Zero Carbon Fuel Monitor

October 2023 Update

The **Lloyd's Register** Maritime Decarbonisation Hub

Executive summary

This report presents insights derived from the latest update of readiness levels within the Zero Carbon Fuel Monitor, offering an overview of trends, priorities and recommended actions to drive the adoption of zero-carbon fuels in the shipping industry.

Trends linked to each fuel and each supply chain stage have been identified. The overall key trends are summarised below:

- **Technology advancements:** Progress in zero carbon fuel technologies is evident across the supply chain. In particular, the advancements in **TRL** for ammonia compared to the last update.
- **Hydrogen growth:** Global green hydrogen production is on the rise, contributing to increased **TRL** across the supply chain. National hydrogen energy strategies and investments support fuel availability and infrastructure.
- **Ports and bunkering expansion:** Government strategies for decarbonisation are driving land-side infrastructure expansion, and successful bunkering trials for various fuels are underway, enhancing readiness.
- **Methanol momentum:** Green methanol production is increasing with numerous projects in progress. Maturing bunkering capabilities and growing orders for methanol dual-fuel ships indicate higher readiness levels.
- **Consequential considerations:** **IRL** and **CRL** are affected by implications such as land use for resource harvesting, environmental effects in case of leakages, and societal impacts.
- **Biofuels feedstock uncertainties:** Sourcing of sufficient sustainable feedstock to meet potential future demand remains a challenge. Efforts to cultivate third-generation feedstocks like macroalgae are underway.
- **Methane slip challenge:** Concerns over methane slip are affecting **TRL** and **CRL** assessments for methane.

Five key priority areas have been identified, which must be addressed to drive forward the transition to zero-carbon fuels:

1. Developing demand profiles

To minimise investment risks, stimulate supply chain interest, and create commercially viable business cases for zero-emission shipping, the industry needs to establish transparent demand profiles, while also considering fuel demand in relation to competing sectors sharing the same feedstocks and energy supply chains.

2. Sustainable resource scale-up

Ensuring a sustainable scale-up of resources is paramount to enable adequate fuel production for future demand.

3. Policy consistency

Achieving stable and consistent policy development and enforcement across the value chain and globally is essential for attracting investments and ensuring a smooth transition.

4. Research, development, and education

Fostering research, development, and educational initiatives is crucial for the safe and sustainable adoption of zero carbon fuels.

5. Technology advancement

The pace of technology development must be maintained and accelerated to meet evolving industry needs.

These priorities are industry-wide. In the report, specific supply chain actors have been identified who can act upon these priorities. However, tackling these cannot be achieved through individual efforts or action in isolation within the shipping industry. Considerations for addressing priority areas include:

- Collaboration within the shipping industry
- Cross-sector collaboration
- Transparency and knowledge sharing

In conclusion, although readiness across the supply chain is increasing, significant barriers to adoption remain with respect to technology, investment and community readiness. The report observes the interconnectedness of all stakeholders and underscores the need for collective action to drive forward and accelerate the transition.

Introduction

This report aims to highlight the trends and priorities identified through the latest update of readiness levels in the Zero Carbon Fuel Monitor (ZCFM)[1].

Zero carbon fuels are defined as energy systems that have the potential to deliver ship power with net-zero carbon dioxide emissions, inclusive of production and use.

The assessment framework[2] addresses three criteria across five supply chain stages for each fuel:

1. **Technology Readiness (TRL):**
   Assessing the maturity of solutions to become marine application-ready.

2. **Investment Readiness (IRL):**
   Evaluating the commercial maturity of marine solutions, taking into account the financial proposition, industry supply chain dynamics, and market opportunities.

3. **Community Readiness (CRL):**
   Gauging the societal maturity of a marine solution, considering its acceptability and adoption by both individuals and organizations. It encompasses regulatory, sustainability, and community acceptance aspects.

By updating this readiness assessment, we have uncovered key trends in the zero carbon fuels landscape, and identified key priorities that need to be addressed to advance readiness further. We have also recommended specific actions that align with these priorities.

A summary of readiness is below, with changes from the July 2022 update shown. A new category of electrification (batteries) has been assessed in ZCFM, and changes to the structure of the biodiesel and nuclear categories have been made to better reflect the current state of these fuel and technology types. Hence, there is no comparison against 2022 data for these fuels.

This assessment is based on the currently available evidence and the objective judgements of our industry specialists. You can explore the specifics of each dataset, including key challenge statements related to each datapoint, by visiting each of the fuel pages on ZCFM.

1 Zero Carbon Fuel Monitor | Lloyd's Register | LR
2 Assessment method - Zero Carbon Fuel Monitor | Lloyd's Register | LR

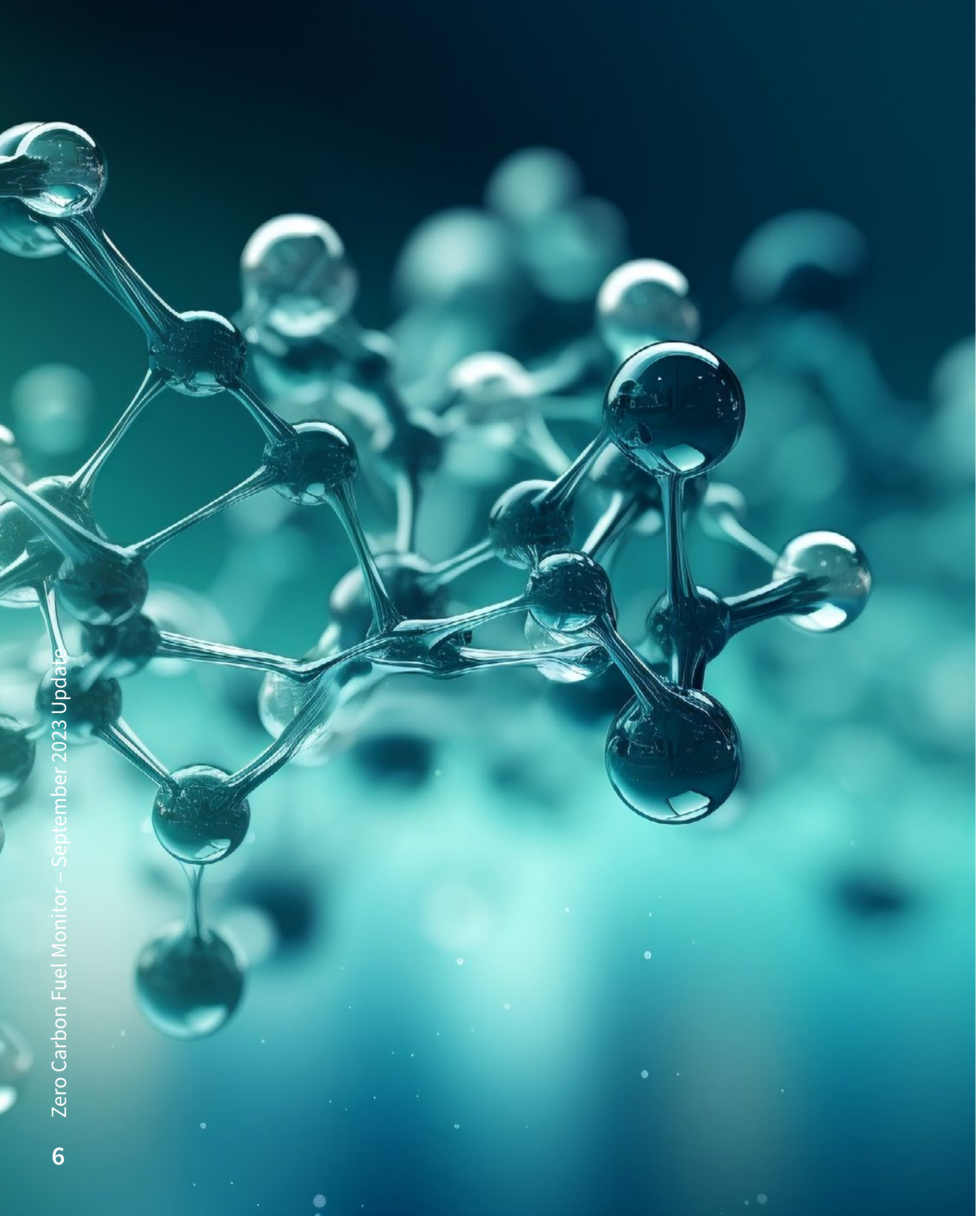
Fuel type	TRL					IRL				CRL			
	Resource	Production	Bunkering and ports	Ship Onboard storage and handling	Ship Propulsion	Resource	Production	Bunkering and ports	Ship	Resource	Production	Bunkering and ports	Ship
Blue ammonia	5 ▲	5 ▲	3 ▲	4 ▲	4 ▲	2	2	1	1	2	4	1	1
E-ammonia	7	5	3 ▲	4 ▲	4 ▲	2 ▲	2	1	1	4	5 ▲	1	1
Biodiesel	7	7	7	7	7	2	2	2	2	3	3	3	3
Blue hydrogen	5 ▲	5 ▲	5 ▲	5	6 ▲	2	2	2 ▲	1	2	4	1	1
E-hydrogen	7	5 ▲	5 ▲	5	6	2 ▲	2	2 ▲	1	4	5 ▲	1	1
Liquefied bio-methane	7	2 ▲	7	9	8 ▼	1	1	2	1	3 ▲	1 ▼	5	1
Liquefied e-methane	7	2	7	9	8 ▼	2 ▲	1	1	1	4	2 ▼	5	1
Bio-methanol	7	3	6	8	8	2	3 ▲	2 ▲	3 ▲	2	2	2	3
E-methanol	7	4 ▲	6	8	8	3	3	2 ▲	3 ▲	4	2 ▼	2	3
Nuclear (pressurised water reactor)	9	4	3	2	1	4	1	1	1	4	1	1	2
Nuclear (heat pipe)	9	4	1	2	1	4	1	1	1	4	1	1	2
Nuclear (molten salt)	9	4	1	2	1	4	1	1	1	4	1	1	2
Electrification (batteries)	7	9	7	5	9	2	2	2	2	4	2	2	2

Overall, there has been notable progress across the supply chain, particularly with respect to **TRL** of ammonia and hydrogen. Additionally, there has been a significant uptick in methanol dual-fuel vessel orders.

However, growing concern around methane slip has affected readiness levels, and challenges around sustainable scale-up of resources is limiting readiness particularly at resource and production supply chain stages of fuels.

The zero-carbon marine fuels landscape is constantly evolving, and the data and insights provided in the monitor reflect LR's expert view on solution readiness and industry priorities at a snapshot in time.

Please contribute
We welcome any knowledge you can contribute to help refine and update the information presented in this tool. Your insights play a crucial role in enhancing our collective understanding of the readiness associated with zero carbon marine fuels.



Emerging trends by fuel

Ammonia

Advancements have been seen across the supply chain, particularly with respect to **TRL**. Additionally, Yara International have ordered 15 floating bunkering terminals, showing increasing certainty and positively impacting **IRL**.

Meanwhile, the recently published joint study, “Recommendations for Design and Operation of Ammonia-fuelled Vessels”, by LR Maritime Decarbonisation Hub and Maersk McKinney Moller Centre for Zero Carbon Shipping has advanced safety knowledge and understanding concerning ammonia handling and storage onboard vessels. Additionally, a supporting document to this study (Human Factors Considerations: Ammonia Fuel End-of-Stage Report), published by LR, provides a preliminary account of the human factors that should be addressed to prepare for ammonia fuel use.

A significant milestone was also achieved by MAN Energy Solutions (MAN ES) with the successful completion of the first test engine running on ammonia at its Research Centre Copenhagen (RCC), advancing **TRL** of propulsion.

Efforts are continuing elsewhere, for example the EU has granted a subsidy for a consortium of maritime companies to conduct research leading to developing full-scale four-stroke and two-stroke engine demonstrators running on ammonia by 2025, and MariNH$_3$ is running a 5 year research programme to advance technologies and policies related to ammonia, which will progress overall readiness of ammonia as a marine fuel[3].

[3] Home - MariNH$_3$ (marinh3.ac.uk)

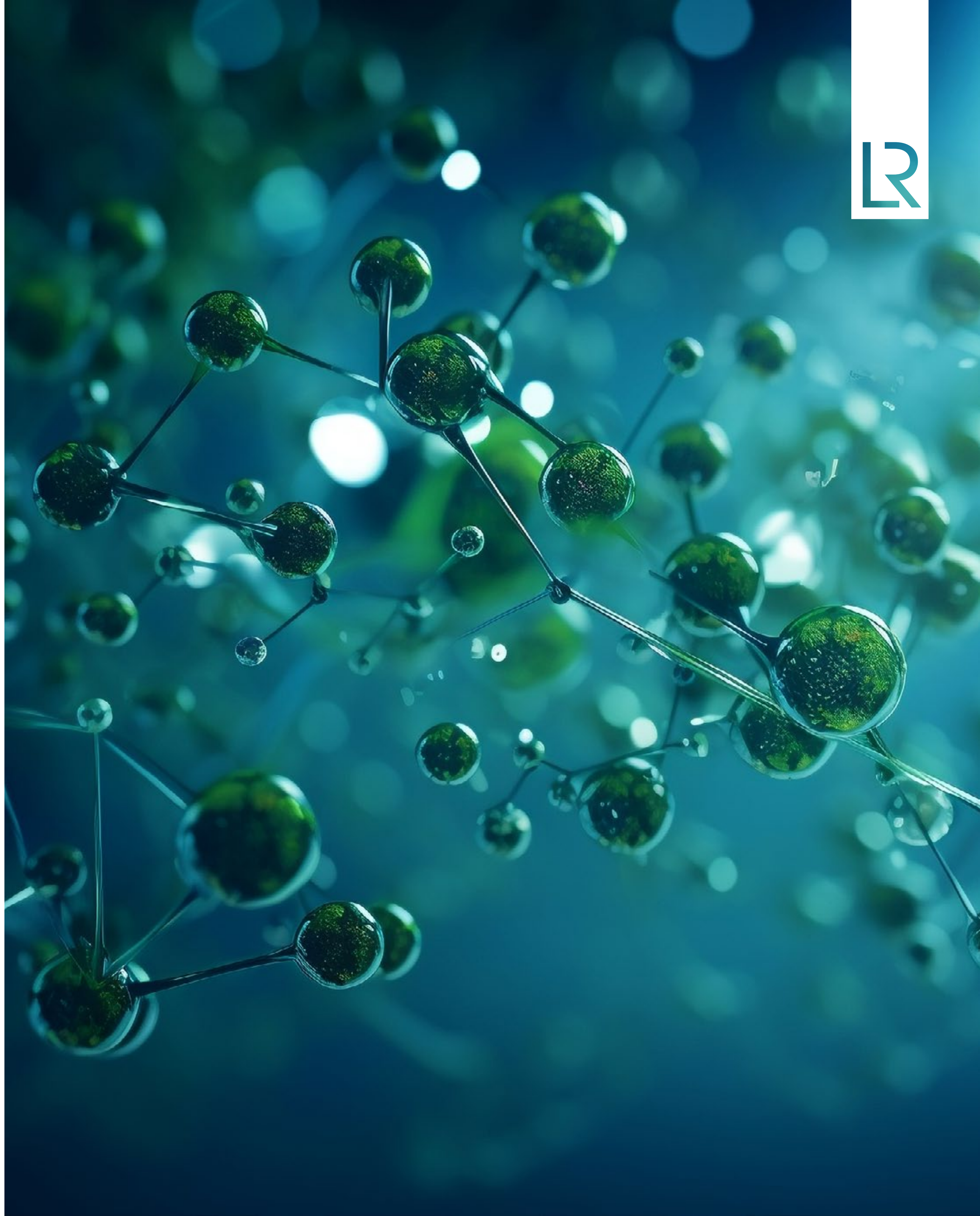
Biodiesel (FAME)

Demand for biodiesel (FAME) has been increasing since the IMO published MEPC.1 CIRC 905, which provides interim guidance on how to calculate the benefits of the biofuels by LCA under MARPOL annex VI (DCS and CII).

Many different feedstock types are now being used for the production of biodiesel. For this reason, ZCFM now assesses the readiness of biodiesel (FAME) as the most commonly used type of biodiesel, and the assessment considers FAME made from all feedstocks in one overall rating for each readiness level and supply chain stage.

Electrification

Whilst electrification is typically only used in small boats and ships, often as a hybrid power source, the use of this technology has the potential to be expanded for wider use in shipping. A recent example of this is the swappable containerised battery technology used on COSCO's 700TEU fully battery-powered container vessel for in-land waterway voyages.



Hydrogen

Global production of green hydrogen is on the rise and progress is being made across the supply chain that is increasing **TRL** in particular.

There has been an increase in national hydrogen energy strategies worldwide[4], with countries actively investing in renewable energy and land-side hydrogen infrastructure, as well as adopting policies that will support first movers. These investments and support at government level have the potential to contribute to fuel availability, port infrastructure and regulatory advancements that will benefit shipping.

In the Netherlands, a hydrogen bunkering license at the port of Ijmuiden has been granted. This license allows Windcat Workboats to bunker the Hydrocat 48 crew transfer vessel with hydrogen, advancing both the **TRL** and **IRL** for hydrogen bunkering.

Studies are being undertaken to assess the feasibility of liquid hydrogen on board[5].

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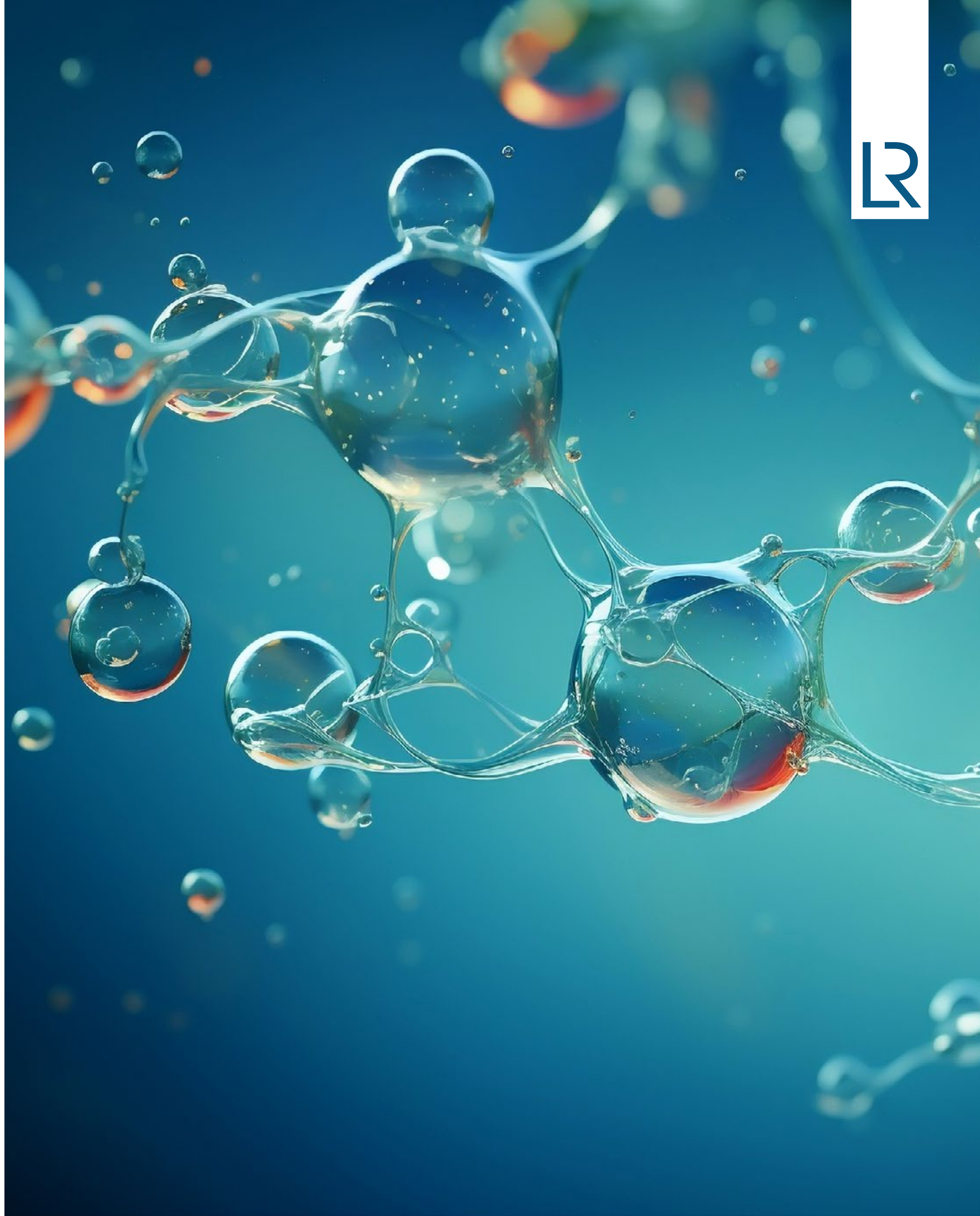
4 Hydrogen - IEA
5 For example: HYDRA, H2Barge1

Methane

There have been increasing concerns around methane slip, impacting both **CRL** and **TRL** assessments. There is, however, ongoing work in this area. For example, the Safetytech Accelerator-led Methane Abatement in Maritime innovation initiative (MAMII), which has doubled its' membership within the first year, is working to identify solutions and mechanisms for capturing, calculating and managing methane slip emissions, and best practices will be shared with industry to tackle this challenge.

Shipowners investing in fossil LNG are considering the viability of switching to biomethane in the future for those vessels, however this has not yet been proven in terms of **IRL**.



Methanol

Green methanol production is on the rise, with around 80 projects in progress that are anticipated to generate nearly 8 million tons annually by 2027[6]. These projects represent a significant step towards sustainable methanol production, and hence an increased **IRL** and **TRL**, although not all of them are solely dedicated to shipping use.

Methanol bunkering is also maturing and has been proven in specific regions. Examples include barge-to-ship bunkering at the Port of Antwerp through the joint venture between Stena Bulk and methanol producer Proman, and the ship-to-containership methanol bunkering of the Laura Maersk container vessel in Singapore, which will now bunker at the Port of Rotterdam with fuel supplied by OCI. As a result of these advancements, **IRL** has increased at the bunkering supply chain stage.

In parallel, there has been a notable increase in the orderbook for dual-fuel ships. Major shipowners such as Maersk Line and CMA CGM are placing orders for large numbers of methanol dual-fuelled vessels, and if all dual-fuel vessels are using methanol all the time by 2028 (based on 2023 orderbook), this demand will reach approximately 25% of the total methanol projected capacity for 2027[7].

[6] Renewable Methanol | METHANOL INSTITUTE
[7] The future of maritime fuels report | LR

Nuclear (onboard)

Nuclear power for shipping is experiencing increasing interest from major shipping players, and the nuclear technology landscape is changing fast. Three main technology types (pressurised water reactors (PWRs), heat pipes and molten salt reactors (MSRs)) with the potential to be deployed in commercial shipping are emerging, although overall readiness currently remains low.

Additionally, new technology development will allow the use of spent fuel from PWR reactors as fuel, thereby reducing radioactive waste that would need to otherwise be safely stored.

Emerging trends by supply chain stage

Resource

Investment and development in Carbon Capture Usage and Storage (CCUS) technologies on-land are on the rise, increasing **TRL** of blue fuel resources, with the potential to facilitate the scale-up of blue fuels production. Although theoretically the capacity of carbon storage sites is not currently a constraint, the identification of new technically and commercially viable sites is the limiting factor, and there is also heightened competition and demand for this capacity from various other sectors. In the US, the Inflation Reduction Act (IRA) incentivises deployment of CCUS through tax credits, potentially stimulating further investment in production of blue fuels.

As demand for renewable energy sources continues to grow, there has been a significant scale-up of renewable energy harvesting to the extent that it is projected that renewables could overtake coal as the largest source of global electricity generation as early as 2024[8]. This sharp rise in renewable energy sources is driving increased investment readiness of green fuels resources. However, this expansion has not been without challenges, as concerns from communities have surfaced regarding environmental and social impacts associated with increased land use for renewable energy harvesting, such as solar and wind farms.

Governments are increasingly investing in clean energy generation. For example, in the US, the IRA has introduced clean energy tax incentives, where tax credits are provided for investment in clean energy projects. The goal is to accelerate deployment of clean energy technology, facilities and infrastructure. An increase of clean energy harvesting will facilitate increased zero carbon fuels production or electrification for shipping.

The key challenge for the scale-up of biofuels adoption remains significant uncertainty in the ability to source the required levels of sustainable feedstock in the long term, located practically for production of marine fuels. Additionally, there will be competition from other sectors, such as aviation, for the feedstock and fuel. In response to the feedstock challenge, there have been efforts in cultivating and harvesting thirdgeneration sustainable feedstocks, such as macro algae, which are characterised by high yields and rapid growth rates.

[8] Electricity Market Report – Update 2023 – Analysis - IEA

Production

The increase in announcements of green hydrogen production facilities, as well as the growing number of national hydrogen strategies, will indirectly have a positive impact on the readiness of all hydrogen-based fuels.

Meanwhile, **CRL** of green methane and methanol production has been impacted by increasing concerns around the scale-up of sustainably sourced carbon. This may be achieved either through direct air capture (DAC) or bioenergy with carbon capture and storage (BECCS) technologies, however both of these currently have high costs and mixed public perceptions associated with them.

Opportunity Green have set up the SASHA coalition with the aim of unifying aviation and shipping sectors to secure green hydrogen and DAC that is needed for the future fuel mix across both sectors. The coalition brings together companies from both sectors to achieve a greater influence on policy and to promote public sector investment in green hydrogen and DAC, with a current focus on the current EU and UK policy landscape supporting the transition in these sectors[9].

Ports and bunkering

Government strategies for decarbonisation will lead to expansion of land side infrastructure for the transportation and storage of alternative fuels. Meanwhile, bunkering trials for methanol and hydrogen have been successfully completed, and a pilot is in planning for ammonia bunkering in Singapore.

Ship

At the IMO's MEPC 80 meeting, the 2023 IMO Strategy on Reduction of GHG Emissions from Ships was adopted, which defined new decarbonisation targets for shipping. The revised strategy states that by 2030, 5% (striving for 10%) of energy usage in shipping will be from zero (or near-zero) GHG emission energy sources. The goal is to reach net-zero GHG emissions by (or around) 2050, and indicative checkpoints have been set at 20% reduction (striving for 30% reduction) by 2030 and 70% reduction (striving for 80% reduction) by 2040, relative to 2008 levels.

A basket of measures to reach these targets will be developed, addressing both the technical element and the economic element, and using the MEPC 80 adopted Guidelines on Life Cycle GHG Intensity of Marine Fuels (LCA guidelines) to calculate the well-to-wake GHG emissions using standardised methodology. These measures will promote the adoption of zero carbon fuels and make the investment case for zero-carbon fuels more attractive, increasing **IRL** and **CRL**.

Additionally at MEPC 80, a circular setting out rules for application of biofuels under the Data Collection System (DCS) and Carbon Intensity Indicator (CII) was approved, meaning that a CO_2 conversion factor can be applied to applicable biofuels. These biofuels must adhere to an international sustainability certification scheme and demonstrate a well-to-wake Greenhouse Gas (GHG) emissions reduction of at least 65 per cent when compared to conventional fossil fuels. This may encourage adoption of biofuels in the shorter term, although much of this uptake is likely to be as blended fuels, rather than as a zero-carbon fuel.

9 The SASHA Coalition — Opportunity Green

Emerging trends across the supply chain for all fuels

Demand for accelerated decarbonisation of shipping is growing, with pressure from end customers with increased scrutiny around ESG and Scope 3 reporting mounting on the shipping industry. In the most recent developments, ZEMBA (a platform for cargo owners) released its request for proposals for zero emission services – defined as fuels reaching 90% reduction in emissions on a lifecycle basis – to be delivered by 2025.

In an effort to support the transition to low-emission fuels for shipping, a maritime book and claim system[10] platform is under development by The Maersk Mc-Kinney Møller Center for Zero Carbon Shipping, RMI, Danish Shipping, and Maersk Oil Trading with funding from the Danish Maritime Fund. The methodology aims to allow the benefits and costs of decarbonisation to be shared across the maritime supply chain through a tokenised system that allows for swapping emissions among users.

A clean energy marine hubs (CEM-hubs) platform has been announced as a partnership between the private sector and governments, integrating shipping into the energy value chain to de-risk and accelerate investments required for production, use and transportation of zero carbon fuels[11]. This includes development of policy and unlocking funding to ensure that the appropriate infrastructure and ships are built. The impact of these hubs has the potential to drive readiness up overall (**TRL**, **IRL**, **CRL**), across the supply chain.

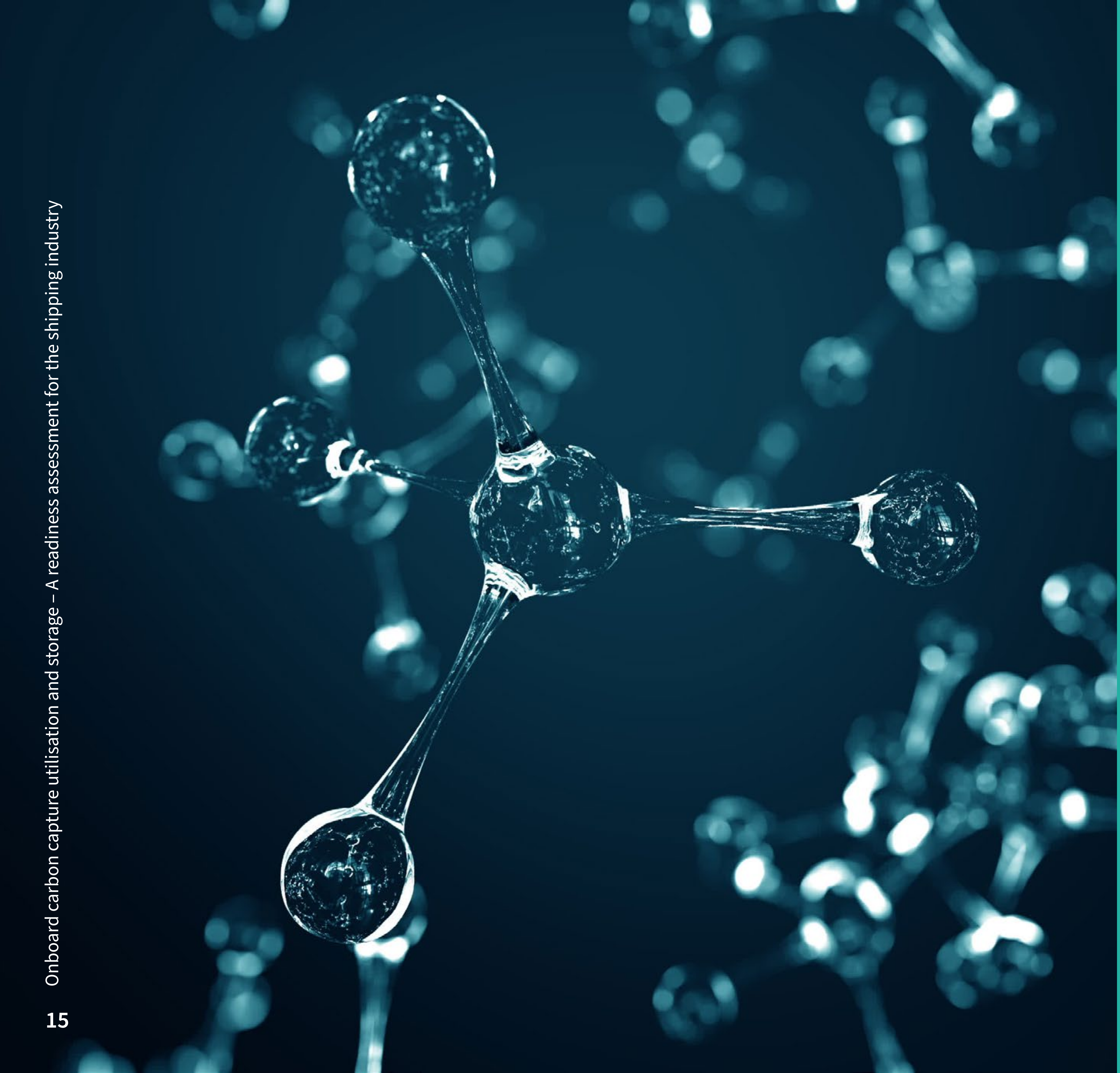
Looking ahead

The direction the industry takes on which fuels will dominate in the future depends on various factors, such as availability, cost and access to resources, as well as assurance that the fuels will be able to reach zero (or near-zero) GHG emissions.

You can find out more about future maritime fuel mix projections here:

The future of maritime fuels report | LR

[10] Maritime Book & Claim | Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
[11] Clean Energy Marine Hubs | Clean Energy Ministerial



Key priorities

Five key priority areas have been identified, which must be addressed to increase readiness of fuels and drive forward the transition to zero-carbon fuels. For each of these priority areas, stakeholder actions have been recommended.

1. Demand profiles need to be defined and finance mechanisms need to be developed to de-risk and stimulate investment across the supply chain (IRL)

- Stakeholders responsible for investing in resource, production, bunkering and port infrastructure need to understand the demand profiles and infrastructure required for alternative fuels in order to unlock investment to supply shipping. Regional, combined strategies across the supply chain, with positive investment cases for each stakeholder, could create benefits from economies of scale and risk-sharing across the supply chain.

- A greater demand for fuel in specific regions would help to stimulate scale-up of supply, and this demand may come from several different sectors. Note that this could also increase competition for resources.

- Development of financing mechanisms and structures will offer more flexibility around financing to support the business case for zero emission shipping where the cost gap remains a limiting factor and will encourage risk sharing discussions among key stakeholders across the shipping value chain. This will in turn help to grow demand. The Poseidon Principles supports this by providing a framework for integrating climate considerations into lending decisions.

- The fuel demand for shipping must also be taken into consideration against the demands of other sectors, particularly those sectors competing for the same feedstocks and energy supply chains.

Stakeholder actions

1. Stakeholders across the supply chain can form green corridor clusters to create and define regional demand that will reduce risks in investments of supply / infrastructure / fleet for each member.
2. NGOs and industry associations with a goal to drive low emission fuel adoption can bring together fuel buyers from multiple sectors (e.g., other transportation, manufacturing) to aggregate demand. This consortium can then act as a unified voice to negotiate with suppliers.
3. Financial institutions can create specialised financing structures tailored to the needs of shipping's decarbonisation. NGOs can bring together key stakeholders to advocate for sustainable financing mechanisms and ensure environmental considerations are incorporated into financing decisions.
4. Governments need to engage with stakeholders across the energy value chain through hubs to strategically catalyse areas of activity for trade of new fuels.

2. Sustainable scale-up of resources needs to be addressed to enable sufficient fuel production (Resources – TRL, CRL)

- For e-methanol and e-methane to be considered scalable zero-carbon solutions, carbon negative supply chains need to be demonstrated at a substantial scale. To achieve this, a significant increase in sustainable carbon sourcing is required using techniques such as DAC and BECCS, which means removing technical barriers to scalability, such as the energy input required for operation, and tackling the high costs associated with these technologies.

- Biofuel feedstocks need to be cultivated and harvested in a sustainable manner and at significantly increased scale for production of biofuels to meet potential demand. To be considered sustainable, these feedstocks should not compete with food resources and must be grown efficiently without imposing excessive demands on land use.

- There needs to be a rapid expansion in renewable energy capacity to meet shipping and other demands. This may be achieved through identifying and securing high-potential locations for new renewable energy sites as well as technology development for more efficient energy harvesting.

- Feasible and economically viable carbon storage sites need to be made available for blue fuel production to scale-up.

Stakeholder actions

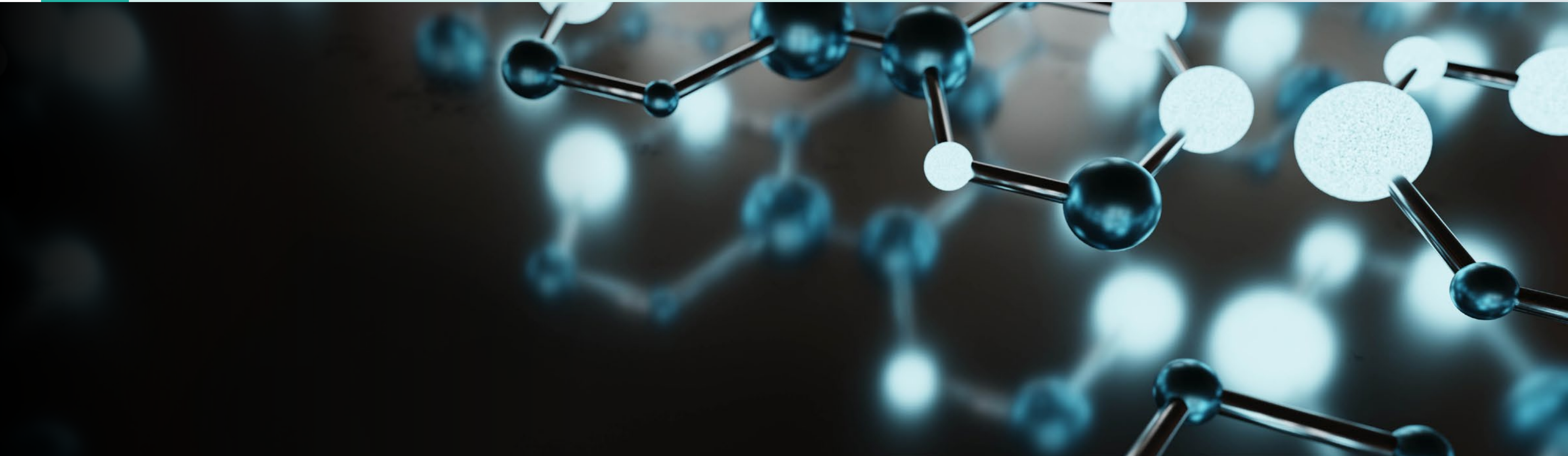
1. Governments, industry, and research institutions need to collaborate on research, development, and demonstration projects to tackle the technology challenge of the significant energy input required to operate DAC and BECCS technology. Additionally, more efforts looking at unlocking investments in DAC (e.g., the SASHA coalition) are needed globally.
2. Research institutions (with support from governments) need to direct efforts into the development of technology and practices for farming of resource-efficient, high yield, sustainable feedstocks, such as 3rd generation macro-algae, that could be located practically to produce marine biofuels.
3. Public-private partnerships (collaboration between governments and the private sector) can be set up to finance and deploy large scale renewable energy projects. Such projects could be for development of new efficient technologies for generating clean energy or to create the required infrastructure to scale-up existing technology applications.

3. Policy needs to be stable and consistent across the value chain and globally to stimulate investment (CRL, IRL)

- The recently adopted IMO guidelines on life cycle GHG intensity of marine fuels need to be applied globally through a regulatory framework to ensure a consistent assessment of lifecycle emissions, which will allow investors to direct funds to the most appropriate projects and assets.
- Globally accepted codes and standards need to be developed for the safe integration of alternative fuel solutions, storage and transfer. The approach needs to be globalised to reduce geographical variations and uncertainties, which will allow for a more stable investment environment.

Stakeholder actions

1. The IMO needs to further develop the guidelines on life cycle GHG intensity of marine fuels and the regulatory framework for applying these guidelines needs to be defined. This work is ongoing.
2. Policymakers need to establish a framework that enables the achievement of the IMO GHG strategy, as well as increasing consistency cross-sectorally and globally as shipping integrates into the wider energy value chain and decarbonises alongside other sectors.



4. Research, development and education is needed to enable a safe and sustainable transition (TRL, CRL)

- New safety risks associated with the introduction of alternative fuels need to be identified and assessed, and appropriate mitigations need to be developed and adopted. This is applicable across the supply chain, although the largest knowledge gap is considered to be onboard. It is crucial to prioritise these safety aspects alongside the rapid progress of infrastructure development and deployment, rather than treating them as secondary concerns.
- Wider communities need evidence-based education so that public perception and support for (or opposition to) zero-carbon fuels and technologies is based on facts. For example, evidence that reveals benefits and disadvantages of land-use for renewable energy harvesting for marine fuel production, comparative analysis of various fuel lifecycle emissions, or comparative analysis of safety of nuclear technology against other technologies.
- There needs to be greater transparency of social impacts and supply chain sustainability. For example, sourcing of the raw materials used in batteries (electrification), and emissions across fuel production processes. Social and sustainability impacts on ports are being considered on a port by port basis through a project in collaboration with EDF, Arup, and LR Maritime Decarbonisation Hub. This type of study needs to be undertaken across more regions globally.
- Knowledge gaps in the safe and sustainable adoption of new fuel solutions need to be identified, investigated and findings shared across industries and supply chains, so that a safe and sustainable transition can happen efficiently on a global scale. For example, lessons learned related to handling and storage of ammonia in the fertiliser industry may be transferrable to the marine industry.

Stakeholder actions

1. Crew training centres need to work with research organisations and experts from both shipping and other sectors to develop effective and complete crew training courses, applicable to new fuels, technologies, and infrastructures.
2. Governments need to incorporate new fuel supply chains into long-term sustainability plans and engage impacted communities in these plans through public information campaigns and community consultations, using evidence and facts.
3. The IMO should establish and enforce regulations that mandate transparency and sustainability reporting in supply chains.
4. NGOs should facilitate partnerships and projects that engage stakeholders in developing countries to evaluate both the potential beneficial and adverse social, economic, and health effects on local communities within the framework of pioneering initiatives.
5. Technology providers, ports, shipowners, and new fuel initiatives should employ experts with experience of handling alternative fuels from other industries to share knowledge and best practices that could be transferred to the marine industry.

5. Technology development needs to continue at pace (TRL)

- **TRL** needs to increase, particularly for ammonia and hydrogen at bunkering and onboard handling and storage supply chain stages.
- Storage of hydrogen in ports and onboard ships remains a challenge, and solutions need to be validated and tested.
- Emissions through methane slip need to be abated. This challenge is being addressed by MAMII, which draws upon the expertise of its diverse members to investigate and endorse a range of scalable technology solutions and transparency mechanisms to assist capture, calculate and manage methane emissions activity.
- The impacts of varying biofuel properties from different feedstock types (e.g., advanced biodiesel from third generation feedstocks) are uncertain and need to be investigated over a longer time period.
- For nuclear, technology development across the supply chain is needed, particularly for heat pipe and molten salt reactor technologies.

Stakeholder actions

1. All ammonia value chain members must dedicate resources to develop and deploy measures, practices, and technology to overcome ammonia safety challenges across the supply chain and onboard, addressing the recommendations in the recently published "Recommendations for Design and Operation of Ammonia-Fuelled Vessels Based on Multi-disciplinary Risk Analysis".
2. Ports and shipowners should partner with technology providers, and research institutions to establish pilot projects in ports and onboard ships for the validation and testing of hydrogen storage solutions, aiming to assess their practicality, efficiency, and safety.
3. Research institutions should collaborate with biodiesel manufacturers to conduct comprehensive, long-term studies assessing the impact of varying fuel properties from different feedstock types on storage and propulsion technologies, with the findings shared openly with the shipping industry to inform decision-making.
4. Government and regulatory authorities should allocate research and development funding and provide regulatory guidance to support the advancement of nuclear technologies, especially heat pipe and molten salt reactor technologies, across the entire supply chain.

Recommendations

Actions for stakeholders have been recommended, aligned with each of these priority areas. However, tackling these cannot be achieved through individual efforts or action in isolation within the shipping industry. Considerations for addressing priority areas include:

Collaboration within the shipping industry

While large corporations are leading the way, greater involvement and collaboration between small and medium-sized ship owners (comprising about 60% of the industry) is vital for widespread adoption.

Cross-sector collaboration

Integrating shipping into the broader energy value chain and aligning with government and investor strategies is essential to drive and accelerate the transition.

Transparency and knowledge sharing

Sharing insights from ongoing projects before formal publication is crucial, as well as sharing insights across different industries. This ensures that critical decisions are made promptly, preventing delays in the transition process, and incidents are not duplicated across industries.

Maritime Decarbonisation Hub

Get in touch

www.maritimedecarbonisationhub.org

To find about more information please visit: **www.lr.org/zcfm**

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