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Challenge 1

Mitigate safety and ecological risks associated with the use of low-emissions fuels, such as ammonia and hydrogen

The use of hydrogen and ammonia as marine fuels presents new challenges in establishing social licence, due to safety and ecological risks. Hydrogen is flammable and presents an explosion risk. Ammonia is highly toxic, presenting a risk to both human health and aquatic life. Therefore, public acceptability is important to facilitate the uptake of these fuels. In particular, it must be established that the risks associated with the handling, bunkering and onboard use of these low-emissions fuels are as low as reasonably practical (ALARP). As a result, there is a need to demonstrate relevant processes, train personnel at ports and onboard vessels, and establish mitigation strategies to minimise risks.

The opportunity for Australia and Singapore

Mitigating the risks associated with hydrogen and ammonia will support industry participants in both Australia and Singapore in achieving the IMO's GHG emissions targets for international shipping. Addressing this challenge will also promote economic growth in both countries. Australia is projected to become a leading exporter of low-emissions hydrogen and ammonia, given its extensive renewable energy resources, as well as its natural gas reserves and potential CO_2 storage sites. Furthermore, Singapore is looking to position itself as a green bunkering hub, which will require importing hydrogen and ammonia from countries like Australia. In a recent study, the Global Centre for Maritime Decarbonisation (GCMD) projected in its 'realistic' scenario that ammonia bunker demand in Singapore will reach 50 Mt by 2050.[1]

Supporting information

Ammonia is considered toxic to both human health and aquatic life following exposure at certain concentrations and durations. Given ammonia is already a widely traded commodity, there are comprehensive assessments relating to the safety of ammonia handling, storage and transportation on land. However, safety analysis relating to ammonia as a marine fuel is still in early stages.[2] Therefore, physical demonstrations of ammonia bunkering and use on vessels are still required to validate the safety of these processes and establish the appropriate standards (including training requirements).

The safety concerns for hydrogen relate to the explosion risk. Hydrogen has high flammability, lacks an odour, can diffuse quickly and has a near-invisible flame when burnt. Therefore, leakages are difficult to detect and have an increased risk of ignition. Hydrogen also has a high risk of explosion when stored under pressure. As a result, demonstrations of hydrogen bunkering and use onboard vessels are required to inform explosion risk mitigation measures (e.g. odour additives, ventilation requirements).

1 GCMD (2023) Ammonia bunkering pilot safety study. <https://www.gcformd.org/ammonia-bunkering-safety-study> (accessed 1 May 2023).

2 Yang M, et al. (2022) Ammonia as a marine fuel. Nanyang Technological University, Singapore.

Existing projects

PROJECT/STUDY NAME	PARTNERS	DESCRIPTION
Ammonia bunkering pilot safety study[3]	Global Centre for Maritime Decarbonisation	A study that outlines suitable sites, operations and risks for bunkering pilot trials in Singapore to enable safe demonstrations
Ammonia as a marine fuel – bunkering, safety and release simulations[4]	Nanyang Technological University, Singapore Maritime Institute	A study that simulates the dispersion pattern of ammonia in the event of a hose rupture scenario during bunkering. It draws on these simulations to make recommendations for bunkering configurations and a review of mitigation measures
Expression of interest to develop an end-to-end low- or zero-carbon ammonia power generation and bunkering solution ('project') in Singapore[5]	Energy Market Authority and Maritime Port Authority Singapore	Projects that enable the verification, demonstration and build-up of capabilities for ammonia use in Singapore, with end use in both power generation and bunkering
Ammonia at sea[6]	Environmental Defense Fund, Lloyd's Register, Ricardo PLC	An environmental assessment report on the impacts an ammonia spill may have on marine life and ecosystems
Yara/PPA ammonia bunkering study[7]	Yara Clean Ammonia, Pilbara Ports Authority (PPA)	A study to identify the required bunkering infrastructure to meet estimated demand, and ensure safe operations and guidelines for ammonia handling/use
Ammonia-powered bulk carrier: Pilot Report[8]	Green shipping Programme, Grieg star	A study to determine the risks and suitability of retrofitting a bulk carrier to operate on ammonia
Ammonia as a marine fuel: Safety handbook[9]	Green shipping Programme, Grieg star, Norwegian Maritime Authority	An outline of safety recommendations for ammonia-powered ship design

Potential projects

PROJECT	DESCRIPTION
Early detection warning systems	Test onboard early detection warning systems in the case of an ammonia leak
Ship-to-ship bunkering pilot	Demonstrate successful ship-to-ship bunkering procedures
Water curtains	Test mitigation impact of water curtains in the case of a leak

3 GCMD (2023) Ammonia bunkering pilot safety study. <https://www.gcformd.org/ammonia-bunkering-safety-study> (accessed 1 May 2023).

4 Yang M, et al. (2022) Ammonia as a marine fuel. Nanyang Technological University, Singapore; Dawson L, et al. (2022) Ammonia at sea: Studying the potential impact of ammonia as a shipping fuel on marine ecosystems. Environmental Defense Fund. <https://www.edfeurope.org/sites/euroedf/files/EDF-Europe-Ammonia-at-sea-FullReport.pdf> (accessed 23 February 2023).

5 MPA (2022) Expression of interest (EOI) to develop an end-to-end low or zero-carbon ammonia power generation and bunkering solution ('project') in Singapore. <https://www.mpa.gov.sg/docs/mpalibraries/media-releases/older/expression-of-interest-for-ammonia-project-(final).pdf> (accessed 10 May 2023).

6 Dawson L, et al. (2022) Ammonia at sea: studying the potential impact of ammonia as a shipping fuel on marine ecosystems. Environmental Defense Fund. <https://www.edfeurope.org/sites/euroedf/files/EDF-Europe-Ammonia-at-sea-FullReport.pdf> (accessed 23 February 2023).

7 Yara (2022) Yara Clean Ammonia and Pilbara Ports Authority team up to assess ammonia as a shipping fuel. <https://www.yara.com/news-and-media/news/archive/news-2022/yara-clean-ammonia-and-pilbara-ports-authority-team-up-to-assess-ammonia-as-a-shipping-fuel/> (accessed 10 May 2023).

8 Green Shipping Programme (2023) Ammonia powered bulk carrier pilot report. <https://greenshippingprogramme.com/wp-content/uploads/2023/06/Ammonia-powered-bulk-carrier.-Pilot-report.pdf> (accessed 19 June 2023).

9 Green Shipping Programme (2023) Ammonia as a marine fuel: Safety handbook. <https://greenshippingprogramme.com/wp-content/uploads/2021/03/Ammonia-as-a-Marine-Fuel-Safety-Handbook-Rev.02.pdf> (accessed 22 June 2023).

Challenge 2

Develop technology and infrastructure at ports to accommodate the adoption of low-emissions fuels

As port and vessel operators in Australia and Singapore transition to using low-emissions fuels, new port technologies and infrastructure will be required, including bunkering, charging and storage facilities. These developments will provide assurance to investors in new vessels that ports will be able to supply low-emissions fuels once they become available.

With the expectation of a multi-fuel future to meet maritime decarbonisation demands, ports face increasing pressure to ensure compatibility with various fuel options (e.g., hydrogen, ammonia, methanol, and electricity). In addition, given that the volume requirements for low-emission fuels will be significantly greater than those for conventional fuels (due to the lower volumetric energy density), more infrastructure and land area are required to store and transfer these fuels. Limited space creates a challenge for port operators to improve existing processes and expand operations to meet user demands while maintaining cost competitiveness.

The opportunity for Australia and Singapore

With many ports in Australia, each specialising in specific vessel types and cargo, there is an opportunity to supply a range of fuel types. The shift to low-emissions fuels will likely lead to bunkering more frequently (due to the lower volumetric energy density than conventional fuels). Although Australian ports are not typically used for bunkering, the added demand could enable several locations to provide this service in support of green corridors.

As a global bunkering hub, Singapore has an opportunity to make use of innovative solutions to optimise storage and bunkering. The limited space available in Singapore means these solutions will be essential for the port to supply low-emissions fuels. There is also an opportunity for shared infrastructure across sectors given that some low-emissions fuels (e.g., ammonia) are viable solutions to decarbonise other sectors (e.g., power generation).

Supporting information

The compatibility of bunkering and recharging infrastructure across ports will be required to support a multi-fuel future. Because fuels such as methanol, ammonia and hydrogen have different material requirements to ensure safety and prevent corrosion or leakage, this creates an extra complexity for ports to coordinate. To minimise upfront investment costs, establishing retrofit options for existing (and future) storage and refuelling infrastructure will provide greater confidence for investors in the short term. For example, LPG and LNG infrastructure could be retrofitted for the use of ammonia, which will reduce the need for new infrastructure investment as ammonia becomes available.

Battery electric vessels present additional challenges. Full battery electric vessels require more frequent recharging for longer periods of time (compared with refuelling), which presents the logistical difficulty of navigating other port traffic. The development of charging technology and infrastructure will also be required. This will be the case not only for short-sea vessels, but also deep-sea shipping, because drawing on shore power while in port can reduce emissions in the short term (assuming renewable electricity is supplied).

To address the space constraints and upfront costs associated with new storage and refuelling infrastructure, ports could consider common user facilities. Before fuel production plants reach large scale, it is likely that multiple producers will be supplying small volumes to ports. As a result, the infrastructure costs pose a large cost barrier to an individual producer. The integration of storage between operators or industries (e.g. power generation and maritime) would reduce the cost of newbuild infrastructure, particularly while the volume of fuel supplied is small. However, this is a rare practice in ports and would require business model development to consider the most cost-effective use of infrastructure for multiple suppliers and users. A pilot trial would likely be needed to demonstrate the feasibility of such a model.

Offshore storage and refuelling options can also address the barrier of limited land availability and potential safety concerns. However, this can present challenges with navigating vessel routes. Because the structure of waterways at each port is unique, feasibility studies for each port to determine the most viable offshore locations would likely be required. Demonstrations that the technology is successful without increasing safety risks would also be needed.

Existing projects

PROJECT/STUDY NAME	PARTNERS	DESCRIPTION
Ammonia floating storage and regasification barge[10]	NYK Line, IHI Corporation, Nihon Shipyard Co., Ltd	Developing an offshore floating facility to store, degasify and send onshore when needed. (The risk-identification portion of the project has been completed)
Charging Infrastructure implementation masterplan[11]	MPA	Conducting a study on locations for electric recharging facilities to support the electric harbour craft
Keppel Offshore and Marine Ltd Consortium[12]	Keppel Offshore & Marine Ltd, Eng Hup Shipping, The Energy Research Institute @ NTU, Envision Digital, Surbana Jurong and DNV	Use Keppel Offshore & Marine's Floating Living Lab as a testbed for electric charging infrastructure
Green Port[13]	Port of Risavika, DNV, Kystverket, Kystrederiene, Kongsberg, ABB, Equinor	A pilot project to identify the feasibility of and technical needs for the electrification of cranes, trucks, shore-power, hybrid vessels etc

Potential projects

PROJECT	DESCRIPTION
Floating storage and refuelling options	A demonstration of floating storage or refuelling kiosks at ports to determine the impact on port traffic and vessel logistics
Common user infrastructure	A feasibility study on the economic benefit of installing common use pipelines
Retrofitting LPG infrastructure to ammonia	Investigating the technological and economic requirements to retrofit LPG infrastructure to ammonia

10 NYK Line (2023) Parties obtain world's first AiP for ammonia floating storage and regasification barge. [Press release] <https://www.nyk.com/english/news/2023/20230105_01.html> (accessed 10 May 2023).

11 MPA (2023) Media Factsheet: Strengthening Singapore's Competitiveness as a Hub Port and International Maritime Centre. <https://www.mpa.gov.sg/media-centre/details/strenghtening-singapore-s-competitveness-as-a-hub-port-and-international-maritime-centre> (accessed 6 June 2023).

12 MPA (2023) Media Factsheet: Strengthening Singapore's Competitiveness as a Hub Port and International Maritime Centre. <https://www.mpa.gov.sg/media-centre/details/strenghtening-singapore-s-competitveness-as-a-hub-port-and-international-maritime-centre> (accessed 6 June 2023).

13 Green Shipping Programme (2020) Green Port. <https://greenshippingprogramme.com/pilot/green-port/> (accessed 19 June 2023).

Challenge 3

Reduce the cost of low-emissions technologies in short-sea vessels

Many large shipping companies are investing in newbuild deep-sea vessels operating on low-emission fuels; however, the cost to smaller firms investing in short-sea vessels can be a larger hurdle. Reducing the initial capital cost barrier for small low-emissions vessels will be the main enabling factor to uptake. Given the capital outlay for these vessel types will be relatively small from an overall funding perspective, investing in these projects presents low-hanging fruit towards decarbonising port operations.

The opportunity for Australia and Singapore

Although not the main contributor to emissions in the maritime sector, short-sea vessels such as tugboats, bunker vessels and ferries will also need to be powered by low-emission fuels to fully decarbonise maritime operations. Introducing low-emissions technologies into the large number of short-sea vessels operating in Australia and Singapore will also give investors confidence that the supply chain is actively working towards full decarbonisation.

Trialling low emissions technologies in short-sea shipping may also provide learnings that can be transferred to other applications. For example, hydrogen fuels cells (FCs) could potentially be adopted for medium-distance journeys on routes where frequent bunkering is possible. Furthermore, incorporating technologies such as methanol or ammonia FCs (direct or indirect) into short-sea vessels may also provide insights that can be applied to deep-sea vessels.

Although each port will have its own combination of short-sea vessels, learnings can be shared across ports and countries. This can provide more certainty on the viability of low-emissions technology in short-sea vessels and reduce costs for later adopters. In Singapore, investments are already being made in this area to support the MPA target for new harbour craft (these vessels must be full electric, capable of using B100 biofuel or compatible with net-zero fuels such as hydrogen by 2030).[14] Learnings from these initiatives could guide Australian ports as to the viable options for decarbonising and ensure that the corridor between the two countries has compatible infrastructure. With 106 ports located around Australia, there is also an opportunity to trial technologies and share those learnings with other ports in Australia.

Supporting information

Battery electric technology is further developed than other low-emission options, making it a favourable short-term solution for short-sea shipping. These systems are currently better suited to smaller vessels and short routes due to the weight and cost of battery technology. Although the high capital cost is still a barrier to adoption for these vessels, this can be offset by the lower fuel costs in the long term.

FCs are being favoured for longer-term adoption in short-sea shipping.[15] There are several types of FCs, such as proton-exchange membrane fuel cells (PEMFC), direct methanol fuel cells (DMFCs), solid oxide fuel cells (SOFC) and molten carbonate fuel cells (MCFC). Currently PEMFC systems that run off pure hydrogen are the most mature (TRL 8). The development of DMFCs (designed to have methanol as the only input) is underway (at TRL 5), but these have much lower efficiencies of around 20%.[16] Finally, SOFCs and MCFCs are higher cost and larger systems that operate at high enough temperatures to allow input from multiple fuels, including methanol.[17]

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14 MPA (2023) Media factsheet: Strengthening Singapore's competitiveness as a hub port and international maritime centre. <https://www.mpa.gov.sg/media-centre/details/strenghtening-singapore-s-competitveness-as-a-hub-port-and-international-maritime-centre#:~:text=MPA%20will%20set%20the%20target,2050%20national%20net%2Dzero%20target> (accessed 10 May 2023); MPA (2022) Maritime Singapore decarbonisation blueprint: Working towards 2050. Maritime and Port Authority of Singapore.

15 Casisi M, Pinamonti P, Reini M (2020) Increasing the energy efficiency of an internal combustion engine for ship propulsion with bottom ORCs. Applied Sciences 10, 6919; Liu M, et al. (2020) A study on the future energy options of Singapore Harbour craft. Nanyang Technological University, Singapore.

16 Ovrum E, et al. (2022) Maritime forecast to 2050. DNV. <https://www.dnv.com/maritime/publications/maritime-forecast-2022/index.html> (accessed 5 June 2023); Tronstad T, et al. (2017) Study on the use of fuel cells in shipping. EMSA. <https://www.emsa.europa.eu/publications/item/2921-emsa-study-on-the-use-of-fuel-cells-in-shipping.html> (accessed 4 May).

17 Tronstad T, et al. (2017) Study on the use of fuel cells in shipping. EMSA. <https://www.emsa.europa.eu/publications/item/2921-emsa-study-on-the-use-of-fuel-cells-in-shipping.html> (accessed 4 May).

Existing projects

PROJECT/STUDY NAME	PARTNERS	DESCRIPTION
Elektra[18]	Behala, Ballard Power Systems, Anleg	Developed a push boat driven by an electric FC hybrid system
Future of the Fjords[19]	Brodrene Aa	Operating an all-electric passenger catamaran with two electric engines, as well as a floating dock for recharging
Incat Electric[20]	Incat	Integrating an electric and hydrogen FC into a RoPax ferry
Largest lightweight battery electric ship[21]	Incat	Constructing the world's largest 100% battery-electric Ro-Pax ferry, with over 40MWh battery storage
Electric Dream[22]	Incat Crowther	Design and development of full electric passenger ferry to carry passengers between mainland Singapore and the island of Bukom
Sea Change[23]	Incat Crowther	Launch of hydrogen fuel cell-powered electric-drive high speed passenger ferry to operate in California
High-speed hydrogen-powered passenger vessels[24]	Kinn Kommune, DNV, Norwedgian Maritime Authority, Kongsberg, Corvus Energy, ABB, Equinor	A project to pilot a high-speed hydrogen fuel cell-powered passenger vessel (100–150 passenger capacity), and to analyse feasibility, investment and operating costs, payback time and environmental benefits

Potential projects

PROJECT	DESCRIPTION
Trial of FCs	Demonstrate FC propulsion on alternative fuels (hydrogen, ammonia or methanol) using a common use or 'lease style' business model for vessel trials to reduce upfront capital expenditure

18 Habibic A (2021) Germany welcomes 1st emission-free hydrogen-fueled push boat. Offshore Energy. <https://www.offshore-energy.biz/germany-welcomes-1st-emission-free-hydrigen-fueled-push-boat> (accessed 4 May).

19 Brodrene AA (2018) The Fjords takes delivery of groundbreaking 'Future of The Fjords'. <https://www.braa.no/news/future-of-the-fjords> (accessed 4 May 2023).

20 Incat (2021) Incat electric: The back to zero revolution. <https://www.incat.com.au/wp-content/uploads/2021/08/Back-to-ZERO-Flyer.pdf> (accessed 10 May 2023).

21 Incat (2023) Australian shipbuilder incat Tasmania to deliver the world's largest battery electric ship. <https://incat.com.au/australian-shipbuilder-incat-tasmania-to-deliver-the-worlds-largest-battery-electric-ship/> (accessed 30 August 2023).

22 Incat Crowther (2021) Electric dream coming to Singapore. <https://www.incatcrowther.com/news/news-feed/posts/2021/sep/electric-dream-coming-to-singapore/> (accessed 30 August 2023).

23 Incat Crowther (2021) Zero-emission hydrogen fuel cell ferry hits the water. <https://www.incatcrowther.com/news/news-feed/posts/2021/sep/zero-emission-hydrogen-fuel-cell-ferry-hits-the-water/> (accessed 30 August 2023).

24 Green shipping programme (2020) High-speed hydrogen-powered passenger vessels. <https://greenshippingprogramme.com/pilot/high-speed-hydrogen-powered-passanger-vessels/> (accessed 19 June 2023).