MariNH3

Clean, green ammonia
engines for maritime

Green Ammonia as a Maritime Fuel: A Summary of Key Aspects Influencing Market Formation.

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Introduction

The IMO has facilitated the agreement of decarbonisation plans with a target of near to net-zero emissions from global shipping by around 2050, including well-to-wake emissions. The addition of well-to-wake emissions in July 2023 introduced an essential socio-economic driver for green ammonia as a maritime fuel, which could save over 40million tonnes of CO_2 annually in Europe (approx. 1.3%).

It is largely agreed that a suite of solutions will be required for the decarbonisation of the shipping industry, with fuel choice dependent on the vessel size, its cargo and type of journey. Ammonia in liquid form is energy dense so is particularly suitable for longer ship voyages, and conservative estimates put green ammonia at 35% of the market ranging up to 79% of the market (Lloyd's Register, 2023b).

Green ammonia as a highly traded chemical has market-based advantages over other potential fuels due to its existing global infrastructure (Elishav et al., 2021) and with crew accustomed to its safe handling. Ammonia has lower storage costs than hydrogen (Kojima, 2013), requires less energy than hydrogen to liquify and half the onboard storage. However, ammonia requires three to four times the space as fossil fuels (Ash and Scarborough, 2019). It is notable that whilst ammonia has challenges within its trajectory to be utilised as a fuel, alternatives also face similar challenges. These are summarised in Table 1:

	Gaseous nature	Toxicity	Low temperature	Flammability	Main Cost	Main engineering challenge
Ammonia	X	X	-33		Renewable energy for production	Toxicity, NOx
Hydrogen	X		-252 becomes gas	X	Storage & transportation	Flammability, low energy density
Methanol	X	X		X		
Methane	X		X	X		

Table 1: Comparison of alternative fuels, author's own.

Green ammonia can be used in the internal combustion engine with some modifications and innovation efforts are currently focused on the retrofit of existing vessels and incorporation of green ammonia in new vessels. Whilst any emissions from ammonia combustion can be managed with existing procedures, innovation is focusing on reducing these levels and the future is likely to include ammonia fuel cells which would eliminate nitrogen oxide residues.

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Barriers and opportunities

Legislation for the use of green ammonia as a fuel

Currently, no legislation exists that unilaterally permits the use of ammonia as a fuel for shipping, nor is there a regulatory framework that would govern its use. The ongoing innovation around the utilisation of green ammonia as a fuel coupled with the infancy of the market is thought by some experts to make it difficult to develop an appropriate framework. However, as a globally traded good, there is ammonia legislation that controls the distribution of this chemical.

Due to the international nature of shipping routes and the ammonia supply chain, this means that the market will be subject to differing legislative regimes that are both national and international. Whilst the UK has left the European Union, the central Westminster government has outlined that it is unlikely that UK-specific legislation will be created due to the complexity this would create vessels that are registered in the UK and operate in European and International waters.

Ship building legislation

Existing legislation for ammonia focuses on controlling risk, occupational safety, impact on the environment and storage. Alongside this, to enable its use as a fuel, ship building legislation will be renewed to accommodate the utilisation of alternative fuels and the design changes that will be necessary.

The International Convention for the Safety of Life at Sea (SOLAS) controls the integrity of vessels, where the Flag State (where the vessel is registered) is responsible for ensuring compliance and certification. Port State control is a procedure that allows the inspection of ships by other States if there are grounds to suspect non-compliance with the Convention.

Under SOLAS and related to the use of fuels, the International Code of Safety for Ship Using Gases of Other Low-flashpoint Fuels (IGF Code) provides an international standard for ships and vessels covered by The International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC code). Adopted in 2015, the IGF Code sets out mandatory criteria for the arrangement and installation of machinery, equipment and systems that use these fuels to minimise the risk to the ship, its crew, and the environment. It is based on naval architecture and engineering principles coupled with understanding of field data and research.

These codes will be instrumental in vessel design and use of alternative fuels. It is likely that ammonia fuel capabilities will be retrofitted on to some ships due to the long lifespan of vessels (20 - 30 years). The MCN 664 (M+F) Certification process for vessels using innovative technology applies to those registered and operating in UK waters and certification is assessed on an individual vessel basis and is supplemental to other regulations.

Protecting the workforce

Whilst SOLAS, IGF, IGC and MCN 664 aim to control risk from a ship design perspective, there is also regulation to control the risk of ammonia as a chemical.

The purpose of EU Regulation No. 1907/2006 for the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) is to improve protection of human health and the environment that can be posed by chemicals, while at the same time enhancing the competitiveness of the EU chemical industry. The EU and UK REACH operate independently of one-another, and it is necessary to ensure compliance with both regulations.

The goal of the UK REACH is to protect human health and the environment, place responsibility on manufacturers and importers to understand and manage the risks, and promote the use of alternative methods to assess the properties of a hazardous substance. Specific to the UK, the Control of Substances Hazardous to Health (COSHH) outlines substances considered hazardous to health and include fumes, dust, vapours, mists and gases.

Human exposure limits have been standardised and are dependent on the airborne concentration and exposure time. The UK sets workplace exposure limits of 25ppm for up to eight hours and 35ppm for up to 15 minutes, the USA Standard 1910.1000 limits exposure of 50ppm for eight hours per forty-hour week. This type of legislation has repercussions on staff management and could be challenging on a vessel with the number of crew available limited. However, the experience of the farming and refrigeration industry shows the suitability of current legislation and the value of approaching the handling of ammonia with care and in combination with other guidelines.

The International Labour Organisation codes anhydrous ammonia with a Hazard ID of 268. ‘2’ refers to the hazard of gas emission due to pressure or chemical reaction, ‘6’ refers to its toxicity and ‘8’ refers to its corrosive nature. Occupational safety is therefore an important area of legislation and the European ATEX directive addresses explosive atmospheres and the prevention of the release of dangerous substances. In the UK, The Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) places duty on employers to eliminate or otherwise control risks from explosive atmospheres through understanding the risks of all substances.

Environmental legislation

Were fuel of any kind leaked or spilled into the fragile marine environment there would be a significant impact, leading to a raft of UK, European and International regulations that include comprehensive survey and certification requirements. It is notable that the impact of ammonia in these environments is less than other fuel

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sources and have greater potential to be cleaned effectively from the environment (Environment Defence Fund, 2022).

The International Convention for the Prevention of Pollution from Ships, extensively referred to as MARPOL, is the main international convention that relates to a wide range of operational or accidental causes of pollution to the marine environment by ships. MARPOL has six technical Annexes relating to oil; noxious liquid substances in bulk; harmful substances carried by sea in packaged form; sewage from ships; air pollution from ships; and rubbish from ships. Annex VI is subject to revision by the IMO to include alternative fuels, with guidelines expected to be completed in 2024.

From this point the IMO Maritime Safety Committee can consider the legal implications of ammonia as a fuel (Managing emissions from ammonia-fuelled vessels - March, 2023).

Safety at port

Risk also needs to be controlled at port and on land. Ports will have an important role in the transition to a global green ammonia maritime industry and the overall reduction of shipping's impact on the environment.

Under The Clydebank Declaration, there are proposals to develop green shipping corridors that link maritime routes between ports that can service net-zero fuels. There are 30 green shipping corridors announced that are in early planning stages, these will be important in promoting a place-based approach to enabling the net zero transition.

120 ports globally (Alfa Laval et al., 2020) already engage with the ammonia industry, these ports could be some of the frontrunners in this industry. European ports have the highest score in terms of port readiness with a clear focus on sustainability, especially when compared to Brazilian and American ports (Grieg Star, 2023).

Under MARPOL, the control of Volatile Organic Compounds (VOCs) at tanker terminals is approached on an individual basis, with applications submitted over 18 months before the date of regulation – introducing a potential time constraint to the development of an ammonia market. The port manages the size of tanker, how vessels are refuelled and operational practices. In the case of ammonia, DNV (2023) suggests that ammonia would be more safely bunkered at sea or anchorage than in a port whilst conducting simultaneous operations (SIMOPs), as is common with shipping vessels, alternatively ammonia could be bunkered at ports where SIMOPS are not practiced.

The EU - SEVESO III (2012/18/EU) deals with the identification of sites, control measures and mitigation measures to limit the effect of an accident, relating directly to onshore major accident hazards. The UK's Control of Major Accident Hazards

(COMAH) also falls under the Seveso III Directive and mainly applies to the chemical industry but also storage activities.

Land-use planning related to COMAH comes under the directive of the devolved governments in the UK. Notably, ammonia is prone to theft and several countries have passed legislation making it a criminal offence to carry stolen ammonia or carry it in nonapproved containers. The UK's Network and Information Systems Regulations 2018 (NIS) relates to the control of accident hazards and essential service loss, placing importance on control systems and cyber security.

Outlook for market formation

Whilst there is extensive legislation around the ammonia supply chain, the lack of specific legislation for its use as a maritime fuel poses a significant barrier to market formation due to the absence of certainty on which much of the supply chain relies.

Much of the current legislation means that those first movers in the ammonia market incur risk and extensive requirements for inspection and certification on a vessel-by-vessel basis. It is necessary for the legislation to keep pace with the innovation as otherwise there is the potential for over (or under) design of devices and practices for the utilisation of ammonia as a fuel. Currently, much of the industry is working on conservative guidelines (MMMCZCS, 2023).

Further, without stringent incentives for the reduction of carbon intensity, there is little economic motivation for the industry to incur reduced profits to adopt low carbon fuels. It is estimated that a global investment of up to 6 trillion USD would be required to decarbonise around 40% of international shipping (container vessel and non-coal dry bulk carrier fleets) (Ash and Scarborough, 2019). However, due to ammonia's suitability for the internal combustion engine, should ammonia become the preferred fuel for the maritime industry, the retrofit will increase the value of the vessel and should ammonia not succeed the vessel can still run on conventional fuel (Grieg Star, 2023, p57).

Regardless, within current legislation the use of green ammonia would be financially beneficial due to the negation of slow steaming, where the vessel slows in order to reduce emissions. There is an estimated 75% reduction in emissions compared to conventional fuel and this will also result in lower costs from carbon tax (Grieg Star, 2023, p52).

The cost of green ammonia is very high when compared to ammonia produced in a conventional way, with predictions that this will become comparable with fossil fuels when the cost of renewable energy drops to below 20 USD per mega-watt hour (Future Bridge, 2022). However, with the International Maritime Organisation's introduction of well-to-wake emissions accounting in July 2023, the cost of ammonia will become increasingly favourable with this sustainable accounting system that changes the conventional cost metrics.

One of the recurrent challenges for market creation is the balancing of supply and demand, which is problematic without governmental support for ammonia (Grieg Star, 2023; Lloyd's Register, 2023b; DNV, 2023). The current level of ammonia production (not green) is already sufficient to run the international fleet of container vessels (Ash and Scarborough, 2019) – this shows that there is the possibility to produce a sufficient scale of ammonia, but consideration must be given to its other uses (Lloyds Register, 2023).

There would need to be three times the current scale of ammonia production to supply the whole internal shipping vessel fleet. On top of this, sufficient ammonia would need to be produced to support the farming sector. This indicates that there will need to be a significant number of new production sites to support green ammonia as a maritime fuel. When coupled with the need for a significant supply of renewable energy this opens opportunities for new countries to enter global shipping as market leaders. Scalability is not a challenge unique to green ammonia as a fuel, and is increasingly the subject of study. Aspects such as green corridors will further support the scaling-up of green ammonia experiments.

Conclusions

International harmonisation of regulation will be important (MMMCZCS, 2023) to enable vessels to operate globally irrespective of crew nationality or flag of ship (Grieg Star, 2023).

To accelerate market formation, Maersk emphasises a need for collaboration to make the technology a success through the design of engines and pollution control simultaneously, outlining that "regulators should follow upcoming tests and technology development closely to ensure that practical, effective, and realistic targets and goals are set from the beginning." It is also necessary for legislation to compensate for the higher costs of more sustainable ammonia production with instruments such as carbon tax levelling perceived costs, particularly when taking into consideration the current need for 'slow sailing' days where vessels seek to reduce their current emissions (Grieg Star, 2023).

The costs involved with facilitating the green ammonia market requires co-ordination between multiple governments, as first adopters will initially pay a higher cost per nautical mile whilst awaiting cost reductions through innovation, economies of scale, and a greater supply of renewable energy electricity. Without supporting policies that drive towards net zero, economic evaluations of transitioning to green ammonia will continue to favour fossil fuels. Conversely, there is the potential of a strategic advantage for those that are front runners in the innovation and deployment of this technology (Nayak-Luke et al., p30). With efforts to reduce renewable electricity costs, a break-even point could be achieved by 2040 at the latest using conservative estimates (Alfa Laval et al., 2020), with well-to-wake emissions factored in this could be achieved sooner.

Other methods of accelerating the market include grants and subsidies to share financial risk (Grieg Star, 2023). However, governments are often reluctant to pick 'winning' technologies, typically setting carbon reduction targets and allowing the market to provide a solution. Within maritime green ammonia, there are interesting examples of industry-led market creation activities, such as the Zero Emission Maritime Buyers Alliance's (ZEMBA) 'Request for Proposals' for 600,000 twenty-foot containers on ocean vessels with zero-emission fuel. This form of supply chain contract will promote market co-ordination and innovation. Furthermore, as ZEMBA has members that include Amazon, IKEA and Nike, it is a strong signal that major shipping customers will increasingly prioritise green-credentials in their contracting arrangements. These hugely influential market actors could complement actions taken at the state level. The EU in particular is identified as a key player to catalyse the green ammonia energy market, and The Ammonia Society calls for public policy support.

The uncertainty around future ammonia related emissions and regulations is not uncommon to new technologies, as evidenced by the 'pacing problem' and precautionary principal that was developed from this. In the instance of green ammonia this allows for the consenting of vessels on an individual basis, but as highlighted by this report it can introduce barriers to technology uptake and market formation. It is in this arena that, MariNH$_3$ as a multi-disciplinary project can contribute through advanced and integrated research around the themes of acceptance, fundamentals and application.

This report identifies potential barriers and opportunities within the innovation system, whilst the engineering teams seek to understand what might be possible for future funnel emissions and assess related impacts, paying particular attention to non-regulated emissions that are strongly related to ammonia end use such as ammonia slip (unreacted ammonia that was intended to react with nitrous oxide to scrub out of combustion-based exhaust gases) and nitrous oxide. Within this framing, it is clear that when the current legislative horizon ends in 2026, new metrics must be introduced that provide stimulus for the rollout of green ammonia as a maritime fuel.

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