	Harmful at low concentrations, causing respiratory distress and skin or eye burns. Fatal at high exposures
Density	Vapors are lighter than air but can act as a heavy gas under high humidity, remaining close to the surface

Key insights:

- Ammonia's reactivity and volatility make it hazardous when released, necessitating advanced containment and mitigation strategies.
- Its ability to form dense vapor clouds under certain conditions increases the risk of inhalation exposure and environmental contamination.

1.2. Risks of accidental releases

Risk	Impact
Toxicity	Ammonia exposure can cause respiratory distress, severe skin burns, and eye damage. Long-term or high exposure can be fatal
Environmental impact	Highly toxic to aquatic life, causing gill damage, mortality, and disruption of ecosystems. Reactivity with water leads to rapid pH changes, harming marine habitats
Flammability	Ammonia is combustible under confined conditions and in specific air-to-gas ratios (5-15%), presenting explosion risks
Cryogenic risks	Direct contact with liquefied ammonia causes severe frostbite and structural embrittlement

Key insights:

- Ammonia spills pose significant hazards to human health, marine ecosystems, and nearby infrastructure.
- Its dual nature as both toxic and flammable requires tailored response measures to address both immediate and long-term impacts.

2. Risk assessment framework

A robust risk assessment framework is essential for anticipating and managing the consequences of accidental ammonia releases at sea. A systematic approach to identifying potential scenarios, mapping vulnerabilities, and utilizing advanced hazard modeling are crucial to mitigate the associated risks effectively.

2.1. Identifying scenarios

Accidental releases of ammonia can occur under various circumstances, each requiring tailored response measures. Key scenarios include:

- *Bunkering spills:* Leakages during fuel transfer operations, either at ports or mid-sea, are among the most common incidents. These spills are often caused by equipment failure, human error, or improper coupling of fuel lines, resulting in localized contamination and vapor release.
- *Tank breaches:* Structural failures or collisions involving ships transporting or storing ammonia can cause large-scale spills. Such incidents may release significant quantities of ammonia, leading to widespread toxic gas clouds and marine contamination.
- *Pipeline ruptures:* Damage to pipelines during the transfer of ammonia to storage facilities or ships can result in both air and water contamination. Factors such as corrosion, natural disasters, or accidental impact from vessels or machinery often contribute to these ruptures.

Consideration: Each scenario requires specific response protocols and equipment to address immediate containment and long-term mitigation.

2.2. Vulnerability mapping

Effective response planning begins with identifying and prioritizing areas most at risk from ammonia spills. Vulnerability mapping highlights critical zones requiring heightened surveillance and preparedness. High-risk zones includes:

- *Ports: s*erve as central points for ammonia transfer and storage, making them highly susceptible to spills. Spill incidents in ports can disrupt economic activities, damage infrastructure, and expose workers and nearby populations to toxic risks.
- *Protected areas:* include ecosystems such as mangroves, coral reefs, and aquaculture zones. Ammonia's toxic and reactive nature poses severe threats to biodiversity, including fish mortality, habitat destruction, and long-term ecological imbalances.

- *Human settlements:* coastal communities and industrial hubs near spill-prone areas face risks of exposure to toxic vapors, displacement, and disruption of economic activities.

Consideration: Vulnerability mapping should include regular updates to account for changing environmental and infrastructure conditions.

2.3. Hazard modelling

Hazard modeling provides a scientific basis for predicting the behavior of ammonia spills and their potential impacts. Advanced tools and simulations can guide response strategies and resource allocation.

- *Airborne dispersion:* Predictive models simulate the spread of ammonia gas clouds under varying weather conditions, including wind speed, temperature, and humidity. Accurate modeling enables responders to establish exclusion zones and prioritize evacuation efforts for at-risk populations.
- *Marine contamination:* Simulations of ammonia dissolution in seawater help assess the extent and severity of contamination. Factors such as water temperature, salinity, and currents influence the dispersion and impact of dissolved ammonia, guiding containment and mitigation efforts.

Scenario	Modeling objective
Small bunkering Leak	Predict localized vapor cloud spread and marine dissolution for immediate containment.
Major tank beach	Simulate large-scale dispersion to inform evacuation and resource deployment plans.
Pipeline rupture	Assess dual impacts of vapor release and water contamination in connected ecosystems.

Consideration: Regular updates to hazard models with real-time data enhance accuracy and effectiveness during actual spill events.

By integrating scenario planning, vulnerability mapping, and hazard modeling, this framework equips Contracting Parties with the tools necessary to anticipate, prepare for, and mitigate the impacts of ammonia spills effectively. Therefore, key steps for CPs to establish a risk assessment framework includes:

- *Scenario identification:* Conduct risk assessments tailored to specific maritime operations, vessel types, and geographic locations.
- *Vulnerability mapping:* Use GIS tools to integrate environmental, economic, and population data for dynamic risk profiling.
- *Hazard modeling:* Invest in advanced modeling tools and regional collaborations to improve predictive accuracy and preparedness planning.

3. Monitoring and detection systems

A well-designed monitoring and detection system is essential for identifying the extent and impacts of accidental ammonia spills at sea. This section categorizes key tools and technologies into air monitoring, water quality monitoring, and advanced surveillance.

3.1. Air monitoring

Ammonia vapor is toxic and can quickly spread, creating immediate health and safety risks. Effective air monitoring systems are critical for detecting ammonia levels and guiding response actions.

Tool	Description	Applications
Fixed sensors	Permanently installed at ports and integrated with centralized systems to trigger immediate alarms, allowing responders to act swiftly during incidents.	Continuous monitoring in high-risk areas.
Portable detectors	Handheld devices for emergency teams to assess ammonia levels at spill sites.	Dynamic assessment and exclusion zone setup.

3.2. Water quality monitoring

Ammonia dissolves in water, altering its chemistry and affecting marine life. Monitoring water quality provides insights into the extent and severity of contamination.

Tool	Purpose	Monitored Parameters
pH sensors	Deployed on buoys or manually, they provide immediate feedback on changes in water chemistry (alkalinity) caused by ammonia, helping responders locate spill hotspots.	pH levels in affected zones.
Nitrogen analyzers	Measure dissolved ammonia concentrations to assess contamination severity, allowing targeted mitigation efforts.	Total Ammonia Nitrogen (TAN)

3.3. Advanced surveillance

Advanced surveillance systems provide broader situational awareness, critical for large-scale or remote spill scenarios.

Tool	Capabilities	Applications
Drones	Offer quick deployment and precision, making them ideal for identifying spill patterns and monitoring ongoing mitigation efforts.	Assess hard-to-reach spill zones and guide response teams.
Satellites	Real-time, wide-area monitoring of spills and long-term environmental impacts. Useful for cross-border incidents and prolonged spills, they provide regional impact assessments and support coordinated responses.	Track large-scale spills across maritime zones.

3.4. Integrated monitoring approach

Each monitoring system complements the others to create a comprehensive response network. By integrating these systems, Contracting Parties can ensure rapid, effective responses to ammonia spills, minimizing harm to both human health and the environment.

- *Air monitoring* detects immediate risks to human health and establishes exclusion zones.
- *Water quality monitoring* identifies contamination levels and guides containment strategies.
- *Advanced surveillance* provides overarching situational awareness for strategic decision-making.

4. Response strategies

This section presents the response strategies for managing ammonia spills at sea. By detailing immediate actions, specialized equipment, and decontamination procedures, it provides actionable guidance to help CPs mitigate health risks and environmental impacts effectively.

4.1. Immediate actions

Immediate actions are critical to minimize harm during an ammonia spill. These steps prioritize safety, containment, and environmental protection.

Action	Description	Purpose
Evacuation	Promptly remove personnel from affected zones and establish exclusion areas based on dispersion models	Prevent exposure to ammonia vapors and ensure responder safety
Containment	Deploy floating booms, barriers, or water curtains to limit the spread of ammonia in the water	Isolate the spill to protect sensitive marine areas and minimize contamination
Neutralization	Carefully introduce acidifying agents (e.g., citric acid, diluted sulfuric acid) into contaminated water	Restore pH levels and reduce ammonia toxicity in aquatic ecosystems

Key considerations includes:

- *Evacuation zones*: Use real-time air monitoring to determine the safe distance for exclusion zones.
- *Containment measures:* Booms should be pre-positioned at key locations, such as ports and high-risk shipping lanes.
- *Neutralization protocols:* Ensure precise application of neutralizers to avoid over-correction, which may harm marine life.

4.2. Specialized equipment

Access to appropriate equipment ensures the safety of responders and the effectiveness of containment and cleanup efforts.

Equipment Type	Description	Applications
Personal Protective Equipment (PPE)	Chemical-resistant suits, gloves, goggles, and gas masks designed for ammonia exposure.	Protect responders from inhalation, skin burns, and frostbite.
Spill response kits	Include absorbents, containment booms, portable pumps, and neutralizing agents.	Provide immediate tools for containment and cleanup efforts.
Monitoring devices	Portable gas detectors and water quality analyzers to assess ammonia levels in air and water.	Support decision-making during evacuation and containment.

Implementation:

- *PPE:* Ensure all responders have access to certified ammonia-resistant PPE.
- *Response kits:* Strategically store kits at major ports and onboard vessels for quick deployment.
- *Monitoring devices:* Maintain calibrated devices to guarantee accurate readings during emergencies.

4.3. Decontamination procedures

Proper decontamination ensures the safety of responders, prevents secondary contamination, and allows for safe equipment reuse.

Target	Procedure	Purpose
Responders	Onsite decontamination stations with showers, neutralizing agents, and medical support.	Remove ammonia residues to prevent prolonged exposure and health risks.
Equipment	Rinse contaminated tools and machinery with neutralizing solutions; dispose of single-use items safely.	Avoid cross-contamination and prepare equipment for future use.
Environmental cleanup	Use specialized absorbents to remove residual ammonia from affected surfaces and water bodies.	Mitigate long-term environmental impacts and ensure compliance with regulatory standards.

Key considerations include:

- *Responder decontamination:* Establish clear procedures for handling severe exposure cases, including transport to medical facilities.
- *Waste management:* Treat all contaminated materials as hazardous waste and follow local regulations for disposal.

Effective implementation of response strategies for ammonia spills requires a **step-by-step approach** to ensure efficiency and safety. **Activate immediate response** by initiating **evacuation**, deploying **containment measures**, and utilizing **monitoring tools** to assess ongoing risks. Focus on **equipping responders** with appropriate **PPE** and **spill response kits**, while ensuring they are adequately trained in **equipment usage** and **safety protocols**. **Execute decontamination** by setting up **decontamination stations** for personnel and equipment and safely **neutralizing and disposing of hazardous materials**. Finally, **collaborate regionally** by engaging with neighboring countries and regional teams to share resources and coordinate actions in **cross-border incidents**. By **integrating these strategies**, countries can establish a **comprehensive framework** to effectively manage ammonia spills, protect **human and environmental safety**, and enhance their **preparedness for future incidents5. Strengthening Governance and Policy.**

5. Training and capacity building

Training and capacity building are essential to equip responders with the skills needed to manage ammonia spills effectively. Comprehensive training should cover ammonia's properties, risks, and the procedures necessary for mitigation.

Key training areas include:

Focus Area	Details
Understanding ammonia	Physical and chemical properties, toxicity, and environmental behavior.
Personal safety measures	Proper use of PPE, safe handling practices, and exposure management.
Spill response protocols	Steps for evacuation, containment, neutralization, and decontamination.
Use of equipment	Hands-on training for using gas detectors, booms, pumps, and neutralizing agents.
Coordination	Communication protocols for local and regional response coordination.

Capacity building recommendations includes:

- *Structured taining programs*: include **annual training** sessions combining theoretical and practical exercises, and **scenario-based simulations** for realistic experience.
- *Regional drills*: collaboration with neighboring countries to practice joint responses to large-scale spills.
- *Technology integration*: use of VR and AR tools for immersive training experiences.
- *Knowledge dissemination*: develop local expertise by training a core team of responders to act as trainers.

Resources for training, among others, includes:

Resource	Purpose
IMO guidelines	International standards for ammonia spill response.
GESAMP[1] reports	Global reports on environmental impact assessments of hazardous material spills.
REMPEC modules	Regional training resources specific to hazardous material spills.
CAMEO chemicals tool[2]	Virtual tool for scenario planning and risk assessment.
Specialized workshops	Courses on ammonia spill response by organizations like SIGTTO[3] and IPIECA[4].
Chemical Safety Data Sheets	Comprehensive details on ammonia handling and exposure management.
MIDSIS-TROCS[5]	A decision-support system developed by REMPEC to assist maritime authorities and responders in managing chemical spills, offering tools for risk assessment, emergency response, and environmental impact mitigation.

[1] **GESAMP**: The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection – an advisory body that provides scientific assessments and reports on marine pollution, including the environmental impacts of hazardous substances like ammonia

[2] **CAMEO Chemicals Tool**: A software suite developed by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) to support hazardous material response planning, including detailed information on chemical properties, compatibility, and spill scenario modeling.

[3] **SIGTTO**: Society of International Gas Tanker and Terminal Operators – an organization providing best practices and standards for the safe handling of gas, including ammonia, in maritime and terminal operations.

[4] **IPIECA**: International Petroleum Industry Environmental Conservation Association – a global association offering resources and training on oil and gas spill preparedness, with applicable methodologies for ammonia spill response.

[5] Maritime Integrated Decision Support Information System for Transport of Chemical Substances – a system providing decision-making support for the safe transport and emergency management of chemical substances at sea.

GUIDELINES
NATIONAL PREPAREDNESS FOR ACCIDENTAL RELEASES OF LIQUEFIED NATURAL GAS AT SEA

This annex serves as a guideline for Contracting Parties (CPs) to establish preparedness and response systems for accidental releases of Liquefied Natural Gas (LNG) at sea.

1. Understanding Liquefied Natural Gas (LNG): Properties and risks

1.1. Properties of LNG

LNG is increasingly adopted as a marine fuel due to its reduced emissions and compliance with IMO regulations, particularly the 2020 global Sulphur cap. However, LNG's unique cryogenic and chemical properties pose distinct challenges for spill response and emergency preparedness. Key properties of LNG include:

Property	Description
State	LNG is a cryogenic liquid stored at −260°F (−162°C) at atmospheric pressure, transforming natural gas into a denser liquid.
Density	Lighter than water (~0.45 specific gravity) and initially heavier than air as vapor at cryogenic temperatures.
Vaporization	Rapidly vaporizes when exposed to ambient heat, expanding approximately 600 times its liquid volume.
Visibility	Creates a visible, ground-hugging vapor cloud due to atmospheric condensation, but vapor becomes buoyant when warmed.
Non-toxic nature	LNG is odorless, colorless, and non-toxic but can displace oxygen, leading to asphyxiation risks in confined spaces.
Flammability	Vapors are flammable at concentrations of 5%-15% in air but are not explosive in unconfined spaces.

1.2. Risks of accidental releases of LNG

Accidental releases of Liquefied Natural Gas (LNG) into the environment pose distinct risks due to its unique properties. Understanding these risks is essential for developing targeted emergency response and mitigation strategies. Key risks of LNG spills include:

Risk	Description
Flammability	LNG vapors ignite when mixed with air at concentrations between 5%–15%, posing risks of flash fires or vapor cloud fires. Ignition in confined or semi-confined spaces can lead to significant safety hazards, especially for responders and nearby populations.
Cryogenic damage	The extremely low temperatures of LNG (-162°C) can cause severe cold burns on contact with human skin. Materials like carbon steel may become brittle and lose integrity, increasing risks to vessels, port structures, or equipment exposed to the spill.
Asphyxiation	LNG vapors displace oxygen in confined or poorly ventilated spaces, creating a high risk of suffocation for responders and individuals in close proximity to the spill.
Vapour cloud formation	Upon vaporization, LNG forms dense, ground-hugging clouds, especially in cold or calm weather. These clouds can drift significant distances, posing risks of delayed ignition and extended hazard zones.

Environmental impact	While LNG is non-toxic and evaporates quickly, its sudden vaporization may cause localized temperature drops, leading to ice formation on water surfaces. These temperature shifts can harm marine organisms and disrupt local ecosystems in the immediate area.

Key insights:

- *Cryogenic hazards and material vulnerability:* The extreme cold of LNG (-162°C) poses severe challenges, including frostbite risks to humans and embrittlement of critical structures and equipment, such as carbon steel. Responders require specialized cryogenic PPE to ensure safety.
- *Rapid vaporization and dispersion:* LNG's rapid vaporization and expansion (1:600 ratio) create dense, ground-hugging vapor clouds, which complicate detection, monitoring, and containment. Wind conditions further influence vapor cloud dynamics, making response strategies highly dependent on real-time environmental factors.
- *Flammability risks:* LNG vapors are flammable at concentrations between 5%-15% in air. Any ignition can lead to intense flash fires, posing radiant heat hazards to responders and nearby infrastructure. Immediate elimination of ignition sources is critical.
- *Lack of residual containment:* Unlike conventional fuel spills, LNG spills leave no physical residue for traditional recovery methods like booms and skimmers. This necessitates a focus on vapor monitoring, containment, and dispersal using advanced tools such as water curtains and high-expansion foams.
- *Localized environmental impacts:* While LNG spills evaporate quickly, localized thermal impacts, such as freezing of seawater or marine habitats, can disrupt ecosystems. Fire hazards further amplify risks to coastal vegetation and structures

2. Risk assessment framework for LNG spills

A comprehensive risk assessment framework is crucial for CPs to manage the impacts of LNG spills effectively, ensuring the safety of ship crew and responders, minimizing environmental harm, and protecting critical infrastructure. The framework integrates scenario identification, vulnerability mapping, and hazard modeling to enhance preparedness and response.

2.1. Scenario identification

Identifying potential LNG spill scenarios is vital for targeted response strategies. Key scenarios include:

- *Bunkering spills:* LNG transfer operations at ports or anchoring areas may face equipment malfunctions or human errors, leading to spills. These incidents risk fire outbreaks and cryogenic exposure for responders, while damaging port infrastructure and berthing facilities.
- *Tank Breaches:* Collisions or structural failures during LNG transport or storage can release significant quantities of LNG. These breaches may compromise vessel integrity, port equipment, and adjacent infrastructure, while exposing ship crew and responders to cryogenic burns and fire hazards.

- *Pipeline ruptures:* LNG transfer pipelines are susceptible to corrosion, natural disasters, or mechanical impact, resulting in pressurized LNG discharges. These incidents can damage loading/unloading systems, disrupt port operations, and endanger responders from vapor cloud ignition and thermal effects.

Consideration: Emergency protocols must include isolating spill sources, assessing structural damage to critical infrastructure, and deploying safety measures to protect responders from vapor exposure and radiant heat.

2.2. Vulnerability mapping

Mapping vulnerable zones helps prioritize protection for sensitive areas, responders, and infrastructure. Key vulnerable areas include:

- *Ports and terminals:* Central hubs for LNG operations face high spill risks. Structural damage to loading arms, storage tanks, and berths can disrupt operations, while spills expose responders to hazardous conditions.
- *Sensitive ecosystems:* Coastal habitats like mangroves, coral reefs, and wetlands are vulnerable to thermal and cryogenic impacts. Infrastructure, such as aquaculture facilities near these ecosystems, may also sustain long-term damage.
- *Coastal communities:* Proximity to spills may expose populations to flammable vapor clouds and radiant heat. Infrastructure supporting these communities, such as water treatment plants and transportation systems, may also face operational risks.

Consideration: Vulnerability mapping should highlight infrastructure critical for spill response (e.g., firefighting systems, evacuation routes) and ensure access to staging areas for responders equipped with cryogenic protective gear.

2.3. Hazard modelling

Hazard modeling provides a scientific basis for predicting LNG spill behavior and impacts, enabling informed response planning. Advanced modeling tools simulate key aspects of LNG spills, including:

Modeling tool	Purpose
Dispersion models	Simulate vapor cloud formation and spread based on wind, currents, and temperature, aiding in containment planning.
Thermal impact models	Predict the radiant heat and potential damage zones from LNG fires, guiding evacuation and exclusion zone establishment.
Impact assessment tools	Evaluate risks to marine biodiversity and infrastructure to prioritize response resources.

Consideration:

- Real-time data integration improves the accuracy of hazard models, supporting rapid decision-making.
- Ecological impact assessments inform long-term restoration strategies and resource allocation.

- Scenario-based simulations optimize equipment deployment and enhance regional collaboration.

3. Monitoring and detection systems for LNG spills

Effective monitoring and detection systems are critical for identifying and managing the impacts of LNG spills, ensuring rapid response to mitigate environmental damage, protect responders, and minimize risks to infrastructure. By leveraging advanced technologies and continuous monitoring, CPs can develop an integrated and precise approach to LNG spill response.

3.1. Detection technologies

State-of-the-art detection technologies provide accurate, real-time insights into the location, extent, and behavior of LNG spills, enabling targeted response actions.

Technology	Description	Application
Remote sensing	Drones and satellites equipped with imaging and gas sensors to track vapor clouds and temperature changes in real time.	Enables large-scale mapping of LNG spill areas and monitoring of vapor cloud dispersion.
In-situ sensors	Cryogenic and hydrocarbon detectors installed on buoys and at spill sites to monitor LNG presence and vapor behavior.	Provides localized, continuous data on cryogenic temperatures and vapor concentrations near spills.

3.2. Air and water quality monitoring

Monitoring air and water quality is essential to assess environmental impacts and ensure the safety of responders and nearby communities.

Parameter	Monitoring Purpose
Methane levels	Real-time measurement of methane concentrations in the air to evaluate fire risks and responder safety.
Water temperatures	Monitoring rapid temperature drops to detect localized ecological disruptions caused by LNG vaporization.
Dissolved methane	Regular water sampling to assess underwater gas concentrations and potential risks to marine ecosystems.

Implementation:

- Deploy mobile monitoring units in spill zones to provide immediate air and water quality analysis.
- Combine automated systems (e.g., buoys with methane sensors) with manual sampling for a comprehensive assessment of real-time environmental and safety impacts.

3.3. Advanced surveillance technologies

Advanced surveillance systems enhance situational awareness, particularly for large-scale or remote LNG spill scenarios, by providing actionable intelligence in real-time.

Tool	Capabilities	Applications
Drones	Quick deployment for high-resolution imaging and vapor cloud tracking in hard-to-reach areas.	Guides response teams in assessing spill zones and monitoring mitigation efforts.
Satellites	Wide-area monitoring of vapor clouds, spills, and thermal changes over time.	Useful for cross-border spills and assessing long-term impacts in regional maritime zones.
Thermal imaging	Detects cryogenic spills and surface temperature changes in low-visibility conditions.	Effective for nighttime operations, spills in extreme weather, or near sensitive habitats.
Acoustic sensors	Identifies underwater leaks and subsurface gas plumes by analyzing soundwave patterns.	Detects hidden spills and guides response strategies for subsurface contamination.

Key considerations for LNG spill monitoring:

- *Integration of technologies:* Combining remote sensing, in-situ sensors, and advanced surveillance ensures a comprehensive and layered monitoring approach.
- Responder safety: Continuous monitoring of methane levels and cryogenic hazards is essential to protect responders from vapor exposure and frostbite.
- *Infrastructure protection:* Early detection of vapor clouds and subsurface gas plumes minimizes risks to port facilities and vessels.
- *Real-time data utilization*: Leveraging real-time data enhances decision-making and accelerates the deployment of mitigation resources.

4. Response strategies for LNG spills

Developing a comprehensive response strategy is essential for mitigating the environmental, economic, and safety impacts of LNG spills. This section outlines immediate actions, specialized equipment, and decontamination procedures, with a focus on the unique challenges posed by LNG’s cryogenic and flammable properties.

4.1. Immediate actions

Swift and effective actions during the initial phase of an LNG spill are critical to limiting environmental damage, protecting responders, and ensuring safety. These steps prioritize containment, fire prevention, and minimizing vapor dispersion.

Action	Description	Purpose
Containment	Deploy floating booms or barriers around the LNG spill area to prevent the spread of vapor clouds.	Minimize vapor cloud formation and protect sensitive marine and coastal zones.
Vapor suppression	Use water curtains to disperse LNG vapor clouds and promote faster dilution.	Reduce the risk of ignition and protect nearby populations or infrastructure.
Evacuation plan	Establish exclusion zones and evacuate personnel from downwind areas to ensure safety.	Prevent injuries from cryogenic burns or inhalation of high methane concentrations.

Considerations:

- Pre-positioning of booms and water curtain systems in high-risk areas ensures rapid deployment.
- Evacuation plans must consider the rapid spread of vapor clouds and potential ignition sources.

4.2. Specialized equipment

The effectiveness of LNG spill containment and response depends heavily on the availability of proper equipment tailored to LNG's cryogenic and vaporization characteristics.

Equipment	Description	Application
Cryogenic PPE	Thermal-resistant suits, gloves, and respiratory gear designed for cryogenic exposure.	Protect responders from frostbite and inhalation hazards.
Water curtain systems	High-capacity water spray systems that break up vapor density and disperse LNG vapor clouds.	Minimize vapor hazards and reduce the risk of ignition.
Advanced sensors	Gas detectors and thermal imaging cameras to monitor vapor cloud movement and detect flammable concentrations.	Ensure real-time situational awareness during response efforts.

Implementation:

- Ensure cryogenic PPE is accessible to all responders working near LNG spills.
- Use water curtain systems in combination with gas detectors to precisely target and neutralize vapor hazards.

4.3. Decontamination and rehabilitation

Post-spill cleanup and rehabilitation efforts are vital for restoring affected areas and minimizing long-term environmental disruption.

Target	Procedure	Purpose
Marine life	Temporarily relocate marine species from affected areas and use controlled heating to reverse temperature impacts.	Mitigate thermal shocks and restore local ecosystems.
Port infrastructure	Inspect and repair LNG handling systems, pipelines, and tanks affected by cryogenic exposure.	Ensure safe resumption of operations and prevent secondary accidents.
Vapor hazards	Use thermal systems to manage residual cryogenic effects on land or water surfaces.	Minimize risks to personnel and equipment during rehabilitation.

Key considerations:

- Thermal remediation is essential to address localized freezing or ice formation caused by LNG spills.
- Coordination with environmental agencies ensures the safe handling of marine species and affected habitats.

5. Strengthening governance and policy for LNG spill preparedness

Effective governance and comprehensive policy frameworks are vital to improving CPs preparedness and response to LNG spills. Unlike traditional fuel spills, LNG spills require specific approaches that account for its unique cryogenic and vaporization properties.

5.1. Regulatory enhancements

Regulatory frameworks should be updated to address the unique risks posed by LNG spills, including fire hazards, vapor cloud dispersion, and cryogenic damage.

- LNG-specific spill contingency plans for vessels and ports should include detailed risk assessments of LNG transfer and storage operations, clear protocols for ignition source elimination and evacuation zones, and inventories of fire suppression systems, water curtains, and cryogenic PPE.
- Standardized reporting and communication systems should be established by CPs and their national authorities to ensure timely and coordinated responses to LNG spills. These systems should facilitate real-time communication between stakeholders and maintain centralized databases for tracking LNG incidents and response outcomes.
- Emergency Shutdown Systems onboard ships and from port sides are of prime importance. Mandating automated emergency shutdown systems for LNG transfer and storage facilities is critical to minimizing vapor release during incidents.

Consideration: LNG-specific regulatory measures must align with international frameworks, such as IMO guidelines, to ensure consistency and effectiveness across jurisdictions.

5.2. Safety measures for LNG terminals and vessels

LNG terminals and vessels play a critical role in minimizing risks associated with LNG spills. Tailored measures for these facilities include:

- *Designated transfer zones:* Establish controlled zones equipped with advanced monitoring systems, such as infrared detectors and hydrocarbon sensors, to detect spills and potential ignition risks.
- *Stockpiling response kits:* LNG spill response kits should include cryogenic PPE for responders to prevent frostbite or other cold-related injuries, and water curtains and high-expansion foam systems to manage vapor dispersion and suppress fires.

- *Training and drills:* Personnel at LNG terminals and onboard vessels must receive regular training in handling cryogenic materials and fire suppression techniques, and training on advanced spill response strategies, such as vapor cloud modeling and containment.

5.3. Regional collaboration

Collaboration among neighbouring CPs is essential for effectively managing cross-border LNG spill incidents and ensuring the efficient use of shared resources. Scenario-based regional drills should be conducted regularly to test coordination between CPs, improve readiness, and identify any gaps in response capabilities. These drills help build a shared understanding of procedures and foster better communication among stakeholders.

Maintaining an updated inventory of shared response equipment, technical expertise, and facilities under frameworks of the REMPEC is crucial. This ensures that resources can be quickly mobilized during emergencies, enabling a collective response to mitigate environmental and economic impacts.

To support these efforts, bilateral or multilateral agreements are of prime importance in facilitating the rapid sharing of resources and expertise during spill events. Additionally, Regional database of LNG scientific studies, along with documented case studies of spill responses, will enhance collective knowledge and improve preparedness across the entire region. This collaborative approach strengthens the overall capacity to manage LNG spills effectively.

6. Training and capacity building for LNG spill preparedness

Training and capacity building are essential for equipping responders with the skills and knowledge to effectively manage the unique challenges of LNG spills. Given LNG's cryogenic properties, rapid vaporization, and associated hazards, specialized training programs must focus on both safety and operational efficiency. Key training areas for LNG spill response includes:

Focus Area	Details
Understanding LNG	Cryogenic and chemical properties, vaporization behavior, flammability, and environmental impacts.
Personal safety measures	Safe handling practices, proper use of cryogenic PPE, and management of risks such as asphyxiation and frostbite.
Spill response protocols	Procedures for ignition source elimination, containment, vapor dispersion, and mitigation of cryogenic hazards.
Use of specialized equipment	Practical training on water curtains, high-expansion foam systems, gas detectors, and thermal imaging tools.
Coordination and communication	Effective protocols for collaboration among local, national, and regional response teams.

Capacity building recommendations for CPs:

- Conduct annual training sessions combining theoretical knowledge with hands-on exercises.
- Include scenario-based simulations tailored to LNG spill scenarios, such as vapor cloud dispersion and fire suppression.
- Organize collaborative drills with neighboring CPs to simulate large-scale or cross-border LNG incidents.
- Test coordination frameworks, communication protocols, and shared resource mobilization.
- Employ Virtual Reality (VR) and Augmented Reality (AR) tools to create immersive training experiences for responders.
- Simulate real-world scenarios like cryogenic burns or vapor cloud behavior to improve readiness.
- Develop a core group of LNG spill response experts to act as trainers in their respective regions.
- Establish knowledge-sharing platforms to disseminate best practices and lessons learned from previous incidents.

ANNEX V. MAPPING OF CURRENT STUDY ACTION PLAN TO THE MEDITERRANEAN STRATEGY 2022–2031

This annex maps the actions proposed in the current study to the Mediterranean Strategy 2022–2031 to ensure alignment and avoid duplication. The annex highlights how the study complements and supports the strategy's objectives, fostering a coordinated approach to marine pollution prevention, preparedness, and response in the Mediterranean.

Area of influence		Action in the Med Strategy 2022-2031	Current study actions to Implement
People	1.1. Networks 1.1. Networks	1.1.1. To maintain and actively participate in the MENELAS, the Mediterranean Technical Working Group (MTWG), the Clean/SeaNet National Competent Authorities (CSN NCAs), and the Mediterranean AIS Experts Working Group (MARE∑ EWG).	S20. Develop a roster of experts in hazardous materials, marine chemistry, and environmental protection L13. Create permanent regional panels of scientific and technical experts to guide policy development and support incident response L14. Ensure the advisory panels regularly review and update response protocols based on new findings
		1.1.2. To capitalize on experience and on knowledge available in other sectors.	M3. Integrate best practices and lessons learned into updated guidelines. L18. Use feedback from drills and incidents to continuously improve regional frameworks and protocols
		1.1.3. To strengthen synergies between relevant networks including IMO Sub-Committee on Pollution Prevention and Response (PPR).	M2. Coordinate between REMPEC and CPs to ensure harmonization of protocols across the Mediterranean S8. Establish cross-border coordination mechanisms L10. Strengthen partnerships between governments, NGOs, private sector entities, and research institutions
		1.1.4. To foster peer learning (exchange of experts and meeting)	S20. Develop a roster of experts in hazardous materials, marine chemistry, and environmental protection L13. Create permanent regional panels of scientific and technical experts to guide policy development and support incident response L14. Ensure the advisory panels regularly review and update response protocols based on new findings
	1.2 Capacity Building / Technical Cooperation	1.2.1. To increase as much as practical, the level of knowledge in the field of preparedness and response to accidental marine pollution by oil and other harmful substances by delivering trainings on specified subjects.	S17. Train personnel in spill response M5. Train and certify additional personnel to operate response hubs effectively L4. Establish permanent training centres to provide continuous professional development for responders L5. Update training modules regularly to reflect advancements in spill response technologies and alternative fuel management L6. Ensure regional certifications for responders are maintained and aligned with international standards.

		1.2.2. To attend workshops, seminars and trainings offered by REMPEC, EMSA and other established networks addressing other topics.	S17. Train personnel in spill response S18. Facilitate annual or biennial workshops focusing on alternative fuel spill protocols M5. Train and certify additional personnel to operate response hubs effectively
		1.2.3. To develop and implement (in cooperation with the chemical industry) multi-sectoral training and contingency planning in case of chemical pollution at sea, for decision makers, citizens and volunteers, on-shore responders, and port authorities.	S17. Train personnel in spill response S26. Hold public consultations to integrate local concerns into response planning M5. Train and certify additional personnel to operate response hubs effectively L19. Collaborate with the private sector to develop next-generation spill response tools and eco-friendly technologies
		1.2.4. To increase awareness on and use of (if needed), the services offered by EMSA in support of the transposition, implementation, and Enforcement following the Ratification of International Conventions including IMSAS within the framework of the SAFEMED project, including the enforcement and implementation of environment related international and European legislation.	S2. Ratify and transpose key IMO conventions S14.Provide technical assistance and capacity building for enforcement S23. Launch awareness campaigns on alternative fuel risks L3. Ensure consistent enforcement across the region
		1.2.5. To develop an e-learning platform on the prevention, preparedness and response to marine pollution	M9. Develop certification programs to ensure responders meet standardized proficiency levels in managing alternative fuel spills M10. Align certifications with international standards such as EUROWA model courses
		1.2.6. To enhance number of REMPEC Mediterranean Assistance Units (MAU) creating a network within MAU and CPs through REMPEC	S21. Expand the network of REMPEC Mediterranean Assistance Units (MAUs)
	1.3 Operations	1.2. To organise annual / biennial national exercises (standard, tabletop; communications) to test national response capabilities, cooperation and mutual assistance between Contracting Parties, REMPEC Mediterranean Assistance Unit (MAU), EMSA pollution response services (where applicable), private sector drills, etc.	S18. Facilitate annual or biennial workshops focusing on alternative fuel spill protocols S19. Conduct scenario-based drills in collaboration with REMPEC, EMSA, and private sector stakeholders S21. Expand the network of REMPEC Mediterranean Assistance Units (MAUs) S25. Involve communities in drills and simulation exercises M6. Organize biennial cross-border exercises involving multiple CPs, REMPEC, and EMSA M7. Test communication channels, resource-sharing frameworks, and response coordination M8. Include drills for handling large-scale incidents involving alternative fuels

			M17. Develop standardized protocols for requesting and providing cross-border assistance L10. Strengthen partnerships between governments, NGOs, private sector entities, and research institutions L17. Implement regular drills, incident reviews, and simulation exercises to test and refine response mechanisms
		1.3.2. To organize sub-regional / regional / international exercises to test cooperation arrangements	M7. Test communication channels, resource-sharing frameworks, and response coordination
		1.3.3. To develop and implement a process to capture lessons identified during real accidents and exercises and to integrate the follow-up in relevant trainings and subsequent exercises	S17. Train personnel in spill response S25. Involve communities in drills and simulation exercises M3. Integrate best practices and lessons learned into updated guidelines L18. Use feedback from drills and incidents to continuously improve regional frameworks and protocols
		1.3.4. To develop a framework for holistic integrated management of marine pollution incidents that enable a coordinated preparedness and response operation at sea and onshore, incorporating the response to oil affected wildlife, at a national level and in the region-wide cooperation	S1. Establish national implementation committees S15. Identify high-risk zones for pollution incidents L2. Conduct periodic reviews to ensure frameworks remain up-to-date with emerging technologies and global best practices
		1.3.5. To establish systems and procedures for national and sub-regional monitoring and surveillance including regular individual or Coordinated Aerial Surveillance Operation for illicit ship pollution discharges in the Mediterranean (OSCAR-MED) in the waters under the jurisdiction of CPs, if the CPs so agree, and results reported to the Meeting of MENELAS	S13. Leverage advanced monitoring technologies L7. Fully deploy AI-powered tools, real-time monitoring systems, and predictive models for spill response L8. Use advanced fuel dispersion models to simulate and predict the behavior of alternative fuel spills L9. Integrate these tools with regional traffic control centres for better coordination
		1.3.6. To increase awareness and facilitate the use of Earth Observation services and RPAS services developed and offered by EMSA	S23.Launch awareness campaigns on alternative fuel risks
		1.3.7. To facilitate the use of EMSA maritime application as platform to exchange AIS information that is shared by the MAREΣ participating countries	M22.Develop platforms for sharing incident data, lessons learned, and response protocols among CPs
		1.3.8. To organise and follow-up analysis of concentrated inspection campaigns on MARPOL-related deficiencies	S11.Enhance inspection procedures for alternative fuels
		1.3.9. To make use of the data collected under THETIS-MeD database to produce meaningful statistics in relation to MARPOL related deficiencies	M14. Ensure the database is regularly updated and accessible to all stakeholders
Institution	1.4 Governance	1.4.1. To strengthen the capacity of individual coastal States to respond efficiently to marine pollution incidents at sea and onshore through the	S8. Establish cross-border coordination mechanisms S15. Identify high-risk zones for pollution incident

		establishment and the update of national system for responding to marine pollution, the development and update of national contingency plan (NCP) and sub-regional operational agreements and contingency plans	
		1.4.2. To set-up an operational network of Subregional Contingency Plans (SCP), and to define and implement synergy activities between the SCPs	S2. Ratify and transpose key IMO conventions S3. Review and update national contingency plans to incorporate alternative fuel response strategies S5. Establish prosecution mechanisms for non-compliance S6. Ensure consistent enforcement and compliance M2. Coordinate between REMPEC and CPs to ensure harmonization of protocols across the Mediterranean
		1.4.3. To extend the mandate of SCP to address prevention of pollution from ships	
		1.3. To set-up the modalities of possible creation and operation, including in terms of governance and financing of a regional "Blue Fund"	L24. Establish a regional fund under REMPEC (Blue Fund) for compensating pollution damages by, inter alia, alternative fuels
	1.5 Ratification / Transposition	1.5.1. To ratify and implement the following legal instrument, to ensure their transposition into national law, and to cooperate to ensure full compliance with their provisions: a) the Protocol concerning Cooperation in Preventing Pollution from Ships and, in Cases of Emergency, Combating Pollution of the Mediterranean Sea, ("2002 Prevention and Emergency Protocol")	M2. Coordinate between REMPEC and CPs to ensure harmonization of protocols across the Mediterranea
	1.6 Implementation	1.6.1. To undertake the IMO Member State Audit Scheme (IMSAS), using the III Code as the audit standard and following the Framework and Procedures for the IMO Member State Audit Scheme and implemented corrective measures to address identified gaps	L1. Finalize the alignment of national and regional regulatory frameworks with international standards
	1.7 Enforcement	1.7.1. To set-up a national legal framework (regulations) as a basis for prosecuting discharge offenders for infringements of MARPOL Annex I, II, III and IV	S5. Establish prosecution mechanisms for non-compliance S12. Establish robust legal framework
		1.7.2. To use the common marine oil pollution detection / investigation report	M11. Implement advanced spill detection technologies, such as satellite monitoring, drones, and predictive modelling tool S13. Leverage advanced monitoring technologies M12. Integrate real-time data with decision-support systems like THETIS-MED and MEDGIS-MAR M22. Develop platforms for sharing incident data, lessons learned, and response protocols among CPs
		1.7.3. To apply criteria for a common minimum level of fines for each offense provided for under MARPOL Annex I, II, III and IV (without prejudice to the	S4. Provide incentives to promote compliance and deterrent penalties for violations/infractions S5. Establish prosecution mechanisms for non-compliance

		sovereign right of each State to freely define the level of fines for infringements taking place within its jurisdiction)	S6. Ensure consistent enforcement and compliance
		1.7.4. To set-up the modalities of possible creation and operation, including in terms of governance and financing of a regional "Blue Fund" (Refer to action 1.4.4)	L24. Establish a regional fund under REMPEC (Blue Fund) for compensating pollution damages by, inter alia, alternative fuels
		1.7.5. To improve effectiveness of the Memorandum of Understanding (MoU) on port State Control (PSC) in the Mediterranean region (Mediterranean MoU) and to facilitate cooperation between the Paris MoU and the Mediterranean MoU	S6. Ensure consistent enforcement and compliance
Infrastructure	1.8 Port Reception Facilities	1.8.1. To provide adequate reception facilities in Mediterranean ports, enabling their use as soon as they are available at a fee which should be reasonable and should not serve as a disincentive for those ships that use them for disposal of: a) oily wastes b) Noxious Liquid Substances (NLS) c) sewage	M15. Upgrade existing response hubs with specialized equipment for alternative fuel spills M4. Upgrade existing response hubs with specialized equipment for alternative fuel spills M16. Establish regional resource networks for rapid deployment of equipment and personnel during incidents L15. Develop a Mediterranean-wide inventory of response resources, including personnel, equipment, and expertise
	1.9 Alternative Energy / New Technologies	1.9.1. To follow-up on international development on response techniques to alternative fuel spills and provide necessary guidance and capacity building to CPs	S7. Standardize spill response protocols S9. Integrate innovative response techniques M11. Implement advanced spill detection technologies, such as satellite monitoring, drones, and predictive modeling tool
	1.10 Response Means	1.10.1. To have and maintain adequate oil and / HNS pollution response capabilities (both in human resources and equipment)	S16. Allocate basic equipment stockpiles M4. Upgrade existing response hubs with specialized equipment for alternative fuel spills M16. Establish regional resource networks for rapid deployment of equipment and personnel during incidents M20. Use Environmental Sensitivity Indexes (ESIs) to prioritize resources for protecting sensitive ecosystems L15. Develop a Mediterranean-wide inventory of response resources, including personnel, equipment, and expertise L16. Ensure the inventory database is fully integrated with decision-support tools and accessible to all stakeholders
		1.10.2. To establish a pool of oil and HNS pollution response means at sub-regional and regional level	S20. Develop a roster of experts in hazardous materials, marine chemistry, and environmental protection M13. Develop a centralized inventory of equipment, personnel, and expertise available across CPs M16. Establish regional resource networks for rapid deployment of equipment and personnel during incidents L15. Develop a Mediterranean-wide inventory of response resources, including personnel, equipment, and expertise

		1.10.3. To raise awareness on the EMSA pollution response services available in the Mediterranean	S23. Launch awareness campaigns on alternative fuel risks S24. Conduct community awareness campaign
	1.11 Surveillance / Monitoring Means	1.11.1. To have and maintain adequate surveillance and monitoring capabilities	S13. Leverage advanced monitoring technologies L7. Fully deploy AI-powered tools, real-time monitoring systems, and predictive models for spill response L8. Use advanced fuel dispersion models to simulate and predict the behavior of alternative fuel spills L9. Integrate these tools with regional traffic control centers for better coordination
		1.11.2. To increase awareness on the Earth Observation services developed and offered by EMSA and on the EMSA RPAS services for surveillance 1.11.3. To increase awareness on the AIS based traffic monitoring services offered by EMSA (e.g., SafeSeaNet Ecosystem Graphical User Interface (SEG) and the regional cooperation entities (e.g., Mediterranean regional AIS server (MAREΣ))	S23. Launch awareness campaigns on alternative fuel risks L7. Fully deploy AI-powered tools, real-time monitoring systems, and predictive models for spill response L8. Use advanced fuel dispersion models to simulate and predict the behavior of alternative fuel spills L9. Integrate these tools with regional traffic control centers for better coordination
		1.11.4. To set up a common emergency communication system for the whole Mediterranean	S22. Develop clear communication plans for informing the public about pollution incidents and safety measures L7. Fully deploy AI-powered tools, real-time monitoring systems, and predictive models for spill response L8. Use advanced fuel dispersion models to simulate and predict the behavior of alternative fuel spills L9. Integrate these tools with regional traffic control centers for better coordination
Information and knowledge sharing	1.12 Standards / Guidelines	1.12.1. To promote, disseminate and revise the existing recommendations, principles and guidelines, to develop new ones aimed at facilitating the implementation of the 2002 Prevention and Emergency Protocol, MARPOL (Annex I, Annex II, Annex III, Annex IV), OPRC Convention, OPRC-HNS Protocol, CLC Convention, BUNKER Convention, The 2010 HNS Protocol	M1. Finalize regional guidelines for alternative fuel spill management, focusing on containment, mitigation, and recovery M2. Coordinate between REMPEC and CPs to ensure harmonization of protocols across the Mediterranean M22. Develop platforms for sharing incident data, lessons learned, and response protocols among CPs
		1.12.2. To consider regional host nation support guidelines (alternatively a dedicated chapter could be included in the Mediterranean Guide on Cooperation and Mutual Assistance)	M1. Finalize regional guidelines for alternative fuel spill management, focusing on containment, mitigation, and recovery M17. Develop standardized protocols for requesting and providing cross-border assistanc
		1.12.3. To apply existing and new guidelines in particular: a) Guide for Combating Accidental Marine Pollution in the Mediterranean Sea (REMPEC, 2000) b) Guidelines for the use of dispersants for	M1. Finalize regional guidelines for alternative fuel spill management, focusing on containment, mitigation, and recovery

		combating oil pollution at sea in the Mediterranean region (REMPEC, 2011)	
	1.13 Decision Making Tools	1.13.1. To improve the quality, speed and effectiveness of decision-making process through the maintenance, update, upgrade, development and inter-connection of technical and decision support tools, including: a) Barcelona Convention Reporting System (BCRS) b) REMPEC Country Profile	M12. Integrate real-time data with decision-support systems like THETIS-MED and MEDGIS-MAR M15. Link the database with decision-support tools for efficient resource allocation M21. Incorporate Environmental Sensitivity Indexes (ESIs) into decision-support tools for strategic response planning M23. Regularly update stakeholders and the public on response efforts and environmental impacts L16. Ensure the inventory database is fully integrated with decision-support tools and accessible to all stakeholders
		1.13.2. To update country specific information on existing and new decision support tool notably the BCRS, REMPEC Country Profile, MENELAS Information system, MEDGIS-MAR, Waste Management and CECIS	M12. Integrate real-time data with decision-support systems like THETIS-MED and MEDGIS-MAR M15. Link the database with decision-support tools for efficient resource allocation M21. Incorporate Environmental Sensitivity Indexes (ESIs) into decision-support tools for strategic response planning L16. Ensure the inventory database is fully integrated with decision-support tools and accessible to all stakeholders
		1.13.3. To establish a system of notification to a vessel's next port of call of the status of its on-board retention of bilge waters, oily wastes, HNS residues, sewage, garbage, ozone-depleting substances and exhaust gas cleaning residues	M12. Integrate real-time data with decision-support systems like THETIS-MED and MEDGIS-MAR M15. Link the database with decision-support tools for efficient resource allocation M21. Incorporate Environmental Sensitivity Indexes (ESIs) into decision-support tools for strategic response planning L16. Ensure the inventory database is fully integrated with decision-support tools and accessible to all stakeholders
	1.14 Monitoring and Reporting Obligations	1.14.1. To ensure compliance with reporting obligations under the Barcelona Convention and the 2002 Prevention and Emergency Protocol by reporting measures undertaken through the BCRS and inter-linked reporting databases, such as the IMAP and MEDGIS-MAR, notably: a) All incidents;	M2. Coordinate between REMPEC and CPs to ensure harmonization of protocols across the Mediterranean M14. Ensure the database is regularly updated and accessible to all stakeholders
		1.14.2. To comply with IMO reporting requirement (SOLAS, MARPOL, OPRC-90 & OPRC-HNS Protocol) notably: a) Mandatory reporting system under MARPOL (MEPC/Circ.318) b) Condition Assessment Scheme	S10. Implement a system for continuous review and dissemination
		1.14.3. To update MEDGIS-MAR with national inventory of response equipment	S10. Implement a system for continuous review and dissemination S16. Allocate basic equipment stockpiles

			M4. Upgrade existing response hubs with specialized equipment for alternative fuel spills M13. Develop a centralized inventory of equipment, personnel, and expertise available across CPs M16. Establish regional resource networks for rapid deployment of equipment and personnel during incidents M23. Regularly update stakeholders and the public on response efforts and environmental impacts
		1.14.4. To further streamline reporting procedures	M23. Regularly update stakeholders and the public on response efforts and environmental impacts
	1.15 Research and Development	1.15.1. To provide assistance to regional institutions and industry in identifying fields of research in which there is a need for enhancement of the state-of-the-art of marine pollution prevention, preparedness and response technologies and techniques	S9. Integrate innovative response techniques M11. Implement advanced spill detection technologies, such as satellite monitoring, drones, and predictive modelling tools M17.Develop standardized protocols for requesting and providing cross-border assistance M19. Conduct collaborative research on the environmental impacts of alternative fuels L19. Collaborate with the private sector to develop next-generation spill response tools and eco-friendly technologies L20. Co-finance projects that address alternative fuel risks and improve response readiness
		1.15.2. To provide assistance and encourage scientific and technical institutions, as well as industry, to actively participate in research and development activities and programmes related to accidental marine pollution prevention, preparedness and response, and to share systematically the results of their research to all Mediterranean Coastal States	M18.Partner with universities and industries to advance spill response technologies, predictive models, and monitoring tools M19.Conduct collaborative research on the environmental impacts of alternative fuels L4. Establish permanent training centres to provide continuous professional development for responders L10. Strengthen partnerships between governments, NGOs, private sector entities, and research institutions L11. Collaborate on joint initiatives such as habitat restoration, environmental monitoring, and fuel spill mitigation projects L12. Leverage NGOs to enhance public trust and support during pollution incidents L19. Collaborate with the private sector to develop next-generation spill response tools and eco-friendly technologies L20. Co-finance projects that address alternative fuel risks and improve response readiness