FINAL REPORT

Australia-Germany Hydrogen Value Chain Feasibility Study (HySupply)

January 2023

GlobH2E ARC Industrial Transformation Training Centre for the Global Hydrogen Economy

UNSW SYDNEY

BDI

acatech

Acknowledgements

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JOINT LETTER

from the HySupply Australian and German Consortia

The HySupply project has been a two-year collaboration between German and Australian consortia to investigate the feasibility of a hydrogen and hydrogen derivatives supply chain between Australia and Germany, and identify how such a partnership can be facilitated.

German participation was led by BDI and acatech, and Australian participation by UNSW Sydney, supported by key partners, and assisted more generally by diverse research, industry and NGO stakeholder participation, and with funding from the German and Australian governments.

We are delighted to present this final joint report of the HySupply project and its key messages – development of this supply chain is possible, key elements are already underway, but it's assured success still needs government facilitation.

Work over the two years includes technical and economic feasibility studies covering renewable hydrogen production to conversion into a range of possible hydrogen derivatives, shipping, reconversion and final use. A set of open-source techno-economic modelling tools has also been released to assist stakeholders in undertaking more detailed and context specific studies. Other outputs included some specific regulatory and renewable hydrogen certification reports. Most Importantly, there was also an Australian supply-side roadmap and German demand-side action plan which laid out key steps for establishing Australian-German trade in renewable hydrogen before 2030.

This report first outlines the motivation for the HySupply project - Australia's renewable energy resources, energy export credentials and determination to become a renewable energy exporting superpower, matched to Germany's strong net zero commitments, need to import clean energy to achieve these goals, and expertise in clean technology.

The two years of the HySupply project have seen extraordinary changes globally, and within Australia and Germany, in the energy sector, in clean energy more generally, and in renewable hydrogen specifically. These include a global energy crisis, supply chain challenges, changing geopolitics in energy trade, and accelerating climate change impacts. It has also seen Australia and Germany sign a Hydrogen Accord and establish new funding initiatives. Our report outlines key developments to highlight how the reasons for the HySupply project have only strengthened over this time.

The report then outlines the diverse range of HySupply outputs, and other activities delivered over the two years of the project, focussing particularly on the feasibility studies and roadmapping and action plans.

Finally, and most importantly, the report then summarises the key findings and suggested actions for government and industry arising from this work. **There are six key messages**.

1. Time is of the essence and decisive early action is required to deliver needed emissions reductions through renewable hydrogen, given the timelines of major new energy infrastructure developments. There is also the risk that limited technology supply chains and key industry capabilities are attracted to faster moving jurisdictions.

2. Industry and government have to transition from feasibility studies and pilot projects to scaled up projects of export size that will prove up the technologies and operational processes required. We also need scaled up projects delivering a number of key renewable hydrogen derivatives including ammonia and e-fuels such as methanol and sustainable aviation fuels. Government will have a key role in helping de-risk the very substantial investments required to deliver these.

3. Governments and key potential renewable hydrogen users have to work together to build demand through off-take agreements that support major renewable hydrogen production projects. This will have to include funding support to cover the 'green' premium between renewable hydrogen and hydrogen derivatives and conventional sources of these. H2Global provides an excellent example of possible approaches, but there are wider opportunities to explore in this regard.

4. Governments must facilitate planning and implementation of necessary, shared, infrastructure on the renewable hydrogen supply, transportation and demand-side of the supply chain.

5. Certification is key in ensuring that Australian renewable hydrogen meets the regulatory requirements of the EU and Germany, as well as hydrogen user preferences. The considerable work underway by both the German and Australian governments, as well as industry stakeholders, provides a solid platform but more needs to be done.

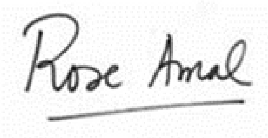
6. Better coordination of Australian and German efforts and collaboration would assist in delivering this partnership. In particular, a central coordinating platform with government, industry and research participants for all of the existing and prospective new initiatives could assist in setting targets, monitoring progress and providing recommendations of future efforts.

The 'take home' message

In summary, for Australia and Germany's opportunity to establish a renewable hydrogen supply chain, there is much to be optimistic about, but much much more still to be done.The HySupply project has delivered on its 'fact finding' objectives and the next steps must focus on moving to 'fact making' over the coming two years, and beyond, by facilitating the delivery of scaled up renewable hydrogen projects. Time is of the essence given our climate and energy security challenges, as well as competing market players and tight supply chains and industry capabilities.

We would like to thank the Australian and German governments for their support of this project, and the contributions of our project partners and wider stakeholders. We would of course be delighted to assist in future work on building an Australian – German renewable hydrogen supply chain.

Professor Iain MacGill



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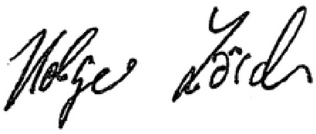


Mr. Holger Lösch

THE HYSUPPLY PROJECT

THE HYSUPPLY PROJECT

HySupply is a collaboration between Germany and Australia to investigate the feasibility of exporting renewable energy in the form of hydrogen from Australia to Germany and identify how this partnership can be facilitated. The project arose from a previous cooperation project, Pathways to the Future of Energy [1], where a fact finding mission by a German delegation in Autumn 2019 met with leading Australian research institutions and companies in the field of energy and hydrogen. The key finding of the trip: Australia is a suitable partner for a long-term hydrogen partnership with Germany.

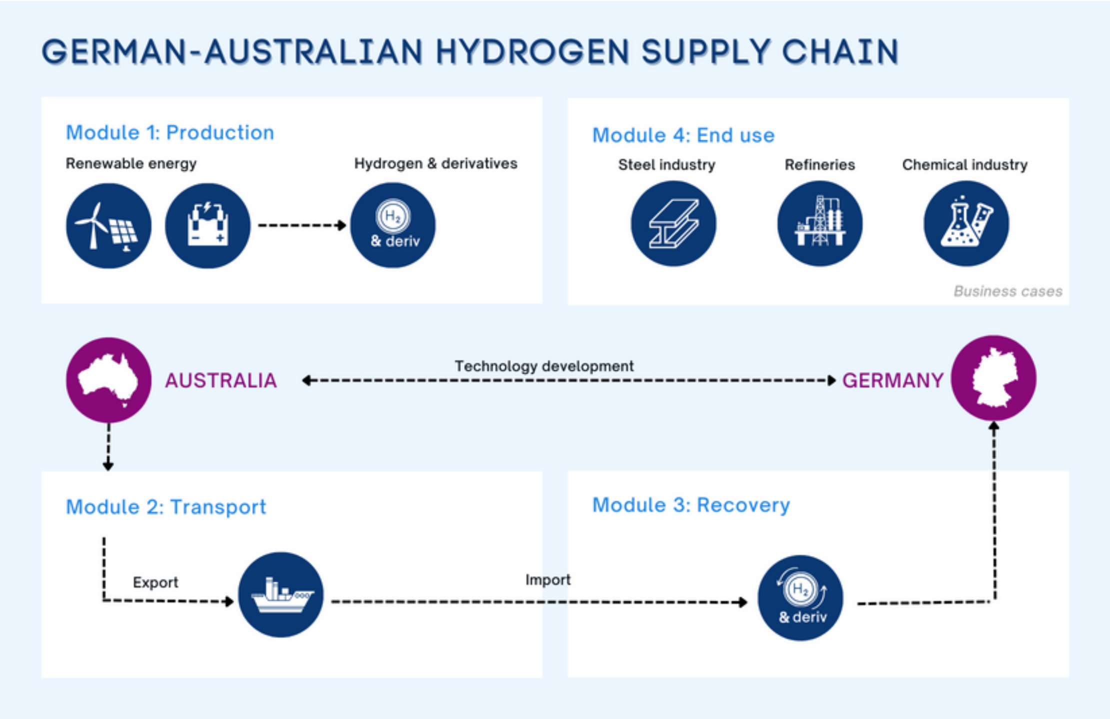


Figure 1: Schematics of Australia Germany Hydrogen Supply Chain (Source: adapted from BDI)

This led to the Joint Declaration of Intent on an Australian-German Supply Chain Feasibility Study of Hydrogen produced from Renewables signed by the Australian and German Governments in 2020. For Australia, the consortium is led by UNSW Sydney and is funded by the Department of Foreign Affairs and Trade (DFAT) and the Department of Industry, Science, Energy and Resources (DISER). For Germany, the project is led by the German National Academy of Science and Engineering (acatech) together with the Federation of German Industries (BDI) and is funded by the Federal Ministry for Education (BMBF). Together, the two sides brought together a unique network of companies and scientific experts to investigate the entire value chain of renewable hydrogen and hydrogen derivative production in Australia to its shipping and then potential use cases in Germany.

[1] https://en.acatech.de/publication/pathways-into-the-energy-future/

A key finding of the study is that Australia and Germany are natural partners in this energy export value chain. Australia's renewable energy resources, energy export credentials and ability to deliver mega-scale energy projects at scale makes it a well-placed contender for this collaboration. Germany's strong net zero commitments and expertise in clean technology makes an ideal fit to import renewable hydrogen and co-develop Australia's hydrogen capability. This alignment is increasingly recognised by industry partners in both countries and there are now at least eight bilateral MoUs signed to advance this trade. However, while there is much to be optimistic about, there is much more still to be done. This final report of the joint Australian and German HySupply consortia is intended to summarise the findings of the two year project, and highlight key actions for stakeholders to achieve the potential of this renewable hydrogen supply chain.

Hysupply Deliverables

Officially kicking off in December 2020 with a bilateral workshop with industry and academic stakeholders, the first formal output of HySupply was the German Meta-Analysis (July 2021), which explored the hydrogen carrier options from Australia to Germany, focusing on the elements for seaborn transport of hydrogen including conversion, storage, shipping, and reconversion and status of these technologies and their potential for scalability by 2030.

This was followed by Australian HySupply State of Play report, released in September 2021, which assessed Australia's potential for major green hydrogen production and export capabilities. 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 clean energy objectives. The report aimed to enhance the shared understanding of industry, government and private sectors across Australia and Germany around the challenges as well as opportunities of such trade.

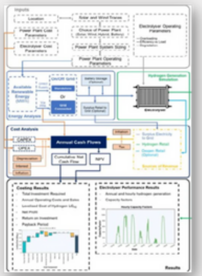
Assessment of the value chain was then complemented by Australia HySupply Consortium releasing a series of open-source modelling tools (October 2021-tll now) for investigating the cost of generating hydrogen, its subsequent conversion to carriers such as ammonia and methanol, and its transport.

HySupply Germany then carried out a legal review (April 2022) of the identified transport pathways in their Meta-Analysis, identifying legal roadblocks that needs addressing for unlocking this value chain.

Australian HySupply then carried out a Supply Side Roadmapping exercise (May 2022) with over 50 stakeholders to identify key barriers and opportunities across thematic areas and formulating strategic steps from now till 2025, 2025 to 2030 and 2030 onwards to realise Australia's hydrogen export potential.

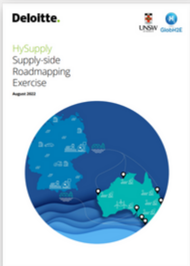
Hysupply - Australia's State of Play Report (2021)

HySupply - Germany's Meta-Analysis (2021)



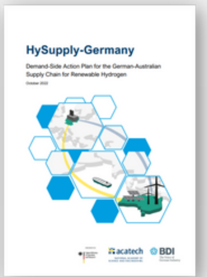
HySupply - Australia's Open Source Models (2021-2022)

HySupply - Germany's Legal Study (2022)



Hysupply - Australia's Supply-side Roadmapping Exercise (2022)

Hysupply - Australia's Certification Report (2022)



Hysupply - Germany's Demand-Side Action Plan (2022)

HySupply Final Report (2023)

May 2022 also saw a combined German government, academia and industry delegation visit Australia, visiting industry partners, state government representatives and projects in Western Australia, New South Wales, Queensland and South Australia. A HySupply event was hosted in UNSW bringing together Australian partners and German partners of HySupply where dialogue was held on challenges and how to take the partnership further.

In **June 2022**, HySupply-Australia, led by ANU, also released the Approaches to certifying Australia-Germany Green Hydrogen Supply Chains report, that described key characteristics and ‘good design’ principles of certification schemes as well as existing and emerging certification schemes that are potentially applicable to bilateral trade of renewable hydrogen between Australia and Germany.

Led by CSIRO and with HySupply participation, an academic delegation visit to Germany was undertaken in **September 2022** as part of the International Hydrogen Research Collaboration Program supported by DCCEEW. It visited a range of industry and research centres and concluded with an event at the Australian Embassy in Berlin, hosted by Ambassador Philip Green.

In **October 2022**, HySupply Germany released the **Demand-Side Action Plan** that provides an update on Germany's evolving hydrogen economy and formulates actions that need to be implemented within the next 24 months to allow for renewable hydrogen imports from Australia by 2030 the latest.

Next Steps

This is the final joint report of the HySupply project. However, HySupply is only one of numerous joint initiatives, government and industry, between Australia and Germany seeking to advance clean energy trade amongst the two countries. While the joint project officially closes with this final report, there is some further work underway by HySupply Australia in 2023, including a report exploring electricity market configurations for large-scale electrolyser operations, an assessment on viable carbon sources and technologies for synthetic fuel production and further open-source costing tools.

As discussed in the Summary Section, the HySupply collaboration recommends a central platform for continuing, expanding and better coordinate the hydrogen partnership between Australia and Germany, bringing together representatives of existing initiatives to better coordinate and align activities including funding and external stakeholder engagement.

AN EVOLVING CONTEXT FOR HYSUPPLY

AN EVOLVING CONTEXT *FOR HYSUPPLY*

The two years of the HySupply project, 2021-2022, have been highly eventful for energy globally, clean energy in particular, and renewable hydrogen.

General Energy Developments

General energy developments include a global energy crisis with record high coal and gas prices, and price volatility, from the second half of 2021 and particularly after Russia's invasion of Ukraine in February 2022. This crisis has both created challenges for clean energy transition as key countries seek to enhance their energy security through targeted fossil fuel investment, but also highlighted the value of renewables to reduce dependency on imported energy from geopolitically troubled regions. Global geopolitical and economic challenges have also renewed attention on the risks associated with concentrated supply chains for strategic resources and technologies, and the value of more diverse and secure trade relationships to deliver these. Some clean energy technologies have actually seen costs rise over the past two years, although the general expectation is that they can continue their historic price reductions as supply chains are strengthened, scale increases and technologies improve.[1]

Of even greater importance, certainly in the longer-term, is the worsening climate crisis and need for accelerated global emission reductions to avoid dangerous warming. There are increasingly ambitious emission reduction and renewable energy targets in key jurisdictions.
The EU released its *REPOwerEU* plan in May 2022 and is seeking to increase the share of renewables in final energy consumption to 45% by 2030 rather than the previous 40% target that was under negotiation. The United States passed it's Inflation Reduction Act (IRA) in 2022 as well, with major funding for a range of clean energy initiatives. China and India have also strengthened their renewables deployment efforts. The IEA has just made its largest ever upward revision of its renewable energy forecasts, up 30% over the coming five years. They now expect renewables to exceed coal's contribution to global electricity generation by 2025.[2]

Germany has a 2045 net zero emissions target and an 80% renewables target for power generation by 2030, with recently strengthened policies including more auctioning, incentives for distributed PV and accelerated permitting processes.

After a change in Federal Government, Australia how has a 43% emissions reduction target from 2005 levels for 2030, and a plan for 82% of the grid to be from renewables. [3]

[1] International Energy Agency (IEA), World Energy Outlook 2022, Paris, November 2022.
[2] IEA, Renewable Energy Report 2022, Paris, September 2022.
[3] https://www.pm.gov.au/media/australia-legislates-emissions-reduction-targets

In Germany, renewables contributed close to 50% of total power generation in 2022, while the Australian National Electricity Market which supplied around 90% of Australian energy consumers achieved 35% renewable contribution. In both countries, renewables uptake is accelerating.

Hydrogen Specific Developments

Hydrogen specific developments globally over the period of the HySupply project have also been marked. The IEA reports that an additional nine countries, covering around 30% of global energy sector emissions, released national hydrogen strategies in 2022, joining 17 existing jurisdictions. Electrolyser manufacturing capacity is growing and there has been progress in new hydrogen applications in steel making, chemicals production transport. New R&D and Demonstration projects have been supported in jurisdictions including the EU and particularly the US through its bipartisan Infrastructure Law.

The IEA identifies policies and targets in more than 25 countries that are expected to deliver 50 GW of wind and PV capacity focused on producing hydrogen over the coming five years, with China followed by Australia, Chile and the United States seen as the key markets.[4] A recent market assessment notes that Government subsidies will begin in 2023 in the United States, the EU, the UK and Germany, and probably in Canada, India and Portugal.[5]

However, these developments are still not on track with the IEA's Net Zero Emissions by 2050 Scenario. In particular, they argue that faster action is required on creating demand for low emission hydrogen and unlocking investment to accelerates scale-up and infrastructure development.[6]

International hydrogen trade developments

International hydrogen trade developments include fifteen new bilateral international Government agreements in 2022, with most focused on the development of international hydrogen trade. Industry MOUs and partnerships are also expanding. The Breakthrough Agenda launched at COP26 includes Hydrogen and had commitments from 44 countries including Australia and Germany. In May 2022 the G7 launched a hydrogen action pact focused on technology development, regulatory frameworks and financial commitments.[6]

The EU is now targeting 10 million tonnes of green hydrogen imports by 2030. Germany's hydrogen targets are extremely ambitious for both domestic hydrogen production as well as imports.

The German H2Global scheme to support renewable hydrogen derivative imports to Germany launched its first áuction' tender process in December 2022 for the import of "green" ammonia to Belgium, the Netherlands or Germany from non-EU states.

[4] IEA, Renewable Energy Report, September 2022
[5] https://www.hydrogeninsight.com/production/prepare-for-lift-off-why-2023-will-be-the-year-that-green-hydrogen-moves-from-idea-to-reality-around-the-world/
[6] IEA, Hydrogen Tracking Report, September 2022.

The Hydrogen Purchase Agreement (HPA) contracts will run for ten years with first deliveries expected by the end of 2024 or early 2025. Producers will have to meet stringent sustainability requirements including temporal and locational matching of renewable generation to hydrogen production. This has been followed by the launch of an auction tender process for green e-methanol and sustainable aviation fuel (e-SAF).

Australia has also been active in expanding its international hydrogen trade efforts with recent hub announcements associated with major ports. The Federal Government's planned investments in regional hydrogen hubs are now well over A$500m with the recent support for a hydrogen hub in Gladstone. Australia joined the Green Shipping Challenge at COP27 and recently signed a Geren Economy Agreement with Singapore that includes measure to implement green shipping corridors.

Looking forward, the IEA, IRENA and World Hydrogen Council have all released studies highlighting the importance of renewable hydrogen and hydrogen derivative trade in order to achieve global climate goals. As IRENA notes, "The critical factor that will determine the cost-effectiveness of trade in hydrogen will be whether scale, technology and efficiency gains can offset the cost of transporting the hydrogen from low-cost production areas to high-demand areas." It notes particular challenges for self sufficiency in a number of countries including Germany and the large project scale (order of 0.5-1 MtH2/year) in order to maximise scale economies. Their modelling suggests that international hydrogen and hydrogen derivative trade in 2050 might represent around one third of total production, similar to the current global gas market, with shipping carrying around 45% of this trade.[7]

Australian and German Government Collaboration

Australian and German government collaboration over the period of the HySupply project centred on the Australia-Germany Hydrogen Accord in June 2021, specifically intended to build on Australia's plans to be a major hydrogen exporter, and Germany's expertise in hydrogen technology and plans to import significant quantities of hydrogen in the future. The Accord includes three major initiatives:

- Establishing the German-Australian Hydrogen Innovation and Technology Incubator (HyGATE) to support real-world pilot, trial, demonstration and research projects along the hydrogen supply chain. Australia and Germany committed up to $50 million and €50 million respectively.
- Facilitating industry-to-industry cooperation on demonstration projects in Australian hydrogen hubs.
- Exploring 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

The first HyGate round was launched by the Australian Renewable Energy Agency (ARENA) in March 2022 for consortia involving both Australian and German industry and research partners. Projects were short-listed in late 2022 and successful consortia are expected to be announced in early 2023.

[7] IRENA, Geopolitics of the Energy Transformation: The Hydrogen Factor, January 2022.

H2Global's recent tenders for renewable ammonia, methanol and SAF were outlined above, and have certainly established an opportunities for projects in Australia as well as other non-EU countries.

Summary

In summary, there have been extraordinary developments for global energy, clean energy specifically and hydrogen and hydrogen derivatives in particular over the two years of the HySupply project. All of these developments have arguably strengthened the case for HySupply's work, and the scale and importance of the opportunity it has been assessing.

KEY PROJECT FINDINGS

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Hysupply Germany Meta-Analysis

The working paper from HySupply Germany highlighted the need for emission reduction in Germany, which will be facilitated through imported renewable hydrogen and its derivatives. The demand for imported hydrogen derivatives is expected to be close to 90% of total hydrogen demand in Germany (**Figure 2**). The projected demand for hydrogen and derivatives in Germany is estimated to be 80 TWh by 2030 and increasing to between 400-800 TWh by 2050.

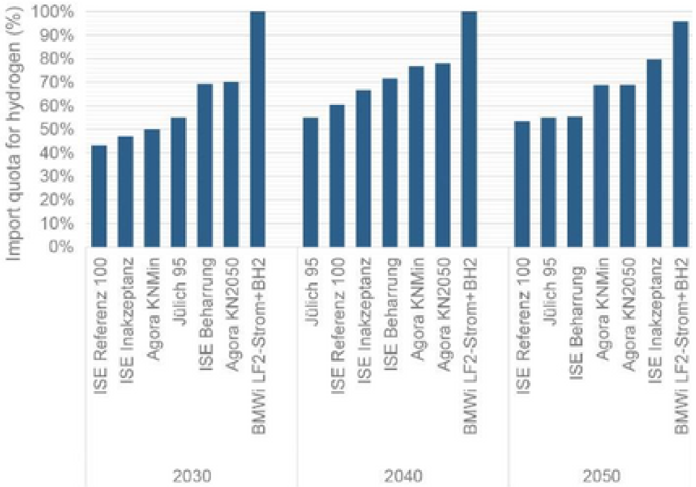


Figure 2: Potential % of total hydrogen import to Germany.[8]

The second aspect that the Meta-Analysis highlighted that long-distance transport of hydrogen and its derivatives between Australia and Germany is technically feasible with renewable ammonia and methanol being overall the most mature pathways. Other carriers such as liquid organic hydrogen carrier (LOHCs) and liquified hydrogen was considered. The study identified potential import terminals in Bremerhaven, Brunsbüttel, Hamburg, Rostock, and Wilhemshaven as well as Antwerp and Rotterdam.

[8] M. Wietschel, L. Zheng, M. Arens, et al., "Metastudie Wasserstoff – Auswertung von Energiesystemstudien. Studie im Auftrag des Nationalen Wasserstoffrats," 2021.

HySupply Australia State of Play

The State of Play (SoP) document built the case for Australia's opportunity to be a key clean energy export superpower to Asia-Pacific and EU, presenting the country's credentials for conventional energy exports, ability to ramp-up projects, infrastructure capability, world-leading renewable potential as well as political alignment to develop a renewable export supply chain. The Australian Hydrogen Competitiveness Matrix clearly highlights the country has the foundation to build a strong hydrogen value chain with strong Federal and State and Territory Government support and this is reflected by takeoff of large-scale hydrogen projects in the country (**Figure 3**).

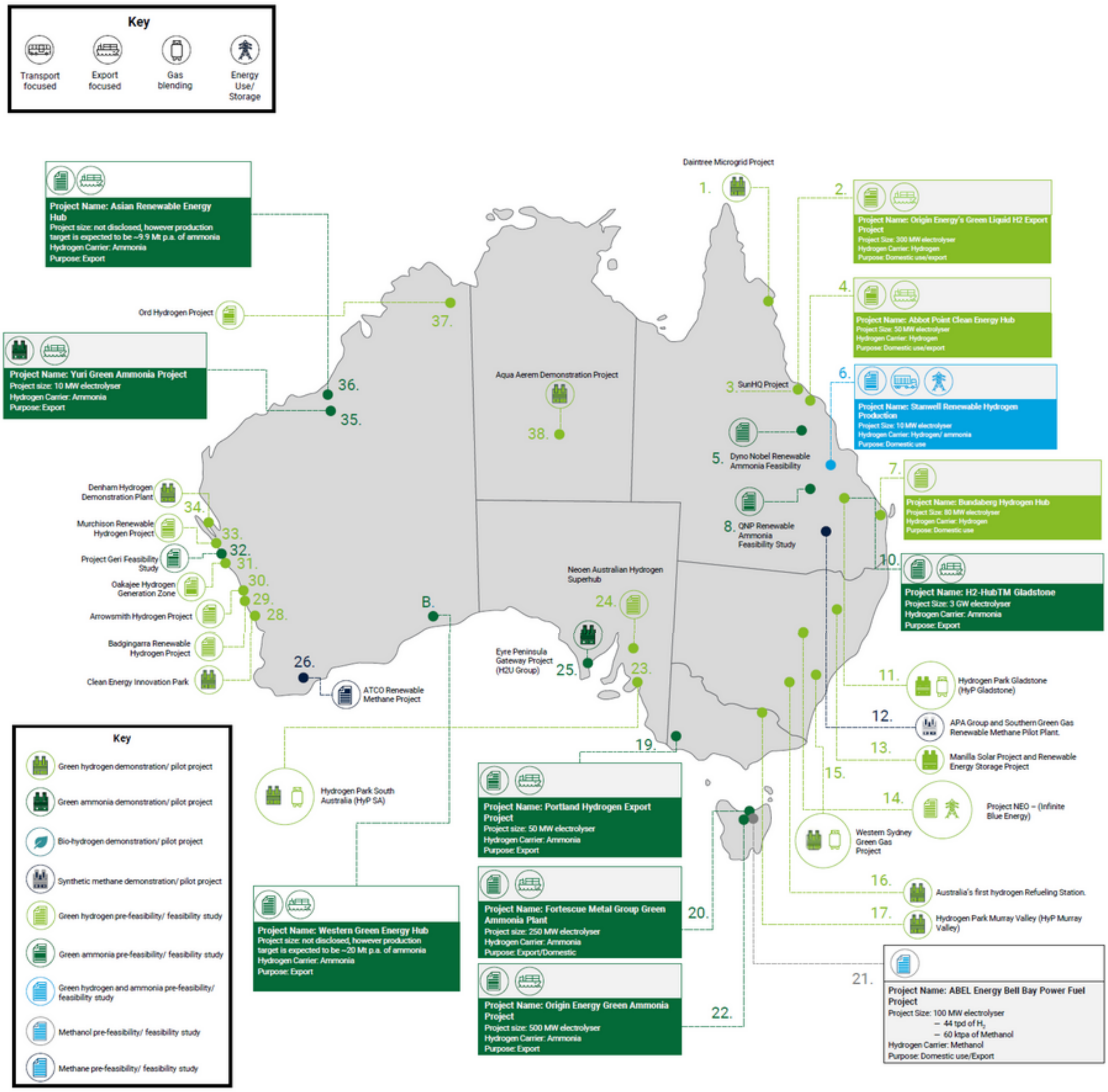


Figure 3: Non-exhaustive list of Australian hydrogen and derivatives projects. For more details please refer to CSIRO HyResource portal.

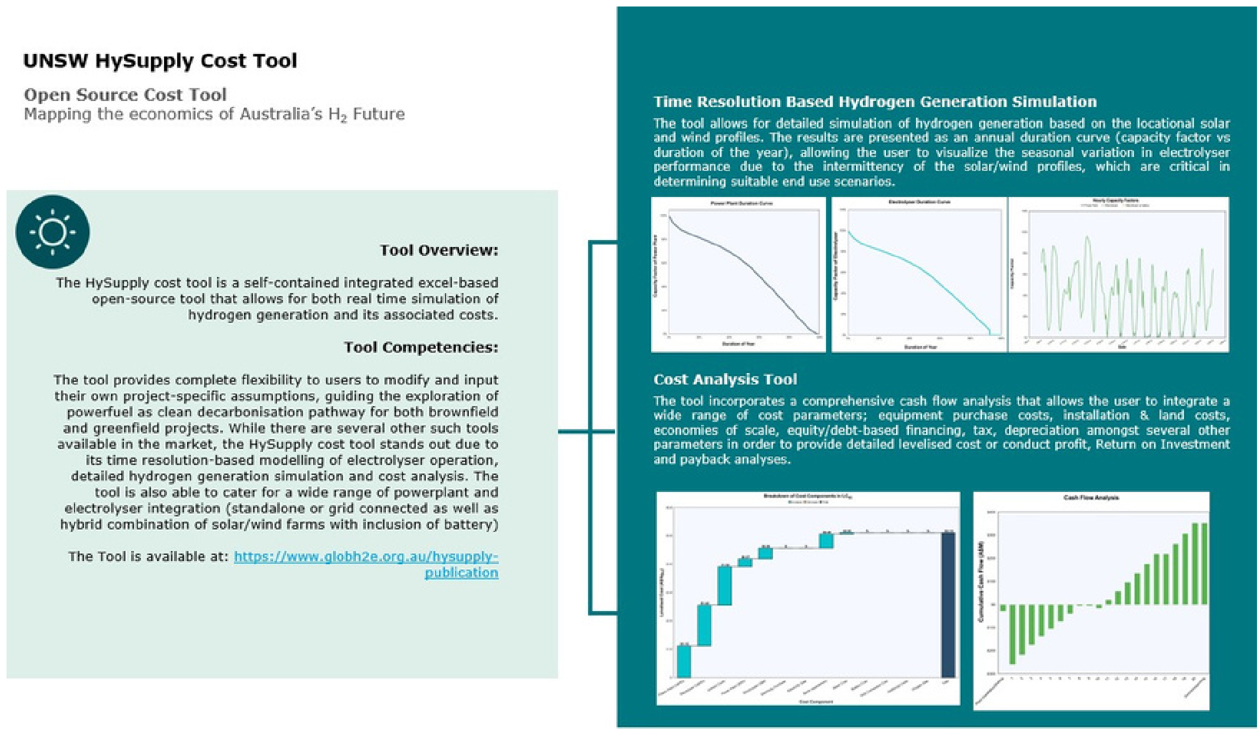
The SoP also identified export pathways under consideration by Australian project developers including liquid hydrogen, ammonia, methanol and LOHCs (all considered by Meta-Analysis) but extended to also include synthetic methane. Given the recent energy crisis in EU and Germany arising from political developments in Eastern Europe, demand for LNG has skyrocketed, which provides a clear and early market for synthetic methane/LNG as off-take opportunity in Germany.

The SoP also provided preliminary technology assessment, cost estimates for the export pathways, which also included shipping costs as well as developing a multi-criteria analysis (MCA) tool for assessing hydrogen derivatives against key techno-economic criteria, such as commercial, hydrogen export, energy export, transportation and decarbonisation benefits.

A key insight arising from this assessment is that while Australia and Germany shipping routes are quite long, shipping costs are not a deal-breaker to the trade and rather the cost of renewable electricity amongst othe factors will continue to play a governing role in dictating feasibility. The report shows that already today, Australia’s best locations can produce renewable hydrogen at 2-6 €/kg. Preliminary modelling also indicates that renewable ammonia offers the most economical pathway with delivered hydrogen cost between 3.5-8.8 €/kg at the Port of Rotterdam.

HySupply Australia Open-Source tools

To allow for flexibility with the changing cost drivers, HySupply Australia has developed a series of open-source tools including renewable hydrogen costing tool, renewable ammonia cost tool, renewable methanol cost tool and an export transportation model tools. These open-source tools are released as an asset of the HySupply project with the intent to iteratively improve existing functionalities and data sets to provide holistic, high-level, pre-feasibility assessments for possible hydrogen projects, as we build towards a complete value chain assessment tool.



HySupply Germany Legal Study

The review of EU and German regulatory framework revealed that the import of renewable hydrogen from Australia to Europe is legally feasible for the four transport vectors considered by the Meta-Analysis. However, legal requirements and barriers were identified for the construction of the vessels, safe handling, documentation and staff, and requires several authorisations at various levels, which can potentially impede timely implementation of the supply chain. Three of the four transport options (ammonia, methanol and liquid H2) are classified as dangerous goods whereas uncertainty remained on classification of LOHCs. The study also revealed that vessels carrying LH2, ammonia and methanol must comply with various technical provisions of EU codes (IGC code, IMDG code, MARPOL) and must be certified by competent authority (e.g., the flag state administration). The transport of these through Suez Canal may not be permitted, increasing transportation distances. Note that transport of LOHC is not yet regulated given the infancy of the transport vector. The review also highlighted the permits and regulatory requirements for import terminals and new terminal construction, in-land shipping as well as pipeline.

HySupply Australia Certification Report

Stakeholder input throughout the project has highlighted the importance of proper certification of green hydrogen and its derivatives to Europe. As a result, a wide range of certification efforts have begun in Australia, Germany and internationally. The HySupply Australia certification report aims to assist project proponents and stakeholders navigate the myriad of certification options available by providing common language and conceptual framework to discuss and understand emerging scheme options. The report also provided a summary of key characteristics that ‘good’ schemes should have.

HySupply Australia Supply Side Roadmap

Involving over 50 stakeholder consultations across the hydrogen value chain in Australia, six key findings were identified which were then translated into guiding principles that Australia can consider. These key findings are as follows:

1. **The willingness of international buyers** to pay for Australian exports of green hydrogen is still **uncertain at this very early stage of industry development**, and will largely rely on clarifying the preferred forms of hydrogen matched to end-use applications, acceptable green price premiums and appropriate embodied carbon emissions for ‘green’ imports to Germany.

2. To attract investors, states and territories in Australia must have clear, **harmonised and streamlined regulations** to develop industry confidence and to attract investors. This will need to include agreed **Guarantee of Origin Schemes** for hydrogen and its derivatives.

3. Governments can best assist **‘first-movers’ by helping to bridge the price gap** between importers (‘buyers’) and exporters (‘sellers’), as well as underwriting off-take agreements, providing investment security for project developers.

4. 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.

5. There are **significant hurdles** involved in scaling to export scale across the green hydrogen value-chain (electrolysers, buffer storage, transportation via pipeline, liquification and/or green derivative conversions, hydrogen-ready ships, hydrogen loading/unloading at ports etc.), including sourcing enough land, water and renewable generation.

6. The **full decarbonisation** of established processes for producing hydrogen carriers, such as **ammonia and methanol, may require a transitionary period**, as the use of **variable wind and solar pose challenges** for the conventional continuous industrial processes currently used for their production.

Export Readiness Tracker for Australian Projects

Australia is currently in between these stages

ER1
Projects/ consortia have been proposed in the 100 - 300 MW scale. In this stage, projects are in pre-feasibility/ feasibility stage.

ER2
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).

ER3
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.

ER4
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.

ER5
Projects do not have technologies uncertainties, but still have a gap in commercial viability. between the off-take price and the deliverables cost of hydrogen/ hydrogen derivatives. Note: At this stage, net zero policy underpins the commercial viability of export projects.

ER6
The value-chain technologies, and operations reach maturity with standards in place and performance expectations. The project reach a 'bankable' grade asset class. **Note**: Government subsidy is no longer required for the export projects.

Figure 3: Export Readiness Tracker for Australian Projects. 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: 2022, 2022 - 2025 and 2025-2030, to address the key barriers and opportunities raised by stakeholders.*

HySupply Germany Demand Side Action Plan

This Demand-Side Action Plan from HySupply-Germany provides an update on Germany's evolving hydrogen economy and formulates actions that need to be implemented within the next 24 months to allow for renewable hydrogen imports from Australia by 2030 the latest. Some key findings are as follows:

1. **More stringent climate policy leads to increased demands for hydrogen and the need for imports.** With Germany's new Federal Climate Change Act, the target of climate-neutrality was brought forward by five years and the emissions reduction targets for 2030 were tightened significantly which increased the demand and need for imports of hydrogen and its derivatives.

2. **The energy crisis calls for new import infrastructures** to achieve independence from Russian fossil fuel imports and realise the REPowerEU import target of 10 million tonnes of hydrogen by 2030. To address this crisis, Germany is accelerating the build-up of new import infrastructures for LNG as well as for hydrogen derivatives such as ammonia.

3. **German manufacturers are gearing up to enter a new era for electrolysers** by continuously driving the commercialisation of modules to 10 MW and beyond, especially for alkaline water electrolysis (AWE) and proton exchange membrane (PEM) electrolysis.

4. **Securing offtake for renewable hydrogen and its derivatives in Germany is crucial to kick-start export projects in Australia.** This can be achieved by creating green lead markets to drive predictable demand in Germany, the successful implementation of H2Global and an Australian specific auction window, as well as Contract for Difference (CfD) mechanisms.

5. **Implementing a certification scheme is central to enable the trade of hydrogen.** Most influential are the legal requirements coming from European Renewable Energy Directive that are however still pending. Germany and Australia should already foster dialogue on the possibilities to implement these requirements in Australia to potentially become the first international certified hydrogen supply chain.

6. **Building up import infrastructures as the cornerstone of the German-Australian hydrogen bridge is key.** To support this, planning and approval procedures need to be significantly accelerated and regulation for and access to infrastructures should be non-discriminatory. Strengthened public-private partnerships can help to de-risk the investments while existing import hubs can provide fast-track solutions for early imports.

SUMMARY

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Technical Feasibility

Reviews undertaken by both the German and Australian HySupply teams confirmed the technical feasibility of green hydrogen (and derivatives) production and shipping, but highlighted the complexities of assessing technology readiness at different stages of the production, storage, conversion, shipping and, potentially reconversion for different possible forms of shipped hydrogen. The Australian work focused on green hydrogen and derivatives production and shipping, while the German analysis focused on the supply chain from conversion to shipping to reconversion and end use.

Shipping of hydrogen as a liquid or using liquid organic hydrogen carriers are less technically mature options at this stage. For liquid hydrogen, storage and shipping are key challenges while for LOHC, the shipping is expected to be relatively straightforward given their similarities and compatibility with current traded chemical commodities, but there are key technical challenges are in the conversion processes.

Ammonia can be made with renewable hydrogen through mature production processes and is already widely shipped around the world. The least mature step is recovery of gaseous hydrogen from ammonia. However, ammonia has many direct applications as an industry feedstock, potential application for direct power generation and shows promise as a fuel for marine engines.

Large scale methanol production from renewable hydrogen and a suitable sustainable source of CO2 still needs some proving, but methanol is already internationally shipped and is both an industrial feedstock and relatively easily utilized fuel.

Green methane from renewable hydrogen and sustainable CO2 is another possible option and could utilize existing and possible future LNG infrastructure. There is also growing interest in sustainable aviation fuels (SAF) from renewable hydrogen, and HySupply Australia will continue to assess technology readiness and value chain costs for SAF generation.

In summary, both ammonia and methanol are relatively technically straightforward to produce, store and ship, and highly useful hydrogen derivatives for a range of roles and provide an early path for international renewable hydrogen trade. Looking forward, the prospects for technology progress to widen our options and reduce costs are also good.

Value Chain Analysis

The economics of renewable hydrogen trade looking forward are even more complex, including technology progress and possible breakthroughs, cost reductions as renewable hydrogen and hydrogen derivative production is scaled up, future fossil fuel costs and volatility and, critically, efforts to reduce emissions towards country and global net zero emission targets. There is widespread agreement that renewable hydrogen has a key role in a global net zero emission future although there are still questions about the scale and nature of its use. It's use for some industrial processes, shipping and aviation certainly seems relatively assured.

There is also wide agreement that internationally traded hydrogen and derivatives will play a key role in such a net zero emission future. One key reason is the relatively limited renewable energy options available to some countries that will necessitate clean energy imports, even given the industrial restructuring that we might expect to see in a net zero world. Another reason is the availability of abundant high quality solar and wind resources in some countries compared to others and the cost advantages for renewable hydrogen and derivative production in those locations. Hydrogen and hydrogen derivative transport costs will be a key factor in such competitive advantage. Certainly, for modest distances, the lowest cost for transporting hydrogen gas is almost certainly by pipelines, particularly if repurposed and upgraded existing pipelines can be utilised. Delivery of hydrogen via liquification or LOHCs faces considerable additional costs for conversion and reconversion. For renewable hydrogen derivatives such as ammonia and methanol, and longer distances, shipping can be competitive, as evident in the current global shipping trade of both these commodities. In a similar way to how current international trade in ammonia and methanol has been driven at least in part by different regional gas availability and pricing, renewable derived ammonia and methanol may also be shaped by renewable energy availability and costs.

Shipping also offers flexibility – something which has proven highly valuable with LNG, particularly over recent times. Indeed, LNG inter-regional trade volumes now exceed those by pipeline.[9] Work undertaken by the HySupply team, and in agreement with other work by the IEA, IRENA and others, suggests that shipped hydrogen derivatives can play a vital role in a future net zero emission world. Finally, global trade relationships can and should be driven by factors other than just price, something highlighted with by the growing interest in more diverse supply chains with appropriate and trusted trade partners.

Both Australia and Germany would benefit from a diverse international market in hydrogen and hydrogen derivatives with multiple buyers and sellers. However, there will likely be particularly important trade relationships. For potential Australia and Germany trade, the shipping distance is certainly considerable – certainly in comparison to shipping from Australia to Asia, and from the Middle East, Africa and Americas to Europe. Still, HySupply and other work suggests that the variable (distance related) costs of shipping hydrogen derivatives may be only a modest component of total delivered costs.

[9] BP, BP Statistical Review of Energy 2022, 2022.

Other factors in support of Australian and German trade including our existing trade relationship, companies working across both countries and shared geopolitical interests, all support the potential for such trade. A relevant example is the growing interest in Australian LNG imports to Europe with the first shipment delivered in 2022 and a number of Declarations of Intent in place.

Roadmapping and key actions

Despite this promise, there is no certainty of success without strategic, coordinated and early action by key Australian and German stakeholders including government as well as industry.

Continuing technical and commercial uncertainties with different pathways creates challenges. So does the range of potential options and pathways itself, as there are multiple opportunities for a range of hydrogen derivatives to achieve market success. A key reason for developing and releasing open-source modelling tools for green hydrogen production, conversion to derivatives and shipping is to support a wide range of stakeholders in assessing different options and pathways as our technical capabilities and knowledge improves, and as markets and policy settings continue to evolve.

Still, extensive stakeholder consultations by both the Australian and German HySupply teams have highlighted a series of key actions and stakeholder contributions to support progress. Further details can be found in the respective supply roadmap and demand action plans. We focus here on shared insights across the work

Time is of the essence

Decisive early action is required. Our shared energy and climate challenges, require rapid emissions reductions across all sectors, hence rapid deployment of renewable hydrogen and hydrogen derivatives. Timelines for taking major infrastructure developments from feasibility studies to front end engineering design (FEED) to full regulatory and environmental approvals to final investment decision (FID) then construction, commissioning and final commercial operation are typically years. The recent German experience with rapid deployment of LNG import facilities has highlighted that such timelines can be shortened when the need arises. Still, there are greater technical uncertainties and less mature supply chains associated with renewable hydrogen projects which will slow development.

Other reasons for speed are the growing efforts of other jurisdictions to develop their own renewable hydrogen production and use. The IRA in the United States is a particularly pertinent example of this. The risk is that faster moving jurisdictions will capture dominant positions in global hydrogen technology supply chains and industry capabilities making it harder for following players to get their projects implemented on both the supply and demand sides of the value chain.

From fact finding to fact making

Many industry and other stakeholders reported growing frustration with repetitive hydrogen feasibility studies that provide limited practical experience for overcoming the challenges and uncertainties in green hydrogen and would like to see prioritisation of scaled-up projects.

Scaling up renewable hydrogen production projects

The viability of hydrogen and hydrogen derivative trade will require larger scale projects than currently being implemented. It seems likely that projects in the scale of 100-300 MW are required. This is an order of magnitude than the 10 MW projects now being implemented in Australia. While larger projects will provide economies of scale and get unit production costs down, they do involve more financing and hence higher financing risk. Governments can play a key role in assisting to de-risk aspects of early scaled-up projects through innovative financing support mechanisms.

An additional complexity is the need to 'make facts' for a range of possible hydrogen derivative pathways, rather than just backing a single exemplar project. A project portfolio approach does require higher levels of total government support but will help reduce risks associated with a single project, support a wider range of end-use applications and provide more lessons on our different options.

Industry collaborations can also assist, in particular the involvement of global industry players with proven technology solutions. Germany certainly has a number of such industry players with the breadth of expertise and scale to assist here. The Australian German hydrogen Accord seeks to facilitate industry-to-industry cooperation on demonstration projects in Australian hydrogen hubs. This could be in the form of a German-Australian hydrogen innovation hub

Building demand through off-take agreements

Australian stakeholders for the roadmapping exercise highlighted that the willingness of international buyers to pay for Australian exports of green hydrogen is still unknown at this, still 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. These buy-side uncertainties make it very difficult to get to FID on renewable hydrogen and hydrogen derivative production, and projects built. Legally binding off-take agreements between industry buyers and sellers that defines terms and conditions regarding quantities and price for the offtake of the desired product over a certain period are key to getting projects built.

However, it is challenging for buyers, German companies, to commit to an offtake agreement due to current uncertainties including the lack of long-term predictability of regulatory framework conditions, the unavailability of import- and distribution infrastructures, the investment cost associated with new hydrogen-based processes, as well as the anticipated higher cost for the imported renewable hydrogen or derivative compared to fossil fuels.

Governments therefore have a key role to play in over-coming this gap between current industry costs and renewable hydrogen-based alternatives, and in managing the technical and market risks potential sellers and buyers face. Mandates for clean hydrogen and hydrogen derivatives use by industry sectors will be key but will take time to implement. The German H2Global initiative, describe above, is a highly innovative approach to addressing this challenge by providing a government intermediary for signing longer-term off-take fixed price and volume agreements with producers, while on-selling to German industry users through shorter-term contracts, and covering the 'green premium' that may be involved from higher supply than demand pricing.

The first tenders for have now been launched. While Australian companies are able to participate, the tight timelines, limited scale of present funding and international competition from other potential market providers may prove challenging. The Australian Government should look for opportunities to support Australian projects in coordination with the German Government. Importantly, while the first round of H2Global the first round of H2Global tenders has €900m to expend, the German government is looking to extend total funding to $4b euro, while the EU is looking to take a similar approach to support its hydrogen import target for 2030. This means opportunities for government collaborations around future tenders if not the present ones which are expected to be signed off by mid-2023.

Parallel development of international and domestic hydrogen production and use

Both Germany and Australia have ambitious plans for the development of domestic renewable hydrogen production and use, as well as for international trade. Australian stakeholders particularly highlighted the value of parallel development of domestic and international projects in creating opportunities for shared infrastructure, helping manage the risks of single stand-alone supply or demand projects, share supply chains and skills and industry capability, and help build social license for renewable hydrogen as an opportunity that extends beyond exporting or importing to or from other countries.

Australia's hydrogen hubs and clusters certainly provide a framework for this, but their development planning might better facilitate and coordinate these parallel pathways. Germany's domestic hydrogen efforts similarly offer opportunities yet also challenges for better integration.

Infrastructure

Both the Australian and German studies highlighted the key importance of government support to develop key infrastructure on both supply and demand ends of the renewable hydrogen supply chain. Private development of infrastructure can create challenges not only for the proponents and developers who must finance it, yet also potentially other projects who could usefully share it, and governments seeking to support wider industry development and improve the efficiency of the industry. This is an issue for both supply and demand infrastructure. And getting infrastructure decisions right requires planning. The Australian Government is currently leading a National Hydrogen Infrastructure Assessment, consulting states and territories regarding needs, availability and gaps in supply chain infrastructure to guide such infrastructure decision making.

Planning for shared infrastructure is also underway in Germany. However, these efforts might be better coordinated given the need to match the quantities of different renewable hydrogen derivatives across buyers and sellers.

Another key infrastructure challenge is to ensure that non-hydrogen related energy infrastructure can appropriate support scaled up hydrogen trade over time. Key German LNG import facilities are preparing to also be capable of ammonia and methanol imports, the Port of Rotterdam is already a major methanol hub and is adding ammonia and hydrogen facilities. Still, there is more to be done, particularly in terms of getting hydrogen and hydrogen derivatives from Port to point of use. On the supply side, there are related issues around getting renewable hydrogen from point of production to port.

Certification

All stakeholders have highlighted the importance of certification to support renewable hydrogen, and particularly trade. Hydrogen and its derivatives can be made in a number of ways with very different emissions and other environmental outcomes. Some stakeholders – buyers and sellers - are also interested in social, cultural and governance aspects of different possible supply chains.

It might be argued that the 'buyer is always right' and should set the conditions of acceptable production. Certainly, Germany and the EU have the primary role – for example, European end-users may wish to account hydrogen purchases towards renewable energy targets. However, there are also the costs and challenges that hydrogen producers might face in delivering hydrogen that meets specific certification requirements. German stakeholders have noted that excessively stringent requirements make it difficult to commit to offtake agreements. Having said that, Australia is well placed to meet stringent standards for sustainable, renewable hydrogen production.

H2Global has set a particularly high standard for additionality and time matching of renewable generation to hydrogen production. Such requirements have cost implications that need full consideration. Australian Government is currently consulting on a proposed design for a Guarantee of Origin (GO) scheme for renewables and renewable hydrogen. The design provides flexibility for Australian producers to show they have met various standards or 'buyer requirements'.

Still, a strengthened dialogue between Australian and German stakeholders will help establish a common understanding of appropriate requirements to enable the import of renewable hydrogen from Australia to Germany. Mechanisms for utilizing existing and emerging schemes in the two countries.

Coordination

The HySupply project was an outcome of Germany and Australia's signing of a Joint Declaration of Intent in September 2020. Since then, more bilateral collaborations have also been established including the Hydrogen Sub-Working Group by the Australia-Germany Energy Partnership, the Germany-Australia Hydrogen Accord and its Task Force, the technology incubator HyGATE, the German-Australian Hydrogen Alliance, and the German-Australian Green Hydrogen Crisis Taskforce.

While these initiatives highlight the extensive engagement across a wide range of stakeholders in this collaboration, they are not fully and coherently aligned. This is a potential disadvantage compared to collaboration efforts with other potential trade partners pursing more coordinated approaches between their governments and industries.

We recommend establishing a central coordinating platform for the hydrogen partnership between Germany and Australia, with representatives of the existing initiatives as well as external stakeholder engagement. It should bring together government ministries, industry and research institutions.

This platform could also undertake ongoing monitoring of progress in the partnership with a focus on target setting, tracking activities, assessing their progress, readjusting and setting up new activities as necessary. Regular delegation visits would also assist in supporting and growing the relationship.

HySupply findings in a global context

While these insights from the HySupply supply roadmapping and demand action plans are Australian and German specific, it should be noted that they align well with other work on key actions for driving progress in renewable hydrogen and hydrogen derivatives. The IEA's most recent hydrogen assessment notes that demand creation for low emission hydrogen is a key gap and highlights the importance of creating incentives for using low emission hydrogen to displace fossil fuels.[10] It also highlights the need to support shovel-ready flagship projects to kick-start the scaling up of hydrogen production and the development of infrastructure and manufacturing capacity from which later projects can benefit. Demonstration projects will also help reduce risks for later projects through operational experience. Importantly, demonstration efforts are needed in hydrogen end-user applications in heavy industry, aviation and shipping. Certification and standardisation schemes and regulatory regimes require greater international agreement. Finally, they highlight the importance of cross-sectoral alliances right across the value chain.

[10] IEA, Global Hydrogen Review 2022, 2022.

The 'take home' message

In summary, for Australia and Germany's progress on renewable hydrogen trade, there is much to be optimistic about, but much much more still to be done.

The HySupply project has delivered on its 'fact finding' objectives and the next steps must focus on moving to 'fact making' over the coming two years through scaled up renewable hydrogen projects

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