ZERO-EMISSION SHIPPING MISSION

APRIL 2022
1ST EDITION

INDUSTRY ROADMAP FOR ZERO-EMISSION SHIPPING

About the Mission

The Zero-Emission Shipping Mission is an ambitious alliance between countries, the private sector, research institutes, and civil society to develop, demonstrate, and deploy zero-emission fuels, ships, and fuel infrastructure together by 2030 and make zero-emission ocean going shipping the natural choice for ship owners. This will lay the foundation for a zero-emission shipping future and accelerate progress towards net zero pathways.

Read more:
http://mission-innovation.net/missions/shipping/

Disclaimer

The Zero-Emission Shipping Mission members and selected industry representatives contributed to the development of this Roadmap through a process that involved a broad set of stakeholders that reached a high level of consensus. Please note that this Roadmap does not represent the views of any specific Mission member country, entity, or organization or their members or the governments they represent.
This Roadmap is intended to support and inform the discussions about the challenges and opportunities related to the green transition for the international shipping sector and its connection to land-based energy infrastructures.

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Executive Summary

International shipping transports most of the world's goods and is responsible for 3% of global emissions, potentially increasing by half by 2050 on its current trajectory. To set international shipping on an ambitious zero emission trajectory, **we need commercially viable, zero-emission ocean-going vessels in the global fleet by 2030**.

Getting to zero emission vessels at sea **involves the entire maritime value chain**, from ship owners to fuel producers to port and terminal operators. In addition, given the international nature of the maritime industry, **international collaboration is required** amongst states, companies, and non-state actors to reach the international climate goals set in the Paris Agreement[1] and in the International Maritime Organization's Initial GHG strategy[2].

The Zero-Emission Shipping Mission is an international public-private innovation alliance that aims to develop, demonstrate, and deploy zero-emission fuels, ships, and fuel infrastructure, activating each part of the value chain to drive forward the decarbonization pathway in this sector. *Public and private sector commitment and collaboration* are key tools for the Mission to achieve its goals and enable the right framework for innovation across the value chain. This collaboration will establish targeted **research, development, and demonstration** (RD&D) activities to address the industry's innovation gaps.

1 to achieve net-zero emissions by 2050, and to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels

2 for greenhouse gas emissions to peak as soon as possible and to reduce shipping's total annual GHG emissions by at least 50% by 2050 compared to 2008.

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To meet its goals, the Mission is organized into three Pillars which lay the foundation for a zero-emission shipping future:

1. **Ships**: By 2030, at least 200 ships primarily use zero emission fuels across main deep sea shipping routes.

2. **Fuels**: By 2030, ships capable of running on hydrogen-based zero-emission fuels such as green hydrogen, green ammonia, green methanol, and advanced biofuels make up at least 5% of the global deep-sea fleet measured by fuel consumption.

3. **Fueling Infrastructure**: By 2030, 10 large trade ports covering at least three continents supply zero emission fuels.

Using the study Innovation needs for the decarbonization of shipping, alongside additional knowledge and engagement, the Mission has identified **5 innovation groups and 120 individual innovation gaps** included in this **Roadmap**. The 5 innovation groups are:

1. **Safety & operational risk management**: innovation needed for safety, guidelines, training, and methodologies for handling and the storage of new fuels

2. **Policy & regulation**: innovation needed for creating or informing regulations or market incentives

3. **Market development, business models & financial innovation**: innovation needed for the economic readiness for new fuels, including novel business models, economic modeling, financial identification of cost drivers, or subsidies and related funding mechanisms

4. **Technology development & adaptation**: innovation needed for the research, development, and deployment of ZEVs, fuels, and infrastructure

5. **Market analysis**: innovation needed the creation, consolidation, and dissemination of market knowledge related to the vessels, fuels, and refueling infrastructure

Engagement with Mission members and selected members of industry provided input and ensured the continuing dialogue across public and private stakeholders around the innovation needs of the industry and national priorities of Mission members. This Roadmap outlines the **existing progress and innovation needs across the industry** to reach the Mission goals.

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It should be noted that this is a temporary viewpoint as **fast-moving innovation work is ongoing** and will deliver solutions to some of the described innovation gaps. The Mission will continue to monitor the innovation needs of the sector and focus its efforts on solving these needs.

To this point, the Mission and its Members are developing an **Action Plan**, building on this Roadmap analysis to outline the practical actions to be taken by Mission members to address the identified innovation gaps and priorities. By focusing on the innovation needs and bringing together public and private stakeholders, **the Mission will foster cross-sector activities and sprints that will speed up innovation**. Potential activities may involve both Mission members and industry, and may include shared research projects, joint demonstrations, and supporting green corridors which enable policy and infrastructure mechanisms to support zero emission shipping.

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The Mission

Launched in June 2021 as part of Mission Innovation 2.0, the **Zero-Emission Shipping Mission** brings together a dynamic and delivery-focused high ambition alliance between countries, the private sector, research institutes, and civil society that seeks to make innovation progress fast enough to **demonstrate zero-emission deep sea shipping by 2030**.

SCOPE

The focus is on the entire value chain: the ship, the fuel production, and the fuel infrastructure at ports to drive the sector to a tipping point in its transition by 2030. The goals are to introduce fit-for-purpose and viable vessels that operate on zero-emission fuels[3] to the global fleet; scale up efficient production of zero-emission fuels; and establish global port infrastructure to support vessels operating on zero-emission fuels.

Based on this focus, the work of the Mission is organized into three Pillars, each with key goals for 2030:

Ships	Fuels	Fueling Infrastructure
New deep-sea ships on zero emission fuels are produced at same price (max +5%) as comparable fossil ships.	Prices (incl. policy support) on some zero emission fuels are at max 10-20% more expensive than fossil fuels.	Large global trade ports need to be able to supply zero-emission fuels for ship owners to use and rely on when investing in ZEVs.
By 2030, at least 200 of these ships to primarily use these zero-emission fuels across the main deep sea shipping routes.	*By 2030, at least 5% of the global deep-sea fleet measured by fuel consumption to be made of ships capable of running on well-to-wake zero-emission fuels.*[4]	*By 2030, 10 large trade ports covering at least three continents supply zero-emission fuels.*

3 The Mission considers ammonia, methanol, advanced biofuels, and hydrogen to be in scope.

4 To put this into context, it is estimated that the overall energy needed for shipping will be 12.9 Exajoules in 2030. 5% of this amounts to 0.64 Exajoules, or 15.8 million tons of heavy fuel oil equivalent. Assuming that the hydrogen-based fuel used is ammonia, to produce it in this amount would require roughly 60 gigawatt of green hydrogen electrolyzer capacity. For additional information, please refer to: Five percent zero emission fuels needed by 2030.

THE MEMBERS

The Mission is driven by our 12 members from around the globe, and co-led by the governments of Denmark, Norway, and the United States, along with the Global Maritime Forum and Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping as industry co-leads.

Co-leads

Denmark
Ministry of Industry, Business and Financial Affairs, Ministry of Climate, Energy and Utilities and Ministry of Foreign Affairs

Norway
Ministry of Climate and Environment

The United States
U.S. Department of Energy

Global Maritime Forum
Representing the Getting to Zero Coalition

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

Core Mission Members

The United Kingdom
Department for Transport

Morocco
Ministry of Energy Transition & Sustainable Development

India
Ministry of Science and Technology

Singapore
Maritime and Ports Authority

Mission Support Group

France
Ministry of the Sea

Ghana
Ghana Maritime Authority

South Korea
Ministry of Trade, Industry and Energy

It is vital that the Mission continues to work together with others who share our ambitious goals, and collaborate with other Missions, like the Green Power Mission and the Clean Hydrogen Mission.

Identifying innovation needs for shipping

A study conducted by Oxford Research and the Danish Technical University "**Innovation needs for the decarbonization of shipping**" provides scientific input to this Roadmap. The aim of the study was to uncover and structure the innovation needs across the value chain to achieve commercially viable zero-emission shipping.

Table 1: Value chain covered in the analysis

Fuel Production	Bunkering infrastructure	Vessel operations
Feedstock provision, Fuel production and facilities	Fuel transport, port and bunkering, storage and supply facilities	Ship design and building, retrofitting, propulsion, fuel storage and safety, emissions, crew and safety management

The analysis used a two-step Delphi approach, which entailed three international expert panels covering the full value chain of international shipping and with representatives from industry and academia in Asia, Europe, and Americas to assess the technological and commercial readiness of zero-emission shipping technologies and identify innovation gaps. The expert panels took place from June to October 2021, and the innovation needs reflect the level of technological and commercial readiness at that time.

Technology Readiness Levels (TRL) and Commercial Readiness Index (CRI)

The study used TRL and an adapted CRI (both globally accepted benchmarking tools) as a standardized way to indicate the technologies' readiness from concept to sailing, and to assess the commercial uncertainty of new technologies.

Green fuel technologies have undergone considerable development already, but there are still significant innovation obstacles. The analysis lists the innovation needs for the decarbonization of international shipping across the value chain. Some innovations are fuel specific, and some are crosscutting and cover all fuels.

Based on the innovation needs, there are **four main conclusions**:

6. **While technologically available, most green fuel technologies are not market ready**.
   Innovation must accelerate the market readiness of vessel technology.

7. **Globally, there is no clear single choice when it comes to zero-emission fuels today.**
   Innovation must stimulate the further development of several fuel options to support a multi-fuel mix future suitable for different modes of operation and geography.

8. **Cross-cutting innovations are essential to address systemic gaps that affect all fuel types.**
   Demonstration projects, fuel and policy standards, and scaling up renewable energy all require innovation.

9. **All three parts of the value chain (fuel production, fueling infrastructure, and vessel design) require fuel-specific innovation at the same time to meet zero-emission targets.**
   Innovation is needed to drive development, demonstration, and deployment of zero-emission vessels, fuels, and fuel infrastructure simultaneously.

Findings of this study were integrated into the wider Roadmap analysis as described in the next section.

Industry Roadmap for Zero-Emission Shipping

Taking the innovation needs identified in the study as a starting point, the Mission conducted thematic Pillar workshops with Mission members in the fall of 2021. The objective was to discuss and prioritize the innovation needs identified in the study and connect the findings to the development of both the Mission's Roadmap and Action Plan.

The sessions focused on integrating key perspectives from ongoing work and priorities in both the public and private sectors, discussing innovation gaps in terms of impact and urgency. **Impactful innovations** are those that will have a large effect on the development and demonstration of the zero-emission shipping value chain. **Urgent innovations** are those that need to be delivered for other important steps in the development and demonstration of zero-emission shipping to be taken.

The workshops and discussions highlighted Pillar-specific priorities and challenges and pointed to specific gaps and opportunities for realizing zero-emission shipping and the goals of the Mission. Through this consultation process, the Mission took the innovation needs presented in the study, and looked for:

- **Similarities and themes** to create specific categories
- **Pillar indicators**, and connections to existing work or national activities
- **Priorities**, in terms of time or national interests
- **Fuel specificities**, if any, for the specific gaps
- **Cross-cutting gaps or measures** to ensure cohesion across the Pillars and across the value chain

The joint findings from the study and Thematic Pillar workshops formed the foundation for the Roadmap. The Mission identified **five Innovation Gap Groups** and **120 Innovation Gaps** to reflect interdependent challenges faced by all three Pillars.

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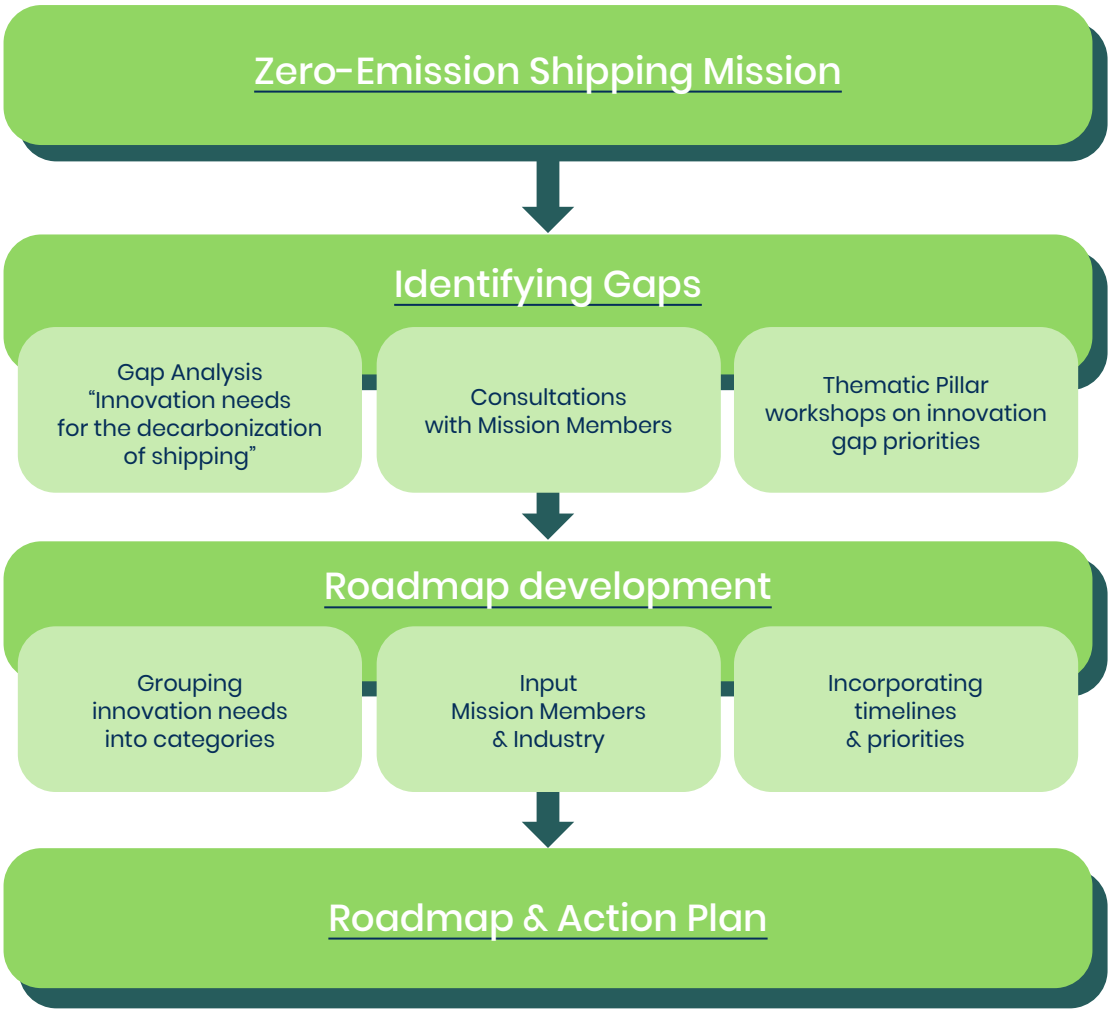

The Roadmap maintains an open and supportive approach toward the four fuel types in scope for the Mission, and focuses on the innovation necessary to address and resolve the differences in the Technology Readiness and Commercial Readiness of the different fuel types, onboard vessel applicability, and the infrastructure needs. In this way, and in the following tables, the Roadmap aims to highlight the gaps to overcome in order to unlock the necessary investment decisions ahead of 2030 to meet the Mission's goals.

The table below presents the five Innovation Gap Groups, their description and scope, and the combined number of innovation gaps for all three Pillars. It is important to note that the content and weight of the Innovation Gap Groups differs per Pillar, and reflects the initial study, input from Mission members and selected industry, and the key challenges faced by the respective actors who have been consulted through this iterative process.

Category	No. innovation gaps	Description
1. Safety & operational risk management	21	Gaps related to safety guidelines, methodologies and procedures for handling or storage of fuels, as well as standards and training for the same.
2. Policy & regulation	11	Gaps related to the national and international policy that inform regulations or market incentives.
3. Market development, business models & financial innovation	15	Gaps related to the economic readiness for new fuels, including novel business models, economic modeling, as well as financial identification of cost drivers, or subsidies and related funding mechanisms.
4. Technology development & adaptation	64	RD&D gaps related to the technical development and adaptation of engines and vessels, fuels, and associated infrastructure. Examples include life cycle emissions modeling, electricity integration, next to retrofits and new designs for vessels and port equipment.
5. Market analysis	9	Gaps related to the creation, consolidation, and dissemination of market knowledge related to the vessels, fuels, and refueling infrastructure. Examples include geographic diversity and feedstock availability assessments, availability of fuels and fueling infrastructure, or sharing best practices.

While the Mission aims to be as inclusive and comprehensive as reasonably possible, the analysis provides a snapshot across the industry, and does not illustrate each and every innovation aspect. The Mission and its Roadmap are an iterative process and require regular assessments and updates - together with our Mission members and industry partners - to account for ongoing activities and progress during the maritime energy transition.

The Roadmap provides guidance on innovation needs for the sector at a global level in order for the Mission to act on these gaps. Continuing engagement with Mission members and select industry members is essential to the success of the Mission, to highlight ongoing work, provide relevant updates and input to Mission activities, and display national priorities of Mission members. Zero-Emission Shipping also relies heavily on the interconnections to other industries and other Missions - like the need for green electricity and hydrogen, and the Power and Hydrogen Missions - but such connections are only briefly highlighted here and can be further outlined in further publications or activities.

The following pages provide a glimpse into the innovation categories and gaps by Pillar, outlined in more detail within the Roadmap tables found in the appendices.

Pillar 1: Ships

34 innovation gaps

The Ships pillar's goal is that at least 200 deep-sea vessels will primarily use zero-emission fuels across the main deep sea shipping routes by 2030, necessitating a significant change in the configuration of the global fleet within the next decade. In addition, the Mission aims for new deep-sea vessels running on zero-emission fuels to be produced at the same price (max. +5%) as comparable fossil fuel ships.

In line with the fuel neutrality of the Roadmap and targets set for the global fleet by 2030, the Ships related innovation gaps identified have a twofold focus. First, to leverage and accelerate onboard vessel technologies. Secondly, to navigate the technological and commercial innovation necessary to unlock the necessary investment decisions for the global fleet ahead of 2030 – either through newbuilds or retrofitting of the existing fleet to accommodate zero-emission fuels.

Technology development & adaptation is marked as a dominant innovation area, focusing on the need to further advance RD&D in key areas. This includes net-zero pilot fuels, fuel cell technology, onboard emission measurements, fuel and engine flexibility, and bunkering. The analysis also points to concrete gaps and priorities for further research per fuel, including considerations on fuel supply and storage for hydrogen, N_20/NO_X emissions and ammonia slip connected to ammonia, fuel system design requirements for methanol, and onboard modification requirements for biofuels.

Market development, business models & financial innovation is an equally dominant innovation area for the Ships Pillar. This gap group relates to the magnitude of the anticipated change in the global fleet and emphasizes the need for further innovation and demonstration on the implications of the energy density and volume of zero-emission fuels for key business and technical vessel considerations, such as speed and range requirements optimization, bunkering frequency, and/or cargo capacity tradeoffs. The analysis further points to the

need for cross-value chain collaboration, to promptly deliver insights on the real-life applicability and performance in reference deep sea shipping routes by 2030 to create a blueprint for the industry.

Policy & regulation is a critical element in achieving the 2030 goals, albeit not in scope for the Mission's activities. Given extensive ongoing work and progress on enabling policy and regulation for concrete Onboard Vessel considerations, the Roadmap and gaps for this Pillar brings attention to the need for enhanced cooperation and knowledge exchange between the industry and authorities to reduce the lead time in translating industry experience in key areas into concrete policy input and development (where relevant).

In terms of ***Safety & operational risk management***, the analysis pinpoints the safety concerns and considerations to be prioritized for the respective fuels, including: mitigating concerns on the flammability; low activation and ignition energy of hydrogen; safety considerations associated with the bunkering and handling of ammonia; NO_x standards associated with biofuels; methane emissions standards; and risk assessment and safety management altogether. Additionally, the analysis highlights the need for updated onboard methods, operational manuals, and review of educational programs across all fuels to ensure the maritime sector is fit to safely use and sail on zero-emission fuels.

Pillar 2: Fuels

53 innovation gaps

The Fuels pillar's goal is that at least 5% of the global deep-sea fleet, as measured by fuel consumption, will be made of ships capable of running on well-to-wake zero-emission fuels by 2030.[3] The Mission has also set a clear target to see prices (including policy support) on some zero-emission fuels at maximum 10-20% more expensive than fossil fuels.

There are multiple fuel options that are being investigated through the Mission that could achieve net-zero emissions on a lifecycle basis. They must also have production processes that are scalable enough to competitively supply the expected demand for future fuels.

Technology development & adaptation is the dominant innovation gap group for the Fuels Pillar. There are several crosscutting innovation gaps that are relevant to multiple fuels, including: better conversion efficiencies of fuel feedstocks; low-cost, safe, efficient, and high-volume storage; better integration of renewable power systems; and ensuring adequate and sustainable supply of feedstocks. For Hydrogen, improving the durability and reliability of PEM[6] electrolyzer equipment is critical for scaling production.

5 The Mission and its goals include green hydrogen, green ammonia, green methanol, and advanced biofuels

6 Polymer electrolyte membrane

Innovation around ***Market development, business models & financial innovation*** is required to develop the right frameworks for the secure and scalable cost competitive production of zero-emission fuels. Related to this challenge is a lack of demand signals that provide confidence to potential producers, as well as a lack of investment and public funding for the production facilities.

Building concentrated networks of demand through green shipping corridors can help, but an analysis, linked to the Fuel Infrastructure Pillar, will be instrumental to allow for planning around fuel specific corridors.

Policy & regulation innovation gaps are largely focused on ensuring that effective tools and standards, informed by research, help drive zero and net-zero fuel production at scale. With regards to the Fuels Pillar, one of the biggest innovation gaps is a lack of standards for certification of fuel feedstock origins and verification of carbon emissions from fuel production. Additionally, there is a need for a simple legal framework to support cross-border supply of maritime fuel to support further commercialization and development.

The innovation gaps within the ***Market Analysis*** group tend to focus on understanding fuel demand and cost drivers. An important innovation gap within this group is the lack of a commonly accepted methodology for assessing the techno-economic potential of each fuel. A techno-economic analysis such as this would need to account for geographic diversity, such as fuel production locations or synthesis capabilities and storage potential at ports, which itself has a clear intersection with green corridors analysis (see text box in Pillar 3).

Clear and well-defined global regulations are needed for ***Safety & operational risk management*** to mitigate toxicity and spillage risks related to the bulk storage of these fuels, especially for methanol and ammonia. Working with ports and local communities to address the stakeholder confidence will be critical for high-volume storage projects.

Pillar 3: Fuel Infrastructure

33 innovation gaps

The Fuel Infrastructure pillar's goal by 2030 is that 10 large trade ports covering at least three continents supply zero-emission fuels. Additionally, large global trade ports need to supply zero-emission fuels for ship owners to use and which they can rely on when investing in zero emission vessel.

Ports and their fueling infrastructure are in some way the anchor of decarbonizing shipping, as they connect the vessels to fuel and energy sources. Each port and its infrastructure vary, however, the below outlines common innovation needs across this part of the value chain.

A **Green Corridor** is a route between two or more ports on which zero-emission shipping solutions are demonstrated and supported.

Green Corridors are defined as a shipping route between two major port hubs (including intermediary stopovers) on which the technological, economic, and regulatory feasibility of the operation of zero-emissions ships is catalyzed through public and private actions, they offer the opportunity to accelerate progress in tackling the challenges of decarbonizing shipping.[7]

7 For additional information, please see: The Next Wave: Green Corridors

Safety & operational risk management is the dominant innovation gap area for the Fuel Infrastructure Pillar. The analysis shows that there remains a lack of understanding around safe handling, appropriate standards and safety mechanisms, as well as workforce training and certification for handling new fuels in bunkering and in or around ports more widely. Novel approaches are needed to provide sufficient flexibility for ports to be able to plan for infrastructure investments whilst ensuring compatibility of systems between docking ships and port fueling equipment and power supplies.

Technology development & adaptation is critical to connect port infrastructure to land-based energy infrastructure. Designs, materials, components, and procedures for bunkering and storage of new fuels need to be adapted where possible and developed where missing.

Both the public and private sectors need to establish new ways of working. ***The Regulation & policy*** innovation gaps require common port regulations and procedures for the bunkering of alternative fuels, as well as near-term levers and policies to unlock fueling infrastructure investments. The private sector needs to innovate around ***Market development, business models & financial innovation*** to address a lack of appropriate business models and commercial strategies for new fuels.

The Market analysis innovation gaps reveal the need for an overview of existing and planned bunkering infrastructure, as well as a mechanism to track developments in key ports. There is a particular need for forward visibility of supply of or production capacity for future fuels in selected key ports.

From Roadmap to Action

This Roadmap provides an overview of the required innovation gaps at Industry level. The Mission's next step is to develop a detailed **Action Plan**, which considers the specific activities, projects, milestones, and resources required from Mission members to achieve the Mission's goals and address critical innovation gaps that are well-suited to the Mission's scope and resources.

3 KEY STEPS FOR ROADMAP TO ACTION PLAN

1. Roadmap

What are the industry innovation needs?

- Mapping existing work
- Prioritizing the gaps

2. Define activities

What types of activities should the Mission do to meet the goals?

- Input from Mission members & industry
- Prioritization of areas best suited to membership, national interests and strenghts

3. Pillar projects & sprints

- What sprints allow us to deliver our priorities with biggest impact?

Action Plan

- What sprints allow us to deliver our priorities with biggest impact?

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There are interdependencies and connections between innovation gaps within the innovation gap groups and even across Pillars. The Mission will highlight and leverage such connections in the Action Plan to develop and support Pillar sprints and milestones, **together with Mission members and selected industry**, to achieve the Mission goals. Ocean-going projects and the development of green shipping corridors are two examples of crosscutting work and are instrumental to further development in the Action Plan.

As previously stated, the Roadmap strives to cover all innovation gaps, but **not all innovation gaps are well-suited to the scope and resources of the Mission**. For example, the decarbonization of shipping heavily relies on policy support and regulatory mechanisms, but the role of the Mission is not to author such policies. The Action Plan will focus on addressing those innovation gaps that are best suited to the Mission and lie on the critical path to achieving its goals.

Achieving the goals set for international shipping depends on broad coalitions and the efforts of **global public private collaboration**. Engagement with Mission members and industry is critical to Action Plan drafting. The Mission will continue to interact with key industry players - from both the maritime and energy sectors - to develop and maintain a pertinent and prioritized Action Plan. Mission members will initiate activities and coordinate their activities in line with the Roadmap and Action Plan. It is also crucial that these two publications guide additional work for those actors who are currently not yet part of the Mission but are part of the broader ecosystem.

This Roadmap will change over time as innovation gaps are addressed, new technologies are developed, and markets shift. Mission members commit to regular updates as needed. This first edition serves as **a starting point** and the foundation of the Mission Action Plan, allowing Mission members to outline the next steps for achieving the goals of the Mission.

Roadmap

The following appendices are the detailed Zero-Emission Shipping Mission Roadmap organized by innovation gap.

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How to read the Roadmap

The Zero-Emission Shipping Mission Roadmap is contained in the following tables and sets out the 120 innovation gaps to be addressed at industry level to achieve the Mission's goals. To achieve the goals by 2030, the innovation gaps are categorized into 5 innovation gap groups across the 3 Mission Pillars.

In the following tables, the 5 groups and their related innovation gaps are reported against when the gaps need to be resolved in view of the 2030 goals. The 3 spans of time included in year columns on the right-hand side denote the timely priority of the gaps:

- Gaps within the **2022–2024** timespan require innovation to take place within the next three years of this roadmap due to the urgency and impact they carry for other innovations to take place in the mid-2020s timeframe. In other words, the technological readiness of innovations within these gaps is expected within the next 2 years.
- Gaps within the **2024–2027** timespan can build on innovations from the first timespan and the technological readiness of these innovations is expected in the next 4-6 years.
- Gaps within the **2027–2030** timespan are in their early stages of development and require a longer time to advance, and may also be dependent on innovations and other developments from the first two timespans.

Interdependencies and connections between groups, Pillars, Missions, or other efforts, will be further explored as part of the Mission's work.

- **Ammonia**
- **Biofuels**
- **Crosscutting**
- **Hydrogen**
- **Methanol**

The colored **fuel indicator** is a key feature of the innovation gaps themselves, as not all gaps are equal across the different fuel types. Numerous gaps are fuel dependent, while others are crosscutting and have learnings and innovations that are applicable across fuel types.

In the upcoming **Action Plan that will be published in Autumn 2022**, the Mission will use the Roadmap to outline what the Mission will deliver through its own activities, demonstration projects, and make connections with other Missions under Mission Innovation or relevant major maritime decarbonization projects across the sector. This process and ongoing consultation with Mission members and industry allows the Mission to build its resources and focus its efforts effectively for the delivery of the Mission Goals by 2030.

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Innovation group 1. Safety & operational risk management

● Ammonia ● Biofuels ● Crosscutting ● Hydrogen ● Methanol

Pillar	Group 1 Gaps	2022-2024	2024-2027	2027-2030
Ships	Lack of knowledge exchange on safety issues concerning ammonia between the maritime sector and relevant industries	●		
	Lack of mature solutions for bunkering ammonia and experience in the bunkering process	●		
	Need for standards for safety, all ship-related regulations, as well as prescriptive rules for hydrogen		●	
	Need for prescriptive rules for ammonia as a fuel		●	
	Need to revise the current NOx standards in terms of the permitted NOx emissions range		●	
	Need for the establishment of standards for methane emissions		●	
	Lack of updated safety on board methods, operational manuals and review of educational programmes		●	
	Need for further research and assessment into addressing and mitigating significant safety concerns connected to hydrogen, including flammability, low activation and ignition energy	●		
Fuels	Low confidence among port communities and stakeholders outside the traditional operators in ammonia production and storage	●		
	Lack of clear and well-defined global regulations in mitigating toxicity risks (methanol and ammonia) for bulk storage			●
	Safe high-volume storage and refueling for hydrogen and ammonia			●
	Framework/guidelines to prevent methanol contamination (e.g. chloride)		●	
Fueling Infrastructure	Identification of technology and safety gaps for transfer of ammonia to fuel storage systems	●		
	Lack of standards for safety/alarm zones in and around ports, types of buildings that can/should be built, safety mechanisms needed	●		
	Lack of understanding barriers to community acceptance of ammonia safety concerns	●		
	Lack of understanding safety requirements for bunkering new fuels	●		
	Need for processes, designs, components, and procedures for bunkering	●		
	Lack of workforce training and certification for handling new fuels in bunkering and ports	●		
	Need for safety and risk management (plans/activities/studies?) for non-bunkering ports		●	
	Current standardization system too prescriptive - flexibility required for ports to be able to plan for infrastructure investments as fuels (e.g. shoreline connection) whilst ensuring compatibility of systems		●	
	Obscurity around responsibility of hose string crossing port (from vessel flange to land-based energy infrastructure)		●	

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Innovation group 2. Policy & regulation

● Ammonia ● Biofuels ● Crosscutting ● Hydrogen ● Methanol

Pillar	Group 2 Gaps	2022-2024	2024-2027	2027-2030
Ships	Lack of common approach to enforcement of NOx emissions compliance	●		
	Need for enhanced knowledge exchange between industry and authorities as a basis for regulation	●		
Fuels	Lack of tools and knowledge for assessing the availability of biofuels and their feedstocks	●		
	Lack of simple legal framework to support further commercialization and development		●	
	Lack of fuel standard for certification of fuel feedstock origins and sustainability or verification of carbon emissions from fuel production		●	
	Lack of simple legal framework to support cross-border supply of maritime fuel		●	
	Lack of sufficient regulatory pressure to transition quickly to green maritime fuel		●	
	Need for legal standard for the use of hydrogen as maritime fuel			●
Fueling Infrastructure	Lack of near term levers/policies to unlock fueling infrastructure investments	●		
	Need for government-driven port mandates to 'serve industry' can hinder low emissions requirements for the port area	●		
	Need for common port regulations & procedures for the bunkering of alternative fuels		●	

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Innovation group 3. Market development, business model & financial innovation

● Ammonia ● Biofuels ● Crosscutting ● Hydrogen ● Methanol

Pillar	Group 3 Gaps	2022-2024	2024-2027	2027-2030
Ships	Need for further analysis and demonstration connected to speed and range requirements optimization, bunkering frequency or cargo capacity tradeoff as a result of energy density and volume considerations	● ● ●		
	Need to secure approval for the different kinds of biofuels by engine producers to secure guidance and investment certainty for industry actors and mitigate commercial losses	●		
	Need for data and demonstration projects on real-life applicability and performance in reference shipping routes and within global supply chains	●		
	Need for testing and assessments on the implications of increased fuel tanks size in regards to methane. (Only methane specific and not other biofuels)	●		
	Need for further development, testing and demonstration on the bunkering considerations including ship to ship and ship to land infrastrucutre	●		
Fuels	Unknown costs with harvesting and collection of bio-feedstocks used for production of biofuels	●		
	Shortage of immediate investment and / or public funding to derisk fuel production plant building	●		
	Lack of market signals and industry wide confidence in fuel transformation	●		
	Lack of knowledge of key actors and/or cost barriers to market participation	●		
	Insufficient knowledge on the cost competitiveness against other fuels			●
	Green corridor analysis that includes fuel specific corridors, i.e. hydrogen, ammonia, methanol, and biofuels based corridors	●		
	Reduction of operational costs for hydrogen production to be more competitive with traditional fuels		●	
	Cost reduction of methanol feedstocks needed		●	
	Production scalability of green methanol is unclear		●	
Fueling Infrastructure	Lack of appropriate business models and commercial strategies for new fuels	●		

Innovation group 4. Technology development & adaptation

● Ammonia ● Biofuels ● Crosscutting ● Hydrogen ● Methanol

Pillar	Group 4 Gaps	2022-2024	2024-2027	2027-2030
Ships	Need for further research and testing on how to continuously lower costs, e.g in terms of redundant systems, double piping, sensors etc	●		
	Lack of commercially available energy converter capable of running on ammonia	●		
	Need for improved solutions enabling fuel flexibility and multi-fuel usage	●		
	Lack of real operational onboard emission measurements to understand potential risk of major differences between engine test bed measurements at fixed loads and dynamic operations at sea with varying engine loads and sea states.	●		
	Need for further testing and demonstration of fuel cell technology including conversion efficiency, lifetime and cost	●		
	Need for further development of fuel design requirements	●		
	Lack of knowledge on N2O/NOx emissions and ammonia slip connected to Ammonia engines		●	
	Need for further testing and demonstration on lean burn gas engine with hydrogen enriched ammonia		●	
	Need for testing and demonstration on the usablity of biofuels a pilotfuels for other green fuels	●		
	Need for further research on the reduction of methane slip from engines	●		
	Need for further research into potential requirements for onboard modifcations (fuel storage, fuel supply and engines) to use certain biofuels including bio-oils		● ●	
	Need for improved solutions for storage of LH2 in order to cover the needed capacity for deep sea shipping		●	
	Need for standardized solutions for modular onboard storage		●	
	Need for further technology development in terms of fuel supply and storage technology relying on hydrogen to address concerns related to temperature requirements and adverse impact on material.		●	
	Need for improved internal combustion engines, in order to improve range and availability of energy converter options		●	
	Need for development, scale up and commercial availability of net-zero pilot fuels (such as biofuels) to enable true net-zero emissions		●	
	Lack of sufficient knowledge and insights on the technical trade offs associated with the use of dual fuel equipment	●		

ZERO-EMISSION SHIPPING MISSION

Group 4: Continued

● Ammonia ● Biofuels ● Crosscutting ● Hydrogen ● Methanol

Pillar	Group 4 Gaps	2022-2024	2024-2027	2027-2030
Fuels	Lack of knowledge of different feedstock options and global availability/supply to scale up different green fuels (biofuels, ammonia)	●		
	Technological development needed to lower the production costs, either by optimizing Haber Bosch or by developing a new process		●	
	Uncertainty of performance and processes of electrochemical ammonia synthesis	●		
	Integrating ammonia production with renewable energy, with emphasis on renewable intermittency	●		
	Development of efficient, thermally integrated catalytic reforming reactors to generate requisite hydrogen fuel onboard the vessel.		●	
	Need to assess N2O Emission potential and avoidance from ammonia combustion	●		
	Further research on the need for low-cost stability additives or other methods to reduce the rate of degradation of biofuel, and thus avoid unnecessary engine wear	●		
	Need the right ratio of biofuel blends and ensuring that different blends of biofuels are within range for lubricity, viscosity, pour point, HFO compatibility, and other fuel properties used to ensure fuel compatibility for marine engines	●		
	Development of a complete set of fuel characterizes for each biofuel that is the focus on the international community. This includes acidity, degradation, stability, LHV/HHV, bunkering stability, miscibility in current fuel systems, etc.	●		
	Unknown impact of using non-renewable energy sources and/or CCUS for (blue) fuel production, and how it compares to renewable energy in terms of emission impacts in short and long-term time horizons	●		
	Asses the use of biofuels as a pilot fuel for methanol and ammonia engines	●		
	Assess methanol production method, e.g. electrolysis or carbon capture	●		
	Assessing the respective merits of bio-methanol and e-methanol	●		
	Technological developments are needed to ensure better conversion efficiency for electrolysis, need at least 75% efficiency		●	
	Technical developments of storing hydrogen at ammonia production facilities or solutions that eliminate the need for storage altogether		●	
	Need for low cost, safe, efficient, storage methods that provide sufficient capacity to accomodate fluctuations when paired with renewable energy		●	
	Technological development into eliminating the risks of spills		●	
	Need for green electrification of existing ammonia plants		●	
	Need for better optimization and/or investigation into alternative uses of waste heat generated from fuel production			●
	Limited knowledge of the supply and characteristics of biofuels produced from different feedstocks, the impact on different fuel production pathways, and availability of feedstock globally		●	
	Scaling up of pre-treatment process		●	
	Improving efficiency of separation and conversion processes		●	

Group 4: Continued

● Ammonia ● Biofuels ● Crosscutting ● Hydrogen ● Methanol

Pillar	Group 4 Gaps	2022-2024	2024-2027	2027-203
Fuels	Uncertainty around effectiveness of use of renewable energy for maritime fuel production		●	
	Insufficient and/or untested energy storage systems		●	
	Lack of low-cost PEM electrolyzer equipment, manufacturing science, and access to high-durability and high-reliability electrolyzers to scale up production.		●	
	Low-cost and efficient high-volume storage			●
	Sourcing sufficient quantities of CO2 to meet fuel demand		●	
	Need to improve the conversion efficiency of bio-methane production		●	
	Need to understand potential e-fuel produciton locations. If at ports, they are often electrically constrained which inhibits their ability to produce e-fuels		●	
Fueling Infrastructure	Need to further design tanks and piping with leak detecting sensors for bunkering vessels	●		
	High operating costs of ammonia storage (e.g. electricity costs for refrigeration)		●	
	Need for innovation, testing, and optimization to cope with the increased frequency of refueling		●	
	Need for terminal infrastructure for simultaneous bunkering and cargo loading/unloading		●	
	Port connections to land-based infrastructure: need for innovative approaches to transfer fuel to the port, innovative siting, onsite production		●	
	Need to develop and/or adapt designs, materials, and processes for bunkering and storage including pipes, tanks, leakage handling, monitoring (sensors), ventilation systems		●	
	Need fit for purpose processes, design, and components for ship-to-ship bunkering		●	
	Need for technology adaptation and methdology development for connection to land infrastructure		●	
	In-situ and remote leak detection system and methodology		●	
	Required adaptation for technology used for ship to ship bunkering for H2 and NH3		●	
	Required adaptation for technology used for truck to ship bunkering			●
	Need for cost effective storage technologies (e.g. liquid H2 cryogenic storage tanks -235C)			●
	Need for mapping/developing the technology needs and infrastructure retrofitting for ports			●
	Need infrastructure conversion of gas pipelines to transport H2		●	
	Need for technology development for H2 transport using trucks with pressurized cylinders		●	
	Required conversion of LPG storage, pipes, and pumps for use with e-methanol		●	

Group 5. Market analysis

● Ammonia ● Biofuels ● Crosscutting ● Hydrogen ● Methanol

Pillar	Group 5 Gaps	2022-2024	2024-2027	2027-2030
Fuels	Understanding the potential of bio-methane to serve as an LNG alternative on a well-to-wake basis, taking into account fugitive emissions	●		
	Missing a common methodology for assessing the technoeconomic potential of each of the fuels	●		
	Unclear fuel production locations or synthesis capabilities and storage potential at ports	●		
	Unknown how seasonality in feedstocks affects fuel availability		●	
	Need for demonstrations to strengthen confidence and knowledge on operational behavior and further proof of concept		●	
Fueling Infrastructure	Lack of global bunkering plan and progress tracker covering key ports (overview of existing and planned: infrastructure, bunkering needs/demand, fuel capacity and availability, port development etc.)	●		
	Lack of overview of fuel storage tank capacity for different fuels at key ports	●		
	Lack of H2 + NH3 supply plans for selected ports	● ●		
	Unknown fuel demand at different ports within member organizations/ countries for the mission	●		

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