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FINAL REPORT: Dialogue Outcomes and Recommendations for Action

Australia-EU Green Hydrogen Dialogue
EU Climate Dialogues (EUCDs)

June 2024

Project partners

CLIMATEKIC Australia

GlobH2E
ARC Industrial Transformation Training Centre for the Global Hydrogen Economy

Power Fuels including Hydrogen Network
DECARB HUB

UTS

About Climate-KIC Australia

Climate-KIC Australia was established in 2017 to catalyse climate action through systems innovation.

Recognising that no single organisation or individual can change systems and solve the climate challenge on their own, Climate-KIC works with a broad network of organisations to develop and deliver systems innovation activities. We often play an orchestrating role, leveraging our collaboration network, bringing systems change intent and agency, working with diverse stakeholders using a broad range of skills, capabilities and knowledge that increases the effectiveness and scale of our impact.

Climate-KIC Australia works within the UTS Institute for Sustainable Futures.

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Executive Summary

The Australia European Union Green Hydrogen Dialogue (AUS EU Dialogue) brought together stakeholders across the green hydrogen and derivative value chain across the various jurisdictions and member states, underscoring the pivotal role of renewable hydrogen in the global energy transition. Recognising the opportunity for Australia to become a major exporter of green hydrogen and derivatives to Asia-Pacific and EU, the Dialogue series undertook a series of deep dives on current bottlenecks and explored solutions to unlock this value chain. Common consensus amongst the practitioners and policymakers is that enhanced international and bilateral cooperation is key to create business opportunities and share knowledge on policies, technical, financial, regulatory and sustainability aspects of green hydrogen production, investment and trade. This report synthesizes key outcomes from the Dialogue, providing recommendations for various stakeholders to address challenges and expedite hydrogen deployment.

The AUS EU Dialogue covered the following five main themes:

1. **Scaling Up Green Hydrogen:** Discussing the global state of play and strategies to accelerate production.
2. **Green Financing:** Exploring pathways and state-of-play in financing hydrogen projects.
3. **Supply Chain Challenges:** Addressing design and development issues.
4. **Social Licence and Environmental Impacts:** Enhancing community acceptance and mitigating impacts.
5. **Opportunities Beyond Hydrogen:** Investigating Power-to-X (PtX) solutions.

The key recommendations arising from the Dialogue series can be summarized as below:

1. **Research and Development:** Emphasize collaboration between research sectors and industry to increase the Technology Readiness Level (TRL) of hydrogen technologies, de-risk their uptake, and reduce costs.
2. **Finance and Investment:** Australian Governments should support market-making schemes to align supply and demand prices, enabling participation in initiatives like H2Global and the European Hydrogen Bank.
3. **Multi-level Governance:** Enhance coordination between Australian federal, state, and local governments to develop and upgrade infrastructure, particularly ports and electrical transmission lines.
4. **Certification and Standards:** Ensure interoperability of the Australian Guarantee of Origin scheme with those in the EU and key export markets.
5. **Social Licence:** Involve local communities early in project design to build social licence and share benefits, with support for local firms' participation in large-scale projects.
6. **Sustainable Finance:** Harmonize approaches to hydrogen-related activities in the Australian and EU sustainable finance taxonomies.

The EU-Australia Green Hydrogen Dialogue underscored the importance of co-operation across government, industry, and research sectors. The integration of these efforts will be crucial in overcoming barriers and facilitating the deployment of green hydrogen, contributing to global sustainability and energy transition goals. The report calls for continued dialogue and collaboration to refine these recommendations and adapt to evolving policy measures.

1 Introduction

The **European Union's Climate Dialogues (EUCDs)** project was launched in February 2022 with the following interlinked objectives, to:

1. Facilitate exchanges on climate policy options, expertise, success stories and good practices between the EU and non-EU major economies with a view to informing policy development in partner countries.
2. Advance bilateral trade, investment, and innovation in pursuit of the Paris Agreement goals.
3. Contribute to improving public awareness, including in the business community, of challenges and opportunities associated with the implementation of the Paris Agreement.

The Australia-EU Green Hydrogen Dialogue (AUS EU Dialogue) funded under the EUCD project aimed to facilitate knowledge sharing and increase awareness through dialogue on technical, financial, regulatory and the sustainability aspects of green hydrogen production, investment and trade related to green hydrogen derived from renewable electricity sources both on land and offshore.

The thematic focus of the AUS EU Dialogue covered the technical, financial, regulatory and sustainability aspects of green hydrogen (and derivatives) production, investment and trade, with the specific topics for each Dialogue proposed by the Project Partners being:

- Dialogue #1: Scaling up and accelerating green hydrogen – Global State of Play (held on 20/03/2024)
- Dialogue #2: Green financing of the hydrogen economy – 23/04/2024
- Dialogue #3: Challenges in the design and development of hydrogen supply chain – 04/06/2024
- Dialogue #4: Social licence, community acceptance and environmental impacts – 02/05/2024
- Dialogue #5: Opportunities beyond Hydrogen: PtX – 27/05/2024

These themes were selected to ensure that discussion was held across the complete green hydrogen and derivative value chain. Preliminary conversation with stakeholders indicated that in addition to technology challenges, attainment of social license, importance of securing port infrastructure, securing low-cost finance and access to cheap renewable energy is critical for green hydrogen projects to be cost-effective with fossil fuel counterparts by 2030. Therefore, to address concerns, deep-dive dialogue sessions were carried out on current and emerging green hydrogen production technology and in manufacturing (Dialogue 1), sustainable financing and risks associated with green hydrogen projects (Dialogue 2), access to firmed renewable energy and at low-cost (Dialogue 3) and attaining project social license (Dialogue 4). Dialogue 5 focused on opportunities beyond green hydrogen and derivative production and in end-use in maritime, aviation and steelmaking, sectors which are considered to be impossible to decarbonise without green hydrogen.

These themes are also aligned with recent policy development in Australia and in EU, reinforcing the thematic focus of this dialogue series. For instance, during the period in which the Dialogues were held from March to June 2024, the Australian Government announced several policy and budget measures that related to identified challenges and recommendations for action eg: Future Made in Australia on matters such as renewable hydrogen, low carbon liquid fuels, strengthening standards and streamlining approvals processes for renewable energy projects, finance and investment. The Australian Federal Government also announced the second iteration of the Hydrogen Headstart Program as well as proposing a $2/kg tax credit for hydrogen production in Australia.

Other recent developments in Australia related to the Dialogue thematic areas include:

- Australian Government released the Sustainable Finance Roadmap, setting out its vision for the implementation of key sustainable finance reforms and related measures
- Consultation on options for, and design of, production incentives and other demand side measures to support a domestic low carbon liquid fuel (LCLF) industry, as part of Future Made in Australia.
- Australian Sustainable Finance Institute commenced first round of public consultation on the development of an Australian sustainable finance taxonomy seeking feedback on the Australian taxonomy's environmental objectives, climate change mitigation criteria for the first three priority sectors under development including: electricity generation and supply.

Recent developments in the EU related to the thematic series includes the announcement of European Hydrogen Bank auction results, funding 7 projects at a cost of 720 million euros. Other EU developments included: European Hydrogen Bank announced the design and funding for a second second round of the green H2 subsidy auction; the launch of a pilot mechanism to support the developments of the European hydrogen market through a "matchmaking" service to facilitate contacts between suppliers and potential off-takers of low-carbon hydrogen and its derivatives by 2025, and to collect data from suppliers and off-takers on demand and supply and to identify incoming infrastructure gaps.

In addition to individual developments, this period also saw bilateral agreements between the EU and Australia, one being the Joint Statement on EU Australia Energy Relations by EU Commissioner for Energy Kadri Simson and Minister for Climate Change and Energy, The Hon. Chris Bowen, and the Memorandum of Understanding between the European Union and Australia to co-operate on a bilateral partnership on sustainable critical and strategic minerals.

Dialogue Design

The Dialogue comprised invitation only roundtable discussions with key stakeholders from Australia and the European Union to exchange insights, experiences and good practices, to:

- **Identify Barriers and Opportunities:** Assess the current landscape of green hydrogen production and trade, including technological, economic, regulatory, and market barriers, as well as opportunities for growth and innovation.
- **Share Knowledge and Expertise:** Facilitate knowledge-sharing among participants regarding successful case studies, innovative technologies, and policy frameworks that have effectively promoted the scaling up of green hydrogen production in Australia and EU regions and its end-use.
- **Foster collaboration and partnerships:** Stimulate dialogue and collaboration among stakeholders to forge partnerships, leverage resources, and align efforts towards advancing the green hydrogen agenda at both national and international levels.
- **Develop actionable strategies:** Generate actionable insights and recommendations for policymakers, industry leaders, investors, and other stakeholders to overcome challenges and expedite the transition towards a hydrogen economy.

Five Dialogue sessions engaged participants from business, policy, civil society and academic sectors between March – June 2024, in either hybrid in-person/online or online only format of 2 hours duration. The final session on the topic of '*Opportunities beyond hydrogen – PtX*' was a hybrid public event, which included a presentation by the Project Partners on the interim policy recommendations from Dialogues to-date.

The Dialogue roundtables involved small groups of generally between 15 -30 expert representatives from Australia and the EU, commencing with initial short presentations on the Australian and European Union policy and industry context to provide a lead into the wider discussion of the key issues. Content experts were invited as facilitators or presenters, with dialogue sessions designed to ensure the most relevant actors were represented.

Participants were sent Background Papers in advance of each Dialogue to facilitate discussion, which provided analysis and examples of the EU and Australian policy/regulatory, technical/technological and socio-political aspects and challenges related to the five themes (See Appendix II – Background Papers). Concept Notes were further provided setting out the Dialogue objectives, topic outline, agenda, biographies of facilitators/presenters, participant details and some key issues proposed for discussion.

The Dialogue format successfully facilitated in-depth and impactful knowledge sharing between a diverse range of high level Australian and EU participants including policymakers, relevant industries and companies, civil society and related stakeholders such as investors and technology providers (see Appendix I: Dialogue Participant Organizations).

A final report on Dialogue outcomes and recommendations for action was developed drawing on the insights from the Dialogue Sessions to the main regulatory, technical and any other challenges to green hydrogen deployment, proposing solutions and actions per stakeholder groups to address these barriers to accelerate the production, trade and investment in green hydrogen between the EU and Australia and globally.

In summary, project related knowledge exchange activities were:

- **Dialogue roundtable sessions (4)** on an invitation-only basis with small groups of 15-25 participants
- **Public seminar (1)** with targeted energy sector invitations and presentations by EU and Australian hydrogen industry and policymakers
- **Background papers and concept notes (10)** setting out the key issues per theme, discussion points, presenter bios, participant details and session program.
- **Knowledge Products (5)** with event reports in accessible format developed for wider dissemination setting out the Dialogue discussions and key outcomes.
- **Policy Recommendations Report (1)** reflecting Dialogue session participant suggestions for areas identified for action by key stakeholder sectors.

2 Dialogue Outcomes – Challenges, Barriers and Solutions

The challenges and barriers identified during each Dialogue session and actions proposed to address these by different stakeholder sectors are summarized below:

#1 Scaling and Accelerating Hydrogen Production – Global State of Play

As the global community intensifies its efforts to combat climate change and transition towards renewable energy sources, green hydrogen has emerged as a crucial component of the clean energy transition. The International Energy Agency (IEA) estimates that up to 12% of all final energy demand in 2050 would be supplemented by green hydrogen and its derivatives. With its potential to decarbonise various hard-to-abate sectors, including land transportation, maritime, aviation, steelmaking, industry, and power generation, green hydrogen production holds promise for achieving ambitious sustainability and net-zero targets. However, scaling up and accelerating the production of green hydrogen presents multifaceted challenges that require collaborative and strategic approaches. This scaleup depends on improvements in the cost of hydrogen production as well as policy support, which must also take into consideration the potential barriers to facilitate investment and trade of green hydrogen across the global economy.

The first AUS EU Dialogue saw opening presentations on the European Union and Australia context and the state of play of the green hydrogen economy in each jurisdiction, to provide industry and policy perspectives on the facilitation of investment and assistance to reduce technology costs, foster coordination and common goals across the hydrogen value chain.

Presentations were provided by:

- Leigh Kennedy, General Manager – Industry and Supply Chain Development, Australian Hydrogen Council
- Mirela Atanasiu, Executive Director (ad interim), European Clean Hydrogen Partnership
- Rebecca Thomson, Director, Hydrogen Guarantee of Origin and Trade Section, Department of Climate Change, Energy, Environment and Water (DCEEW)
- Siobhan McGarry, Policy Officer, DG GROW (Directorate-General for Internal Market, Industry, Entrepreneurship and SME's) European Commission
- Thilo Krupp, Advisor for Hydrogen and Decarbonisation, Environmental and Climate Affairs, Ministry of Economic Affairs, Ports and Transformation, State of Bremen, Germany
- Agnese Dagile, Team Leader for International Relations, DG ENERGY European Commission

Discussions focused on the topics of:

1. Facilitating investment and assistance in reducing technology costs and improving performance through support for research, development, and demonstration (RD&D), tax incentives as well as setting manufacturing or deployment targets, and other de-risking mechanisms.
2. Fostering coordination and common goals along the hydrogen value chain, across borders, across relevant sectors and between stakeholders, including establishing regulations, common standards, and certification schemes.

3. Essential role of ports and associated infrastructure in enabling a hydrogen economy in both exporting as well as importing countries.

Summary of Discussions

Support for Research and Development

The importance of coordination in research and development and demonstration was highlighted by the EU Clean Hydrogen Partnership, which is the partnership of the European Commission with private associations comprising more than 550 industries/companies and 150 research organizations or academia. The Partnership has supported over 370 projects, with €1.6 billion in funding over the past 15 years, of which a considerable portion goes beyond university and research institutions to support start-ups and industry. Funding is also distributed across the value chain, with 33% being provided towards the end use of hydrogen in transportation and 18% for use of hydrogen in clean heat and power generation projects.

In hydrogen production, a key focus of funding is green electrolysis with other pathways such as biomass reforming, direct splitting of water using sunlight (photocatalysis) and renewable waste to hydrogen projects also being explored. In recent times, anion exchange membrane electrolysis and solid oxide electrolysis has received considerable attention, with a research theme for alkaline electrolysers being pressure management.

The EU adopts a technology agnostic approach to green hydrogen production and funding for research and emerging technology programs which are developed through co-design with industry. It was recommended that Australia adopt a similar approach to its hydrogen R&D funding schemes.

The EU Clean Hydrogen Partnership has since 2019 funded the global Hydrogen Valleys initiative for collaboration and information on innovative large scale flagship projects. Of the 91 Hydrogen Valleys listed on the H2V platform across some 34 countries, 60 are located in Europe and four in Australia. The aim of the Hydrogen Valleys Platform is to promote the emergence and implementation of value chain integrating hydrogen projects and to facilitate international collaboration and information for project developers.

Questions were raised by participants on the viability of liquid organic hydrogen carriers (LOHCs), which are receiving considerable attention in Europe but not considered in Australian hydrogen projects. In Europe, some companies are presenting the business case for LOHC for funding, but project developers and technology suppliers in Australia have indicated that LOHCs are currently not cost-competitive with ammonia, the prevalent hydrogen carrier, albeit they may be more viable than liquified hydrogen for long-distance shipping of hydrogen.

Manufacturing Scaleup

A key EU focus has been on technology scaleup, which has seen a recent increase in the scale of EU electrolyser deployment. For example, the first trials for the deployment of high temperature electrolysis within Neste Biorefinery in Rotterdam, Netherlands in 2015 were for 150 kW, which by 2019 scaled up to 2.4 MW.

The scaling up of localized manufacturing capacity has been a strategic focus for the EU. The EU has a target of approximately 100 GW of electrolyser capacity by 2030, with a further target of 25 GW per year of manufacturing capacity by 2025. The EU Electrolyser Partnership was established to tackle this challenge and coordinate collaboration, comprising 20 European electrolyser manufacturers as well as 24 companies across the supply chain. As a result, the manufacturing capacity in the EU of electrolysers has been reported to be ~21 GW per year by 2025, a considerable feat considering that the manufacturing capacity in 2022 was less than 2.5 GW per year. Considerable funding supports electrolyser and component manufacturing in EU, such as the €1.4 billion in the Innovation Fund for clean tech manufacturing. However, inflationary pressures were eroding some of the gains arising from economies of scale for hydrogen electrolyser manufacturing. The EU has also ratified the Net-Zero Industry Act which mandates 40% of clean technology used in Europe has to be locally manufactured by 2030.

Existing EU-Australia Partnership

The Australian Hydrogen Council highlighted the number of EU companies involved in the hydrogen industry in Australia, including both as project developers as well as technology providers, such as BOC, Iberdrola, Thyssenkrupp, Engie, Siemens, Yara, Air Liquide and others. For example, technology provider BOC is working alongside ATCO to develop hydrogen based peaking power generation as part of a South Australian government supported project. Similarly, the Abel Energy Bell Bay Methanol project is using Thyssenkrupp technologies. And it was further noted that European capital is also involved in the financing and investment of many Australian projects.

With export being the focus for the majority of Australian hydrogen projects, it was noted that EU off-take would play a pivotal role in shaping Australia's hydrogen economy. Unlocking demand and off-take agreements remains key, which could be assisted through a mechanism such as H2Global to support international business collaboration and exchange across the hydrogen value chain.

Critical Role of Ports and Hubs

The critical role of ports and hydrogen hubs (or hydrogen valleys as referred in EU) was highlighted by presentations and in discussions during the Dialogue. As is the case for the Port of Rotterdam, the German federal state of Bremen, with its ports and infrastructures, will be a key hub of the European Hydrogen backbone and the German hydrogen core network. Given that Germany expects to import the majority of its future hydrogen demand, the development of import infrastructure at its ports is crucial.

However, there are challenges associated with the build-up of hydrogen import infrastructures in the ports, such as: (1) space limitations leading to competition with other potential uses such as offshore wind, and especially (2) insufficient financing of port infrastructure, which is an issue for all major German sea ports.

It was suggested that collaboration between hydrogen importing/exporting ports in the EU and Australia could provide opportunities for knowledge exchange on good practices and standards for handling hydrogen and derivatives, particularly ammonia, which is becoming the carrier of choice for global export-focused hydrogen projects.

As the majority of the shortlisted/announced projects under the Australian Hydrogen Headstart and regional hydrogen hubs programs were around existing port locations, the need to develop port infrastructure for hydrogen exports would likely be reduced in Australia.

Government Initiatives

The range of enabling government policies in both Australia and EU were outlined by the respective government speakers. The Australian Net Zero Authority has been established to co-ordinate and support Australia's commitment to 43% emission reduction by 2030 and to reach net-zero by 2050. The 2019 National Hydrogen Strategy was recently reviewed to reflect three key changes: (1) Enhanced focus on domestic decarbonization, (2) updates on international developments following growing global policy support, and (3) a focus on domestic value-adding, given high shipping costs.

Initiatives in growing Australia's hydrogen industry include (1) $2 billion Hydrogen Headstart program, (2) $0.5 billion in hydrogen hub initiative, (3) $38 million Guarantee of Origin scheme, (4) national hydrogen infrastructure assessments, (5) legal frameworks reviews, (6) First Nations Clean Energy Strategy and (7) a review of skills and training. Currently, 15 projects have reached FID, with a combined investment of A$225 billion. The Australian government is actively pursuing numerous hydrogen partnerships including Singapore, Germany, South Korea, Japan, India, USA, UK and Netherlands.

In the EU, the focus has been on market development for hydrogen, with priorities in the decarbonization of existing hydrogen use cases, such as fertiliser production, followed by decarbonization of hard-to-abate sectors that cannot be directly electrified (such as steel and long-distance transport). As the demand for low-carbon hydrogen is expected to grow significantly by 2050, EU has adopted numerous policies including (1) definition of renewable fuels of non-biological origin, (2) methodology to assess greenhouse gas emissions savings including Renewable Energy Directive (voluntary scheme), (3) domestic auctions for import of hydrogen. EU priorities for international collaboration include supporting decarbonization and the energy transition in partner countries (signing up to 10 MoUs), setting up frameworks for a functioning and global rules-based hydrogen market, and reducing EU supply uncertainty to develop industrial supply chains at competitive prices.

Participants raised questions about the EU policy on green ammonia, this being a policy focus proposed in the next EU mandate. It was noted that Australian green ammonia producers were raising concerns that consumers are not ready to pay green premium, whereas the European farmers are yet to raise any concerns or objections to this. It was recommended that lessons be drawn from the green steel market in Germany, where buying green steel was found to increase cost of cars only nominally.

Standards and Certification

A major discussion point during the Dialogue was the issue of hydrogen certification and the need to ensure that EU and Australian Guarantee or Origin (GoO) certification schemes were coherent and interoperable. Given that the Australian scheme is still under development, it was recommended that the scheme be designed around the regulatory settings of numerous overseas markets (including Asia-Pacific and Europe).

Australia is a participant in Mission Innovation and multilateral forums such as the International Platform on Hydrogen Energy (IPHE), to ensure coherence in certification schemes. In Europe, certification schemes are voluntary, and it remains yet to be seen how this will shape up in the next few years. Questions on the suitability of using carbon based synthetic fuel from a sustainability certification perspective was raised, an issue that has implications for social acceptance.

Key Discussion Outcomes

1. Research and Development is being supported in the EU with funding distributed across the value chain, in the private sector, at universities and research institutions, and at start-ups. Funding is technology-agnostic and is allocated towards technologies of both high and low TRL. Funding projects are co-designed with industry.
2. Technology Scaleup in the EU is mostly focused on scaling electrolyser production and deployment, especially on achieving local manufacturing capacity. A partnership of manufacturers and other companies across the supply chain is being established.

3. The Australian Hydrogen Economy can be unlocked through EU offtake agreements, that will provide a demand for the local production of green hydrogen. Initiatives such as H2Global can play a role to assist in matchmaking.
4. Ports and Hubs are crucial infrastructures for the hydrogen economy. Challenges for implementation include lack of space and competition with other uses, as well as access to financing (for port infrastructure). Engagement and collaboration is proposed between Australian and EU port initiatives to share knowledge and practices, for example, the North Sea Hydrogen Valley Ports and Ports of Rotterdam, Flanders and Bremen and the Hydrogen Valleys program.
5. Enabling Policies in the EU and Australia should include investment and market development for hydrogen in hard to abate sectors such as fertiliser production. Concerns have been raised by ammonia producers of consumer reluctance to pay green premium for ammonia, however car manufacturers such as BMW have shown that they are willing to pay for green steel. Policy should further define aspects such as what constitutes renewable fuels of non-biological origin (RNFBOs).
6. Certification Schemes have been and are in development in the EU and Australia. It is important for mutual recognition and coherence between these schemes, which must also be designed to facilitate export to markets which may not have such a scheme in place. It was noted that the EU has adopted voluntary schemes to assess greenhouse gas emissions for hydrogen production.

#2: Green Financing of the Hydrogen Economy

Despite considerable financing commitments around the world, challenges remain for financing hydrogen and derivative projects. This is reflected by the typical high weighted average cost of capital (reflection of project risks) associated with hydrogen and derivative projects, which poses challenges around securing offtake agreements, as well as the technical integration challenges and safety and social license considerations. Early hydrogen projects in both EU and Australia (and to date) have required de-risking by governments through government grants and underwriting with large institutional organizations such as sovereign wealth funds and cross-border financing only recently entering the market. There is also public criticism about oil and gas companies transitioning to blue hydrogen projects, which are seen as ‘greenwashing’ initiatives. The environmental sustainability and economic returns of such investments are also a concern, with most hydrogen projects still in the front-end engineering and design (FEED) phase and not yet having achieved the final investment decision (FID).

To ensure more planned projects are proceeding towards FID and construction, both EU and Australian Governments are providing funding support, such as through the Hydrogen Headstart program in Australia that is funded by the Australian Federal Department of Climate Change, Energy, the Environment and Water (DCCEEW), and the Australian Government’s $2/kg tax credit for green hydrogen production, Germany’s H2Global reverse auction scheme, and green bonds such as those supported by European Commission. This complex discussion ties in with financing challenges raised in Dialogue #1 and with concepts introduced in Background Papers on social licence and renewables.

The second Dialogue heard from EU and AU participants on green financing pathways and state of play in their respective jurisdictions, insights and perspectives on the unique challenges of financing hydrogen projects, the role of sustainable finance taxonomies, and the need to foster co-ordination and common goals across the hydrogen value chain.

Presentations on the EU and Australian context were provided by:

- Johanna Schiele, Innovation Fund, DG Clima, European Commission
- Matt Walden, Partner, Climate and Sustainability, Deloitte
- Marie Espitalier-Noel, Manager, Funding and Financing, Hydrogen Europe

The major focus of discussions was around the following topics:

1. Key financing issues for the de-risking of hydrogen projects and deployment challenges
2. Role of government and subsidies in mitigating such risks and to close the commercialization cost gap
3. How social license and certification schemes will guide decision making for hydrogen project investments.
4. How do we ensure there is co-ordination and coherence in developing sustainable finance taxonomies between EU and Australia in respect of hydrogen related activities.

Summary of Discussions

Supply Side Developments: Deployment Gap and Industry Positioning in Australia

While it is accepted that hydrogen will play a key role in the decarbonization of hard to abate sectors, the question ultimately boils down to “by how much” and “by whom”. Lack of concrete off-takers in certain markets and the price gap between what buyers are willing to pay and the price sellers are able to deliver hydrogen and derivatives is a key issue for the development of the hydrogen industry.

Large-scale production and export would decrease this price gap, although inefficiencies resulting from varying government priorities can arise for instance where governments may emphasise the development of blue hydrogen projects while others may emphasis green production. Governments are also making trade-offs as part of overcoming the deployment gap, in deciding between cost optimization and project diversity and how much support to offer export projects given the limited domestic decarbonization benefits.

Several announced projects, spanning from small scale to export scale, have not progressed to final investment decision (FID) stage due to risk allocation concerns. Early projects often assume risks and then seek grants to mitigate them. The Hydrogen Headstart Initiative, administered by the Australian Renewable Energy Agency (ARENA), stands as a cornerstone of Australian Government funding efforts. The participants noted that whilst challenges in hydrogen project financing are not novel, they however are diverse, mirroring risk allocation issues encountered by other industries such as early investments in solar, which necessitated government support.

Properly navigating these risks was paramount, especially considering the integrated landscape of risks, such as infrastructure, land and the pivotal role that state governments in Australia play in mitigating these risks. Lessons from the development of the Australian renewable electricity sector emphasized the necessity of early stakeholder group identification and engagement, specifically for social license and regulatory compliance.

Co-ordination and integration across complex hydrogen supply chains was required between multiple levels of government, industry, investors and infrastructure providers to develop the required physical and market infrastructure. Hydrogen supply chains were highly differentiated involving multiple site facilities, local planning and approvals, generation and storage technologies, heavy vehicle transport or pipeline transmission, desalination and waste-water treatment, and port and shipping facilities. The diverse range of stakeholders at each stage consequently need to be identified early in the development process to bring these along the supply chain development and hydrogen production journey.

Buyer Side Developments: Funding Mechanisms, Offtakes and Auctions

Scaling up investments in clean hydrogen production was an imperative for the long-term viability of the hydrogen industry. Estimates indicate that Europe will require between EUR 1.2-2.6 trillion for renewable hydrogen (and value chain) projects in Europe by 2050, while globally, the figure could range from EUR 6-30 trillion. Various EU funding mechanisms, from Horizon Europe to the ETS Innovation Fund, support projects from proof of concept to rollout.

New market-making schemes such as the Inflation Reduction Act (IRA) in United States and the SIGHT Program in India, along with initiatives like Hydrogen Headstart in Australia, aim to support both supply and demand. The H2Global initiative similarly supports and matches both demand and supply. However, challenges remain in establishing fixed offtake prices amidst fluctuating market conditions, addressed in part by EU taxonomy developments to combat greenwashing and redirect finance to sustainable activities. There is a further imperative to have clear rules of the game for project promoters and developers to reduce regulatory risk, in terms of a definition of renewable hydrogen and harmonized standards.

The European Hydrogen Bank conducted its inaugural pilot auction on August 29th, 2023, allocating funds from the EU Innovation Fund of EUR 800 million to green hydrogen projects. The auction reviewed 132 bids from various hydrogen initiatives. Projects participating in the auction were subject to a price ceiling of EUR 4.5 per kg of hydrogen, with a stipulated development timeframe of 5 years, with project bidders obliged to provide a deposit. Failure to meet these conditions would lead to forfeiture of the bid. The pilot auction scheme sought to streamline administrative processes for member states, including prequalification checks of participants. It was noted that Germany is contributing an additional 300 million euros towards this initiative, demonstrating a blueprint for integrating national and EU funds.

Sustainable Finance Taxonomy

Globally harmonized standards as part of sustainable finance taxonomies were imperative for further investments into green hydrogen and derivative projects. The Dialogue participants discussed the high degree of alignment between the way hydrogen is treated in the EU and in Singaporean/ASEAN taxonomies and the Australian taxonomy currently being developed. The emerging Australian finance taxonomy will propose technical criteria that cover measures and emission boundaries, including hydrogen in the mining and minerals sector where electrification is not feasible, such as heavy vehicles and in minerals processing.

Activities covering the hydrogen value chain will be addressed under (and dispersed across) several industry sectors in the Australian taxonomy, but most prominently in the manufacturing and industry sectors. The Australian sustainable finance taxonomy is being developed by the Australian Government and the Australian Sustainable Finance Institute in close collaboration with the EU Platform on Sustainable Finance and the Climate Bonds Initiative to ensure there is interoperability and credibility between how the EU and Australia taxonomies consider hydrogen related activities.

It was noted that the EU's taxonomy imposes obligations on large companies and member states to ensure that their funded activities adhere to environmental sustainability standards and alignment with the six environmental objectives, which encompass:

1. Climate change mitigation,
2. Climate change adaptation,
3. Sustainable use and protection of water and marine resources,
4. Transition to a circular economy,
5. Pollution prevention and control, and
6. Protection and restoration of biodiversity and ecosystems.

CBAM: Carbon Border Adjustment Mechanism

The EU CBAM scheme prices carbon content in imports based on the weekly EU carbon price, encompassing iron, steel, cement, aluminium, ammonia as fertilizer, electricity, and hydrogen, but excluding hydrogen derivatives. Plans are in place to assess and gradually expand to additional industries, with a phased approach.

The CBAM mechanism is expected to trigger a "race to the top" on the international scale.

To remain competitive, nations may need to adopt their own CBAM mechanisms, thus fostering a global movement towards higher environmental standards. The internalization of the real costs of CO_2 in fossil fuels was a pre-requisite for a sustainable green hydrogen market, as ongoing subsidies were neither politically nor financially sustainable. It was suggested that development of an Asian CBAM scheme to create the international trade price signal leveraging and reinforcing the EU CBAM, would incentivise further embedding of renewable energy (and hydrogen) within Australian industry and export sectors.

Project Finance challenges

Private finance, particularly equity finance, has seen involvement from entities like Copenhagen Investment Partners (CIP) in Australia, although debt financing has faced challenges according to a 2023 report by the Boston Consulting group (BCG). Challenges include securing long-term offtake agreements, proven technology, clear industry and regulatory standards, and the need for established markets. To unlock asset finance, additional support for demand (offtake) is necessary, including allowing producers to lock in long-term contracts and providing blended finance support.

While green bonds were effective at a corporate level, diverse sources of finance, including export credit agencies (ECAs), commercial debts, grants, and government support are deemed essential to the management of risk allocation and development of green hydrogen projects. There was a role for more flexible government investment in large scale hydrogen projects eg: such as special investment funds at the federal level that take a cornerstone position in the project finance structure and a larger and longer-term role with more flexible and potentially concessional terms.

Additionally, land use and supply chain risks (such as electrolyser ordering time and electrical connection issues) pose significant challenges to project viability, prompting calls for cross-sectoral and national coordination and a cohesive national strategy. In the face of international competition, collaboration by 'Team Australia' was crucial, with state governments needing to ensure a level playing field for electricity, ideally priced at $40/MWh.

Greater focus on technological advancement i.e.: Technology Readiness Level (TRL) progression was imperative, as there is potential for a backlash if technologies are “oversold” and do not meet hydrogen and other industry expectations. With hydrogen demand profiles/distribution strategies being heterogeneous, and global demand still weak, it was a challenge for manufacturers to test at scale for each application/usage/distribution eg: in terms of electrolyser deployment.

In comparison, the LNG industry had not been based on a ‘build it and they will come’ approach, rather dedicated supply infrastructure was built to deliver on pre-determined contracts between the suppliers and consumers which enabled asset utilization and optimization across the supply chain in terms of production, storage and shipping. In the case of the hydrogen sector, it was questionable whether offtake agreements adequately underpin the end-to-end build of infrastructure from source to consumption and guarantee low cost and reliability of supply and the optimum utilization of infrastructure.

Cross Border Finance: How can this be enhanced?

There has been a growing emphasis on the Asian market, given the long freight distance to Europe. In terms of finance, export credit agencies have a role to play, already financing two-thirds of debt for sectors such as iron ore and LNG, an aspect that is occasionally overlooked.

Concerns persist around technology, with hopes for improved process operation data to enhance bankability. Moreover, industry is under mounting pressure to increase onshore processing and manufacturing, especially in the context of green iron and steel production, indicating a broader shift towards onshore embodiment of sustainable practices. The notion of embedded minerals further raises issues whether the EU might consider relocating segments of its value chain to Australia.

Queries were raised around the risk implications of an increased focus in industry policy on sovereign manufacturing capability of critical cleantech technologies including those involved in hydrogen production, storage and use, and whether this placed additional risk on projects and the risk appetite required from governments.

Key Discussion Outcomes

1. Green hydrogen projects, spanning from small to export scale, face challenges in progressing to commercial decision (i.e. FID) due to risk allocation concerns. Risk factors were multifold and diverse, ranging from technology, offtake agreements, land availability, and supply chain risks. A national approach to co-ordination across supply chains was called for to identify and mitigate these risks and to overcome deployment challenges.
2. Government support was critical to the commercial viability of hydrogen projects, with new market-making schemes like the US IRA, EU Hydrogen Auction and the SIGHT Program in India, along with initiatives like Hydrogen HeadStart in Australia, required to support and match both the supply and demand side.
3. Diverse sources of finance were essential to the management of risk allocation and development of green hydrogen projects, including more flexible, larger and longer-term government investment in large scale hydrogen projects eg: such as special investment funds.
4. Interoperable sustainable finance taxonomies between the EU and Australia were critical to facilitate further investment into hydrogen and derivative projects.

6. The Carbon Border Adjustment Mechanism (CBAM) introduced in the EU could trigger a "race to the top" on the international scale, as to remain competitive, nations may need to adopt their own CBAM mechanisms, fostering a global movement towards higher environmental standards and creating an international trade price signal leveraging and reinforcing the EU CBAM.
7. A greater focus on technological advancement i.e.: Technology Readiness Level (TRL) progression across the supply chain was imperative to meet hydrogen and other industry expectations.

#3 Challenges in the Design and Development of Green Hydrogen Supply Chains

Challenges in green hydrogen production and the scaling up of the solar and wind resources required as part of the green hydrogen supply chain, include firming issues for renewable energy and how capacity factor can be increased sustainably, transmission challenges, social license related to solar and wind infrastructure, financing and regulatory challenges for renewable projects. The upstream and downstream renewable energy infrastructure required for hydrogen supply chains presents further challenges, which could impact scalability and therefore economic performance of green hydrogen production, including: upstream: utility scale renewable power generation – mainly solar and wind – requires access to land for power plant(s). Furthermore, the equipment for power generation (solar PV modules, wind turbines etc.) and hydrogen production (electrolyser) must be accessible within the region of hydrogen production, which could raise challenges especially in remote areas of Australia. Whereas downstream - once produced, the hydrogen must be transported to the point of use – either to industry customers such as the iron and steel or chemical industry or via distribution networks such as pipelines or ports. The utilization of local renewable energy resources for hydrogen production will reduce potential electricity production for domestic electricity usage, that could negatively impact public acceptance for utility scale solar and or wind projects.

The third Dialogue featured presentations from EU and Australian participants, who emphasized the need for greater co-ordination of green hydrogen and its derivatives across value chains. Participants discussed their experiences and shared lessons from the perspective of renewable energy production and manufacturing in the context of scaling up the green hydrogen economy, highlighting lessons from project developments and the challenges in developing global supply chains.

Presentations on the EU and Australian context were provided by:

- Dr Sven Teske, Research Principal, Institute for Sustainable Futures, University of Technology Sydney
- Martijn Coopman, Program Manager, International Hydrogen Supply Chains, Port of Rotterdam
- Arthur Daemers, EU Policy Manager, Renewable Hydrogen Coalition
- Mox Murugan, Business Development Director for Hydrogen, Nordion Energi
- Dr. Amy Philbrook, Australasia Hydrogen Technical Lead, ARUP
- Jorge Garcia Martinez, Green Hydrogen Business Development, Iberdrola Australia
- Kiran Ranbir, Manager – Hydrogen and Clean Fuels Development, ATCO.

The session was moderated by Liz Boylan, Partner, Energy and Climate Deloitte

The discussions focused on the topics of:

1. Australia’s renewable energy potential and potential to generate green hydrogen and derivatives
2. Challenges in developing new value chains, focusing on international trade
3. Technological impact on value chain development
4. Opportunities for developing shipping value chains with the EU

Summary of Discussions

Australia’s renewable energy potential

Australia boasts significant renewable energy potential, particularly in solar and wind power. Moreover, the country’s vast landmass and high solar radiation make it an ideal location for large-scale solar projects. Additionally, Australia’s onshore wind potential is estimated at 2000 GW, with particularly strong prospects in the southern regions (from Brisbane downward), with wind energy potentially serving as a baseload power source in some areas.

Acknowledging this potential, the Port of Rotterdam (as well as other EU entities) recognise Australia as one of the top ten countries with significant renewable hydrogen production potential. For instance, Western Australia's Midwest coast, particularly the Oakajee region, shows a promising overlap of solar and wind resources, making it a prime location for green ammonia production at a lower cost than all other locations considered by the Port of Rotterdam.

Challenges in developing new value chains

Dialogue participants discussed the challenges arising from community acceptance and grid infrastructure limitations in Australia, which present barriers for large-scale renewable project development. It was noted that the acceptance for wind energy in Australia is not as high as in Europe with Australia only recently embarking on offshore wind developments.

Secondly, the majority of Australia’s renewable energy potential is in regions far from the coast and accessible water, therefore requiring renewable electricity to be transmitted to regions with ports for export, and necessitating development of major transmission infrastructure. Development of transmission lines however presents considerable challenges, which include land accessibility issues as well as the high costs given the large distances involved. Addressing these challenges was crucial to fully realising Australia’s renewable energy potential and transitioning to a green hydrogen economy.

The development of dedicated renewable energy assets and robust infrastructure was highlighted as key to overcoming these obstacles and capitalising on Australia's substantial renewable resources. Supply chain challenges also extend to post-hydrogen and derivative production and related shipping, with initiatives such as the green corridor agreement with Singapore being crucial for establishing efficient supply chains.

Water was an oft neglected resource in planning hydrogen projects, both as a feedstock for electrolysis as well as for use in hydrogen plants, raising issues as to water quality and the availability of water sources such as seawater, groundwater and wastewater. A further issue in the development of supply chains that has implications from a social licence perspective, was that wind power infrastructure was increasing in scale with ever bigger turbines being developed.

An example of a regional and integrated approach to system and infrastructure planning across the supply chain was by the Hunter Hydrogen Taskforce, involving all those with critical inputs including utilities for water and electricity, project proponents, industry, ports, and research, to co-ordinate and advise government and the private sector on shared infrastructure requirements for hydrogen production scaling and export. Similarly, the Port of Rotterdam, as a shareholder in port facilities has been able to catalyse the development of the supply chain to Europe for a major export hub in Brazil.

Incentivizing demand from off-takers for green hydrogen and derivatives is critical for unlocking the supply chain. An example of the green steel industry was provided, where the development of green iron (as hot briquetted iron (HBI)) is being seen as a promising method for nations with large iron ore reserves and renewable energy potential to export this renewable energy in the form of value-added products. However, one of the challenges associated with the development of such a supply chain is not the green premium associated with these products, but instead the fact that as this market develops, only a few suppliers will be able to provide HBI. Steelmakers would be apprehensive to rely only on one or two key suppliers of HBI, as this opens them up to commercial risk, preferring to import raw materials and produce value-added products themselves.

Innovation impact on value chain development

The future of hydrogen exports from Australia hinges on technological innovation and strategic infrastructure development. Developing necessary infrastructure, such as new ports, remains challenging. Innovative solutions like floating ammonia terminals are being considered to overcome these logistical hurdles. However, there is a risk that current and planned infrastructure investments, such as those for ammonia or methanol, may become obsolete with new technologies (e.g., advanced hydrogen storage). This highlights the need for value chains to be technology-agnostic, welcoming new technologies and innovations to optimise the hydrogen value chain as they emerge.

Opportunities for developing value chains with the EU

The EU is considered at the forefront of green hydrogen regulation, encouraging trading nations to adopt similar regulations and protocols to ensure their products meet the same "green" standards when imported into the EU market. The EU market currently presents huge opportunities for renewable energy supply chain development, especially for nations looking to capitalise on these opportunities. The EU is not only considering energy imports from nations that can provide reliable energy but also from those with similar democratic values. This presents huge opportunities for nations such as Australia to develop new trade relationships with the EU, as they seek to do more business with nations which hold similar democratic values.

Key Discussion Outcomes

1. Australia possesses significant renewable energy potential, particularly in solar and wind power, making it ideal for large-scale green hydrogen projects.
2. Despite high potential, challenges such as community acceptance and limited grid infrastructure (and in some cases, limited port infrastructure) hinder scaling up hydrogen production and exports in Australia.

4. Encouraging both production and demand for green hydrogen and its derivatives is crucial to developing these value chains. Challenges in the green steel industry highlight the importance of diversifying suppliers and mitigating commercial risks.
5. The future of hydrogen export hinges on technological innovation and strategic infrastructure development. Investments in infrastructure must be adaptable to accommodate emerging technologies to optimise the hydrogen value chain.
6. The EU's leadership in green hydrogen regulation presents significant opportunities for trade, particularly for nations like Australia. The EU seeks to do business with nations sharing similar democratic values, providing avenues for developing new trade relationships and renewable energy supply chains.

#4 Social Licence, Community Acceptance and Environmental Impacts

As the global hydrogen economy ramps up with more projects being announced, it is critical to also ensure that these projects are developed in a sustainable manner that is acceptable to all. Key to this is attaining social license and community acceptance as well as ensuring that the hydrogen and derivative projects have minimal environment impact. Such attainment of public acceptance is now a requirement for project approval and from consumers and investors. This complex discussion also ties in with standards and certification challenges explored in Dialogue #1 on '*Scaling and accelerating hydrogen - global state of play*'.

Presentations from both EU and Australian participants highlighted the importance of gaining social license for renewable energy and hydrogen projects, elaborating on international methodologies and processes involved in gaining community acceptance, and sharing their insights and perspectives on the themes of environmental and social dimensions of the energy transition.

Presentations on the EU and Australian context were provided by:

- Dr. Antti Arasto, Vice President, Industrial Energy and Hydrogen, VTT Technical Research Centre of Finland
- Dr. Stefanie Baasch, Senior Researcher, artec Research Center for Sustainability, University of Bremen
- Professor Roberta Ryan, Executive Director, Institute for Regional Futures, University of Newcastle
- Bridget Ryan, Director Policy and Industry Engagement, RE-Alliance

The discussions focused on the topics of:

1. Social license and community acceptance for new technologies and the need for a just transition
2. The drivers and barriers of social acceptance of the hydrogen economy
3. The role of standards, certification, and subsidies in social licence and community acceptance
4. The role of the state in facilitating collaboration and engagement across multiple levels of government, private actors and local and regional communities.

Summary of Discussions

Social license and community acceptance for new technologies and the need for a just transition

Historically, energy transitions have not been implemented fairly or equitably, fostering new inequalities amid emerging changes. Mere labeling of initiatives as "clean" or "green" does not inherently ensure fairness or justness. This is evidenced by ongoing conflicts over land and natural resources in Northern Europe related to solar, wind, and green steel projects, which raise concerns about biodiversity, noise, and visual disturbance. Within the same communities, in many regions there can be both supporters and opposition, as illustrated by the case of a wind farm development in Finland.

A significant issue is the geographical disparity in the distribution of benefits and burdens; while coastal regions may benefit from renewable hydrogen projects, other areas may suffer from the closure of fossil fuel plants. Thus, the imperative lies in achieving a just transition, sharing both benefits and burdens equitably. Central to this are considerations of social acceptance, understanding the drivers and barriers, and prioritizing Diversity Equity and Inclusion (DEI) concepts to address all relevant needs and perspectives.

Urgent reskilling initiatives are also needed to prepare the workforce for evolving demands, especially in regions facing disruption from new technologies. Furthermore, workforce shortages in Europe, exacerbated by an aging population, present challenges for clean energy integration.

Stringent project financing processes are needed which incorporate considerations of First Nations' interests, social license, and thorough risk assessments and evolving financing strategies that emphasize the importance of national guidelines - such as those being developed in Australia for transmission projects - to streamline social license procedures. An industry-led and community-informed framework has the potential for balanced decision-making and the fostering of trust among stakeholders.

The drivers and barriers of social acceptance of the hydrogen economy

To attain social license for renewable energy projects, a sophisticated and evidence-based approach is essential to ensure future-proof decisions. This involves systematically identifying social license through co-creation with customers, municipalities, and government ministries. Benefit sharing and community participation in decision-making are crucial, drawing lessons from successful models in Germany where co-operation with municipalities has led to high public approval rates (rated to be above 80%) for renewable projects. Texas also stands out for its leadership in renewable projects, promoting the use of benefit sharing and prioritizing economic benefits over philosophical issues. A key lesson learned is the positive impact of awareness and knowledge sharing by communities and project developers.

In Australia, an educational, communicative, and coordinated approach is advocated, focusing on place rather than specific activity or infrastructure. Challenges include governmental understanding of overlapping agency efforts (specifically at state government level) and community concerns and aspirations for the energy transition, which necessitates deep engagement and project-based benefit sharing.

Co-investment and co-ownership models, though challenging, have proven successful in various Australian projects. Further, federal government investment in regional hydrogen hubs and clear communication about energy transition projects are vital for fostering long-term perspectives and strategic benefit sharing.

Community concerns about safety are increasingly significant, especially regarding the production, use, and transportation of hydrogen and its derivatives. Regulations governing these aspects are vital for ensuring the safe implementation and operation of such facilities. For instance, Orica's investment in the development of the Hunter Valley hydrogen hub has sparked community concerns about the use of ammonia and ammonium nitrate. To address these concerns, initiatives such as site tours, community education programs, and collaborations with local universities are crucial for demystifying safety issues and building trust in safety measures. These efforts aim to foster transparency and open communication can enhance safety perceptions and interactions between the community and project proponents.

Water

Additionally, water plays a critical role in hydrogen production, with its importance varying depending on the area. Water security is an increasing concern, due to population pressures and climate change. As one of the key inputs, the water requirements of any region will dramatically change where hydrogen is produced and can lead to community water restrictions. Community perceptions can impact social licence which affects whether projects proceed, with hydrogen often perceived as exporting water for the use of others. For example, there has been strong community engagement as part of developing a plan around water security in the Hunter Valley, with several options considered for hydrogen use including desalination, recycling, surface and groundwater. Different communities will have different options, with early engagement and partnering with the water utility as a trusted partner in the region a key part of developing positive and sustainable water solutions for hydrogen production.

The role of standards, certification, and subsidies in social licensing

National standards and certification in obtaining social license for renewable energy and hydrogen projects is crucial. Communities are particularly concerned about the fate of projects after their operational lifetime in terms of end-of-life waste and recycling, expecting developers to maintain visibility and engagement over project lifecycles. Having relevant standards and certification processes in place could ensure these requirements are met and adhered to.

Hydrogen subsidies and the reliability of the legal and regulatory frameworks are also significant concerns, not only at the community level but also for project funding and access to long-term capital. These factors affect the financial viability and stability of hydrogen projects, impacting their attractiveness to investors and the overall feasibility of implementation.

The role of the state in facilitating collaboration and engagement across multiple levels of government, private actors, and local and regional communities

The role of local and state governments is critical for facilitating the social license for energy projects. Local government is a key stakeholder providing public infrastructure and services. They can provide local knowledge and access to community networks. However, councils are usually not the consent authority and local impacts may not be addressed sufficiently through the approval process. As hydrogen projects will develop across state borders and local government areas, collaboration is essential for success, there is a need for state governments to develop co-ordination initiatives such as Queensland's establishment of a Gas Commission, reflecting the importance of government action in fostering social acceptance and co-operation within communities.

Key Discussion Outcomes

1. Energy transitions historically have lacked fairness, necessitating a just transition for equitable distribution of benefits and burdens. A systematic and comprehensive approach to value creation is required to assess the social, environmental and economic impacts on diverse groups impacted by energy innovations and industries.
2. Social license for renewable energy projects requires an evidence-based understanding of the social context, with lessons to be learned from successful models in Germany and Texas that emphasise community participation in the development of longer-term visions and an understanding of future needs to inform proactive policy design.
3. Hydrogen production raises specific community concerns around safety and water security, highlighting the importance of regulations and early community education and engagement to build trust and transparency around hydrogen production and place-based sustainable water solutions.
4. Standards and certification are vital to ensure there are clear conditions around engagement and planning consents applied to renewable energy projects so communities can see tangible social benefits for their region. Project proponents can demonstrate their recognition of and commitment to the critical role of First Nations Project peoples and indigenous traditional owners of land and waters through, for example, Reconciliation Action Plans.
5. Co-ordination and collaboration across multiple levels of government – federal, state and local – which takes a community and place-based rather than a project focused perspective is essential to overcome organizational silos and cumulative project impacts and to foster local and regional community social acceptance.

#5 Opportunities Beyond Hydrogen – PtX

The majority of green hydrogen demand worldwide is for subsequent conversion to derivatives for use in hard-to-abate sectors such as in fertiliser production, decarbonizing maritime and aviation and manufacturing including steelmaking, and chemical processing etc. These derivatives are produced through pathways, which are grouped together as “Power-to-X” or PtX, which refers to using renewable energy to convert water into hydrogen and subsequent secondary conversion to hydrogen derivatives such as renewable ammonia, methanol, renewable diesel, sustainable aviation fuel (SAF) and others.

The key advantage of PtX is that the infrastructure for adopting these clean fuels and chemicals is pre-existing, and there is considerable expertise in handling and using these products, with standards and regulation in place. Moreover, these derivatives can provide more energy-dense and cost-effective hydrogen transport, long-term storage and can be used directly without further reconversion back to hydrogen, with the majority of Australian hydrogen export projects focused on renewable ammonia. Furthermore, many of these derivatives can be used directly at the import countries, thereby removing requirements for reconversion back to hydrogen.

There are of course challenges in relation to PtX pathways, for instance the integration of intermittent renewable energy requires steady-state secondary conversion pathways for derivative production. There are also questions relating to end-use of these PtX generated fuels, for instance ammonia combustion in maritime and implications in maritime from potential spillage and NOx emission is flagged as a social license concern. Further, there are sustainability questions about the suitability of carbon feedstock and biomass for synthetic fuel production such as methanol and SAF, and also on consumer preferences for such fuel given utilization of these fuels would also generate carbon dioxide.

In recent times, the usage of hydrogen in the mineral processing value chain, specifically for green iron and green steel production has gained attention worldwide, given the significant emission profile of the global steel industry. In the Australian context, this opportunity is considered to be a pathway for green hydrogen export in the form of embedded green minerals, with the Australian Federal Government commissioning a new feasibility study for the export of green iron and steel to Germany, a continuation of the previous bilateral Australian German HySupply partnership. This however presents challenges, in addition to technical challenges in integrating green hydrogen within current direct reduced iron (DRI) plants, with questions on cost-effectiveness of the approach, compatibility with various low-iron ore grades as well as socio-political challenges of manufacturing bases shifting overseas.

This complex discussion on ‘Power-to-X’ ties in with technical, social and financing challenges raised in Dialogue #1 and the issues considered in Dialogues #2, #3 and #4.

The fifth Dialogue was a public hybrid online/in-person event, with the EU and Australian introductory presentations highlighting the importance of green hydrogen in enabling production of derivatives that can be used to decarbonise hard-to-abate sectors such as maritime and aviation. Presenters shared their insights into the social and environmental dimensions of Power to X, the role of green methanol and renewable ammonia in developing green shipping corridors and the use of sustainable aviation fuel and green hydrogen in aviation. Australian project proponents shared insights on their project developments and challenges with offtake and funding. Concerns and questions around social license of green low-carbon synthetic fuels and green ammonia were discussed.

Presenters providing the EU and Australian policy and industry context were:

- Bartlomiej Gurba, Policy Officer, Air, Rail, Water and Intermodal Policy Unit, Directorate-General for Climate, European Commission
- Sébastien DUBOIS, Head of Unit – Programme Development and Communications, EU Clean Aviation Joint Undertaking
- Jan-Hendrik Scheyl, Head PtX Sustainability & Certification, International PtX Hub
- Fiona Simon, CEO, Australian Hydrogen Council
- Leigh Holder, Director, Business Development, Yara Clean Ammonia
- Ignacio Hernandez CEO, HIF Global Asia Pacific

The European Climate Dialogues Project Director Ms Gabriele Wagner joined the session in-person, providing an overview of the international activities and aims of the Project. Professor Iain McGill, Centre for Energy and Environmental Markets, University of New South Wales moderated the session.

The discussions primarily focused on the topics of:

1. Building an enabling framework for renewable Power-to-X
2. Disruptive green hydrogen and derivative technologies for the aviation sector
3. Green shipping corridors and scope of maritime emission trading scheme for the maritime sector
4. Importance of gaining social license for green carbon molecules and the need for the scalability of direct air capture technologies for practical deployment.

Summary of Discussions

Green Corridors for Shipping

Incentivizing the use of green fuels and cleaner technologies can lead to considerable reduction in the carbon footprint of maritime transportation. Currently both green methanol and renewable ammonia are considered as key to decarbonizing this sector, specifically in enabling green corridors to be developed. Participation in green shipping corridors can create market opportunities for companies by aligning with the growing demand for sustainable shipping solutions. However, implementing these corridors requires collaboration among various stakeholders, including governments, shipping companies, port authorities, and technology providers.

Insights from the EU indicate that considerable CO2 emissions are rising from both inter-EU voyages as well as from global supply chains. As part of the Fit-for-55 policy package, the EU Commission has established a series of initiatives tailored towards reducing the GHG emissions from shipping sector, including extension of EU ETS scheme to the maritime sector as well as a FuelEU maritime initiative. The forthcoming EU Innovation Fund call will focus on EU maritime decarbonization projects, for which Australia can play a key role as a supplier of green fuels for the sector. Opportunities arising from green corridors include investments and business in green fuels, bunkering and charging sites for ports and industry, and the opening-up of further shipping and trade corridors. The challenges for the establishment of green corridors were outlined, which include the need for infrastructure upgrades to support alternative fuels and zero-emission vessels, as well as the necessity for international cooperation to harmonize regulations and standards across jurisdictions.

Enabling Dimensions of Power-to-X

It was generally agreed that one of the first applications for green hydrogen would be for Power-to-X, either to generate derivatives for transportation or for direct end-use. Australian participants indicated that contrasting with the EU, the discussion in Australia around green hydrogen refers mostly to hydrogen derivatives and Power-to-X rather than direct uses for hydrogen, which has seen limited application and interest. To maximise the benefits of Power to X, an enabling framework encompassing standards, regulation, certification, policies and sectorial strategy is suggested.

A key advantage in enabling Power-to-X is that it builds upon on existing regulation and policies in each country, given considerable trade already in renewable methanol and ammonia. Furthermore, unlocking the true benefit of Power-to-X requires incorporation of sustainable dimensions including economic, social, governance and environmental (EESG) factors. It was also recognized that not all of the EESG dimensions would be covered by government policies and regulations and thereby there is scope and opportunity for all stakeholders to work together to ensure a sustainable Power-to-X economy. Other ways to deal with the EESG dimensions include sustainable finance criteria, voluntary certification schemes, and market and subsidy instruments eg: the European Hydrogen Bank.

SAF and Hydrogen in Decarbonising Aviation

It was noted that both sustainable aviation fuel (SAF) and energy efficiency measures such as efficient engine operations will lead to considerable decarbonization of the aviation sector. Green hydrogen can also potentially be used for short to medium range flights, either for direct hydrogen combustion or through fuel cells. However to enable this, safety concerns related to the handling, storage, and transportation of hydrogen also need to be addressed, along with the development of specific regulatory frameworks and safety standards for hydrogen-powered aviation.

Direct Air Capture

Critical to Power-to-X is the role of sustainable sources of carbon dioxide, which can be combined with green hydrogen to generate synthetic fuels to decarbonize both aviation and maritime sectors. Whilst there still remains questions on what constitutes sustainable sources of carbon dioxide, there is consensus that carbon dioxide captured using direct air capture (DAC) technology will meet emerging sustainability and stringent certification standards of green fuels. Scalability and cost-effectiveness of

DAC however an issue, and questions were raised on how large-scale deployment can be incentivized or funded.

Key Discussion Outcomes

1. Hydrogen derivatives including renewable ammonia and methanol will play a key role in enabling green shipping corridors to decarbonise the maritime sector, which is seeing increased policy and funding support to reach net-zero.
2. To unlock the true benefits of Power-to-X, an enabling framework encompassing standards, regulation, certification, policies and sectorial strategy is required.
3. The role of direct air capture technologies in a future green fuel supply chain is critical and more investment and research is required to advance this.

3 Recommendation for Actions per Stakeholder Sector

The Dialogue discussion outcomes have informed the proposed recommendations for action by different stakeholder sectors to overcome the identified challenges and to expedite hydrogen deployment as follows:

Australian Federal Government

The Federal Government in Australia and the EU and its Member States have a key role in developing sustainable global hydrogen supply chains. As outlined above, the risk profile of this emerging industry arising from technical financial and regulatory challenges and lack of clear market signals for off-take underpins the critical role of government to unlocking this value chain. Some actions for the Federal Government, proposed by Dialogue discussions include to:

Government support and incentives

1. Continue and enhance current funding support provided to both project developers and off-takers to bring down the price mismatch between the supply price at which green hydrogen and derivatives can be generated and exported to EU and at the same time, the demand price at which green hydrogen and derivatives can be used by consumers in EU without taking a significant toll on the consumer budget. Transparency in such support is a must for the Australian Federal Government, with the per kg hydrogen subsidy provided to producers and end-users needing to be communicated to all stakeholders.

   Based on insights provided by project developers in Australia in response to the Hydrogen Headstart program in Australia, it is recommended that the funding amount be increased to bring additional export focused projects into FID and potentially design and develop schemes that target projects for the EU market, in partnership with the EU and member states. Similarly, initiatives such as H2Global and the European Hydrogen Bank could be further tailored to increase Australian participation.

Research and Development across the supply chain

2. Support further research and development to bring emerging technology in this industry to market to ensure further cost reductions. In Australia, while there remain funding opportunities to bring up the technology readiness level (TRL) of hydrogen and derivative technologies, they are mostly focused for lab-scale and at present significant funding is required to trial these technologies in larger prototype and demonstration facilities. In the EU, the Horizon Europe program and other funding schemes such as Clean Hydrogen Partnership are shown to successfully enable such TRL enhancement and it is recommended to replicate such models in Australia.

   Cross jurisdictional funding that allows trialling of EU technologies in Australia (and vice versa) is also recommended. To this end, Australia's participation in the Horizon Europe research program through government co-funding is recommended as an early, low-hanging pathway for enhanced joint-research. Furthermore, programs such as HyGate, which was jointly funded by Australian and German Governments to integrate emerging technologies within demonstration plants led by commercial entities are recommended to be further scaled up.

Enhanced co-operation and knowledge sharing between EU and Australia

3. Facilitate further co-ordination, co-operation and knowledge sharing amongst Australian and EU partners. Dissemination of project learnings and research findings is critical for the broader ecosystem to advance the green hydrogen economy. In Australia, CSIRO maintains and operates the HyResource website, which is an online portal that outlines and links both industry and research projects related to hydrogen. In the EU, initiatives by the Clean Hydrogen Partnership such as the European Hydrogen Observatory and Hydrogen Valleys platforms also assist with knowledge sharing by providing data, information and collaboration on large-scale integrated hydrogen projects along the value chain. Dialogue participants indicated that the exchange of knowledge through readily accessible knowledge platforms and bilateral engagement such as that facilitated by the AUS EU Dialogue series, should continue to play a key role in facilitating such bilateral co-operation and co-ordination.

   An initial knowledge sharing initiative suggested was that the exporting/importing ports in EU and Australia co-ordinate the development of the hydrogen value chains and share knowledge on challenges related to safety, and concerns around ammonia handling. Other themes for future collaboration and knowledge sharing suggested were in the development and regulation of critical minerals/strategic raw materials value chains.

Co-ordination role of national government

4. National governments and the European Union are recognized as having to play an active role to play in co-ordinating the various activities of respective state and local and regional governments. In the case of Australia, states often have multiple government departments all working to support hydrogen economy but without synergy, causing bureaucratic red-tape and duplication for project approvals and development. Similarly, the EU importing ports will play a critical role in facilitating the hydrogen economy not just for their member state but across the European region. Access to EU funding for the upgrading of port infrastructure if therefore required, which national governments alone are unable to support.

   Land use and supply chain risks (such as electrolyzer ordering time and electrical connection issues) pose significant challenges in project viability, prompting calls for Australian national co-ordination. Whereas Australian states were putting initiatives in place to address these issues, a cohesive national strategy was needed. Such collaboration within ‘Team Australia’ is crucial for the hydrogen industry, including urging state governments to ensure a level playing field for electricity pricing.

Interoperability of hydrogen standards and certification schemes

5. The Australia Federal Governments and the EU and member states can play a major role to ensure hydrogen certification schemes are developed to be coherent and interoperable. As the Australian certification scheme is under development, it is recommended that the Australian Government Guarantee of Origin scheme be designed in the context of the regulations and standards in numerous overseas markets (including Asia-Pacific and Europe).

Globally harmonized sustainable finance taxonomies

6. Development of coherent sustainable finance taxonomies by both the EU and Australia, spearheaded in Australia by the Federal Government, is key to ensuring critical finance and investment necessary for the green hydrogen economy development. The Australian Federal Government can play a key role in communicating the development of this taxonomy with the relevant stakeholders and the harmonization of how hydrogen is treated under such schemes in Australia.

State and Local Governments

In both Australia and the EU, sub-national ie: local and regional governments play a crucial role in project permits, land and water approvals, assisting with attaining project social license and providing funding and subsidies to close the pricing mismatch between hydrogen production price and the consumer preferred buying price. Dialogue participants suggested that Australian state and local governments increase support through the following actions:

1. The State and Local Governments can play a key role in co-ordinating and supporting processes related to planning, land purchase and electrical connectivity outlined above. In the EU, it would be of value if Member States and regional/provincial governments were co-ordinate amongst each other to develop a coherent import and end-use strategy for imported hydrogen and derivatives.
2. Local governments play a critical role in renewable energy and hydrogen projects gaining social license. With hydrogen and derivative project spanning multiple states and regions, broader Federal and State government cross-border and cross-local government collaboration is required.
3. The State and Local Governments should work closely and co-ordinate with the Federal Government on the upgrading of infrastructure, notably that of ports and electrical transmission lines, that underpins the hydrogen and derivative value chain. In both EU and Australia, this has typically not yet been a priority.
4. Identification and supporting local firms within the state and local government region to be part of large hydrogen and derivative projects. This would not only enable local participation in projects to allow attainment of social license, it would also help improve regional and local economies. In many cases, project developers working in a new region would not be privy to local business capabilities, which state and local governments can play a key role in promoting.

Industry and Business

Despite considerable support from governments and some market demand, many of the hydrogen and derivative projects have failed to proceed beyond FEED and into FID, sometimes raising questions about the viability of green hydrogen and derivatives being able to accelerate in the next decade. On the off-take side, clarity is required on concrete demand and price expectations from consumers arising from the integration of green hydrogen within current supply chains. To address these issues, industry stakeholders proposed the following actions:

1. Off-takers in Europe should carry out analysis on how much integration of green hydrogen at various prices will impact final product prices and convey this clearly to consumers. Dialogue participants opined that consumers in Europe are quite open to an increase in steel pricing arising from green iron/green steel pathways and similar market analysis should be carried out for other hydrogen derivatives and their end-use.

2. Industry can work with research organizations and universities to further support and demonstrate emerging hydrogen technology within the value chain, to de-risk uptake of these technologies to reduce costs. In recent times in both Australia and in EU, many grant funding pathways encourage such technology translation activities.
3. To attain social license and alleviate project concerns, industry can and should involve the local and regional community early in the project design and decision-making process, a step that has been historically overlooked until project announcements were made. It was noted that early onboarding of local communities has led to significantly more positive views and acceptance of projects.
4. Developers of publicly supported projects should clearly convey FEED findings more widely to community and other stakeholders and outline the complexities that may hinder proceeding towards FID. Such transparent communication will help alleviate concerns from stakeholders on the potential for wastage of public finance in developing risky projects.

Whilst publicly funded hydrogen projects in both the EU and Australia are required to publish knowledge sharing reports, the communication of their findings to the broader public has been limited. Industry has a key role in such communications and could address community concerns through initiatives such as site tours, community education programs, and collaborations with local universities to demystify safety issues and build trust.

Research

By its very nature, research can be pursued in various directions for hydrogen and its derivatives. Whilst this may lead to a wide range of outcomes, it is recommended that greater co-ordinated research efforts along the value chain are needed to ensure that constrained resources and technical expertise are used to solve specific and applied industry problems, in addition to the fundamental research that has underpinned the development of numerous hydrogen and derivative technologies.

Some recommendations for the research community are:

1. Research between Australia and EU should be co-ordinated and facilitated through further research exchanges and dialogues. For instance, in the EU, liquid organic hydrogen carriers (LOHCs) receive considerable attention but in Australia they are not yet considered to be the carrier of choice and hence stakeholders raise questions whether these types of projects should indeed be funded. These questions can indeed be avoided through further exchanges between Australian and EU research partners.
2. The research community should work alongside government to recalibrate technology advancement, specifically through proper categorization of what constitutes a level in the Technology Readiness Level (TRL) scale. The research community would potentially face industry backlash if technologies “oversold” and do not meet industry expectations.
3. Focus on scalable research efforts and develop more prototype and demonstration units of technologies to test real-world deployability of lab-scale findings and results.
4. Reflecting the approach of the Clean Hydrogen Partnership in the EU and ARENA TRAC Program in Australia, projects should be co-designed with industry with research funding distributed across the value chain for the private sector, research institutions and start-ups.

4 Conclusions

The AUS EU Dialogue has underscored the significant potential of renewable hydrogen in addressing global energy transition needs. Through a series of expert dialogues, the initiative has identified key areas for collaboration and action between Australian and European stakeholders, emphasizing the necessity of integrated efforts across research, finance, governance, certification, and community engagement. The key areas for future policy and other actions by government, industry and research sectors that were highlighted by participants during the Dialogue sessions are:

1. **Research and development:** Collaboration between the research sector and industry across the value chain for emerging hydrogen and derivatives technology to increase the Technology Readiness Level and de-risk uptake and reduce costs.
2. **Finance and investment - off-take and supply/demand prices:** Enhanced Government support for market-making schemes for both project developers and off-takers to reduce the price mismatch between supply price and demand price, including to enable Australian participation in initiatives such as H2Global and the European Hydrogen Bank auctions.
3. **Multi-level governance:** Greater co-ordination and collaboration between Federal, State and local governments in the development and upgrading of infrastructure that underpins the hydrogen and derivative value chain, notably that of ports and electrical transmission lines.
4. **Certification and standards:** Australian Guarantee of Origin scheme to be interoperable with schemes in the EU and key export markets in the Asia Pacific region.
5. **Social licence:** Project developers to involve local and regional communities t early in the project design and decision-making process to build social licence and ensure sharing of the costs and benefits, with State and local government support for local and regional firms to participate in large-scale hydrogen and derivative projects.
6. **Sustainable finance:** Ensure harmonization and coherence in the approach to hydrogen related activities in the Australian and EU sustainable finance taxonomies
7. **EU and Australian ports initiative:** An initial focus for co-operation and knowledge sharing between the EU and Australia is proposed between the exporting/importing ports in the EU and Australia as being critical for the broader hydrogen ecosystem and value chains.

The dialogue series has highlighted the necessity of ongoing international co-operation to overcome challenges and leverage opportunities in the green hydrogen sector. The recommendations provided aim to facilitate a robust and sustainable hydrogen economy, contributing to global efforts in mitigating climate change and promoting energy security. Such continuous exchange of knowledge and experiences between the EU and Australia is crucial for advancing the hydrogen agenda and achieving mutual energy and environmental goals.

Appendix I: Dialogue Participant Organizations

Acciona Energia

ACEN

AECOM

AEMC

ANZ

Ark Energy

ARUP

Australian Stock Exchange

ATCO

Aurecon

Australian Academy for Technology Sciences and Engineering

Australian Gas Infrastructure Group

Australian Hydrogen Council

Australian Local Government Association

Australian Sustainable Finance Institute

Beyond Zero Emissions

Bluescope Steel

Bureau Veritas

Carbon280

Central Queensland University

Certscape

Clean Energy Council

Clean Energy Finance Corporation

Clean Hydrogen Partnership

Climate Energy Finance

Climate-KIC Australia

Committee for the Hunter

CPB Contractors

Commonwealth Scientific and Industrial Research Organisations (CSIRO)

Cultural Chameleon

Department of Energy, Environment, Climate and Action, State of Victoria

Deloitte

Department of Climate Change, Energy, Environment and Water (DCEEW), Federal Government, Australia

Department of Foreign Affairs and Trade (DFAT), Federal Government, Australia

DG CLIMA European Commission

DG ENER European Commission

Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) European Commission

DNV Australia

Endua

Energy Cycle

European Union Delegation to Australia, Canberra

Ferron Energy

Food Agility CRC

Fortescue Future Industries

Gary Testro Law

German Australian Chamber of Commerce and Industry

German Australian Hydrogen Alliance

GHD

Gladstone Regional Council

Global Centre for Climate & Security Governance (GCSG), University of Queensland

Global Counsel

Greenhouse

Griffith University

H2 Society Australia

H2Q Hydrogen Queensland

HIF A/Pac

Hunter Water Corporation

Hydgene

Hydrogen Europe

HYpe Certification

Iberdrola Australia

Inner West Council

Institute for Sustainability, Energy and Resources, University of Adelaide

Institute of Sustainable Futures, University of Technology Sydney

Linde/BOC

Low Emissions Technology Australia (LETA)

Macquarie Group

Macquarie University

Ministry of Economic Affairs, Ports and Transformation, Bremen, Germany

Ministry of Foreign Affairs, Denmark

Monash University

Net Zero Economy Agency

Net Zero Network

NewH2 Cluster

Nordion Energi

Norton Fulbright

NSW Decarbonisation Innovation Hub

ORICA

OTK

Ottereon Group

Parrington Group

Pollination

Port of Newcastle, New South Wales

Port of Rotterdam, Netherlands

Queensland Farmers Federation

RE-Alliance

Regional Area Planning and Development (RAPAD) Queensland

Renewable Hydrogen Coalition - Europe

Renewables, Climate and Future Industries, Department of State Growth, Tasmania

RES Group

Roundtable on Sustainable Biofuels

Smart Energy Council

Star Scientific

Sustain Intelligence

The Superpower Institute

Thyssenkrupp, Australia

TPG

University of Bremen

University of New South Wales

University of Newcastle

University of Queensland Energy Systems

University of Technology Sydney

University of Wollongong - Green Steel Research Hub

UTS DAB School of Built Environment

Vestas

Vireo Energy

Wood Plc

Woodside Energy

Woolworths Group

Yara Clean Ammonia

Appendix II: Dialogue Background Papers

Scaling and Accelerating Hydrogen Production – Global State of Play

Green Financing of the Hydrogen Economy

Challenges in the Design and Development of Green Hydrogen Supply Chains

Social Licence, Community Acceptance and Environmental Impacts

Opportunities Beyond Hydrogen: PtX

AUS European Union Green Hydrogen Dialogue #1: Background Paper

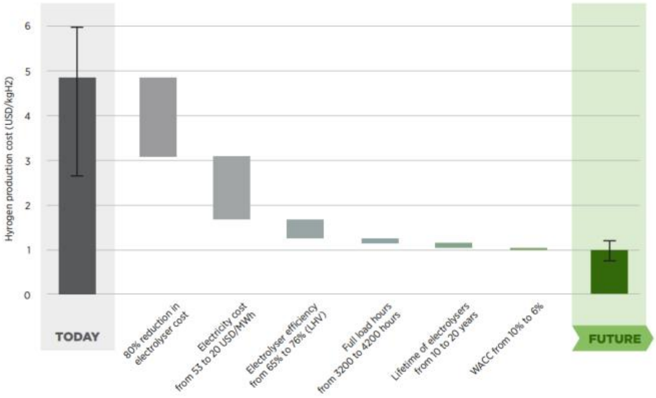
Scaling and Accelerating Green Hydrogen: Global State of Play

Hydrogen production, investment, and trade must be scaled and accelerated to meet jurisdictional national hydrogen strategy targets and assist in global decarbonisation efforts to reach net zero. This scaleup depends on improvements in the cost of hydrogen production through technical and economic levers, as well as policy support, which must also take into consideration the potential barriers to scaleup and the requirement for robust and uniform hydrogen regulations, standards, and certification. This background paper provides an overview of these aspects of green hydrogen, and details in brief the current state of play across the EU, Australia, and select key global players. Note that this paper focuses only on green hydrogen and not the key derivatives, which are discussed in future background papers.

Technical and Technological Analysis of Aspects aimed at Scaling and Accelerating Green Hydrogen Production, Investment, and Trade

Cost Considerations[1]

The cost of hydrogen production is a critical barrier to the uptake of green hydrogen, with the cost of green hydrogen still around 2 – 3 times higher than blue hydrogen (which is produced through fossil fuels with CO2 captured). A key benchmark for the levelised cost of hydrogen (the net present value of the capital and operating expenses of a hydrogen project against the lifetime production of hydrogen) is often proposed at around US $1 – 2 per kg of H_2, at which cost electrolysis-based hydrogen is expected to be viable with fossil fuel prices. Key cost considerations include renewable electricity prices, electrolyser production costs, achievement of economies of scale, and the cost of capital (**Figure 1**).



Note: 'Today' captures best and average conditions. 'Average' signifies an investment of USD 770/kilowatt (kW), efficiency of 65% (lower heating value – LHV), an electricity price of USD 53/MWh, full load hours of 3200 (onshore wind), and a weighted average cost of capital (WACC) of 10% (relatively high risk). 'Best' signifies investment of USD 130/kW, efficiency of 76% (LHV), electricity price of USD 20/MWh, full load hours of 4200 (onshore wind), and a WACC of 6% (similar to renewable electricity today).

Based on IRENA analysis

Figure 1: An 80% reduction in hydrogen production costs can be achieved through a combination of cost reductions in electricity and electrolysers, combined with increased efficiency and operating lifetime. Note that "Today" refers to 2020.[2]

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[1] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

[2] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

Electricity prices play a significant role in the overall cost, due to the energy intensity of electrolysis process, which requires around 50 – 80 kWh per kg of hydrogen for alkaline electrolysers (AE) and polymer exchange membrane (PEM) electrolysers. Currently, the largest single operating cost component for on-site production of green hydrogen is the cost of the renewable electricity. A low cost of electricity is therefore critical to producing competitive green hydrogen and presents an opportunity to regions with abundant renewable resources (i.e., solar and wind), such as Australia, the Middle East and North Africa region (MENA), and South America, highlighting the necessity of hydrogen trade between countries in the future.

Electrolyser capital expense is the second largest cost component for green hydrogen production, and includes electrolyser design and construction, economies of scale, and procurement of raw materials.

- Electrolyser design and construction includes the module and stack design and manufacturing costs, which vary between each type of electrolyser.
- Achieving economies of scale can significantly reduce the cost of electrolyser manufacture. For example, at low manufacture rates, the stack is estimated at around 45% of the total cost, whilst at higher manufacture rates, this value can reduce to ~30%. Strategies for achieving economies of scale include automating electrolyser production at GW scale manufacturing facilities, as well as standardisation of system components and plant design.
- Typical electrolyser components comprise expensive and/or rare elements, including iridium, titanium, and platinum. Whilst these elements are expensive (contributing around 10% of the stack cost for a 1 MW PEM electrolyser), their use may also become a barrier to scaling up due to their low natural abundance. Titanium, whilst less scarce than other materials, is required in significant quantities for current PEM systems.

It is estimated that green hydrogen production costs can be reduced in the short term by 40%, and in the long term by 80%, through a combination of these factors in addition to improvements in electrolyser efficiency and operation (**Figure 1**).[3]

Technical Improvements in Driving Down Costs

A number of technical improvements can assist in scaling and accelerating hydrogen production by reducing the capital and operating costs of electrolyser systems (and enhancing output) and hence decreasing the levelised cost of hydrogen. These include:

- Stack efficiency and Balance of Plant: Intrinsic electrolyser stack operation, as well as the auxiliary balance of plant (BoP) energy needs (water cooling/purification unit, dryers, electrical components) limit the overall process efficiency, which is currently around 70% on a lower heating value (LHV) of hydrogen basis. In the long term, these efficiencies are expected to reach >80% of LHV basis. Several companies such as Hysata[4] (Australia) and Hystar[5] (Norway) are in the process of scaling benchtop systems that can attain such efficiencies.

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[3] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

[4] https://hysata.com/news/hysata-delivers-the-step-change-needed-in-electrolysis/

[5] https://hystar.com/the-explorer-hystar-makes-green-hydrogen-more-competitive/

- Stack lifetimes: Currently AE and PEM systems are rated for over 60,000 hours of operation, corresponding to project operation of 20 years with 1 or 2 replacement cycles. Shorter lifetimes are achieved with solid oxide electrolysers (SOECs) and anion exchange membrane electrolysers (AEM) of around 5,000 to 20,000 hours of operation. Improving the electrolyser lifetime could lead to significant cost reductions, as the cost of electrolyser stacks can be up to 50% of total system costs.
- Electrode performance: Significant research is focused on improving the activity of the electrodes used for hydrogen generation, which will increase production rates and thus reduce the levelised cost. Strategies include the use of lower cost and more abundant metals, and reducing the metal loading, in order to both minimise the dependence on critical minerals and reduce the capital costs of electrolyser systems.

Research and Innovation investment (both nationally and through international collaboration) into improving these aspects is critical, as further detailed below. Whilst these technical considerations are focused on hydrogen production, it is likely that in many end use cases, hydrogen must be converted to derivatives such as methanol, ammonia, or sustainable aviation fuel, which entail unique technical challenges that will be explored in background paper 5.

Policy Levers for Deployment

Policy support can significantly improve the scale and speed of green hydrogen deployment. Such policies should be considered in parallel to national hydrogen strategies, and should address aspects such as:

- Facilitating investment into production, logistics (such as port infrastructure), and utilisation of green hydrogen. This includes assistance in reducing technology costs and improving performance through supporting research, development, and demonstration (RD&D), as well as tax incentives.
- Establishing regulations, common standards, and certifications (mutually recognised schemes). This includes setting manufacturing or deployment targets, as well as mandatory quotas in hard to decarbonise sectors and other de-risking mechanisms.
- Fostering coordination and common goals along the hydrogen value chain, across borders, across relevant sectors and between stakeholders.

Potential Barriers

The mitigation of potential barriers to scaling green hydrogen production and end use is a further consideration. Example of such barriers include procurement of materials, as well as supply chain considerations. Consultations with stakeholders now indicate long lead times for electrolysers, which are a potential barrier to project implementation.

The critical materials used in electrolysers (i.e., platinum and iridium) are some of the scarcest, most energy-intensive and most emission-intensive metals to mine and refine. The availability of these metals limits the scaleup of electrolyser manufacturing capacity, for example it is estimated that the global Iridium production of around 7.5 tonnes per year would support the deployment of 3 – 7.5 GW of electrolysers per year, or 30 – 75 GW of electrolyser capacity in the next decade, highlighting the importance of reducing Iridium content in PEM electrolysers. In addition, the supply of critical minerals for electrolysers is localised within a few countries (for example, South Africa supplies over 70% of global Platinum and over 85% of global Iridium, and China supplies most of the critical minerals required for SOECs), which could strongly link electrolyser manufacturing capacity to a few countries.[6]

A potential barrier that must also be considered is the supply chain. This includes the storage and transportation of produced hydrogen, which requires infrastructure including pipelines, large-scale storage, and ports, as well as the manufacturing capacity of key equipment including electrolysers, solar PV panels, and inverters. Electrolyser manufacturing capacity has increased by over 25% in the past year, to over 10 GW.[7] The expected global manufacturing capacity is expected to reach around 70 GW by 2025, over half of which (over 40 GW) is expected to be developed by China,[8] followed by the EU and USA. However, it should be noted that scaling electrolyser manufacturing capacity can be challenging due to supply chain and operational issues, such as those faced by manufacturer Plug Power.[9]

Furthermore, the solar PV supply chain must be ramped in parallel with electrolyser installation, as most systems will be run on solar electricity. Global solar PV manufacturing capacity has increasingly moved from Europe, Japan, and the USA to China over the past decade, who invested over US $50 billion in new PV supply capacity – ten times more than Europe.[10] The geographical concentration of key hydrogen component manufacturing capacity may create potential challenges that governments must address. In Australia, the local manufacturing of key components required for hydrogen production could assist in securing and fast-tracking the ambitious production targets.

Current State of Play

The European Union

The European Commission released a Hydrogen Strategy in July 2020,[11] aimed at accelerating the development of green hydrogen from renewables, potentially accounting for 13 – 20% of the EU's energy supply by 2050. This strategy also includes the Fit-for-55 package, translating the European hydrogen strategy into a hydrogen policy framework. This includes a set of proposals to make the EU's climate, energy, transport, and taxation policies consistent with reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. A key part of this package includes laws to increase the demand for and supply of sustainable aviation fuels (SAF), which is expected to be 63% of aviation fuels by 2050.[12] In December 2023, the EU agreed on plans to facilitate the uptake of renewable and low-carbon gases, including hydrogen, on the EU's gas market as part of the European Green Deal. The review and revision of the Gas Directive 2009/73/EC and Gas Regulation (EC) No 715/2009 (referred to as the Hydrogen and gas markets decarbonisation package) aims to remove barriers to decarbonising the gas market, through measures including the definition of low-carbon hydrogen and a certification system for low-carbon hydrogen, including a methodology for determining emission saving, as well as promoting dedicated hydrogen infrastructure.[13]

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[6] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

[7] https://www.iea.org/energy-system/low-emission-fuels/electrolysers

[8] https://www.hydrogeninsight.com/electrolysers/interview-china-is-overbuilding-hydrogen-electrolyser-manufacturing-capacity-and-may-have-to-shut-some-of-it-down-citigroup/2-1-1506515

[9] https://www.hydrogeninsight.com/electrolysers/wrongful-acts-leading-hydrogen-electrolyser-maker-plug-power-faces-class-action-lawsuit-launched-by-five-legal-firms/2-1-1435005

[10] https://www.iea.org/reports/solar-pv-global-supply-chains/executive-summary

[11] https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en

[12] https://www.easa.europa.eu/en/light/topics/fit-55-and-refueleu-aviation

[13] https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/hydrogen-and-decarbonised-gas-market-package_en

By 2030, the EU will target the production of 10 million tonnes of green hydrogen per annum (Mtpa), with at least 40 GW of renewable hydrogen electrolysers installed.[14] Between 2020 and 2050, investments in production capacities is estimated at between €180 – 470 billion in the EU. The EU has also launched and promoted several industrial, funding, and research and innovation initiatives on hydrogen, including the Clean Hydrogen Partnership, the European Clean Hydrogen Alliance, and the Hydrogen Public Funding Compass. Australia and Germany have joined forces on green hydrogen, with the Australia-Germany Hydrogen Accord announced in 2021. The HySupply project investigated the feasibility of a hydrogen and hydrogen derivatives supply chain between Australian and Germany, and identified how such a partnership could be facilitated.[15]

Australia

Australia released its National Hydrogen Strategy in 2019,[16] and in 2023 initiated a Review of the National Hydrogen Strategy to ensure it positions Australia on a path to be a global hydrogen leader by 2030. A key element of the Strategy is the creation of hydrogen hubs – clusters of large-scale demand aimed at making the development of infrastructure more cost-effective and promoting efficiencies via economies of scale. The Federal AU $2 billion Hydrogen Headstart program is targeted at supporting large-scale renewable hydrogen projects in Australia. State governments have also committed to hydrogen, for example the NSW government has provided up to AU $3 billion of incentives to support industry development.[17]

Australia currently has an announced pipeline of over 100 hydrogen projects, representing around AU $230 – 300 billion in potential investments and around 40% of all global clean hydrogen projects.[18] It is estimated that Australia will provide between 2 – 20 Mtpa of the hydrogen export market by 2050, with partnerships currently in place with Germany, India, Japan, The Republic of Korea, Singapore, UK, USA, and The Netherlands.[19]

Other Key Players

The USA announced the Inflation Reduction Act in 2022, which includes clean energy tax credits and other provisions in order to increase domestic renewable energy production. In particular, the 45V tax credit provides increasing levels of tax credit for each kilogram of clean hydrogen produced, up to US $3 per kg. This credit is expected to significantly kickstart the clean hydrogen market in the US.[20] Domestic clean H_2 production targets are 10 Mtpa by 2030, 20 Mtpa by 2040, and 50 Mtpa by 2050.

China released its long-term plan for hydrogen in March 2022, with aims to produce 100 – 200 Mtpa of green hydrogen and have a fleet of 50,000 hydrogen fuelled vehicles by 2050. China is currently the world's largest producer of hydrogen, at 33 Mtpa (around one third of global generation), however this is mostly produced through fossil fuel-based methods. Another focus of this plan is

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[14] https://research.csiro.au/hyresource/policy/international/european-commission/

[15] https://germany.embassy.gov.au/beln/hydrogen.html

[16] https://www.dcceew.gov.au/sites/default/files/documents/australias-national-hydrogen-strategy.pdf

[17] https://www.energy.nsw.gov.au/nsw-plans-and-progress/government-strategies-and-frameworks/nsw-hydrogen-strategy

[18] https://www.dcceew.gov.au/sites/default/files/documents/state-of-hydrogen-2022.pdf

[19] https://www.dcceew.gov.au/climate-change/international-climate-action/international-partnerships

[20] https://rhg.com/research/clean-hydrogen-45v-tax-guidance/

manufacturing capacity, as China plans to supply both domestic and international markets with electrolyser equipment and components.[21]

Japan updated their 2017 Basic Strategy for Hydrogen in 2023, with plans to increase hydrogen supply from the current 2 Mtpa to 20 Mtpa by 2050, and to install 15GW of electrolyser capacity globally, by Japanese affiliated companies.[22] Further, the plan details ~US $110 billion of public and private investment in the development of the country's hydrogen supply chain over the next 15 years. Australia's Clean Hydrogen Trade program aims to develop the Australian hydrogen export industry to become a supplier of choice for Japan and the region.[23]

Korea's Hydrogen Economy Roadmap details the national targets for the fuel cell and fuel cell electric vehicle sectors.[24] This includes the supply of 6.2 million hydrogen fuel cell electric vehicles (3.3 million for export and 2.9 million for domestic use) by 2040, as well as the manufacture of hydrogen fuel cells for power generation to reach a combined capacity of 15 GW by 2040 (of which 7 GW is exported). The roadmap foresees hydrogen demand of ~2 Mtpa by 2030 and ~5 Mtpa by 2040, both produced domestically and imported.

Singapore's National Hydrogen Strategy outlines the potential for hydrogen to supply up to half of the country's power needs by 2050.[25] The Strategy suggests that this hydrogen will be mostly imported, with an emphasis on working closely with industry and international partners to enable the formation and scaling up of supply chains for low-carbon hydrogen.

MENA is an emerging hydrogen market, with export potential due to strong renewable energy resources. For example, the US $8.4 billion Neom Green Hydrogen Project[26] is expected to be the world's largest utility scale, commercially based hydrogen facility powered entirely by renewable energy. When commissioned in 2026, the plant is expected to produce 1.2 Mtpa of green ammonia, produced from green hydrogen and nitrogen separated from air. There are also several agreements between the EU and MENA countries for hydrogen trade, including Egypt and Morocco.[27]

India's National Green Hydrogen Mission was approved in January 2023, which aims to make India a global leading producer and supplier of green hydrogen. The government has set out a green hydrogen production target of 5 Mtpa, with an associated renewable energy capacity of about 125 GW, and electrolyser capacity of 15 GW, by 2030.[28] The expected investment is over €90 billion, which is targeted at reducing the green hydrogen production cost to US $1.5 per kg by 2030.

Figure 2 outlines the locations of announced and operational low-carbon hydrogen projects. It is seen that many projects are located in the EU and Australia, as well as across China and the USA.

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[21] https://www.csis.org/analysis/china-unveils-its-first-long-term-hydrogen-plan

[22] https://research.csiro.au/hyresource/policy/international/japan/

[23] https://www.dfat.gov.au/about-us/publications/trade-investment/business-envoy/business-envoy-february-2022/clean-hydrogen-collaboration-japan

[24] https://research.csiro.au/hyresource/policy/international/republic-of-korea-south-korea/

[25] https://www.mti.gov.sg/Industries/Hydrogen

[26] https://acwapower.com/en/projects/neom-green-hydrogen-project/

[27] https://www.hydrogeninsight.com/production/analysis-europe-courts-green-hydrogen-supply-from-north-africa-but-when-can-the-region-deliver-/2-1-1598009

[28] https://gh2.org/countries/india#:~:text=The%20National%20Green%20Hydrogen%20Mission%20aims%20to%20make%20India%20a,about%20125%20GW%20by%202030.

Figure 2: A global map of announced and operational low-carbon hydrogen projects.[29]

Regulations and Certifications

Overview and Purpose

Regulations, standards, and certification schemes are required to define what qualifies as renewable hydrogen, such that a customer is able to verify the source of hydrogen, whilst the producer is able to quantify and disclose the environmental attributes, in particular the associated emissions of hydrogen production. Such certification schemes play a key role in:[30]

- Enabling the implementation of government policies such as targets, quotas, and tax credits.
- Creating transparency for consumers, enabling consumer choice, and allowing consumers to signal demand for hydrogen based on its sustainability credentials.
- Creating trust between prospective importers and exporters, fostering global cross-border trade in hydrogen and derivatives.

Current Certification Schemes

CertifHy[31] have developed hydrogen certificate schemes across Europe (known as CertifHy certificates), that enable EU-wide consumption of hydrogen regardless of location. The certificate is an electronic document providing proof that the purchased hydrogen is produced by a registered production device with a specific quality and method of production. The certificate details the plant that produced the hydrogen, the energy source of the hydrogen, the share of renewable energy, and notably the greenhouse gas intensity of the hydrogen. This intensity is defined as the amount of CO2 equivalent per unit of energy throughout the production process, from “well-to-gate”.

Australia is designing its own Guarantee of Origin (GO) scheme,[32] an assurance scheme designed to track and verify emissions associated with the production of hydrogen and renewable electricity in Australia, with the potential to expand the scheme to products such as metals and low emissions

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[29] https://www.thehydrogenmap.com/?type=11

[30] https://hydrogencouncil.com/wp-content/uploads/2023/08/Hydrogen-Certification-101.pdf

[31] https://www.certifhy.eu/

[32] https://www.cleanenergyregulator.gov.au/Infohub/Markets/guarantee-of-origin

fuels including hydrogen derivatives. Similarly, to the CertifHy scheme, the GO scheme will show where a product has come from, how it was made, and its lifecycle carbon intensity, including mutual recognition agreements with trade partners. As a potential supplier of green hydrogen to both domestic and international markets, the GO scheme would help unlock economic opportunities for Australian industry to meet growing demands for verified renewable electricity and low emissions products, including hydrogen and its derivatives, however this is still a work in progress.

EU and Australia Cross-Border Issues

There are several issues that could affect the trade of hydrogen between the EU and Australia. These include:

- Shifts in relations. For example, negotiations for a free trade agreement (FTA; a treaty between two or more countries designed to reduce or eliminate certain barriers to trade and investment, and to facilitate stronger trade and commercial ties) between the EU and Australia have stalled, highlighting the role of political dynamics on economic ties.
- Historic trading partners. Australia has historically engaged with Asian-Pacific partners for energy exports and has agreements in place for hydrogen exports to nations such as Japan. As such, it is possible that the majority of hydrogen exports from Australia will be directed towards this region, unless market signals from the EU are strong.
- Hydrogen production costs and long distances for export. It is possible that the long distances between Australian hydrogen producers and Europe could lead to the EU importing hydrogen from nearby countries via pipeline. The economics will depend strongly on the production costs that could be achieved in renewable resource-rich locations such as Australia compared to nations located closer to the EU, as well as other external geopolitical factors. It should be noted that certification schemes could play a role in justifying higher hydrogen production costs, by validating the emissions intensity of the produced hydrogen.

Summary

This background paper outlines the current state of play for global hydrogen production, from the lens of both technical and technological ANALYSIS of aspects aimed at scaling and accelerating green hydrogen production, as well as the status of the global hydrogen economy in key regions and nations. In general, the most significant costs associated with hydrogen production are the cost of electricity, as well as the electrolyser capital expense. The capital expenditure and operation cost of electrolyser systems can be reduced through technical improvements, including in stack efficiency and lifetime, as well as electrode composition.

A key consideration in the development of the hydrogen economy is the introduction of regulations and certifications that define and qualify the production of green hydrogen, in order to create transparency and provide associated credits. Such schemes include the EU CertifHy and Australian Guarantee of Origin Schemes. However, there are also social and environmental issues that must be addressed in the development of hydrogen and derivatives projects. These aspects are explored in the following paper.

This publication was funded by the European Union. Its contents are the sole responsibility of Climate KIC Australia and does not necessarily reflect the views of the European Union.'

Funded by the European Union

This activity is part of the European Union
Climate Dialogues (EUCDs) Project

AUSTRALIA EUROPEAN UNION GREEN HYDROGEN DIALOGUE #2

Green Finance for the Hydrogen Economy

Introduction

Financing of hydrogen and derivatives projects has gained interest as investors have shifted focus to the consideration of climate change and broader sustainability concerns.[1] Early hydrogen projects in the EU and Australia required de-risking by governments, however whilst government underwrite hydrogen projects to bring confidence, large investors such as sovereign national funds are entering the market. However, there are still challenges regarding the environmental sustainability and economic returns of such investments, with most hydrogen projects still in the front-end engineering and design phase and having not yet achieved the final investment decision.

It is estimated that around 70% of clean energy investment over the next decade will need to be carried out by private developers, consumers, and financiers.[2] Australia and the EU are in the process of developing and implementing sustainable finance taxonomies that address this concern, with further application to guarantee of origin schemes, a requirement for international hydrogen (and derivative) trade. This paper provides an overview of these developments and discusses the current trade environment between the EU and Australia in regard to the hydrogen economy.

Financing and Trade Between EU and Australia

Hydrogen Project Risks

The production costs of green hydrogen are currently high compared to conventional methods of hydrogen produced for existing industries, such as for ammonia production and steelmaking. As discussed in an earlier Background Paper, high electrolyser capital costs are a major factor constraining the cost-competitiveness of green hydrogen. In addition to capital costs, other factors such as financing play a role in dictating the cost of production. Factors contributing to the high weighted average cost of capital (WACC) include offtake risks, lack of credible offtakers, price uncertainty of green hydrogen, and the absence of hydrogen trading markets[3]. The WACC heavily affects the levelised cost of hydrogen (**Figure 2**). For example, an increase in the cost of capital of 3% could raise the total project cost by nearly a third[4]. With global inflation affecting equipment and financial costs, the bankability of projects is at risk, and as such, rapidly increasing investment in clean technologies depends on enhancing access to low-cost financing.

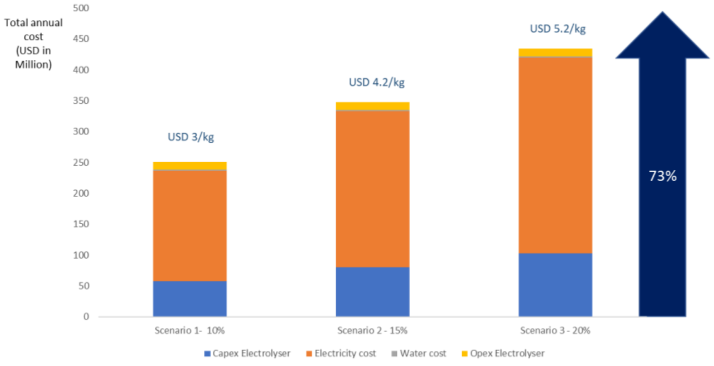

Figure 1. The impact of WACC on the levelised cost of hydrogen (in USD/kg hydrogen) and total annual cost (USD million).[5]

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[1] https://blogs.worldbank.org/ppps/laser-focused-bridging-climate-finance-gap-cop28
[2] https://www.iea.org/articles/the-cost-of-capital-in-clean-energy-transitions
[3] https://one.oecd.org/document/ENV/WKP(2023)19/en/pdf
[4] https://www.iea.org/reports/global-hydrogen-review-2023/executive-summary
[5] https://one.oecd.org/document/ENV/WKP(2023)19/en/pdf

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Sustainable Financing

There are several pathways towards financing green hydrogen projects. Green bonds (bonds intended to encourage climate-related or other types of special environmental projects) may come with tax incentives that enhance the viability of investing in green hydrogen projects. For example, the EU is developing the European Green Bond Standard, which relies on the detailed criteria of the EU taxonomy (discussed below).[6]

As part of the taxonomy regulation, The Platform on Sustainable Finance is an advisory body that brings together the best expertise on sustainability from the corporate and public sector, from industry as well as academia, civil society and the financial industry, in order to advise on the usability of the EU taxonomy and wider sustainable finance framework.[7]

The Climate Bonds Initiative is an international organisation working to mobilise global capital for climate action, by developing a large and liquid Green and Climate Bonds Market that will help drive down the cost of capital for climate projects in developed and emerging markets.[8]

As part of the Hydrogen Headstart program in Australia, successful projects will have the opportunity to receive funding as a production credit, which can cover the current commercial gap between the cost of producing renewable hydrogen and its market price, enabling producers to offer hydrogen to users at a price that will encourage its use.[9]

Trade Between the EU and Australia

The EU and Australia share a commitment to the rule of law, global norms, and free and open markets, and as such are natural trade partners. In 2022, Australia was the EU's 18th largest trade partner for goods, whilst the EU was Australia's third largest trade partner, with China, Japan, and the USA rounding out the top four.

In 2018, negotiations were launched between the EU and Australia for a free trade agreement (FTA; a treaty between two or more countries designed to reduce or eliminate certain barriers to trade and investment, and to facilitate stronger trade and commercial ties) that could result in the trade of goods and services between the two increasing by around a third[10]. However, as of October 2023 the deal has not progressed, with negotiations unlikely to resume until at least the conclusion of the EU elections in June 2024. The FTA may yet be favourable for both parties, particularly in relation to hydrogen and the net zero economy. The EU may gain secure access to Australia's critical minerals, such as lithium, copper, and rare earth elements, whilst Australia may target reducing trade dependence on China while gaining greater participation in EU-centred supply chains.

Investment into Projects

Combined, the EU are one of the largest investors into Australia. As of 2022, of the $4.5 trillion invested into Australia, 24% was invested by the United States, 22% by the United Kingdom, 8% by Belgium, and 6% by Japan. The share invested by the EU member states is approximately 14%. These investments primarily target the mining sector, manufacturing, finance and insurance, and real estate[11]. In 2021, the stock of foreign direct investment in Australia by the EU was around €121 billion (~AU $200 billion) and the stock of Australia's investment in the EU was €22.2 billion (~ AU $36 billion).[12]

There are several Australian hydrogen projects in partnership with the EU, highlighting the capital flow that is currently taking place. These include:

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[6] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/european-green-bond-standard-supporting-transition_en

[7] https://finance.ec.europa.eu/sustainable-finance/overview-sustainable-finance/platform-sustainable-finance_en

[8] https://www.climatebonds.net/about

[9] https://www.dcceew.gov.au/energy/hydrogen/hydrogen-headstart-program

[10] https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/australia/eu-australia-agreement_en

[11] https://www.lloydsbanktrade.com/en/market-potential/australia/investment#:~:text=In%202021%2C%20total%20FDI%20inflows,In%20Figures%2C%20October%202022).

[12] https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/australia_en

- French company Engie are developing the Yuri project in Western Australia in collaboration with Norwegian chemicals manufacturer Yara, targeting completion in 2024. The first phase of the project will produce up to 640 tonnes of renewable hydrogen per year as a zero-carbon feedstock for green ammonia, through a 10 MW electrolyser. The AU $87 million project is supported by around AU $50 million of funding from the Australian Government and the Western Australian Government[13].
- Spanish company Iberdrola has invested in renewables in Australia, including The Port Augusta Renewable Energy Park, a hybrid wind-solar plant with a total installed capacity of 317 MW. The company aims to invest AU $3 – 5 billion in Australia with the aim of reaching 3,000 MW of renewables, in addition to the ~AU $3 billion spent on projects such as the Avonlie solar farm and the Flyers Creek wind farm in New South Wales.[14]
- Danish company European Energy has acquired a majority stake in Austrom and is undertaking the development work as well as managing the grid process for the Pacific Solar Hydrogen Project in Queensland. The project is targeting a capacity of up to 3,600 MW of solar PV, to supply renewable energy for a planned hydrogen production plant located at the port of Gladstone[15].

There is also considerable funding opportunities in the EU, where the first European Hydrogen Bank auction was launched in November 2023, with an initial €800 million of emissions trading revenues to support the production of renewable hydrogen in Europe.[16] There were 132 bids received from 17 European countries, far exceeding the available budget, and highlighting the enthusiastic market response to the pilot auction.[17] The second EU hydrogen auction worth €2.2 bn will proceed this year, however may be delayed to from spring to autumn 2024.[18] Following talks with the German government to jointly fund a €400m auction for the import of Australian renewable H2 to Germany, Australia is set to join the H2Global green hydrogen subsidy auction scheme.[19]

Sustainable Finance Taxonomy Developments

Overview

Sustainable finance taxonomies are a set of common definitions for sustainable economic activities. These can then be used to define sustainable investments credibly and transparently[20]. Sustainable finance definitions and taxonomies can bring potential benefits, including improving market clarity by providing clear and consistent definitions of what is classified as a sustainable activity, easier tracking of sustainable finance flows to be able to measure them, and taking policy action such as setting incentives.

Several jurisdictions have started to legislate the create official definitions of sustainable finance, including the EU, China, and Japan, with more than 30 taxonomies in development globally.[21] In addition to developing green taxonomies, many economies are increasing their financial incentives designed to attract investors in low-carbon sectors, potentially providing a lead in the global race for green jobs and investment. As such, sustainable taxonomies can increase sales opportunities through partnerships with international financial institutions, as well as enhance export competitiveness and attract overseas investment.[22]

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[13] https://engie.com.au/yuri

[14] https://www.iberdrola.com/about-us/iberdrola-australia

[15] https://research.csiro.au/hyresource/pacific-solar-hydrogen-project/#:~:text=In%20December%202022%2C%20European%20Energy,%2DGladstone%20region%20of%20Queensland).

[16] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_5982

[17] https://climate.ec.europa.eu/news-your-voice/news/european-hydrogen-bank-pilot-auction-132-bids-received-17-european-countries-2024-02-19_en

[18] https://www.hydrogeninsight.com/production/exclusive-second-eu-hydrogen-auction-worth-2-2bn-set-to-be-delayed-to-autumn-2024/2-1-1605711

[19] https://www.hydrogeninsight.com/production/australia-poised-to-jointly-fund-a-400m-h2global-green-hydrogen-subsidy-auction-with-german-government/2-1-1588281

[20] https://www.asfi.org.au/taxonomy

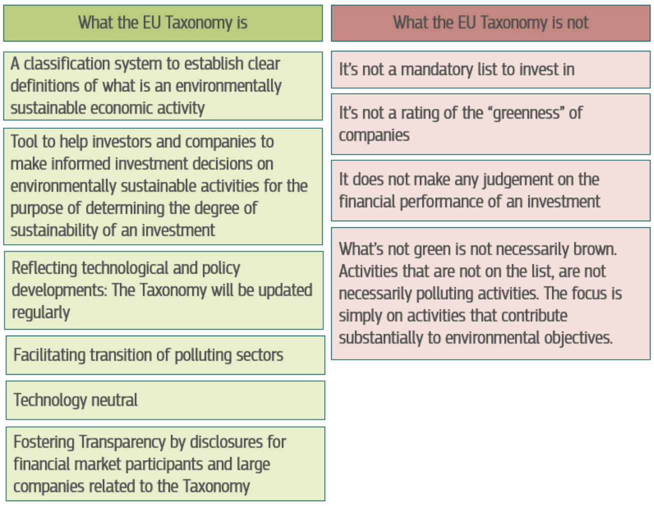
[21] https://www.edie.net/act-now-on-green-finance-taxonomy-or-risk-losing-investment-overseas-uk-government-told/

[22] https://www.edie.net/act-now-on-green-finance-taxonomy-or-risk-losing-investment-overseas-uk-government-told/

The European Union

To reach the objectives outlined in the European Green Deal (zero net emissions of greenhouse gases by 2050), the EU must direct investments into sustainable projects and activities, requiring a clear definition of what is sustainable. The EU Taxonomy Regulation entered into force on 12 July 2020, however the timeline for reporting obligations extends to 2026.[23] In July 2023, specific nuclear and gas energy activities were included in the list of economic activities covered by the EU taxonomy.

The EU taxonomy (**Figure 1**) defines sustainable economic activities as those providing a substantial contribution to one of six environmental objectives: climate change mitigation, adaptation, protection of water, ecosystems, circular economy and tackling pollution, whilst doing no significant harm (DNSH) to the other five, where relevant. This is enforced by the legislated Taxonomy Regulation.[24] Sustainability is defined under the DNSH principle (to be further defined by the European Commission), which ensures that an economic activity causing more damage to the environment than creating benefits cannot be classified as sustainable. Environmentally sustainable activities should also respect human and labour rights.



What the EU Taxonomy is	What the EU Taxonomy is not
A classification system to establish clear definitions of what is an environmentally sustainable economic activity	It's not a mandatory list to invest in
Tool to help investors and companies to make informed investment decisions on environmentally sustainable activities for the purpose of determining the degree of sustainability of an investment	It's not a rating of the "greenness" of companies
Reflecting technological and policy developments: The Taxonomy will be updated regularly	It does not make any judgement on the financial performance of an investment
Facilitating transition of polluting sectors	What's not green is not necessarily brown. Activities that are not on the list, are not necessarily polluting activities. The focus is simply on activities that contribute substantially to environmental objectives.
Technology neutral	
Fostering Transparency by disclosures for financial market participants and large companies related to the Taxonomy	

Figure 2. Primary aims of the EU taxonomy.[25]

Under the taxonomy, the greenhouse gas emissions threshold for hydrogen production must meet the lifecycle GHG emission savings of 73.4%, in comparison to 94g of CO_2 equivalent per MJ for fossil-based hydrogen[26], resulting in GHG emissions lower than 3 tonnes of CO_2 per tonne of H_2. This favours green hydrogen, however low-carbon blue hydrogen, (which uses carbon capture, storage and potentially utilisation) and turquoise hydrogen (which releases solid carbon) may also qualify as taxonomy-aligned[27]. The production of hydrogen-based fuels is also included as an eligible activity.

The EU taxonomy creates security for investors, protects private investors from greenwashing, assists companies become more climate-friendly, and mitigates market fragmentation. The rules and criteria used by the EU taxonomy will likely spread into other areas of EU law, such as state aid and guarantee of origin schemes. It should be noted that the EU taxonomy does not prohibit investment in any activity (**Figure 1**). It is a tool for identifying sustainable economic activities and directing financial flows towards these, but it is not prescriptive.[28]

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[23] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
[24] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852
[25] https://ec.europa.eu/sustainable-finance-taxonomy/
[26] https://ec.europa.eu/sustainable-finance-taxonomy/faq
[27] https://www.wr.no/en/news/how-does-the-eu-taxonomy-regulate-hydrogen
[28] https://www.unpri.org/policy/eu-policy/eu-taxonomy

Case Studies in the EU

As the reporting obligations for the EU taxonomy are yet to be fully implemented, some case studies have investigated the potential impact of the taxonomy. For example, the Principles for Responsible Investors (PRI) Taxonomy Practitioners Group (a leading proponent of responsible investment) have released a report discussing case studies of funds offered in Europe described as "environmentally sustainable", that must explain how, and to what extent, they have used the Taxonomy in determining the sustainability of the underlying investments[29]. The case studies illustrated the methods, challenges and solutions drawn on to implement the Taxonomy in their investment processes. For example, Aberdeen Standard Investments (ASI) used Bloomberg's Watchlist Analytics function, which enables the calculation of the percentage of revenue of underlying assets that sits within Taxonomy-eligible activities[30], as well as the MSCI environmental, social, and corporate governance (ESG) Manager to screen for DNSH and social safeguards[31]. It was determined that only 2.17% of the fund is aligned with the EU taxonomy, whilst 9.81% of the fund is potentially aligned.

The built environment sector has the second highest environmental impact in the EU, exceeded only by food and as such the EU Taxonomy holds significant potential to drive ambition and incentivize the closure of this circularity gap. Draft recommendations by the Platform on Sustainable Finance (PDF; established to offer continuous advice to the European Commission) for contribution to circular economy in the construction of new buildings and renovation of existing buildings, include (i) a focus on the design stage to ensure resource efficiency and avoid over-specification, (ii) keeping construction products and materials in use and at their highest value, and (iii) data driven approaches such as life cycle assessments (LCA) and digital databases[32].

Australia

The Australian Taxonomy Development Project (a joint industry-government initiative led by the Australian Sustainable Finance Institute) commenced in July 2023, with the aim of developing an Australian sustainable finance taxonomy in coordination with the development of taxonomies in other jurisdictions, across the Asia-Pacific region, the European Union, Canada, and the United Kingdom[33]. The first phase of the taxonomy's development will run until the end of 2024 and encompasses the development of climate change mitigation technical screening criteria for several of the priority sectors (Electricity generation and supply, Minerals, mining and metals, Construction and the built environment, Manufacturing/ industry, and transport, and Agriculture). The development phase will provide a foundation for an enduring taxonomy framework, which may include permanent institutional arrangements for taxonomy development and maintenance, and the incorporation of finalised taxonomy criteria into regulatory architecture to support sustainable finance.

Conclusion

This paper discusses the relevant aspects of financing for green hydrogen and derivatives projects. A significant amount of funding will be directed towards such projects over the next decades, requiring sustainable finance taxonomies in order to define sustainable investments credibly and transparently. The EU Taxonomy Regulation recently entered into force, whilst the Australian sustainable finance taxonomy is in development. Increasing investment in clean technologies hinges on enhancing access to low-cost financing, as the cost of capital is a critical influence on the levelised cost of hydrogen and derivatives. There is currently considerable investment by European-based companies into Australian renewable energy and hydrogen projects.

This publication was funded by the European Union. Its contents are the sole responsibility of Climate KIC Australia and does not necessarily reflect the views of the European Union.

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[29] https://www.unpri.org/download?ac=11662

[30] https://assets.bbhub.io/professional/sites/12/EU-Taxonomy-fact-sheet.pdf

[31] https://www.msci.com/documents/10199/0d289772-c7de-4bb3-8b37-7414600a900b

[32] https://www.chathamhouse.org/2023/06/making-sustainable-finance-taxonomies-work-circular-economy/02-eu-sustainable-finance

[33] https://www.asfi.org.au/taxonomy

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Australia European Union Green Hydrogen Dialogue #3: Background Paper

Challenges in the design and development of hydrogen supply chains.

Introduction

Significant efforts are needed to tackle the climate crisis by achieving the greenhouse gas (GHG) emission reduction targets of the Paris Agreement and limit global warming to 1.5°C. Since the Paris Agreement of 2015, the market for renewable energy – especially solar photovoltaics and wind power – increased significantly. Hydrogen has been discussed for decades but renewable electricity generation costs was too high to achieve cost competitiveness with fossil fuels. The drastic cost reduction of solar and wind energy over the past decade could make hydrogen cost competitive within the next few years.

For a truly sustainable hydrogen economy, a sustainable renewable production of hydrogen via renewable energy is required.This paper provides a short overview on hydrogen production and the solar and wind resources to discuss their scaling up as part of the green hydrogen supply chain, including firming issues for renewable energy and how we can increase capacity factor sustainably, transmission challenges, social license related to solar and wind infrastructure, financing issues with offshore wind and regulatory challenges for renewable projects.

Further challenges in the design and development of complex hydrogen supply chains and the diversity of applications for hydrogen and its derivates includes the needs for co-ordination between governments, industry and investors as well as infrastructure providers to develop the required physical and market infrastructure.

Renewable energy potential for hydrogen

Green hydrogen production will require significant amounts of additional renewable electricity generation capacity. Therefore, the solar and wind potentials of Australia and the EU will play a significant role in future hydrogen supply policies. The required hydrogen production in comparison with the available suitable land for renewable electricity generation will have a major impact whether the hydrogen will be produced domestically or imported. In this sector we compare the solar and wind potential of the EU27 with Australia.

The aim of mapping the solar and wind resources for Australia and Europe (EU27) is to quantify their short- and long-term potential and to identify possible locations for additional renewable energy zones. This analysis has been undertaken by UTS/ISF between July 2023 and March 2024 as part of the One Earth Climate Model research financed by the European Climate Foundation[1] and the Australian Climate Council[2]. The cited publication provides details about the applied methodology.

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[1] Teske, S., Rispler, J., Niklas, S. et al. Net-zero 1.5 °C sectorial pathways for G20 countries: energy and emissions data to inform science-based decarbonization targets. SN Appl. Sci. 5, 252 (2023). https://doi.org/10.1007/s42452-023-05481-x

[2] Teske, S., Rispler J., Miyake, S. (2024) Australia: Aim High, Go Fast: Why Emissions Need to Plummet this Decade. Limiting global warming to 1.5 °C.; Sectoral pathways & Key Performance Indicators for Net-Zero Target Setting , Infrastructure Requirements for the National Electricity Market (NEM), Western Australian and the Northern Territory; prepared for the Climate Council. by the University of Technology Sydney, Institute for Sustainable Futures; March 2024, https://www.uts.edu.au/oecm/australia

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Australia's Solar Potential

Australia 's power sector integrates rapidly increasing solar and wind electricity shares. In 2022, solar photovoltaic produced 22 TWh and wind around 19 TWh, both playing major roles in 2022 in combination with hydropower (16 TWh) and bioenergy (4 TWh)[3]. Given Australia's renewable electricity target of 82% by 2030, significant additional renewable electricity—especially solar photovoltaics and wind power—is required.

The yearly total solar irradiation (DNI) level in Australia is 334–2,980 kWh/m^2, and the higher end of that range is in the central outback regions of the Western Australia, South Australian, the Northern Territory, Queensland, and New South Wales. Solar radiation is lower in the southern and eastern coastal regions and in Tasmania.

Australia's solar potential has been mapped under two different scenarios:

Scenario 1. Available land excluding protected areas (PA), extreme topography (slope > 30%, mountainous areas; S30), and certain land-cover classes (including closed forests, wetlands, moss and lichen, snow and ice, and water [permanent water bodies]; LU).

Scenario 2. See Scenario 1, with the additional restriction that excludes areas ≤ 10 km from an existing transmission line (PT10).

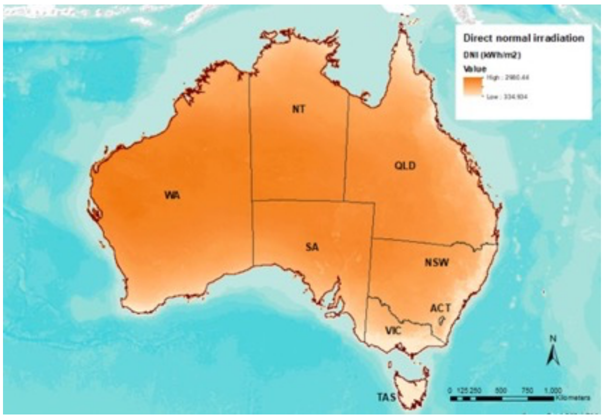

Figure 1: Australia's direct normal irradiation (DNI) (generated from data from the Global Solar Atlas)

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[3] International Energy Agency: https://www.iea.org/data-and-statistics/charts/tanzania-electricity-generation-by-technology-in-the-stated-policies-scenario-2010-2040

Table **1** shows the solar potential areas under Scenario 1 (LU + PA + S30) Figure 1 and Scenario 2 (LU + PA + S30 + PT10) (Figure2). All results indicate extremely large solar energy potentials in Australia.

Table 1: Australia's potential for utility-scale solar photovoltaic

Scenarios	**1. LU + PA + S30**		**2. LU + PA + S30 + PT10**	
Scenario Regions	Solar Potential Area (km^2)	Solar Potential (GW)	Solar Potential Area (km^2)	Solar Potential (GW)
Australian Capital Territory	721	18.0	700	17.5
New South Wales	657,654	16,441.4	137,056	3,426.4
Northern Territory	621,277	15,531.9	11,545	288.6
Other Territories	9	0.2	0	0.0
Queensland	1,419,857	35,496.4	132,412	3,310.3
South Australia	512,137	12,803.4	57,203	1,430.1
Tasmania	19,134	478.3	10,128	253.2
Victoria	134,222	3,355.5	45,922	1,148.0
Western Australia	1,775,960	44,399.0	81,251	2,031.3
TOTAL	5,140,970	128,524.3	476,217	11,905.4

Scenario 1 provides 5,140,970 km^2 of area with solar potential and a total potential solar photovoltaic capacity of 128,524 GW and excludes all protected areas and areas with slopes > 30%, because installing and maintaining solar panels in steep areas is unrealistic. Most agricultural and rural land-use classes (e.g., grazing, cropping, horticulture) and some urban land-use classes (for example manufacturing and industrial, services, utilities) in the catchment-scale land use of the Australia dataset (Australian Bureau of Agricultural and Resource Economics) are included. However, certain land-use classes (e.g., nature conservation, managed resource protection, all forest land-use classes, some urban and infrastructure land uses, and water bodies) are excluded from the scenarios selected for the consideration of solar energy potential.

Figure 2 shows the areas of solar potential under Scenario 2 (LU + PA + S30 + PT10). When the land area is restricted by its proximity to electricity transmission lines (10 km), the potential solar areas decrease to 476,217 km^2. However, solar energy in Australia can still harvest 11,905 GW of solar photovoltaic under Scenario 2.

Australia’s Onshore Wind Potential

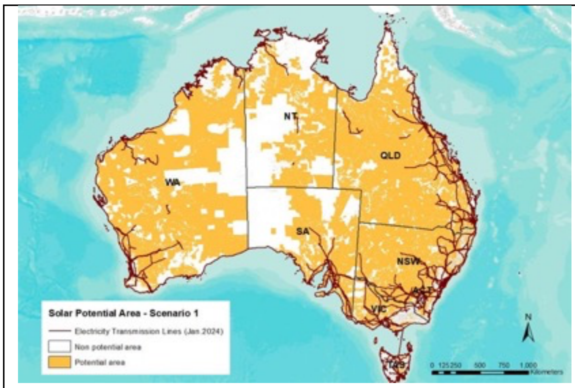

Figure 2: Australia’s areas of solar potential (Scenario 1: LU + PA + S30)

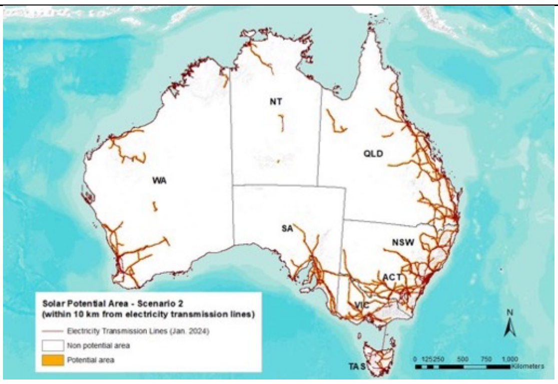

Figure 3: Australia’s areas of solar potential (Scenario 2: LU + PA + S30 + PT10)

The overall onshore wind resources are low in Australia compared with its solar potential. The wind speeds in Australia range from 1.7 to 17.3 m/s at 100 m height, and high-wind-speed areas are located around Victoria and Tasmania (Global Wind Atlas).

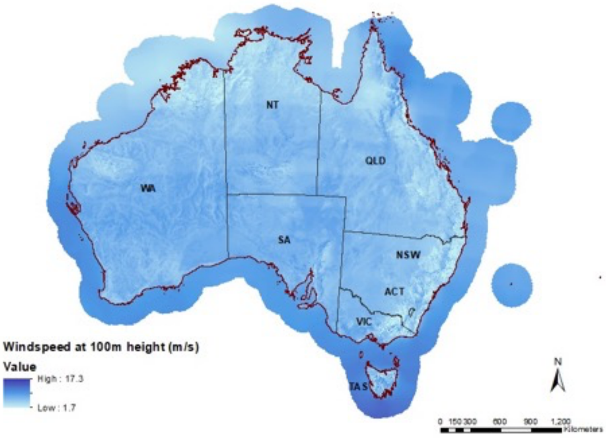

Figure 4: Australia’s wind speeds at 100 m height (m/s) (data generated from the Global Wind Atlas)

In this analysis, we include only areas with an average annual wind speed of ≥ 5 m/s for onshore projects. Australia’s wind potential has been mapped under two different scenarios. The current use of wind energy in Australia involves utility-scale wind turbines in the range up to 10 kilowatts, operated both on- and off-grid as battery chargers.

- Scenario 1: Available land—excluding protected areas (PA), extreme topography (slope > 30%, mountain areas; S30), and some existing land use, including forests and urban areas (LU).
- Scenario 2: See Scenario 1, with the additional restriction that areas ≤ 10 km from existing transmission lines are excluded (PT10).

Most agricultural and rural land-use classes (grazing, cropping, rural residential and agriculture, farm buildings) are included in the available land (LU) for the two wind scenarios, whereas the land-use classes of nature conservation, managed resource protection, all forest land-use classes, intensive agriculture, urban/built-up areas, and permanent water bodies are excluded in this analysis of wind potential.

Table 2 shows that the overall total onshore wind potential under all restrictions is 24,254 GW for Scenario 1. Overall, the spatial analysis identified limited wind potential in Australia, especially under Scenario 2 (2,006 GW) because there are limited areas with an annual wind speed of ≥ 5 m/s and most of these areas are not located within close proximity to transmission lines (≤ 10 km). However, the results show that Australia has a large wind energy potential, even with all the restrictions.

Table 2: Australia’s potential for utility-scale onshore wind power

Scenarios	1. LU + PA + S30		2. LU + PA + S30 + PT10	
Regions	Onshore Wind Potential Area (km²)	Onshore Wind Potential (GW)	Onshore Wind Potential Area (km²)	Onshore Wind Potential (GW)
Australian Capital Territory	146	0.7	145	0.7
New South Wales	598,145	2,990.7	106,622	533.1
Northern Territory	566,679	2,833.4	6,698	33.5
Other Territories	7	0.0	0	0.0
Queensland	1,326,639	6,633.2	109,726	548.6
South Australia	505,265	2,526.3	54,480	272.4
Tasmania	16,362	81.8	8,226	41.1
Victoria	121,555	607.8	38,874	194.4
Western Australia	1,715,955	8,579.8	76,601	383.0
Total	4,850,753	24,253.8	401,370	2,006.3

Australia’s Offshore Wind Potential

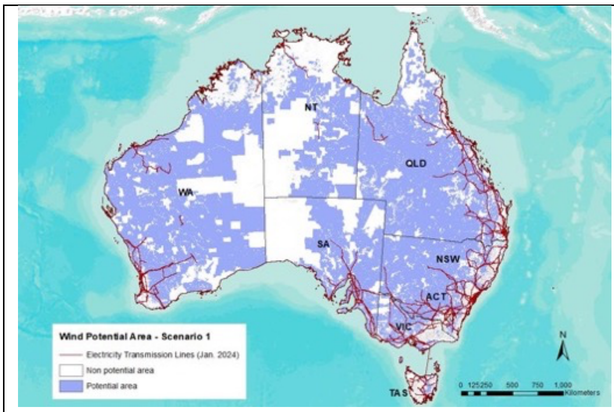

Figure 5: Australia’s areas of onshore wind potential (Scenario 1: LU + PA + S30)

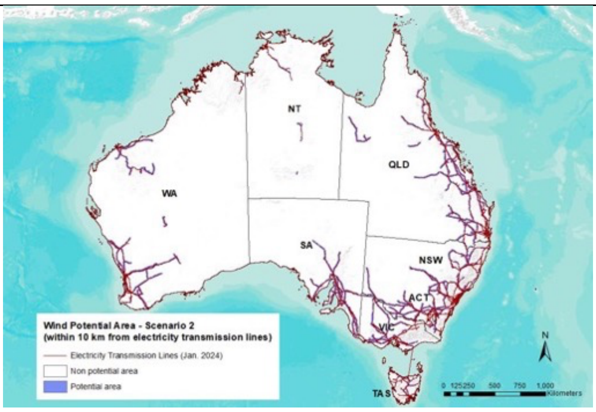

Figure 6: Australia’s areas of onshore wind potential (Scenario 2: LU + PA + S30 + PT10)

The wind speeds in the offshore areas of Australia range from 2.7 to 12.2 m/s at 100 m height (Global Wind Atlas). For the analysis of offshore wind, we have included areas with an average annual wind speed of ≥ 6 m/s, because offshore wind projects usually require higher wind speeds than onshore wind projects to ensure its economic viability. Australia’s offshore wind potential has been mapped under two different scenarios.

- Scenario 1: Available offshore areas—excluding protected areas (PA), ocean depths ≤ 50 m (WD50), and proximity to major maritime ports (≤ 50 m, PRT50) (PA + WD50 + PRT50).
- Scenario 2: Available offshore areas—excluding protected areas (PA), ocean depth of ≤ 500 m, WD50), and proximity to major maritime ports (≤ 50m, PRT50) (PA + WD500 + PRT50).

The overall total area of offshore wind potential is 347,578 km^2 (1,738 GW) for Scenario 1 and 1,063,527 km^2 (5,318 GW) for Scenario 2.Figure 8 show the offshore wind potential areas for Scenario 1 and Scenario 2.

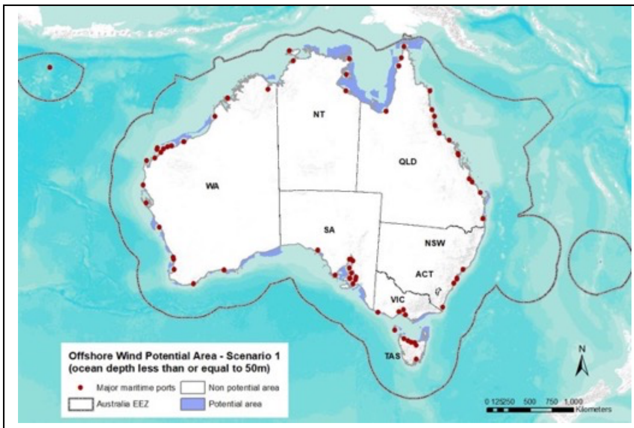

Figure 7.: areas of offshore wind potential (Scenario 1: PA + WD50 +PRT50)

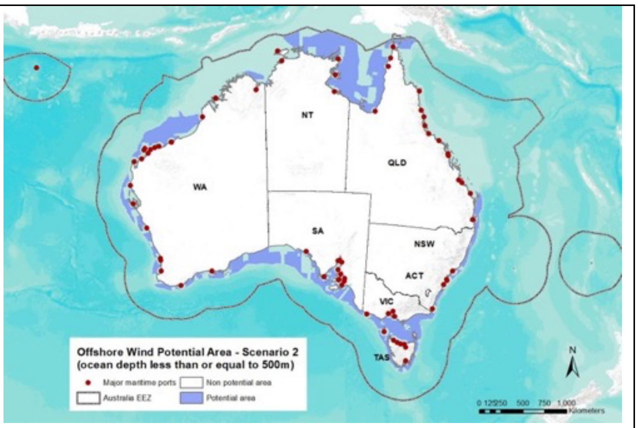

Figure 8.Australia's areas of offshore wind potential (Scenario 2: PA + WD500 + PRT50)

Europe's solar and wind potential

The European solar and onshore wind potential has been analysed using the same methodology that was used for the Australian analysis. Table 3 shows the results for Europe in comparison with Australia.
Australia's solar and wind potential is - each - around 4.5 times larger than Europe's (EU27). Therefore, Australia is likely to become a green hydrogen exporter while the densely populated Europe is likely to import hydrogen.
Table 3: Solar and onshore wind potential for EU27, Germany, France and Italy in comparison with Australia

Countries	Land Area (km2)	Solar Potential Area (km2)	% of land area	Solar Potential GW	Solar Electricity generation Potential in [TWh/a]	Wind Potential Area (km2)	% of land area	Wind Potential GW	Wind Electricity generation Potential in [TWh/a]
EU 27 total	**11,338,961**	**1,376,111**	**12.1%**	**34,403**	**39,563**	**1,341,500**	**11.8%**	**6,708**	**20,123**
France	1,164,260	265,673	22.8%	6,642	7,638	249,777	21.5%	1,249	3,747
Germany	908,408	57,837	6.4%	1,446	1,663	139,764	15.4%	699	2,096
Italy	560,984	158,793	28.3%	3,970	4,565	49,817	8.9%	249	747
Australia	**9,649,980**	**6,478,611**	**67.1%**	**161,965**	**186,260**	**6,126,725**	**63.5%**	**30,634**	**91,901**

Note: Calculate capacity factors (in full load hours) for the solar generation potential 1150 hour per year and wind 3000hours per year

Australia's renewable energy market: state of play and constraints[4]

Australia is now one of the global leaders in the transition from a coal-dominated electricity system to renewable energy. The share of renewable energy in the National Electricity Market was around 38 per cent for 2023. In the 2024 Integrated System Plan (ISP), the Australian Energy Market Operator (AEMO) outlines a series of scenarios for energy transition which see the exit of coal-fired power in 2038 and an electricity system dominated by renewable energy from the early-2030s.

There are however, risks to achieving a successful energy transition, including enabling investment to fund 6 gigawatts of new large-scale renewable **per annum**. Whilst there is a very large pipeline of renewable energy projects at various

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[4] Business Renewables Centre Australia – Corporate Renewable Power Purchase Agreements in Australia State of the Market 2023, 2024.

stages of development, there has been a slowdown in investment, construction, and connection of large-scale renewable energy in recent years due to factors such as delays in planning approvals, transmission congestion and inadequate commitments to offtake agreements.

The slowdown in renewable energy investment and a large pipelines of projects

The installation of large-scale renewable energy has slowed significantly after the rapid growth to achieve the Renewable Energy Target. Strong growth in new solar and wind farms occurred from 2017 – 2021, reflecting Power Purchasing Agreements (PPAs) signed by retailers to meet commitments under the RET and the growing Corporate PPA market.

However, there has been a slowdown in new investment in solar and wind farms due to a combination of factors including:
- Lower interest amongst major electricity retailers following the achievement of the 2020 RET;
- Grid connection issues which have led to delays and increased risks for new projects;
- Global supply-chain inflation and emerging skill shortages have increased project costs;[5]
- Increased financing costs due to rising interest rates and risk premiums.

The Australian Energy Market Operator's (AEMO) project pipeline illustrates that there remains an enormous volume of renewable energy projects under development. Based on AEMO's generator information, there is over 40 GW of solar, almost 70 GW of wind and almost 40 GW of battery storage projects proposed. Only a small proportion of projects in the pipeline have secured finance: there is a large number of projects seeking a power purchase agreement to proceed.

Since the election of the Labor Government, there have been a series of major policy and program developments at Federal and State level such as Rewiring the Nation to accelerate transmission construction. In the draft 2024 Integrated Systems Plan, AEMO has continued to highlight that increased investment certainty is required to enable the rapid, large-scale investment in renewable energy required to transition the National Electricity Market.

For large-scale renewable energy procurement, there are major programs in Federal and State jurisdictions. At a state level, New South Wales (Electricity Infrastructure Investment Roadmap), Victoria (Victorian Renewable Energy Target) and Queensland (Energy and Jobs Plan) continued to implement transition programs. The major development at the Federal level in 2023 was the announcement of the Capacity Investment Scheme. Reverse auctions will be undertaken in partnership between the Federal and State Government to support $10 billion of investment in renewable energy generation supported by batteries, pumped hydro and other long-duration storage.

Offshore Wind

As outlined above there is significant offshore wind potential along the Australia coastline. It is in the very early stages of development in Australia in comparison to onshore wind, large scale solar PV and the offshore wind markets in Europe. It is expected to be a key component in the country's renewable energy transition and could play a key role if located nearshore to land based hydrogen production and other off-takers.

The Offshore Electricity Infrastructure Act 2021 (OEI Act) provides a licensing scheme to enable the construction, operation and decommissioning of offshore renewable energy and offshore electricity infrastructure projects. The OEI Act framework applies to offshore locations from three nautical miles from the coast to the boundary of Australia's exclusive economic zone (coastal waters remain the responsibility of the adjacent state and Northern Territory governments). A regulation has been passed and 2 zones (6 are planned) have been formally declared – Gippsland in Victoria and the Hunter in NSW.

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[5] Bloomberg New Energy Finance estimates the global cost of onshore wind increased 7 per cent and solar 14 per cent during 2022 due to supply-chain factors. See Bloomberg New Energy Finance (2022) 'Cost of New Renewables Temporarily Rises as Inflation Starts to Bite', https://about.bnef.com/blog/cost-of-new-renewables-temporarily-rises-as-inflation-starts-to-bite/.

There are still significant gaps in the OEI Regulatory Framework. Existing laws allow proponents to apply for, and the government to grant, feasibility licences, however, until future regulations are released relating to financial security and management plans, substantive feasibility, construction, operation and decommissioning activities cannot occur.

Proponents will need to manage state-based approvals and will be require environmental approval under the Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth). A number of major Australian and International project developers and funders have entered the Australian offshore wind market with the announcement of various project proposals, including CIP, DP Energy, EDF Renewables, Equinor, Iberdrola, Flotation Energy and BlueFloat Energy (among others).[6]

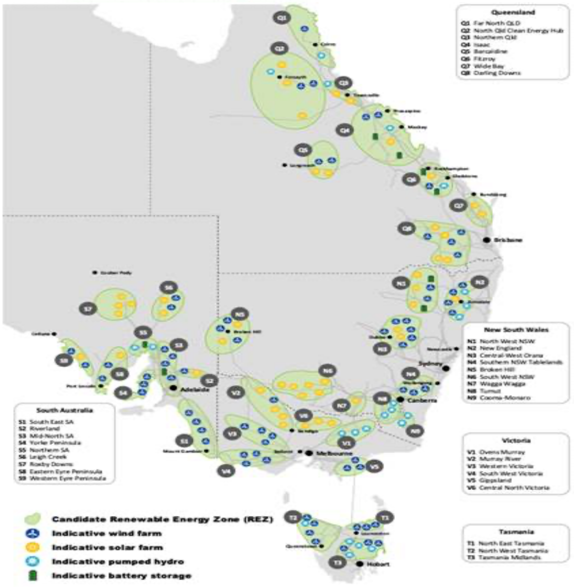
The upstream and downstream renewable energy infrastructure required for hydrogen supply chains presents further challenges, which could impact scalability and therefore economic performance of green hydrogen production:

Upstream: Utility scale renewable power generation – mainly solar and wind – requires access to land for the power plant(s). Furthermore, the equipment for power generation (solar pv modules, wind turbines etc.) and hydrogen production (electrolyser) must be accessible within the region of hydrogen production, which could raises challenges especially in remote areas of Australia.

Downstream: Once produced, the hydrogen must be transported to the point of use – either to industry customers such as the iron and steel or chemical industry or to distribution networks such as pipelines or ports.

The utilization of local renewable energy resources for hydrogen production will reduce potential electricity production for domestic electricity usage. This might have a negative impact on public acceptance for utility scale solar and or wind projects. Australia has identified renewable energy zones (REZ) – priority zones for renewable energy production to optimize the use and integration of variable power generation. There are 9 REZ in NSW and South Australia, 8 REZ in Queensland, 6 REZ in Victoria and 3 REZ in Tasmania. (see map below).

Figure 13 Identified candidate Renewable Energy Zones (REZs) for assessment in developing the optimal development path in the NEM



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[6] Norton Rose Fullbright - Global offshore wind: Australia, 2024 - https://www.nortonrosefulbright.com/en/knowledge/publications/ec2a685f/global-offshore-wind-australia

Conclusion

This paper summarizes some key issues in the renewable energy and hydrogen supply chain. There is no limit to the potential capacity in the Australian landscape to produce the required GW of renewable energy required for large scale hydrogen industry in Australia both for domestic use and large potential export markets.

The challenges are common across the EU and Australia:

- Grid integration and capacity constraints.
- Global supply chain issues, access to hardware and specialised skills sets.
- Ensuring adequate offtake agreements to trigger project financing.
- Balancing complex environmental and social licence issues
- Resolving planning and co-ordination challenges issues across jurisdictions

The expansion of a green hydrogen industry in Europe and Australia will require a shared view in relation to technology and market trends to develop the policy and regulatory frameworks that enable investments for the renewable energy industry but also for the financial institutions who are committed to net-zero pathways

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AUSTRALIA EUROPEAN UNION GREEN HYDROGEN DIALOGUE
Background Paper #4:

Social License, Community Acceptance, and Environmental Impacts

Introduction

Social license, environmental impact, and community acceptance are key issues that must be addressed in the development of hydrogen and derivatives projects to gain and maintain public acceptance and to preserve the natural environment to the greatest extent possible. This is a requirement from both the production side (for project approval) and from the market side (to ensure that the hydrogen is renewable and has met the necessary sustainability criteria – note that this is explored in Background Paper 1 and 3). This paper explores several key issues including land use, water use, and hydrogen safety, and elaborates on lessons learned from current hydrogen projects.

Social License, Environmental, and Community Acceptance Issues

The scaleup of green hydrogen production poses several environmental and social challenges. Consideration must be given to land and freshwater resources (**Figure 1**),[1] whilst the social acceptance of hydrogen depends on public acceptance of hydrogen (and derivative) use and safety measures, as well as community trust, project transparency, distributive justice, and benefit sharing.[2]

Land

Large-scale generation of hydrogen and derivatives requires land availability for both renewable electricity generation and for hydrogen electrolysis, along with the required associated infrastructure (such as storage facilities, pipelines, ports or other transport, etc.). Even in regions with abundant land, such as Australia, North Africa, and the Middle East, who are positioning themselves to be large-scale hydrogen producers, availability near port and necessary infrastructure and water sources is discussed as key issues. Constraints and issues relating to land use include:

- **Plant footprint.** Solar and wind farms require around 0.5 – 3.0 hectares per MW, whilst an electrolyser system can take up around 30 – 100 m^2 of space per MW, corresponding to an area of around one football field for a 100 MW system[3]. These requirements may extend themselves as challenges to the implementation of large-scale projects in areas with low land availability, for example coastal areas in Australia (that have access to seawater for hydrogen production) have higher population density and more forested areas. Hydrogen production could be undertaken in one location and renewable electricity generation in another location; however, this then necessitates the use of transmission lines, which themselves require land across a large corridor. For example, the cost of the HumeLink transmission line from the Snowy 2.0 pumped hydro project in the Mount Kosciuszko National Park in Australia has blown out by 30% to around AU $5 billion.[4] Consideration is being given to building the line underground, however this may double the cost, whilst the overground line could increase risk of bushfires during storms, as well as affect the local biodiversity.
- **Land clearing.** High levels of forested land or agricultural land may require deforestation or land clearing, potentially hindering national land use, land-use change and forestry (LULUCF) targets, as well as potentially causing damage to the surrounding environment (such as by polluting waterways or affecting native or endangered flora and fauna). Further, it may be challenging to gain local community acceptance in areas that require this land clearing. For example, there has been opposition to the Chalumbin Wind Farm in Queensland, which would entail the clearing of 1,000 hectares of forested land, causing biodiversity damage and the loss of species.[5] A consideration of the likely

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[1] https://www.nature.com/articles/s41467-023-41107-x

[2] https://iopscience.iop.org/article/10.1088/1748-9326/ac991a/pdf

[3] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

[4] https://www.afr.com/policy/energy-and-climate/transgrid-inflated-cost-of-running-power-line-underground-farmers-20230718-p5dp2o

[5] https://www.abc.net.au/news/2023-08-04/chalumbin-wind-farm-proposal-draws-traditional-owners-ire/102682158

impacts of a development on the natural and built environments, and social and economic impacts in a locality, must be undertaken through an Environmental Impact Assessment (EIA).

- **Restrictions**. Site selection can be restricted by proximity to sensitive land uses such as residential use, the requirement for transport infrastructure, as well as land use zonings that may exclude protected areas, forests, wetlands, urban centres, and areas with unsuitable slope or water availability, among others [6]. A key element of Australia's hydrogen strategy is the creation of hydrogen hubs – clusters of large-scale demand that may be located at ports, cities, or in regional locations, aimed at making the development of infrastructure more cost-effective, and promoting efficiencies via economies of scale. However, these are likely to be developed in areas that currently have the appropriate infrastructure, and are thus highly developed and/or industrial zones, where space may be limited and local populations may oppose large-scale projects.
- **Leasing or acquisition of land from traditional landowners.** Projects in Australia must undertake an assessment of potential impacts on Aboriginal cultural heritage and nonaboriginal heritage. Queensland and Western Australia have both implemented policies and South Australia is developing legislation that requires renewable energy developers to negotiate an agreement with First Nations land holders.[7] A $593 million hydrogen plant and storage facility project in development in Whyalla, South Australia has mostly gained favour with local communities, who raise the key issues of environmental impact and effect on local employment and health. Increasing population and employment in the region was touted as a primary benefit.[8] In Norway, the Indigenous Sami people have opposed the expansion of wind energy, due to the migration patterns of reindeer and the impacts on Indigenous ways of life.[9]

Water

Hydrogen production is water intensive. On a stoichiometric basis (i.e., the number of molecules of hydrogen that are released from a molecule of water), electrolysis requires around 9 kg of water per kg of hydrogen produced. In reality, the water required is much higher (up to 95 L, i.e. 95 kg, per kg of hydrogen[10] – note that this value is even higher for the production of hydrogen derivatives), due to several factors:

- **High purity water is required.** Depending on the type of electrolyser, the input water must be demineralised and deionised, with a low total organic carbon content and a low conductivity of <1 µS/cm) to ensure optimum operation. This can be a challenge when only low-purity water is available, such as groundwater in Australia that has competing use in the mining industry.
- **Desalination processes may be required.** Whilst the deionisation of fresh water may lend to the majority of input water being used in the electrolysis process, alternative sources of water are being considered in light of water availability challenges, including seawater, wastewater from sources including municipal, industrial, and resource extraction (wastewater from natural gas/oil and mining), as well as brackish groundwater. The purification and deionisation of seawater can more than double the water requirement, as reverse osmosis (RO) might recover only 40 – 50% of water as the permeate. A further challenge is the disposal of the reject brine from desalination processes, which contains a salt load approximately twice that of seawater, which can cause adverse effects to local waters and aquatic life upon discharge to the environment. For example, desalination in the Middle East may face challenges in the future due to the increasing salinity of the Gulf region, due to the discharge of highly saline brine.[11]
- **Process cooling.** Additional water is required to support the balance of plant (BoP) and electrolyser operations, primarily for cooling.

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[6] https://www.planning.nsw.gov.au/sites/default/files/2023-03/hydrogen-guideline.pdf

[7] https://theconversation.com/beyond-juukan-gorge-how-first-nations-people-are-taking-charge-of-clean-energy-projects-on-their-land-213864

[8] https://www.abc.net.au/news/2023-10-24/whyalla-residents-wary-hydrogen-project-partners-announced/103008968

[9] https://www.rifs-potsdam.de/en/blog/2023/01/grabbing-land-or-benefitting-communities-renewable-hydrogen-norwegian-arctic

[10] https://www.sciencedirect.com/science/article/pii/S277242712200078X

[11] https://www.mei.edu/publications/water-issues-gulf-time-action

It is estimated that water purification, cooling, and BoP requirements will increase the water requirement from 9 kg per kg of hydrogen, to between 20 – 75 kg per kg of hydrogen[12]. Current options for reducing water usage include recovery and recycling of water used for cooling, the use of air cooling where possible, and the use of zero liquid discharge (ZLD) solutions for water desalination, converting reject brine into fresh water and potentially valuable mineral by-products.

Many countries with ambitious hydrogen strategies and abundant renewable resources, including Australia, Chile, India, the MENA region, and China, are facing water availability challenges, which may become exacerbated in the face of global climate change. For example, Australia is projected to require over 200 billion gigalitres of water for the hydrogen industry by 2050, equivalent to around 3% of the water currently used for agriculture.[13] However, fresh water in Australia is already mostly allocated to towns, cities, agriculture, industry, and the environment, and thus it may be difficult to allocate this water with a growing population and decreasing freshwater availability. Groundwater (commonly used for mining) is another possible source; however this causes lowering of the water table, and this low-quality water would require significant processing for hydrogen production, requiring significant energy input and leading to large volumes of waste.[14]

Future policy must balance the management of water resources with the long-term plans for the hydrogen industry, which will potentially require additional investment and energy consumption.

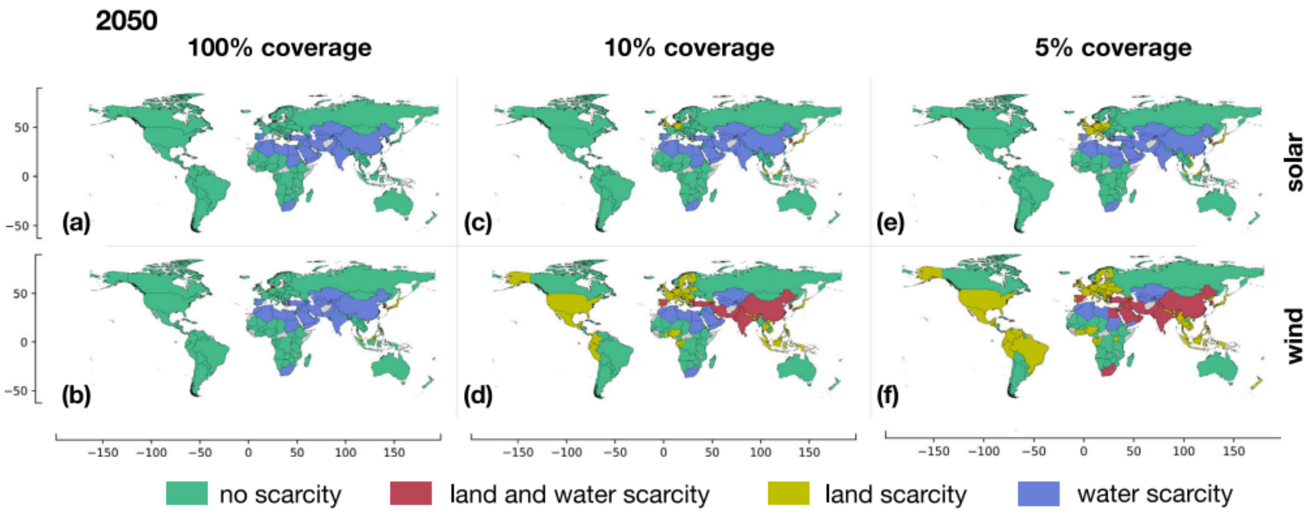

Figure 1. Projected land and water scarcity induced by projected hydrogen production in 2050 for all countries worldwide, considering various fractions of land coverage (the area that can be technically used for renewables) for **a, c, e** solar and **b, d, f** onshore wind power production.[15]

Safety

The safety of hydrogen is a primary issue in achieving social license and community acceptance. The primary safety-related aspects of hydrogen include:

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[12] https://aecom.com/without-limits/article/hydrogen-and-the-water-challenge/#:~:text=Water%20availability%20and%20ramping%20up%20hydrogen%20production&text=Given%20that%20each%20kilogram%20of,these%20projects%20were%20to%20materialise.

[13] https://theconversation.com/for-australia-to-lead-the-way-on-green-hydrogen-first-we-must-find-enough-water-196144

[14] https://www.igrac.net/the-five-main-issues-and-challenges-of-groundwater-mining.html

[15] https://www.nature.com/articles/s41467-023-41107-x

- Hydrogen is highly flammable and burns with an invisible flame. Hydrogen has a very wide flammability range (from 4% to 74% in air) and has a very low ignition energy. The risk of fire and explosion is therefore very high in some applications.[16]
- Hydrogen can easily leak and cause embrittlement in equipment such as storage vessels, pipelines, and flanges due to its small molecular size, however, as it is much lighter than air it dissipates quickly in open environments if it leaks.
- Hydrogen can be difficult to detect, as it has no odour or taste. Hydrogen gas is non-toxic but can be an asphyxiant if it dilutes or replaces air.
- Liquid hydrogen can cause damage to tissue due to its low temperature. Loss of liquid hydrogen via boiloff occurs during transport and storage, increasing the pressure within vessels. Liquid hydrogen can also cause the condensation of other gases, potentially causing solidified air to plug pipes and orifices and jam valves. On the Suiso Frontier, the world's first liquid hydrogen carrier vessel, flames emerged on the deck only one day after loading its first shipment, due to an incorrectly fitted valve and an ineffective automated safety system in the boiloff procedure.[17]

As hydrogen use becomes more widespread in industry and the community, management is critical to ensure safety during production, storage, handling, transport, and end use. This includes the development and implementation of regulations and standards, which is an ongoing process as hydrogen is an evolving field, with new methods of generation, application, and storage rapidly emerging.

If handled properly, hydrogen is safe, however social acceptance of hydrogen relies upon alleviating public concerns regarding its safety. Most concerns centre around the transportation (via road, rail, pipeline, and shipping), storage, and end use of hydrogen. Additional safety measures are required for hydrogen derivatives. For example, ammonia vapour is reactive and toxic, whilst ammonia spills can cause significant environmental damage. Ammonia derivatives such as ammonium nitrate are highly explosive; the Beirut ammonium nitrate blast in 2020 claimed the lives of 220 people and injured more than 6,500.[18] Renewable methanol and sustainable aviation fuel share the same safety requirements as their fossil-based counterparts, the primary risk on an industrial scale being their flammability.

Distributive Justice and Benefit Sharing

On a local scale, communities nearest to large scale hydrogen projects are likely to be the most affected. Direct community benefits are important to ensuring local communities are treated fairly, while simultaneously building support that can bolster project development[19]. Several methods by which governments can ensure the fair treatment and integration of project-affected communities include:

- Community consultation or co-design of regional benefit-sharing arrangements.
- Access to effective and accessible grievance mechanisms.
- Shared community ownership, where communities receive a fair distribution of benefits from renewables projects. For example, the East Kimberly Clean Energy Project in Australia is majority owned by the region's Traditional Owners.[20]
- Intergenerational benefits beyond the local community and affected landowners.

In Australia, the First Nations Clean Energy Strategy will give First Nations people a say in renewable energy policies and programs and will identify improvements and areas for future investment.[21] The First Nations Clean Energy Network

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[16] https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/h2_safety_fsheet.pdf

[17] https://www.hydrogeninsight.com/transport/cause-of-one-metre-flames-on-world-s-first-liquefied-hydrogen-vessel-identified-after-year-long-investigation/2-1-1398008

[18] https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2021.657996/full

[19] https://ccsi.columbia.edu/sites/default/files/content/docs/ccsi-benefit-sharing-policy-guidance.pdf

[20] https://www.re-alliance.org.au/first_nations_co-ownership

[21] https://www.energy.gov.au/energy-and-climate-change-ministerial-council/working-groups/first-nations-engagement-working-group/first-nations-clean-energy-strategy?utm_source=sendgrid.com&utm_medium=email&utm_campaign=website%5C

provides guides for Best Practice Principles for Clean Energy Projects, Clean Energy Planning Toolkit for First Nations, and Clean Energy Negotiations Guide for First Nations, assisting First Nations people in understanding and playing a role in renewables projects, and advocating for their share of the benefits.[22]

On an international scale, questions of benefits and fairness arise from the global disparity between climate targets, infrastructure, export and import capabilities, and renewable resources[23]. For example, whilst the EU has committed to using green hydrogen, land and renewables constraints[24] may mean that the production of this hydrogen must be undertaken in regions such as Australia, Asia, Africa, and South America. This in turn effectively outsources many issues discussed above, including water and land use, and effects on the local environment. Further, such regions may realise an economic benefit in place of their own sustainable development in order to facilitate the nations to which they export. This can further inequities rather than leading to a more just energy transition, and thus policy must focus on ensuring that benefits of the hydrogen economy are equally distributed.

Case Studies and Lessons Learned

Land

In general, the EU does not always require consideration of traditional land ownership as in other nations (such as Australia). Land availability issues are more centred around the lack of available land, particularly in strategic import, export, and distribution hubs in the EU, which may lead to hydrogen production facilities that are decoupled from renewable electricity generation plants. For example, Lhyfe has unveiled plans for a new 800 MW project in Lubmin, Germany, which aims to primarily source renewable power for electrolysis from the grid and cover it via a power purchase agreement (PPA), rather than directly building new wind or solar capacity to supply the plant[25]. The plant will be built on the site of a decommissioned nuclear power plant, which improves public acceptance.

In Australia, the Murchison Green Hydrogen Project in Western Australia will use combined onshore wind and solar energy of approximately 5.2 GW capacity to produce green hydrogen, which will be converted to an estimated 2 Mtpa of green ammonia for export to emerging green energy markets. The project has been in consultation with the Nanda Aboriginal Corporation to develop an Indigenous Land Use Agreement that will include business, employment, and training opportunities, including adopting Australia's Reconciliation Action Plan, and undertaking heritage site surveys with Aboriginal heritage monitors and monitored representatives of the Nanda people[26]. In South Australia, the South Australian Aboriginal Renewable Energy Forum (SAAREF) was formed to provide a two-way conversation between Aboriginal people and the Government to help inform the development of the Hydrogen and Renewable Energy Act, and to and facilitate a discussion on how the renewable transition can be a vehicle for Aboriginal self-determination.[27]

Land right laws vary by the legal regime that the land is under. For example, in the Pilbara region, Fortescue Metals Group did not reach an agreement with the Yindjibarndi people who hold native title to the area, and controversially built their Solomon iron ore mine with access to the land granted by the government.[28] On the northern coast of Australia, Indigenous community members from the Tiwi Islands took Santos Limited to court over plans to drill in the Barossa gas project, where the court ruled in favour of the Indigenous community.[29] In Western Australia, the East

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[22] https://www.firstnationscleanenergy.org.au/network_guides

[23] https://iopscience.iop.org/article/10.1088/1748-9326/ac991a/pdf

[24] https://www.carbonfreeeurope.org/product/european-land-use-constraints-in-a-net-zero-world

[25] https://www.hydrogeninsight.com/production/french-developer-announces-massive-green-hydrogen-project-in-germany-to-feed-into-h2-pipeline-network/2-1-1563067

[26] https://www.murchisonrenewables.com.au/community-and-sustainability/traditional-owners-engagement/

[27] https://www.energymining.sa.gov.au/industry/modern-energy/south-australian-aboriginal-renewable-energy-forum-saaref

[28] https://theconversation.com/why-aboriginal-people-have-little-say-over-energy-projects-on-their-land-139119

[29] https://news.mongabay.com/2022/09/indigenous-leaders-court-win-halts-one-of-australias-dirtiest-gas-projects/

Kimberley Clean Energy Project is led by a partnership between MG Corporation and the Balanggarra Aboriginal Corporation, who majority-own the project.[30]

Water

The Holland Hydrogen Project in Rotterdam aims to use offshore wind to produce 60 tons of renewable hydrogen per day via 200 MW of electrolysers. The water is to be sourced from the nearby Lake Briel, a freshwater body that will reduce the waste produced in comparison to seawater desalination. The facility is also designed in keeping with the principles of sustainability and the circular economy, including the collection of rainwater on site.[31]

The Murchison Green Hydrogen Project will use a desalination plant to provide the pure water required for hydrogen production. The waste brine from seawater desalination will be diluted with the waste cooling water stream for discharge to the ocean.[32]

For smaller projects, water may be purchased at wholesale prices. For example, the Hydrogen Park Gladstone project in Australia will produce hydrogen using a 175-kW electrolyser, to be blended (10% hydrogen) with natural gas. Water will be supplied by the Gladstone Regional Council Water Network.[33]

Due to the varying statutory processes across Australia for granting licences and approvals to take and use water for industrial purposes, desalination is a viable alternative that does not affect agriculture (which currently accounts for more than 65% of national water consumption), mining, or domestic use of water.

Community Acceptance

The EU has undertaken a range of studies, public education programs, and workforce skill development initiatives that have resulted in Europeans across all sociodemographic subgroups having a high level of awareness of hydrogen energy, such as GREENSKILLS4H2,[34] GreenSkillsforH2,[35] and the Awareness of Hydrogen Technologies Survey.[36]. This awareness has been found to correlate to increased support of hydrogen projects (see below), and thus it should be noted that public education is critical in achieving community acceptance[37]. In the future, the European Hydrogen Academy aims to improve hydrogen education across universities and schools.[38]

The Murchison Green Hydrogen Project is committed to providing benefits to the local community, including the creation of over 1500 construction jobs and over 450 permanent jobs during operations. Additional benefits include local workforce training, upskilling and skills transfer support, work opportunities for local Nanda people, and the implementation of a Community Investment Plan.

In Australia, the EIA must also consider the key environmental factors of Benthic communities and habitats, Coastal processes, Marine Environmental Quality, Marine fauna, Flora and vegetation, Terrestrial fauna, Inland waters, Air quality, and Social surrounds. If a project does not fulfil these requirements, it is shelved or cancelled in the planning

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[30] https://thewest.com.au/business/renewable-energy/west-australia-to-be-home-to-east-kimberly-clean-energy-project-billed-as-the-countrys-biggest-solar-project-c-11298911?utm_source=csp&utm_medium=portal&utm_campaign=Streem&token=TQLO6DeEXZsg%2B7nlfCTsXutyb%2FD8bF1Y751pcNOhb7PjiGoknnoH9s9%2F8bSSElsRLjqLrFCe6X8t9WRDuRWnFA%3D%3D

[31] https://www.shell.nl/about-us/what-we-do/waterstof/_jcr_content/root/main/section_2001009258/call_to_action/links/item0.stream/1700559096526/0a5bcc38e8969b5b30bc923805b910b1722d63fc/shell-hydrogen1-mcw-v3.pdf

[32] https://www.epa.wa.gov.au/sites/default/files/Referral_Documentation/Murchison%20Hydrogen%20Renewables%20-%20Environmental%20Referral%20Supporting%20Document_Rev2.pdf

[33] https://research.csiro.au/hyresource/hydrogen-park-gladstone/

[34] https://hydrogeneurope.eu/h2-talks/eu-projects/

[35] https://greenskillsforhydrogen.eu/

[36] https://www.clean-hydrogen.europa.eu/media/publications/awareness-hydrogen-technologies-survey-report_en

[37] https://www.clean-hydrogen.europa.eu/media/news/what-do-europeans-know-about-hydrogen-technologies-2023-07-07_en#:~:text=Europeans%20across%20all%20sociodemographic%20subgroups,a%20new%20public%20opinion%20survey.

[38] https://cordis.europa.eu/project/id/101137988#:~:text=HyAcademy.EU%20will%20considerably%20contribute,and%20acceptance%20of%20hydrogen%20technologies.

stage. For example, plans for a potential six gigawatt-scale wind and solar backed renewable hydrogen production hub in South Australia were shelved due to unacceptable risks around water supply, based on EIA findings[39].

Studies

A wide range of studies have investigated the social science challenges of hydrogen. The distribution of these studies is heavily weighted towards Europe (particularly Germany and the UK) and Asia (particularly South Korea and Japan). The USA and Australia have also undertaken such studies. Some key takeaways and lessons learned are discussed below:

- **Education is critical.** Studies have shown that in nations where hydrogen energy is underused and has poor infrastructure, there is greater fear and apprehension associated with hydrogen use[40]. Many surveys have noted the correlation between knowledge of hydrogen (notably the benefits that green hydrogen can bring) and support for hydrogen.
- **The role of governments is critical in public acceptance.** In countries with high levels of official support for hydrogen technologies, whether at the production, storage, or consumption stages, higher levels of public acceptance are noted. Further, it was found that there was trust in the government and local industry to carry out projects safely in nations such as Australia and Taiwan.
- **National context plays a key role in achieving social acceptance of hydrogen and related technologies.** For example, Asian countries such as Japan and South Korea emphasise the use, perception, and social acceptance of hydrogen technologies, as these countries are targeting hydrogen economies that rely in part on importing hydrogen rather than producing hydrogen. On the other hand, nations that are targeting hydrogen production must focus on additional factors relating to the production phase, such as the land use and water requirements discussed above[41].
- **Favourable aspects of hydrogen highlighted by a survey of the Australian public included the opportunities that may emerge from a hydrogen economy, as well as the potential for projects in regional areas to create new jobs and skills.** Reduced greenhouse gas emissions and climate change mitigation potential were also key benefits. The most frequently cited concerns related to safety, cost, and environmental impacts, particularly concerns around pollution, emissions, and water use. [42]

In Australia, the Australian Energy Infrastructure Commissioner (AEIC) recently led the independent Community Engagement Review in 2023, which made recommendations to improve engagement with renewable energy infrastructure developments.[43] These included:

- Developers should invest in early in community engagement, well before the commencement of the permit approval phase.
- Developers should proactively identify and establish effective working relationships with key community stakeholders, including those opposed to the project.
- Developers should provide a range of information and education opportunities for community members to better understand the benefits and impacts of the project and address any questions or concerns.
- Developers should establish a formal complaint and enquiry process, including a system to record and manage complaints.
- Developers should aim to involve the local community, such as by hiring local tradespeople, contractor staff and other suppliers, establishing and maintaining a community engagement fund, and providing offers for community members to become shareholders in the project.

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[39] https://reneweconomy.com.au/massive-6000mw-renewable-hydrogen-plans-shelved-over-water-issues/
[40] https://www.mdpi.com/2071-1050/15/1/303
[41] https://www.mdpi.com/2071-1050/15/1/303
[42] https://arena.gov.au/assets/2018/12/the-australian-publics-perception-of-hydrogen-for-energy.pdf
[43] https://www.dcceew.gov.au/energy/renewable/community-engagement-review

Conclusion

This background paper outlines the social license, environmental, and community acceptance issues pertaining to the development of green hydrogen projects. Land availability is limited in some regions, whilst in nations with large available areas such as Australia, consultation with traditional landowners is of paramount importance. There is a correlation between regions with high renewable resources (such as solar), and water availability, which may be exacerbated in the face of climate change and the growing global population. Additionally, purification of water can lead to large volumes of waste discharge. Social issues in the development of hydrogen projects includes the sharing of benefits (both locally and internationally), as well as enhancing the public perception and acceptance of hydrogen.

A further consideration for developing hydrogen and derivatives projects is in attaining investment. Projects must have their sustainability aspects verifiable, involving the development of sustainable finance taxonomies and guarantee schemes. These aspects are explored in the following paper.

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AUSTRALIA EUROPEAN UNION GREEN HYDROGEN DIALOGUE #5

BACKGROUND PAPER: Opportunities beyond Hydrogen - Power-to-X and key hydrogen derivatives

Introduction

Whilst green hydrogen shows considerable promise for decarbonisation and the target of net zero emissions, however there are areas of industry that are challenging for hydrogen to be directly utilised, including in maritime and aviation transport, as well as in the synthesis of chemicals such as fertilisers and plastics.[1]

For these applications, hydrogen can be further converted into derivatives (including ammonia, methanol, and sustainable aviation fuel) that exhibit unique characteristics and are applicable to the decarbonisation of key sectors that electrification and pure hydrogen may not be able to completely decarbonise. In addition, these derivatives can provide more energy-dense and cost-effective hydrogen transport and long-term storage, leveraging currently available infrastructure.[2]

This paper provides an overview of the key hydrogen derivatives, how they are produced, their primary advantages, and the sectors for which they are targeted.

Power-to-X

Overview

Renewable Power-to-X (also known as PtX or P2X) is an umbrella term used to describe technologies that make use of excess or underutilised renewable energy resources and abundant feedstocks to generate green chemicals and fuels.

Some examples of renewable Power-to-X within the green hydrogen landscape include[3]:

- The use of renewable energy to drive the electrolysis of water into hydrogen and oxygen.
- The renewable conversion of nitrogen and green hydrogen into ammonia via the Haber-Bosch process (known as green ammonia)
- The renewable conversion of waste CO_2 and green hydrogen into methanol (known as e-methanol).
- The renewable conversion of waste CO_2 and green hydrogen into sustainable aviation fuels and renewable diesel (known as e-SAF and e-diesel).

Other emerging Power-to-X pathways include the renewable conversion of waste CO_2 to value-added products, and the renewable conversion of waste nitrates to ammonia. Power-to-X presents significant advantages compared to the direct use of renewable electricity[4]. Notably, intermittent and unreliable renewable energy sources (such as solar and wind), are converted into stable chemicals and power fuels, that can be easily stored, transported, and used within the current energy infrastructure.

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[1] https://decarbonisationtechnology.com/article/188/hydrogen-derivatives-key-to-the-global-renewable-energy-trade

[2] https://www.irena.org/Energy-Transition/Technology/Hydrogen

[3] https://www.chiefscientist.nsw.gov.au/rd-action-plan/future-industries-reports/nsw-power-to-x-industry-pre-feasibility-study#:~:text=Power%2Dto%2DX%20(P2X,methane%2C%20methanol%20and%20aviation%20fuels.

[4] https://pubs.acs.org/doi/10.1021/acsenergylett.0c02249

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GlobH2E ARC Industrial Transformation Training Centre for the Global Hydrogen Economy
Power Fuels including Hydrogen Network DECARB HUB
UTS

These carbon-negative or carbon-neutral alternatives can therefore replace fossil fuels in a range of industries, such as in energy generation, transportation, and chemicals production, acting as either a stopgap or permanent solution in the global shift to decarbonisation and net-zero emissions (**Figure 1**).

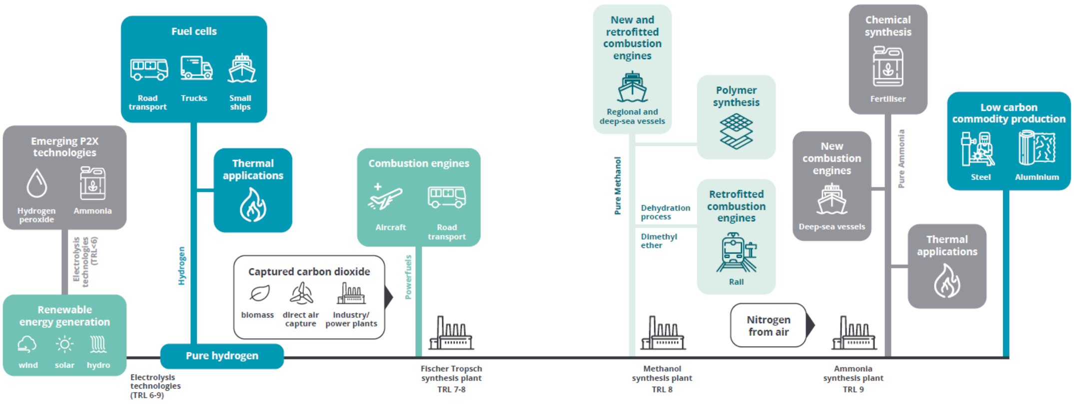

Figure 1. Example of a Power-to-X value chain.[5]

In particular, the derivatives of hydrogen (green methanol, green ammonia, and sustainable aviation fuels) have seen recent global attention for their application to key sectors, that are difficult to decarbonise through either renewables or pure hydrogen. The production and use cases of these derivatives is expanded upon below.

Hydrogen Derivatives

Methanol

Green methanol is produced via one of two primary pathways (**Figure 2**). The first, known as e-methanol, consists of the combination of CO_2 and hydrogen. The CO_2 is captured from either from industry waste via carbon capture, or from ambient air via direct air capture. The hydrogen is produced without the emission of CO_2, through the electrolysis of water powered by renewable electricity. The second method, known as bio-methanol, utilises CO_2 and hydrogen generated from biogas, biomass, or municipal solid wastes. These production pathways are commercially established.

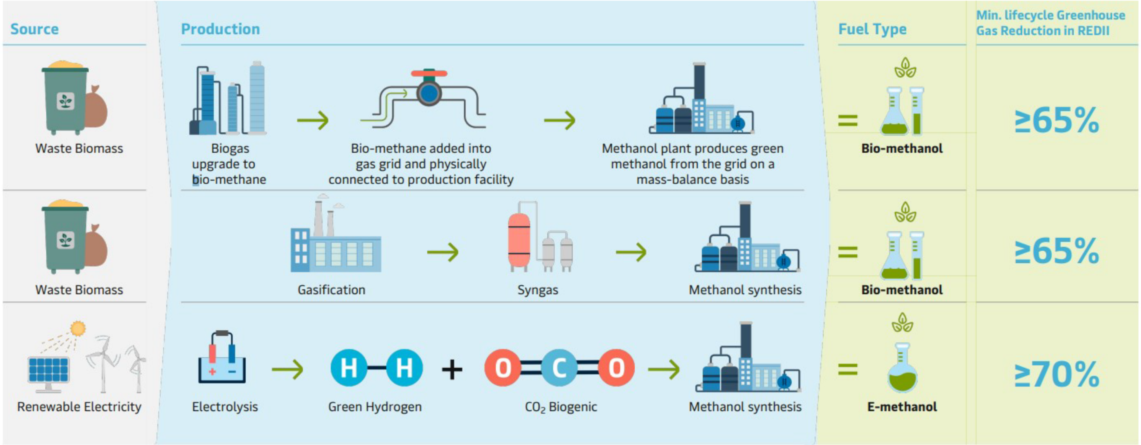

Figure 2. Some pathways to produce e-methanol and bio-methanol.[6]

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[5] https://www.globh2e.org.au/post/released-of-nsw-power-to-x-industry-feasibility-study

[6] https://splash247.com/maersk-taps-equinor-to-supply-fuel-for-its-landmark-green-methanol-powered-feeder-boxship/

The primary advantage of green methanol is that it is a liquid at ambient temperature and pressure, and is thus simple to store and transport, compared to gaseous or liquified hydrogen. In addition, it has a high energy density (15.8 MJ per litre) compared to liquid hydrogen (9.1 MJ per litre). Although the combustion of green methanol will release CO_2, these emissions are largely offset by the use of captured CO_2 in production. Carbon accounting is needed to accurately quantify the emissions from feedstock acquisition, production, use, and disposal. This ensures that the overall impact on the environment is quantified, enabling an accurate assessment and comparison of renewable fuel options. Green methanol can achieve more than 90% emission reduction compared to fossil derived methanol.

Green methanol is a promising fuel for transportation (including for fuel blending and for maritime applications), for long term energy storage and energy generation (either through methanol boilers, combustion engines, or fuel cells), as well as a precursor for the production of chemicals such as dimethyl ether, formaldehyde, acetic acid, and plastics[7].

Currently, the primary barrier to green methanol uptake is its higher production cost compared to fossil fuel-based alternatives. Challenges are presented in running a steady-state methanol plant running on intermittent and unreliable renewable electricity, which will affect the production of hydrogen. Balancing technologies such as storage or battery systems may be used, which can increase the capital expense and impact the achievable levelised cost of methanol.[8] Additionally, there are social licence issues (detailed in Paper 2) such as land and water use, as well as the fact that CO_2 is still emitted upon combustion of methanol, resulting in a carbon-neutral situation at best.

Ammonia

Green ammonia is produced through the combination of green hydrogen and nitrogen. The hydrogen is produced without the emission of CO_2, most commonly through the electrolysis of water powered by renewable electricity, and the nitrogen is separated from air without CO_2 emissions (**Figure 3**). As the Haber-Bosch process for ammonia synthesis is independent of the hydrogen source, the process can be integrated with renewable electrolysis for hydrogen generation.

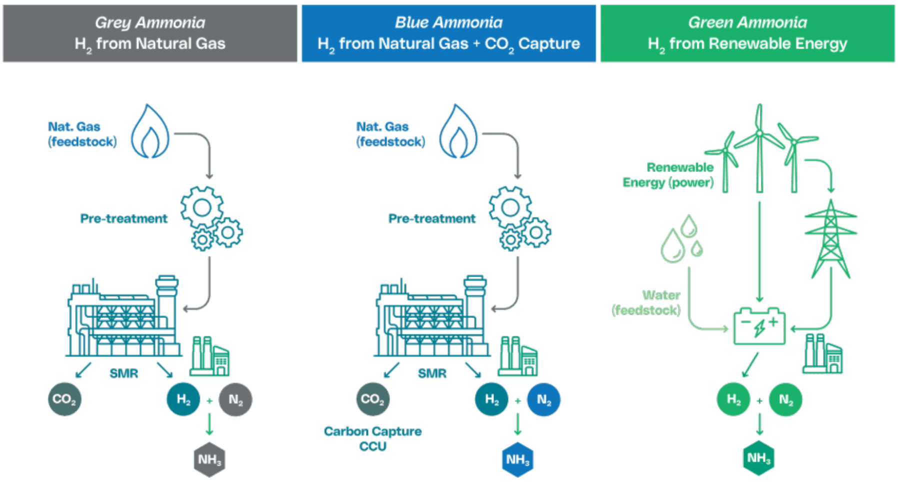

Figure 3. Grey, blue, and green ammonia production.[9]

The primary advantages of green ammonia are that (i) it is a liquid at ambient temperature and pressure and is thus simple to store and transport compared to gaseous or liquified hydrogen, and (ii) the combustion of ammonia does not

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[7] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Innovation_Renewable_Methanol_2021.pdf
[8] https://www.sciencedirect.com/science/article/pii/S0360319923019560?via%3Dihub
[9] https://hydrogentechworld.com/green-ammonia-right-where-you-need-it

release CO_2, only nitrogen and water. Ammonia also has a higher energy density (13.7 MJ per litre) than liquid hydrogen (9.1 MJ per litre)[10].

However, ammonia releases various nitrous oxides upon combustion, which are environmental pollutants and greenhouse gases. Additionally, ammonia itself is toxic, and can cause significant damages to the environment due to leakages or spills. Similar to methanol, the production of green ammonia via the steady-state Haber Bosch process requires a consistent source of hydrogen, which may require balancing technologies to achieve.[11]

The cost of green ammonia production currently hinders it from forming a core element of the global energy supply, however this cost is decreasing as the cost of renewable energy decreases, and it may find application in sectors where renewable electricity cannot be directly used, such as in shipping, small scale energy storage and power generation, in the production of nitrogen-based fertilisers such as urea and ammonium nitrate, and even co-firing with coal.[12,13]

Sustainable Aviation Fuel

Sustainable Aviation Fuel (SAF) can be produced through a wide range of pathways, from sustainable feedstocks such as waste or purposely grown biomass, and waste or captured CO_2 emissions. These pathways can be separated into two categories, (i) Biomass-to-Liquid processes, which make use of biological input as a carbon source, and (ii) Power-to-Liquid pathways, which involves the electrolysis of CO_2 and combination with green H_2. These processes are commercially mature[14].

The primary advantage of SAF is that it can significantly reduce the carbon footprint of the aviation industry, as the CO_2 that is released upon combustion is largely offset by the use of captured CO_2 in production (**Figure 4**). Further, SAF can be used in existing engines and infrastructure (currently accounting for less than 0.1% of all fuels consumed), and easily blended with fossil-based aviation fuels, as they share similar chemical, physical, and thermal properties. SAF can reduce lifecycle carbon emissions by up to 80% compared to traditional jet fuel.

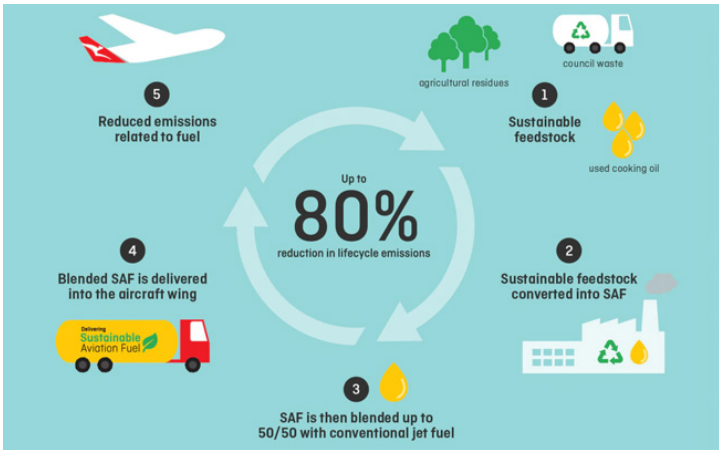

Figure 4. SAF can reduce the emissions associated with jet fuel by up to 80%.[15]

However, the price disparity between SAF and fossil-based jet fuel is large, with the former costing more than twice the price of conventional jet fuel. In addition, whilst the production of SAF is a mature process, the availability of suitable and sustainable feedstock is a critical challenge, as social license and community acceptance issues must be addressed to determine suitable biomass or carbon sources. Strong demand and policy-driven actions are required to

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[10] https://www.ammoniaenergy.org/

[11] https://www.sciencedirect.com/science/article/pii/S0196890422011918

[12] https://iea.blob.core.windows.net/assets/6ee41bb9-8e81-4b64-8701-2acc064ff6e4/AmmoniaTechnologyRoadmap.pdf

[13] https://www.reuters.com/business/energy/jera-start-trial-co-firing-ammonia-coal-power-plant-march-2023-11-29/

[14] https://afdc.energy.gov/fuels/sustainable_aviation_fuel.html

[15] https://actionrenewables.co.uk/news/sustainable-aviation-fuel-saf/

achieve economies of scale in the future[16]. Similar to methanol, SAF also emits CO_2 upon combustion, and so at best is carbon neutral.

Decarbonisation of Key Sectors

Maritime Transport

The maritime industry is the international network of ships and ports that facilitate the global economy. The industry consists of largest machines on earth, as well as smaller vessels such as ferries, tugs, and trawlers. It is estimated that the global emissions from these vessels accounts for around 2 – 3% of total greenhouse gas emissions per year, as well as being responsible for 9% of sulphur oxides (SO_x) and 18% of nitrogen oxides (NO_x) emissions annually.[17]

This industry cannot be electrified in the same manner as light road vehicles, i.e. through the use of batteries, as the weight of the battery required would be greater than large shipping vessels could carry. There are also issues with using hydrogen as a shipping fuel, including the low energy density of compressed hydrogen, and the boiloff and low temperature requirements of liquified hydrogen. As such, hydrogen derivatives such as methanol and ammonia have seen recent interest for maritime fuel applications.

Advantages of methanol as a shipping fuel include that it is currently the lowest-cost carbon-neutral shipping fuel, it has a high energy density compared to LNG, ammonia, and hydrogen, it is easily scalable, and it lowers emissions of SO_x, NO_x, and particulate matter. Advantages of ammonia as a shipping fuel are that it does not release CO_2 during combustion, it has a high energy density compared to hydrogen, and it is easily scalable. It is estimated that by 2050, shipping will require a total of 46 million tonnes of green hydrogen. Of this total, 73% will be needed to produce ammonia, 17% for methanol, and 10% for liquid hydrogen[18].

The EU's ReFuelEU Maritime initiative sets GHG intensity reduction targets with a sub-target for low-emission e-fuels of 2% by 2034. Leading shipping companies, including AP Moller-Maersk, CMA CGM, China COSCO Shipping Corporation Limited, Methanex Waterfront Shipping, and Stena have committed to marine methanol, whilst Yara Clean Ammonia (YCA), CMA CGM, and Maersk are also researching ammonia for maritime applications. Companies such as Wartsila are developing ammonia and methanol fuelled engines for the industry.

Additional decarbonisation efforts in maritime transport are focused on improving energy efficiency and optimisation, as well as treatment of exhaust gases and carbon capture.

Aviation Transport

The aviation industry is estimated to be responsible for around 2 – 3% of total greenhouse gas emissions per year. The aviation industry is difficult to decarbonise, because of (i) the large power requirements of aircraft, and (ii) the significant costs and time taken to develop new engines and aircraft designs. Similar to maritime transport, large aircraft cannot be electrified due to the significant battery weight required, whilst a significant drawback in the use of hydrogen in aircraft is the requirement for new aircraft architecture and design to accommodate larger hydrogen tanks, resulting in a long lead time in implementing hydrogen as an aviation fuel[19].

Alternatively, SAF can be used within the current infrastructure, either alone or blended with conventional fuels. SAF therefore represents the most promising option to reduce the aviation industry's emissions in the short term[20].

There are currently around 290 SAF production facilities that have been announced, corresponding to around 78 Mtpa of total capacity, compared to the ~300 Mtpa of jet fuel used by commercial airlines.[21] Globally, new policy is targeting

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[16] https://www.bp.com/en/global/air-bp/news-and-views/views/what-is-sustainable-aviation-fuel-saf-and-why-is-it-important.html

[17] https://www.energy.gov/eere/maritime-decarbonization#:~:text=Maritime%20decarbonization%20is%20the%20process,rise%20to%201.5%2Ddegrees%20Celsius.

[18] https://www.irena.org/Digital-content/Digital-Story/2021/Oct/Shipping_Sector

[19] https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/fact_sheet7-hydrogen-fact-sheet_072020.pdf

[20] https://www3.weforum.org/docs/WEF_Clean_Skies_Tomorrow_SAF_Analytics_2020.pdf

[21] https://www.icao.int/environmental-protection/Pages/SAF.aspx

the use of SAF; the EU's ReFuelEU Aviation initiative requires EU airports and fuel suppliers to supply SAF as at least 2% of aviation fuels in 2025, to 6% in 2030, and 70% in 2050, whilst the UK plans a SAF mandate in 2025. In Australia, Qantas is targeting 10% of their fuel to come from SAF by 2030, and approximately 60% by 2050.[22]

SAF is estimated to contribute to achieving ~65% of decarbonisation within the aviation industry, whilst other contributions include improvements in energy efficiency, infrastructure, and operations, as well as carbon capture. Currently, planned production capacities will provide just 1 – 2% of jet fuel demand by 2027[23].

Chemical and Materials Synthesis

Hydrogen and derivatives can be employed to replace fossil-based alternatives in the synthesis of a range of chemicals and materials produced at scale, for example:

- Steel. The steel industry is responsible for around 8% of global greenhouse gas emissions. In addition, global demand for steel is expected to increase by more than a third through to 2050. Hydrogen may be used in steel manufacturing as a replacement for carbon as the reducing agent in producing iron, known as direct iron reduction. The oxygen in the iron ore combines with the hydrogen to produce water (instead of with carbon to produce CO_2), eliminating the CO_2 emissions from this part of the process. Hydrogen (or derivatives) can also be used as the furnace fuel.
- Plastics. Methanol and its derivative products such as acetic acid and formaldehyde are used in the synthesis of plastics. The annual production of methanol is over 100 Mtpa, ~30% of which is converted to a variety of plastics via formaldehyde[24], representing a significant opportunity for the decarbonisation of plastics manufacture through green methanol.
- Fertilisers and explosives. Ammonia is a key component in the manufacture of fertilisers, with around 70% of ammonia used for this purpose globally, of the ~180 Mtpa produced. The remainder of ammonia is used in industrial applications such as the production of explosives, plastics, and synthetic fibres. Fertilisers are of critical importance in providing sufficient food for the global population, which is expected to rise across the next decades[25]. The decarbonisation of ammonia production via green ammonia could mitigate around 1.8% of global greenhouse gas emissions.

Conclusion

This background paper outlines the key principles of Power-to-X and provides an overview of the primary hydrogen derivatives, ammonia, methanol, and sustainable aviation fuel. Power-to-X describes the technologies that can convert intermittent renewable energy sources and abundant chemical feedstock to stable chemicals and fuels, a primary example of which is the electrolysis of water to green hydrogen driven by renewable electricity.

Green hydrogen can be further converted into chemicals that exhibit unique characteristics, that lend to their application to key industries that are difficult to decarbonise using renewables or hydrogen alone. These derivatives include methanol, ammonia, and sustainable aviation fuel, that can assist in the decarbonisation of maritime and aviation transport, fertilisers and chemicals production, and off-grid and small-scale power generation.

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[22] https://www.qantas.com/au/en/qantas-group/sustainability/our-planet/sustainable-aviation-fuel.html

[23] https://iea.blob.core.windows.net/assets/9e0c82d4-06d2-496b-9542-f184ba803645/TheRoleofE-fuelsinDecarbonisingTransport.pdf

[24] https://www.essentialchemicalindustry.org/chemicals/methanol.html

[25] https://royalsociety.org/-/media/policy/projects/green-ammonia/green-ammonia-policy-briefing.pdf