Fuelling the decarbonisation of iron ore shipping between Western Australia and East Asia with clean ammonia

Green shipping corridor feasibility assessment

Supplied by Pilbara Ports Authority

GLOBAL MARITIME FORUM

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Supplied by BPH

Acronyms and glossary

Acronyms

AiP Approval in Principle

AREH Australian Renewable Energy Hub

BAF Bunker Adjustment Factor

CAPEX Capital Expenditure

CCS Carbon Capture and Storage

CfD Contract for Difference

CII Carbon Intensity Indicator

COA Contract of Affreightment

EEDI Energy Efficiency Design Index

EOI Expression of Interest

ETC Energy Transitions Commission

EU ETS European Union Emissions Trading Scheme

FID Final Investment Decision

GCMD Global Centre for Maritime Decarbonisation

GMF Global Maritime Forum

GO Guarantee-of-Origin

GtZ Getting to Zero Coalition

GW Gigawatt

H2 Hydrogen

HFO Heavy Fuel Oil

IEA International Energy Agency

kg Kilogram

LCA Life Cycle Assessment

LCOP Levelised Cost of Production

LNG Liquified Natural Gas

LOI Letter of Intent

ICS International Chamber of Shipping

IFO Intermediate Fuel Oil

IGF Code International Code of Safety for Ships using Gases or Other Low-flashpoint Fuels

IRENA International Renewable Energy Agency

IMO International Maritime Organisation

MCR Maximum Continuous Rating

MoU Memorandum of Understanding

MPA Maritime and Port Authority of Singapore

MPP Mission Possible Partnership

Mt Million tonnes

NGO Non-Governmental Organisation

NH_3 Ammonia

nm Nautical mile

OEM Original Equipment Manufacturer

PPA Pilbara Ports Authority

SGMF Society for Gas as a Marine Fuel

SOLAS International Convention for the Safety of Life at Sea

STCW International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

STS Sector Transition Strategy

SZEF Scalable Zero-Emission Fuel

UMAS University Maritime Advisory Service

UN United Nations

Glossary

Clean ammonia

Low and zero-carbon ammonia. This umbrella term includes both “green” ammonia, produced with electrolytic hydrogen, and “blue” ammonia, produced from conventional hydrogen with applied carbon capture and storage.

Zero-emission vessels and fuels

Vessels and fuels with the potential to achieve zero- or near-zero greenhouse gas emissions on a lifecycle basis. See the *Getting to Zero Coalition’s definition of zero carbon energy sources* for further clarification.

Ammonia-powered vessels

Vessels with the ability to use ammonia as their primary fuel.

Clean-ammonia-powered vessels

Vessels that operate on clean ammonia as their primary fuel.

“Upper envelope” of clean ammonia demand

The amount of clean ammonia needed to power the full zero-emission fleet on the corridor, used for stress testing the fuel’s potential to contribute to the greening of the route.

Port regions

The geographical focus of this report covers seaborne trade of iron ore between Western Australia and the following groups of ports in East Asia:

- Port region 1: Bayuquan, Caofeidian, Caojing, Changzhou, Dalian, Dandong, Dongjiakou, Fangcheng, Huanghua, Jingtang, Kemen, Lanshan, Lianyungang, Liuheng, Majishan, Ningbo, Qingdao, Rizhao, Shanghai, Tianjin, Zhangjiagang, Zhanjiang
- Port region 2: Gwangyang, Onson, Pohang, Pyeongtaek, Ulsan, Yeosu
- Port region 3: Chiba, Fukuyama, Higashiharima, Hirohata, Ichihara, Kashima, Kawasaki, Kisarazu, Kobe, Kure, Mizushima, Oita, Tokuyamakudamatsu, Tokyo Bay, Yokohama
- Port region 4: Kaohsiung, Mailiao, Tiachung

Endorsements

This report is based on analysis by the Energy Transitions Commission, on behalf of the Australia to East Asia Iron Ore Green Corridor Consortium, a collaboration between the Global Maritime Forum, BHP, Rio Tinto Shipping (Asia) Pte. Ltd., (Rio Tinto), Oldendorff Carriers GmbH & Co (Oldendorff Carriers) and Star Bulk Carriers Corp. (Star Bulk).

"Through this collaboration with the Global Maritime Forum and the consortium members, BHP is pleased to see that the rigorous, data-led analysis of this study indicates the feasibility of using clean ammonia on vessels sailing through the West Australia to East Asia corridor. In line with our net zero ambitions, we seek to influence this supply chain, with our ecosystem partners, by creating demand for low- and zero-GHG emission fuels and energy efficient vessels."

Rashpal Bhatti, Vice President Maritime and Supply Chain Excellence, BHP

"The West Australia – East Asia iron ore Green Corridor represents a great opportunity to aggregate green fuel demand and supply in support of the industry's journey towards net-zero in this major trade lane. As we build on the study to realise a safe and economic green shipping corridor, public-private partnership is key to bring this project to life. Rio Tinto remains committed to collaborating with value chain partners in support of this initiative as we work to deliver our climate commitments on shipping."

Laure Baratgin, Head of Commercial Operations, Rio Tinto

"Being one of the founding members of the West Australia to East Asia iron ore Green Corridor Consortium was an excellent opportunity for Oldendorff Carriers to collaborate and share perspectives with the other Consortium members on the feasibility of reducing emissions on this strategic iron ore trade.
We are pleased to join in sharing this feasibility assessment to show how a well-considered Green Corridor can facilitate our collective desire to decarbonize shipping with an alternative fuel.
While outside the scope of this report, the safety concerns and environmental risks of ammonia have yet to be adequately addressed. As the safety of our crew is paramount, these challenges must be overcome to enable adoption."

Scott Bergeron, Managing Director Global Engagement & Sustainability, Oldendorff Carriers

"Working closely with our business partners to assess the feasibility of green fuels and technologies is a core pillar of Star Bulk's strategy. This study has allowed us to examine the potential for the demand, supply, and bunkering of clean ammonia in the West-Australia – East Asia corridor, an important trade route for our larger vessels. Through this work, we aim to complement parallel efforts of the industry to tackle other challenges related to ammonia as a marine fuel, including safety protocols and new engine designs, and to help advance the sector's understanding on the pathway to a greener future."

Charis Plakantonaki, Chief Strategy Officer, Star Bulk

Acknowledgements

About the Global Maritime Forum

The Global Maritime Forum is an international not-for-profit organisation dedicated to shaping the future of global seaborne trade to increase sustainable long-term economic development and human wellbeing.

About the Australia to East Asia Iron Ore Green Corridor Consortium

The Australia to East Asia Iron Ore Green Corridor Consortium is a collaboration between the Global Maritime Forum, BHP, Rio Tinto, Oldendorff Carriers and Star Bulk Carriers, that was launched in April 2022, to assess the development of an iron ore Green Corridor between Western Australia and East Asia.

About the Getting to Zero Coalition Iron Ore Green Corridor Task Force

Members of the Getting to Zero Coalition and leading Australian shipping and energy stakeholders formed a Task Force, convened and chaired by the Global Maritime Forum, to support the development of the Western Australia-East Asia Iron Ore Green Corridor. Its Members are BHP, BP, Bureau Veritas, Cargill, ClassNK, the Clean Energy Finance Corporation, Fortescue Future Industries, Intercontinental Energy, Lloyd's Register, Maritime Industry Australia Ltd, NYK Line, Oldendorff Carriers, Pilbara Ports Authority, Rio Tinto, Scaling Green Hydrogen Cooperative Research Centre Bid, Star Bulk, Woodside Energy, Yara Clean Ammonia.

About the Energy Transitions Commission

The Energy Transitions Commission (ETC) is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century in order to limit global warming to well below 2°C and as close as possible to 1.5°C. Our Commissioners come from a range of organisations – energy producers, energy-intensive industries, technology providers, finance players and environmental NGOs – which operate across developed and developing countries and play different roles in the energy transition. This diversity of viewpoints informs our work: our analyses are developed with a systems perspective through extensive exchanges with experts and practitioners. Our ambition is to inform the decisions of public and private decision-makers and support the leaders at the forefront of climate action to speed up the deployment of low and zero-carbon solutions.

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Disclaimer

Presentation of information and data and forward-looking statements

This document contains forward-looking statements which make assumptions, including about long-run demand for iron ore in East Asia, levels of and potential constraints to clean ammonia-powered vessels deployment, and clean ammonia fuel and bunkering availability based on a combination of independent and new analysis by the Energy Transitions Commission. These assumptions are adopted to seek to assess the feasibility of implementing an iron ore green corridor between Western Australia and East Asia with clean ammonia as a fuel and shall be used for this purpose only. Except as required by applicable regulations or by law, neither ETC, Global Maritime Forum nor the Consortium members undertake to publicly update or review any forward-looking statements, or other content in this document, whether as a result of new information or future events.

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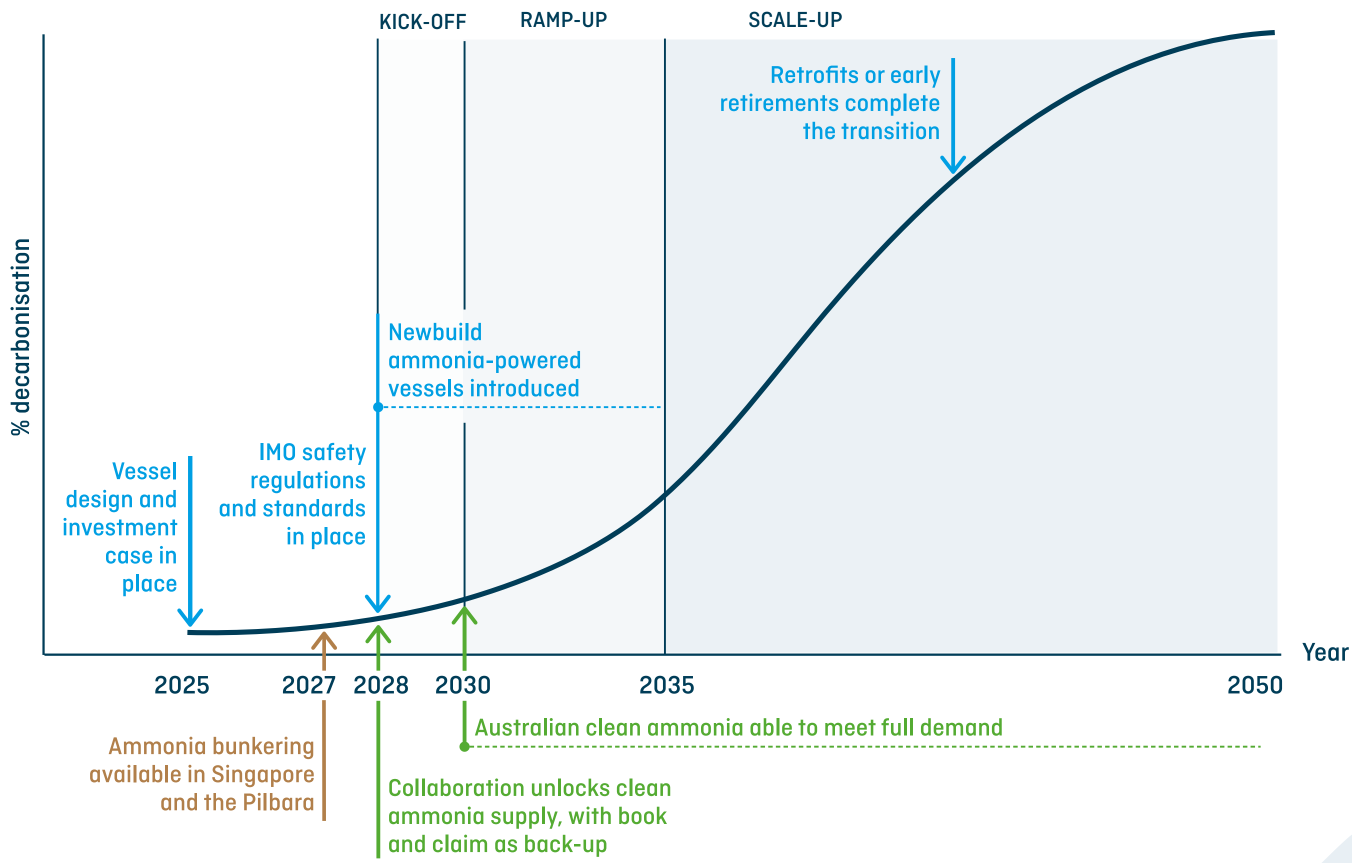
Executive summary

The Next Wave report by the Getting to Zero Coalition identified the iron ore shipping routes from Western Australia to China and Japan as strong candidates for first-mover green shipping corridors, with favourable conditions for early action and the potential to have a large impact on the decarbonisation of the sector. An accompanying pre-feasibility assessment found that clean ammonia – "green" ammonia, produced with electrolytic hydrogen, and "blue" ammonia, produced from conventional hydrogen with applied carbon capture and storage – would be the most likely fuel to power the green corridor.

This study takes the findings of the earlier pre-feasibility study as a point of departure and assesses the feasibility of implementing an iron ore green corridor between between Western Australia and East Asia with clean ammonia as a fuel.

The study considers the feasibility of a scenario where clean ammonia-powered vessels are first deployed in 2028 and then ramped up following an S-shaped curve to full decarbonisation in 2050. It attempts to answer three questions:

- Vessels: **Can ammonia-powered vessels be put on the water when needed?**
- Fuel: **Could enough clean ammonia be available to power these vessels?**
- Bunkering: **Could ammonia bunkering be available in Singapore and/or the Pilbara region of Western Australia?**



Vessels

Our assessment suggests it could be feasible to get ammonia-powered bulk carriers on the water by 2028. Based on current activity, key technologies – including suitable engines – and regulations – including International Maritime Organisation safety guidelines – covering ammonia-powered vessels should be in place on time.

However, some risks would need to be mitigated over the coming years to successfully move forward, most notably:

- **Safety case for use of ammonia as a marine fuel validated and accepted, with suitable regulations in place**: There is currently limited clarity about when the IMO and other relevant standards-setting bodies will pass regulations for the safe operation of ammonia-powered ships, which are key for their large-scale adoption. Clarity should be provided as soon as possible, and efforts intensified to develop these regulations. To support their development and create the necessary confidence among stakeholders, ammonia-powered vessel pilots, risk assessments, and safety studies will need to be progressed over the coming years.
- **Investment case**: Although not assessed in detail in this report, it is expected that there will be a significant cost gap between clean ammonia-powered and conventionally-fuelled vessels for the foreseeable future. Additional policy action over the coming few years will be essential to create a viable investment case for ordering ammonia-powered vessels on the corridor.
- **Availability of a suitable design for an ammonia-powered bulk carrier**: Given normal lead-in times for building ships, a suitable design for an ammonia-powered bulk carrier needs to be ready by 2025 at the latest. While several projects are ongoing globally to bridge this gap, stakeholders on the corridor should come together to request or jointly advance a design for the corridor.
- **Crew upskilling**: It will be essential that seafarers are trained to safely operate ammonia-fuelled vessels. Progress is being made in this area, but to enable ammonia as a marine fuel at scale, as on the corridor, it will be crucial that the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) is updated to include ammonia when it is reviewed over the coming years.
- **Shipyard availability**: With many of the large Asian shipyards already having limited berths available for 2025/2026, it may be challenging to secure a slot to have ships built by 2028. To help maximise the chance of securing a yard slot, shipowners should consider ordering vessels as soon as feasible.

Following initial kick-off, 23 clean ammonia-powered vessels would need to be operational on the corridor by 2030, 81 by 2035, and roughly 360 by 2050 to meet the scenario.

Provided the right economic conditions are in place and sufficient shipyard slots available, evidence suggests this scale up should be feasible. The study finds that enough vessels will be retiring to enable the introduction of most of the clean-ammonia vessels required, with limited need for retrofits or early retirements. If orders are placed over the coming years, almost all clean ammonia-powered vessels on the corridor up to 2035 could be deployed in this way.

Fuel

Enough clean ammonia will likely be available to meet the corridor's near and long-term requirements, even when accounting for demand from other sectors and uncertainties.

Assuming clean ammonia production scales up as expected, the corridor's long-term fuel demand could be fully met by Australian production, which is estimated to reach 52 million tonnes by the 2030s, or even by production in the Pilbara specifically, which is likely to reach at least 9 million tonnes in this period. Should Australian production, however, not scale up or reach the cost levels expected, other production locations globally would be able to supply clean ammonia for import to Australia, Singapore, or another bunkering location on the route.

There is less clarity about the volumes of clean ammonia that will be available in the corridor's kick-off period between 2028-2030, since most production projects are still in development and start-up dates, therefore, to be determined.

Nonetheless, the study identifies five potential pathways for the corridor to secure the required supply in this period:

Attractiveness

- **Green ammonia from the Australian Renewable Energy Hub project in the Pilbara, which could be online between 2028-30**
- **Clean ammonia from additional projects that could be developed in the Pilbara in this timeframe**
- **Clean ammonia from elsewhere in Australia, which could reach 3 million tonnes in 2028 and 15 million tonnes by 2030**
- **Clean ammonia imports from projects elsewhere in the world, including the US, Chile and countries in the Middle East, enabled by the low cost of shipping ammonia**
- **Use of 'swapped volumes' in a book and claim system, leveraging international clean ammonia production**

In the first four cases, to meet production projects' requirements and access competitively priced fuel, actors on the corridor may need to consider joint offtakes with early movers in other sectors, such as fertiliser and power generation. Securing clean ammonia for this shipping corridor is, therefore, less likely to be a matter of competition than one of collaboration.

In parallel, policy and regulatory support will be needed to help production projects achieve final investment decision in a timely fashion. This support could take the form of Contracts for Difference to close the gap between the market and production price for clean ammonia, blending mandates, and/or clean ammonia tax credits.

Should it not be possible to secure physical volumes of clean ammonia, the corridor would still be able to kick off on time by using so-called 'swapped volumes' from *book and claim systems*, which are likely to be available well in advance of 2028. Under this system, ships on the corridor would use grey ammonia while claiming the benefit of clean ammonia produced elsewhere in a fuel producer's portfolio.

Bunkering

The study examines two potential locations for bunkering on the corridor - the Pilbara ports in Western Australia and Singapore – which were identified as promising options in the pre-feasibility stage. While other bunkering locations for the corridor are possible, given the significant early momentum around clean ammonia production in Australia and future fuel bunkering in Singapore, the decision was made to focus on these locations for the assessment.

The assessment shows that there could be at least two workable options for bunkering on the route.

Subject to safety and regulatory developments, both sets of ports – Singapore and Pilbara – could introduce clean ammonia bunkering in the next 5 years, in time for the corridor's kick off.

While there is no bunkering in the Pilbara at present, the analysis confirms that if clean ammonia bunkering were to become available it would represent a competitive option for the corridor going forwards. Not only could the fuel be relatively efficiently delivered to the port from local production sites, but, importantly, bunkering in the Pilbara would avoid the need to make costly deviations from the trade route.

Singapore would also be well-positioned to serve as a bunkering location for the corridor. Ongoing feasibility studies and plans for piloting and infrastructure development suggest that commercial clean ammonia bunkering could be available in the port by 2027 or potentially earlier, and it is likely that it could offer competitive and efficient bunkering alongside other advantageous services.

Conclusions and next steps

These results suggest that there is a feasible pathway to implement the Western Australia-East Asia iron ore corridor using clean ammonia, with the core elements – developing and deploying ammonia-powered vessels on time, access to sufficient fuel, and the availability of bunkering – within reach. This could include having the first clean-ammonia powered vessels on the corridor by 2028, 5% uptake by 2030 and full decarbonisation by 2050.

As such, the report reinforces the corridor's potential to be a first mover in shipping's decarbonisation and help put the sector on track to reach zero emissions by 2050, by deploying zero-emission solutions at scale starting this decade.

While the opportunity to decarbonise the corridor is within reach, to seize it the following important conditions must be in place:

- **Confidence in and acceptance of ammonia as a safe marine fuel** – safety is a top priority for all actors in the shipping sector. As such, the corridor will only be able to move towards implementation if a high level of confidence is established that ammonia can, indeed, be safely used as a marine fuel. Substantial work is ongoing to validate ammonia's safety case, and the results will be crucial for the corridor's next steps.
- **Policy support** – partnership and support from the public sector will be essential to move clean ammonia-powered vessels, bunkering, and production from concept to reality. In particular, measures to close the cost gap between clean ammonia and conventional fuels will be needed to unlock investments. Grants supporting vessel and infrastructure development, production tax credits, and/or a Contracts for Difference scheme focused on the corridor, are all possible elements that should be considered by policymakers.
- **Continued collaboration and coordinated action through the corridor's value chain** – the whole value chain – from fuel producers and suppliers, to ports, shipowners, cargo owners, and investors – has a role to play in bringing green corridors to life. There is already a high level of industry collaboration around the Western Australia-East Asia iron ore corridor, including through the Getting to Zero Coalition's Australia-East Asia Iron Ore Corridor Task Force. To achieve their shared ambitions, interested actors should come together through platforms like the Task Force to tackle the barriers, reduce the risks, and drive the innovation needed to take the corridor forward. As a next step in this direction, a forthcoming analysis from the Task Force will seek to identify the commercial frameworks and policies that can deliver the corridor, as a complement to this study.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1 Background and introduction

Supplied by Oldendorff

1.1 Green shipping corridors and why they matter

The creation of green corridors – defined as specific trade routes where the feasibility of zero-emission shipping is catalysed by public and private action – offers the opportunity to accelerate shipping's transition to zero emissions.

Shipping is a hard-to-abate sector, but some trade routes offer relative advantages, either because they are near potentially attractive fuel supply hubs, have comparatively simple operational profiles, or are likely to have advantageous economics. The idea behind establishing green corridors is to identify and leverage these advantageous routes for accelerated action.

As they may with special economic zones, policymakers can target these routes to create an enabling ecosystem of fit-for-purpose regulatory measures, financial incentives, and safety regulations. At the same time, industry may develop corridor-specific arrangements, such as joint ventures, demand-pooling initiatives, or transparent and standardised emissions reduction crediting and tracking, that lower the threshold for action throughout the value chain.

While corridors are focused enough to make decarbonisation manageable, they are also large enough to be impactful:

- They offer scope for participation from all value chain actors needed to scale low or zero-emission shipping, including fuel producers, shipowners and operators, cargo owners, and regulatory authorities
- They could provide offtake certainty to fuel providers, supporting investments in zero-emission fuel plants and essential bunkering infrastructure
- They could generate strong demand signals to shipowners and operators, shipyards, and engine manufacturers to catalyze and scale investments in zero-emission shipping technologies

Creating green corridors could lower the threshold for action by industry and policymakers, but they will not emerge by themselves; key stakeholders need to commit to action and contribute to the analysis, evaluation, and planning that could underpin their development.

1.2 The Western Australia-East Asia iron ore green corridor opportunity

The iron ore shipping routes between Western Australia and East Asia have been identified as a major opportunity for establishing first-mover green shipping corridors.

The Getting to Zero Coalition's *The Next Wave* (2021) report demonstrated how green corridors can be conceived, prioritised, and designed. The report identified ten routes as strong candidates for establishing green corridors worldwide.

High volume routes (1–7)
Rapid decarbonization routes (8–10)

	Metric		1 Aus-China iron ore Large volumes, fewer policy enablers	2 Brazil-China iron ore High volume, with higher shipping costs	3 Aus-Japan iron ore Lower volumes with committed stakeholders	4 Transpacific containers Major mainline route	5 Aus-Europe containers Long, high-emission mainline route	6 Transatlantic containers Small volumes, more policy enablers	7 North-South containers Low volumes, limited ability to pass on costs	8 Saudi-India ammonia Potential future fuel, small traded volumes	9 Asia-US automotive Low volume, high value, and carbon intensive	10 Saudi-China methanol Potential future fuel, small traded volumes
IMPACT	**A. Trade and logistics**											
	Share of global trade volume	Basis points	650	195	60	181	210	52	14	2	4	1
	Expected future growth, CAGR 2021-2025	%	4%	3%	3%	2%	3%	3%	8%	5%	2%	6%
	B. Emissions											
	Carbon intensity on route	kgCO2e/tonne cargo	28	48	29	61	93	56	99	104	197	137
	Current carbon emissions on corridor	tonne CO_2e	20,200,000	10,500,000	1,900,000	12,300,000	21,700,000	3,200,000	1,500,000	300,000	900,000	160,000
FEASIBILITY	**C. Value and cost pass-through**											
	Relative price increase of traded good	%	11%	28%	11%	3%	2%	2%	12%	4%	1%	4%
	Scope 3 importance for traded good sector	1=low, 5=high	3	3	3	2	2	4	2	1	3	1
	D. Zero-emission fuel supply											
	Delivered cost of zero-emission fuel in 2025	$/GJ	35	37	35	38	30	40	35	30	38	30
	E. Stakeholder readiness											
	National policies/regulations (net zero, green H2)	1=low, 5=high	2	2	4	1	3	3	4	1	3	1
	Ease of stakeholder environment	1=low, 5=high	2	5	4	1	1	1	2	4	5	4

Figure 1: Multi-criteria assessment of shortlisted corridors from the The Next Wave report, including Australia-China and Australia-Japan iron ore (red)

Among those shortlisted, the iron ore shipping routes from Western Australia to China and Japan were identified as especially promising, 'game changing' opportunities, based on their high potential impact in decarbonising the sector and favourable conditions for early action.

An accompanying pre-feasibility assessment on the Western Australia-Japan route found that clean ammonia would be the likely fuel choice for this corridor, for three main reasons:

- **Significant planned capacity:** Given Australia's location and rich renewable resources, it would be well-placed to produce hydrogen-based fuels for a green shipping corridor. Green hydrogen production capacity in Australia was, at the time, already projected to reach 29 GW by 2030, of which a significant proportion was expected to be converted to ammonia, responding to growing demand from export and industrial uses. This contrasted with the limited pipeline of clean methanol production announced in the country.
- **Existence of willing stakeholders:** Regional consortiums were already exploring the potential for ammonia-powered shipping (e.g. ITOCHU MoU, Singapore bunkering studies), signalling broader support and momentum for the fuel in the region.
- **Potential for an enabling environment:** The Australian Government published a National Hydrogen Strategy in 2019, flagging regulatory support for clean hydrogen production, with specific mention and focus dedicated to ammonia.

Building on these findings, in April 2022 a consortium, led by the Global Maritime Forum and consisting of BHP, Rio Tinto, Oldendorff Carriers and Star Bulk, signed an *LOI* to further assess the clean ammonia supply, bunkering, and support mechanisms required for a viable Western Australia to East Asia iron ore green corridor. This report is an output of that collaboration and is intended as a contribution by the members of the Consortium to deeper exploration of the corridor.

While acknowledging that The Next Wave report spotlighted the routes to China and Japan, this report expands the focus to all four key East Asian regions for the import of iron ore from Western Australia, as defined in the Glossary. Expanding the focus in this way enables exploration of wider possibilities for action, provides a full perspective on the potential impact of the corridor, as well as reflecting the interconnections between the routes, with accelerated decarbonisation on one route likely to reduce emissions on the other routes.

1.3 Report objectives and approach

The objective of this report is to assess the feasibility of a clean ammonia pathway for decarbonising the wider Western Australia-East Asia iron ore corridor – including how much clean ammonia can contribute to the greening of the route, what this pathway could look like, and what would be required to realise it. The core emphasis is on the supply and demand of clean ammonia. As such, commercial or detailed safety requirements, which are being advanced in other fora, are not assessed in detail. In this way, the report aims to refine, update, and extend the pre-feasibility assessment carried out for the Western Australia-Japan iron ore corridor as part of The Next Wave report.

While members of the Consortium represent key actors in the value chain for this trade, a broad range of stakeholders operate on the route; as such, the analysis covers the full fleet on the corridor, including but not limited to the vessels owned/operated by the Consortium members.

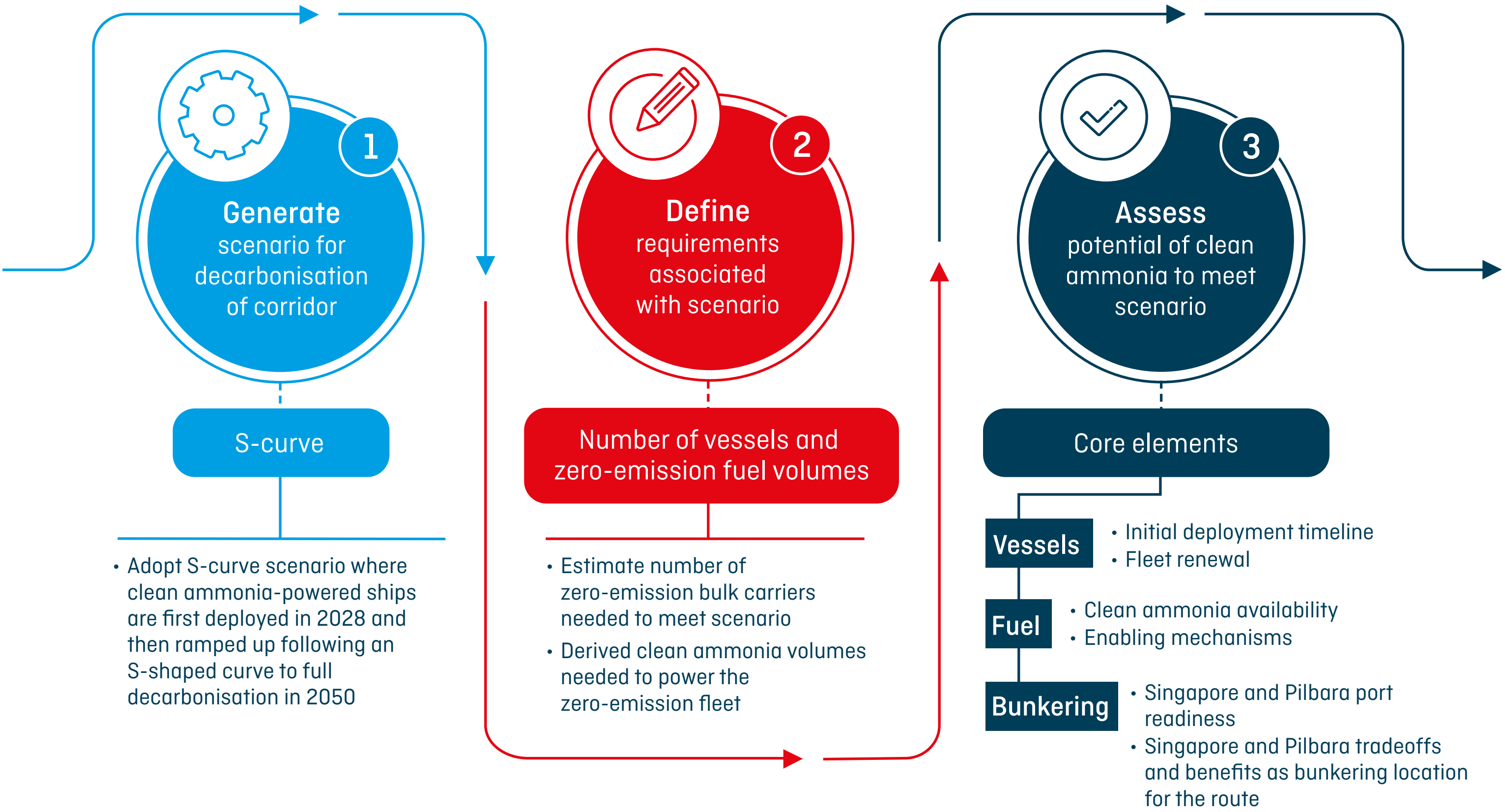
A three-step approach is used to perform the assessment:

1. Generating a potential scenario for decarbonisation of the corridor;
2. Defining a set of requirements across vessels, fuel, and bunkering to meet the scenario;
3. Assessing clean ammonia's ability to meet these requirements, and what this might look like over the short, medium, and long-term.

The report comprises two main sections after this introduction.

Section 2 establishes and describes the decarbonisation scenario that serves as a foundation for the analysis. **Section 3** assesses whether a clean ammonia pathway could meet its requirements and what this might look like.

Methodology: Three-step approach



2 Defining and exploring a decarbonisation scenario for the corridor

To assess clean ammonia's potential to contribute to the development of the corridor, a plausible scenario for decarbonisation of the route has been defined.

In a *2021 article*, the Getting to Zero Coalition, UMAS, and COP26 Climate Champions illustrated how the adoption of zero-emission fuels in the shipping sector would most likely follow an S-curve – starting with a slow emergence period, followed by a rapid growth phase, before eventually flattening out, as the new fuels are established and become the "new normal".

The decarbonisation of the Western Australia-East Asia iron ore green corridor could be aligned with the article's illustrative uptake of zero-emission fuels of 5% by 2030, ~25% by the mid-2030s, and ~90% by the mid-2040s (Figure 2). This is viewed as a fit-for-purpose scenario for this analysis for two reasons. First, it is ambitious but credible, landing at zero-emissions by 2050 with a pathway based on insights from past industrial transformations. Second, because it, therefore, offers a robust baseline for testing the feasibility of a clean ammonia pathway for implementation of the corridor.

The version of the curve adopted for the analysis follows the same milestones as the sector-wide S-curve, with one difference. Since ammonia is still in development as a zero-emission solution for shipping, the starting point for the curve has been set to reflect a reasonable potential start date for commercial operation of ammonia-powered bulk carriers on the corridor. Based on a high-level assessment of technology, regulatory, and commercial development timelines as well as expectations and forecasts from other stakeholders relevant to the corridor[1], this potential kick-off is set in 2028. The feasibility of kicking the corridor off by this starting point is explored further in Section 3.

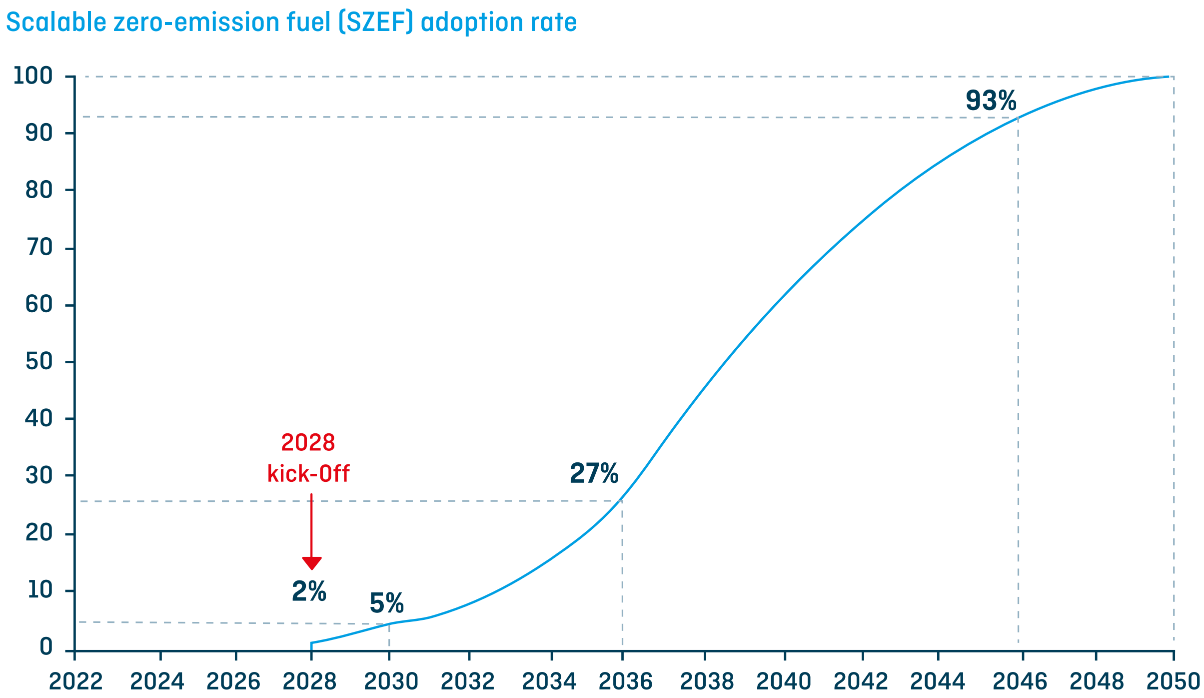


Figure 2: SZEF adoption curve from UMAS/GMF (2021) with an adapted kick-off year of 2028 for the Australia-East Asia iron ore green corridor.

1. Cf. Yara Clean Ammonia's most recent expectations around commercial deployment of ammonia-powered vessels in 2028-2029. Source: *Yara Clean Ammonia* Capital Markets Day (June, 2022).

2.1 Applying the scenario to the Western Australia-East Asia iron ore corridor

2.1.1 Demand for zero-emission cargo transport

Disclaimer

For the purposes of this segment of the report, the Consortium relied on independent third-party data from the Steel Sector Transition Strategy published by the Mission Possible Partnership (MPP). While the Consortium is of the view that the forecasts on cargo volumes transiting through the Western Australia to East Asia green corridor mentioned in the MPP Steel Sector Transition Strategy appear to be reasonable, the Consortium is unable to independently validate the findings from the MPP.

The first step in exploring what such a decarbonisation pathway for the corridor would look like is determining "S-curve aligned" demand for iron ore transport on the corridor between now and 2050. Independent analysis undertaken for the MPP Steel Sector Transition Strategy report, which models global trends in the decarbonisation of primary ore-based steel making and the transition to scrap-based steel production technologies, is used for this purpose. Insights for this study focus on the trajectory in the Transition Strategy's Baseline Scenario to 2050 in East Asian markets[2].

As of today, China is the largest importer of iron ore from Australia, accounting for approximately 85% of total Australian exports to the region. The remaining 15% of imports are currently split across the remaining East Asian markets. In the Sector Transition Strategy scenario by 2050 total combined demand for iron ore across the four countries is expected to reach approximately 900 to 1000 million tonnes per year.

By overlaying the decarbonisation curve on the Sector Transition Strategy projections, an outlook is generated for zero-emission iron ore transport on the route. Assuming imports from Australia to the four markets maintain their 7-year historical average, this arrives at **approximately 36 million tonnes of zero-emission iron ore transport on the corridor in 2030, rising to nearly 600 million tonnes by 2050**, as shown in the Figure 3.

2. To note: This analysis does not cover exports to Southeast Asian markets, which have the potential to become a significant demand hub for iron ore out of Australia.

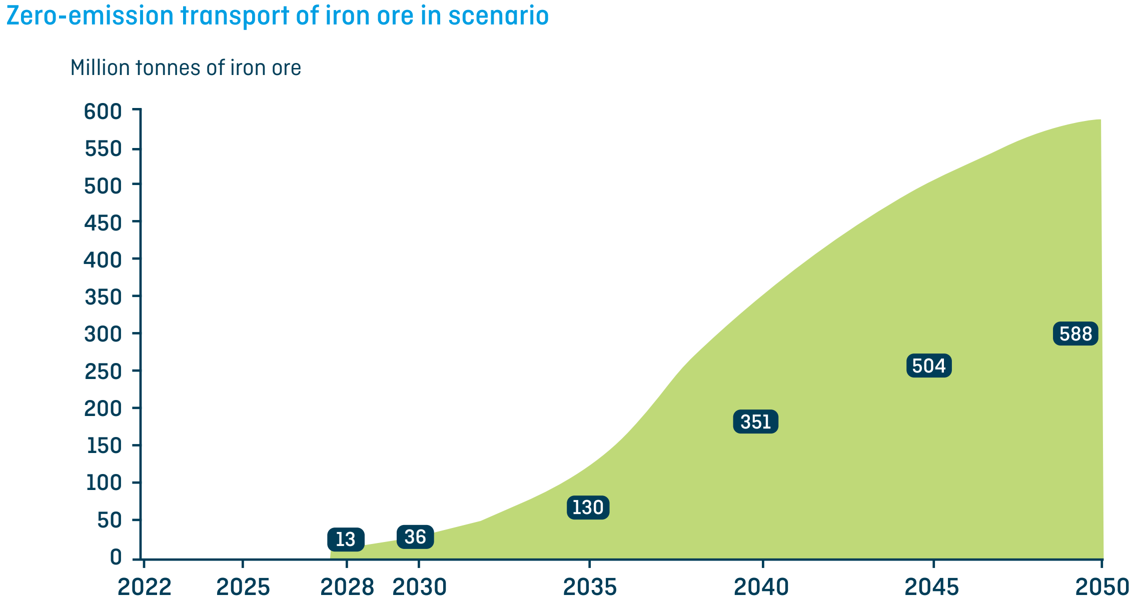
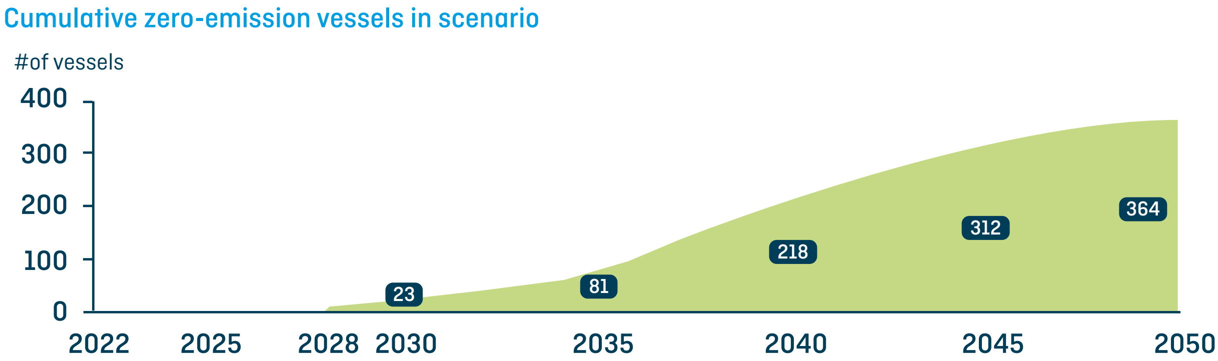


Figure 3: Scenario decarbonisation rate applied to cargo volumes on the Western Australia-East Asia iron ore green corridor. ETC analysis (2023) based on the Mission Possible Partnership's Steel Sector Transition Strategy Baseline Scenario (2022).

2.1.2 Required number of zero-emission vessels and clean fuel volumes

As a second step, the zero-emission transport demand is translated into required numbers of zero-emission vessels and quantities of clean ammonia. A model with vessel and voyage parameters representative of the fleet on the corridor is used for the analysis, for which a full list of assumptions can be found in Appendix 4.1.

As shown in the top of Figure 4, a **total of 8 zero-emission vessels would need to be operational on the corridor in 2028, increasing to 23 zero-emission vessels by 2030, and topping out at approximately 360 by 2050**. The annual deployment rate is shown in the bottom of the Figure, highlighting the number of additional vessels that would need to be deployed yearly to 2050 to provide zero-emission transport of the calculated cargo volumes. Overall, the greatest growth in zero-emission vessels would be in the 5-year period between 2035-2040, with approximately 135 zero-emission vessels being deployed.



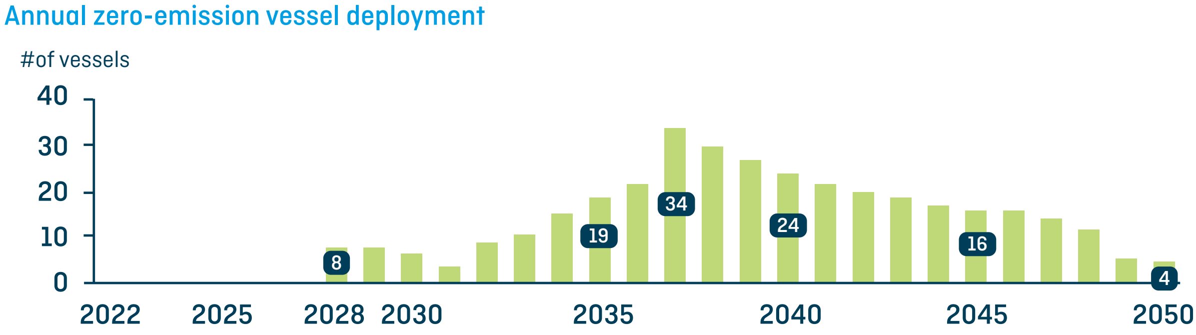


Figure 4: Cumulative (top) and annual (bottom) deployment of zero emissions vessels on the Western Australia-East Asia iron ore green corridor. ETC analysis (2023).

This generates an "upper envelope" of approximately 1.2 million tonnes of clean ammonia demand by 2035, or the amount of clean ammonia needed to power the full zero-emission fleet. While, in practice, the level of demand could be lower than this "envelope", due to other low and zero-emission fuels featuring in the fuel mix, using the "envelope" provides a robust stress test of clean ammonia's potential to contribute to the greening of the route. See Section 3.2 for this assessment.

As seen in Figure 4, after accounting for efficiency improvements over time, the scenario would have an "envelope" of 0.1 million tonnes of clean ammonia in 2028, 0.3 million tonnes in 2030, and up to 4.9 million tonnes by 2050.

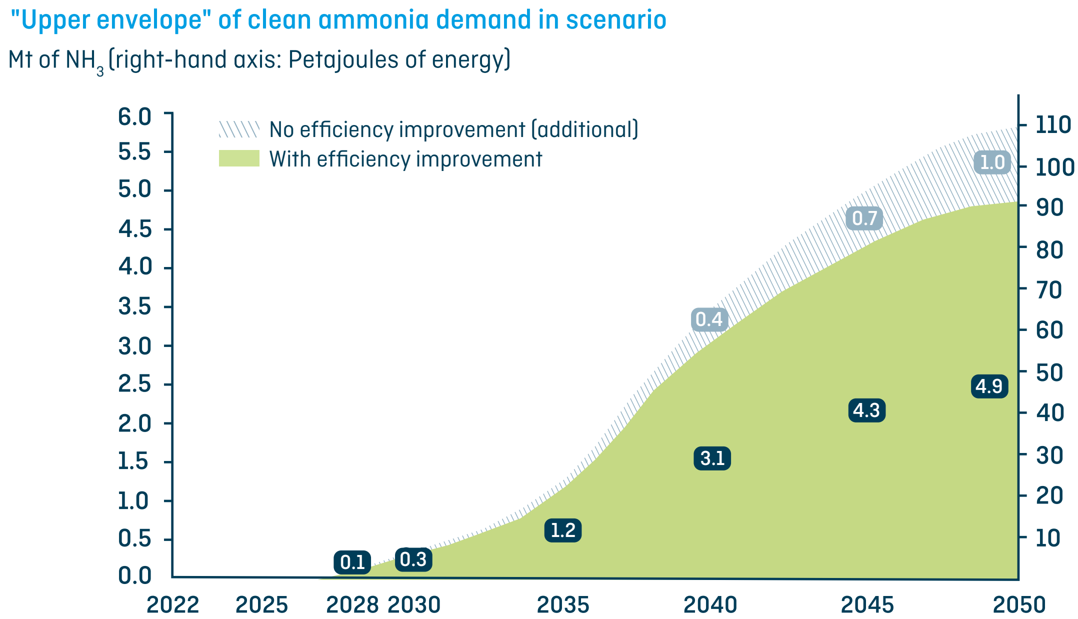


Figure 5: "Upper envelope" of clean ammonia demand on the Western Australia-East Asia iron ore green corridor with and without energy efficiency improvements. ETC analysis (2023).

It is important to note that the corridor's fuel requirements will be affected by increasing adoption of energy efficiency measures. Tightening environmental regulations, and the urgency to decarbonise, are spurring a move towards increased energy efficiency in the sector. Key existing examples of regulations targeting energy efficiency improvements include:

- IMO's Carbon Intensity Indicator (CII) rating, which is targeting a 40% reduction in carbon intensity in the maritime sector by 2030 relative to 200
- IMO's Energy Efficiency Design Index (EEDI) Phase 3, stipulating a 10% lower fuel consumption compared to Phase 2 EEDI requirements

Before factoring in measures to mitigate the increased cost of zero-emission fuel, efficiency improvements are conservatively expected to result in around a 17% reduction in fuel consumption on the corridor by 2050. As such, an approximate annual 0.6% reduction in fuel consumption, taken from IRENA's 1.5-degree scenario[3] for decarbonisation of the sector, is incorporated into the clean ammonia demand calculations.

Examples of measures that could contribute to increased energy efficiency include, but are not limited to:

- Optimisation of voyage parameters, i.e. route and speed
- Use of energy management systems
- Ensuring proper vessel maintenance and optimal operation of the propulsion system
- Installation of energy saving devices, such as wind-assisted propulsion technology
- Use of low friction paints with antifouling protection

Key takeaways: Corridor decarbonisation scenario

A scenario where clean ammonia-powered vessels are first deployed in 2028 and then ramped up following an S-shaped curve to full decarbonisation in 2050 is adopted for this study. This trajectory would require the following number of zero-emission vessels to be deployed and volumes of clean ammonia:

Year	Required zero-emission vessels operating	"Upper envelope" of clean ammonia demand
2028	8	0.1 Mt NH_3
2030	23	0.3 Mt NH_3
2035	81	1.3 Mt NH_3
2050	364	4.9 Mt NH_3

3. IRENA's 1.5°C scenario assumes a 20% decrease in emissions by 2050 (relative to 2018) via energy efficiency improvements, translated here to an average annual decrease in fuel consumption required per roundtrip. These measures are assumed to apply equally across all vessel types (conventional, ammonia, etc.). Source: A pathway to decarbonise the shipping sector by 2050 (IRENA, 2021).

3 Feasibility evaluation

Supplied by Pilbara Ports Authority

This section looks at the feasibility of clean ammonia delivering the decarbonisation scenario described in section 2. The evaluation is done in three parts – covering vessels, fuel, and bunkering –, structured around the questions in Table 1 below:

Table 1: Key questions used to address feasibility of the Western Australia-East Asia iron ore green corridor.

Report Section	Key questions
3.1 – Vessels	• Could clean ammonia-powered bulk carriers feasibly be put on the water by the scenario kick-off in 2028? What would this require? • Could clean ammonia-powered bulk carriers be deployed at a rate consistent with the scenario after this point? How many could be newbuilds?
3.2 – Fuel	• Could enough clean ammonia feasibly be available in the Pilbara and/or the rest of Australia to hit the "upper envelope" of demand implied by the scenario? Could imports serve to fill any gaps? • What challenges are buyers and suppliers expected to face in contracting for clean ammonia, as a new fuel? How can these challenges be solved?
3.3 – Bunkering	• Could bunkering feasibly be available for the first wave of clean ammonia-powered vessels? • What are the tradeoffs between bunkering the corridor in Western Australia versus Singapore?

3.1 Vessels

In this section the feasibility of deploying ammonia-powered bulk carriers on the corridor is explored from two perspectives:

- **Initial deployment:** Ammonia is still in development as a zero-emission solution for shipping, as such the feasibility of having clean ammonia-powered vessels on the water by 2028 is dependent on a number of technological, regulatory, commercial, safety and crew-related advances.
- **Vessel availability:** Over the medium to long-term, as the corridor transitions the existing fleet to new clean ammonia-powered vessels, the ability to introduce vessels at a rate consistent with the deployment curve will be a key success factor.

3.1.1 Initial deployment

To assess the feasibility of deploying ammonia-powered vessels by 2028, this sub-section focuses on whether required safety regulations, technological developments, training procedures, and economic incentives could be in place by that date. Across these 4 areas, 7 vessel-related prerequisites are identified and assessed:

A. IMO interim guidelines for ammonia-powered vessels in place
B. IMO updates to IGF Code to include ammonia in place
C. Ammonia engines for bulk carriers commercially available
D. Design for ammonia-powered bulk carrier suited to this corridor available
E. Shipyard berths secured
F. Crews upskilled to safely handle ammonia
G. Investment case in place

Required roadmap

Figure 6 plots the deadlines by which the 7 prerequisites would need to be in place, highlighting the need for critical elements to be in position by 2025 and 2028 to enable vessels orders and operation respectively.

To undertake the assessment, each of the prerequisites are assigned a "required by" deadline, estimating the latest possible point by which they would need to come into place to enable a kick-off in 2028, in view of relevant lead-in times, interdependencies between the prerequisites, and the decision-making process associated with ordering a vessel. Rather than referring to the expected point by which they will be in place, the deadlines should be understood as responses to the question *"working backwards from 2028, when would the different prerequisites need to be in place to have an ammonia-powered vessel on the water?"*

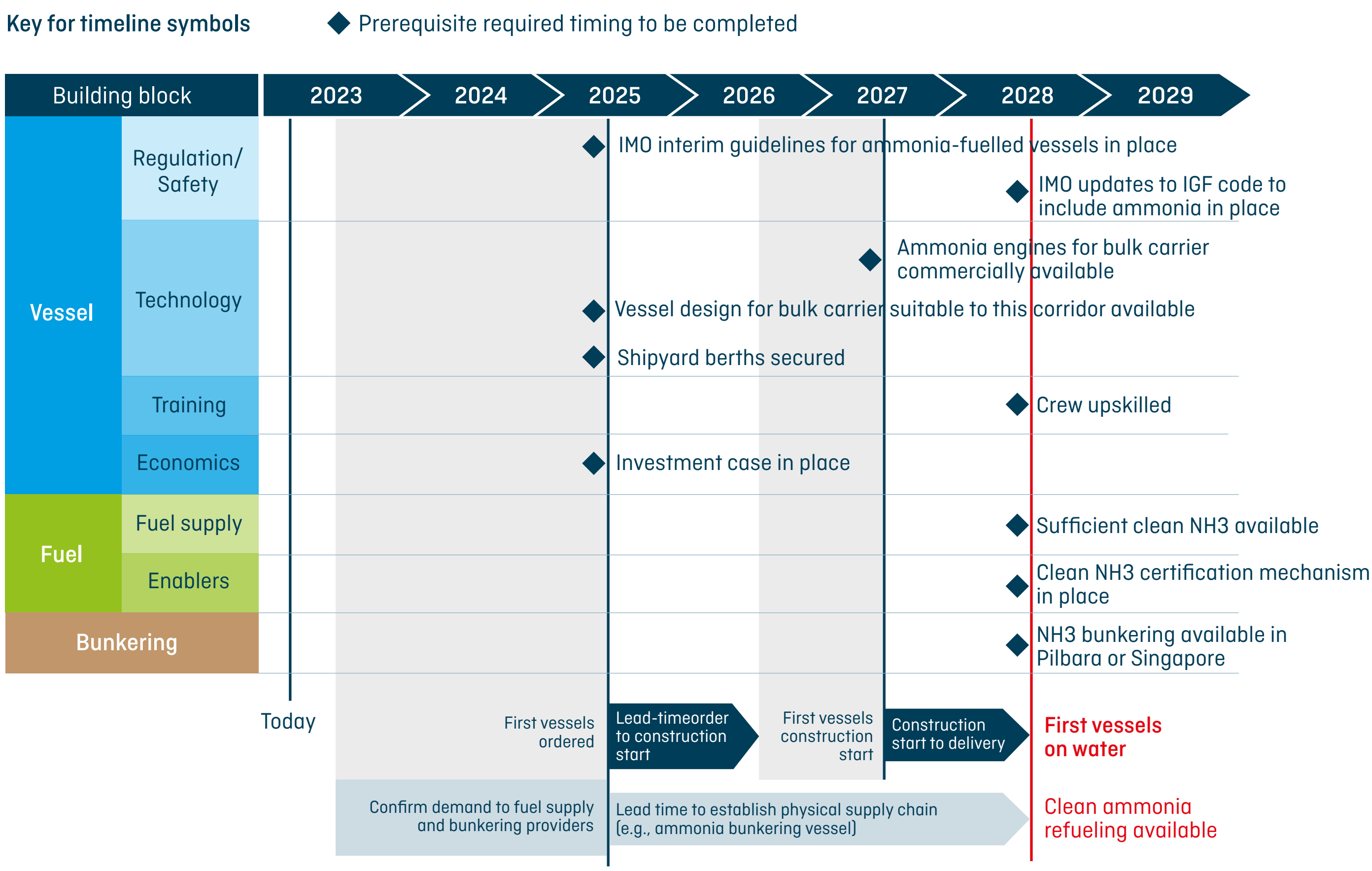


Figure 6: Roadmap showing deadlines by which prerequisites would need to be in place in order to get ammonia-powered vessels on the corridor by 2028. ETC analysis (2023).

The timeline is centred around three main milestones, represented by the blue and red vertical lines:

1. **To secure the shipyard berth(s) for construction, it is expected that a vessel order would need to be made by 2025 at the latest**. 3 prerequisites are needed to trigger the order – the availability of a design for an ammonia-powered bulk carrier suitable to the corridor, IMO interim guidelines for ammonia-powered vessels being in place, and a clear investment case being in place for ordering ammonia-powered vessels.
2. The next milestone is the start of vessel construction. Based on construction times for conventional bulk carriers plus a "buffer" to account for the novelty and added complexity of an ammonia-powered design, **construction is expected to take between 1 and 1.5 years, and so required to commence by no later than 2027.** For this to happen, ammonia engines with suitable specifications for large bulk carriers would need to be commercially available.
3. **Lastly, the delivery of the first ammonia-powered bulk carriers is set in 2028, in line with the scenario kick-off**. Two prerequisites would need to be in place before this point – IMO updates to the International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code) as well as crews being upskilled to operate the new vessel(s).

Three non-vessel related prerequisites are also included in the timeline, all before the 2028 red line: sufficient clean ammonia being available for the corridor, certification being in place to enable tracking and verification of clean ammonia greenhouse gas intensity, and bunkering of clean ammonia being available in the Pilbara and/or Singapore. While these prerequisites refer to developments elsewhere in the value chain, they are included in the roadmap to stress the interconnected relationship between vessel and fuel infrastructure deployment. They are examined in further detail in Sections 3.2 and 3.3 on fuel and bunkering.

The roadmap should not be seen as fully exhaustive. In particular, it is worth highlighting that, in addition to the IMO, other standards-setting bodies – including flag states, municipalities, and port authorities – will play a role in establishing the regulatory framework for safe operation of ammonia-powered vessels. On top of regulations, a high level of confidence and acceptance will need to be reached among stakeholders that ammonia can, indeed, be safely used as a marine fuel. In both cases, ammonia-powered vessel pilots, risk assessments, and safety studies will need to be progressed over the coming years. For simplicity's sake, it is assumed that these elements are successfully pursued and in place; this is not to minimise the importance of real-world action in this area.

Assessing progress on the vessel prerequisites

Evidence suggests that to meet a 2028 start date, some low, medium and high level risks would need to be mitigated.

Based on desk research and expert discussions, developments towards meeting the deadlines are assigned a risk rating, highlighting where additional effort is required to achieve a 2028 kick-off. The ratings are shown in Figure 7:

Key for rating On track to meet | Low risk identified | Medium risk identified | High risk identified

Building block			Prerequisite	Required timing	Expected timing	Rating
Vessel	Regulation/ Safety	A	IMO interim guidelines for ammonia-fuelled vessels in place	By 2025	Q4 2024	On track to meet
		B	IMO updates to IGF code to include ammonia	By 2028	2027-2028	Low risk identified
	Technology	C	Ammonia engines for bulk carrier commercially available	By 2027	2025-2026	On track to meet
		D	Vessel design for bulk carrier suitable to this corridor available	By 2025	2023-2024	Low risk identified
		E	Shipyard berths secured	By 2025	2023-2025	Medium risk identified
	Training	F	Crew upskilled	By 2028	2026-2028	Medium risk identified
	Economics	G	Investment case in place	By 2025	2023-2025	High risk identified

Figure 7: Rating of vessel-related prerequisites on regulation/safety, technology, training, and economics.

The following subsections highlight the rationale behind and supporting evidence for each rating. In those cases where risks are identified, actions that could be taken to mitigate the risks are suggested.

On track

Prerequisite A – IMO interim guidelines for ammonia-powered vessels in place

IMO interim guidelines for ammonia-powered vessels are expected to be finalised in 2024, on time for vessel orders by 2025.

The development of interim guidelines for ammonia as a fuel was initiated at the IMO's Sub-Committee on Carriage of Cargoes and Containers 8th session in Q3 2022. The workplan, agreed by the Sub-Committee, envisages finalisation of the guidelines in 2024 at the latest. Formal adoption is likely to follow in 2025.

The design of an ammonia-powered vessel intended for delivery in 2028 would be developed and approved under the alternative design approach, where a design is approved by a Flag state and class based on risk assessments. While not strictly required for the deployment of the vessels, it would, however, be beneficial to factor the interim guidelines into the design process, to ensure the design is in line with emerging IMO requirements.

Prerequisite C: Ammonia engines for bulk carrier commercially available

Suitable ammonia engines are expected to be available between 2025-2026 based on engine manufacturers' most recent announcements and work programmes.

The development of ammonia engines is being driven by three of the sector's main manufacturers - MAN ES, WinGD, and Wärtsilä. All three manufacturers are moving forward with engine concepts[4]:

- MAN ES is planning to perform full-scale engine tests in 2023, with first delivery to a shipyard expected before the end of 2024. Stakeholder engagement conducted for this study suggests that the first models will be ammonia versions of MAN's S60 and G60 engines, with further engine types to be developed after this point.
- WinGD envisions its ammonia engine technology to be available in 2025. This includes an agreement with CMB.TECH to construct 10 bulk carriers with WinGD 2-stroke ammonia engines in 2025/26.
- Wärtsilä is coordinating a consortium of shipping stakeholders with the aim of having an ammonia engine concept running on 100% ammonia in 2023. The project aims to present a lab-based demonstrator of a 4-stroke ammonia engine, and lab-based test engine plus retrofit of a 2-stroke engine by 2025.

Based on these developments, it is expected that a suitable ammonia engine for the bulk carriers on the corridor will be commercially available between 2025-26. Nonetheless, to ensure the engines are compatible, shipowners and cargo owners on the corridor should clearly signal their demand for ammonia engine sizes and specifications relevant to the bulk carriers that operate on the route.

Low risk identified

Prerequisite B – IMO updates to IGF Code to include ammonia

A low risk has been identified for IMO making updates to the IGF Code to include ammonia by 2028.

After the adoption of the interim safety standards for ammonia-powered vessels, necessary amendments to the International Convention for the Safety of Life at Sea (SOLAS) will be made. This will include further specification of ammonia-powered vessel safety, design and operational requirements as part of the International Code of Safety for Ships using Gases or Other Low-flashpoint Fuels (IGF Code).

While no official timeline has been set, according to expert engagement, this process is likely to take 2-3 years after the adoption of interim guidelines.

4. Company report by MAN ES (2022). Press-release by WinDG (2021). Press-release by Wärtsilä (2022).

Prerequisite D - Design for bulk carrier suitable to this corridor available

A low risk has been identified for a suitable ammonia-powered bulk carrier design being available, with a number of designs having already been granted Approval in Principle (AiP).

The "required by" timing for this prerequisite implies obtaining an AiP for an ammonia-powered Capesize or Newcastlemax bulk carrier[5] suited to the operational requirements of the corridor. This would need to be available by no later than 2025 to enable the finalisation of construction contracts.

Expert discussions conducted with classification societies, cargo owners and shipowners suggest that a vessel design can be developed in as little as 6-9 months and receive AiP in 1-1.5 years total. There are already several design projects for ammonia-powered Capesize and Newcastlemax vessels underway, with AiPs being granted to Anglo-Eastern, K-Line, DSIC, and MOL & Mitsui[6] between 2022-Q1 2023. These concepts can provide a starting point for the development of a relevant design. Hence, it is expected that an AiP for an ammonia-powered vessel design for this corridor could be reached in 2024.

In terms of guidelines, as previously noted, the design would need to be developed and approved under the alternative design process. Major classification societies have already issued safety guidelines for ammonia-powered vessels, which can be used to support this process and provide assurance that the design meets current levels of safety performance.

While this prerequisite has a low risk rating, to mitigate against delays, shipowners, cargo owners and original equipment manufacturers on the corridor should either provide firm and detailed requests for a design in the near future or consider starting a joint industry project to spearhead the development of a design.

Medium risk identified

Prerequisite E – Shipyard berths secured

A medium risk has been identified for securing shipyards berths on time, in light of the busy orderbooks of relevant Asian shipyards.

Given typical lead times from ordering a vessel to the start of construction and delivery, a slot at a relevant shipyard would need to be secured by no later than 2025.

However, expert engagement indicates that most major shipyards in East Asia already have limited capacity in 2024-2025, due to large numbers of container ship and LNG carrier orders. To ensure a berth at a suitable shipyard is secured on time, shipowners on the corridor should signal their intent to have ammonia-powered bulk carriers built to the yards soon. This should be followed by concrete orders as soon as possible once an ammonia-powered vessel design is available, i.e. in 2024.

5. Bulk carriers of the Capesize and Newcastlemax sizes are currently widely used on the Australia-East Asia iron ore corridor. At the same time, it should be noted that as shipowners look to add more modern and efficient tonnage to their fleets in the future, the proportion of Newcastlemax vessels, designed to carry greater volumes of cargo, can be expected to gradually increase.

6. In Q4 2021 *Anglo-Eastern Technical Services* (AETS) has been granted an AiP by ABS for an ammonia-fuelled Newcastlemax bulker design, final delivery timeline yet to be determined; Japanese *K-Line* plans to deliver its ammonia-powered bulk carrier, the design of which has been recently granted an AiP by ClassNK, in 2026; Chinese *DSIC* has been granted an AiP from Lloyd's Register in Q2 2022 for the construction of an ammonia-powered Newcastlemax, final delivery date yet to be determined; in Q1 2023 *MOL & Mitsui* acquired an AiP from ClassNK for Capesize bulker, delivery timelines yet to be determined.

Prerequisite F – Crew upskilled

A medium risk has been identified around crew upskilling, with further research and action needed in this space.

Shipowners would need to ensure that crews are upskilled and certified to safely operate ammonia-powered vessels by the time of their delivery.

The key piece of IMO regulation relating to seafarer training, The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), is to undergo a revision starting in 2023, providing an opportunity to integrate zero-emissions fuels, including clean ammonia[7]. The last two revisions to the STCW took 3-4 years, followed by an 18-month grace period before coming into force. This suggests that by 2028 the STCW could be updated to include seafarer training and certification for ammonia-powered vessels.

However, with no real-world experience to draw on at this stage, there remain significant knowledge gaps around best practices for operating ammonia-powered vessels. These gaps must be bridged through further research and action. A series of projects, including under the Zero-Emission Shipping Mission, the ICS and UN Global Compact's 'Just Transition Taskforce', as well as from Lloyd's Register Maritime Decarbonisation Hub and the Maersk Mc-Kinney Moller Center for Zero-Carbon Shipping, are studying the issue and preparing recommendations, which are expected to support progress in this area. Findings from such efforts, and the first ammonia-powered vessel pilots, should be fed into the ongoing STCW revision process to ensure timely progress is made.

Stakeholders interested in the development of the green corridor can play a role in mitigating the risk associated with delays in crew upskilling by taking concrete actions:

- In the immediate term, fuel providers can engage with maritime academies to share best practices on ammonia handling from existing industries, such as fertiliser production.
- Looking ahead, governments can fund training centres that offer specialised courses for seafarers on handling ammonia while,
- Ship managers can explore ammonia training courses and recruit ammonia specialists to prepare their crews for fuel.

High risk identified

Prerequisite G – Investment case in place

A high risk has been identified for the economic prerequisites for making clean ammonia-powered vessel orders being in place by 2025.

Analysis in The Next Wave suggested that, without action, there will be a roughly 65% gap between the total cost of ownership of a clean ammonia-powered vessel and HFO vessel in 2030[8]. This gap is largely a result of the increased cost of clean ammonia relative to HFO. In this context, the introduction of incentives and regulations to promote the use of clean ammonia is essential for the corridor.

However, progress in implementing such measures remains uncertain, with the timing and nature of potential "medium-term measures" at the IMO still unclear, and policy frameworks at the national level also yet to fully crystallise. For this reason, and given the need for clarity in the next

7. Source: *BIMCO* (2022).
8. Source: *The Next Wave* (GMF, 2021). Exhibit 7: Total cost of ownership of pathways for iron ore bulk carriers.

2 years, this prerequisite is given a high risk. It should be noted that this applies as much to first mover action in the sector generally as this corridor specifically.

Further action will be needed to support a viable investment case, which could include:

- National and international policy measures focused on closing the fuel cost gap, such as clean ammonia tax credits, Contracts for Difference, and/or greenhouse gas pricing.
- Public investment through credit guarantees, anchored blended finance and grant finance to lower cost of capital as well as.
- Green premiums on iron ore shipped using zero-emission vessels and,
- Reduced port fees for zero-emission vessels.

Key takeaways: Vessel prerequisites

- It would be feasible to have clean ammonia-powered bulk carriers on the water by 2028, if action is taken to mitigate several risks.
- Key technologies, including suitable engines, and regulations, including IMO safety guidelines, covering ammonia-powered vessels should be in place when needed.
- There is a low risk around a suitable design for an ammonia-powered bulker carrier being available and updates to the IMO's IGF Code to include ammonia-powered vessels being made on time.
- A medium risk is associated with the following elements:
  - Securing a slot for the construction of ammonia-powered vessels, which may be challenging due to a lack of shipyard berths. Shipowners should consider ordering as soon as feasible.
  - Crew upskilling, with the STCW Convention needing to be updated to include ammonia when it is reviewed starting this year.
- Finally, there is likely to be a significant cost premium between clean ammonia-powered and conventionally-fuelled vessels for the foreseeable future, posing a high risk to hitting a 2028 kick-off for the corridor. Policymakers' actions over the coming few years will be essential to create a viable investment case for ordering ammonia-powered vessels.

3.1.2 Vessel availability

The previous section highlighted that progress on technology, safety/regulation, training, and economics could allow ammonia-powered bulk carriers to be delivered in line with a 2028 starting date. The next question is: could they be deployed at the pace needed?

In general terms, there would be 3 ways to get new ammonia-powered vessels on the water:

1. Newbuild ammonia-powered vessels could replace conventionally-powered vessels on the route when they would naturally be replaced
2. Conventionally-powered vessels on the route could be retired early to enable accelerated deployment of newbuild ammonia-powered vessels
3. Conventionally-powered vessels could be retrofitted with ammonia technologies

All else being equal, newbuilds replacing conventionally-fuelled vessels at their natural age of retirement is expected to be both the least disruptive and least cost option. By analysing the age distribution of the iron ore carriers regularly operating on the route and overlaying the required number of zero-emission vessel deployments generated in Section 2 of this report, it is possible to assess how many vessel deployments on the corridor could be met in this way. To note, the economics of deploying the new vessels and expected shipyard capacity are not included in the assessment, which would also impact on the eventual feasibility.

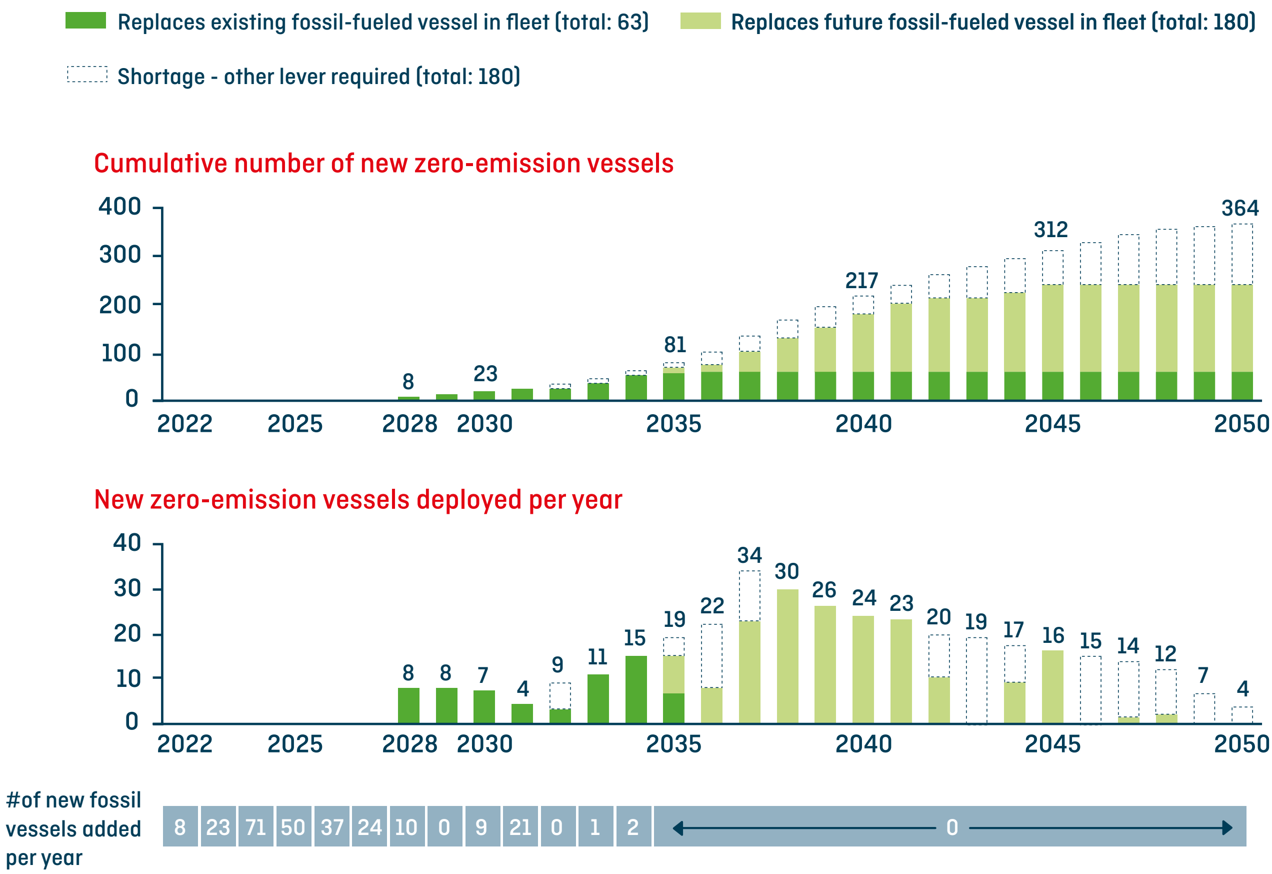


Figure 8: Fleet turnover curves to new zero emissions vessels. ETC analysis (2023). See Appendix 4.4 for further details on the fleet turnover age assumption.

The analysis reveals that roughly two thirds of the zero-emission vessels needed to meet the decarbonisation scenario could come from natural fleet renewal – that is, shipowners replacing old conventionally-powered vessels on the route with new ammonia-powered vessels when renewing their fleets. This is particularly the case in the near-term. If orders were made in the coming years, **almost all of the 81 clean ammonia-powered vessels on the corridor up to 2035 could be deployed this way.**

On the other hand, either retrofits or early retirements would be required during the steepest part of the S-curve in the mid-2030s,and particularly in the 2040s, to complete the corridor's transition.

Modelling undertaken for the Getting to Zero Coalition *'Strategy for the Transition to Zero-Emission Shipping'* report suggests that, in a zero emissions future for the sector, roughly half of all zero-emission vessels could be retrofits by 2050[9]. In this context, the relatively late occurrence and small proportion of retrofits or early retirements needed on the corridor bolsters its favourability for ambitious action. At the same time, it will be important to find a solution to meet the shortage that does exist. Policy action that provides clarity over the sector's decarbonisation trajectory and facilitates retrofits and/or early retirements would be important to enable this.

Key takeaways: Vessel availability

- Following initial kick-off in 2028, it is estimated that a total of 23 clean ammonia-powered vessels would need to be operational on the corridor by 2030, 81 by 2035, and approximately 360 by 2050 to meet the decarbonisation scenario.
- Enough vessels will be retired to enable the introduction of most of the clean-ammonia vessels required. If orders were placed over the coming years, almost all clean ammonia-powered vessels on the corridor up to 2035 could be deployed in this way.
- After this point, some retrofits and/or early retirements would be required, supported by regulatory clarity and policy incentives.

9. A Strategy for the Transition to Zero-Emission Shipping (UMAS/GtZ, 2021) - pages 9-10

3.2 Fuel

The assessment in Section 2 of the report determined that the corridor could have an "upper envelope" of 0.1 million tonnes of ammonia demand in 2028, increasing to approximately 4.9 million tonnes by 2050. At present, however, clean ammonia is not widely available at scale, raising the question of whether there could be enough clean ammonia available to meet the "upper envelope" of demand on the corridor. In this section, this question is assessed from two perspectives:

- **Fuel availability**: Could enough clean ammonia feasibly be available in the Pilbara and/or the rest of Australia to hit the "upper envelope" of demand implied by the scenario? Could imports serve to fill any gaps?
- **Enabling mechanisms**: What challenges are buyers and suppliers expected to face in contracting for clean ammonia, as a new fuel? How can these challenges be solved?

3.2.1 Clean ammonia fuel availability

Analysis suggests that clean ammonia is likely to be available in sufficient quantities to meet the corridor's near- and long-term demand, even when accounting for demand from other sectors and uncertainties.

Figure 9, as previously shown in Section 2, highlights clean ammonia requirements during the kick-off phase between 2028-2030, ramp-up phase between 2030-2035, and scale-up phase between 2035-2050

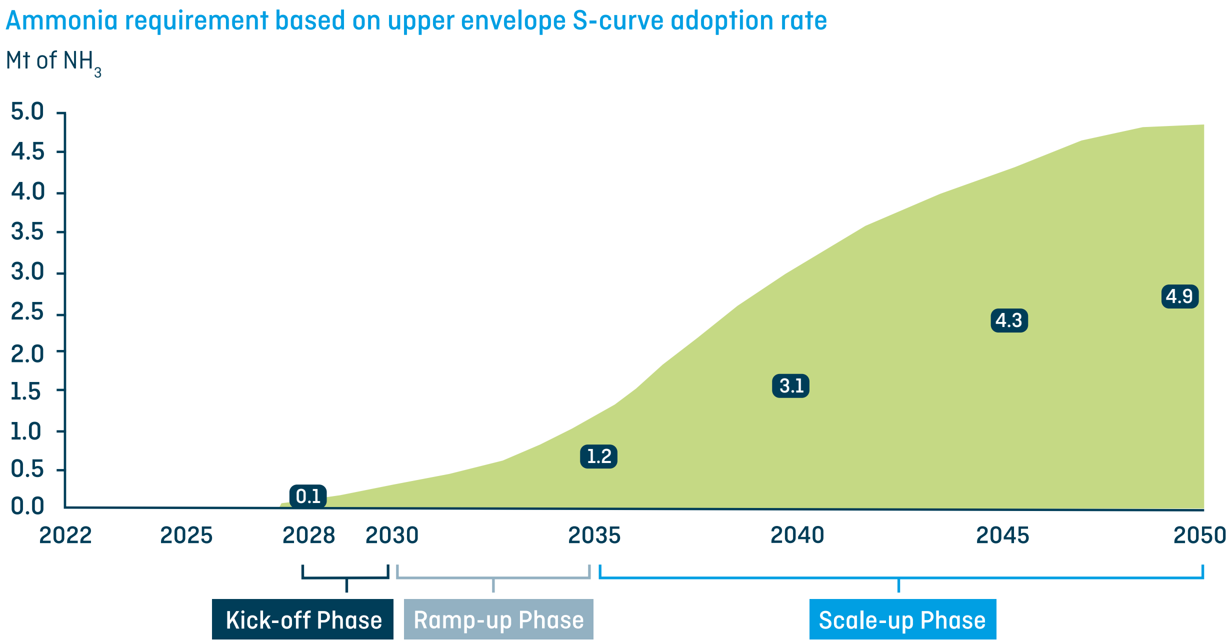
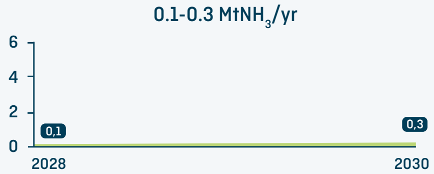
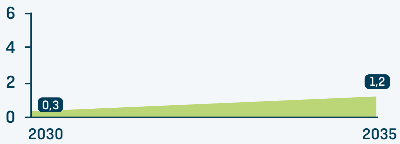
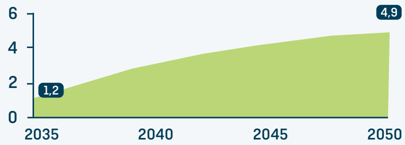


Figure 9: "Upper envelope" of clean ammonia demand on the Western Australia-East Asia iron ore green corridor. ETC analysis (2023).

The study's main takeaways regarding the availability of clean ammonia in each of these phases are summarised in Table 2. Additional evidence is provided in the sub-sections below, describing key local, regional, and global factors expected to impact fuel supply for the corridor.

Table 2: Takeaways for clean ammonia fuel availability on the Western Australia-East Asia iron ore green corridor[10].

Phase	**Kick-off 2028-2030**	**Ramp-up 2030-2035**	**Scale-up 2035-2050**
Demand	0.1-0.3 $MtNH_3$/yr 	0.3-1.2 $MtNH_3$/y 	1.2-4.9 $MtNH_3$/y 
Summary	Likelihood of physical clean ammonia availability between different procurement pathways, with the use of a book and claim system available as a back-up solution, if required	High likelihood of clean ammonia availability from either local projects or others in the rest of Australia	High likelihood of clean ammonia availability in Australia as well as globally
Procurement pathways	• The corridor's initial demand **has the potential to be bundled into a first phase final investment decision (FID)** for AREH or a similar project in Australia, contingent on finding larger offtakers (e.g., export to East Asia). • **Additional clean ammonia production (e.g., blue ammonia) is under investigation in the Pilbara** and could also be developed to meet the fuel requirement for the kick-off phase of the corridor in these time frames. • **Globally a significant number of projects** are currently seeking offtakers; given the relatively low cost to transport ammonia by ship, imports from these projects could be established to Western Australia or other potential bunkering locations for the corridor, such as Singapore or discharge ports in East Asia. • In all of these cases, because production volumes for many projects are **higher than kick-off demand from the corridor**, there is an opportunity to engage with project developers to participate in initial project phases alongside other offtakers. • **Failing this, book-and-claim systems** are likely to be in place by 2028, which would offer a back-up option for securing clean ammonia supply for the corridor.	• There is a high likelihood that the corridor's demand in this phase could be met by either local or other Australian projects – as **part of AREH's expansion phases** or from the 13-52 million tonnes of clean ammonia per year of capacity that could be available in Australia as a whole in this period.	• The corridor's l**ong-term demand could be fully met by the AREH project** (~9 million tonnes of ammonia per year at full-scale); this will, again, be highly dependent on the volumes of additional offtakers secured by AREH. • **Global clean ammonia fuel supply in the 2030-50 period is unlikely to be constrained** should fuel production in Australia face deployment barriers – imports or other bunkering options (e.g., Singapore) are likely to be available.

10. Book-and-claim system herein refers to the purchase of clean ammonia volumes decoupled from the physical supply of grey ammonia. The buyer (e.g. shipowner, cargo owner) "claims" the emissions reductions of clean ammonia via a mass-balance certification mechanism scheme that provides assurance on the production of clean ammonia in a fuel supplier's wider global portfolio.

Clean ammonia availability in the Pilbara

The Pilbara region could be a global first mover in clean ammonia production, with large-scale availability this decade. As shown in Figure 10, supply of green ammonia in the Pilbara is currently contingent on the Australian Renewable Energy Hub (AREH) project [11]. AREH is currently in the pre-final investment decision phase, with a planned start-up date before 2030 and capacity of up to 9 million tonnes of ammonia per year at full scale.

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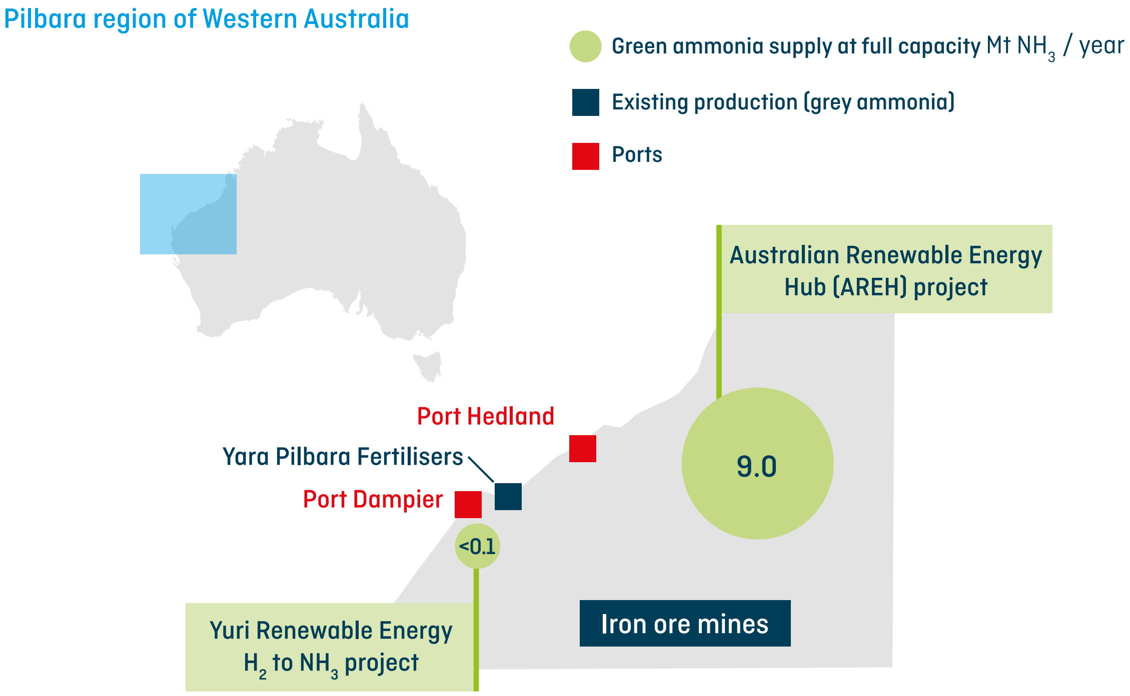


Figure 10: Map of the Pilbara region in Western Australia showing currently currently announced clean ammonia supply projects[12].

Based on typical project requirements and stakeholder engagement conducted for this study, it is likely that there will be a minimum offtake volume for the first phase of the project of roughly 1 million tonnes per year. Since the corridor's initial demand is expected to be approximately 0.1 million tonnes per year in 2028, it is unlikely the corridor could provide sufficient offtake volumes for the AREH project to reach FID on its own. However, there is the potential for the initial clean ammonia volumes required to be bundled into a wider first phase FID in 2028 with larger offtakers, such as importers in East Asia.

Should the AREH project fail to reach FID and kick-off by 2028, other clean ammonia projects are under investigation in the Pilbara. This includes blue ammonia supply, which has the potential to be produced by applying CCS to existing grey ammonia production in the Pilbara. While a large-scale blue ammonia project has yet to be announced, stakeholder engagement undertaken for this study suggests early demand signals could drive the development of blue ammonia production to meet the corridor's kick-off requirements.

11. AREH is a joint venture between bp (45%) InterContinental Energy (26.4%), CWP Global (17.8%) and Macquarie Capital / Green Investment Group (15.3%).

12. Yuri green ammonia demonstration project is a joint venture between Engie Renewables, Yara Fertilisers and Mitsui. Further expansion phases not yet announced. Stakeholder engagement suggests it is unlikely for any possible expansion phases to be completed within the timeframes for the corridor kick-off in this study.

A further alternative, deemed a back-up option, would be the acquisition of 'swapped volumes' of clean ammonia from book-and-claim systems [15] (see example from Yara Clean Ammonia highlighted in section 3.2.2).

In the medium-to-long term, the Pilbara region is likely to see hydrogen/ammonia demand from other sectors, which exceed the corridor's demand. The largest source could be export demand, with Western Australia's Hydrogen Strategy estimating exports from the Pilbara in the range of 3-10 million tonnes of hydrogen per year by 2050. While this could limit the clean hydrogen available for ammonia production. Conversely, it could enable the long-term scale-up of and reductions in the cost of clean ammonia, should the projects have sufficient capacity for all end-users.

Further demand may come from mining operations (~0.6 million tonnes of hydrogen per year) and existing ammonia production (~0.2 million tonnes of hydrogen per year)[13], which, when combined, would be comparable to the corridor's 2050 hydrogen demand (~0.9 million tonnes per year)[14]. These sources of hydrogen demand offer opportunities for the corridor to collaborate on joint offtakes. Aggregating demand via joint offtakes would enable production projects to achieve larger economies of scale – see the case study below highlighting how clustering could lead to reduced ammonia production costs in the Pilbara.

13. Demand for hydrogen from existing ammonia production and mining operations taken from Australia ETI (2022). Assumes that energy demand remains stable over time and mining diesel-based haulage is fully decarbonised by hydrogen fuel cell electric vehicles. Additional demand could come from port operations (e.g. reach trackers / terminal tractors) or harbour craft, but demand projections not found.

14. Equivalent to 4.9 $MtNH_3$. Conversion factor used: 0.176 $tH2/tNH_3$ from the IEA Hydrogen Project Database (2022).

Case study: Potential for clustering to reduce clean ammonia costs in the Pilbara

A key opportunity for reducing the final cost of clean ammonia is clustering, which can facilitate economies of scale in production and transportation infrastructure. Given the large distances between hydrogen supply and demand in the Pilbara region, this could result in meaningful cost savings for the corridor (and other offtakers involved).

In the illustrative scenario shown in Figure 11, clustering could result in a potential ~7-8% cost reduction for hydrogen, translating into a ~5-6% cost reduction for clean ammonia. This assumes clustered clean ammonia demand in the order of 5 million tonnes in 2035, which is made up of demand from shipping (~1.2 million tonnes from the corridor) and representative demand from export and/or other domestic uses (~3.8 million tonnes). In the study's decarbonisation scenario, where the corridor requires a cumulative ~55 million tonnes of ammonia between 2035-2050, this could unlock approximately. $1-1.5bn in total fuel cost savings.

Levelised unit of capex for hydrogen transport and compression

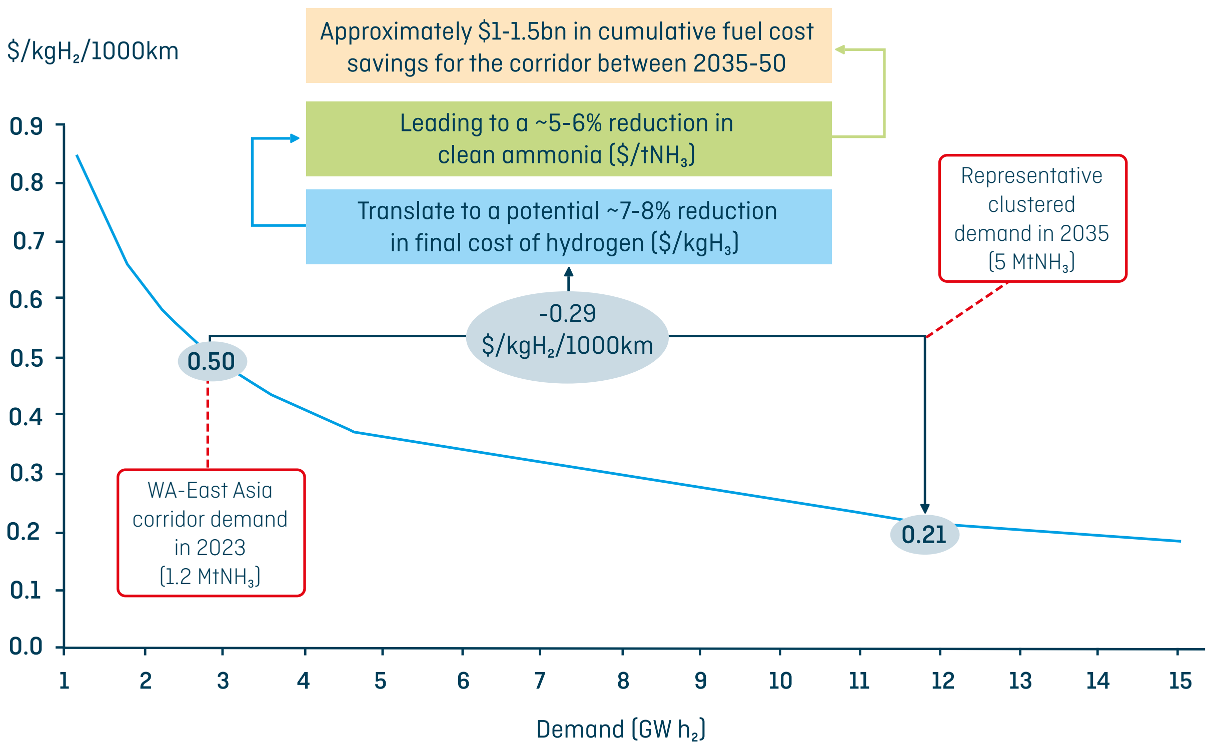


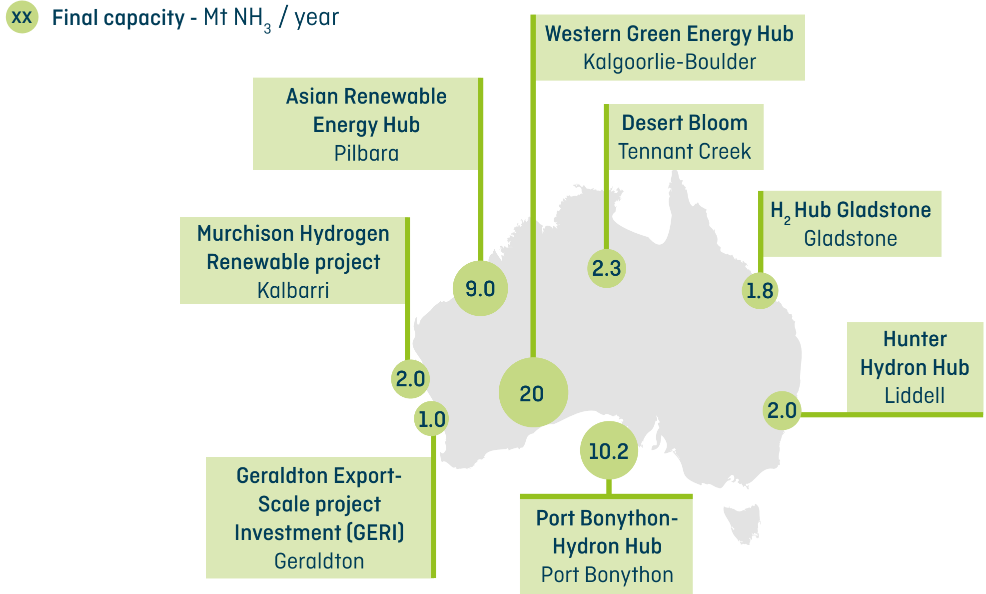
Figure 11: Indicative case study on infrastructure / fuel cost reductions as a result of clustering[15] Sources: ETC analysis (2023); EU Hydrogen Backbone (2022); Ammonia Sector Transition Strategy (MPP, 2022).

15. Includes CAPEX for new pipelines and compressors (data extrapolated for scaling, assuming new 500km pipeline) and cost of green hydrogen production in 2035 of ~$2/kg H2.

Clean ammonia availability in the rest of Australia

With the potential for an array of projects to come online this decade, (clean ammonia is expected to be available at scale elsewhere in Australia earlier than in the Pilbara. As of today, approximately 52 million tonnes' worth of projects have been announced in Australia. While many projects are still under development and start-up dates uncertain, Australia could see significant clean ammonia production capacity coming online in the 2030s.

Largest Australian green ammonia projects at full capacity



Corridor demand vs. Australian supply of clean ammonia (speculative)

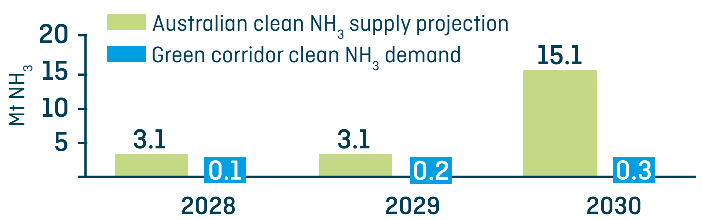


Figure 12: Map of 8 largest currently announced green ammonia projects in Australia[16] (top) and near-term outlook for corridor demand versus clean ammonia supply based on current announcements of project start dates[17] (bottom).

Figure 12 provides a map of the top 8 largest clean ammonia projects currently announced/under development in Australia, and expected capacity in the period between 2028-2030 period[18]. As shown, not including AREH, there could be approximately 3 million tonnes of ammonia per year of capacity online by 2028, increasing to 15 million tonnes per year by 2030 – significantly more than the corridor's 0.1-0.3 million tonne per year demand in this period. The corridor's initial demand , therefore has the potential to be bundled into a first phase FID for a project elsewhere in Australia.

16. For projects which are classified as export-focused on HyResource (2023).
17. Only includes projects for which full operational capacity is known and occurs before/in 2030.
18. See Appendix 4.2 for a full list of clean ammonia projects in Australia currently under development.

Many projects in Australia are taking an export-oriented offtake approach, which may prove a roadblock to reaching FID and full-scale production. Recent analysis has suggested that eventual imports of hydrogen and ammonia may be lower than announced 2030 targets globally, owing to infrastructure lead times and insufficient policy support to achieve government targets (e.g. co-firing ammonia for power in East Asia)[19]. However, even if this does hold true, there would still be the potential for projects to reach FID with local offtakers. Measures such as the Australian Government's recent reform of the *Safeguard Mechanism*, which targets a gradual reduction of emissions limits, or "baselines", for large industrial facilities down to net-zero by 2050 – are likely to aid in accelerating the domestic demand for clean energy vectors, including hydrogen or ammonia. Supporting industrial clusters is also a priority of the Australian government, which is running a *Regional Hydrogen Hubs programme*, allocating $526 million towards the establishment of 8 future hubs.

Supplied by Star Bulk

19. BNEF estimates global hydrogen imports demand to be 3x lower than export supply by 2030. Hydrogen Export: Tough Competition Ahead (BNEF, 2022).

Global clean ammonia availability

The landscape of announced projects suggests that global clean ammonia production should be well above the volumes required in the corridor's kick-off phase. As shown in Figure 13, there are currently 20 clean ammonia projects with production capacities of greater than 0.5 million tonnes expected to hit operation globally by 2028. Of these projects, 2 have reached FID, with the remaining projects in a pre-FID stage,i.e. concept phase or undergoing feasibility studies. Because shipping ammonia is expected to have a minimal impact on its final delivered cost, offtake and imports from these projects to Western Australia, Singapore, or other ports on the corridor would be an additional pathway for procuring the required fuel.

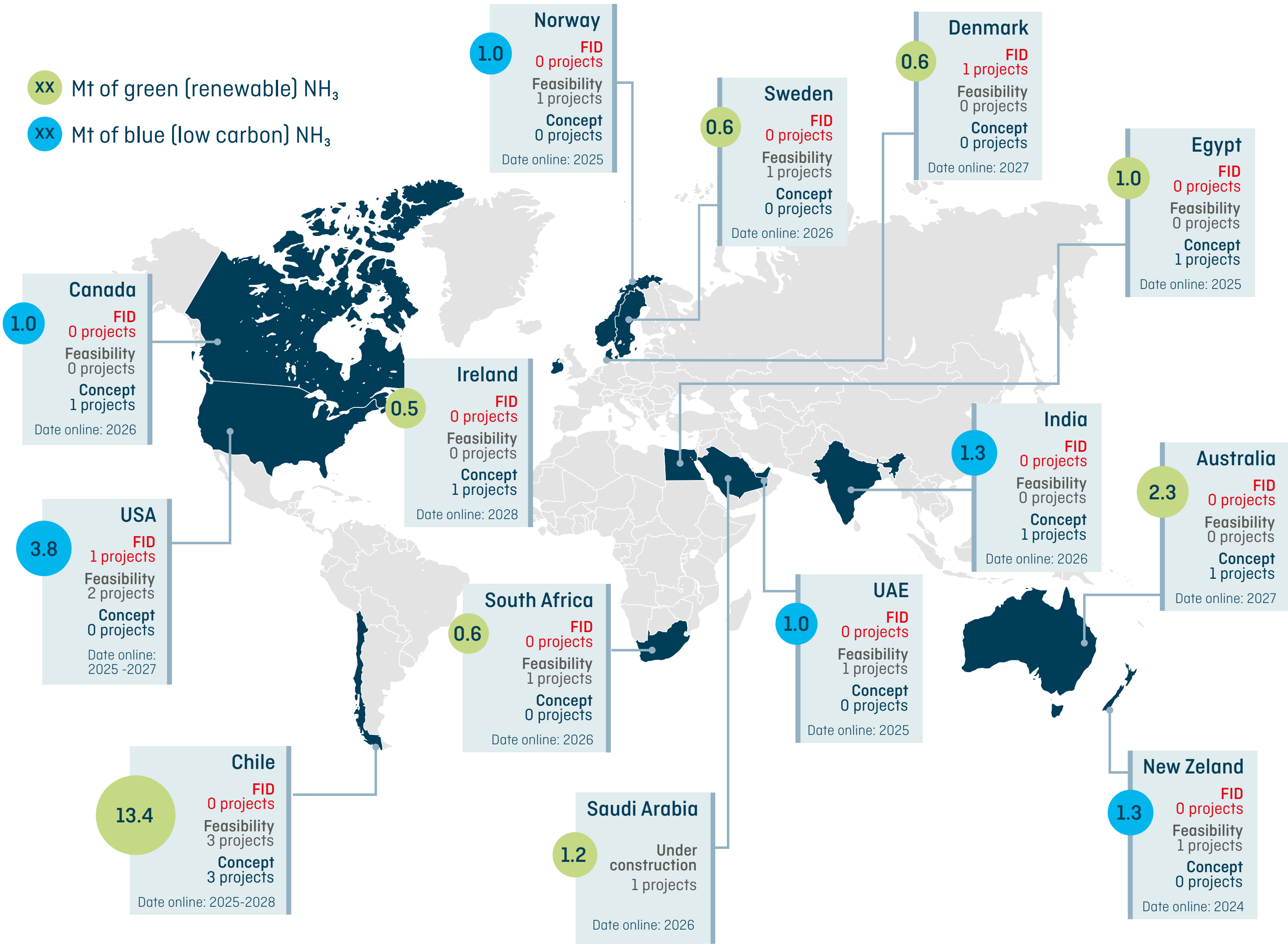


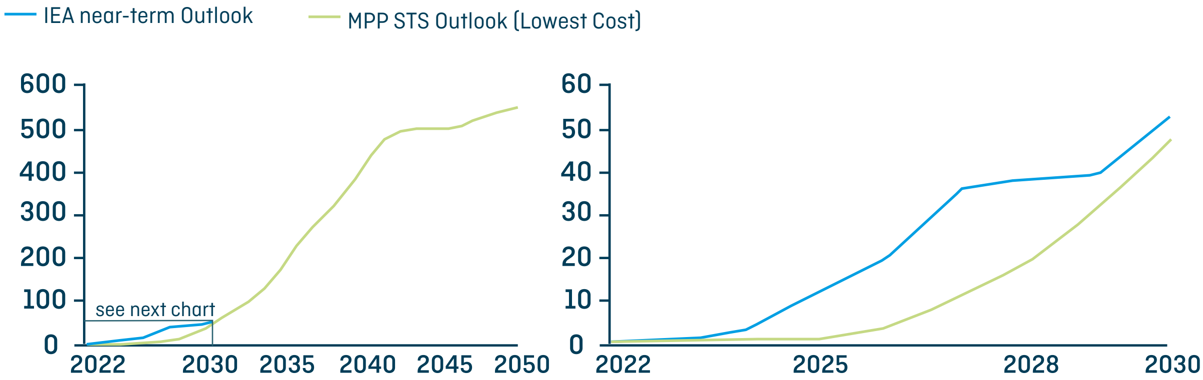
Figure 13: Global map of clean ammonia projects with planned online dates in 2028 or earlier[20]. HyResource (2023), IEA Hydrogen Projects Database (2022).

20. Totals shown here only include projects greater than 0.5 $MtNH_3$/y capacity and for which online dates are announced at the time this study was conducted.

Overall, supply outlooks suggest the corridor will represent a modest 0.5-1% share of global clean ammonia production. In the ramp-up phase for the corridor between 2028-2035, outlooks for global clean ammonia production suggest demand from the corridor will represent between ~0.3-0.7% of global supply. Based on global production estimates from the MPP *Ammonia Sector Transition Strategy*, the corridor's long-term ammonia demand between 2035-2050 would continue to account for ~1% or less of total clean ammonia production. As such, there are unlikely to be constraints on securing clean ammonia in the period between 2030-50.

Global clean ammonia supply outlooks

Mt of NH_3



Australia-East Asia iron ore green corridor representative share of global clean ammonia supply

Percent of annual global clean NH_3 supply

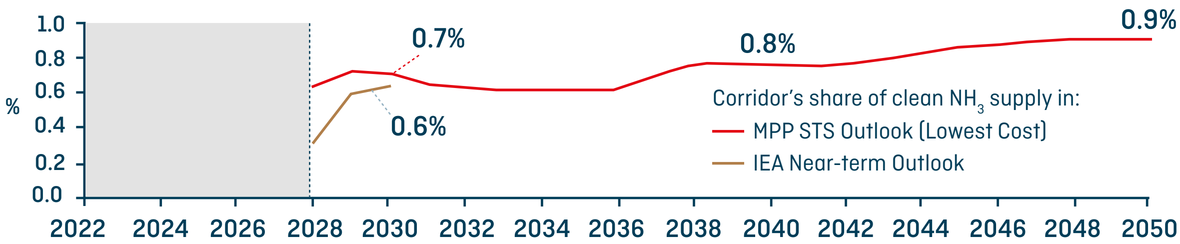


Figure 14: Global clean ammonia supply outlooks (top) and share of supply against corridor demand for each outlook (bottom)[21][22]. Sources: IEA Hydrogen Projects Database (2022); MPP Ammonia Sector Transition Strategy (2022); ETC Analysis (2023)

21. IEA Near-term Outlook: Based on speculative/announced projects with start-up dates to 2030; excludes ~33 Mt clean ammonia per year capacity from projects without an announced production start date.

22. MPP STS Outlook (Lowest Cost): Long-term global production outlook taken from Mission Possible Partnership's Ammonia Sector Transition Strategy; Lowest Cost is the net-zero scenario for decarbonizing the ammonia sector while optimising for lowest cost of production; it assumes a carbon price starting at US$10/t in 2026 and reaching US$100/t by 2035.

While production volumes for many projects are expected to be higher than the corridor's kick-off demand, shipping is not the only sector that will be seeking to secure volumes from the initial wave of global projects. As shown in Figure 15, by 2030, the global fertiliser and industrial sectors could account for ~22 million tonnes of clean ammonia demand in a net zero-aligned future, exceeding expected demand from shipping, at around ~20 million tonnes.

Clean ammonia demand outlook by sector

MT NH_3 in 2030

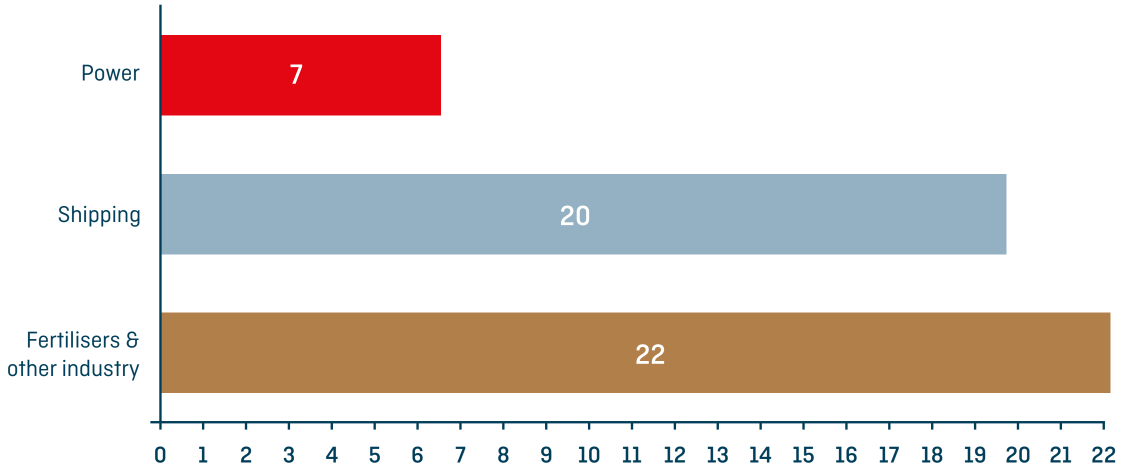


Figure 15: Global clean ammonia demand outlook to 2030 for power, shipping, and fertilisers & other industrial sectors[23]. Sources: ETC analysis (2023) based on Ammonia Sector Transition Strategy (MPP, 2022), Making Hydrogen Economy Possible (ETC, 2021)

Indeed, market leaders in fertilisers (e.g. CF Industries, Nutrien, OCI N.V.[24]) have already started securing clean ammonia supply at scales of up to ~1 million tonnes per year, starting 2025-2027. This presents a potential opportunity for the shipping sector, including actors interested in the development of this corridor, to collaborate on joint offtakes to help clear minimum offtake requirements.

But securing fuel supply will still come with a degree of risk. To mitigate against these risks, in the kick-off phase of the corridor, potential fuel buyers, including cargo owners and shipowners, could seek to:

- Register interest in and negotiate offtakes with relevant producers and projects early in pre-FID project phases.
- Support the development of relevant demand-driving policies, such as CfDs and mandates.
- Engage in dialogue with fuel providers regarding commercial frameworks that reflect risk and benefit sharing (on which see below).

23. Forecasted ammonia demand is taken from MPP Ammonia STS' 'Lowest Cost' scenario. Power demand is based on ammonia import targets from Japan and the Republic of Korea. Shipping demand is based on an S-curve, with ammonia use starting in the mid-2020s and reaching a ~55% share of total fuel use by 2050, per DNV low electricity cost-high ambition modelling scenarios. Fertiliser and other industry demand growth follows a business-as-usual trajectory, with clean ammonia estimated to reach ~10% of total ammonia demand by 2030. Further details can be found in the MPP Ammonia STS' Technical Appendix.

24. CF Industries have signed an MoU with JERA for the supply of up to 0.5Mt/yr of clean ammonia by 2027; Nutrien has partnered with thyssenkrupp for 1.2Mt/yr clean ammonia project, with FID in 2023 and full production expected by 2027; OCI N.V. has broken ground on a 1.1Mt/yr blue ammonia site in Texas, production to start in 2025

3.2.2 Enabling mechanisms

In addition to enough clean ammonia being available, a number of mechanisms will need to be in place to facilitate the corridor securing this fuel. Two key enabling mechanisms are addressed in this section:

- **Fit-for-purpose contractual models**. This sub-section compares the various challenges buyers and suppliers could face in contracting for new zero-emission fuels and suggests potential solutions different actors can take to address these challenges.
- **Clean ammonia certification**. One of these solutions, clean ammonia certification, is investigated in greater detail. Ongoing activities on clean ammonia verification, tracking and registries are explored, forming an outlook on when a framework to assure GHG emissions reductions from clean ammonia could be in place.

Bridging fuel supply contracting challenges

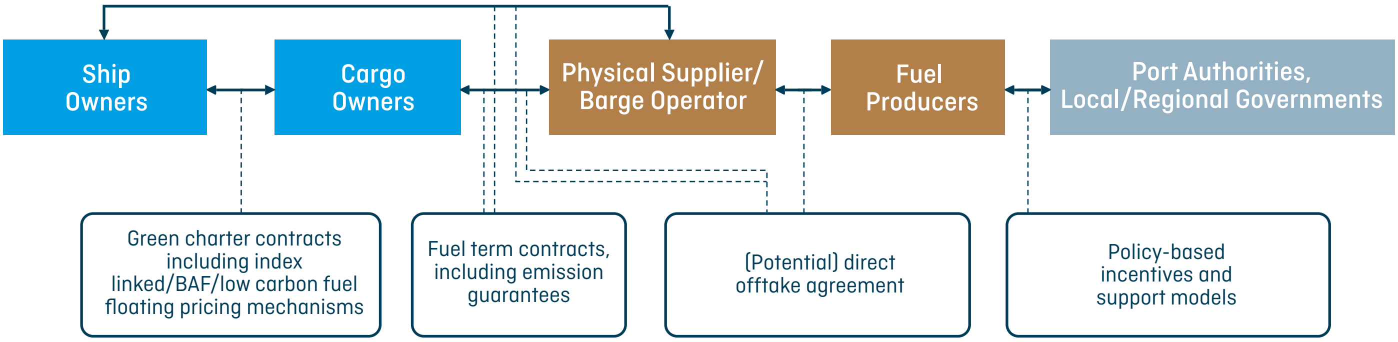
Multiple solutions will be required to address challenges in initial clean ammonia contracts.

Figure 16 presents a simplified value chain for the corridor, highlighting the potential contractual relationships between the various actors involved. They are split into three core groups:

- **The demand side** of the corridor, represented by shipowners and cargo owners. These actors have contractual agreements between themselves, in the form of charter contracts, as well as downstream, with fuel suppliers
- **The supply side**, represented by physical suppliers/barge operators and fuel producers. These actors typically have additional fuel supply contracts between each other
- **Other stakeholders**, including governments and port authorities, who may influence fuel supply contracts via policy incentives and/or support mechanisms for producers

It is expected that cargo owners will have either a fuel term contract to purchase clean ammonia from a fuel supplier or a direct offtake agreement with a fuel producer, although configurations in which shipowners sign fuel term contracts are also possible.

In all cases, the demand and supply sides will have requirements relating to the agreements, summarised at the bottom of Figure 16; these requirements will need to be balanced in an equitable way that works for both sides in order to move forwards.



Buyer-side challenges

- Assurance of the carbon intensity of clean fuels and systems/certificates to ensure the benefit is conferred to the correct parties
- Risk of lock-in at initial high fuel prices before fuel production and tank turnover increase over time
- Uncertainty around technology and infrastructure readiness (e.g., delayed vessel deliveries or bunkering/port availability)

Supply-side challenges

- Securing a multi-year (10+ years) and large-scale offtake to enable investment certainty and reach a successful final investment decision (FID) for the project
- Guarantee of zero-emissions fuel price premium proportional to production cost increment (particularly relevant for initial volumes)
- Uncertainty around timing and level of policy support/incentives

Figure 16: Simplified value chain structure for the corridor, with potential fuel contracting challenges [25, 26, 27].

A core challenge facing the supply side is bankability, i.e. the ability to attract investment, with clean ammonia production projects requiring a level of revenue certainty to achieve final investment decisions and access financing. For this reason, long-term fuel agreements are likely to be of importance for at least the initial period of the corridor's operation. To help bridge other risks and requirements, these agreements could include:

- **Clauses relating to uncertainties** on both the buyer side, such as clauses for adjusting fuel delivery dates or volumes in the case of delays in bunkering or vessel readiness, and supply side, such as clauses which allow for adjustments depending on policy development and confirmed levels of support.
- **Ramp-down mechanisms** or **price discounts in subsequent delivery phases** to avoid locking-in initial prices as fuel production increases, reducing the cost of producing clean ammonia.

Policy support and/or green premia will also be required as part of the overall framework to reduce costs and risks for the buyer, namely paying high fuel prices, and supplier, namely covering high production costs.

25. Diagram does not cover all nuanced contractual flows. In some cases, fuel producers and physical supplier/barge operators may be the same entity.

26. Potential measures include: Contracts for Difference tax incentives, government backed offtakes or guarantees, government purchases of low-carbon fuel, fuel mandates, legislated performance standards, loans or equity co-investments, public-private partnerships.

27. COA (Contract of Affreightment) refers to an agreement between an owner and a charterer for the carriage of a certain amount and type of goods between agreed ports over a given period of time.BAF (Bunker Adjustment Factor) refers to an additional surcharge levied on the ship operators to compensate for the fluctuations in fuel prices (imposed to make up for the extra charges incurred during the shipment of goods).

Finally, **clean ammonia certification mechanisms** will be needed to assure reductions in scope 1-3 emissions from the use of clean ammonia, and facilitate investments. While there is no relevant scheme in operation today, ongoing activities suggest that one **could be implemented by 2025-27** – see more below.

Clean ammonia certification

A clean ammonia certification mechanism would take the form of a multi-stage verification process, aimed at capturing and passing on emissions reduction guarantees from fuel producer to ship operator, cargo owner and customer. Potential verification steps, as depicted in Figure 17, include:

1. **Upstream verification**: Clean ammonia producer "verifies" the origin of clean ammonia by obtaining a guarantee-of-origin (GO) from an independent certification organisation.
2. **Certificate registry**: A joint registry between ammonia producers, shipping, mining, and steel companies is operated by the certification organisation and tracks the transfer of GO certificates.
3. **Downstream verification**: The registry operator certifies the claims of the ship operator for scope 1 emissions reduction, mining company for downstream scope 3 emissions reduction, and steel company for upstream scope 3 emissions reduction.
4. **Retirement**: After the GO is passed down the value chain, it is eventually cancelled or retired to close the transaction and avoid double counting.

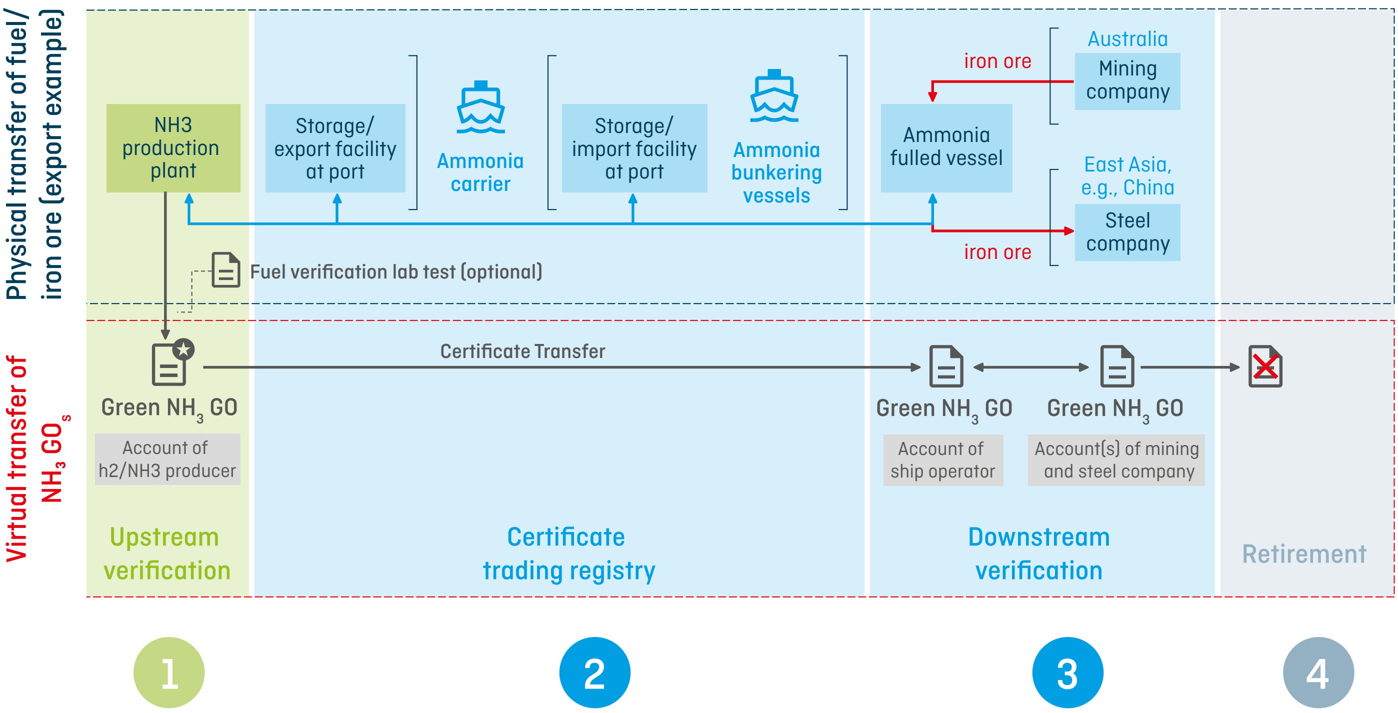


Figure 17: Possible emission reduction certification mechanism for green ammonia in the shipping sector value chain.

International organisations, private partnerships and companies have been progressing on the development of clean ammonia certification and transfer mechanisms, with initial outputs expected this year.

Active international cooperation is needed to establish unified international methodologies and standards for clean ammonia certification. In this regard, the IMO is currently developing lifecycle emissions guidelines for maritime fuels as part of its Initial GHG Strategy, which should be finalised in summer this year[28].

Meanwhile, Safetytech Accelerator, Lloyd's Register, TYMLEZ and Authentix are exploring technological solutions for upstream verification and downstream traceability, including the creation of a blockchain database to collect emissions data during the production of ammonia. A pilot version of the solution is expected to be finalised mid-2023[29]. Benchmarking against similar activity in other sectors, such as aviation, it is expected that full-scale implementation of the solution could happen approximately 2-4 years after piloting activity commences.

At the local and national level, several schemes are underway in the certification and tracking mechanism chain.

The Australian Government is developing a voluntary GO scheme to track and verify the emissions associated with the production of hydrogen and derivatives, such as ammonia. Following a public consultation, the scheme is planned to go live in 2024[30].

Yara is developing an internal certification scheme based on a multi-site mass balance model[31]. This system would enable the purchase of clean ammonia volumes decoupled from the physical supply of ammonia. In 2022, Yara also collaborated with the Australian Clean Energy Regulator on pre-certification of its Yuri green ammonia demonstrator plant, which is intended to serve as a launchpad for clean ammonia certification in Australia.

Supplied by BHP

28. Press-release by *IMO* (2021).
29. TYMLEZ *Letter to Shareholders* (2023).
30. Press-release by *Australian Government Clean Energy Regulator* (2023).
31. Yara Clean Ammonia *Capital Markets Day* (June 2022)

3.3 Bunkering

Based on existing analysis and ongoing activity levels, two sets of ports were pre-selected for study as potential bunkering locations for the corridor – the Pilbara ports and Singapore.

While they do not currently offer bunkering services, the bunkering assessment conducted in the Next Wave suggested that Western Australia's Pilbara ports – including Port Hedland and Dampier – could become the primary bunkering ports for the corridor, based on the relative simplicity and low cost at which they could potentially supply clean ammonia. Singapore was also suggested as a possible bunkering location in the report, as one of the leading bunker hubs in the region, with the potential to source zero-emission fuels from low-cost fuel productions globally, such as Chile or China.

The following section of the report explores the potential for the corridor to bunker clean ammonia in the Pilbara and Singapore. The sub-sections provide a summary of findings on:

- **Ammonia bunkering readiness**, including anticipated timelines for the development of commercial ammonia bunkering in the two sets of ports based on ongoing ammonia bunkering projects and activities.
- **Location tradeoffs**, providing an evaluation of possible tradeoffs between bunkering in the Pilbara and Singapore, by comparing the potential cost of clean ammonia, and expected availability of complementary services in the ports.

3.3.1 Ammonia bunkering readiness in Singapore and the Pilbara

Ongoing projects and recent announcements suggest that both of the Pilbara ports and Singapore could introduce ammonia bunkering in the next 5 years (see Table 3 below). It should be noted that the estimated timelines are subject to the passing of the necessary safety and environmental regulations for ammonia as a marine fuel and port authorities receiving clear demand signals to develop ammonia bunkering in the coming years, including shipowners and charterers placing orders for ammonia-powered bulk carriers.

Current projects and announcements suggest ammonia bunkering infrastructure could be in place in the Pilbara ports by 2027-2028. The development of ammonia bunkering in the Pilbara is being driven by Yara, Lloyd's Register, and Pilbara Ports Authority (PPA), who are jointly conducting a *feasibility study* to assess the technical, economic, and regulatory requirements for establishing ammonia bunkering in the area. The study is expected to be completed in the final quarter of 2023. Insights from stakeholder engagement undertaken for this study suggest no additional onshore infrastructure would need to be developed in the near term, with adequate jetties and fuel storage already in place to service up to roughly 2 million tonnes of ammonia per year of demand, only a suitable ammonia bunkering vessel.

The timeline for a potential ammonia bunkering vessel from Yara is yet to be determined and will depend on the results of the study. However, a clean ammonia-powered bunkering vessel provided by Australian vessel developer Oceania Marine Energy is expected to be in service by 2028.

Ongoing activity in Singapore suggests full-scale ammonia bunkering options could be in place there by 2027 or potentially earlier. There are several feasibility studies – by *GCMD and DNV*, *SABRE* and others – assessing ammonia bunkering in Singapore, and plans for initial bunkering pilots in 2024. In addition, the Maritime and Port Authority of Singapore (MPA) is calling on stakeholders to develop a new import terminal, storage facility and jetty for ammonia to support power generation and bunkering, initially at a capacity of approximately 0.1 million tonnes of ammonia per year. The initiative is complemented by activity from *Vopak*, who are exploring adding additional ammonia storage capacity at their Banyan terminal on Jurong Island. The development of ammonia bunker vessels is also underway, with *Fratelli Cosulich*, *Sembcorp*, and *MOL* at different stages, from design through to orders. The first vessel is expected to be delivered shortly after 2025.

A comprehensive list of technological and regulatory developments, and associated timelines for ammonia bunkering in Singapore and the Pilbara is provided in Table 3.

Table 3: Comparative assessment of ammonia bunkering developments in the Pilbara ports and Singapore[32].

Indicator		Pilbara	Singapore
Technology and infrastructure	Feasibility studies	**Expected completion in Q4 2023** • **Yara Clean Ammonia, PPA, and Lloyd's Register** are investigating the potential for ammonia bunkering in the Pilbara ports, including market, modality, safety, and regulatory assessments.	**Two studies completed; another expected for completion in Q2 2023** • **SABRE Phase 1**, involving MPA, Maersk Mc-Kinney Moller Center, Keppel, ABS and Sumitomo, aimed to demonstrate an ammonia supply chain in Singapore. A technical and commercial feasibility study, as well as preliminary ammonia bunkering vessel design, was completed in 2022. • **GCMD, DNV, Surbana Jurong**, and 22 other industry partners carried out an ammonia bunkering feasibility study, which was released in April 2023. GCMD envisions ammonia bunkering pilots with proxy assets in late 2023-early 2024 and operational assets in mid-2025. • **NTU Singapore, ABS, ASTI and Eastern Pacific Shipping** released a joint study in 2022 exploring the potential of ammonia as a marine fuel. • **MHI and Jera** have signed an MoU to conduct a joint study on the development of an ammo bunkering terminal at Jurong Port (no announced completion date).
	Onshore infrastructure	**In place for early stages** • **Engagement suggests existing infrastructure (i.e. jetties, storage tanks) would be able to provide ammonia bunkering in the early stages of the corridor's development** (up to ~2 million tonnes per year). • **Western Australia Govt** has recently announced it will invest $565 million to support wider port upgrades in Pilbara.	**Timeline yet been defined** • **EOI by between Singapore EMA and MPA** to design an ammonia import terminal, storage facility and jetty for at least 0.1 million tonnes of ammonia by 2027. • **Vopak Singapore and ITOCHU** exploring adding new storage capacity for ammonia to support power generation and bunkering at Banyan terminal (announced Q4 2022).

32. Sources: *Pilbara Ports Authority* (2022), *Government of Western Australia* (2023), *NERA* National Energy Resources Australia (2022); *GCMD* Global Centre for Maritime Decarbonisation (2022), *Maersk Mc-Kinney Moeller Centre* (2022), Press-release by *MHI* Mitsubishi Heavy Industries (2022), Press-release by *NTU* Nanyang Technological University (2022), *MPA* Marine Port Authority of Singapore (2022), Press-release by *Vopak* (2022), *Fratelli Cosulich* orders ammonia bunker tanker in China (Offshore Energy, 2022), Press-release by *Sembcorp* (2022), Press-release by *MOL* (2022), Press-release by *Paxocean* (2022), Press-release by *ITOCHU* (2022). Stakeholder engagement and consortium feedback.

Technology and infrastructure	Bunkering vessel	**Expected deliveries in 2027-2028** • The above-mentioned ammonia **bunkering feasibility study led by Yara** is exploring potential bunkering vessel design options, tailored to the ports' requirements and anticipated bunker demand. • **Oceania Marine Energy** is developing a bunkering vessel able to supply both LNG and ammonia for delivery after 2026, followed by a clean ammonia-powered ammonia bunkering vessel, aiming for delivery in 2028.	**Expected deliveries in 2025-2027** • **SABRE Phase 2**, focusing on commercial feasibility via supply chain FIDs, acquiring a bunkering permit and ordering bunkering vessel. Expected for completion in early 2024. • **Fratelli Cosulich** MoU for the construction of an ammonia bunkering vessel, delivery after 2025 • **Sembcorp Marine, MOL, ITOCHU** AiP from ABS for an ammonia bunkering vessel. • **Paxocean, Hong Lam and Bureau Veritas** MoU to develop an ammonia bunkering vessel design.
Regulations and safety[33]		• Will be evaluated as a part of **PPA, Yara and Lloyd's Register** feasibility study. • Regulations, licensing, and standards also likely to leverage developments elsewhere (**e.g. SGMF guidelines, Singapore studies**).	• **GCMD** ammonia bunkering study performed locational HAZID/HAZOP studies and created draft technical, procedural and competency/training guidelines. • **Joint Study Framework for Ammonia Bunkering Safety**, launched by ITOCHU and 16 other partners in Q2 2022, aims at creating a framework for sharing knowledge on safety and guidelines for ammonia bunkering.
Fuel supply		See section 3.2.1 *Clean ammonia fuel availability.*	EOIs and ongoing supply chain studies suggest likelihood of availability (detailed assessment out of scope).

3.3.2 Tradeoffs between Singapore and Pilbara bunkering

An assessment of factors influencing the choice of bunkering in the Pilbara or Singapore suggests that neither location has a decisive advantage over the other.

This section provides an assessment of the following factors which could potentially influence the bunkering decisions of ship operators and charterers on the corridor:

- Indicative fuel costs
- Deviations and associated fuel requirements
- Complementary services and other benefits

Fleet-wide bunkering decisions are impacted by a number of different factors, many of which are subject to variation over time, such as daily hire costs, infrastructure availability, and the scale of fuel demand. The results presented in this section should be taken as initial and should not be used in isolation to determine whether bunkering in the Pilbara, Singapore, or any other port in East Asia would be optimal for the corridor in the future. Further detailed assessments will need to be completed to reach firmer conclusions, as the markets for clean ammonia supply and bunkering services develop.

33. While out of scope of this assessment, regulatory changes will also be required in discharge ports to allow entry by ammonia-powered vessels.

Indicative fuel costs

Clean ammonia in Australia is likely to be cost-competitive with clean ammonia in Singapore from low-cost regions[34]. As shown in Figure 18, the delivered cost of ammonia[35] to ports in the Pilbara could be lower than Singapore, which would need to import clean ammonia from low-cost production locations elsewhere in the world, such as the Middle East or Latin America.

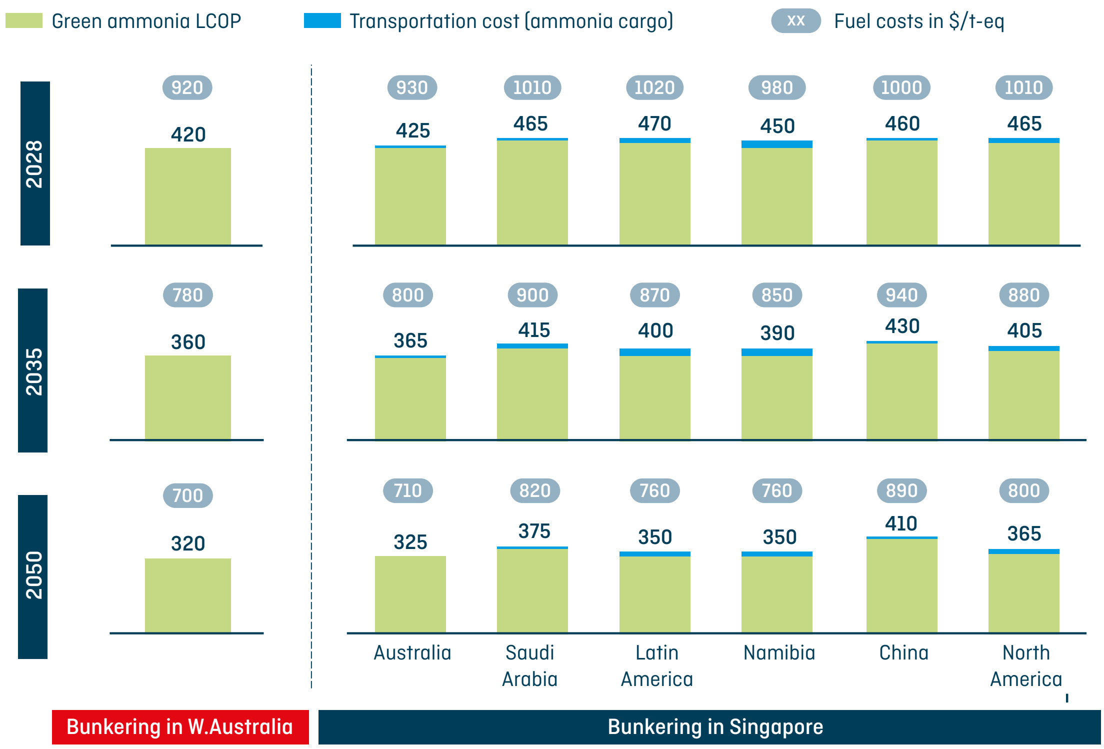


Figure 18: Indicative future fuel costs between Australia and Singapore ($/t NH_3)[36]. Sources: Mission Possible Partnership, 2022: Ammonia Sector Transition Strategy; Al-Breiki et al (2020): Comparative cost assessment of sustainable energy carriers produced from natural gas accounting for boil-off gas and social cost of carbon; expert interviews and Consortium feedback.

These figures do not include last mile costs[37]. While somewhat uncertain, overall, it is expected that last mile costs will be higher in Australia than Singapore, due to higher labour costs in Australia and the larger scale of bunkering services in Singapore, including greater fuel volumes and numbers of suppliers. Over the medium and long term, the expansion of renewable generation and clean ammonia production capacities in Australia may lead to decreased production costs and economies of scale for last mile delivery.

34. Import volumes of green ammonia from low-cost regions will depend on project development timelines by 2028 (e.g. IEA Near-term Outlook expects ~14Mt clean ammonia per year to be available in Latin America and ~4 Mt clean ammonia per year in the Middle East by 2028).

35. Projected costs do not account for policy support or incentives (e.g. USA's Inflation Reduction Act) which will be decisive in the cost-competitiveness of ammonia supply, but are still crystallising.

36. Levelised cost of production (LCOP) for ammonia is derived from MPP's Ammonia Sector Transition Strategy (2022), which does not factor in any potential policy/financial support mechanisms. Transportation costs include the fuel demand and operational costs of transporting ammonia via ship to Singapore from the overseas regions shown.

37. Last mile costs encompass costs for ammonia handling (transport and storage), bunkering services, and fuel testing services. They are dependent on port infrastructure availability, turnover costs, labour costs, fuel volumes and other regionally differing factors. Uncertainty exists around future ammonia last mile costs in Australia and Singapore, which may in future be based on market indices (reflecting a % of the fuel cost) or fixed delivered premiums in contracts (i.e. additional $/t$NH_3$).

Route deviations and associated fuel requirements

Increased travel distances for bunkering in Singapore would increase fuel requirements. As a result of voyage deviations, roundtrip raw fuel costs for bunkering in Singapore could be ~9% higher compared to bunkering in the Pilbara, as shown in the indicative case-study in Figure 19[38]. In addition to these potential fuel savings, the length of time spent by vessels at port in the Pilbara could be minimised by refuelling while at anchorage, turning idle time into operational time.

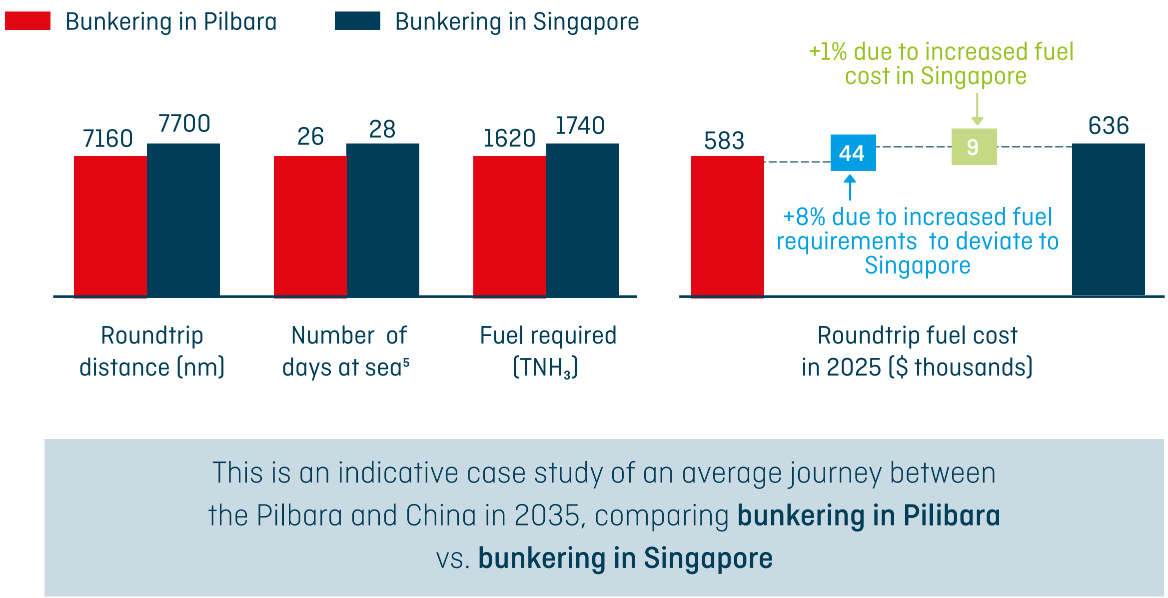


Figure 19: Potential differences in fuel requirements[39] and fuel costs[40] between bunkering in Pilbara and Singapore in 2035. Sources: ETC Analysis (2023); Ammonia Sector Transition Strategy (MPP, 2022); Sea-Distances.org

However, it is possible that the Singapore will charge lower port fees for ammonia bunkering, due to the greater scale of bunkering services and government subsidies.

Future commercial assessments would need to undertake more detailed costs analyses incorporating, for example, daily hire costs for vessels and last mile costs at ports, to see how these elements impact on the difference in fuel costs.

38. Cost difference shown is indicative based on ETC analysis with many uncertain factors influencing future fuel costs (fuel supply cost, delivered fuel premiums, policy support, etc.). Note that time spent at port for bunkering, daily hire costs and wider tradeoffs will also factor into fleet-wide bunkering decisions.

39. Roundtrip distances in this example based on Port Dampier (Australia) and Port of Qingdao (China), assuming bunkering in Singapore on a single leg of the roundtrip voyage.

40. Based on a 2035 indicative fuel cost of $360/tNH_3$ in Australia and $365/tNH_3$ in Singapore (includes added transportation costs in the scenario where ammonia is imported from Australia). Excludes last mile costs. Increased number of days at sea would also lead to increased costs (not shown here) under time- and voyage-charter contracts, wherein the charter rate is typically based on the distance traveled or the time required to complete the voyage.

Complementary services and other advantages

Both the Pilbara ports and Singapore provide a range of complementary services.

Port Hedland is one of the busiest crew change centres in Australia, which would allow crew changes alongside bunkering. Furthermore, the Australian Government has expressed support for the long-term growth of renewable industries and trade diversification, and is planning significant investment in infrastructure upgrades at the Pilbara ports.

As well as crew changes, Singapore has drydocks for vessel repair and maintenance services, which are unlikely to become available in the Pilbara. However, experts indicate that availability of maintenance and repair services is of relatively low importance for the corridor's bunkering location, given the relative infrequency with which vessels must go into drydock and the clear preference of the shipowners operating on the corridor towards more competitively priced drydock options elsewhere in East Asia, mostly in China.

Key takeaways: Bunkering

- Two potential locations for bunkering on the corridor – Singapore and the Pilbara – were examined in this section. It was found that both locations could introduce ammonia bunkering in the next 5 years, making them among the first ports worldwide to do so.
- Ammonia bunkering in the Pilbara would represent a competitive option for the corridor, with the potential for clean ammonia to be efficiently delivered to the port from local production sites and fuel savings from bunkering directly on the trade route.
- Singapore would also be well-positioned to serve as a bunkering location for the corridor, with the high level of activity to pilot and develop ammonia bunkering creating a strong likelihood the fuel will become available in the coming years, potential for competitive last mile costs, and the availability of multiple advantageous services.
- Other bunkering locations for the corridor are possible, particularly in the medium to long-term, but were not in scope for this study.

1 Appendix

Supplied by Pilbara Ports Authority

4.1 Vessel and voyage assumptions

Table 4 shows the key voyage and vessel archetype assumptions used to calculate fuel demand and vessel requirements. Note the majority of voyage, vessel and fuel specifics given in Table 4 are assumed to be stable over time, with the exception of fuel requirements and main engine power (MCR), which are considered to follow downward trends to 2050 as result of vessel and system-wide efficiencies (refer to Section 2.2 for more detail).

Table 4: Voyage, vessel and fuel consumption assumptions based on ETC Analysis (2023), Sandia National Laboratories (2017), Nature Energy (2022), MAN (2022) and real-world data shared by Consortium members.

	Assumption	Units	Port region 1[41]	Port region 2[42]	Port region 3[43]	Port region 4[44]
Voyage	Corridor distance (single leg)[45]	nm	3501	3568	3598	2752
	Days per round trip	days	39	40	40	34
	At sea[46]	days	25	26	26	20
	At port[47]	days	14	14	14	14
	Number of annual roundtrips	number	9	9	9	11
	Average cargo shipment[48]	tonnes iron ore	181,400	181,500	165,400	148,300
	Fuel requirement per roundtrip[49,50]	IFO tonnes	951	1004	1000	802
		NH_3 tonnes	1759	1856	1849	1482

41. Comprised of Bayuquan, Caofeidian, Caojing, Changzhou, Dalian, Dandong, Dongjiakou, Fangcheng, Huanghua, Jingtang, Kemen, Lanshan, Lianyungang, Liuheng, Majishan, Ningbo, Qingdao, Rizhao, Shanghai, Tianjin, Zhangjiagang, Zhanjiang

42. Comprised of Gwangyang, Onson, Pohang, Pyeongtaek, Ulsan, Yeosu

43. Comprised of Chiba, Fukuyama, Higashiharima, Hirohata, Ichihara, Kashima, Kawasaki, Kisarazu, Kobe, Kure, Mizushima, Oita, Tokuyamakudamatsu, Tokyo Bay, Yokohama

44. Comprised of Kaohsiung, Mailiao, Tiachung

45. Corridor distance is a proportional weighted average based on annual real-world journeys from MarineTraffic AIS data, covering journeys from Dampier and Port Hedland in Australia torelevant East Asian ports

46. Days at port calculated based on averaging real-world data shared by the Consortium.

47. Days at port calculated based on averaging real-world data shared by the Consortium.

48. Carrying capacity calculated based on average of data for different vessel classes from MarineTraffic and average cargo shipment from averaging real-world data shared by the Consortium.

49. Gravimetric energy density used to convert tonnes of fuel consumption between fuel types (HSFO: 40.2 MJ/kg, VLSFO: 41.5 MJ/kg, NH_3: 18.8 MJ/kg). IFO energy density (40.9 MJ/kg) based on real-world average between HSFO/VLSFO taken from Singapore bunkering

50. Baseline in 2021; does not account for reductions due to efficiency measures over time. Output from theoretical model validated to be within 5% difference of consortium real-world fuel consumption data.

Vessel and fuel	Average speed Ballast[51]	nm/h (knots)	11.8	12.0	12.0	12.0
	Average speed Laden[49]	nm/h (knots)	11.2	11.3	11.3	11.3
	Max speed	nm/h (knots)	14.5	14.5	14.5	14.5
	Main engine power (MCR)[52]	kW	13900	14600	14400	15100
	Overall system efficiency[53]	%	37%	37%	37%	37%
	Engine load factor ballast[54]	fraction	0.386	0.386	0.386	0.386
	Engine load factor laden[52]	fraction	0.453	0.453	0.453	0.453
	Fuel margin[55]	%	12%	12%	12%	12%
	Pilot fuel requirement [56](assuming IFO as a pilot fuel)	% energy	15%	15%	15%	15%
		% mass	7.5%	7.5%	7.5%	7.5%
	Weighted average fuel consumption	tonnes IFO/hr	1.6	1.7	1.6	1.7
		tonnes NH_3/hr	2.9	3.0	3.0	3.1

51. Based on average of real-world data shared by the Consortium..
52. Based on weighted average between Capesize and Newcastlemax engine powers shared by Consortium.
53. Refers to the percentage of overall fuel/energy consumed by the vessel for propulsion and other energy demands over total energy expended during the voyage. Based on Consortium and expert feedback, this has a highly variable range depending on voyage conditions, vessel class, fuels utilised, and so on. An average conservative estimate of 37% was taken to represent the corridor fleet.
54. Based on real-world data shared by Consortium.
55. 12% fuel margin accounts for fuel used at port and sea variance (e.g. weather/swell conditions)
56. Assumption based on MAN ES Marine Engine Programme (2022) and Consortium feedback.

4.2 List of relevant planned Australian clean ammonia projects

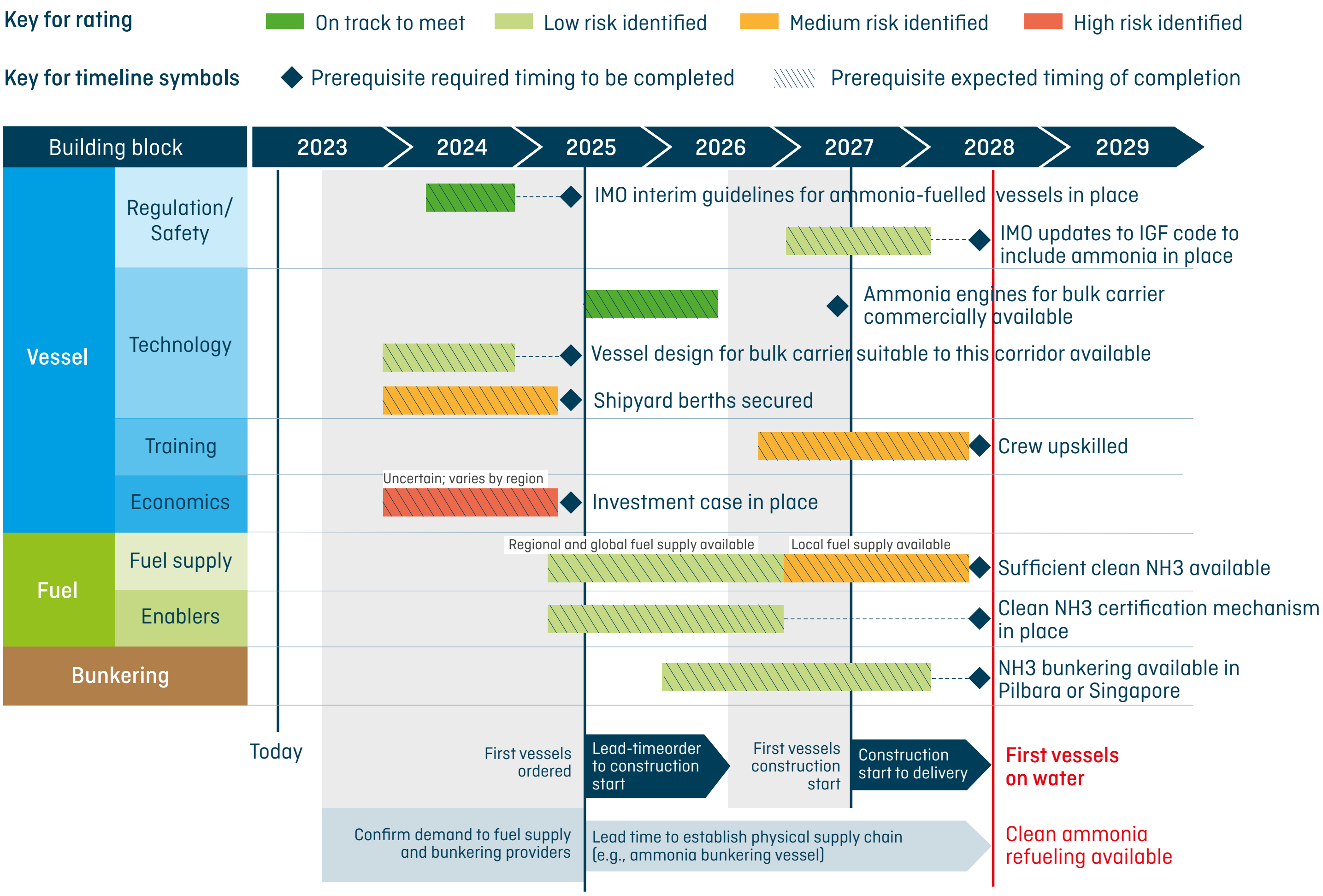
Table 5: Planned clean ammonia production projects in Australia. "TBC" indicates year or capacity is still "to be confirmed". Source: HyResource (2023); IEA Hydrogen Projects Database (2022)

Project Name[57]	Ammonia type	Project statuss	Start-up year	Full-capacity year	Capacity (Mt NH_3/y)	
					Start-up	Final
Western Green Energy Hub	Green	Under development	2030	TBC	TBC	10.2
Port Bonython H2 Hub	Green	Feasibility study	TBC	2030	TBC	10.2
Australian Renewable Energy Hub[58]	Green	Under development	2028-30	TBC	5.2	9.0
Desert Bloom	Green	Under development	2023	2027	<0.1	2.3
Murchison H2 Renewable Project	Green	Under development	TBC	2030	TBC	2.0
Hunter Energy Hub	Green	Feasibility study	TBC	TBC	0.1	2.0
H2 Hub Gladstone	Green	Under development	2025	2030	0.5	1.8
GERI	Green	Under development	2026	2031	<0.1	1.0
Sun Brilliance Western Australia	Green	Under development	2025	TBC	0.4	0.8
H2 Perth	Blue	Under development	TBC	TBC	<0.1	0.6

57. Only projects which are classified as export focused on HyResource.
58. Start-up and full capacity year estimates are based on desk research and stakeholder engagement.

H2Tas Project	Green	Under development	2025	TBC	0.2	0.6
Origin Green H2&NH_3 Project	Green	Under development	2025	2025	0.4	0.4
Gibson Island Green NH_3 Project	Green	Under development	2025	TBC	0.4	0.4
Fortescue Green H2&NH_3 Plant	Green	Feasibility study	TBC	TBC	TBC	0.3
Mid West Clean Energy Project I	Blue	Under development	2027	2027	TBC	0.2
Port Pirie Green H2 Project	Green	Under development	2024	TBC	<0.1	0.2
Mid-West Clean Energy Project II	Green	Under development	TBC	2027	TBC	0.1
Yuri Renewable H2 to NH_3 Project	Green	Under construction	2024	2024	<0.1	<0.1

4.3 Detailed risk rating assessment for initial clean ammonia-powered vessel deployment in 2028



Building block		Prerequisite	Required timing	Expected timing	Rating	Comments and Evidence	Mitigation (if needed)
Vessel	Regulation/safety	IMO interim guidelines for ammonia-powered vessels in place	By 2025	Q4 2024		The development of interim guidelines for the safety of ships using ammonia as a fuel was initiated at IMO CCC 8 in Q3 2022. The workplan, agreed by the Sub-Committee, envisages finalisation of the guidelines by 2024 at the latest, with an interim report in 2023.	
Vessel	Regulation/safety	IMO updates to IGF Code to include ammonia	By 2028	2027- Q1 2028		Amendments to SOLAS and the IGF Code are expected to take 2-3 years following adoption of the interim guidelines. There is low risk of major misalignment between the Code and interim guidelines.	
Vessel	Technology	Ammonia engines for bulk carriers commercially available	By 2027	2025-2026		The first ammonia engines are expected to be available between 2024-26, based on latest announcements from manufacturers such as MAN, Wärtsilä, and WinGD. However, there is some uncertainty as to whether the first engines will be the correct types/sizes for the specific needs of bulk carrier on the corridor.	Sending clear demand signal for ammonia engine sizes and specifications suited for bulk carriers.
Vessel	Technology	Vessel design for bulk carrier suitable to this corridor available	By 2025	2023-2024		AiPs for the design of ammonia-powered Newcastlemax and Capesize bulk carriers have been already granted to a number of projects (Anglo-Eastern, K-Line, DSIC, MOL & Mitsui). However, these designs would require modification to be suitable for the corridor.	Starting joint industry projects to accelerate the development of vessel design.
Vessel	Technology	Shipyard berths secured	By 2025	2023-2025		Most East Asian shipyards have very limited capacity available over the coming years. For example, expert interviews suggest major Korean shipyards have slots up to 2026 sold out, while most of China's major shipyards have slots solid out up to the end of 2024.	• Conducting a market assessment on shipyard availability and the cost of vessel construction. • Ordering vessels as early as possible after vessel designs become available (i.e., 2023-24).

	Training	Crew upskilled	By 2028	2026-2028		The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) will undergo a revision in 2023. The last two revisions took 3-4 years, followed by an 18-month grace period before coming into force. Individual initiatives (Just Transition Taskforce, Lloyd's Register Maritime Decarbonisation Hub) are also studying the issue and preparing recommendations.	Supporting national and international work to develop training schemes and voluntary programs, e.g., funding training centres, offering specialised courses for seafarers on handling zero-emission fuels; collaborative efforts between fuel providers and maritime academies to share best practices from existing industries; recruiting ammonia specialists to prepare ship crews for the fuel transition.
	Economics	Investment case in place (i.e., financial incentives, regulations and fiscal policy to promote ammonia fuel and SZEF vessels adoption)	By 2025	2023-2023 (uncertain and varies by region / country)		• Fuel cost gap: Slow emergence of national/international policy to close fuel cost gap, uncertainty around the implementation of support mechanisms (e.g. US IRA). • CAPEX subsidies: Limited funding programs or grants to help first-movers cover the additional costs associated with zero-emission vessel construction. • Carbon pricing: Slow development of the schemes to promote further emissions reduction among ship operators and downstream producers (e.g. at IMO). • Customer willingness to pay: Lack of green premiums on iron ore shipped using SZEF vessels.	Action by regulators in the early 2020s e.g., through supporting the procurement of low-carbon fuel such as via contract-for-differences, SZEF vessel construction subsidies, regulations accelerating sector-wide emissions reduction.

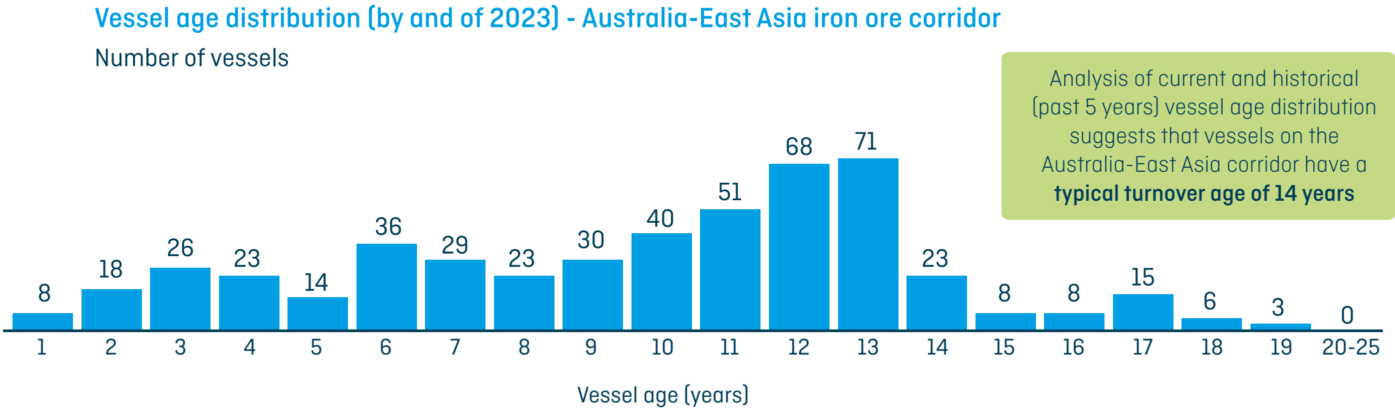
Building block		Prerequisite	Required timing	Expected timing	Rating	Comments and Evidence	Mitigation (if needed)
Fuel	Fuel supply	Local (Pilbara) fuel supply available	By 2028	2027-2028		• Near term supply of green ammonia is contingent on the Australian Renewable Energy Hub (AREH) project (pre-FID, ~9 million tonnes of ammonia per year at full-scale); minimum volume for 1st phase expected to be ~1 million tonnes of ammonia per year to achieve economies of scale.	**Local/regional:** Additional clean ammonia production in the Pilbara (e.g. blue NH_3 from applying CCS to existing grey NH_3 production) or in wider Australia could be developed to meet the kick-off phase for this corridor, or book-and-claim systems could be set up by 2028 to enable a 'last resort' option to guarantee clean ammonia supply. **All geographies:** • Register interest in offtakes with relevant producers/projects in pre-FID phase to mitigate the risk arising from minimum production volumes. • Engage in dialogue with fuel providers regarding commercial frameworks that reflect risk and benefit sharing. • Support the development of relevant demand-driving policies (e.g. CfDs and mandates).
		Regional (Australia) fuel supply available		2025-2027		• ~3.1 million tonnes of clean ammonia per year announced available in Australia by 2028). Contingent on project(s) kicking-off between 2025-2027 with a larger offtaker(s), but lower risk identified given greater number of projects.	
		Global fuel supply available		2025-2027		• A total of ~37 million tonnes of ammonia per year clean ammonia projects (average project size ~0.5-1 million tonnes of ammonia per year) in pre-FID phases today, with scheduled online dates between 2023-28, dependent on securing offtakers. Given the relatively low cost to transport NH_3 via ship, could be imported to W. Australia. • However, production volumes for these projects are higher than pre-2035 corridor demand (e.g. ~0.1 million tonnes of ammonia in 2028) and therefore the corridor may struggle to serve as an anchor offtaker.	

	Enabler	Clean ammonia certification mechanisms in place	By 2028	2025-2027		• International organisations, private partnerships and companies have been progressing on the development of clean/green ammonia certification and for transfer along the value chain. • IMO is developing LCA guidelines for marine fuels, expected to be finalised in 2023. • Safetytech Accelerator, Lloyd's Register, TYMLEZ and Authentix have been focusing on the delivery technologies for chemical verification of green/clean ammonia purity, creating a blockchain-backed database aggregating emissions-related performance data during the production of ammonia fuel. Pilot version is expected mid-2023. • Given pilots are ongoing and expected to be completed this year, expert discussions point towards full-scale implementation in ~2-4 years.	Active international cooperation needed in order to establish unified international standards and regulations, promote the development of LCA methods for the new types of fuels, set assessment boundaries and methodologies for certification, as well as to ensure validity of issued GOs across countries.

Building block	Milestone	Required timing	Expected timing	RAG Rating	Comments and Evidence	Mitigation (if needed)
Bunkering	NH_3 bunkering available in Pilbara or Singapore	By early 2028	2026-2027 (Singapore) 2027-2028 (Pilbara)		There are a number of ongoing activities to develop ammonia bunkering in Singapore: • In total four feasibility studies assessing ammonia bunkering options (SABRE Phase 1, completed in 2022; DNV and Surbana Jurong, targeting Q2 2023; ongoing studies between MHI & Jera and EPS & NTU) include the development of a ammonia bunkering vessel and emergence of the first pilots around 2024-2025. Alongside this, several private companies, incl. Fratelli Cosulich, Sembcorp Marine, Paxocean, Navig8 and others are in the various stages (from AiP to vessel order) of the development of ammonia bunkering vessels. • MPA of Singapore is calling on stakeholders to develop a new import terminal, storage facility and jetty for ammonia to support power generation and bunkering, with the bunkering construction timeline not yet defined. The initiative is complemented by activity from Vopak, which is looking into adding additional capacities for ammonia at their terminal Banyan. • Based on the current dynamics and announcements, it is expected full-scale ammonia bunkering at the port of Singapore to be available in 2026-27. In the Pilbara region, ongoing activities include: • PPA, Yara Clean Ammonia and Lloyd's Register are investigating the potential uptake of ammonia bunkering in the ports of Hedland and Dampier, including the assessment of required shore side infrastructure, safety considerations and regulations. The study is scheduled for completion in Q4 2023. • Insights from stakeholder engagement suggest in the early stages of development (up to ~2 million tonnes of ammonia per year demand), no expansion of jetties and additional port infrastructure is expected, except for an ammonia bunkering vessel. • First ammonia bunkering vessels for Pilbara ports could potentially come online in 2027-2028, provided by Australian developer Oceania Marine Energy and/or Yara. • Given the current activity/announcements, infrastructure for ammonia bunkering in Pilbara is expected to be available around 2027-2028.	• To accelerate lead times for ammonia bunkering infrastructure (e.g. ordering and construction of ammonia bunkering vessels), port authorities could move quicker should they receive clear and earlier demand signals, i.e., shipowners or charterers committing to use ammonia as a fuel and placing orders for ammonia--powered bulk carriers. • Development of the safety standards by relevant regulators based on the outcome of the feasibility studies. • In the early stages, acceptance of diesel-powered ammonia bunkering vessels should be viewed as a transitional option should ports face constraints on the design and/or delivery of ammonia-powered ammonia-bunkering vessels.

4.4 Corridor vessel age distribution and turnover projections

Analysis suggests that the majority of vessels in the existing fleet could require replacement in the next 5-10 years given a 14-year turnover age (Figure 20). Turnover age is herein defined as the age by which conventional-fuelled vessels on this corridor are estimated to be displaced and replaced by a new vessel to meet typical safety and performance requirements from charterers. Note this is different than the vessel's technical end-of-life (typical ~25 years). Based on the fleet age distribution shown in Figure 20, the average age of the existing fleet on the corridor is approximately 10 years, with 70% of the fleet lying within the 6-13 years range. There are also a greater number of conventional-fuelled vessels in the existing fleet in need of replacement during the 2020s compared to the 2030s.



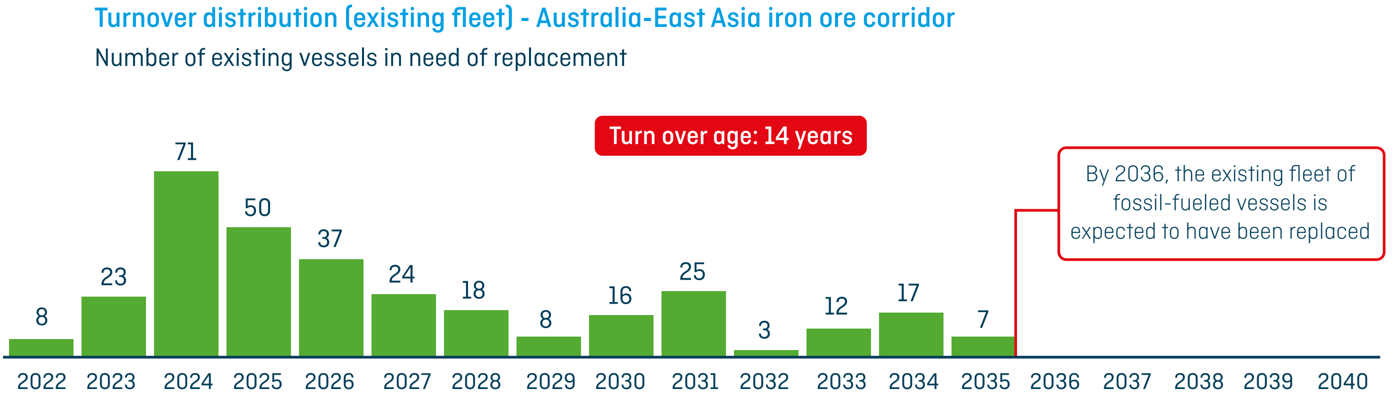


Figure 20: Vessel age distribution (top) and turnover distribution (bottom) of the existing fleet on the Australia-East Asia iron ore corridor[59]. ETC analysis (2023). MarineTraffic AIS data (2023).

59. For 500 unique ships in the existing fleet which complete the greatest number of voyages over an annual period. Turnover distribution excludes vessels which do not need replacement at their turnover age because of reduced vessel requirements over time (e.g. year on year reduced cargo demand).