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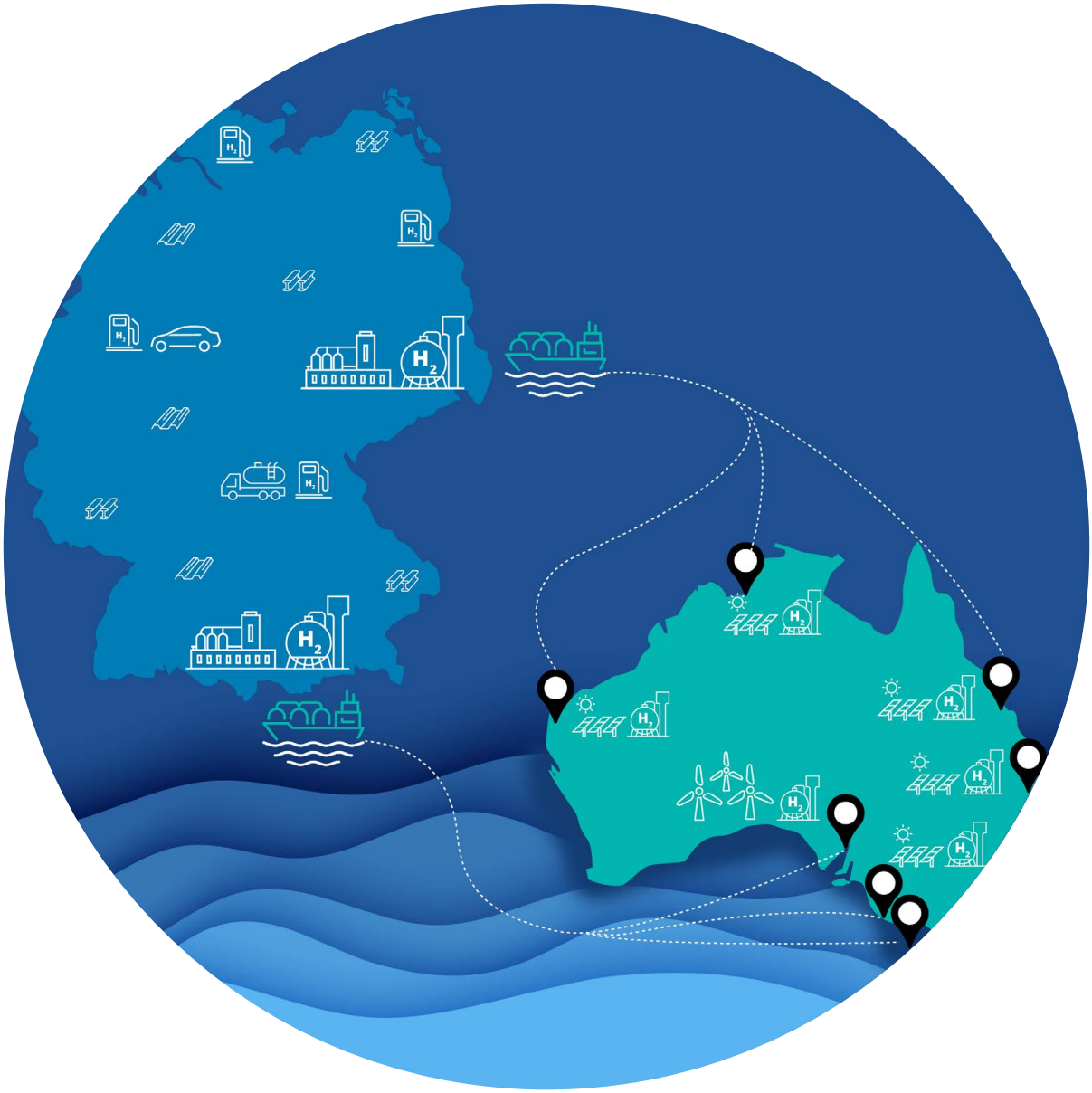
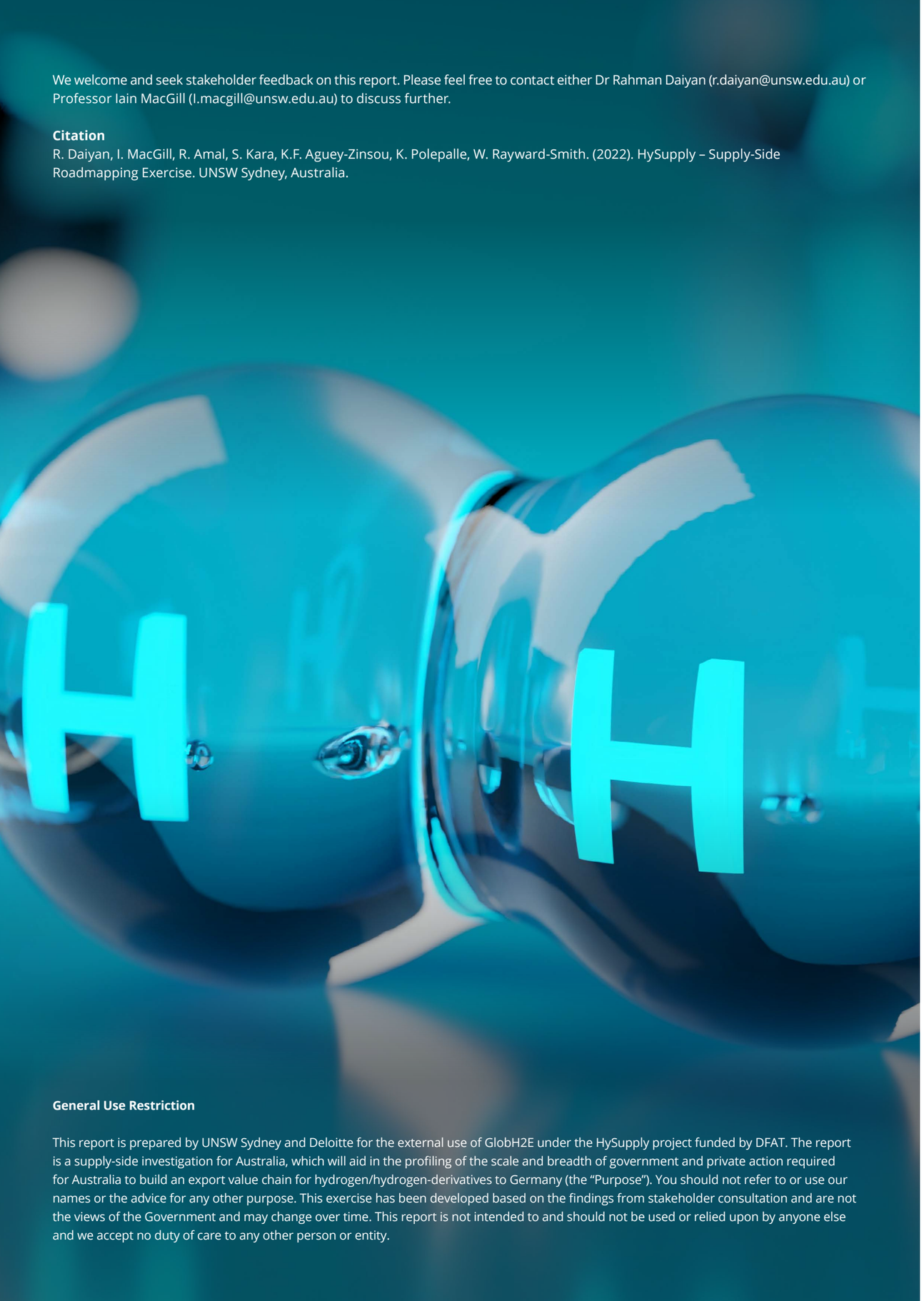
HySupply
Supply-side Roadmapping Exercise

August 2022





We welcome and seek stakeholder feedback on this report. Please feel free to contact either Dr Rahman Daiyan (r.daiyan@unsw.edu.au) or Professor Iain MacGill (I.macgill@unsw.edu.au) to discuss further.

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Executive summary

The transition to a green net zero economy is well under way with many countries, including Australia, now committed to achieving net zero greenhouse gas emissions over the coming decades. The future green economy will rely on a variety of clean energy solutions including maturing technologies such as solar and wind power, along with emerging solutions that have yet to reach their commercial potential. One of these emerging solutions is hydrogen. Australia and Germany recognise the value of hydrogen both as a clean solution and as an economic opportunity. In its 2019 ***National Hydrogen Strategy***, the Australian Government set a vision to become a major exporter of hydrogen by 2030. Germany is looking to accelerate its hydrogen demand by 2030 and has identified Australia as a key future trading partner. HySupply seeks to build on this shared aspiration by detailing the practical steps (commercial, regulatory and technological) that can support Australia to become a hydrogen, and hydrogen derivative, export partner for Germany.

Australia's Potential as an exporter

Australia has enormous potential to become a major hydrogen/hydrogen-derivatives (ammonia, methanol, liquid organic hydrogen carriers (LOHCs) and methane) producer and exporter and has been widely identified as a potential global hydrogen powerhouse.[1] Australia has natural resources, the space, and the skills[2] to successfully build a network of hydrogen hubs and export infrastructure. Geoscience Australia estimates that ~11% of Australia is highly suitable for renewable hydrogen production.[3] The development of a hydrogen industry is strongly supported by both industry and Government. Numerous private sector companies, have recently pledged significant investment into green hydrogen,[4] and there is significant expertise to be leveraged from the LNG and other export industries, and renewable energy projects. The Australian Government's recent commitment to achieving net-zero by 2050, along with national, state and territory strategies and roadmaps, provide strong political encouragement for the establishment of a national hydrogen industry.

The Export Opportunity from Australia to Germany

The export opportunity for Australia is significant. As more countries commit to net zero targets, the interest in and demand for hydrogen is ramping up, with countries, such as Germany, expressing interest in developing trade relationships with Australia. The International Energy Agency is predicting that by 2030 global demand for hydrogen could reach as much as 110 million tonnes per year.[5] Germany alone is predicting it will need to import between ~23-39 Mt of renewable hydrogen per year by 2030.[6]

Australia has the opportunity to play a key role in meeting this demand and has been encouraged by Germany to do so. A study conducted by the Australian Government found that Australia has the potential to export up to 500,000 tonnes of hydrogen by 2030.[7] This is a major economic opportunity for Australia – the hydrogen export industry has the potential to create thousands of new jobs and add billions of dollars to GDP as Australia transitions away from exporting fossil fuels.[8] However, this opportunity will not exist forever. If Australia waits too long to act, it risks losing market share to other potential hydrogen export countries in North Africa, the Middle East and the Americas.

Australia-German Hydrogen Progress

In September 2020, Australia and Germany signed an agreement to initiate a joint feasibility study into the potential for developing a hydrogen supply chain between the two countries. In November 2020, a consortia led by UNSW and supported by Deloitte was appointed to conduct this feasibility study. This roadmap is an outcome of that work, focusing on the

1 https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf
2 https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf
3 https://energyministers.gov.au/sites/prod.energycouncil/files/publications/documents/nhs-australian-hydrogen-hubs-study-report-2019.pdf
4 https://statements.qld.gov.au/statements/93812
5 https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf
6 https://www.globh2e.org.au/hysupply-publication
7 https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-roadmap
8 https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf

supply-side (Australian) potential to export hydrogen. Since the initial study was announced, Australia and Germany have strengthened their agreement through the ***Declaration of Intent between the Government of Australia and the Government of Germany on the Australia-Germany Hydrogen Accord***. The Accord seeks to build on Australia's potential as a hydrogen exporter and Germany's hydrogen demand and expertise to advance technology, accelerate the hydrogen industry, and create jobs across both nations. The Accord includes three main initiatives:

01. Establish the German-Australian Hydrogen Innovation and Technology Incubator (HyGATE). Applications commenced March 2022.
02. Facilitate industry-to-industry cooperation on demonstration projects in Australian hydrogen hubs
03. Explore options to facilitate the trade of hydrogen and its derivatives produced from renewables (such as ammonia) from Australia to Germany, including through Germany's H2Global Initiative, which supports long-term supply agreements with German industry[9]

HySupply Supply-Side Roadmapping Exercise

UNSW has partnered with Deloitte for the development of this roadmapping paper that aims to provide a supply-side pathway for Australia to develop a green hydrogen/hydrogen-derivatives export value-chain. In the development of this roadmapping paper, Deloitte and UNSW have consulted widely across various stakeholder groups to capture the diverse perspectives, challenges and opportunities for Australia in paving a path forward.

Over 50 stakeholders across industry, government agencies, and research organisations were consulted on the following key topic areas: commercial viability, technology uncertainty, policy gaps, regulation gaps, certification and social acceptance for hydrogen export and workforce capability. The purpose of the consultations was to identify the key barriers and opportunities across the key topic areas and formulate strategic next steps for Australia in realising its export potential.

HySupply Supply-Side Roadmapping Framework Structure

Six key findings were identified during the stakeholder consultation and these have been translated into guiding principles that Australia can consider in its transition to becoming a hydrogen export leader. The guiding principles and consideration of current Australian government policies were used as the basis for developing the roadmap actions. Below is a summary of the guiding principles:

01. Harmonise regulation
02. Collaborate between stakeholders
03. Target investment
04. Leverage a hub model
05. Build social acceptance
06. Draw on the learnings from Australia's current export industries

Summary of takeaways from consultations

Some notable takeaways emerged from the consultations:

01. The **willingness of international buyers** to pay for Australian exports of green hydrogen is still **unknown at this very early stage of industry development**, and will largely rely on clarifying the preferred forms of hydrogen matched to end use, acceptable green price premiums and acceptable carbon-intensity for imports.

02. To attract investors, States and Territories in Australia must have **clear, harmonised and streamlined regulations** to develop industry confidence and to attract investors. Accelerated progress on Guarantee of Origin Schemes for hydrogen and key hydrogen derivatives is needed.

03. The Government can best assist **'first-movers'** by **helping bridge the current price gap** between importers ('buyers') and exporters ('sellers'), as well as underwriting off-take agreements, providing investment security for exporters.

04. Many in industry are growing **frustrated with repetitive hydrogen feasibility** projects that provide limited practical experience for overcoming the challenges and uncertainties in green hydrogen export, and would like to see prioritisation of **scaled-up pilots** and projects.

05. There are **significant hurdles** involved in scaling to export scale across the value-chain (electrolysers, buffer storage, transportation via pipeline, liquification, hydrogen-ready ships, hydrogen loading/unloading at ports etc.) including sourcing enough land, water and renewable generation. Addressing these hurdles requires a coherent and comprehensive effort across a wide range of stakeholders.

06. The **decarbonisation** of established processes for producing hydrogen carriers such as **ammonia and methanol, will likely require a transitionary period** given challenges with **firming variable wind and solar** to match the conventional continuous industrial processes used for their production, as well as emissions elsewhere in the supply chain.

Key Considerations

The key considerations extrapolate on the stakeholder inputs and note some broader, strategic-focused areas that will require more deliberation moving forward:

01 **Speed to action is critical** if Australia is to become the market leader in hydrogen export. Delaying risks losing market share as potential investors will look to other developing hydrogen exporters in North Africa, the Middle East and the Americas to fill their demand.

02 **Parallel development of the domestic and export market** will be required for cost-competitive exports, whilst supporting local industry transformation, maintaining social license and maximising Australian jobs and economic development.

03 **Investment on multiple fronts is required**, as Australia needs to take a hydrogen carrier-agnostic investment approach. In the near-term this is likely to be ammonia, followed by long-term opportunities in other and potentially emerging carrier options.

04 **Carrier ships, port upgrades, co-location of hydrogen infrastructure and access to spare capacity of renewable energy will be critical** to ensuring hydrogen is produced, converted and transported – both domestically and internationally – in the most efficient manner possible, at least cost.

9 https://www.minister.industry.gov.au/ministers/taylor/media-releases/australia-and-germany-partner-hydrogen-initiatives

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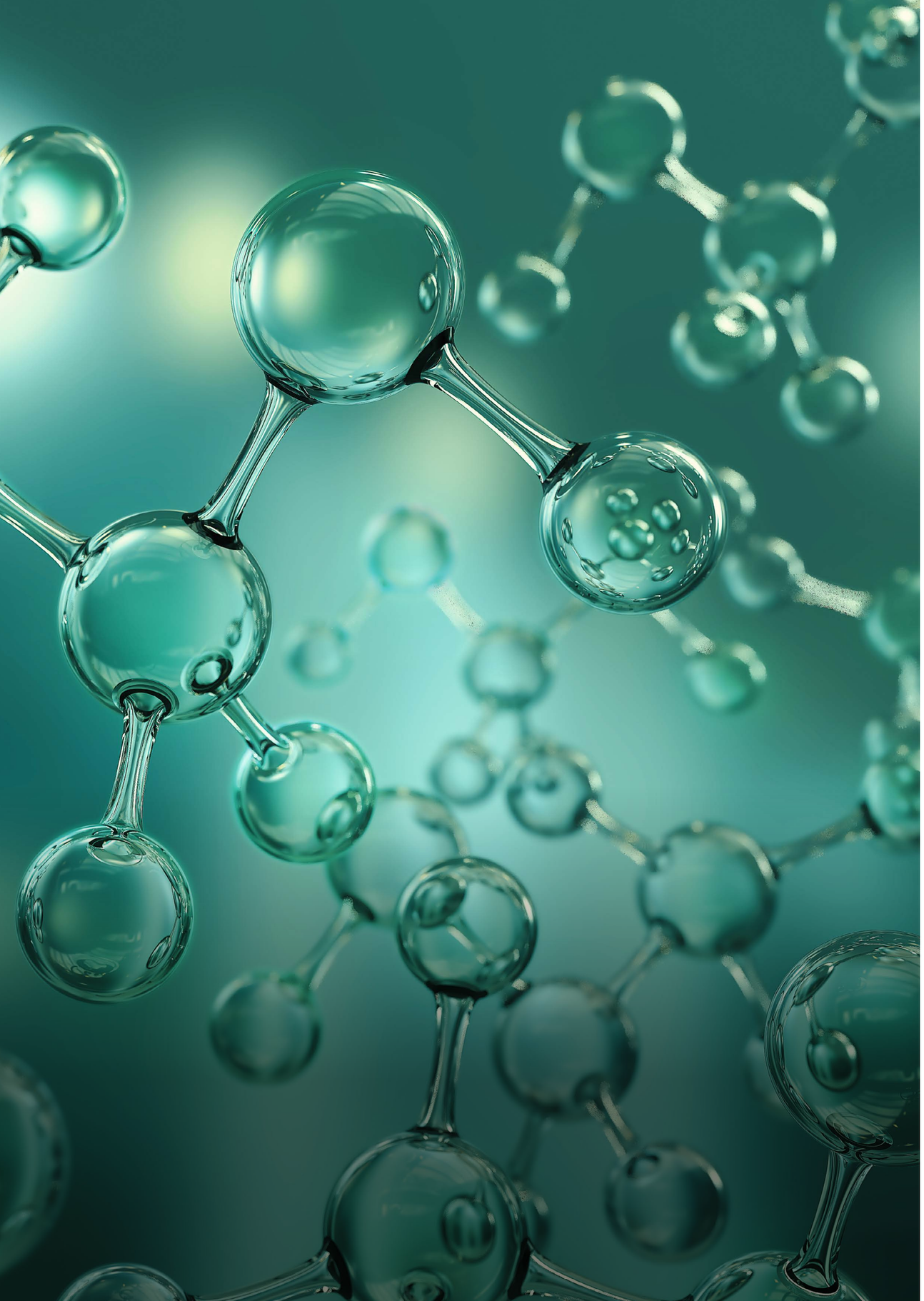

Glossary

Term	Definition
Key findings	The major themes to emerge from the 50+ interviews conducted with stakeholders in relation to the feasibility of developing an Australian hydrogen/hydrogen-derivatives export value-chain
Key considerations	Extrapolated from the stakeholder inputs, they note some broader, strategic-focused areas that will require more deliberation moving forward
Takeaways	Notable conclusions reached regarding Australia's hydrogen potential based on the stakeholder interviews
Guiding principles	A set of guidelines, informed by the key findings, to help focus and give direction to Australia's emerging hydrogen/hydrogen-derivatives export strategy
Actions	Distinct, actionable activities that can be undertaken by various stakeholders over time to build Australia's hydrogen export industry
Australia-Germany Hydrogen/Hydrogen-Derivatives Export Roadmapping	Outlines actions, mapped over three time horizons, specific to the Australian/German hydrogen export roadmap. The actions suggest a range of activities that can be undertaken by relevant German and Australian stakeholders to develop the Australia-Germany hydrogen/hydrogen-derivate export market
Supply-side Roadmapping	Outlines actions specific to Australia for the development of the supply-side value-chain. The actions are mapped over two time horizons and are categorised by 'guiding principle'. The actions aim to provide clear, actionable steps for the Australian Government and industry to ensure that Australia is in a position to export hydrogen/hydrogen-derivatives to Germany and more broadly to Australia's other potential export opportunities.

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1 HySupply background

HySupply

HySupply is a two-year feasibility study between Australia and Germany to explore the export opportunities for hydrogen and its derivatives

HySupply Background

Australia's Department of Foreign Affairs and Trade (DFAT) and Department of Climate Change, Energy, the Environment and Water (DCCEEW) and Germany's Federal Ministry of Education and Research (BMBF) have jointly funded the HySupply Project, a two-year feasibility study to investigate the export of hydrogen/ hydrogen-derivatives from Australia to Germany. The University of New South Wales (UNSW) has been appointed by DFAT and DCCEEW as the project lead for HySupply Australia. The broader project however is being delivered alongside, HySupply Germany, led by BDI and Acatech.

State of Play (SoP) – Consultation Paper

The SoP report is the first deliverable that was released by HySupply Australia. The report assesses Australia's export potential for hydrogen and its derivatives. This is done to provide both German and Australian stakeholders with an overview of how Australia's well established and globally leading role in conventional energy exports, and world-class renewables resources, can be leveraged for the development of a new export energy value chain assisting other countries such as Germany to achieve their decarbonisation objectives. The report is also intended to enhance the shared understanding of industry, Government and private sectors across Australia and Germany.

HySupply Open Source Tools

As part of the project, HySupply Australia developed a cost tools that allows for both real time simulation of hydrogen generation and its associated costs. A shipping analysis tool has also been developed to model the cost of shipping hydrogen (as liquid hydrogen (LH2) and hydrogen carriers (ammonia, methanol, methane (LNG) and LOHC (as toluene/ methylcyclohexane (TOL/MCH)). See **Appendix** for more details.

Federal Government Actions

The Australian Government is undertaking actions to develop a hydrogen industry, including providing funding of over $1.5 billion, regulatory reviews, an infrastructure assessment and the trial of a Guarantee of Origin scheme

Federal Government Actions:

- The Australian Government has pledged to reduce Australia's emissions by 43% below 2005 levels by 2030, achieving net zero by 2050.[1]
- The National Hydrogen Roadmap (2018) & National Hydrogen Strategy (2019) have been released, detailing Australia's direction for the development of a national hydrogen economy.[3]
- Australian Government funding for building a hydrogen industry exceeds $1.5 billion, including:
  - $300 million through the Clean Energy Financing Corporation (CEFC) Advancing Hydrogen Fund.[2]
  - The Clean Hydrogen Industrial Hubs program.[2]
  - The Australian Research Council has received $33 million in grants for hydrogen research.
  - ARENA is overseeing funding for numerous projects and initiatives such as the $50 million committed to the German-Australian Hydrogen Innovation and Technology Incubator (HyGATE) and $71.9 million Future Fuels Fund.[5,6]
- A regulatory review by various states and territories is underway, driven by Federal Government leadership, targeting greater regulatory consistency.[2] This review will focus specifically on legal frameworks and standards relevant to hydrogen industry development and safety.
- DCCEEW has commenced trials for the hydrogen Guarantee of Origin (GO) scheme.[2] DCCEEW also recently published a discussion paper which highlights the methodologies for guaranteeing the origin of clean hydrogen and discusses how the GO will evolve over time to include additional hydrogen production pathways.
- The Australian Government is currently leading a National Hydrogen Infrastructure Assessment, consulting states and territories regarding needs, availability and gaps in supply chain infrastructure.[2]
- The Australian Government is supporting the development of nationally consistent training materials and guidelines for handling, producing, using and transporting hydrogen.[2]
- Australian National Gas Law is being amended to bring hydrogen, bio-methane and other renewable gas blends under the scope.[2]
- The Australian Government is supporting the development of nationally consistent training materials and guidelines for handling, producing, using and transporting hydrogen.[2]

1 https://www.industry.gov.au/news/australia-submits-new-emissions-target-to-unfccc#:~:text=commits%20Australia%20to%20a%20more%20ambitious%202030%20target.,net%20zero%20emissions%20by%202050

2 https://www.industry.gov.au/data-and-publications/state-of-hydrogen-2021

3 https://www.industry.gov.au/data-and-publications/australias-national-hydrogen-strategy

4 https://www.afr.com/politics/federal/morrison-pledges-hydrogen-hubs-for-townsville-gladstone-20220425-p5afzt

5 https://arena.gov.au/funding/german-australian-hydrogen-innovation-and-technology-incubator-hygate/

6 https://arena.gov.au/funding/future-fuels-program/

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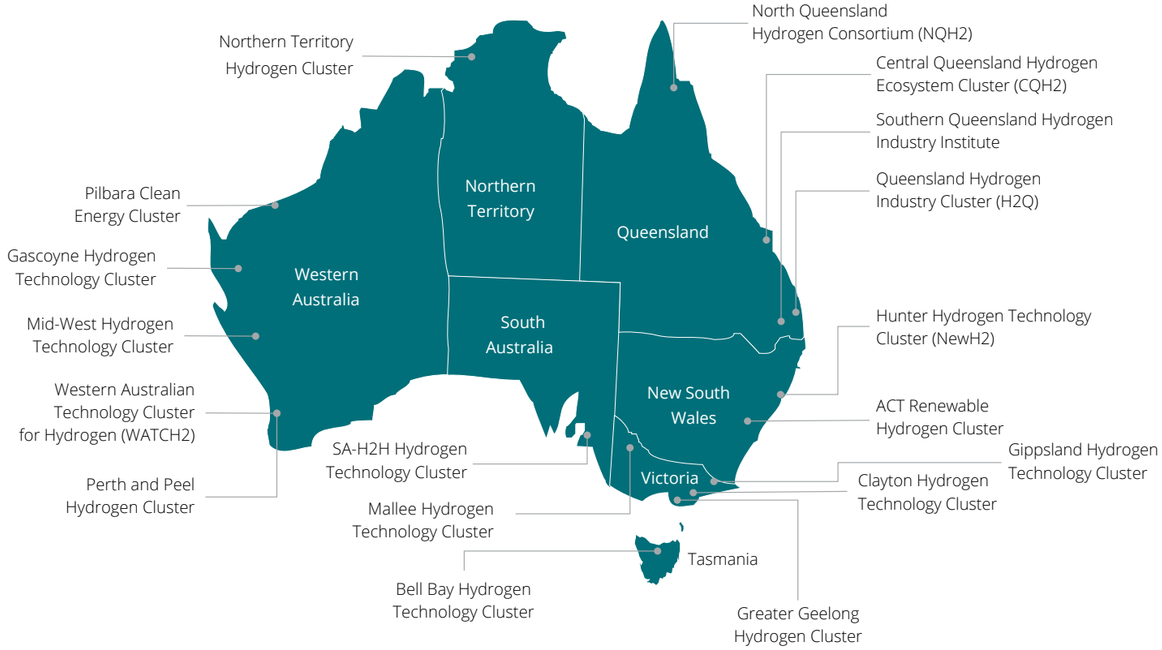
NERA Hydrogen Technology Clusters Australia (H2TCA)

The NERA H2TCA is a network of 18 hydrogen clusters aimed at accelerating the development of the hydrogen equipment, technology and services sector. The network was formed in partnership with government and industry to enhance skills, capabilities and commercialisation pathways in the hydrogen sector.



HySupply | Supply-side Roadmapping Exercise

State, Territory and Federal Government Actions

Australian State, Territory and Federal Governments are taking action to implement an export-scale hydrogen value chain

Northern Territory

- **2021 Renewable Energy Investment:** $47 million invested last year to grow capacity by 36 MW.[7]
- **Renewable Energy Target:** targeting 50% renewables supply in the electricity grid by 2030 and net zero by 2050.[2]
- **NT Renewable Hydrogen Strategy (2020):** strategy developed with the goal of becoming a global hub for hydrogen research, production and technology manufacturing.[2]
- **Renewable Hydrogen Mater Plan (2021):** identifies foundation actions to reduce investment risk and provides a framework for an export-scale renewable hydrogen industry in the NT.[2]
- The NT Government is supporting the Middle Arm Sustainable Development Precinct in Darwin, focusing on an hydrogen export industry and other advanced gas-based and critical minerals manufacturing projects.[2]

Western Australia

- **2021 Renewable Energy Investment:** $1.3 billion invested with capacity growth of 170 MW.[7]
- **WA System Plan:** Target established to convert WA's energy supply capacity to 70% renewables by 2040.[8]
- **WA Renewable Hydrogen Strategy and Roadmap (2020):** The state has established long-term goals to develop a hydrogen industry. Key short-term goals (2022) include development of a renewable hydrogen export project and injecting hydrogen into the gas grid.[2]
- **WA Renewable Hydrogen Strategy (2019 and updated 2021):** the state has four focus areas for hydrogen development, including export and reducing reliance of diesel for remote areas, and has established a $10 million Renewable Hydrogen Fund.[2]
- The WA Government has announced $117.5 million in funding for the Pilbara Hydrogen Hub and a Mid-West Hub (Oakajee).[9]
- In 2021 the WA Government opened $10 million of funding opportunities for the Hydrogen Fuelled Transport Program.[2]

South Australia

- **2021 Renewable Energy Investment:** $850 million invested with capacity growth of 500 MW.[7]
- **Renewable Energy Target:** Target established to convert SA's grid to 500% renewables to become net energy exporter to the Australia National Energy Market.[11]
- **SA's Hydrogen Action Plan (2019):** developed to establish SA as a key renewable hydrogen exporter, providing $17 million in grants and $25 million in loans to hydrogen projects.[2]
- **The SA Government has awarded $40 million in grants and loans to 3 MW-scale projects:** HyP SA, H2U Eyre Peninsula Gateway and the Neoen Australia Hydrogen Superhub.[2]
- The SA government has invested $37 million into upgrading the Port of Bonython, a prospective hydrogen hub location.[2]

Tasmania

- **2021 Renewable Energy Status:** The state has the highest share of renewable electricity in power generation (~99%).[7]
- **Tasmanian Renewable Energy Target:** Achieving 200% of current energy demand with renewable electricity supply by 2040 and become a net exporter.[12]
- **Tasmanian Renewable Hydrogen Action Plan (2020):** $50 million package committed to develop a green hydrogen economy, commencing hydrogen export by 2025 and becoming a global export hub by 2030. $2.6 million in first round funding has been allocated to support four feasibility studies for hydrogen projects by Origin Energy, ABEL Energy, Grange Resources and Fortescue Future Industries.[2]

Queensland

- **2021 Renewable Energy Investment:** $3.6 billion invested with capacity growth of 2.1 GW.[7]
- **Renewable Energy Target:** targeting 50% renewable power supply by 2030 and net zero by 2050.
- **Renewable Energy Corridors:** $145 million committed to develop renewable energy zones in the north, central and south-western regions of the state.[17]
- **Renewable Energy Fund:** $500 million in additional funding committed as part of the Covid-19 Recovery Plan to support energy projects and to develop infrastructure.[18]
- **Queensland Hydrogen Industry Strategy (2019):** The state government has committed $15 million to support the emerging hydrogen economy.[2]
- **Queensland Hydrogen Hubs:** QLD government has recently backed the development of a hydrogen hub in Townsville, with $70 million in federal funding promised in 2022.[4]

New South Wales

- **2021 Renewable Energy Investment:** $9.0 billion invested last year to grow capacity by 4.7 GW.[7] (Highest amongst states)
- **NSW Climate Change Policy Framework:** State target of reaching net zero by 2050.[15]
- **NSW Electricity Infrastructure Roadmap:** The state expects investment of $32 billion by 2030 to increase its renewable capacity by 12 GW.[14] Hydrogen is expected to be a key growth driver.
- **NSW Net Zero Plan Stage 1:** $2 billion committed in partnership with the Commonwealth for low emission technology including hydrogen.[15]
- **NSW Hydrogen Strategy (2021):** supporting the development of clean manufacturing precincts, targeting a green hydrogen cost of $2.80 per kg over the next decade and providing up to $3 billion of incentives to support industry.[2]
- **NSW Hydrogen Hubs:** $70 million committed to Hunter and Illawarra Hydrogen Hub as part of the $750 million Net Zero Industry and Innovation Program.[2]

Victoria

- **2021 Renewable Energy Investment:** $3,5 billion invested with capacity growth of 1.8 GW.[7] (2nd highest amongst states)
- **Victorian Renewable Hydrogen Industry Development Plan (2021):** $6.2 million committed to accelerate pilot projects, $10 million committed for Victorian Hydrogen Hub (VH2) and $1 million available in grants.[2]
- **Zero Emissions Vehicle (ZEV) Roadmap:** a $100 million package for transitioning to battery and hydrogen-powered electric vehicles.
- **Victoria Emissions target:** net zero by 2050.[2]
- **Hydrogen Energy Supply Chain Project:** The state is host to the world's first hydrogen supply pilot. The project was provided with $50 million in funding by the state government.[2]
- The Geelong Hydrogen Hub is seeking expressions of interest from market participants.

7 https://www.cleanenergycouncil.org.au/resources/resources-hub/clean-energy-australia-report

8 https://www.mediastatements.wa.gov.au/Pages/McGowan/2020/10/McGowan-Government-launches-Whole-of-System-Plan.aspx

9 https://www.mediastatements.wa.gov.au/Pages/McGowan/2021/11/117-point-5-million-dollars-to-progress-two-renewable-hydrogen-hubs.aspx

10 https://www.liberal.org.au/latest-news/2022/04/19/backing-western-australia-global-resources-and-energy-powerhouse

11 https://reneweconomy.com.au/south-australia-set-sights-on-stunning-new-target-of-500-pct-renewables-97917/

12 https://reneweconomy.com.au/tasmania-sets-world-leading-target-of-200-per-cent-renewables-by-2040/

13 https://www.premier.tas.gov.au/site_resources_2015/additional_releases/continuing_to_help_tasmanians_with_the_cost_of_living/another_step_forward_for_tasmanias_green_hydrogen_hub

14 https://www.energy.nsw.gov.au/government-and-regulation/electricity-infrastructure-roadmap

15 https://www.environment.nsw.gov.au/topics/climate-change/net-zero-plan

16 https://www.h2-view.com/story/two-hydrogen-hubs-to-be-developed-in-australias-hunter-region-following-government-funding/

17 https://reneweconomy.com.au/palaszczuk-announces-investment-in-three-queensland-renewable-energy-corridors-68164/

18 https://statements.qld.gov.au/statements/90683

2 Purpose of the roadmapping exercise

HySupply Australia's roadmapping exercise

HySupply Australia has performed a supply-side roadmapping exercise to identify the preliminary barriers and opportunities for Australia in realising their hydrogen export vision. A key focus of the exercise is to also highlight the key next steps for Australia to create a hydrogen-centric trade relationship

Supply-Side Roadmapping Exercise

UNSW has partnered with Deloitte for the development of a preliminary roadmapping paper that aims to provide a supply-side pathway for Australia to develop a hydrogen/hydrogen-derivatives export value-chain. In this roadmap, we aimed to create a collective view across the different stakeholder groups, as it ensures creation of an aggregated path forward.

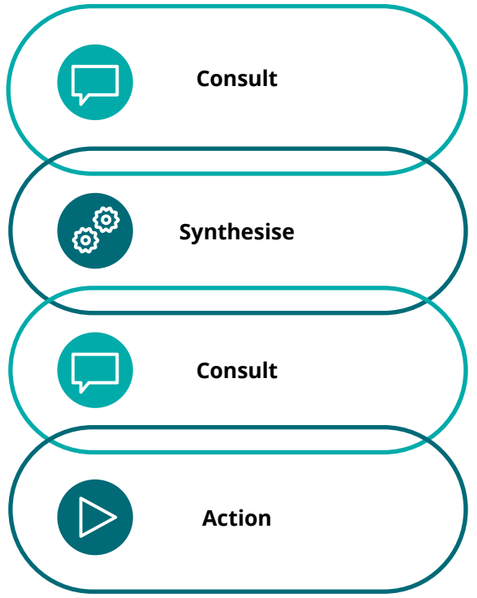
50+ stakeholders were consulted on five key topic areas: **commercial viability, technology uncertainty, policy and regulation gaps, social acceptance for hydrogen export and workforce capability**. The stakeholder groups featured, technology manufacturers, current and potential hydrogen off-takers, EPC firms, investors, policy makers and the three levels of Government.

The key purpose of the consultations was to identify the key barriers and opportunities across the five topic areas and formulate strategic next steps for Australia in realising this export potential.

The supply-side roadmapping exercise was developed and then tested with selected HySupply consortia members and wider stakeholders.

Key Objectives of the Supply-Side HySupply Roadmapping Exercise

01. Aims to explore and build on the actions from the COAG National Hydrogen Strategy (NHS), CSIRO National Hydrogen Roadmap (NHR) and other hydrogen related reports in Australia.
02. Highlights the key barriers and opportunities for Australia in developing a hydrogen/hydrogen-derivatives export value chain.
03. Provides a framework for realising these opportunities for Australia in the form of potential short-, medium- and long-term next steps.



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HySupply roadmapping timeline

This supply-side roadmap represents the first phase of the broader HySupply roadmapping activities over the next 6 months

The purpose of this investigation

HySupply Australia's Supply-Side Roadmapping Exercise

Early 2022

Summary of the key actions for Australia from now until 2030, to develop a supply-side export value-chain.

Note: This roadmap focuses on the value chain from hydrogen/hydrogen-derivatives (ammonia, methanol and liquid organic carriers) generation through to delivery at the German ports.

HySupply Germany's Supply-Side Roadmapping Exercise

Summary of the key actions for Germany from now until 2030, to develop a demand-side import value-chain.

Note: this roadmap focuses on the value chain from hydrogen/ hydrogen-derivatives (ammonia, green methanol and liquid organic carriers) delivery at the German ports to the various off-takers within Germany.

Collaboration

HySupply Australia and Germany will discuss the key learnings from the various roadmapping exercises to identify the key next steps for a joint Australia-Germany hydrogen/hydrogen-derivatives value-chain.

In this phase, key stakeholders (Government, HySupply consortia etc.) are involved to identify the key next steps for both parties, including facilitating the HyGate initiative and providing a matchmaking platform..

HySupply Joint Findings (v1.0)

A joint roadmap will highlight the key next steps for the Australian and German Governments and private sector to 'kick-start' the export value-chain.

HySupply Joint Roadmap Iteration

A joint roadmapping exercise to establish a stakeholder driven pathway for both nations to progress.

Contribution of this Roadmapping Exercise to Australia's Growing Capability

The Australian Government and several other stakeholders have undertaken a range of strategic, roadmapping driven activities to date. This roadmap seeks to build on the current work, to identify and detail opportunities within the Australian export market, with a focus on Germany.

	CSIRO National Hydrogen Roadmap (NHR)(2018)	National Hydrogen Strategy (NHS) (2019)	A Hydrogen Guarantee of Origin Scheme for Australia(2021)	AHC Unlocking Australia's Hydrogen Opportunity(2021)	HySupply Roadmapping Exercise Paper (2021)
The case for hydrogen	Explores benefits of H_2 and considers Australia's potential	Explores benefits of H_2 and considers Australia's potential	-	Explores benefits of H_2 and considers Australia's potential	Builds the case specifically for export opportunities with a focus on Germany
Technology Assessment	Provides a top-down overview of the value-chain and the next steps to drive down costs	Provides a top-down overview of the value-chain and the next steps	-	-	Highlights the technology uncertainties at export scale and the next-steps
Detailed review of national policy and regulation	-	Identifies national regulation and the next steps	Outlines certification process for green hydrogen production	-	Identifies how the NHS and NHR actions can be leveraged to enable export opportunities for Australia; Aggregates the next steps from stakeholders
Pathways forward	Describes R&D investment opportunities; summary of actions	Identifies 57 national steps and actions for domestic growth	Pilot trials commenced-	Outlines 8 recommendations; reiterates National Hydrogen Strategy	
Identified export opportunities	Identifies export focused barriers and high-level actions	Acknowledges the export opportunity and provides foundational next steps	-	-	Identifies export leaders, best practice; identifies gaps
Detailed export market mapping	-	Identifies potential hubs near ports for export	-	Lists various international commitments to H_2	Assesses current and future infrastructure; details commercial viability mapping
Pathways forward in exports	Provides high-level actions	Provides high-level actions	-	-	Identifies timeline to 2030 with key milestones for export

3 Framework for the roadmapping exercise

Roadmapping framework

Through stakeholder consultation, six guiding principles were identified to facilitate the development of a green hydrogen/hydrogen-derivatives based export value-chain

Guiding Principles

Six key findings were identified during the stakeholder consultation, these findings have been translated into guiding principles that Australia should consider as they seek to transition into becoming a hydrogen export leader.

Principle 1: Harmonise regulation across all levels of Government to facilitate hydrogen infrastructure adoption

Principle 2: Strategic collaboration and planning is required between Australia and German Governments, alongside the private sector to develop a commercially viable export value-chain over the decade ahead

Principle 3: Targeted and nationally unified investment is required towards a diverse range (e.g. different hydrogen derivatives, different scales etc.) of high-quality hydrogen export projects that aim to de-risk scale-up uncertainties and maximise opportunities for market development

Principle 4: Leverage the hub model to create synergies between domestic and export markets for hydrogen/ hydrogen-derivatives

Principle 5: Through the emerging hydrogen export economy, look to maximise local benefits such as: job creation and community benefits

Principle 6: Draw on the learnings from Australia's LNG industry and other major export industries to develop a sustainable hydrogen export economy

The guiding principles are designed to help Australia reach it's hydrogen potential by...

Learning by doing – A staggered approach is required to develop an export value-chain for Australia. The immediate objective is to target the de-risking of technologies across the value-chain and address scale-up uncertainties at the 100-300 MW scale. This is a ~100-300x scale-up from Australia's current capability, a 1.25 MW electrolyser (HyP SA project). ARENA has however, recently funded three 10 MW hydrogen projects, so the deployment of 3-5 projects in one greater magnitude of scale will provide a backbone for Australia's export capabilities. This will also be a key enabler for downstream regulation, and will facilitate reproducibility and scale-up for future deployments.[1]

Unlocking private capital – Australian State, Territory and Federal Governments have a key supporting role in fostering the development of an export value-chain. In the early stages, this will involve supporting the private sector to negotiate long-term off-take agreements for hydrogen/hydrogen-derivatives export and to potentially underwrite the off-take agreements to de-risk private sector investment in Australia.

Australia's next moon-shot – Hydrogen and hydrogen-derivatives exports have the potential to be one of Australia's leading export sectors in the future. In order to realise this opportunity Australia will require clear leadership at a federal level with export milestones underpinned by financial incentives/subsidies from State, Territory and Federal Governments. For example, Japan's Green Growth Strategy milestones are funded by the Green Innovation Fund, to ensure Japan reaches its 10% hydrogen/ammonia based energy mix target by 2050.[2] Failure to take aggressive action in the near-term may also result in Australia losing the 'race' for hydrogen export market share to countries in North Africa, Middle East and the Americas.

1 https://www.agig.com.au/hydrogen-park-south-australia

2 https://www.lexology.com/commentary/energy-natural-resources/japan/nishimura-asahi/japan-selects-first-round-of-recipients-for-green-innovation-fund

Roadmapping framework

An export readiness tracker has been developed as an indicative mechanism to demonstrate how the roadmapping actions result in commercial outcomes for Australia's emerging hydrogen/hydrogen-derivatives export economy

The Development of an Export Readiness (ER) Tracker

The export readiness tracker is designed to provide an indicative mechanism to demonstrate how the successful execution of the roadmapping actions translates into Australian hydrogen/hydrogen-derivatives export becoming commercially viable.

Note: actions were developed across three major time horizons: now-2022, 2022-2025 and 2025-2030, to address the key barriers and opportunities raised by stakeholders.

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Australia is currently in between these stages

ER 1

Projects/consortia have been proposed in the 100-300 MW scale.

In this stage projects are in pre-feasibility/ feasibility stage

ER 2

Feasibility studies have been completed to identify 'early mover' export projects in the 100-300 MW scale.

In this stage projects transition to the front-end engineering design (FEED)

ER 3

The 'early mover' projects in the 100-300 MW scale are built and commissioned.

Note: These projects are heavily supported by Government subsidy to de-risk scale-up and operational uncertainties, and uplift/ repurpose existing infrastructure, for hydrogen/ hydrogen-derivatives use

Final Investment Decisions (FID) achieved and projects are built, commissioned, and are operational

ER 4

Learnings from the early mover projects are utilised for the next tranche of projects. In this tranche, projects are designed to reach 'export-scale' (>100 MW)

Note: Subsidies are still needed, however the technology risks are reduced.

ER 5

Projects do not have technology uncertainties, but still have a gap in commercial viability, between the off-take price and the delivered cost of hydrogen/hydrogen-derivatives.

Note: At this stage, net zero policy underpins the commercial viability of export projects.

ER 6

The value-chain technologies, and operations reach maturity with standards in place and performance expectations. The projects reach a 'bankable' grade asset class.

Note: Government subsidy is no longer required for the export projects.

4 Australia-Germany Hydrogen/Hydrogen-derivatives export roadmapping

ER 1 ER 2 ER 3 ER 4 ER 5 ER 6

Horizon One | now to end of 2023

Horizon One focuses on laying the groundwork for the export market to take shape, including confirmation of contracts and guarantees and insurance from the Governments

Now-2022

	Action	Ownership	
		Primary	**Support**
1.1	**Perform a 'match-making' exercise between Australian and German industries**, to identify a pool of potential suppliers and off-takers	Industry, HS	Australian states and territories, Australian Government, German Government
1.2	**Confirm the export quantities for the hydrogen-derivatives, expected delivery timeline and willingness to pay** from German off-takers	Industry, German Government	HS, Australian states and territories, Australian Government
1.3	**Create a cross-Government 'safeguard' mechanism to provide off-take security for Australian suppliers and German importers**	Australian states and territories, Australian Government, German Government	Industry
1.4	**Sign contract agreements** with German off-takers, utilising programs such as H2Global	Industry	Australian states and territories, Australian Government, German Government
1.5	**Create a cross-Government initiative to identify three to five consortia for the export of different hydrogen/ hydrogen-derivatives**. The purpose of these 'flag-ship' projects will be to de-risk the technology uncertainties for the various value-chains at 100-300 MW scale	Australian Government, German Government	Industry, Australian states and territories
1.6	**Commence cross-Government feasibility investigations for the flag-ship projects** ***Note****: these investigations need to be supported by the Australian and German Governments*	Australian Government, German Government	Industry, Australian states and territories

Industry · HS HySupply · Australian states and territories · Australian Government · German Government

ER 1 ER 2 **ER 3** ER 4 ER 5 ER 6

Horizon Two | 2023 to 2025

Horizon Two focuses on securing the supply chain and building infrastructure and expertise

2022-2025

	Action	Ownership	
		Primary	**Support**
2.1	**Complete front-end-engineering design, final investment decision and engineering, procurement and construction** steps for the flag-ship projects. **Note**: these projects need support from the Australian and German Governments, to ensure commercial viability. Set a condition for the grant to include knowledge sharing.	Industry	Australian states and territories, Australian Government, German Government
2.2	**Commission construction** of the value-chain and manufacture equipment for the flag-ship projects. ***Note**: these projects need to be subsidised by the Australian and German Governments, to ensure commercial viability*	Industry	Australian states and territories, Australian Government
2.3	**Australian and German Governments foster knowledge exchange for the uplift of skills and technologies for the sector**	Australian Government, German Government, Industry	German Government, HySupply, Australian states and territories
2.4	**Source and train skilled workforce** for operation and maintenance of infrastructure, and **leverage the knowledge-base from the chemicals manufacturing, LNG export and renewable generation industries**	Australian Government, Industry	HySupply

Industry · HySupply · Australian states and territories · Australian Government · German Government

ER 1 ER 2 **ER 3** **ER 4** ER 5 ER 6

Horizon Three | 2025 to 2030

Horizon Three focuses on carefully commencing the export of hydrogen

2025-2030

	Action	Ownership	
		Primary	**Support**
3.1	**Commence first export** from Australia to Germany	Industry, German Government	Australian states and territories, Australian Government
3.2	**Learn from the first export** and implement findings and improvements	Industry	Australian states and territories, Australian Government, German Government
3.3	**Set targets for Australian export expansion to Germany and transition from Government-supported to private-sector driven exports**	Industry	Australian states and territories, Australian Government, German Government
3.4	**Identify opportunities** to build further **export relationships** and **convert into partnerships** (incl. trade agreements)	Industry	Australian states and territories, Australian Government, German Government
3.5	**Commence gradual scale up of production and export so that Australia can suitably meet Germany's energy target for hydrogen exports**	Industry	Australian states and territories, Australian Government

Industry · Australian states and territories · Australian Government · German Government

5 Supply-side roadmapping actions for now – 2025 and 2025-2030

Actions for Principle 1

Harmonise regulation across all levels of Government to facilitate hydrogen infrastructure adoption

Now-2025

1.1 (NHS)

Review relevant current state, territory and national regulation and make necessary updates for the hydrogen/hydrogen-derivatives export value-chain.
Note: This is underway by various states and territories under Federal Government leadership to drive greater regulatory consistency, but requires further action. This review will focus specifically on legal frameworks and standards relevant to hydrogen industry development and safety.[1]

1.3 (IEA)

Governments provide support in navigate the regulation processes for early stage hydrogen projects. The sandbox approach for initial projects may be considered to facilitate projects

2025-2030

1.2 (IEA, NHS)

Support the development of an international Certification of Origin scheme for hydrogen and its derivatives. As well as develop a carbon accounting framework for synthetic methanol and methane exports. This may also include life cycle sustainability assessment and Cradle to cradle and social aspects of projects.
Note: DCCEEW has commenced trials for the hydrogen Guarantee of Origin (GO) scheme.[2] DCCEEW also recently published a discussion paper which highlights the methodologies for guaranteeing the origin of clean hydrogen and discusses how the GO will evolve over time to include additional hydrogen production pathways.[3]

1.4 (NHS)

Exempt green hydrogen production from liability for electricity schemes and waive green electricity certification fees for export projects to improve the commercial viability of the value-chain

1.5 (NHS)

Streamline the approval processes for hydrogen/hydrogen-derivatives export projects

1 https://www.industry.gov.au/data-and-publications/state-of-hydrogen-2021
2 https://www.minister.industry.gov.au/ministers/taylor/media-releases/trials-start-hydrogen-guarantee-origin-scheme
3 https://consult.industry.gov.au/hydrogen-guarantee-of-origin-scheme

Note: A report icon next to an action indicates, either the stakeholder referencing a report action during the consultation or the action from the cited report is relevant to our findings from stakeholder consultation.

IEA IEA Global Hydrogen Review
NHS National Hydrogen Strategy
HH National Hydrogen Hubs Study Report
HR CSIRO National Hydrogen Roadmap

Actions for Principle 2

Strategic collaboration and planning is required between Australian and German Governments, alongside the private sector to develop a commercially viable export value-chain

Now-2025

2.1 Australian State, Territory and Federal Governments support the private sector in off-take agreement negotiations for the flag-ship projects, as well as promote the use of H2Global for 'first mover' projects to de-risk commercial outcomes for the project.

2.2 Develop modelling for various export supply chain configurations and bridge the gap in production costs

2.3 Develop 'Centres of Excellence' combining the expertise of industry and academia in Australia and Germany — HH

2.4 Provide Government incentives and tax concessions for hydrogen technology scale-up and R&D — NHS

2025-2030

2.5 Establish frameworks for the commercial progress of hydrogen/hydrogen-derivatives export

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Actions for Principle 3

Targeted investment is required towards a diverse range of high-quality hydrogen export projects that aim to de-risk scale-up uncertainties

Now-2025

3.1 Provide funding to projects >100 MW in scale to de-risk technology uncertainties within the hydrogen value-chain (e.g. scaling up liquification systems, integrating large-scale carrier production processes for ammonia and methanol with electrolysers and intermittent energy sources etc.) — NHS

3.2 Provide funding for proof of concept testing for transport of hydrogen from generation to the ports and onto ships (e.g. gas pipeline funding) — NHS

3.3 Partnership between Australian and German industries to complete pilot projects (similar to the arrangement Japanese organisations have with Australia, such as the HESC Consortium) — NHS

3.4 Leverage the HyGATE platform to invest in promising technologies and export infrastructure e.g. ammonia storage and shipping — HR, IEA, NHS

2025-2030

3.5 Invest in upgrading ports and carrier ships to be able to store and transport hydrogen/hydrogen-derivatives

3.6 Target the launch of the hydrogen trade's first international shipping route — HH

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HR CSIRO National Hydrogen Roadmap

Actions for Principle 4

Leverage the hub model to create synergies between domestic and export markets for hydrogen/hydrogen-derivatives

Now-2025

4.1 Support the assessment of nation-wide infrastructure (incl. ports) to determine which ports are best positioned for hydrogen/hydrogen-derivatives export.
Note: The Australian Government is currently leading a National Hydrogen Infrastructure Assessment, consulting states and territories regarding needs, availability and gaps in supply chain infrastructure.[1]
HH NHS

4.2 Undertake a nation-wide study to compare the relative merits of locations for large-scale production and export – identify regions that provide the benefits of co-location to feedstock (renewable energy, fresh water/desalination plants, salt-caverns, ports etc.)

4.3 Support the involvement of German stakeholders in current hydrogen hub work to foster the parallel development of domestic and export capabilities
HH

4.4 Develop bi-lateral partnerships and run pilot programs from Australian ports to international import ports, including Europe

2025-2030

4.5 Conduct competitive grant funding rounds with states and territories for building hydrogen-ready ports and upgrading existing ports for hydrogen/hydrogen-derivatives export

4.6 Consider learnings from initial hub implementations and identify ways to scale for export-value chains

1 https://www.industry.gov.au/data-and-publications/state-of-hydrogen-2021

Note: The Australian Federal Government has developed the Clean Hydrogen Industrial Hubs program and this may be a key source of funding that can be leveraged for hydrogen export centric hubs. State and Territory specific funding is also available.

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Actions for Principle 5

Through the emerging hydrogen export economy, build local benefits such as: job creation and community benefits

Now-2025

5.1 Engage with research, industry and training institutions to build hydrogen skills and capabilities within local workforces
Note: the Australian Government is supporting the development of nationally consistent training materials and guidelines for handling, producing, using and transporting hydrogen[1]
HR NHS

5.2 Promote community engagement and target the maximisation of local benefit. This can be achieved via local provision of equipment, community support funds and hydrogen export-based roadshows
NHS

5.3 Develop a social-license framework that captures the key social acceptance criteria with hydrogen/hydrogen-derivatives export and delivers regional development (such as job creation and community benefits)

1 https://www.industry.gov.au/data-and-publications/state-of-hydrogen-2021

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HR CSIRO National Hydrogen Roadmap

Actions for Principle 6

Draw on the learnings from Australia's current export industries to develop a sustainable hydrogen export economy

Now-2025

6.1 Establish committee involving Government, hydrogen industry and LNG, ammonia and iron ore stakeholders to discuss learnings and pathways forward for hydrogen

6.2 Create an environment that is appealing to investors by introducing tax benefits, low cost debt (e.g. CEFC) and policy that indicates strong commitment to the sector

6.3 Secure firm demand commitments for industry, Australian State, Territory and Federal Governments have a role to play as matchmaker for the Australian private sector and for offtake derivatives export scenarios

6.4 Promote collaboration across industry and sharing of infrastructure in the early stages of development to avoid cannibalising growth as businesses compete for scare resources, infrastructure, skilled employees and Government funding.[1]
Note: the Australian Government investment into the Clean Hydrogen Industrial Hubs program aims to promote this collaboration

2025-2030

6.5 Leverage some of the LNG and ammonia regulation and infrastructure for the transport and storage of hydrogen.
Note: this is applicable also to other Australian industries (such as ammonia)

6.6 Enable off-takers to own equity share in the value chain helps to provide investment security because it creates personal investment

6.7 Australian ports commence the provision of zero-emission shipping infrastructure by providing bunkering facilities for hydrogen/hydrogen-derivatives based fuel storage and use. This is a critical step towards enabling a emission free hydrogen/hydrogen-derivatives export supply chain. This next step is also critical in the eventual certification of the hydrogen/hydrogen-derivatives exports under the Guarantee of Origin scheme, which is likely to be dependant on lifecycle emissions.

1 https://www.industry.gov.au/data-and-publications/state-of-hydrogen-2021

Note: A report icon next to an action indicates, either the stakeholder referencing a report action during the consultation or the action from the cited report is relevant to our findings from stakeholder consultation.

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Measures of success

Industry Advances Quickly	2025	Industry Advances Slowly
Increased clarity of regulation and rollout of incentives to encourage industry to confidently invest in hydrogen/hydrogen-derivatives projects helping Australia to become a hydrogen leader	**Harmonise regulation and incentivise export**	Policy incentives remains minimal and industry remains hesitant to commit to investing in hydrogen/hydrogen-derivatives export projects
Australia develops strong relationships with German hydrogen/hydrogen-derivatives importers which helps drive demand for Australian hydrogen and contributes to the development of a multi-billion dollar export industry	**Bi-lateral planning & collaboration**	Australia is slow to develop relationships with potential German importers and Australia loses potential market share
The Government invests in high-quality hydrogen/hydrogen-derivatives flag-ship projects which helps to make 'early mover' projects commercially viable thereby assisting with the scale-up process and encouraging further investment	**Targeted investment**	The Government is slow to invest in high-quality hydrogen/hydrogen-derivatives flag-ship projects so industry does not develop export capability because they are not commercially viable without assistance
Hub projects are signed off and built, providing an example to inspire further investment. An export hub is an opportunity to refine the hydrogen/hydrogen-derivatives export supply chain, helping Australian industry to learn and grow	**Leverage hub model**	The hubs remain an unrealised concept, investment in hydrogen/hydrogen-derivatives is left with no clear direction or meaningful strategy and might be wasted on trial projects that go in alone and fail due to lack of support
The Australian public is well informed about hydrogen/hydrogen-derivatives and understand the safety and environmental factors, they also recognise the local opportunities for economic and community benefits	**Build social acceptance**	The Australian public is not educated on hydrogen/hydrogen-derivatives and remain hesitant to accept the economic and community benefits, therefore resulting in higher resistance for hydrogen/hydrogen-derivative projects, to get off the ground
The industry is able to scale faster and with less costly mistakes because it learns from the LNG export journey	**Draw on LNG learnings**	The industry is slower to scale, less efficient and more costly because it falls into similar challenges as the LNG industry

6 Consultation findings

Key findings

Based on an analysis of recent literature and 50+ interviews with industry, 6 key themes have emerged in relation to developing a hydrogen/hydrogen-derivatives export value-chain from Australia

Policy, regulation, social acceptance

To create an export market the Government must invite investment **through strong and clear policy**, regulation, and community messaging

Leadership and co-investment

While the **private sector** is interested in developing a hydrogen/hydrogen-derivatives export market, there must **be Government leadership and financial encouragement to execute**

Infrastructure and co-location

Existing infrastructure should be used where possible in the early stages of development; **proximity to ports** and **renewable energy** is critical to the success of the export industry

Commercial viability

There is interest in financing the hydrogen/hydrogen-derivatives export sector, however there is an **uncertainty on the willingness to pay from off-takers and the commercial viability in the early stages**

Technology uncertainty

There are some technological uncertainties that must be overcome to successfully scale to export, this includes **optimising transportation** and **storage supply-chains**, and commissioning and operating large-scale electrolysers (100-300 MW)

Capability and timeline

Australia must **act now** to win the 'race' to become a preferred hydrogen supplier in the future of hydrogen/hydrogen-derivatives export, this requires building a **skilled workforce** and investing in **shared infrastructure**

Finding 1

Policy, Regulation and Social Acceptance

Theme	Description	Quote and References
Harmonise regulation	• To attract investors, states and territories in Australia must have clear, harmonised and streamlined regulations to develop industry confidence. **Note**: This is currently, a challenge for liquid and gaseous hydrogen, particularly at the scale >10 MW as no commissioned projects exist in Australia for learnings to be leveraged for the development of export-scale regulation. Plants in the 10 MW scale are currently within the construction pipeline. • **Ammonia and methane** – regulation is in place for ammonia and methane in Australia, however the issue lies in export-scale value-chains for these hydrogen carriers.	“ *“We need harmonisation of regulations across the states and territories in line with the National Hydrogen Strategy”*
Adopt international standards for hydrogen infrastructure	• To compete in the international markets, Australia needs to adopt emerging international regulation, which will facilitate ease of trade and accelerate the timeline for industry development. • Australia should play a larger collaborative role in developing international standards.	“ *“We need to adopt international standards, Australia does not need to develop its own, as presents an additional barrier to entry”*
Introduce policy	• The industry is looking for more policy and incentives to be enacted at state, territory and federal levels to facilitate large scale commercialisation of infrastructure. This could also be a catalyst in attracting investment capital.	“ *“There is a lack of support from the federal Government… Europe’s market picked up when the govt. introduced policy”* “ *“We need policy and incentives to push the uptake of green technology”*

References:
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Finding 1

Policy, Regulation and Social Acceptance

Theme	Description	Quote and References
Increase Government funding	• The Government can best assist industry by providing further funding and guaranteeing assistance to support early movers by **helping bridge the commercial gap between importers and the export price**. • **Note**: funding will also be required from the off-taker Government to help bridge the commercial gap. As this may be viewed as a miss use of decarbonisation-related Government funding, as the decarbonisation benefit is passed onto the off-taker.	“ *“Government can best help through funding”*
Clarify certification	• A Guarantee of Origin Scheme is critical for the export market and will help build Australia’s reputation as a reliable and high-quality producer. • **Green vs blue imports** – Australia must collaborate with importers, to develop clear regulation for the carbon intensity of hydrogen, as this can be a metric importers can use to determine their ‘willingness to pay’ for low-carbon vs net-zero hydrogen.	“ *“In the future, there has to be grading available for hydrogen or else they’ll just buy the cheapest hydrogen”* “ *“As an importer, a Guarantee of Origin Scheme would be critical for us”*
Build social license	• Government and industry must work together to generate social acceptance of hydrogen/hydrogen-derivatives export projects, this includes communicating with the public, publishing information guides, demonstrating how hydrogen will create local jobs, and considering ‘optics’.	“ *“Social license can be hard to acquire if you are exporting as it may increase local concerns that the projects do not directly benefit locals.”* “ *“Messaging is important – green hydrogen sounds great, but ammonia plant sounds terrible”*

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Finding 2

Leadership and Co-investment

Theme	Description	Quote and References
Focus on commercialisation and scale-up	• Many in industry are growing frustrated with repetitive hydrogen feasibility projects that provide limited practical experience for overcoming the challenges and uncertainties in green hydrogen export. Hence the **priority should be on commissioning infrastructure and scale-up to 100-300 MW electrolysers**.	*"The only active electrolyser in Australia is a 1.25 MW electrolyser, we need to commission electrolysers in the 100 MW, not conduct more repetitive feasibility studies"*
Led by industry	• There is a growing sentiment that industry has the technological capability and business expertise to implement hydrogen, and are waiting to see policy, regulation and incentives before ramping up.	*"Once the Government sets the policy, suppliers and industry can do it ourselves, it is our role to bring down costs"*
Co-invest to scale	• Although industry will take on the bulk of the commercialisation and export market development, the Government has a role to play in co-investing and sponsoring projects while the industry scales up operations.	*"Government needs to invest in high-quality projects with firm off-take, high-quality technologies with warranties and insurance, to de-risk supply-chain uncertainty and scale-up risks"*
Introduce early – mover incentives	• To incentivise industry to scale, commercialise and export, the Government should **provide early-mover benefits**. • Australia is currently missing **'show case' projects that can act as an example for the market and encourage further investment**.	*"There needs to be a subsidy for the price and cost gap"* *"There needs to be something to encourage companies to go first. Government must help bridge the gap to support the first big player"*

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Finding 3

Infrastructure and Co-location

Theme	Description	Quote and References
Source inexpensive, renewable electricity	• A major barrier to the production of hydrogen and downstream hydrogen derivatives is the cost and available spare capacity of renewable power. To reach the national target of AU$2/kg, renewable power (solar) costs need to come down to at least AU$25/MWh. **Note** – Australia's new technology investment roadmap targets a solar PV price of $15/MWh.	*"Customers are happy as long as we can prove the power is 100% renewable"*
The role of existing infrastructure	• There is significant interest in using existing infrastructure in the early stages of commercialisation, this could involve leveraging existing ports. **Note**: regulation will also need to be adapted if existing infrastructure is utilised. • As the industry scales, it will be able to support the construction of new, purpose built infrastructure, which will support in the reduction of systems losses, across the value-chain.	*"In the short-term we want to use as much existing infrastructure as possible"*
Co-locate with feedstocks	• Hydrogen facilities should be built as close to feedstocks as possible to minimise expenses and increase efficiency • Feedstocks include renewable generation, electricity transmission, access to pure water/wastewater treatment plants/ desalination plant, suitable land, storage solutions such as salt caverns, and port access for export • **Example:** NortH2 is a Dutch hydrogen project located near an off-shore wind farm for electricity procurement, a desalination plant for fresh water, and naturally formed salt caverns that allow for storage of the hydrogen produced.	*"You'll get maximum benefit the closer you are to the renewable energy provider, as you'll become subject to not having the transmission network available the farther you are from the generation"* *"Grid connections are not as straightforward or as cheap as expected"*

References:
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Finding 4

Commercial Viability

Theme	Description	Quote and References
Access to debt financing	• Access to finance for hydrogen projects with large lenders/Government-backed financing institutions is available under suitable commercial terms. However, the key issues lies in the commercial viability of the projects. For export projects other key uncertainties include: **importer's willingness to pay and long-term off-take certainty**.	*"Availability of debt is not an issue"* *"There is no difficulty in securing financing for hydrogen projects as there is a lot of interest"*
Gap in commercial modelling assumptions for export-scale projects	• Since hydrogen at export scale is still in its infancy, it is difficult to model project costs, including asset lifespan, maintenance and operational costs. • **Note**: Technology disruption and changing market conditions also make it difficult to accurately forecast hydrogen.	*"Everyone is talking about hydrogen, but we don't know what degree of investment to expect"*
Reduce equipment costs	• Economies of scale must be implemented to optimise efficiency, the **development of large-scale electrolyser modules (>20MW) will be a key driver in reducing electrolyser costs** and their footprint to make export more viable.	*"To reduce cost in electrolyser manufacturing we need access to locally mined resources and support R&D"* *"The cost of producing hydrogen through electrolysis and supply chain is highly uneconomical"*

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Finding 4

Commercial Viability

Theme	Description	Quote and References
Scalability	• The required scale for hydrogen export is uncertain, as developers see value at the 200MW-1GW scale. Some estimates suggest green hydrogen projects in the 400kt/year scale are required for export viability. • **There are significant hurdles involved in scaling to export scale across the value-chain (electrolysers, buffer storage, transportation via pipeline, liquification, hydrogen-ready ships, hydrogen loading/unloading at ports etc.)** including sourcing water and renewable generation. • **Ammonia**: Because there is a pre-existing ammonia export market, it has strong potential for scale.	*"We have the ability to provide the supply, but is there enough demand?"* *"There are only so many places you can find the transmission capacity available, for 200-300MW it's not too bad, but at the GW scale there are very few places to go"*
Optimise electrolyser supply chain	• There are currently some concerns surrounding the strength of the supply chain; the **delivery timelines for electrolysers is estimated to be between 18-24 months**, there are further delays caused by **fluctuation in metal prices, power control systems and transformers are bottlenecked**. • There is room for further exploration around what parts of the supply chain can be viably housed in Australia. Australia is a high cost country in some aspects and manufacture can be done at less expense overseas. However, Australia may have a role to play if the integration of automation is accelerated in the electrolyser manufacturing process.	*"We see the most value in ammonia and liquid hydrogen supply chains"* *"Upstream technology is available, but the downstream market is the worry"* *"Every part of the supply chain has room for improvement"*
Support continued R&D	• While technology already exists, to begin developing Australia's hydrogen export market, further technological advances will be critical in continuing to bring down costs and increase efficiencies. • **Areas for development include:** carrier ships for liquid hydrogen, minimisation of boil-off rates during shipping, scaling up liquefaction.	*"Technology development will be needed to make the production of hydrogen economical"*

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Finding 5

Technology Uncertainty at Export Scale

Theme	Description	Quote and References
Optimise Hydrogen Transportation	• Currently liquefied hydrogen is being transported using trucks, however this is expected to shift to pipelines at larger scales due to **issues with boil-off rates when transporting by truck**. • **Transport via pipeline is largely untested**, there is currently only one company in Europe capable of testing hydrogen pipelines and only two standards exist for hydrogen pipelines based in the US. This lack of certainty may lead industry to being overly conservative in regards to safety and equipment.	*"The cost of hydrogen-ready pipelines are high, whereas transporting of methanol/ MCH for instance is not a challenge "*
Optimise Storage	• The large-scale storage of hydrogen is challenging. Some difficulties include the **energy demand necessary for liquefaction**, the footprint of compressed hydrogen, and the explosive nature of hydrogen/hydrogen derivatives.	*"Storage will be very important for commercial viability – we need cost efficient ways to manage seasonal peaks and valleys in renewables"*
Issues with Scaling Liquification pathway	• **The compressor unit in the liquification process is the most energy intensive consideration in liquefied hydrogen export**, it requires 14kWh per kg of liquified hydrogen (around a third of hydrogen's energy content), Currently the **maximum capacity for liquification plants is ~30-50 tonnes a day**. • Liquification storage tanks are **difficult to scale due to issues with temperature** being a challenge at larger volumes. • Designing liquification units modularly, this could facilitate large scale production. • **Ammonia and methanol:** due to the difficulties of liquification, ammonia is a stronger alternative.	*"80% of export projects are ammonia, there is a little bit of liquid hydrogen but this is being deferred"* *"Liquification isn't done at scale and therefore not cost competitive"*

References:
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HySupply | Supply-Side Roadmapping Exercise

Finding 5

Technology Uncertainty at Export Scale

Theme	Description	Quote and References
Provide strong electroliser supply	• Electrolysers manufacture and deployment is a long and costly process. • OEMs have differing views on the ideal utilisation rates of electrolysers. **Electrolyser economics improves with higher utilisation, however, beyond 60-70% the electrolyser begins to degrade more rapidly over the asset life**. Higher utilisation will also require greater amounts of electricity, potentially requiring connectivity to the more expensive grid. **Note: Greater utilisation also places downward pressure on the economics of hydrogen projects, as grid-connected projects will be exposed to fluctuations in electricity pricing and behind the meter projects will require batteries if the projects will require electrolysers to operate beyond the capacity factor of the renewable power generation, adding to the CAPEX. Note**: Connecting to the grid also raises questions on the certification of the hydrogen/hydrogen-derivatives, as the carbon intensity may be difficult to quantify. • Export production will likely be via behind the meter generation, which raises concerns on the asset life and warranties of electrolysers.	*"It is not the manufacture of electrolysers that is expensive, it is the deployment of them that is the issue"*
Invest in carrier ship fuel	• Carrier ships are a vital part of the export value chain, it is **important to consider the fuel that these hydrogen/hydrogen-derivative will use**. • Hydrogen fuel cells are a potentially sustainable option for powering carrier ships. • **Case study:** Norway's MF Hydra is the world's first liquid hydrogen powered ferry and was launched in September 2021.	*"We must consider how hydrogen transport ships will be powered – some shipping companies have committed to making methanol work as a fuel"*

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Finding 5

Technology Uncertainty at Export Scale

Theme	Description	Quote and References
Hydrogen/hydrogen-derivatives carrier export analysis	• Whilst there any many carrier options for hydrogen, each comes with its own limitations. **Ammonia** • Ammonia is likely to be the carrier of choice due to the pre-existing regulations, market and infrastructure. As well as the opportunity to be a net-zero energy carrier. • **Haber-Bosch processes are being designed to operate with variable renewable generation, however this is still an untested opportunity and requires R&D and commercialisation.** **Liquified Hydrogen** • Liquified hydrogen is receiving significant interest as a carrier from Japan, with Australia's Hydrogen Energy Supply Chain project expected to be scheduled for delivery by the end of 2021-early 2022 and commercialise following that. • **Note**: liquid hydrogen export value-chains are more sensitive to distance related costs, due to the higher energy demand for carrier export and the boil off rate. **LOHCs** • There is very little demand from Germany for LOHCs. **Note**: LOHC does have the advantage of it being well understood in its handling and shipping and could use existing infrastructure in the receiving country. **Methane** • **Methane/methanol have sustainability and carbon feedstock procurement issues, and will likely require a transitionary period** given challenges with **firming variable wind and solar** for continuous production • **Note**: Certain stakeholders suggested there may be a reduced interest in low-carbon methane off-take in Germany.	“*Ammonia synthesis is being designed to enable variable input from renewables, so the plants can ramp up and down as required, there is confidence this will be achievable, however it is untested, so this will require iterative testing.*” “*Our preference for a carrier is ammonia because we know how to handle it*” “*Green methane as a hydrogen carrier may not be viewed as a high priority import*”

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Finding 6

Capability and Timeline

Theme	Description	Quote and References
Determine export horizons	• Hydrogen is expected to be exported as liquified hydrogen from Australia as part of the Hydrogen Energy Supply Chain in late 2021-early 2022, however there are still **significant challenges in the liquified hydrogen export value-chain such as the volume of liquification required**. • **Case study:** The H2U project in Cultana predicts to be commercialised by early 2023 using a 75-100MW electrolyser and will export ~40,000 tonnes of ammonia by 2025 to Japan, South Korea, and Rotterdam.	“*For Europe to complete decarbonisation by 2045, there needs to be export well within a decade in order to meet the hydrogen demand to decarbonise this quickly*”
Scalability	• **From 2025-2030 hydrogen production will likely need to be at the GW scale to remain competitive.** • Stakeholders flagged export of hydrogen is expected to be a mixture of liquified hydrogen and ammonia projects, with **ammonia expected to play a significant role in earlier stages**. Production of hydrogen will need to be **competitive with European production at the 160-200MW scale by 2025**, with ~400,000 tonnes of hydrogen being exported each year from Australia.	“*Any development of export scale must underpin development of local capability*” “*420,000 tonnes per year of ammonia is our minimum export scale*”
Invest in Australian capability	• Australia has existing capabilities from the production of ammonia and LNG that can be leveraged for the production of hydrogen. • Australia is currently **missing some expertise for EPC, operations, maintenance and engineering, building** these skills in the workforce is a priority. • Manufacturing is not likely to exist in Australia as this can done more cheaply in overseas 'gigafactories'. However, Australia has the potential to locally perform maintenance and refurbishment activities.	“*By 2025 all major engineering consultants will likely have the necessary expertise*” “*There are current workforce capability gaps*”

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Some learnings from Australia's LNG export sector

Theme	Description
Secure firm demand commitment	• To manage uncertainty, it is important to secure firm demand commitments • Australian State, Territory and Federal Government's have a **role to play as matchmaker for the Australian private sector** and for offtake agreements.
Create an environment for investment	• Create an environment that is appealing to investors by creating **tax benefits, low cost debt and policy that indicates strong commitment to the sector**.
Enable off-takers to own equity share in value chain	• **Enabling off-takers to own equity share in the value chain** helps to provide off-take security for the suppliers. **Note**: Australia's LNG industry was underpinned by overseas private sector investment, which accelerated the development of the sector.
Promote shared infrastructure	• Whilst there is still limited infrastructure it is important to **promote sharing so that the Australian industry can thrive** as a whole, increasing Australia's market share in the global hydrogen market. • Shared infrastructure includes ports, pipelines etc.
Collaboration vs competition	• In the early stages of **development collaboration is important**, because aggressive competition too early can cannibalise growth as businesses compete for scarce resources, infrastructure, the same skilled workforce and Government funding.

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HySupply | Supply-Side Roadmapping Exercise

Learnings from BP's Feasibility Study

The Study, conducted by GHD on behalf of BP, determined that a clear pathway to commercial scale production exists, but relies on export scale and cost reductions.

Theme	Description
Global demand	• There is a great opportunity for an Australian hydrogen industry; by 2050 total demand could be as high as 62Mtpa combined domestic (16.7Mtpa) and export (45Mtpa). • The race to supply hydrogen to the South East Asian and European market is becoming increasingly competitive.
Government support	• **Success depends on the level of Government support and policy endorsement.** • Support is needed across: **reliability of power, transmission upgrades, port development, supportive tax structures, prioritised approval pathways, decarbonisation incentives, investment in R&D, negotiating favourable options for securing land.**
Logistics & Infrastructure	• The **costs associated with pipeline injection are much more favourable than trucking.** • Export port locations for the **commercial scale facility currently do not have facilities suitable for bulk liquid ammonia export** operations and would require significant upgrades to accommodate export.
R&D	• **Success is dependent on the development of hydrogen related infrastructure** (such as refuelling, roads, rail, ports and storage) and continued R&D. • A transition from carbon emitting energy into a hydrogen economy will require significant investment in manufacturing technologies, infrastructure development, customer equipment and refuelling stations, together with significant innovation and scale, to achieve cost improvements within the next five years.
Local Opportunity/ Social License	• Although community understanding of hydrogen is relatively low there is an expectation that industry will operate in a safe and responsible manner. • However, the project may have the potential to impact: Property and land use, local amenity during construction and operation, traffic and transport, community values, perceptions about safety.

References:
https://arena.gov.au/assets/2021/08/bp-ghd-renewable-hydrogen-and-ammonia-feasibility-study.pdf

Learnings from Stanwell's Feasibility Study

The study, conducted by Stanwell, concluded that hydrogen through power-to-gas or power-to-ammonia is commercially viable, with reductions in electrolyser capital costs and appropriate Government funding

Theme	Description
Global demand	• The demand for imported green hydrogen and green ammonia is particularly strong in Asian countries, specifically Korea, Japan and Singapore.
Government support	• The **current lack of Government support and grants makes a demonstration project uncommercial.**
Regulation and Certification	• The regulatory approval requirements are relatively simple given the project would be on an existing site. • Green hydrogen and ammonia will need to be **underpinned by a 'green premium' reflecting the avoided cost of carbon**, but the availability of secure offtake with a significant green premium.
Logistics & Infrastructure	• The potential demand for green hydrogen and ammonia could require electrolysis capacity in excess of 800 MW by 2026 and in excess of 3000 MW by the early 2030s. • The project is already technically feasible, with suitable industrial land, electrical connection and demineralised water available. • A 10 MW hydrogen electrolyser plant is expected to require approximately 15 megalitres per annum of demineralised water and up to an additional four megalitres of water per annum of for cooling and ancillary purposes.
R&D	• R&D is needed to bring electrolyser costs down.
Local Opportunity/Social License	• There is public reputational risk for Government and energy industry stakeholders if regulatory settings are not appropriate. • It is important to maintain relationships with and consult traditional owners.

References:

https://arena.gov.au/assets/2021/05/stanwell-hydrogen-project-feasibility-study.pdf

Appendix

HySupply cost tool

Capability and Timeline

Tool Overview:

The HySupply cost tool is a self-contained integrated excel-based open-source tool that allows for both real time simulation of hydrogen generation and its associated costs.

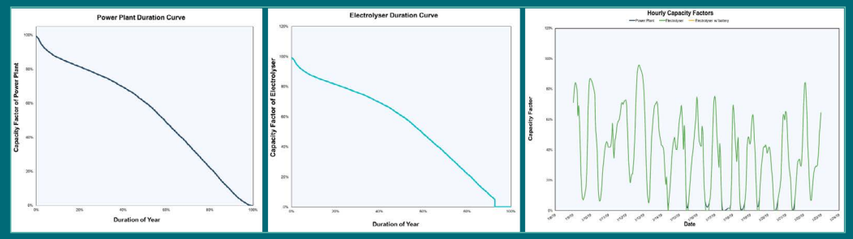
Tool Competencies:

The tool provides complete flexibility to users to modify and input their own project-specific assumptions, guiding the exploration of powerfuel as clean decarbonisation pathway for both brownfield and greenfield projects. While there are several other such tools available in the market, the HySupply cost tool stands out due to its time resolution-based modelling of electrolyser operation, detailed hydrogen generation simulation and cost analysis. The tool is also able to cater for a wide range of powerplant and electrolyser integration (standalone or grid connected as well as hybrid combination of solar/wind farms with inclusion of battery)

The Tool is available at: https://www.globh2e.org.au/hysupply-publication

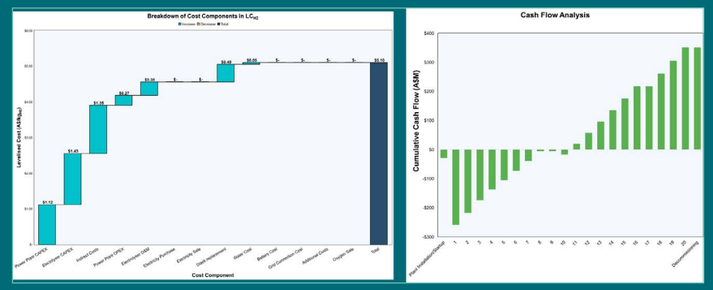
Time Resolution Based Hydrogen Generation Simulation

The tool allows for detailed simulation of hydrogen generation based on the locational solar and wind profiles. The results are presented as an annual duration curve (capacity factor vs duration of the year), allowing the user to visualize the seasonal variation in electrolyser performance due to the intermittency of the solar/wind profiles, which are critical in determining suitable end use scenarios.



Cost Analysis Tool

The tool incorporates a comprehensive cash flow analysis that allows the user to integrate a wide range of cost parameters; equipment purchase costs, installation & land costs, economies of scale, equity/debt-based financing, tax, depreciation amongst several other parameters in order to provide detailed levelised cost or conduct profit, Return on Investment and payback analyses.



HySupply Shipping Analysis Tool

Tool Overview:

The HySupply Shipping Analysis Tool is a self-contained integrated excel-based open-source tool developed to model the cost of shipping hydrogen (as liquid hydrogen (LH2) and hydrogen carriers (ammonia, methanol, methane (LNG) and LOHC (as toluene/methylcyclohexane (TOL/MCH)).

Tool Competencies:

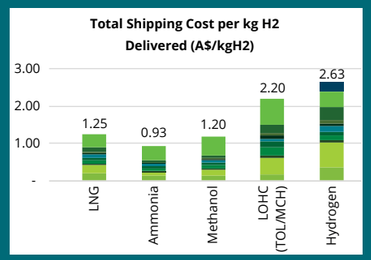
Users input all relevant shipping costs and can either select a shipping route from list of pre-determined routes linking major Australian and global ports to those in Europe and Asia, or can define their own shipping route data, hence enabling users to cost shipping transport via any route.

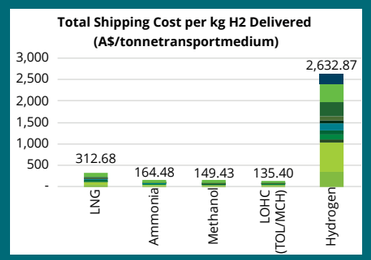
The Tool is available at: https://www.globh2e.org.au/hysupply-publication

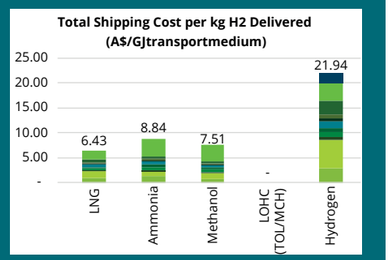
Shipping Analysis Tool

The tool includes a comprehensive range of costs designed to emulate a close to reality analysis for shipping transportation of hydrogen and hydrogen carriers (transport mediums). These costs include ship investment, storage investment, additional capital costs, labour, canal, port, maintenance, miscellaneous, insurance, storage operating costs, additional operating costs, fuel, carbon emissions and boil-off gas (BOG) costs. To best enable comparison between transport mediums the levelised cost of transport via shipping is calculated by adding the total annual costs and dividing by the annual total energy delivered. This levelised cost is presented per kilogram (kg) of hydrogen, per gigajoule (GJ) of transport medium and per tonne (t) of transport medium.

Total energy delivered is dependent on the storage capacity of the ship (in tonnes) and the number of trips made per year, which in turn is influenced by the ship speed, shipping route length, time spent docked at port and ship availability (days per year the ship is available for operation). Total annual costs are a summation of capital and operating costs. Annual capital costs were calculated using a capital recovery factor for the ship capital costs (outright cost of buying the ship). Annual operating costs were given through the addition of labour, canal use charges, port service charges, maintenance, miscellaneous, insurance, storage operating cost, fuel, carbon emissions and boil-off gas (BOG) costs. Users are also given the option to incorporate any other additional capital and operating costs into the model if required.







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