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STUDY

Status of Hydrogen and Potential for Cooperation

Australia, Germany, Japan, and Korea

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Disclaimer

This study was prepared by adelphi on behalf of the German Federal Ministry of Economics and Climate Action as part of the projects "Energy Cooperation with Australia and New Zealand" and “Energy Partnership with Japan and Korea”.

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Supported by: Special thanks to the German Chamber of Commerce and Industry in Japan and the German Chamber of Commerce and Industry in Korea as well as Lena Grimm (adelphi). Your feedback and additional information enriched and improved the study.

Layout and Graphics: Tilman Zastrow

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Date of Publication: July 2024

Initiated by

Federal Ministry for Economic Affairs and Climate Action

Implemented by

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List of Abbreviations

AEM	Anion Exchange Membrane
AEMO	Australian Energy Market Operator
AHC	Australian Hydrogen Council
ARENA	Australian Renewable Energy Agency
AWE	Alkaline Water Electrolysis
BAM	Bundesanstalt für Materialforschung und -prüfung [Germany]
BDI	The Voice of the German Industry
BMBF	Federal Ministry of Education and Research [Germany]
BMJ	Federal Ministry of Justice [Germany]
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection [Germany]
BMVI	Federal Ministry for Transport and Digital Infrastructure [Germany]
BMWK	Federal Ministry for Economic Affairs and Climate Action [Germany]
CBAM	Carbon Border Adjustment Mechanism
CCfD	Carbon Contract for Difference
CEFC	Clean Energy Finance Corporation [Australia]
CEM	Clean Energy Ministerial
CH_4	Methane
CH_4O	Methanol
CHP	Combined Heat and Power
CSIRO	Commonwealth Scientific and Industrial Research Organisation [Australia]
CCU/S	Carbon Capture Utilisation and Storage
DCCEEW	Department of Climate Change, Energy, the Environment and Water [Australia]
Dena	German Energy Agency
EEG	Renewable Energy Sources Act [Germany]
EPO	European Patents Office
ETS	Emissions Trading System
FC	Fuel Cell
FCEV	Fuel Cell Electric Vehicles
FID	Final Investment Decision
GHG	Greenhouse Gas
GW	Gigawatt
GX	Green Transformation [Japan]
H_2	Hydrogen
H2PA	Hydrogen Production Analysis
HESC	Hydrogen Energy Supply Chain
IEA	International Energy Agency
IPCEI	Important Project of Common Interest [European Union]
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IRA	Inflation Reduction Act [US]
IRENA	International Renewable Energy Agency
JBIC	Japanese Bank for International Cooperation
JH2A	Japan Hydrogen Association
JOGMEC	Japanese Organisation for Metals and Energy Security
Ktpa	Kilotonnes per year
KDB	Korea Development Bank
KEEI	Korean Energy Economics Institute
KfW	German Development Bank
KIAT	Korean Institute for Advancement of Technologies
KOGAS	Korea Gas Corporation
LNG	Liquefied Natural Gas
LOHC	Liquid Organic Hydrogen Carrier
METI	Ministry of Economy, Trade and Industry [Japan]

MOTIE Ministry of Trade, Industry and Energy [Korea]

Mt Million metric tonnes

MoU Memorandum of Understanding

NEDO New Energy and Industrial Technologies Development Organisation [Japan]

NEM National Electricity Market [Australia]

NH3 Ammonia

NHIA National Hydrogen Infrastructure Assessment [Australia]

NWR National Hydrogen Council [Germany]

PEM Polymer Electrolyte Membrane

P2H2P Power-to-Hydrogen-to-Power

PtX/P2X Power-to-X

RED Renewable Energy Directive

RFNBO Renewable Fuel of Non-Biological Origin

SMEs Small and Medium-Sized Businesses

SMR Steam Methane Reforming

SOEL Solid Oxide Electrolysis

TJ Terajoule

TWh Terawatt-hour

UBA Umweltbundesamt [Germany]

UNECE United Nations Economic Commission for Europe

VCI German Chemical Industry Association

WEF World Economic Forum

WTO World Trade Organisation

Executive Summary

For a global hydrogen market to emerge, multilateral cooperation needs to be strengthened significantly.

Australia, Germany, Japan, and Korea are well placed to push forward in the direction of a global hydrogen market by initiating quadrilateral activities. Germany, Japan, and Korea will be among the biggest importers of low-carbon hydrogen globally. There are three main reasons for this: These countries have ambitious decarbonisation goals, limited potential for the build-out of renewables and hence domestic hydrogen production, and large industrial sectors with hard-to-abate emissions. It is therefore in their joint interest to secure sufficient supplies. A collaborative approach can help balance market power dynamics by strengthening their position vis-à-vis exporters. Australia, on the other hand, has the potential to become one of the main producers and exporters of hydrogen globally, as it has abundant space, sun, and wind resources as well as ample experience with energy exports. Entering into agreements with three big importers is, therefore, highly interesting for Australia. However, since all four countries are already very active across the entire hydrogen value chain with often complementary fields of expertise and industries, the potential for quadrilateral cooperation stretches beyond a simple import-export relationship. This study investigates where each country's expertise lies, who the key hydrogen stakeholders are, and which political framework conditions exist in each country. Based on this, and in conjunction with an examination of global developments, this study develops suggestions for quadrilateral cooperation activities to accelerate the hydrogen market ramp-up.

International developments in the field of hydrogen have picked up in recent years. The relevance and potential of a global hydrogen economy is widely acknowledged and many countries are eager to position themselves in the emerging market. To date, more than 40 countries have published hydrogen strategy papers. These include major nations such as the US, China, India, and Canada, which see huge economic opportunities and provide political and financial support accordingly. In addition, groups of countries and international organisations including the G7, G20, and the United Nations [UN] establish fora and declarations to institutionalise cooperation on hydrogen and develop common methodologies for accounting for its carbon content. Yet, innovations and technological improvements are still required for the concrete implementation of hydrogen production and trade.

Australia is looking to become a renewable energy superpower and sees new business opportunities in the export of hydrogen and in locating new value chains domestically. Australia was among the first three countries globally to publish a hydrogen strategy. It realised early on that its geographic preconditions and its energy export experience put it in a prime position to play a central role in the global hydrogen economy. In fact, according to some predictions, Australia could produce up to 100 Mt of low-carbon hydrogen by 2050. The Australian government is currently revising its strategy and developing a Guarantees of Origin Scheme as well as offering numerous funding opportunities such as the 2 billion AUD (1.2 billion EUR) Hydrogen Headstart Programme. These efforts are already bearing fruit and Australia is home to 30% of all announced hydrogen projects. While larger projects haven't reached FID yet, the newly announced Hydrogen Production Tax Incentive is certain to give Australia's renewable hydrogen industry a significant push.

Germany is acutely aware of the importance of hydrogen for the continued success of its strong industrial sector and the vital nature of imports to meet its expected hydrogen demand. In 2023, Germany published its revised hydrogen strategy, which sets the goal of 10 GW of domestic production capacity by 2030. Still, 50% - 70% of the demand from key sectors, such as steel, in 2030 will have to be covered through imports. Accordingly, the German government is developing a hydrogen import strategy and supporting a number of funding mechanisms, such as H2Global (5.33 billion EUR), which provide subsidies to both domestic and international projects. Despite the limited production potential in Germany, German companies are market leaders in several areas of the hydrogen value chain. This is especially true for the development and production of electrolysers and other technical components as well as for various applications, particularly in the transport and industry sectors.

Japan has positioned itself as one of the biggest potential hydrogen markets, with widespread plans and funding for the application of hydrogen in the power, mobility and industrial sectors. Even more than Germany, Japan will rely significantly on imports due to limited domestic production abilities. Nevertheless, Japan has identified hydrogen as the key solution for its decarbonisation efforts. The Japanese government expects to consume, and largely import 3 MT of hydrogen by 2030, 12 MT by 2040 and up to 20 Mt annually by 2050. It has been the first country to publish a hydrogen strategy in 2017, with an in-depth revision in 2023. Together with the Japanese GX-Strategy, the revision and subsequent legislation introduced ample financing instruments for hydrogen, such as the new CfD-mechanisms for low-carbon hydrogen of 3 trillion JPY (20 billion EUR). Industry and the power sector are expected to be the main offtakers in the beginning, for example, Japan intends to use ammonia and hydrogen to lower the emissions of thermal power plants. Additionally, Japanese companies try to establish themselves as global market-leaders in the application of hydrogen and its derivatives in different sectors.

Korea, too, sees hydrogen as a key solution for its decarbonisation efforts in the power, mobility, industry, and household sectors and is preparing for substantial import volumes. In fact, Korea expects to import 51% of its hydrogen by 2030 and 82% by 2050. While Korea is committed to producing some hydrogen itself, the build-out of renewables is likely to be a bottleneck. Additionally, Korea is one of the most advanced countries when it comes to the application of hydrogen in the power sector: In 2023, it was the first country globally to have an installed capacity of more than 1 GW of fuel cells for power generation. This is mirrored by Korea's innovative activity in this area, with further strengths lying in the mobility sector, including marine transport solutions.

Given their often complementary competencies and globally leading efforts, all four countries are already highly engaged in bilateral cooperation activities. For instance, the German government maintains energy partnerships with all three countries, in which hydrogen is a focus topic. Meanwhile, Japan and Australia have signed the Japan-Australia Statement of Cooperation on Hydrogen and Fuel Cells, and Australia and Korea have created the Low and Zero Emissions Technologies Partnership, which includes the establishment of hydrogen supply networks. Japan and Korea agreed in November 2023 to jointly procure clean hydrogen and ammonia. These political ties are flanked by various collaborative activities in the private sector, including Memoranda of Understanding [MoU] for hydrogen deliveries as well as joint projects in each country.

Building on these national and bilateral activities, a logical and powerful next step would be to move towards quadrilateral cooperation between Australia, Germany, Japan, and Korea. The build-up of a global hydrogen economy is complex and time-intensive, with many issues naturally requiring a multilateral approach. Meanwhile, as the global carbon budget is shrinking, the remaining timeframe for achieving the Paris temperature goal of 1.5°C is shortening rapidly. This demands a strategic and targeted approach to the establishment of a global hydrogen economy**.** Complementing the existing bilateral partnerships, a multilateral approach would reduce dependencies, build on each country's comparative advantages, reduce power imbalances between suppliers and importers, and use early market power to shape global developments. This report recommends focusing quadrilateral cooperation on the following topics, as these are highly relevant and covered by the four countries' expertise: (1) Transportation of Hydrogen, (2) Bankability of Projects, (3) Workforce Development, (4) Hydrogen in the Electricity Sector, (5) Green Steel, and (6) Rules and Regulations for the Use of CCU/S.

To implement quadrilateral collaboration in these areas, this study suggests the establishment of a Germany-APAC Hydrogen Leaders Forum, either as a one-off or a regular meeting, where the four countries can discuss the above topics, including, if opting for a longer-term cooperation approach, the establishment of a joint flagship project covering the entire hydrogen value chain. This would be an important demonstration of the feasibility of large-scale, multilateral hydrogen projects and could act as a catalyst for similar projects and provide more certainty for investors. In addition, specific subjects, such as green steel, hydrogen in the electricity sector, etc. could be addressed through roundtables and workshops.

With production capacities and global transport solutions still being developed and still pending ultimate economic viability, this study is intended as a starting point to intensify international discussions on how hydrogen can play an effective role in the wider decarbonisation efforts and future energy policies of the four countries featured in this study. A variety of approaches and activities will be required to ultimately get the global hydrogen market off the ground. The hope is that this study can show the relevance of adding a quadrilateral approach to the tool box.

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1 Introduction

Hydrogen has been a topic of intense interest and discussion for a number of years by now. However, with 2030 approaching quickly, the pressure to get the global hydrogen economy off the ground is growing. Consequently, there is a surge in innovative activities worldwide, focusing on the development of new technologies for hydrogen production, transportation, and application (International Energy Agency [IEA] & European Patents Office [EPO] 2023). This is being flanked politically by the development, and in some cases the revision, of hydrogen strategies and roadmaps. Moreover, nations and businesses are forging partnerships, while governments are establishing diverse international fora to create standards and guidelines for the burgeoning hydrogen industry.

However, despite the heightened activity, the tipping point at which hydrogen production is scaled and its trade initiated has yet to arrive. The key assumption of this study is that for this to happen, **countries need to further strengthen their hydrogen cooperation activities and move beyond a predominantly bilateral approach towards targeted multilateral collaboration and concrete project implementation.** With this in mind, this study looks at Australia, Germany, Japan, and the Republic of Korea (in the following “Korea”). These countries will be key players in the international trade of hydrogen. Germany, Japan, and Korea have ambitious decarbonisation goals, large industrial sectors resulting in high demand for hydrogen, and a limited potential for the buildout of renewables and hence the domestic production of low-carbon hydrogen. Consequently, these three countries are among the handful of countries which will heavily rely on hydrogen imports (the other countries being Belgium and the Netherlands and potentially the US and China to some extent) (Fraunhofer ISI 2024). Meanwhile Australia with its tremendous supply of wind, solar, and space is well positioned to become one of the main producers and exporters of hydrogen and its derivatives. Additionally, each of the four countries is already highly engaged in the nascent hydrogen economy and possesses distinct strengths that collectively contribute to the entire hydrogen value chain.

Since hydrogen can be produced in a variety of ways and because these production methods will play an important role in the trade of hydrogen, it is important to provide some **definitions** to secure a common understanding at the outset of this study. Germany largely focuses on the production and use of renewable or **green hydrogen** produced via electrolysis (Alkaline Water Electrolysis [AWE], Polymer Electrolyte Membrane [PEM] Electrolysis, Solid Oxide Electrolysis [SOEL]) as well as some fossil + Carbon Capture, Utilisation and Storage [CCU/S]-based or **blue hydrogen** produced via steam methane reformation coupled with CCU/S technologies (seldomly, orange hydrogen produced via waste heat is mentioned as well). Australia, Japan, and Korea on the other hand mostly speak of **“clean” hydrogen**, which encompasses both green and blue hydrogen and sometimes also pink hydrogen produced with nuclear power. Since green hydrogen is the cleanest and preferred long-term choice in terms of its environmental impact, this study will summarise green, blue and pink hydrogen as **low-carbon hydrogen** but also refer to green hydrogen separately.

The following paragraphs provide a very brief overview of the energy supply and consumption in all four countries to characterise the countries’ unique conditions and provide a common basis for the subsequent chapters. Chapter 2 considers the broader context of the global hydrogen economy, including existing multilateral fora, developments in other major nations, technological progress, and approaches to certification. Chapter 3 offers a detailed account of hydrogen-related policies, funding, and industry developments in Australia, Germany, Japan, and Korea. Chapter 4 highlights existing bilateral cooperation activities between each of these countries before Chapter 5 suggests future quadrilateral cooperation activities and concludes the study.

1.1 Country Energy Profiles

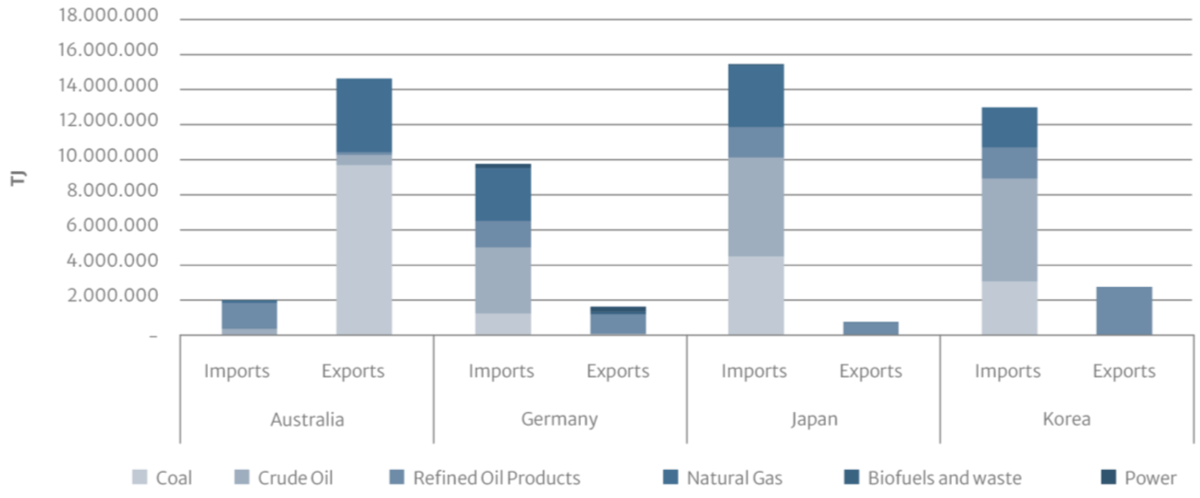
Among the four countries, **Australia** is the only net exporter of energy (see Figure 1 for a comparison of export and import volumes as well as a breakdown by energy source across all four countries). In fact, Australia exports around 2/3 of its produced energy, mainly in the form of LNG and black coal as well as some crude oil. Imports mainly comprise refined oil products due to declining domestic oil refining capacities. As can be seen in Figure 2, Australia's total energy supply mix (incl. exports) is dominated by coal, oil, and natural gas. Only 4% were supplied by wind and solar in 2022. If biomass and waste as well as hydro power are added to this, a sum of 8% of Australia's total energy supply comes from non-carbon-based sources. This fossil-based (export) economy presents a major challenge for Australia's future economic prosperity amidst global decarbonisation efforts. But though still a minor share, Australia possesses vast renewable resources, boasting world-class solar and wind potential that surpasses both current and anticipated domestic demand. Prime Minister Anthony Albanese wants Australia to become a "renewables superpower", leveraging renewable energy not only to address domestic decarbonisation needs but also to establish a thriving renewable export industry (Department of Climate Change, Energy, the Environment and Water [DCCEW] 2024; IEA 2023a).

Germany is a net importer of energy, with imports mainly comprising refined oil products, natural gas, and black coal. According to the International Renewable Energy Agency [IRENA], Germany's energy self-sufficiency rate was at 34% in 2020 (IRENA 2023a). In 2022, half of its total energy supply came from oil (31%) and natural gas (27%) with coal (19%) and renewables (11%) adding up to another 30% (see Figure 2) (IEA 2023b). Domestically produced energy mainly comes from wind, solar, biomass, and brown coal (Umweltbundesamt [UBA] 2024). In April 2023, Germany ceased the production of nuclear power, despite the double challenge of reduced natural gas supplies from Russia and a planned coal exit by 2038 at the latest. With one of its major import partners for cheap natural gas gone, Germany will need to expand its domestic renewable capacity as much and as quickly as possible, while also reducing, decarbonising, and diversifying its imports, especially molecular imports. This happens against the background of Germany being Europe's largest energy consumer, followed by France and the UK. The coming years will therefore require substantive investments, particularly in the buildout of energy infrastructures, and a rethinking of how the German energy system can operate with increasingly intermittent energy sources as well as how the industrial and transport sectors will decarbonise demand that can't be electrified. The availability of funding (especially after the shortfalls emerging in 2023) and of skilled workers as well as considerations of how Germany can remain an attractive location for industry will be among the key challenges policy makers face (IEA 2023b; EY 2023; U.S. International Trade Administration 2023a).

Japan is highly dependent on energy imports. According to data by IRENA, its energy self-sufficiency rate was at 11% in 2020 (IRENA 2023b). In 2022, oil was Japan's largest energy source, followed by coal and gas (see Figure 2). Australia is Japan's main source of LNG (39.1%) and coal (59.6%) imports. Similar to Australia, renewables only made up 4% of the total energy supply mix in 2022, however, especially solar energy saw a rapid expansion over the last 12 years due to generous feed-in tariffs by the government, following the accident at the Fukushima Daiichi nuclear power plant in 2011. In its decarbonisation efforts, Japan plans to also rely on the expansion of its nuclear capacities, which is planned to be achieved through longer lifetimes for existing reactors as well as the commissioning of new nuclear facilities. In the coming years, Japan will face the double challenge of decarbonising its energy supply and ensuring energy security despite its low energy self-sufficiency and lack of connection to neighbouring grids. While a build-out of renewable energies appears as a consistent solution to both issues, limited space onshore adds a third challenge to the mix (IEA 2021b, 2023b; World Economic Forum 2023b). However, with ample coastlines and the sixth largest exclusive economic zone in the world, the potential for (floating) offshore wind is enormous (Renewable Energy Institute 2024).

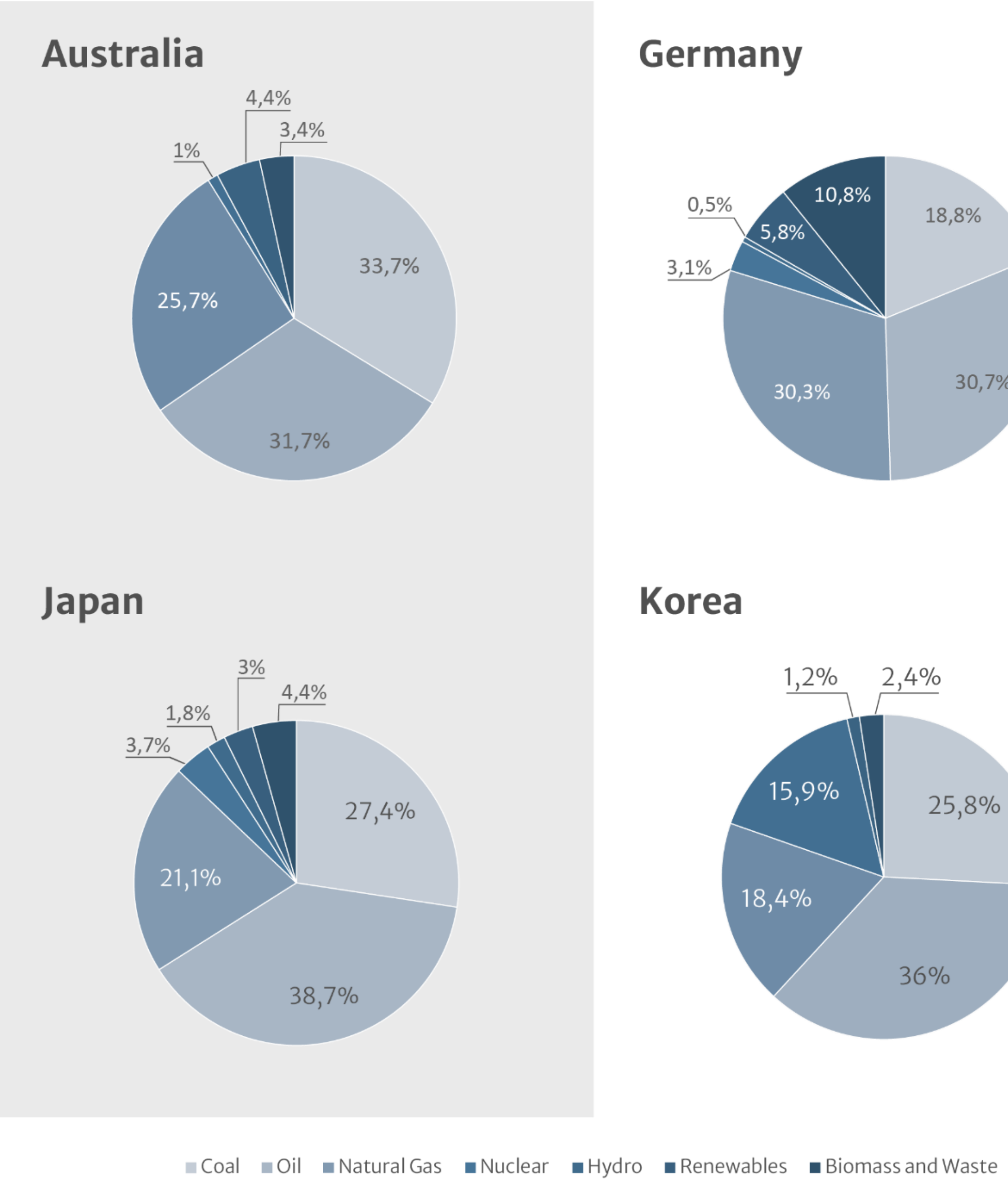
Korea is a major energy importer. It is the 4th largest importer of coal, the 5th largest importer of oil, and the 6th largest importer of gas worldwide. In 2020, its energy self-sufficiency rate was at 19% (IRENA 2023c). As can be seen in Figure 2, the total energy supply mix of Korea is dominated by oil (36%) followed by coal (26%). While former president Moon Jae-in sought to phase out nuclear power in Korea, the government under Yoon Suk-yeol plans to increase its relevance as an additional non-fossil-based energy source next to renewables. In its 10th Basic Plan on Electricity Supply and Demand, Korea sets targets for its power generation mix in 2030. Here, nuclear features prominently with 32.4% (from 29.6% in 2022), while the goal for renewables is set at 21.6% (from 8.9% in 2022). The latter is rather unambitious compared to other industrialised nations. Having been the seventh largest energy consuming nation globally in 2022, Korea is now under pressure to step up its contribution to global decarbonisation efforts. Besides the necessary and possible more ambitious build-out of renewable energy systems, Korea's ability to build-out its transmission, distribution, and storage network will be key to this (Seitz et al. 2023). These factors have been identified as decisive for why the Korean government delayed its target of 30% renewable capacities in the power generation mix by six years (from 2030 to 2036) in the 10th Basic Plan (Financial Times 2022a; IEA 2024; Energy Tracker Asia 2023; U.S. International Trade Administration 2023b).

Figure 1: Comparison of Energy Imports and Exports



Source. Own graphic based on data by the IEA (2023b)

Figure 2: Energy Supply in Australia, Germany, Japan, and Korea in 2022



Source. Own graphic based on data by the IEA (2023b)

2 International Developments

2.1 Political Developments in Other Major Nations

To date, 41 countries have published a national hydrogen strategy (IEA 2023a). In addition, many countries have established funding programmes to support the roll-out of their hydrogen economies. To be able to adequately contextualise the measures and trends in the four countries covered by this study, it is helpful to consider the global context. Therefore, the following section examines the most important developments in four other countries with significant production and export potential: the US, China, India, and Canada.

The **US** published its reworked National Clean Hydrogen Strategy and Roadmap in June 2023, in which it lays out a development pathway for its national hydrogen production: 10 Mt/year (333.7 TWh[1]) by 2030, 20 Mt/year (667.4 TWh) by 2040, and 50 Mt/year (1668.5 TWh) by 2050. For this, the US follows three key strategies: Concentrating on high-impact use areas for clean hydrogen, reducing the cost of hydrogen with the aim to reach 1 USD/kg (0.92 EUR/kg) within one decade, and creating regional networks by establishing clean hydrogen hubs. These approaches are supported by substantive funding. In 2022, the Bipartisan Infrastructure Law [BIL] allocated 9.5 billion USD (8.7 billion EUR) to clean hydrogen, 7 billion USD (6.5 billion EUR) of which will go to seven regional hydrogen hubs, which have been announced in mid-October 2023[2] (Mui 2023), and 1 billion USD (922.8 Mio. EUR) to clean hydrogen electrolysis projects (U.S. Government 2023). In 2023, the US issued the Inflation Reduction Act [IRA], which, due to its ample tax credit provisions for a number of clean energy areas, caused concerns among foreign industry actors and governments. For hydrogen, the IRA enables a maximum support of 3 USD/kg (2.77 EUR/kg) over 10 years[3]. This is significantly higher than what is available, for instance, through the EU Important Projects of Common European Interest [IPCEI] funding of 1 USD/kg (0.92 EUR/kg) for green hydrogen, thus creating an incentive for hydrogen production within the US (Eckardt et al. 2023). Overall, it can be expected that a strong hydrogen economy will form within the US in the coming years. Yet, as of now it remains unclear whether the US will also pursue hydrogen exports and if so, when.

China, which is the largest producer of (grey) hydrogen today and has identified hydrogen as a “frontier” area as well as one of six industries for focused advancement in its 14th Five Year Plan (2021-2025), released its Medium- and Long-Term Plan for the Development of the Hydrogen Energy Industry for the period of 2021-2035 in March 2022. According to this plan, China aims to produce 100,000 to 200,000 tonnes (3.3 to 6.7 TWh) of low-carbon hydrogen annually by 2025, a modest goal when considering China’s ambitious goals for the build-out of wind and solar capacities. In fact, the China Hydrogen Alliance, a government-supported industry group launched in 2018, projects that China could produce 100 Mt (3,337 TWh) annually by 2060, which would require a substantive acceleration in the build-up of capacities between 2025 and 2060. Further goals are to have a fleet of 50,000 hydrogen-fuelled vehicles by 2025 and to increase technological capabilities, which are thus far strongly concentrated on Anion Exchange Membrane [AEM] electrolysis. To reach these goals, China established a state-wide subsidy programme for the development of fuel cell batteries and provides various tax exemptions, for instance for fuel cell vehicles (Center for Strategic & International Studies 2022a, 2022b). A recent report by the World Economic Forum [WEF] foresees a significant need and potential for green hydrogen in the Chinese energy transition, but concludes that China has joined late and will first have to focus on creating a clearer roadmap for the domestic industry before being able to play a substantive role in international markets, although some initial cooperation efforts have been initiated lately (World Economic Forum 2023b). However, although China is performing below its potential, it is still a leader in electrolyser installations and accounts for 40% of the world's projects that have already achieved final investment decision [FID] (IEA 2023c).

[1] All conversions from Mt to TWh, and the other way round, were made using this website, based on the lower heating value of hydrogen.

[2] Among these hubs there appears to be a strong focus on blue hydrogen (natural gas with CCS), with four of the seven hubs producing, inter alia, blue hydrogen. This is despite the fact that only one blue hydrogen hub was mandatory under the BIL. Only two hubs will focus on green hydrogen, while three other hubs will produce green hydrogen alongside blue and pink (nuclear) hydrogen (Mui 2023).

[3] Tax credit provisions under the IRA range from 0.12 USD/kg H_2 to 3 USD/kg H_2, with the height of the credit depending on the carbon intensity of the hydrogen produced and whether specific labor provisions are implemented. In some cases the hydrogen tax credit (45V) may be combined with other tax credits under the act, for instance for the production of renewable energy, which further increases the economic viability of such projects (IEA 2023c).

India released its National Green Hydrogen Mission in January 2022. This sets the goals of producing at least 5 Mt of green hydrogen and increase electrolyser manufacturing capacity to 15 GW by 2030. To achieve this, the Indian government plans to install usage quotas for industries, develop a standards and regulations framework, establish a public private partnership framework (Strategic Hydrogen Innovation Partnership/ SHIP), and initiate a skill development programme. Additionally, the government provides a transmission fee waiver for renewable energy used to produce hydrogen until January 2031 and has installed a 2.2 billion USD (2 billion EUR) subsidy programme (Strategic Interventions for Green Hydrogen Transition Programme [SIGHT]), where producers are to get incentives worth at least 10% of their production costs. Both funding instruments are aimed at reducing the price of green hydrogen to 1/5 of today's costs, that is to 1 - 1.5 USD/kg (0.92 - 1.38 EUR/kg) (Ministry of New and Renewable Energy 2023; Financial Times 2023; Reuters 2023a, 2022). With India increasingly being regarded as an emerging superpower, it is likely to play a crucial role in the international hydrogen economy, especially if it is able to realise its ambitious cost reduction goals.

Canada is already among the top 10 producers of hydrogen today and has published its hydrogen strategy in December 2020. This lays out a vision for 2050 according to which Canada aims to be one of the top three producers of hydrogen globally with a domestic supply greater than 2 Mt/year (66.7 TWh/year). Moreover, Canada seeks to reduce the price of hydrogen to 1.5 - 3.5 USD/kg (1.38 - 3.23 EUR/kg) and aims at 30% of its energy to be in the form of hydrogen (Natural Resources Canada 2020). In its 2023 budget, the Canadian government has allocated 17.7 billion CAD (12.1 billion EUR) to a Clean Hydrogen Investment Tax Credit[4]. The credit is available to projects producing hydrogen via electrolysis or with natural gas and CCU/S. It supports 15% to 40% of a project's eligible costs[5], depending on the project's carbon intensity and the fulfilment of labour requirements (Government of Canada 2023; Pillsbury Law 2023). Internationally, Canada is actively positioning itself as a hydrogen exporter, for instance, by signing the Canada-Germany Hydrogen Alliance in August 2022 with the aim to establish a hydrogen export corridor where first shipments are planned for 2025 (Canada-Germany Energy Partnership 2023).

2.2 Advancements Through Multilateral Institutions

Several fundamental aspects of a global hydrogen economy and global hydrogen trade require international cooperation in order to ensure the compatibility of different approaches. Examples of such aspects include emission-related certification, rules and regulations for international trade, technical standards (as opposed to emission-related certification), hydrogen safety as well as the treatment of hydrogen under climate-related international agreements. Since emission-related certification is of crucial importance to enabling the market ramp up and trade of green hydrogen, it will be treated separately in the subsequent chapter.

Especially the trade of hydrogen has gained more and more attention over the recent years. In this regard, it is worth noting the Hydrogen Trade Forum launched by the Clean Energy Ministerial as well as the Hydrogen Trade Rules [H2TR] Task Force of the International Partnership for Hydrogen and Fuel Cells in the Economy [IPHE] (IPHE 2023b).

In a broader sense, both the G7 and the G20 have become important fora for the advancement of the international hydrogen economy. The G20 Leaders Declaration as well as the High-Level Voluntary Principles on Hydrogen both cover a broad range of issues relating to hydrogen trade, production, innovation, and finance (G20 Secretariat and Ministry of External Affairs, Government of India 2023). In the G7 context, the 2022 Hydrogen Action Pact contains commitments to the acceleration of hydrogen deployment and the establishment of regulatory frameworks (Hydrogen Insight 2022).

Individual institutional players have also sought to support ongoing discussions. IRENA, for instance, seeks to facilitate multilateral discussions around green hydrogen through its Collaborative Framework on Green Hydrogen [CFGH], which is focused on finance, infrastructure, and the role of the global south (IRENA 2023d). In addition, UNECE, the United Nations Economic Commission for Europe, announced that they are working on an international hydrogen classification system (UNECE 2022).

[4] The credit is to be initiated in 2023 and to be phased out by 2034.
[5] Eligible costs entail equipment costs but exclude costs for feasibility studies, front-end engineering design studies, and operating expenses.

In the past years, the COPs, or world climate conferences, have also brought hydrogen more into the spotlight, for example through the announcement of the Global Renewable Hydrogen Forum at a roundtable chaired by the Egyptian President and German Chancellor (Hydrogen Council 2022a). The Forum is a multi-stakeholder public-private platform to advance the usage of green hydrogen for decarbonisation, supported by UN institutions such as the United Nations Industrial Development Organisation. Most recently, COP28 saw the launch of several relevant initiatives, such as the "Hydrogen Declaration of Intent to pursue mutual recognition of hydrogen certification schemes".

On the side of technical standards, the work of ISO/TC 197 (Hydrogen technologies) has to be highlighted as the establishment of international technical standards is crucial to the development of compatible hydrogen infrastructure (ISO 2023b).

Beyond these purely international approaches, a range of national initiatives with an international focus have also been established, for instance Korea's "Clean Hydrogen Trade Initiative" under which it seeks collaboration with like-minded countries (H2 MEET 2023).

In addition to national and sub-national public initiatives, private companies are also connecting in order to steer the promotion of a global low-carbon hydrogen market. To this end, the Hydrogen Council was launched at the World Economic Forum in 2017. While 13 companies, with Japanese and German enterprises heavily featured, became initial members, the council now has almost 150 member companies, comprising known actors from the energy transport and manufacturing sectors (Hydrogen Council 2024a). The Council publishes a yearly study called "Hydrogen Insights" providing market updates and facilitates various activities aimed at increasing dialogue around the topic (Hydrogen Council 2024b).

2.3 Certification

Certification of low-carbon hydrogen is an essential pillar for the establishment of an international hydrogen market in the context of net zero commitments. Without clear certification, the CO_2 footprint of procured hydrogen – and therefore its value for decarbonisation – is unclear, which severely limits the willingness of market participants to pay for the additional cost that is – at least for now – associated with green or low-carbon hydrogen. If this is not addressed, the information asymmetries between buyer and seller will, according to standard economic theory, lead to a crowding-out of green or low-carbon hydrogen and hinder the development of a global low-carbon hydrogen economy.

It is therefore unsurprising that many of the leading hydrogen economies are working on the establishment of certification systems for hydrogen, on the national, supranational, and global level. Regarding the latter, there are two frameworks in which certification of hydrogen is being discussed. The first and most important of these is IPHE, the International Partnership for Hydrogen and Fuel Cells in the Economy, an organisation seeking to enable and promote "the transition to clean and efficient energy and mobility systems using hydrogen" (IPHE 2022b). In order to build a foundation for international trade, IPHE, which consists of 23 member countries, including all four countries of interest to this study, sees the measurement of the carbon footprint of hydrogen and a guarantee-of-origin or certification system as crucial (IPHE 2022a).

To support the creation of such systems in practice, IPHE has set up a related task force, the Hydrogen Production Analysis or H2PA Task Force, which aims to "develop a mutually agreed methodology framework to determine the greenhouse gas emissions associated with hydrogen produced from different pathways". This Task Force has already presented a draft methodology in the fall of 2021, which was the result of a process led by European countries and Australia, with participation of experts from Japan and Korea. Even though this document is only a first step and does not constitute a final recommendation by the IPHE, it is crucial in the sense that it presents the first global attempt to develop a unified methodology. It is also noteworthy that the suggestion lags behind more stringent approaches, such as the European Hydrogen Strategy and the EU Renewable Energy Directive. The document is, however, continuously updated, with the most recent version being from July 2023 (IPHE 2023a).

Important in this context is that ISO has developed and, in the context of COP28, published a normed methodology for determining greenhouse gas emissions associated with hydrogen production (ISO 2023a), which is broadly based on IPHE methodology (H2Global and Hydrogen Europe 2023). This is seen as the "most mature standard methodology […] developed at global level by an [Standards

Development Organisation]" [SDO], while NGOs criticise it as insufficient (IPHE et al. 2023; Hydrogen Insight 2023a).

Furthermore, IPHE has also established a dedicated Hydrogen Certification Mechanisms [H2CM] Task Force, which aims at "providing a deeper understanding of certification mechanisms, as well as a sound basis to support reaching consensus on implementing interoperable certification […] across regions" (IPHE 2023b).

Beyond IPHE, the Clean Energy Ministerial [CEM] of the International Energy Agency is also an important format in which hydrogen cooperation takes place. In the Ministerial's Hydrogen Initiative, which is based on non-binding agreements between member ministries, an activity on Hydrogen Certification was launched as part of the 2021-2022 work programme. This was intended to complement IPHE draft methodology by providing a basis for utilising and testing the methodology. While there is no information available regarding the current status of the activity, the CEM also launched its Hydrogen Trade Forum in 2023, which aims at addressing trade barriers, without mentioning certification specifically (Clean Energy Ministerial 2023).

Most recently, in September 2023, the G20 started playing an important role for the topic of hydrogen certification, as it approved the leaders' declaration on hydrogen. The signatories of the declaration aim to support the global hydrogen market through developing "mutually recognised and inter-operable certification schemes" (Hydrogen Insight 2023i). The declaration also references the "G20 High Level Voluntary Principles on Hydrogen" from July 2023, which explicitly encourage a "globally harmonised approach to certification for hydrogen produced from zero and low emission technologies" (G20 Secretariat and Ministry of External Affairs, Government of India 2023). COP28 saw the launch of the Intergovernmental Declaration of Intent on Mutual Recognition of Certification Schemes for Hydrogen and Hydrogen Derivatives, which was endorsed by 39 countries, who vow to accelerate the development of standards that allow the mutual recognition of methodologies (Hydrogen Council 2023; Habibic 2023).

Another international approach, launched by the non-profit Green Hydrogen Organization in Switzerland, is the establishment of the voluntary "Green Hydrogen Standard 2.0", which has been endorsed by major developers in the context of COP28 (Hydrogen Insight 2023h). TÜV SÜD, a private company based in Germany, has also launched a new standard for low-carbon and blue hydrogen (Hydrocarbon Engineering 2023).

2.4 Technological Developments

Currently, the majority of hydrogen production still happens via steam reforming and most hydrogen is used on-site. However, with the increasing need to rapidly reduce GHG emissions and shift global economies to net zero, green and low-carbon hydrogen are gaining attention. Also, as the demand for hydrogen increases, longer distance transportation becomes more relevant. A joint study by the IEA and the European Patent Office [EPO] has registered a clear increase in patent applications for hydrogen technologies motivated by climate concerns, especially in technologies at the production stage. Here, patenting activities are heavily focused on electrolysis and are led by Europe, the US, and Japan. Storage, distribution, and transformation technologies, after having peaked in 2012 in terms of patent applications, have seen less innovative activity in recent years. Moreover, innovation efforts are focused on improving established technologies such as pipeline networks and ancillary equipment. Innovation in storage solutions has long been focused on pure hydrogen but has expanded to include liquid storage, metal hydrides, and vehicle refueling more recently. Air Liquide, Linde, and Air Products are the clear frontrunners in patent applications, however, the automotive industry is also highly engaged with the Japanese companies Toyota and Honda at the forefront. Innovation in end-use applications is dominated by advancements in the automotive sector but increasing attention is being paid to applications in the aviation and shipping sectors as well. While Japan is leading in the automotive sector, the US dominates in the aviation sector and the EU in the shipping sector. In the steel, power generation, and buildings sector innovative activity is comparably low, with European and Japanese players leading in the steel sector (IEA and EPO 2023).

Several innovative approaches are already being tested in demonstration efforts. For instance, the offshore production of green hydrogen has seen advancements: In a joint initiative, the Dongfang Electric Corporation and a research team led by the Chinese Academy of Engineering produced green hydrogen on a floating offshore platform via seawater electrolysis, while the French start-up Lhyfe also succeeded in producing green hydrogen at sea on its Sealhyfe platform (RenewEconomy 2023a, 2023b). Meanwhile, the Norwegian Norsk Hydro ASA has produced the world's first batch of aluminum using green hydrogen at its plant in Navarra, Spain (Financial Post 2023).

In accordance with the lower volume of innovative activity in the area of storage, transport, and distribution, fewer demonstration projects exist. Probably the most prominent one is the world's first shipments of liquid hydrogen from Australia to Japan in 2022 as part of the Hydrogen Energy Supply Chain [HESC] demonstration project. However, technological improvements, lower costs, and higher efficiency are required for similar endeavors to be employed at scale (IEA 2023e). Currently, seven projects are developing hydrogen tankers for the commercial transportation of liquid hydrogen before 2030. Three of these projects are by Korean companies (IEA 2023c). A study by a research consortium consisting of the Forschungszentrum Jülich, the University Erlangen-Nuremberg, and Fraunhofer ISE demonstrated the potential for new, innovative approaches in the field of transportation: The study finds dimethyl ether [DME], conventionally used as a propellant in deodorant sprays, to be a viable and thus far underestimated option for storing and transporting hydrogen over long distances[6]. The advantages of this approach compared to using ammonia or methanol as vectors include "a higher technical hydrogen capacity, higher gravimetric energy density and lower toxicity [as well as] comparatively low heat demand and temperature level for H_2 release" (Schühle et al. 2023, p.3011).

The storage and subsequent conversion of hydrogen to electricity, heat, etc. [P2X] can play an important role in the flexibilisation of the power sector. This is necessary as intermittent renewable energy sources are increasingly integrated into international power systems. In the area of Power-to-Hydrogen-to-Power [P2H2P] applications, a consortium led by Siemens Energy had a major break-through at the end of 2023, when, as part of the HYFLEXPOWER project, the consortium was able to run its gas turbines on 100% green hydrogen. The hydrogen had previously been produced and stored on-site. HYFLEXPOWER is the first project of its kind and is seen as crucial to the decarbonisation of the industry sector (Siemens Energy 2023). Households can make use of the re-electrification process as well, however, here fuel cells [FCs] are the more efficient solution. While Europe and Japan are market leaders in the development of micro-cogeneration PEMFC installations already, large-scale application of P2H2P technologies is yet to occur and companies including Siemens, General Electrics, Linde, and Kawasaki Heavy Industries are continuously working on improvements and new innovations (Siemens Energy 2023; Risco-Bravo et al. 2024).

[6] The approach works by bonding renewable H_2 to CO_2 "under formation of DME and water at a harbor site". The liquid DME can be shipped using existing tanker and port infrastructures. At the destination port, H_2 and CO_2 are released via DME steam reforming, with the CO_2 being liquefied and backshipped to the original harbor.The resulting H_2 can be distributed in the destination country via pipelines (Schühle et al. 2023, p.3011)

3 National Hydrogen Overviews

3.1 Hydrogen in Australia

Status of Policy and Legislation

Quick Facts

Projected H_2 Demand

- **2030:** 0.04 to 7 Mt
- **2050:** 6 to 100 Mt

Projected H_2 Production

- **2030:** 6 Mt (green)

Projected H_2 Import

- **none**

In 2019, Australia was among the first three countries in the world to publish a hydrogen strategy, which is currently being updated. The original strategy identified 57 actions across seven action areas (national coordination; developing production capacity, supported by local demand; responsive regulation; international engagement; innovation and research and development [R&D]; skills and workforce; and community confidence). "H_2 under 2 AUD/kg" is the key overarching goal (DCCEEW 2019).

One year later, in 2020, Australia published a Technology Investment Roadmap to prioritise government investment in sustainable technologies, distinguishing between short-term (2020 - 2022), medium-term (2023 - 2030) and long-term (2030 - 2050+) measures. In the case of hydrogen, the Australian government aims to establish an industry and lead technology in the short-term, reduce the cost of hydrogen in the medium-term, and focus on export demand in the long-term. Since the publication of these two key documents (which were developed by the previous government), Australia has initiated various measures, most of which are still in the implementation phase. These include an ongoing evaluation of national gas laws for their applicability to hydrogen; an evaluation of all federal, state, and territorial laws to identify potential barriers to the development of a hydrogen economy; the development of training materials and guidelines for professionals, and the development of a Guarantees of Origin Certification Scheme for hydrogen and its derivatives (DCCEEW 2023d, 2023c). More recently, the scheme, which is based on the recommendations by IPHE (see chapter 2.3), has been expanded to also include the certification for renewable energy sources. The Australian government first ran a consultation on the scheme in late 2022/early 2023 and committed 38.2 Mio. AUD (23.8 Mio. EUR) to the creation of the scheme (DCCEEW 2023b). While the final design of the scheme remains to be seen, the Government plans to use it to provide a methodology to measure carbon emissions and certify renewable electricity without setting benchmarks for what counts as "green" or "low-carbon" hydrogen (products).

In 2023, the Australian government published "The State of Hydrogen Report 2022" which looks at the development of Australia's hydrogen economy since the release of the National Hydrogen Strategy. It finds that in many areas Australia is making rapid progress (e.g. in the areas of investment, electricity generation, and project scale) or is at least progressing (e.g. in the areas of exports, gas networks, and industrial heat applications). However, the report also finds slow progress in four areas: power grid support, heavy and light transport, and steel and iron manufacturing (DCCEEW 2023c).

Currently, the DCCEEW is reviewing Australia's National Hydrogen Strategy. Inputs from the public have been considered in a public consultation process. The aim is to increase the competitiveness of Australia in the international hydrogen market, a goal that must be regarded against the backdrop of more than 40 countries having published their own hydrogen strategies and Australia feeling the pressure created by the US Inflation Reduction Act [IRA] (Australian Government 2019). Besides the national level, all states and territories also have their own strategy papers.

Last but not least, there are also six decarbonisation plans that are currently being developed by the government and which will likely include hydrogen targets for individual sectors including transport, energy, resources, and industry. These plans will likely prove to be very important for domestic decarbonisation and provide more detail than the updated hydrogen strategy. Low-carbon domestic hydrogen use will be incentivised under the reformed safeguard mechanism, which requires Australia's 215 highest-emitting industrial facilities to reduce emissions by 4.9% per year from financial year 2023/24 onwards.

Funding

In May 2024, the Australian government announced its budget for 2024/2025, which contains significant new funding announcements for the ramp-up of the hydrogen economy. As part of the 23 billion AUD (14 billion EUR) Made in Australia Act, which can be regarded as Australia's answer to the US' IRA and the EU's Net Zero Industry Act, green hydrogen production projects that conclude an investment decision by 2030 will be eligible for a tax credit of 2 AUD/kg (1.24 EUR/kg) for hydrogen. A total of 6.7 billion AUD (4.2 billion EUR) is available for this purpose over 10 years. In addition, 2 billion AUD (1.3 billion EUR) will be made available for a second round of the Hydrogen Headstart programme (see below). There are also funds for the implementation of further measures of the hydrogen strategy and for the Guarantee of Origin Scheme (Australian Hydrogen Council 2024; Federal Budget 2024).

As of before the budget announcements, the Australian government supports the production of hydrogen with 3.64 billion AUD (2.3 billion EUR) (Commonwealth Scientific and Industrial Research Organisation [CSIRO] as of 1 December 2023). Besides the newly announced Hydrogen Production Tax Incentive, the four largest funding programmes are:

- The Hydrogen Headstart Program, which thus far provides 2 billion AUD (1.2 billion EUR) through contracts for difference for two to three green hydrogen projects and was passed as part of the 2023/24 budget. In December 2023, six projects[7] were shortlisted to submit full applications (DCCEEW 2023a). The tender will award successful projects in October 2024 and they will receive the subsidy over a 10-year period starting in 2026/2027.
- The Regional Hydrogen Hubs Program, which provides 513.7 Mio. AUD (319.7 Mio. EUR) to build hydrogen hubs in Gladstone, Hunter Valley, Bell Bay, Port Bonython, Kwinana, and the Pilbara region, as well as nine development and design projects across Australia (441.8 Mio AUD (275 Mio. EUR) in total) – an additional hub in Townsville, Queensland is planned, with 71.9 Mio. AUD (44.8 Mio. EUR) allocated to this.
- The Clean Energy Financing Corporation [CEFC] Advancing Hydrogen Fund, which provides 300 Mio. AUD (186.7 Mio. EUR) for projects that are in line with the National Hydrogen Strategy and support the development of the hydrogen economy.
- The Australian Renewable Energy Agency [ARENA] Advancing Renewables Program, which allocates 106.3 Mio. AUD (66.2 Mio. EUR) to projects aimed at the commercialisation of hydrogen[8].

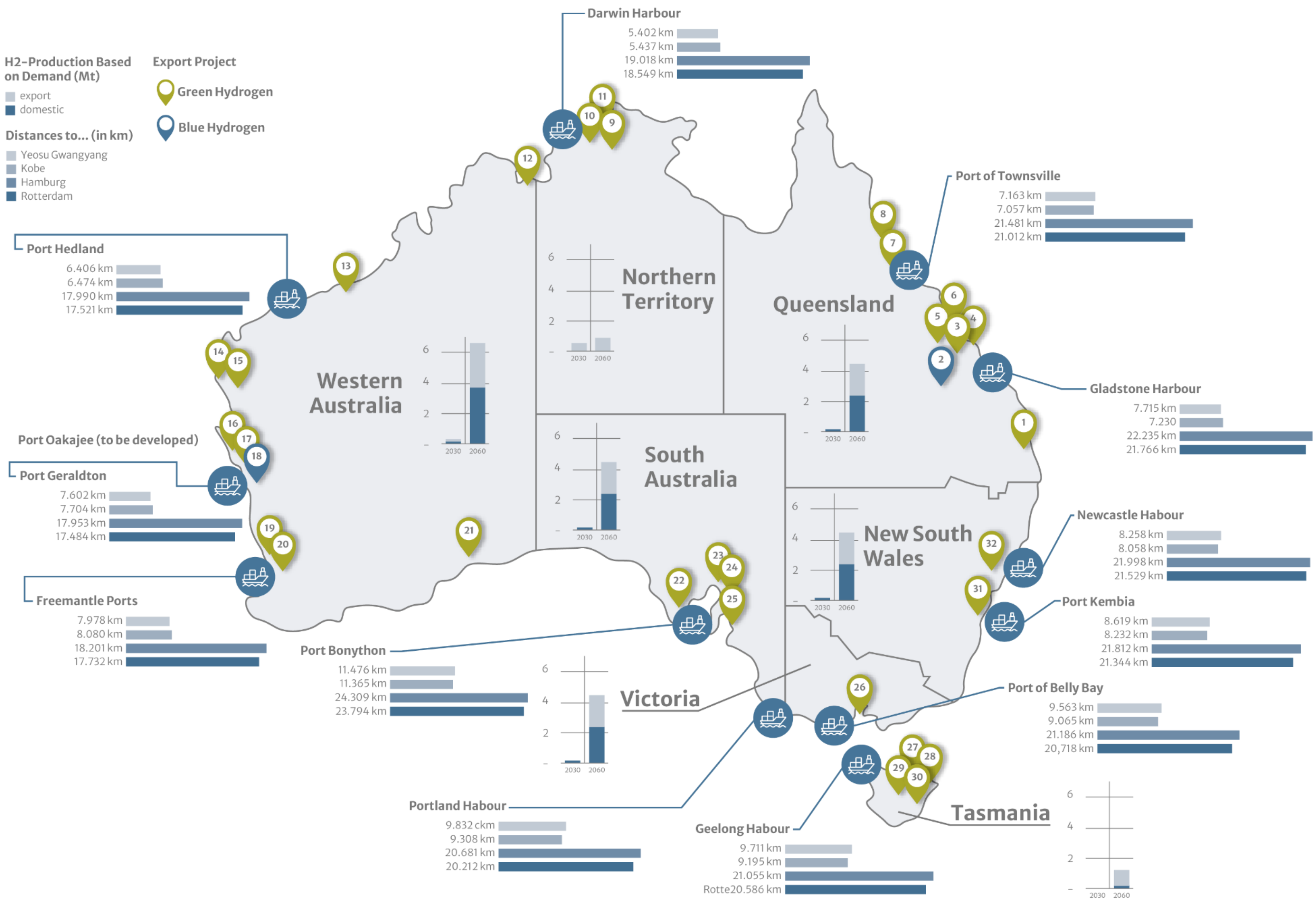
These and other national funding measures are complemented by 4.7 billion AUD (2.9 billion EUR) of funding at the level of the states and territories. New South Wales [NSW] is the frontrunner with 3.26 billion AUD (2 billion EUR), followed by South Australia [SA] with 682 Mio. AUD (424.5 Mio. EUR). In NSW, 3 billion AUD (1.9 billion EUR) have been made available under its hydrogen strategy alone, including for example 1.5 billion AUD (933.6 Mio. EUR) in concessions, where green hydrogen producers can receive a circa 90% reduction in electricity network charges if "they connect to parts of the network with spare capacity" (NSW Department of Planning, Industry and Environment 2021, p.53) and be exempted (90-100%) from various other charges including those related to the Electricity Infrastructure Roadmap, Climate Change Fund, Energy Security Safeguard and GreenPower (NSW Department of Planning, Industry and Environment 2021; Australian Hydrogen Council 2023). In South Australia, the Hydrogen Jobs Fund invests 593 Mio. AUD (369.1 Mio. EUR) into the construction of a hydrogen power station, electrolyser, and storage facility in Whyalla, which is expected to be operational in 2025 (CSIRO 2023).

[7] The shortlisted projects include : H2Kwinana by bp Low Carbon Australia, HIF Tasmania eFuel Facility by HIF Asia Pacific, Port of Newcastle Green Hydrogen Project by KEPCO Australia, Hunter Valley Hydrogen Hub by Origin Energy Future Fuels, Central Queensland Hydrogen Project by Stanwell Corporation, and Murchison Hydrogen Renewables Project by Murchison Hydrogen Renewables.
[8] The programme additionally allocates funding on a rolling basis to projects aiming to optimise the transition to renewable electricity as well as projects supporting the transition to low emissions metals.

Demand and Production

Australia has enormous potential to become a major producer and exporter of low-carbon hydrogen. Today, Australia produces around 650 ktpa of hydrogen via natural gas steam methane reforming [SMR]. In addition, 30% of the planned hydrogen projects worldwide, valued at 230 - 300 billion AUD (143 - 186.7 billion EUR), are in Australia. The IEA (2023c) predicts that Australia could produce 6 Mt of green hydrogen by 2030. Given Australia's infinite access to wind and solar energy, the country has great potential to grow its green hydrogen production well beyond 6 Mt in subsequent years. Accordingly, the IEA (2023c) suggests that Australia could become the second largest exporter of hydrogen after Latin America, with its main target markets being in the Asia-Pacific region, followed by Europe (Daiyan et al. 2021). Currently, there are 33 export projects planned across Australia. Their location, type of hydrogen produced, and distance to ports relevant to the countries in this study are shown in Figure 4.

Figure 3: Planned Export Projects in Australia



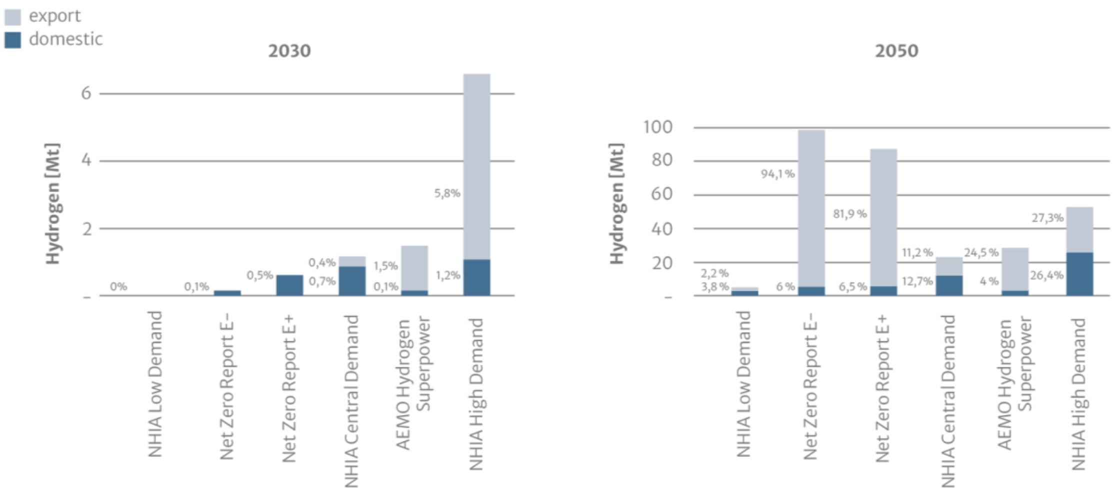
Source: Own graphic based on data by CSIRO

However, limiting factors such as workforce availability, speed of processes, availability of power, water, components and capital are likely to constrain Australia's potential. Therefore, predictions at this stage have to be treated with caution.

Since Australia will not need to import any hydrogen, demand scenarios offer a good picture of possible future production scenarios, although the limiting factors named above might have a dampening effect. For the purpose of this study, it is assumed that the sum of domestic and export demand illustrates what future production might look like. Over the past few years, various scenarios have been developed that map the demand for hydrogen (either alone or in conjunction with developments in other (renewable) resources. The most recent ones are the National Hydrogen Infrastructure Assessment [NHIA][9] and the Net Zero Australia Report[10]. Other prominent modulations are Deloitte's Australian and Global Hydrogen Demand Growth Scenario Analysis from 2019[11] and the Australian Energy Market Operator's [AEMO] 2022 Integrated Systems Plan. When comparing these scenarios, the wide range of predictions becomes apparent, which is due to the relative nascency of the hydrogen industry and the long time periods for which predictions are made. Moreover, different assumptions underly the scenarios, which can alter the predictions: For instance, the AEMO analysis only considers the National Electricity Market [NEM], thus excluding demand in Western Australia [WA] and the Northern Territory [NT].[12]

In 2030, low to moderate demand scenarios predict that the majority of hydrogen demand will be domestic. High demand scenarios, on the other hand, see a strong role for exports in 2030 already. Overall, demand ranges from 0.04 Mt to 6.98 Mt (1.3 to 232.9 TWh), of which up to 5.82 Mt (194.2 TWh) come from exports. The high end is in line with the IEA's projection of 6 Mt of production in Australia by 2030. The lowest hydrogen demand scenarios are those where electrification takes the lead role in the quest for decarbonisation (Deloitte Electric Breakthrough, Net Zero Australia E+, and NHIA Low Demand). By 2050, all scenarios agree that exports play a significant role in the demand for Australian hydrogen. The overall level of demand in 2050 is predicted to be at around 5.9 Mt to 100.06 Mt (196.9 to 3,339 TWh), with 2.15 Mt to 43.7 Mt (71.7 to 1,458.3 TWh) being from exports (AEMO 2022; Arup Australia 2023; Deloitte 2019). A visual comparison of the demand predictions is shown in Figure 5 below.

Figure 4: Demand Predictions for Australian Hydrogen in Mt



Source: Own graphic based on AEMO 2022; Arup Australia 2023; Net Zero Australia 2023; Deloitte 2019

As of today, Australia's hydrogen is largely consumed by associated ammonia synthesis (65%) and crude oil refineries (35%). In the near future, the National Hydrogen Infrastructure Assessment expects domestic demand to come primarily from the transport sector, although this is highly dependent on the availability of refuelling networks and infrastructure as well as on car manufacturers bringing hydrogen vehicles to the market by 2025. Another important domestic demand sector is the mining industry, where

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[9] For this report, the three main demand scenarios, i.e. the Low, Central, and High Demand Scenarios, were considered.
[10] Although all scenarios of this report were considered, only two scenarios (E+ and E-) are displayed in Figure 2 to ensure readability.
[11] The scenarios from this study will only be accounted for in narrative form as the data is not publicly available.
[12] AEMO's Integrated Systems Plan 2022 only accounts for hydrogen exports in its Hydrogen Superpower scenario. Hence, to ensure comparability, only the AEMO Hydrogen Superpower scenario will be considered here.

low-carbon hydrogen could make a significant contribution to decarbonisation, especially in off-grid regions. As costs fall, the use of low-carbon hydrogen will also become interesting for other sectors, such as the industrial sector (here especially for the production of green steel), the aviation sector, the shipping sector, and the electricity sector (Arup Australia 2023).

Projects and Current Developments

CSIRO's HyResource platform keeps track of the state of hydrogen projects in Australia. The data show that the great majority of projects currently under construction or development use electrolysis as the main production method. Of overall 109 projects, only seven projects are using fossil fuels to produce hydrogen, of which five use CCU/S technologies. Three projects are biomass and waste based, one of them with hybrid electrolysis (CSIRO 2024a). This means that currently only 6% of all operating and proposed Australian projects are based on production from fossil fuels. The National Hydrogen Infrastructure Assessment finds that while there will still be locations where blue hydrogen is the preferred solution (Queensland and Northern Territory) in the 2030s, from 2040 this will no longer be the case and green hydrogen will be the most cost-effective solution for all production sites (Arup Australia 2023).[13]

Yet, there are very few electrolysis projects that have reached financial close in 2023 and all of them are in the lower MWs. One notable exception is the South Australian Government's funding for a 250 MW electrolyser, which has been announced in October 2023 (although FID will be taken next year, see chapter 4.1 for more details). Since the expansion of renewable generation projects in Australia has recently stalled, even for the purpose of decarbonising the national electricity demand, there are question marks around the feasibility of medium- to large-scale renewable hydrogen projects that at least partly rely on grid-connected electricity in the short- to medium-term.

The competitiveness of green hydrogen is further curtailed by major energy demand countries, particularly Japan and Korea, being focused on low-carbon rather than green hydrogen, and the fact that fossil-based hydrogen projects remain more attractive economically, especially if CCU/S technologies are not integrated at all or not to the extent required for having a real positive impact in terms of emission reductions. Together with Australia's mixed track record on large-scale CCU/S projects, all this could lead to lock-in effects for fossil-based hydrogen, which could even increase global emissions (Nikkei Asia 2022b; Herbert Smith Freehills 2023; Australia-Korea Business Council 2021). Consequently, a strong commitment and expansion of investment in green hydrogen projects by the Australian federal government, state governments, and industry are urgently required to realise the renewable opportunity and avoid lock-in effects.

Another area that requires targeted attention is the transport infrastructure for hydrogen. By 2030, the National Hydrogen Infrastructure Assessment expects hydrogen production to still be located close to demand centres. By 2050, however, 78% of hydrogen is expected to be produced in separate, more distant production facilities and transported to demand locations. Between 2025 and 2030, most hydrogen will be transported by truck; by 2040 rail will also play a role; from 2040 most hydrogen will be transported by pipeline. This will require an extensive expansion of the transport infrastructure, especially of suitable pipelines (reuse of existing gas pipelines is only possible to a limited extent and requires more in-depth assessments). Additionally, to enable the large-scale export of hydrogen and its derivatives, Australia will need to upgrade its ports (Arup Australia 2023).

[13] This is based on the assumption that the CAPEX costs of electrolysers will decrease significantly. Sensitivity analyses show that if this is not the case, blue hydrogen could play a more prominent role in 2030 (73% instead of 15% in the study's Central scenario) and remain relevant in 2040 (30% instead of 0% in the study's Central scenario) (Arup Australia 2023). Yet, all of this also needs to be considered against the background of Australia's thus far rather unsuccessful history of deploying CCU/S technologies.

Industry

Australia's unique strength for a future hydrogen industry lies in its endowment with space and vast natural resources, importantly wind and sun, as well as geologic structures that allow for the storage of hydrogen (DCCEEW 2023c). Hence, Australia has a competitive advantage at the production stage. While Australia, together with Europe, is leading in terms of prospective electrolysis project applications, the previous section showed that Australia now needs to ascertain that it implements its potential (IEA 2022a). At the production stage, Australia is also active with regards to hydrogen derivatives, especially green ammonia, for which there are 23 projects (17 of these are export related) (DCCEEW 2023c). For methanol production (3 projects) and methylcylohexane [MCH] production (1 project) there is less activity as of now.

However, while the production stage is Australia's focal point, there is the desire to use the energy transition and nascent clean energy industry to move beyond the "dig-and-ship" mentality and try to build a broader manufacturing base. Accordingly, industry players are already starting to move into other parts of the hydrogen value chain. Fortescue, one of the key players in Australia's hydrogen industry, has, for instance, produced the first Australian-made electrolyser in its newly built Gladstone electrolyser manufacturing plant, which will have an initial capacity of producing 2 GW annually (DCCEEW 2023c). Another notable example in the electrolysis field is the start-up Hysata, which originated at the University of Wollongong and is developing a highly efficient electrolysis technology to help reduce the energy needs and hence production costs of green hydrogen. Hysata is among the recipients of funding from the German-Australian Hydrogen Innovation and Technology Incubator (HyGate) Initiative, through which it will receive 8.98 Mio. AUD from ARENA and 5.9 Mio. EUR from the German Federal Ministry of Education and Research [BMBF] (Hysata 2022, 2023). The Australian government and territorial governments are actively encouraging similar endeavours by other companies. For instance, the Western Australian Government has drawn up the WA Government Electrolyser Manufacturing Initiative, providing funding to industries to conduct feasibility studies on the creation of electrolyser capabilities within WA (DCCEEW 2023c). Since storage technologies will be crucial for implementing Australia's export ambitions, this is another area where Australian companies are active in. For example, the start-up Lavo aims to demonstrate the safety and validity of its metal hydride storage system in a major export project by Marubeni Corporation, which will ship green hydrogen from South Australia to Indonesia (Lavo 2023).

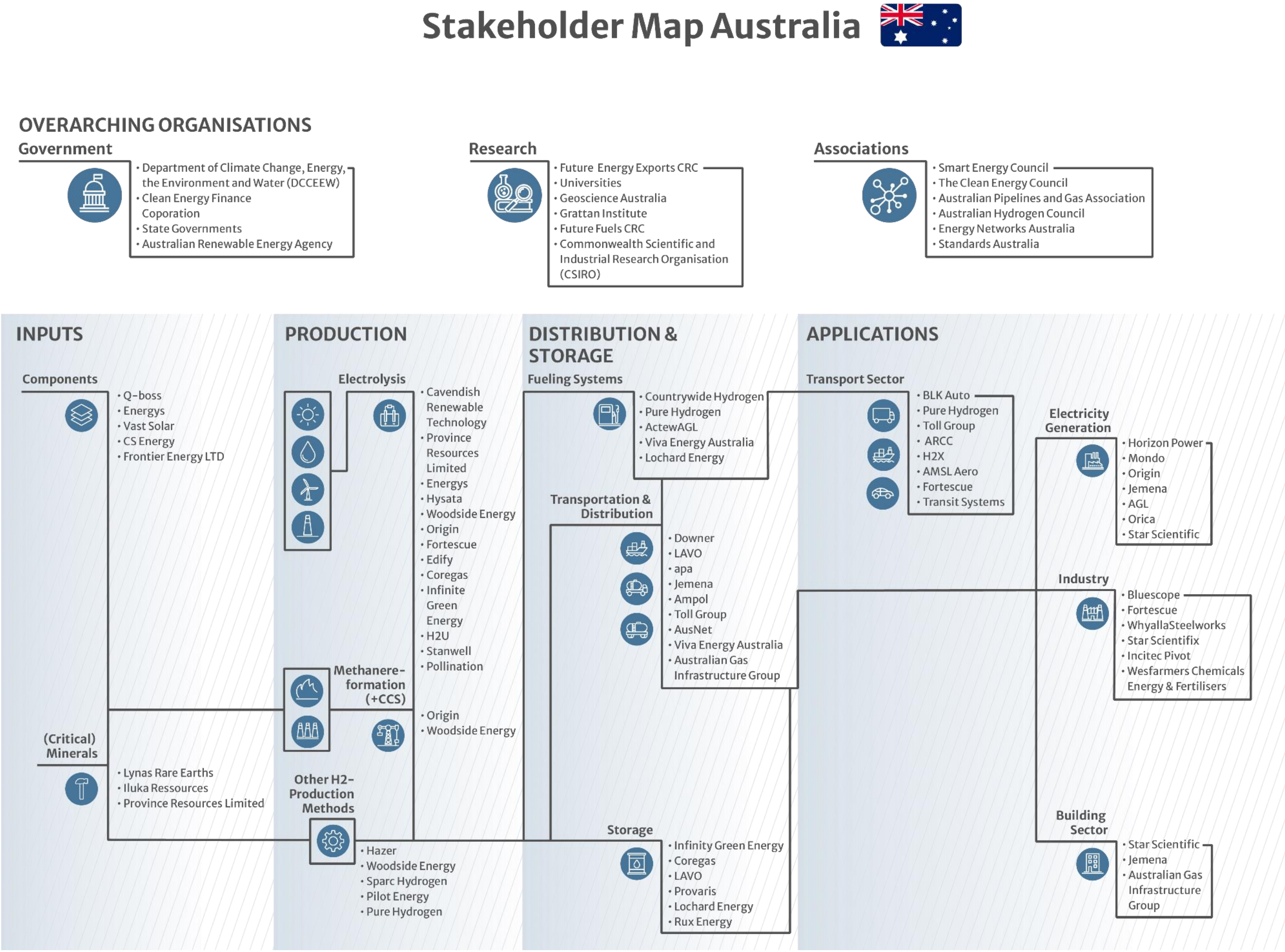
Australia also has potential further up the value chain. Grattan Institute expects that green iron and steel will play an important economic role for Australia, generating 65 billion AUD (40.5 billion EUR) per year and 25.000 jobs in 2050 (Grattan Institute 2020). While Australia today is the greatest iron ore producer globally, it processes relatively little of the iron ore domestically. With its renewable and hydrogen potential, Australia however has optimal conditions for establishing a domestic processing industry and thus to become an important player in the global green steel industry (DCCEEW 2023c). Feitz et al. (2023) stress that Australia has a competitive advantage in this field due to its huge existing iron ore reserves, mining experience, and excellent conditions to co-locate green hydrogen hubs with mining facilities and steel manufacturing, where the wind and solar facilities required for the production of green hydrogen can benefit from the existing power and transportation infrastructure of the iron ore mines. Such co-location would reduce the cost of Australian produced green steel (due to reduced transportation and storage needs of the hydrogen) and thus increase its international competitiveness. Costs can be reduced further when a mix of solar and wind installations is employed, as this would reduce the need for energy storage applications (Feitz et al. 2023). In fact, a recent analysis of the production of hot briquetted iron [HBI] in South Australia indicates that green steel produced with SA HBI is competitive with conventional steel by 2030. Additionally, the analysis shows that it is cheaper for Germany to import SA HBI than producing steel from locally produced direct reduced iron [DRI] (Government of South Australia and Port of Rotterdam 2024). However, any shift in the iron and steel supply chains comes with major risks for the importing countries. Effects on the local workforce and the security of supply are two important considerations that must not be neglected and the costs of which need to be added to mere production costs. Therefore, the German Hydrogen Association, for instance, advises against such a relocation of the supply chain (Deutscher Wasserstoff-Verband [DWV] and HySteel 2023).

For these manufacturing and production ambitions to materialise, large amounts of critical minerals and resources will be required. Circling back to the very beginning of the hydrogen value chain, Australia with its large deposits of most of the minerals required for the green energy transition already plays a key role in the mining sector and wishes to extend its role to also include the processing and refining of these minerals. Lynas Rare Earths and Iluka Resources are two companies that are actively working on expanding their businesses in this direction. With this, Australia could position itself as a valuable, more reliable alternative trading partner to China, which currently dominates the critical minerals market (The Guardian 2023). The Critical Minerals Strategy 2023 – 2030 by the Australian federal government reflects Australia's ambitions in the mining sector and its intention to build an ethical and sustainable industry (Australian Government 2023a). The budget for 2024-25 takes concrete steps in this direction by announcing a tax credit of 10% on the processing and refining costs associated with the processing of critical minerals.

Overview of Stakeholders

The following stakeholder map (Figure 6) provides an overview of Australian institutions and businesses active across the hydrogen value chain. Please note that the map does not represent a complete depiction of actors and that these were selected on the basis of desk research independently by the authors.

Figure 5: Overview of Stakeholders Australia



Source: adelphi

3.2 Hydrogen in Germany

Status of Policy and Legislation

Hydrogen Strategies

> **Quick Facts**
>
> **Projected H_2 Demand**
> - **2030:** 2 to 4 Mt
> - **2050:** 12 to 24 Mt
>
> **Projected H_2 Production**
> - **2030:** 10 GW of planned capacity
>
> **Projected H_2 Import**
> - **2030:** 1 to 3 Mt

Germany published its original National Hydrogen Strategy in June 2020, thus creating the framework for the German hydrogen industry. The central goal of this original strategy was to build 5 GW of domestic hydrogen electrolysis capacity by 2030[14]. In July 2023, the government released the update of Germany's hydrogen strategy, which establishes four key objectives: Securing the sufficient availability of hydrogen, expanding the hydrogen infrastructure, establishing hydrogen applications across sectors, and creating suitable framework conditions (BMWK 2023a). Each of these objectives is underpinned by short-, medium-, and long-term measures, only some of which can be outlined here. To secure sufficient supply, Germany doubled its goal for domestic electrolyser capacity to 10 GW[15] in 2030 and is actively working on establishing trade relationships to enable the import of hydrogen in the near future. The expansion of hydrogen infrastructure is to be achieved by repurposing gas pipelines and building new hydrogen pipelines, contributing to the creation of a European backbone network, and by installing import infrastructure. Germany foresees the application of hydrogen solutions in the industrial, transport, electricity, and heating (building) sectors and accordingly aims to support the up-take of hydrogen with sector-specific interventions, for instance, the establishment of specific funding systems and co-design of international certification schemes. In May 2024, the government proposed the Hydrogen Acceleration Act (Wasserstoffbeschleunigungsgesetz) which seeks to simplify, digitalise, and thus speed up planning, approval, and award procedures for hydrogen infrastructure projects and electrolysers. Further acceleration is to be achieved by categorising hydrogen infrastructure (including electrolyser) projects as being of pre-eminent public interest (BMWK 2023a, 2024c). The German parliament is expected to vote on the act in the autumn of 2024. In July 2024, the federal government published the long-awaited import strategy, which outlines Germany's import requirements overall and across sectors and stresses Germany's desire to have a diversified import base with imports reaching Germany both via pipelines and ship. Moreover, it re-iterates that Germany will import both green and blue hydrogen (BMWK 2024b; German Federal Government 2024c).

In addition, all federal states (Bundesländer) have developed their own or collaborative (as is the case for Berlin and Brandenburg as well as for Bremen, Hamburg, Mecklenburg-Western Pomerania, Lower Saxony, and Schleswig Holstein) strategies and roadmaps (dena 2022). The strategies and roadmaps differ in their focal points, which is due to differences in existing industrial, geographical, and economic structures in the states. Hessen, for instance, puts one focus on the development of e-kerosene via hydrogen, as it is an international hub for air traffic. The North-German Hydrogen Strategy, a joint endeavour by Bremen, Hamburg, Mecklenburg-Western Pomerania, Lower Saxony, and Schleswig Holstein, on the other hand, ties together the individual strengths of the different federal lands: On-and Offshore Wind (Bremen, Hamburg, Mecklenburg-Western Pomerania, Lower Saxony, and Schleswig Holstein), geologic formations for storing hydrogen (Schleswig Holstein, Mecklenburg-Western Pomerania, Lower Saxony) as well as access to the sea and thus international trade (Hamburg, Lower Saxony, Mecklenburg-Western Pomerania, Schleswig Holstein). The aim is to create hydrogen hubs in

[14] To support the roll-out of the German hydrogen economy, the strategy identified 38 activities (among them hydrogen cooperation in energy partnerships) and allocated €7 billion to the domestic market as well as €2 billion to the international market (acatech 2021).
[15] Of this, 0.2 to 0.3 GW are installed already or are currently being installed. 8.7 GW of additional capacity are being planned. However, estimates by frontier economics (November 14, 2023) suggest that only 20% of these are likely to be realized. Hence, a substantial and rapid expansion of capacity is still required (frontier economics 2023).

which all these assets can be combined and used to, for instance, decarbonise the industry and transport sector of the region (dena 2022; NWR 2021).

Individual industrial sectors also recognise the centrality of hydrogen for their future developments and explicitly consider this in their strategy papers. The Steel Action Plan, which has been developed jointly by the German government and the steel industry, stipulates that the availability of large amounts of green (and temporarily blue) hydrogen will be indispensable for the sustainable transformation of the steel sector and requires sufficient renewable energy capacities within Germany, an expansion of the electricity grid, funding for the domestic production of green hydrogen as well as the creation of conditions where hydrogen can be imported from a variety of countries. Given that the production costs of green steel will initially be higher than for conventional steel, Carbon Contracts for Difference are identified as a potentially useful tool to support a swifter transition within the steel industry (BMWK 2020). The action plan for the chemical and pharmaceutical industry also recognises hydrogen as "key to the transformation" of the sector and emphasises the expansion of the supply infrastructure and economic incentives for investments in electrolysers (Verband der Chemischen Industrie e.V.[VCI] 2021).

Relevant Laws and Regulations

Beyond explicit strategy papers, several laws and regulations in the area of climate protection have direct implications for the German hydrogen economy. Firstly, there is the Climate Protection Programme 2030 (Klimaschutzprogramm 2030), which was already passed in October 2019 and enshrined in law as part of the Climate Protection Act (Klimaschutzgesetz) in 2019. The Climate Protection Act stipulates Germany's targets for reducing greenhouse gas emissions: -65% by 2030, -88% by 2040 and climate neutrality by 2045 (all reductions compared to emission levels in 1990) (Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection [BMUV] 2021). The Climate Protection Programme defines the climate protection measures for all sectors and, importantly, introduced a CO_2 price of 25 EUR/t CO_{2e} for the transport and heating sector (as of 2024 the price is at 45 EUR/t CO_{2e} and will increase to 55 EUR/t CO_{2e} in 2025, and 55 - 65 EUR/t CO_{2e} in 2026), which will be integrated at EU level by 2027 (German Federal Government 2019; Tagesschau 2023b; German Federal Government 2024b). In the long-term, the government seeks to establish a mechanism by which some of the profits from the CO_2 price are paid back to the citizens in the form of a climate fond (Klimageld) (Tagesspiegel Background 2023b). In April 2024, the government reformed the Climate Protection Act, by introducing an obligation for each consecutive federal government to develop long-term climate protection programmes until 2030 and 2040 at the beginning of the legislative period, defining how all sectors together can achieve Germany’s climate goals. At the same time, the April reform abolished the need for individual ministries to issue an immediate programme if its respective sector missed its sectoral goals, as did for instance the transportation sector for the past three years (German Federal Government 2024a; Tagesschau 2024).

These regulatory measures are supplemented by laws and regulations in the energy sector. The Renewable Energy Sources Act (Erneuerbare Energien Gesetz [EEG]) contains requirements for the production of green hydrogen, including that hydrogen may only be categorised as "green" if it has not been produced with renewable energies that have received funding by the EEG (Federal Ministry of Justice [BMJ] 2023). This seeks to ensure that the renewable power used for the production of hydrogen is additional and does not curtail the build-out of renewable power. In the Energy Industry Act (Energiewirtschaftsgesetz), hydrogen has been recognised as an equivalent energy carrier alongside electricity and gas since 2021, and a separate regulation for pure hydrogen transport networks has been created (BDI 2021). In May 2023, an amendment to the Energy Industry Act was enacted, including regulations for the development of a hydrogen network: first, the long-distance network operators had to develop a hydrogen core network until the end of 2023, which is to become operational by 2037 and be approved and managed by the Federal Network Agency (Bundesnetzagentur [BNetzA]). In April 2024, the German government agreed on the financing mechanism for this core network, which will be 9,700 km long, 60% of which will be existing gas pipelines, and is expected to cost 20 billion EUR. The network will be built by private companies and costs will be covered entirely through user fees. To buffer initial excessive costs, the government decided to create an amortisation account, which is to be balanced (through the user fees) by 2055. The federal government also decided that it will bear the liability risk if one of the transmission system operators should become insolvent (BNetzA 2024a; Reuters 2024). Additionally, a comprehensive hydrogen grid development plan is to be integrated into the Energy Industry Act (BNetzA 2024b).

In an amendment to the Combined Heat and Power [CHP] Act, the German government introduced conditional incentives for new CHP plants with an electrical capacity above 10 MW, which now have to be H_2-ready to receive funding (BMWSB 2023; German Parliament 2023; Tagesschau 2023c; BMJ). At the end of 2023, the German government also passed an amendment to the Building Energy Act (Gebäudeenergiegesetz), which is crucial for the future of heating technologies deployed in German buildings. Concretely, it requires that all new heating systems installed in new buildings in new development areas need to be powered by 65% renewables from 2024 onwards. For existing buildings and new buildings outside of new development areas, municipalities must first determine whether these can be connected to district heating networks powered by waste heat. If this is not the case, gas heating systems that are hydrogen-compatible may be installed if the building is located in a designated hydrogen area. If the buildings concerned are located in decentralised areas (neither within a district heating nor a hydrogen area), biogas may be used, with increasingly strict requirements from 2029 onwards (15 % from 2029, 30% from 2035, 60% from 2040) (BMWSB 2023; German Parliament 2023; Tagesschau 2023c).

Currently, the government is devising the so-called power plant safety act (Kraftwerksicherheitsgesetz). The aim of the act is to ensure that sufficient energy is available, particularly for industry, in an electricity system that is increasingly based on intermittent renewable energies. For this, the government intends to tender 12.5 GW of power plant capacity and 500 MW of storage capacity. This is to be executed in a two-phased approach. Initially, 5 GW of H_2-ready gas-fired power plants and 2 GW of H_2-conform modernisations are to be tendered. Additionally, 500 MW of 100% hydrogen plants (hydrogen sprinters) and 500 MW of storage will be tendered. The government will subsidise the investment costs (CAPEX) and the differential costs between hydrogen and natural gas (OPEX) for 800 full utilisation hours per year. This first tender is planned to be executed by the end of 2024/ the beginning of 2025. In a second step, further 5 GW of gas-fired power plants will be tendered (again, investment costs will be subsidised), which will serve as a back-up for the system to secure supply. By 2028, these power plants are intended to be integrated into a comprehensive capacity mechanism (BMWK 2024a).

The production of green hydrogen is supported further by the exemption of production plants from grid fees and some additional levies, including the electricity tax, levy for combined heat and power production, renewable energy act levy, and offshore grid levy.[16]

Relevant Supporting Bodies and Organisations

The roll-out of the hydrogen economy is supported and implemented by a number of supportive bodies. Within the framework of the National Hydrogen Strategy, a National Hydrogen Council (Nationaler Wasserstoffrat [NWR]) was established, which is composed of representatives from science, industry, and civil society and acts as an independent advisory body to the government. In particular, the Hydrogen Council advises the State Secretaries Committee for Hydrogen and supports it in the further development of the National Hydrogen Strategy (NWR 2023). In this context, the Hydrogen Coordination Office (Leitstelle Wasserstoff), which was also set up as part of the National Hydrogen Strategy and is run by a number of government-owned or -funded organisations (dena, GIZ, PtJ, ZUG, and NOW GmbH), also plays a supporting role. Additionally, the Bundesanstalt für Materialforschung und -prüfung [BAM], a federal scientific and technical institute, has set up a competency centre, which advises the government on all issues related to hydrogen safety (BAM 2024).

The EU Context

German regulations and initiatives are embedded in the wider context of EU regulation and legislation. Hydrogen will play an important role in the decarbonisation efforts of the EU, even more so after the Russian invasion of Ukraine and the efforts to end EU-dependence on Russian natural gas. The EU has published its hydrogen strategy in 2020 in which it identifies five focal areas: investment support, support for production and demand, the creation of a hydrogen market and infrastructure, research and cooperation, and international cooperation. The REPowerEU plan, published in 2022, amended the EU

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[16] Grid fees are applied to any actor using the grid. An amendment to the aforementioned Energy Industry Act (Energiewirtschaftsgesetz) allows production plants for green hydrogen to be exempted from paying grid fees for 20 years. To be eligible the electrolyser must have been newly built before 1 December 2008 and be commissioned within 18 years from 4 October 2011. Additionally, the amendment to the Act also lifted the StromNEV levy, which is issued to enable the reduction of grid fees for energy-intensive industry. The KWKG levy is issued as an additional fee to the grid fees in order to support the build-out of combined heat and power plants, the offshore levy is issued to support the offshore industry, specifically the connection of offshore wind parks to the grid. According to the Energy Financing Act (Energiefinanzierungsgesetz) both levies are lifted if the electricity is used for the production of green hydrogen or in a facility that produced green hydrogen and has been commissioned before 1 January 2030 and is connected to the grid via its own metering point. Additionally, the government has passed an exception to the Electricity Tax Act (Stromsteuergesetz), which allows manufacturers, who use the electricity for electrolysis, to apply for the electricity tax to be waived, reimbursed, or refunded Graf von Westphalen 2024.

hydrogen strategy and increased its ambition by introducing the target of 10 Mt domestic hydrogen production and 10 Mt of hydrogen imports by 2030 (European Commission 2022a).

The Fit-for-55 package, which was introduced in 2021, is the EU's policy framework for climate policy more broadly and the implementation of the EU hydrogen strategy specifically. A central element within this framework is the EU Emissions Trading System [ETS], the world's first and biggest carbon market (European Commission 2023a). Working via a cap and trade system, the EU-ETS covers the power sector, the aviation and maritime sectors, and large industry[17]. It is now within its fourth trading phase (2021-2030) and has reached a price per tonne of CO_{2e} of nearly 100 EUR, which increases the competitiveness of green hydrogen. The CBAM ensures that this is also true for imported green hydrogen. It treats hydrogen as a good but does not include indirect emissions (e.g. electricity for electrolysis) and thus favours the import of green over conventional hydrogen, which has direct emissions.

Another crucial element within the Fit-for-55 package is the Renewable Energy Directive [RED], which sets the EU's targets for the deployment of renewable energy sources. Therefore, it is also relevant to the employment of green hydrogen in the EU. There are several iterations of the RED, the latest being RED III. In terms of hydrogen usage, the original RED II, enacted in 2018, recognised hydrogen as a "renewable fuel of non-biological origin" [RFNBO] in the transport sector, provided it is produced via electrolysis based on renewable energy. The associated Delegated Acts (Art. 27 and Art. 28) outline the detailed requirements for sourcing renewable electricity used in the production of RFNBOs including renewable hydrogen[18] as well as the GHG calculation methodology and eligible carbon sources for RFNBO production. These provisions lay the foundation for the certification of hydrogen in the EU. RNFBOs including renewable hydrogen produced both inside and outside of the EU can be certified by national or international schemes if they comply with the RED II criteria and are thus accepted by the European Commission. RED III extends the provisions of RED II to the industrial and building sectors and, importantly, introduced a more stringent target for the utilisation of renewable energy and RFNBOs in the EU overall as well as sub-targets for the transport, building, and industry sectors[19]. With regard to hydrogen, for instance, 42% of the hydrogen used in industry must be renewable by 2030 and 60% must be renewable by 2035 (FfE 2023; PWC 2023; European Parliament 2023b). RED III is, therefore, crucial to the creation of demand for green hydrogen within the EU.

Other hydrogen relevant regulations within the Fit-for-55 package are the Hydrogen and Gas Market package, which established the foundations for hydrogen terminology and certification, the Alternative Fuels Infrastructure Regulation with mandatory deployment targets for hydrogen refueling infrastructure for road vehicles, FuelEU maritime with targets for the maritime sector, and RefuelEU aviation with targets for the aviation sector (The Oxford Institute for Energy Studies 2024a).

Additionally, the EU has several funding mechanisms to enable the implementation of its targets and support the hydrogen market ramp-up. In 2023, the EU Commission introduced the European Hydrogen Bank whose objective is "to unlock private investments in hydrogen value chains, both domestically and in third countries, by connecting renewable energy supply to EU demand and addressing the initial investment challenges" (European Parliament 2023a). This will be achieved through a two-pillared approach: The domestic pillar will receive 3 billion EUR of funding from the EU Innovation Fund (based on revenues from the EU's carbon market) to run supply-side auctions within the EU. The first round of auctions launched in November 2023 and 720 billion EUR were awarded in April 2024 to seven renewable hydrogen projects whose production offers were the most cost-effective (European Commission 2024c). Another funding avenue within the domestic pillar are so called auctions-as-a-service. These auctions enable member states [MS] to provide a pre-defined amount of national funding to hydrogen projects on their territory and are open to companies from all MS. This funding avenue saw its kick-off in early 2024, when the European Commission approved Germany's initiative to allocate 350 Mio. EUR to companies for the construction of up to 90 MW of electrolysis capacity to incentivise the production of up to 75,000 tonnes of green hydrogen (Hydrogen Central 2024). The international pillar will entail supply-side auctions as well as short-term off-taker contracts for third countries. However, little details on the exact design and workings of this second pillar are known yet. Lastly, the European Commissioner for Energy Kadri Simson and Germany's Minister for Economic Affairs and Climate Action Robert Habeck have introduced the idea of linking the European Hydrogen Bank to Germany's H2Global. The exact workings of this interlinkage have not been decided yet and are subject to ongoing

[17] EU-ETS II will be a separate trading system for the building and road transport sectors, which will enter into operation in 2027 with monitoring starting in 2025 (European Commission 2023a).
[18] Key criteria are additionality, termporal correlation, and geographical correlation. More detailed information can be found here.
[19] RED III has no implications for the criteria outlined in the delegated acts passed in conjunction with RED II.

discussions with the member states (European Commission 2023b; H2Global 2023; H2Global and Hydrogen Europe 2023).

Further funding is provided through Important Projects of Common European Interest [IPCEIs], which allow EU member states to allocate state aid at much higher levels than normally allowed under EU competition law to transnational projects that are central to the EU's economic growth and competitiveness. This applies, inter alia, to hydrogen projects. Additionally, funding is provided through the EU Innovation Fund (The Oxford Institute for Energy Studies 2024a).

Funding

Germany has a number of funding programmes to support the roll-out of hydrogen and hydrogen-relevant projects along the entire value chain. However, funding is largely reserved for projects targeting green hydrogen. Projects on the application of blue, turquoise, and orange hydrogen can receive limited funding and are subjected to ambitious GHG-thresholds including for the entire pre-chain (BMWK 2023a). Examples of big funding programmes are, among many others:

- Joint funding by the BMWK and the Federal Ministry for Digital and Transport [BMVI] in the context of the European funding programme "Important Project of Common European Interest" [IPCEI] for hydrogen projects across the entire hydrogen value chain (Germany originally proposed 62 projects in total, with e.g. 15 in the steel sector and 12 on fuel cell systems, vehicles and refuelling infrastructure – the European Commission so far approved four IPCEIs consisting of several projects each, 26 German companies are involved in the three latest IPCEIs, Hy2Infra, Hy2Tech, and Hy2Move) (European Commission 2022b, 2024d; Federal Ministry for Digital and Transport 2022; European Commission 2024a).
- 2.2 billion EUR in direct grants to industry for the decarbonisation of processes. To be eligible, companies must reduce emissions by 40% either through the electrification of processes or the substitution of fossil fuels by low-carbon hydrogen or low-carbon hydrogen-derived fuels. The funding is limited to 200 million EUR per applicant and has to be issued before the end of 2025. In April 2024, the German government obtained approval for this funding programme from the European Commission (European Commission 2024b).
- "Hydrogen Flagship Projects" (Wasserstoff Leitprojekte), for which the government provides 700 Mio. EUR to three industry-led projects in the areas of electrolyser production (H2Giga), offshore hydrogen production without grid connection (H2Mare) and hydrogen transport technologies (TransHyDE) (Wasserstoff-Leitprojekte 2024).
- The National Innovation Programme Hydrogen and Fuel Cell Technologies (Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie), which has been supporting hydrogen projects in the transport sector since 2006 with over 1 billion EUR (NOW GmbH 2024a).
- The National Decarbonisation Programme (Nationales Dekarbonisierungsprogramm), which has been supporting investments in technologies and large-scale plants with 1 billion EUR between 2020 and 2023.

Additionally, the Carbon Contracts for Difference [CCfD] scheme (Förderprogramm Klimaschutzverträge), announced in June 2023, will play a crucial role in Germany's funding landscape. The scheme will run until 2045 and is supposed to support heavy industry in shifting towards less carbon-intensive production methods. The aim is to avoid 350 Mt CO_2 emissions over the term of the funding programme (i.e. 20 Mt per year), which corresponds to just over a third of the sector target for industry for 2030. The scheme is organised in the form of auctions, where companies bid how much state support they need to reduce one tonne of CO_2 with their chosen innovative technology. Only companies with the cheapest means of transforming their production will receive a 15-year contract, usual documentation and verification obligations as well as approval methods will be omitted to speed up the process (BMWK 2023b). In March 2024, the BMWK announced that companies who participated in a preparatory process in summer 2023 will be able to apply for overall 4 billion EUR of funding over the next four months. Another 19 billion EUR bidding round will be initiated in the summer of 2024 (Energy Voice 2024; BMWK 2024d). With this, Germany is the first EU member state using a CCfD scheme.

To ensure continued innovative activity with regards to hydrogen technologies, Germany has stepped up its funding for this purpose specifically. In 2022, the German government spent 170 Mio. EUR on research projects concerning hydrogen. This is three times as much as two years before. The majority of the funding (140 Mio. EUR) went to projects focused on the production of hydrogen (Tagesspiegel Background 2023a).

Since Germany is significantly reliant on hydrogen imports, its funding activities are not limited to the domestic hydrogen market. Several funding instruments, including the funding guideline for international green hydrogen projects, H2Global, H2Uppp (for European and German small and medium sized enterprises [SMEs]), and the PtX Development Fund (for projects in developing and emerging countries), among others, explicitly target hydrogen projects abroad and hydrogen trade (PtX Platform 2024). H2Global is among the most well-known instruments. It provides auction-based long-term hydrogen purchase agreements, which aim to promote the market launch of green hydrogen and Power-to-X products. Companies are temporarily compensated for the difference between the purchase price and the sales price for green hydrogen and its derivatives. The German government has earmarked 5.33 billion EUR in government funding for this, 900 Mio. EUR of which are to be spent in the first round. The first pilot tender for renewable ammonia resulted in a maximum contract value of 397 Mio. EUR for a cumulatively supply of 397,000 tonnes between 2027 and 2033 from Egypt (Hintco 2024). The EU Hydrogen Bank is also working on the design of an international auction to secure renewable hydrogen imports in to the EU, complementing the EU domestic auction that awarded nearly 720 Mio. EUR to seven hydrogen projects in Spain, Portugal, Finland, and Norway (European Commission 2024c).

Demand and Production

Today, Germany has a hydrogen demand of 55 TWh (1.6 Mt), mostly from the desulphurisation of conventional fuels in refining (21.3 TWh/ 0.6 Mt), ammonia production plants (20.6 TWh/ 0.6 Mt), and methanol production plants (4.7 TWh/ 0.1 Mt), where it is produced via steam methane reforming [SMR] (acatech 2021). By 2030, the BMWK expects demand to be at 95 to 130 TWh (2.85 to 3.9 Mt), of which 50 to 80 TWh (1.5 to 2.4 Mt) will be for green hydrogen (BMWK 2023a). In comparison, a meta-study by the Fraunhofer Gesellschaft estimated in 2021 that German demand for hydrogen and its derivatives will add up to no more than 80 TWh (2.4 Mt) in 2030 (with most studies expecting it to be below 50 TWh/1.5 Mt) and between 400 to 800 TWh (12 to 24 Mt) in 2050 (Fraunhofer ISE et al. 2021). Hence, projections by the BMWK for 2030 are significantly above what has been expected by a number of other studies thus far. However, a recent study by Germany's National Hydrogen Council makes quite similar demand predictions as the BMWK, expecting a demand of 94 to 125 TWh (2.8 to 3.7 Mt) in 2030. In 2045, it expects this demand to increase to between 620 and 1288 TWh (18.6 to 38.6 Mt). The wide range for demand in 2045 reflects the significant uncertainties with regard to actual demand (NWR 2024).

The main source of demand in Germany is expected to be the industry sector, particularly heavy industry (key industry players include Thyssenkrupp, Salzgitter AG, Aurubis, and ArcelorMittal) and the chemical industry (key players include BASF, Bayer, and Covestro). The steel industry alone is expected to demand 24 to 29 TWh (0.6 to 0.7 Mt) of green hydrogen by 2030, that is 20% of Germany's national demand and 80% of Germany's domestic green hydrogen production in 2030. Some demand will also come from the transport (33 TWh / 0.8 Mt) and heating sector (5 to 10 TWh). For the former, heavy-duty vehicles are likely to be the main application (22 TWh / 0.6 Mt) (Fraunhofer ISE et al. 2021; NWR 2024). In 2045, the National Hydrogen Council expects the industry sector to remain the main source of hydrogen demand in Germany (254 to 402 TWh / 6.5 to 10.2 Mt). Here, the chemical industry is likely to be the main offtaker (148 to 283 TWh / 4.4 to 8.5 Mt). Additionally, the council predicts the energy sector (80 to 200 TWh / 2.4 to 6 Mt) to emerge as an important offtaker for green hydrogen. Within the transport sector heavy duty vehicles (88 TWh / 2.6 Mt) and aviation (60 to 85 TWh / 1.8 to 2.5 Mt) remain the main applications for green hydrogen. While the National Hydrogen Council also predicts the heating sector (125 to 500 TWh / 3.7 to 14.9 Mt) to become a significant application for green hydrogen, this has so far been rather controversial and must therefore be viewed with caution.

Germany will not be able to produce enough hydrogen to meet its domestic demand (Fraunhofer ISI 2024). In fact, the BMWK expects that 50-70% (45 to 90 TWh/ 1.4 to 2.7 Mt) of Germany's demand in 2030 will have to be met by imports. Therefore, Germany will need to import hydrogen and its derivatives from both EU and non-EU countries. A study by Fraunhofer ISE compared 12 potential export countries[20] and found that in 2030 imports from Brazil, Australia, and Spain are the most cost-effective options for Germany. This is due to the very low production costs of green hydrogen in these countries,

[20] The countries assessed were Brazil, South Africa, Ukraine, Colombia, India, Namibia, Tunisia, Algeria, Morocco, Mexico, Spain, and Australia.

which are mainly achieved through the low levelised cost of renewable electricity and which can even compensate for the costs associated with the long-distance transportation particularly from Australia. Yet, it is important to stress that in the case of Australia, the low price points apply to ammonia, methanol, and jet fuels. In the case of liquid hydrogen, Australia's performs in the upper middle field of the assessed countries (Fraunhofer ISE 2023). While the study does not offer a comprehensive assessment of hydrogen imports to Germany as it does not look at key export countries such as Canada and Norway, it does demonstrate that long transport routes are not a prohibitive criterion and that the conditions in the production country itself are decisive. This result is supported by another meta-study by Fraunhofer ISI (2024), which finds that international trade is particularly viable for hydrogen derivatives, while liquid hydrogen ought to be transported by pipeline to be cost-competitive. Additionally, a recent study by the Oxford Institute for Energy studies (2024b) stresses the need to consider variables beyond the levelised cost of hydrogen [LCOH] when identifying the most suitable hydrogen export countries for the EU and hence also Germany. Such factors include the degree of liquidity of the export country's banking system, the presence and suitability of seaports, existing collaborative ties with the EU, and plans as well as ability for renewable power generation buildout specifically for the production of green hydrogen.

Industry

The German industry is highly active across the entire hydrogen value chain. In fact, German companies are among the most innovative in Europe and globally in the hydrogen field: In the years 2011 to 2021, German companies accounted for the largest number of patent applications in Europe and filed one in ten patents worldwide (IEA and EPO 2023). Particularly in the fields of electrolysis, liquid organic hydrogen carriers [LOHC], and the production of ammonia [NH_3] and methanol [CH_4O] German companies are industry leaders.

In alkaline water electrolysis [AWE], two of eight European producers are German (thyssenkrupp Industrial Engineering and Sunfire) and in proton exchange membrane [PEM] electrolysis three of six European producers are German (Siemens Energy, Greenerity, and h-tec Systems) (acatech 2021). For AWE and PEM, German producers are already working on the commercialisation of modules with a capacity of 10-20 MW, a magnitude that will be required for the realisation of export projects (acatech and BDI 2022). The start-up Sunfire is also one of only two companies in Europe engaged in Solid Oxide Electrolysis [SOEL], which, by using industrial waste heat, can achieve a higher conversion efficiency than other technologies and thus produce more hydrogen with a given amount of electricity. This is particularly useful for industrial use cases, where waste heat is readily available (acatech 2021; Sunfire 2023). Meanwhile, the German company, Enapter, is among the few producers worldwide of Anion Exchange Membrane [AEM] electrolysers, which promise to be a more cost-effective alternative to PEM electrolysers. The company was the first to produce a multi megawatt AEM electrolyser (Enapter 2023b). Overall, the German electrolysis industry is expected to be valued at 5.5 billion EUR annually if "the global capacity of electrolysers increases by 20 GW between 2020-2030 and by 200 GW annually thereafter" (acatech 2021, p.9).

Apart from electrolysis, German companies are also highly present in the provision of technologies and services for renewable energies as well as P2X technologies like pyrolysis, Fischer-Tropsch, methanol and ammonia synthesis, and methanation. In the area of plant engineering, German companies are market leaders, which is due to Germany's historically leading position in chemical industry processes (acatech 2021). Further down the value chain, German companies are actively working on technical solutions for the transportation and storage of hydrogen. The ROSEN Group, for instance, is researching possibilities to repurpose existing gas infrastructure for hydrogen in its Lingen test lab, while Thyssenkrupp Uhde has developed an ammonia cracking technology with an efficiency of 78% and a hydrogen purity of 99.96% (IEA 2022a).Several companies are involved in feasibility studies as well as demonstration projects concerning the underground storage of hydrogen in salt caverns[21]. Meanwhile, the industrial and transportation sectors are exploring various applications for hydrogen. In 2021, the German NGO Atmosfair initiated the first project for the production of synthetic fuel made from renewable hydrogen, for which it secured an off-take agreement for 25.000 litres of synthetic kerosene annually with Lufthansa, while EVBs hydrogen trains started regular operation in Lower Saxony in 2022, a world's first (Clean Energy Wire 2022; IEA 2022a). Road transport is also catching up, with Daimler

[21] Already existing projects include the H2Cast Etzel project by a project consortium consisting of Storag Etzel, KBB, Deutsches Zentrum für Luft und Raumfahrt, Hartmann Valves, TU Clausthal, and SOCON, further projects, such as the H2 Gronau-EPE project by RWE Gas Storage West, are planned to be inaugurated in the second half of the 2020s IEA 2022a.

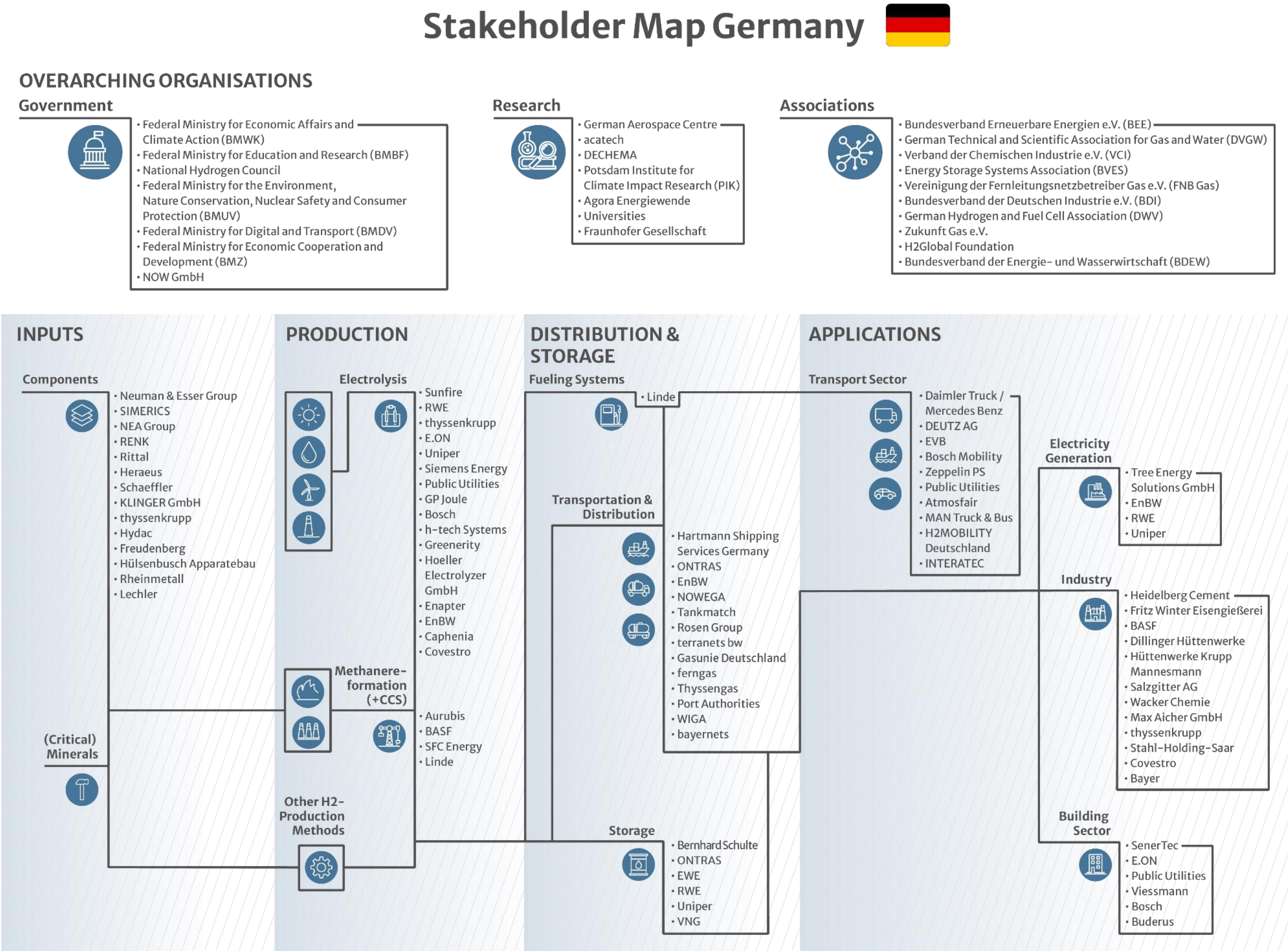
Truck/Mercedes Benz developing its GenH2 liquid hydrogen truck, which is said to have a range of 1.000 km and is likely to start production in 2027 (IEA 2022a). Paul Group is already one step further and has delivered its first 25 hydrogen-powered trucks to customers including DHL in the beginning of 2024. The PH2P trucks have a reach of 450 km and will now be trialled in different use cases across Germany (Paul Nutzfahrzeuge 2024). In the shipping sector, the Fraunhofer Institute for Large Structures in Production Technology [IGP] is building a large engine test facility for hydrogen-based PtX fuels in Rostock. The institute is developing and testing marine engines for their suitability for alternative fuels. The aim is to develop retrofit solutions for engines of existing ships, their infrastructure, fuelling systems, and pipelines to reduce so-called "material-technical interactions" caused by the new fuels (energate 2024). In the steel sector, thyssenkrupp steel has been awarded 2 billion EUR for the construction of Germany's biggest green steel plant. The direct reduction plant will be situated in Duisburg, Northrhine-Westphalia, and will start operation in 2026[22] (Tagesschau 2023a). In January 2024, thyssenkrupp launched the tender to set up the contract for the necessary clean hydrogen deliveries of up to 155.000 tonnes per year to supply the plant (Hydrogen Insight 2024g).

Overview of Stakeholders

The following stakeholder map (Figure 7) provides an overview of German institutions and businesses active across the hydrogen value chain. Please note that the map does not represent a complete depiction of actors and that these were selected on the basis of desk research independently by the authors.

[22] Initially, the plant will still be operated with natural gas, which is to be fully replaced by green hydrogen by 2037 (Tagesschau 2023a).

Figure 6: Overview of Stakeholders in Germany



Source: adelphi

3.3 Hydrogen in Japan

Status of Policy and Legislation

Japan is in a situation broadly comparable to Germany and Korea. It is a highly industrialised economy with a significant heavy industry sector, but with limited renewable capacities. The renewable energy share in the Japanese electricity grid is relatively low with currently 22.7% (ISEP 2023). Due to its geography the country lacks grid interconnections to other countries – a challenge shared with Korea. Hydrogen is set to play a key role in Japan's path to net zero, both in industry as well as in the power and mobility sectors. The import of low-carbon hydrogen is therefore considered a key necessity and priority by the Japanese government.

Quick Facts

Projected H_2 Demand
- **2035:** 3 to 21 Mt
- **2050:** 20 to 33 Mt

Projected H_2 Production
- **2030:** 15 GW Capacity*

Projected H_2 Import
- **2030:** 3 Mt
- **2040:** 12 Mt
- **2050:** 20 Mt

*Goal for global production capacity held by Japanese companies. No domestic production target was formulated.

Japan stands out in comparison to other leading hydrogen economies. It was the first one to formulate a national hydrogen strategy. This motivated other countries to publish their own strategies as well. The strategy itself was published in December 2017. It was followed by the Strategic Hydrogen and Fuel Cell Roadmap as well as the Hydrogen and Fuel Cells Technology Development Strategy in 2019. Noteworthy is additionally Japan's "Green Growth Strategy through Achieving Carbon Neutrality in 2050" from December 2020 (METI 2022a), which sets out industrial policy targets for several sectors, including hydrogen and fuel ammonia, in connection with government funding for their advancement.

In February 2023, Japan's cabinet announced a new and transformative industrial and energy policy called the "Basic Policy for the Realization of GX [Green Transformation]" (GX Policy). It is the central policy strategy of the Japanese government in the energy and climate context. The objective is to deliver simultaneous emission reductions to achieve carbon neutrality by 2050 and economic growth through increased competitiveness of the Japanese industry. The GX Policy introduces several key initiatives with the intention to mobilize approximately 150 trillion JPY (870 billion EUR) of private-public investment over the next decade. This includes a range of support options for companies. The government issues Climate Transition Bonds, also referred to as GX bonds, over the next ten years for upfront investment of a total of 20 trillion JPY (120 billion EUR). The first tranche of 1.6 trillion JPY (9.3 billion EUR) was issued in February 2024 (Climate Bonds Initiative 2024). A significant part of these bonds will be used to support hydrogen technologies through targeted investment. The overall share allocated to hydrogen and ammonia through the GX-Policy is expected to be around 7 trillion JPY (41 billion EUR) (Miyagawa et al. 2023).

Subsequently, the Hydrogen Strategy from 2017 was overhauled and has been replaced by a new version published mid-2023. The revision follows what the responsible Ministry of Economy, Trade and Industry [METI] calls the S+3E Principle – Safety, Energy Security, Economic Efficiency and Environment (METI 2023a). In this context, global standards for safety as well as the role of hydrogen for energy security, grid stability and as a cost-effective alternative for when carbon pricing is established in Japan, are highlighted. Central goals of the new strategy are the increase of hydrogen demand and production, the transition to low-carbon hydrogen, as well as the establishment of domestic and international supply chains (The Diplomat 2023b). The strategy further included the announcement that the government plans to generate 15 trillion JPY (87 billion EUR) of public and private investment in the hydrogen supply chain of Japan over the next 15 years (Hydrogen Insight 2023b). The strategy also sets a range of new goals on the supply side, namely the goal of increasing the overall supply of hydrogen and ammonia together to 3 Mt per year by 2030, 12 Mt by per year by 2040 and 20 Mt per year by 2050 (METI 2023a). Furthermore, it aims to reduce costs to 334 JPY (1.94 EUR) per kg by 2030 and 222 JPY (1.28 EUR) per kg by 2050 (METI 2023a). It additionally aims for 15 GW electrolysis capacity by Japan-related companies, which also includes component suppliers by 2030 (The Diplomat 2023b).

A crucial aspect of the new hydrogen strategy is that it establishes a clear definition of “clean hydrogen” following a carbon intensity cut-off of 3.4 kg of CO_2 emissions per kg of hydrogen following a well-to-gate methodology and 0.84 kg of CO_2 per kg of ammonia, following a gate-to-gate methodology (The Diplomat 2023b; METI 2023a). The hydrogen standard is roughly equivalent to 28.3 gCO_{2eq}/MJ, compared to 33 gCO_{2e}/MJ in Korea and 28.2 gCO_{2e}/MJ in the EU per kg of hydrogen (The Diplomat 2023b; METI 2023a; International PtX Hub 2023). Additionally, the hydrogen strategy, which also references the guidelines developed by IPHE, outlines that the methodology for calculating the carbon footprint will be based on international standards. However, it is supposed to reflect the special geography of Japan and the emissions associated with long-distance transport of imported hydrogen. The strategy explicitly references both green and blue hydrogen as well as the goal to support the development of carbon capture and storage [CCS], but sees blue hydrogen as the main focus for the short- to medium- term, while green hydrogen is considered as an important alternative in the long-term (METI 2023a).

Regarding the usage sectors, the new strategy focuses mostly on power and heat generation, mobility, and industry. In concrete terms, the strategy envisions the usage of a producer support scheme with a price gap subsidy. Additional subsidies support the build-up of the required infrastructure and technology development. Both instruments are introduced in the subsequent funding sub-chapter. The strategy furthermore has the aim to improve competitiveness of key hydrogen-related industrial sectors, namely hydrogen supply, power production, fuel cells, and the usage of hydrogen in metallurgy, chemicals, and transportation.

Regarding the power sector, the new strategy sets the explicit goal to achieve increasing coal co-firing rates of hydrogen in conventional thermal power plants, both with hydrogen and ammonia. An intermediate goal was previously set by the Japan’s sixth Strategic Energy Plan with a share of 1% hydrogen and ammonia in the power mix by 2030.This goal is supported through specific funds for research and development. To achieve carbon neutrality, the goal in the long run is to transition from co-firing to thermal power plants using uniquely hydrogen or ammonia. The wide-spread use of co-firing in fossil power plants has been criticised by independent experts for its apparent lack of efficiency in reducing emissions and risk of locking-in fossil infrastructure (E3G 2023; Hydrogen Insight 2023c).

In the mobility sector, the hydrogen strategy spells out the aim to support both personal and commercial fuel cell vehicles alongside e-fuels. Compared to Japan’s first hydrogen strategy, there is a prioritisation of commercial vehicles over personal ones. In the industrial sector, the usage of hydrogen for heat and as a resource in the steel and chemical industries is planned and will be supported through grants for research and development as well as demonstration projects.

In addition, the new strategy also puts an emphasis on international cooperation, especially regarding the establishment of supply chains in collaboration with countries in the Indo-Pacific, Europe, and the Middle East, and by building on existing partnerships, particularly with Australia and the United Arab Emirates. This also entails the active support of multilateral formats, with both the CEM and IPHE being explicitly mentioned.

To deal with the issue of hydrogen safety, METI has assembled a hydrogen safety study group encompassing actors from research institutions in August 2022. The group is tasked with developing recommendations for a Hydrogen Safety Strategy and has published an interim report in March 2023, with a plan for the long-term development of a safety regulation system covering the entire supply chain by 2050. The interim report maps out three action policies areas with nine general measures, ranging from the collection of further data, strengthening of the research environment, building and developing third party certification and inspection bodies to risk communication and human resource development for the safe hydrogen usage (METI 2023b).

Funding

The Japanese government has set up a range of large funding schemes to support the advancement of the hydrogen economy. As laid out in the hydrogen strategy, this includes power generation, heating, mobility, and different industrial sectors.

Japan's Green Growth Strategy from December 2020 (METI 2022a), identifies 14 key sectors for achieving decarbonisation objectives and with future growth potential for Japanese industry. With regard to energy related industries, the hydrogen and fuel ammonia industry are part of the core focus areas. For projects, this results in further funding possibilities to stimulate innovation and growth in the hydrogen sector. The Green Growth Strategy established the Green Innovation Fund of 2 trillion JPY (12 billion EUR) for such projects. The fund, for the which the METI assigned the administration to the Japanese New Energy and Industrial Technology Development Organization [NEDO], provides funding over ten years for activities like R&D, demonstration projects or solutions for issues of social acceptance (METI 2021; NEDO 2024b).

By the end of 2023, funded projects under the Green Innovation Fund for hydrogen and fuel ammonia included several companies and projects clustered around the overarching topics: "Large-Scale Hydrogen Supply Chain Establishment" (300 billion JPY - 1.74 billion EUR), "Hydrogen Production through Water Electrolysis Using Power from Renewables" (70 billion JPY - 410 Mio. EUR), "Hydrogen Utilization in Iron and Steelmaking Processes" (193.5 billion JPY - 1.12 billion EUR), and "Fuel Ammonia Supply Chain Establishment" (68.8 billion JPY – 400 Mio. EUR) (NEDO 2023). NEDO also administers additional smaller scale funding of hydrogen and ammonia technology projects as well as of related research and development. Through NEDO, specifically its FC and Hydrogen Technology Office, the Japanese government also aims to support its hydrogen industry to achieve the goals specified in the hydrogen strategy (NEDO 2024a). In the revised hydrogen strategy from June 2023, the Japanese government announced the additional aim to generate over 15 trillion JPY (87 billion EUR) of public and private investment in the hydrogen supply chain over the next 15 years (METI 2023a). These long-term targets are supposed to work as another incentive for companies and other stakeholders to invest in the Japanese hydrogen economy (Hydrogen Insight 2023b).

The hydrogen strategy further introduced a price gap subsidy scheme for the supply of low-carbon hydrogen and ammonia. In January 2024, METI provided more details on these plans, considered a crucial corner stone for hydrogen market development in Japan. More than 3 billion JPY (17 billion EUR) are earmarked to subsidise the delivery of both domestic and imported low-carbon hydrogen. This scheme follows a contract-for-difference [CfD] approach. The respective "Hydrogen Society Promotion Act" passed the Japanese Diet in May 2024 (Hydrogen Insight 2024c; METI 2024a).

The existing cost gap between low-carbon hydrogen and fossil fuels is to be closed with the CfD-scheme. Funding is available for both locally produced and imported products. A combination with funding programs from other countries (e.g. tax credits) is likely to be possible. Funds will be allocated on the basis of submitted business plans and not through an auction process. Producers must look for suitable offtakers themselves beforehand and apply together with them. Eligible products are: hydrogen, ammonia, e-fuels, and e-methane. The Japan Organization for Metals and Energy Security [JOGMEC] is the designated governmental organisation responsible for the implementation of the scheme. Projects that aim to develop a commercial pilot supply chain for low-carbon hydrogen and its derivatives will be funded over 15 years. The award criteria and the start of applications are under consideration by METI at the moment and announced to be published around August 2024, with first allocations already planned for the end of 2024 as well. Projects will have to begin production by 2030 at the latest and will receive funding under the CfD-scheme over a period of 15 years. However, a continuation without subsidies for another 10 years after the subsidy period needs to be assured additionally. The new law does not provide a precise definition of "low-carbon hydrogen", but describes it as hydrogen (or its derivatives) whose production keeps carbon dioxide emissions below a certain level and fulfils the international standards for calculating CO_2 emissions. However, it is expected that the standard of max. 3.4 $kgCO_{2e}/kgH_2$ (regardless of the type of production) adopted as part of the hydrogen strategy amended in 2023 will be applied (Hydrogen Insight 2024c; METI 2024a; IEEJ 2024).

The subsidy is granted for the difference between a strike price and a reference price. The strike price is the price specified in the application for production (if necessary, including transport and dehydration). The reference price is the price for conventional fossil energy sources. However, at the moment of the development of the award criteria by METI in July 2024, there is still uncertainty about the possibility of two separate reference prices. It is being discussed to apply a reference price for grey hydrogen and coal/gas, depending on whether hydrogen or ammonia would be supplied. This presumably reflects plans by Japanese energy companies to co-fire ammonia with coal in existing power plants at a rate of 20% by 2030. However, the selection of coal as a reference price could result in the Japanese government having to pay significantly more for the difference to the price of low-carbon products compared to a reference price for grey hydrogen. These increased subsidies could lead to fewer projects being funded and less low-carbon hydrogen being produced with the same budget (Hydrogen Insight 2023d, 2024e).

Moreover, the Japanese government announced an additional 1.3 trillion JPY (7.5 billion EUR) to support the decarbonisation of heavy industries, e.g. the steel and chemicals sector. This is expected to involve the use of low-carbon hydrogen. Under the Hydrogen Society Promotion Act, an additional programme will be set up to support hydrogen hubs and will also include funding for hydrogen infrastructure and storage, which is not directly covered under the CfD-scheme (Hydrogen Insight 2024b; MFAT 2023; Allwn & Overy 2023; IEEJ 2024).

Part of the funding for these activities, especially the CfD-scheme, will be financed through the before mentioned government-issued “Climate Transition Bonds” introduced under the GX policy (METI 2024b). The government plans to issue these bonds over the next ten years for upfront investments of a total of 20 trillion JPY (120 billion EUR). In February 2024, the first tranche of 1.6 trillion JPY (9.3 billion EUR) was issued. The next issuances, 350 billion JPY (2.04 billion EUR) each, are scheduled for the end of July, October 2024 and January 2025 (Ministry of Finance Japan 2024). A significant part of these bonds will be used to support hydrogen technologies through targeted investment, e.g. from the first tranche, 254 billion JPY (1.47 billion EUR) are targeted for R&D of hydrogen-powered blast furnaces for steel-making and 32.5 billion JPY (190 Mio. EUR) for reducing emissions from industrial furnaces. The full list of eligible projects spans a wide range, from increasing use of renewables, nuclear power, hydrogen and ammonia to developing carbon-capture technologies and decarbonising ships. The new model is designed to incentivise the Japanese private sector to transition away from investing in carbon-intensive, fossil fuel-centric production to funding decarbonised manufacturing (IEA 2022b; Climate Bonds Initiative 2024).

Further support mechanism announced in the hydrogen strategy include investment and debt guarantee mechanisms for production or storage of hydrogen or ammonia projects supported by the Japan Organization for Metals and Energy Security [JOGMEC]. Lastly, yet to be specified new opportunities for blended financing are planned to be introduced in the future. This includes the development of financial support schemes under the involvement of public financial institutions, e.g. the Japan Bank for International Cooperation [JBIC], Development Bank of Japan, Nippon Export and Investment Insurance, in order to mobilise additional funding (METI 2023a).

Demand and Production

As a highly industrialised economy, Japan has an already a high hydrogen demand. This entails mostly grey hydrogen and ammonia mainly for refineries and other chemical processes, 30.2 billion cubic meters or 2.7 Mt as of 2022 (Statista 2023a). This demand is expected to increase, especially considering the move towards hydrogen usage in thermal power plants. The Japanese hydrogen strategy targets the import and consumption of 3 Mt of hydrogen by 2030, 12 Mt by 2040 and 20 Mt annually by 2050. The METI explains the 2040 target by referencing IEA projections and converting them to national estimates based on its GDP share as well as on a linear projection of the expected 2030 demand (METI 2015). However, considering Japan’s strategy to use hydrogen for power generation on a large scale, this approach could potentially underestimate the actual hydrogen demand Japan will face towards the middle of the 21st century. A 2012 study assumed a somewhat higher hydrogen demand of 21 Mt of hydrogen per year by 2035 and around 33 Mt by 2050. Regarding the distribution of demand by sector, the hydrogen strategy makes no assumptions (Yoshino et al. 2012).

Another study analysed the role of hydrogen in potential scenarios for 100% renewable energy supply in Japan by 2050. It concluded that hydrogen will largely be used in transportation, with a smaller fraction used to decarbonise iron and steel production, even though this study generally assumes only a small fraction of hydrogen power generation across most of the analysed scenarios (Kuriyama et al. 2024). A different analysis by Mizuho Bank concluded a demand of around 9 Mt of hydrogen and hydrogen-equivalent ammonia for power generation by 2050. This alone would represent almost half of the estimated demand in the hydrogen strategy (Mizuho 2023). A report by BloombergNEF, in contrast, shows that Japan could reach net zero with a significantly lower hydrogen demand of just 7 Mt overall by 2050 if it relied on accelerated deployment of renewable sources instead of co-firing (BloombergNEF 2023). Another report by White and Case also estimates a lower hydrogen demand of 800 thousand to 4 million tonnes by 2030 and 1.9 to 9.6 Mt by 2040 (White & Case LLP 2020). A 2021 study analysing the need for hydrogen imports concludes that the usage of hydrogen will greatly depend on its price, with imports reaching up to 12 Mt for the industry sector and around 2.5 Mt each for mobility, residential, and district heating under the cheapest scenario. The study overall assumes a demand of 19 Mt by 2050, which is broadly in line with the current hydrogen strategy (Burandt 2021). In financial terms, a survey estimated the future value of the entire hydrogen market to be worth 4.7 trillion JPY (270 billion EUR) – more than 200 times the current value (EnergyShift 2021). The Japan Hydrogen Association [JH2A], the main industry association for the entire hydrogen value chain in Japan, diverges from the lower previous estimates. Based on own projections, including a widespread use of hydrogen of electricity generation, the association estimates a potential demand of 70 Mt of hydrogen by 2050 (JH2A 2023).

Regarding the production of green hydrogen, Japan had 19 electrolysis plants with a total capacity of around 12 MW operational in 2021 (Sieler et al. 2021). Projects worth mentioning are, for example, the installation of a 10 MW alkaline water electrolysis system at the Fukushima Hydrogen Energy Research Field [FH2R] by Asahi Kasei in 2020 as well as the development of an alkaline water electrolysis pilot plant in Kanagawa Prefecture by the same firm (Asahi Kasei 2020). Moreover, in February 2024, Japanese companies Eneos, Idemitsu Kosan, and Hokkaido Electric Power Company announced their plans to build around 100 MW electrolyser capacity for green hydrogen on the wind rich island Hokkaido in northern Japan (Hydrogen Insight 2024d). Nonetheless, Japan‘s green hydrogen production capacities will likely remain insufficient for its increasing demand due to its slow pace of renewables expansion. If Japan decides to tap into its renewable potentials more, especially regarding offshore wind, it could reduce its dependence on energy imports. Nevertheless, it will still need to import hydrogen to satisfy demand with an increased number of use cases. Therefore, Japan sees a significant role for hydrogen imports and is already driving the development of global hydrogen supply chains with some of its partner countries.

Industry

The key industries for hydrogen usage in Japan are also laid out in the country's hydrogen strategy and comprise power and heat generation, mobility, and industry. As the world's fourth largest economy and its third largest steel producer, the decarbonisation of Japan's industry presents a considerable challenge. However, the Japanese steel industry is pushing forward with the announcement of a timeline for the development of decarbonised steel and the unveiling of a first hydrogen-co-firing blast furnace by Nippon Steel, supported by NEDO. Nippon Steel and JFE Steel are also developing trial furnaces running only on hydrogen (Nikkei Asia 2022a; World Steel Association 2023). In the COURSE50 project, four major Japanese steel companies have joined forces with NEDO to research the use of hydrogen in the industry (Hydrogen Steelmaking Consortium 2024).

As outlined above, Japan furthermore sees a significant role for hydrogen in the decarbonisation of electricity generation and heating, specifically through coal-co-firing. However, Kawasaki and IHI have also developed turbines that can be used with 100% hydrogen, making them world leaders regarding this technology. The country has recently broken ground on its first hydrogen power plant, the Fujiyoshida hydrogen power plant in Yamanashi Prefecture, which is set to produce power exclusively from hydrogen (H2 View 2021). Japanese companies are also seeking to export this technology. Mitsubishi Power has for instance started work on a joint hydrogen power generation project with 30% hydrogen co-firing in the United States (METI 2022b).

The country also sees small-scale fuel cells as a promising option to decarbonise residential heating, potentially also through so called "ene-farms", combined heat and power fuel cells. In total, more than 400,000 of these small-scale residential fuel cells have been installed throughout Japan as of 2022 (METI 2022b).

Leading Japanese automotive companies are among the first movers of hydrogen vehicle development and Japan seeks to defend the technology leadership of its industry in this regard. Honda for example developed the first government certified hydrogen vehicle as well as the first series production hydrogen car (The Japan Times 2002; Autoblog 2007). Japanese companies have also been crucial in the development of hydrogen buses, with one of the first examples being run by a Fuji fuel cell (Larkins 1998). Toyota is, besides Korean Hyundai, the only company producing a mass market hydrogen car as of 2023 (Voelcker 2022). Both the current and the previous Japanese government have sought to improve hydrogen infrastructure and increase the deployment of hydrogen vehicles, for example through direct purchase subsidies. As of 2022, Japan had a total of 169 hydrogen refuelling stations – the world's largest network, which caters more than 100 hydrogen buses and more than 6000 fuel cell cars. Additionally, Japan is working on the development of fuel cell trains and trucks (METI 2022b). However, the market for hydrogen vehicles in Japan has been struggling and the sale of hydrogen cars fell by 83% between 2022 and 2024. Simultaneously, the share of battery-electric vehicles has been steadily increasing (Hydrogen Insight 2024a).

Japan also stands out as one of the trailblazers with regards to hydrogen applications technology with many of its companies being industry leaders. Japan was second only to the EU as a whole in the number of hydrogen patents in the period from 2011 to 2020 and led the world with 28% of all patents in end-use hydrogen applications (World Economic Forum 2023a). Regarding power generation, Mitsubishi Power, IHI, and Kawasaki lead on hydrogen turbines. Regarding hydrogen ships, Nippon Yusen has developed commercial ships equipped with ammonia engines, while other hydrogen powered ships and passenger ferries have been deployed or are currently developed by several Japanese companies, including Iwatani (The Diplomat 2023a; Nikkei Asia 2023b). Fuel cells and related products are produced by a range of Japanese companies, with leading examples being Toshiba, Denso, which also produces hydrogen powered trains for cars, Mitsubishi Hitachi Power Systems, Fuji, Panasonic, Aisin, and Kyocera (Mordor Intelligence 2024; AI Think 2023; Blackridge 2023; KYOCERA GROUP GLOBAL 2024).

Beyond usage sectors, the Japanese government also seeks to support the Japanese electrolyser industry (METI 2022b). Beyond the domestic electrolyser capacity described previously, Japan is also working on exporting its electrolyser technology as well as integrated solutions, for example through the joint Advanced Clean Energy Storage Hub project in the US, for which Mitsubishi Power supplied the first electrolysers in October 2023, which are manufactured by the Norwegian company HydrogenPro (POWER Magazine 2023). When finalised, the project will encompass 220 MW of electrolyser capacity.

Japanese companies themselves are also pushing forward when it comes to hydrogen production, despite lagging somewhat behind global leaders like Germany, with companies like Toshiba and Toray developing improved PEM electrolysers (Nikkei Asia 2023a). Other electrolyser producers include Asahi Kasei, which launched the world's largest electrolysis system at the time in 2020, and Mitsubishi. Noteworthy is furthermore Iwatani, Japan's leading hydrogen supplier, who plans to develop proprietary hydrogen production technology as well as ENEOS, Japan's largest oil refiner, which produces by-product hydrogen (Asahi Kasei 2020; Reuters 2023b; The Diplomat 2023a). Alternative technological approaches are pursued by Showa Denko, producing hydrogen through plastic recycling and Air Water, producing turquoise hydrogen from biogas (Asahi Kasei 2020; Reuters 2023b; The Diplomat 2023a; Nikkei Asia 2023a).

Japanese stakeholders have initiated a range of projects aimed at demonstrating the feasibility of international hydrogen supply chains and long-range hydrogen transport. Notable Japanese companies regarding hydrogen transport include companies like the Chiyoda Corporation, which works on the transport of hydrogen via liquid organic hydrogen carrier [LOHC]. Japan generally experiments on the usage of MCH, LOHC, NH_3, and LH_2 as carriers. Other notable industry players include the renewable developer Marubeni, which contributed to the first green hydrogen demonstration in natural gas networks as well as Kawasaki Heavy Industries, which developed the Suiso Frontier, the first liquid hydrogen carrier ship (Chiyoda Corporation 2024; Marubeni 2023; Hydrogen Council 2022b; Kumagai 2020).

The first notable international cooperation project is a project established in cooperation with Brunei. In this project, which is developed by a Japanese consortium consisting of Chiyoda, Mitsubishi, Mitsui, and Nippon Yusen Kaisha financed by NEDO, hydrogen produced in Brunei is chemically bonded to toluene for transport to Japan by ship. The hydrogen is then used for power generation (Kumagai 2020). This project had already completed 10 months of testing by the end of 2020 and has shown that the transport solution is technically feasible and can be scaled up (Clifford Chance 2022). The second noteworthy project is from the "CO_2-free Hydrogen Energy Supply-chain Technology Research Association" (HySTRA) project implemented in cooperation with Australia, in which a consortium of the Japanese companies Iwatani and Kawasaki Heavy Industries (formerly also J-POWER, Marubeni, ENEOS, Kawasaki Isen Kaisha) and Australian companies has successfully established a hydrogen supply chain demonstration (HySTRA 2024). Hydrogen generated from brown coal in Australia was successfully shipped to Japan on the purpose-built "Suiso Frontier" in 2022 (Clifford Chance 2022). However, the CCU/S part of the project is so far not implemented, which means that the project – just like the Brunei one – is not yet low-carbon as promised by the project developers. Both of these projects are intended as trailblazers for further hydrogen cooperation, with Japan envisioning an import of around 300.000 tonnes of hydrogen from both countries by 2030 (International Trade Administration 2021).

Other projects are currently developed with the Gulf region. In cooperation with Saudi Aramco, the Japanese Institute for Energy Economics, SABIC, Mitsui and the Japan Oil Company enabled the first shipment of blue ammonia from Saudi Arabia to Japan in 2020, a project that successfully captured associated emissions (Saudi Aramco et al. 2020). Further Japanese companies, including its largest refiner, ENEOS, and its leading power provider JERA have since signed MoUs with different actors in Saudi Arabia targeting the development of low-carbon hydrogen projects and supply chains (Middle East Institute 2023). Similar processes are taking place with the UAE, with INPEX, JERA, Idemitsu, and Itochu forming agreements with UAE-based companies regarding the import of low-carbon hydrogen and ammonia. In the context of this study, it is particularly relevant that the Japanese company Mitsui and Korea's GS Energy have both acquired stakes in a blue ammonia plant, also supported by ENEOS. Sumitomo Corporation and IHI Corporation have furthermore explored project cooperation with Oman (Middle East Institute 2023).

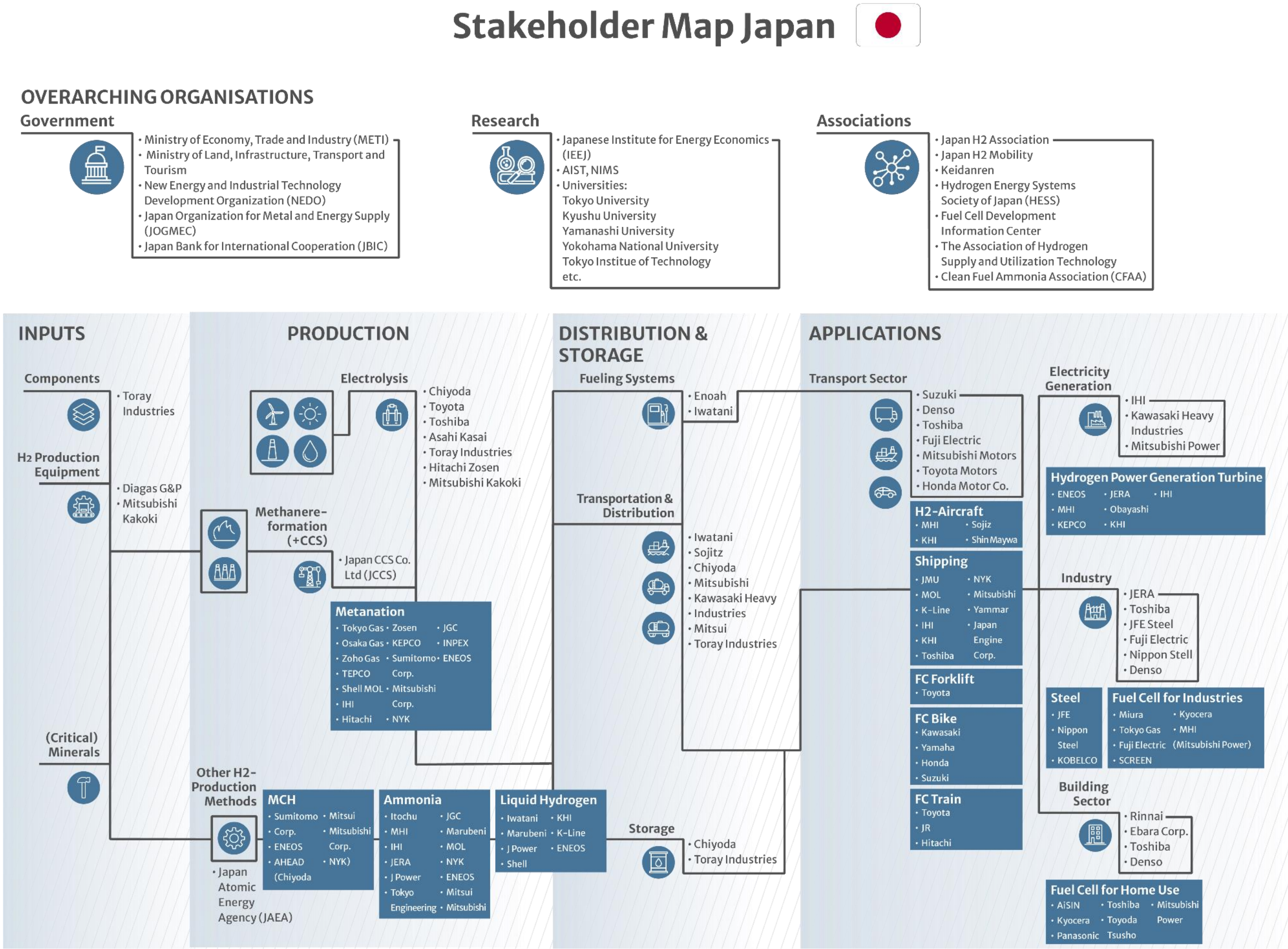
Beyond these lighthouse projects, it is relevant to focus on Japan's current energy trade. With a relatively low energy self-sufficiency ratio of 11% in 2020, the country is already heavily reliant on imported energy and is the world's leading importer of LNG as well as its fifth-largest importer of oil (EIA 2023; IRENA 2023b). Due to the lack of international pipeline connections, Japan imports all of these resources by ship, which also means that the country's infrastructure for the import of gases is already well developed. It boasts for instance the highest regassification capacity of any country in the world, even though there is no precise information available as to how costly it would be to convert this infrastructure to hydrogen. The maritime nature of Japan's energy imports, however, also means that it is relatively flexible in choosing its suppliers and can theoretically change trading partners more quickly than other countries. Nevertheless, it is valuable to look at Japan's current suppliers to evaluate the environment it is operating in. Focusing on LNG in particular, the main suppliers are Australia (42%), Malaysia (17%) as well as Indonesia and Brunei in the Asia Pacific Region and to a lesser extent Russia (9%), the US (6%) as well as Qatar and Oman (4% each) as of 2022 (EIA 2023). Regarding oil imports, the picture is more mixed, with the US (26%), South Korea, as an intermediary, (14%), and the UAE leading the field, while other countries in the Middle East as well as Australia (5%) also play a role. Australia's role is of particular interest for this study, as it is not only the largest LNG exporter to Japan, but also the largest coal exporter (67%) and is part of the HySTRA project, which suggests that Australia will play a significant role in Japan's hydrogen future. As of now, however, hydrogen is largely imported from other countries, with China and the US as well as – to a lesser extent – Germany, Vietnam, and Taiwan being the main exporters as of 2021 (The Observatory of Economic Complexity 2024).

Regarding bilateral collaboration, the Japanese government has some notable bilateral agreements. These include long-standing energy partnerships with Australia and Germany, as well as a climate partnership with the US (DFAT 2022; U.S. Government 2021). Japan and Korea have also taken first steps towards a collaboration on hydrogen in the form of a director-level meeting on the topic (H2 Energy News 2023). The two countries also share the format of the Japan-Korea Energy Cooperation Dialogue between the respective ministries, the Japanese Ministry of Economy, Trade and Industry [METI] and Korean Ministry for Trade, Industry and Energy [MOTIE], which was held for the second time in May 2023 (METI 2023c). Further collaborations exist with other potential exporters of hydrogen, such as the Japan-UAE Collaboration Scheme for Advanced Technology, which also discusses clean energy, as well as a MoU on Hydrogen with the EU (Middle East Institute 2023; METI 2022c).

Overview of Stakeholders

The following stakeholder map (Figure 8) provides an overview of Japanese institutions and businesses active across the hydrogen value chain. Please note that the map does not represent a complete depiction of actors and that these were selected on the basis of desk research independently by the authors.

Figure 7: Overview of Stakeholders Japan



Source: adelphi

3.4 Hydrogen in Korea

Status of Policy and Legislation

In 2020, the previous Korean government established the country's goal of climate neutrality by 2050 (Government of the Republic of Korea 2020). Achieving this target will require a fundamental shift in the country's energy supply, which is currently dominated by fossil fuels. In 2021, fossil fuels accounted for 82.6% of Korea's final energy consumption, while wind and solar together only made up about 1% of the energy mix. Nuclear is another important energy source in Korea, adding around 14% to the final energy mix (IEA 2024). Similar to the previous government, the current Korean government assigns hydrogen a key role for achieving the 2050 carbon neutrality target. The country sees the hydrogen market as a major future growth market and intends to become a global leader in the application of hydrogen fuel cells for mobility, power generation, and in the household sector. The incumbent Yoon administration announced its ambition of "establishing a clean hydrogen supply chain and nurturing a world-leading hydrogen industry" (MOTIE 2022b).

Quick Facts

Projected H_2 Demand
- **2030:** 4 Mt
- **2050:** 28 Mt

Projected H_2 Production
- **2030:** 2 Mt
- **2050:** 5 Mt

Projected H_2 Import
- **2030:** 2 Mt
- **2050:** 23 Mt

In January 2019 under the previous government, Korea published its Hydrogen Economy Roadmap, a strategic plan to promote the hydrogen industry as a cooperative effort of multiple ministries, indicating the importance attributed to hydrogen by the Korean government. The roadmap addresses the timeframe until 2040 and sets a 2040 hydrogen supply target of 5.26 Mt (175.3 TWh). In the Roadmap, electrolysis appears as a hydrogen supply method from 2022 onwards. Hydrogen supply, as well as the proportion of green hydrogen, is to be increased by 2040 through domestic electrolytic hydrogen production, Korean-owned overseas production, and imports (MOTIE 2019). The goal is to gradually bring down the cost of green hydrogen from 6,000 KRW per kg (4 EUR/kg) at the early market stage to 3,000 KRW per kg (2 EUR/kg) in 2040 (KEEI 2021).

The 'Hydrogen Economy Promotion and Hydrogen Safety Management Act' ('Hydrogen Act') was passed in 2020 and "provides the legal framework for policy instruments in the field of hydrogen, and aims to guarantee a stable demand for clean hydrogen and to provide government support to hydrogen producers". The first amendment made to the Hydrogen Act in May 2022 increases the targets for power generation from low-carbon hydrogen, includes Clean Hydrogen Energy Portfolio Standards [CHPS], and adds the implementation of a clean hydrogen certification scheme as a requirement (Chosun Biz 2022; H2 News 2022b).

In November 2021, the "1st Basic Plan for the Implementation of the Hydrogen Economy" was adopted by a special committee dedicated to the establishment of a hydrogen economy introducing goals and guidelines for the creation of domestic production and import capacities ("Hydrogen Economy Committee") (MOTIE 2021). When the same committee convened for the first time under the newly elected administration of president Yoon in November 2022, a growth strategy for the hydrogen sector called "3 Up" was published. It included the build-out of a low-carbon hydrogen supply chain ("Scale-Up"), the setting-up of the necessary infrastructure ("Build-Up"), and the promotion of technological innovations ("Level-Up") (MOTIE 2022a).

In May 2023, MOTIE announced another amendment to the Hydrogen Act addressing issues such as setting low-carbon hydrogen standards and setting up certification procedures. Korea's national certification system ("Clean Hydrogen Certification System"), that was introduced in late 2023 during the 6th meeting of the Hydrogen Economy Committee and came into effect in March 2024, establishes a definition of "clean hydrogen" not based on a specific production method but on its carbon content. "Clean hydrogen" as defined by the Korean government therefore corresponds to the term "low-carbon hydrogen" in this study. As of 2023, the emission threshold for clean hydrogen is at around 4 $kgCO_{2e}/kgH_2$ (or approx. 33 gCO_{2e}/MJ) (MOTIE 2023c), reflective of the carbon intensity of domestic blue hydrogen with a capture rate of 95% (electimes 2023). For comparison, the European Union is aiming for a significantly lower clean hydrogen threshold of 28.2 gCO_{2e}/MJ (International PtX Hub 2023). The Korea Energy Economics Institute [KEEI] was designated as the clean hydrogen certification authority. In May of 2023, a “Hydrogen Safety Management Roadmap 2.0” was published addressing safety concerns in a hydrogen economy (MOTIE 2023a).

Furthermore, the government plans to commercialise electricity generation from hydrogen and ammonia by 2027. To this end, the Korean government has introduced the world’s first hydrogen power generation bidding market with a yearly volume of 1,300 GWh for district electric service producers and other buyers in June 2023 (MOTIE 2023c). Independent experts have voiced concerns over the inclusion of ammonia co-firing into the bidding market and the inclusion of blue hydrogen within the Clean Hydrogen Certification System. Experts question the effectiveness of hydrogen-based co-firing in existing fossil power plants regarding decarbonisation goals and energy efficiency (Solution for Our Climate 2023). To foster the use of clean hydrogen for electricity generation specifically, a Clean Hydrogen Portfolio Standard [CHPS] was introduced already in December 2022 (Samchully 2024). In May 2024, the Korean government followed up on the CHPS with the launch of the clean hydrogen power generation market. Eligible are power generation companies that have obtained domestic clean hydrogen certification for their production. For 2024, the annual tender volume is 6,500 GWh with a contracted period of 15 years (MOTIE 2024b).

To meet its increased future hydrogen demand, Korea plans to import large volumes of clean hydrogen in the future. Through the establishment of a Clean Hydrogen Trade Initiative in 2022, the country has sought to solidify its role as a driving force towards the establishment of a global low-carbon hydrogen value chain. While the initiative has seen a conference in Korea promoting its launch, so far, no future activities have been labelled under its roof. However, the recent flurry of legislation and other government initiatives shows that Korea is serious about establishing a hydrogen economy within its borders. In addition to official government actors, other organisations are actively pursuing the ramp-up of hydrogen supply chains in Korea. For instance, H2KOREA, a public-private consultative organisation, has been an important stakeholder in the establishment of international partnerships (H2Korea 2024). The agency is also contributing to the drafting of hydrogen-related policies, the planning of infrastructure build-up, and aiding technology development (Kim 2021).

Funding

The beforementioned Hydrogen Act features provisions on public funding of hydrogen projects. Article 10 states that the Korean government will subsidise or provide loans for hydrogen projects, including projects abroad, while Article 11 clarifies funding for hydrogen-specialised companies and Article 13 explicitly permits the establishment of private funds for the fostering of a hydrogen economy (CMS 2023).

In December 2023, the Korean government signalled extended financial support for low-carbon hydrogen through tax relief measures. In a statement following a Hydrogen Economy Committee meeting, Prime Minister Han has made a series of remarks reinforcing the administration’s commitment to securing the ramp-up of the low-carbon hydrogen market, including by hinting at a system of tax credits for low-carbon hydrogen, like in the US Inflation Reduction Act [IRA], in Korea. It was therefore subsequently speculated that future financial support in Korea could be tiered depending on the CO_2 intensity of production (Hydrogen Insight 2024j).

Currently, companies can already receive tax credits of 30% plus a percentage of research and development costs for investments depending on the size of the company and other circumstances for the deployment of technologies provided these fall under the category “New Growth Cutting-Edge Technology” or tax credits between 30% and 50% for technologies under the “National Strategic Technologies” programme (KIAT 2024b). Technologies eligible for tax credits are specified in a document on “Implementation Rules” and include hydrogen-related technologies (Ministry of Government Legislation 2024). Companies’ requests for tax credits are examined in a multi-step process and ultimately awarded by Korea Institute for Advancement of Technology [KIAT] (KIAT 2024a).

Additionally, the government has provided funding for companies under the “1st Hydrogen-Specialised Company Support Programme” in 2023 on the legislative basis of Article 11 of the Hydrogen Act in order to foster the establishment of hydrogen-specialised companies. Said companies are defined as earning a minimum of 30% of their sales volume from hydrogen-related business or invest a minimum of 20%

of their research and development expenses on hydrogen technologies (CMS 2023). Companies that were awarded funding received up to 150 Mio. KRW (100k EUR) for their projects (H2 Korea 2023). By the time of writing, a follow-up programme in 2024 was not yet announced (H2 News 2022a).

In the beginning of 2023, the Korean government announced plans to fund the establishment of six "hydrogen cities" along with the local governments of the respective mid-sized cities. With a focus on blue hydrogen production, distribution and usage, depending on the respective cities capabilities, the cities are intended to become models for integrating hydrogen use into almost all levels of daily life, especially in the housing and transport sectors. Each city will receive 40 billion KRW (27 Mio. EUR) annually for establishing hydrogen infrastructure locally (Hydrogen Insight 2024e).

The government is also taking demand-side initiatives by subsidising specific use cases. As the Ministry for the Environment announced in 2023, funding for hydrogen-fuelled buses will be expanded to 262 Mio. USD (241.5 Mio. EUR) in 2024, enough to subsidise the purchase of 1,500 buses by local traffic operators (Hydrogen Insight 2023e). Korea also heavily subsidises the purchase of passenger FCEV with public funding of 50% of sales prices. However, even the decreased funding budget was likely to be underspent as rising hydrogen fuel prices and significant fuel shortages as well as the low variance of FCEV model options has led to a sharp decrease in FCEV sales in Korea (Hydrogen Insight 2024l). In the first half of 2023, Korea, being the biggest market for FCEVs globally, saw a 39% drop in purchases. In January 2024, only two FCEV were sold in Korea, marking a further 99.4% decrease (Hydrogen Insight 2024f). Globally, FCEV sales also fell substantially in 2023 as battery EV's market share further increased, calling into question the sustainability and economic viability of Korean carmakers' decision to focus on hydrogen-fuelled cars (Hydrogen Insight 2024i).

In addition to public funding, the industry association Korean H2 Business Summit has launched a hydrogen fund in 2022 under Article 13 of the Hydrogen Act with administrative support by MOTIE. The summit has formulated the goal of supplying the fund with 500 billion KRW (330 Mio. EUR) by the end of 2023 (Korea Certification 2023). However, in the months after its launch, the fund had not attracted any further investments (Asia Times 2023).

In July 2023, MOTIE announced the goal to double "new energy industry exports" by 2030. In order to achieve this target, the New Energy Industry Public-Private Alliance, composed of companies, academic institutions, associations, and public supporting bodies, was launched and a public fund of about 500 billion KRW (330 Mio. EUR) was set up. This fund is to be complemented with over 100 trillion KRW (67 billion EUR) of "public-private financial investment". The government further plans to facilitate market entry for Korean companies through government-to-government cooperation and the use of official development assistance [ODA] grants. Technologies included in the target are small modular nuclear reactors [SMRs], hydrogen turbines, and high voltage current cables (Asian Power 2023; MOTIE 2023b).

Demand and Production

Korea's present hydrogen demand is predominantly covered by grey hydrogen (KED Global 2021) and stands at 1.8 Mt (60 TWh) (IEA 2021a). However, the Korean accounting methodology typically omits hydrogen demand for refineries and lists it much lower at between 7.3 TWh (0.22 Mt) and 15 TWh (0.45 Mt) (Intralink 2022; MOTIE 2021). Hydrogen demand mostly stems from industrial activities in the petrochemical and steel industries. In the Korean political and social discourse, hydrogen utilisation is seen as viable not only in industry but also in transport, electricity, and heating (CMS 2023).

The abovementioned 1st Basic Plan for Implementing the Hydrogen Economy, released in 2021 by the former government, sets hydrogen import and supply targets and contains projections on expected future demand. Due to the comparably high number of expected use cases, government plans expect hydrogen demand to rise faster than in other countries. As a result, Korea's hydrogen demand in 2030 is projected to increase more than threefold to 3.9 Mt (130 TWh), most of which (117 TWh) is expected to be used in the power sector (KED Global 2021; MOTIE 2021).

In order to account for its steeply rising hydrogen demand, Korea will be heavily reliant on imports. According to the 1st Basic Plan from 2021, Korea plans to import 2.0 Mt (67 TWh) of green hydrogen in 2030, resulting in an import rate of 51%. The rest of the increased demand is to be covered by domestic production capacities, with 0.94 Mt of grey hydrogen, 0.75 Mt of blue hydrogen, and 0.25 Mt of green hydrogen targeted in 2030 (S&P Global Commodity Insights 2021).

By Korea's net-zero-year 2050, according to the 1st Basic Plan, the government expects hydrogen demand to further increase reaching 27.9 Mt (929 TWh), with power at 13.5 Mt (446 TWh), industry at 12.2 Mt (403 TWh), and transport at 2.2 Mt (73 TWh) contributing the most to rising demand. According to the plan, annual supply is to be covered by the domestic production of 3 Mt of green and 2 Mt of blue hydrogen and the import of 22.9 Mt of low-carbon hydrogen (MOTIE 2021).

Despite the change in government in 2022, only individual policies have been updated by the new administration with demand projections and targets remaining intact. However, the current administration's definition of clean hydrogen, the increased focus on nuclear power, and decreased attention to renewable projects is likely to lead to a shift in import priorities.

Similar to Japan, Korea plans to secure Korean-owned supply chains with its companies investing in overseas production capacity, which is supposed to make Korea less vulnerable to political instability (S&P Global Commodity Insights 2021). Nevertheless, with a projected hydrogen import rate of 82% in 2050, Korea will rely heavily on international partners like Australia to ramp-up their low-carbon hydrogen production capacities. Accordingly, innovations in maritime transport are crucial to meeting Korea's import needs and the construction of a hydrogen pipeline network is necessary for distribution within the country, which is already planned in some parts of the country (Hydrogen Insight 2024k; Offshore energy 2023). In this regard, the Incheon Liquefied Hydrogen Plant started operations in May 2024 with a maximum annual production capacity of 30,000 metric tonnes of liquid hydrogen (MOTIE 2024c).

To meet hydrogen demand, the production of pink hydrogen using nuclear power is becoming more central to Korea's strategy. In June 2024, Korea Hydro & Nuclear Power [KHNP], Samsung C&T Corporation, Doosan Enerbility, Hyundai E&C, Korea Electric Power Corporation E&C, Korea Gas Technology Corporation, and Korea Power Exchange signed a 'Memorandum of Understanding [MOU] on the Production and Commercialisation of Clean Hydrogen from Nuclear Power'. The public and private companies and institutions will work together to establish and operate large-scale facilities for the commercialisation of clean hydrogen from nuclear power. They will also develop business models for the production of clean hydrogen for domestic use and export in a timely manner.

The scale-up of green hydrogen production within the country will depend on the expansion of renewable electricity in Korea, which is likely to be a bottleneck. In 2022, renewables have contributed 7% to Korea's electricity mix (IEA 2023d). Despite solar PV capacity additions reaching 4.4 GW annually by the end of 2021, inadequate grid expansion has thus far hampered the integration of renewables into the market (PV Magazine 2022). Compared to the last Basic Plan, MOTIE slightly increased the targeted share of renewable electricity in 2030 to 21.6%. However, this is still much lower than the 30.2% pledged in Korea's last Nationally Determined Contribution [NDC] in 2021 (Renewable Energy Institute 2023). Moreover, the targets for renewable capacity buildout of 46.5 GW for solar and 19 GW for both onshore and offshore wind will not nearly be enough to contribute a significant part to Korea's increased hydrogen demand. As a consequence of this lack of political ambition, the IEA decreased its five-year forecast for renewable expansion in Korea by 42% in 2023 compared to the forecast a year earlier (IEA 2023d). In May 2024, the Korean government released a draft of the 11th Basic Electricity Plan (for the years 2024-2038) which calls for the achievement of a solar capacity of 53.8 GW and wind capacity of 18.3 GW by 2030. Despite these increased targets, the share of renewable energies for electricity generation is estimated to remain at 21.6% in 2030 due to an increased electricity demand (MOTIE 2024a).

Industry

Many of Korea's key industries are highly engaged in the development of hydrogen technologies and the establishment of hydrogen value chains. This is, for instance, evidenced by Korean automotive companies Hyundai and Kia being among the leaders in global hydrogen patent applications. Additionally, Korean research institutions are among the world's most active in patent applications for technologies along the entire hydrogen value chain (IEA and EPO 2023).

The industrial sector supplies about a third to Korea's Gross Domestic Product (Statista 2023b) and features many energy-intensive industries. With Korea being one of the global hubs of vessel construction, the country is also the fifth largest steel producer globally (World Steel Association 2022). Steel production is widely seen as one of the most important use cases for low-carbon hydrogen. Additionally, Korea was the sixth-biggest exporter of chemicals in 2021, making it a relevant player in another industry crucial to the global energy transition (Statista 2022). Since Korea wishes to maintain its strong industry despite growing competition, both regionally and globally, there is a high interest in securing the availability of low-carbon forms of energy (The Korea Times 2023b).

In recent years, key industry players have called for an accelerated shift towards decarbonisation (RE100 2022). Accordingly, in 2021, fifteen of Korea's biggest companies launched a business council called the "H_2 Business Summit" to coordinate their low-carbon hydrogen activities, create shared infrastructure, and secure supplies to the country. Members, including Hyundai Motor, SK Group, and POSCO, have pledged to dedicate 37.3 billion USD (43.5 billion EUR) by 2030 to the establishment of low-carbon hydrogen supply chains and infrastructure (Nikkei Asia 2021). However, Korean companies are not just very active offtakers seeking to secure a sufficient supply of hydrogen products to keep their production running, but are also present in other areas of the hydrogen value chain.

One rather specific Korean phenomenon pertains to big economic conglomerates (chaebols) seeking to cover virtually all parts of the hydrogen value chain through affiliates. One example of this is Hanwha Group, one of the largest business conglomerates of the country, whose affiliates are active in the production, storage, transportation and utilisation of hydrogen (see also stakeholder map below) (Hanwha 2023). Hyundai Motor Group is another conglomerate, with its affiliates working on the production, storage, and transportation of hydrogen as well as on the establishment of different use cases (Hyundai Motors 2024). SK Group, another one of Korea's biggest chaebols and active, inter alia, in the energy and the chemical industry, is investing over 16 billion USD (14.8 billion EUR) within five years with the aim to establish a domestic hydrogen ecosystem encompassing production, distribution, and consumption (Green Car Congress 2021). The Korean steel major POSCO, the seventh-largest steel producer globally in 2022, has unveiled plans to produce 7 Mt of low-carbon hydrogen per year by 2050 in order to meet parts of the demand from its hydrogen-reduction ironmaking facilities (The Korea Times 2023a).

Vehicle manufacturer Hyundai is a world-leading producer of fuel cell vehicles and also developing battery systems for other automation appliances. The company is also active in setting up distribution networks for hydrogen mobility (Fuel Cells Works 2020). Kia Motors is not only developing FC vehicles for civilian passenger use, but has recently unveiled a hydrogen-power all-terrain vehicle for military purposes (Janes 12.02.2024). Combing its industry expertise in both shipbuilding and hydrogen technologies, Korea is also very active in the development of maritime transport solutions for hydrogen. In a key development regarding hydrogen carrying vessels, Hyundai's subsidiaries Korea Shipbuilding & Offshore Engineering and Hyundai Heavy Industry have received approval for a new system for a liquified hydrogen carrier in 2023 (Lepic 2023). DSME, another Korean shipbuilding company, has cooperated with the American company CB&I on a feasibility study regarding the use of a large liquid hydrogen carrier (McDermott 2022). In a move to ensure the future provision of decarbonised marine mobility, Samsung Heavy Industries has developed a liquid hydrogen fuel cell system designed to power ships (Globuc 2022).

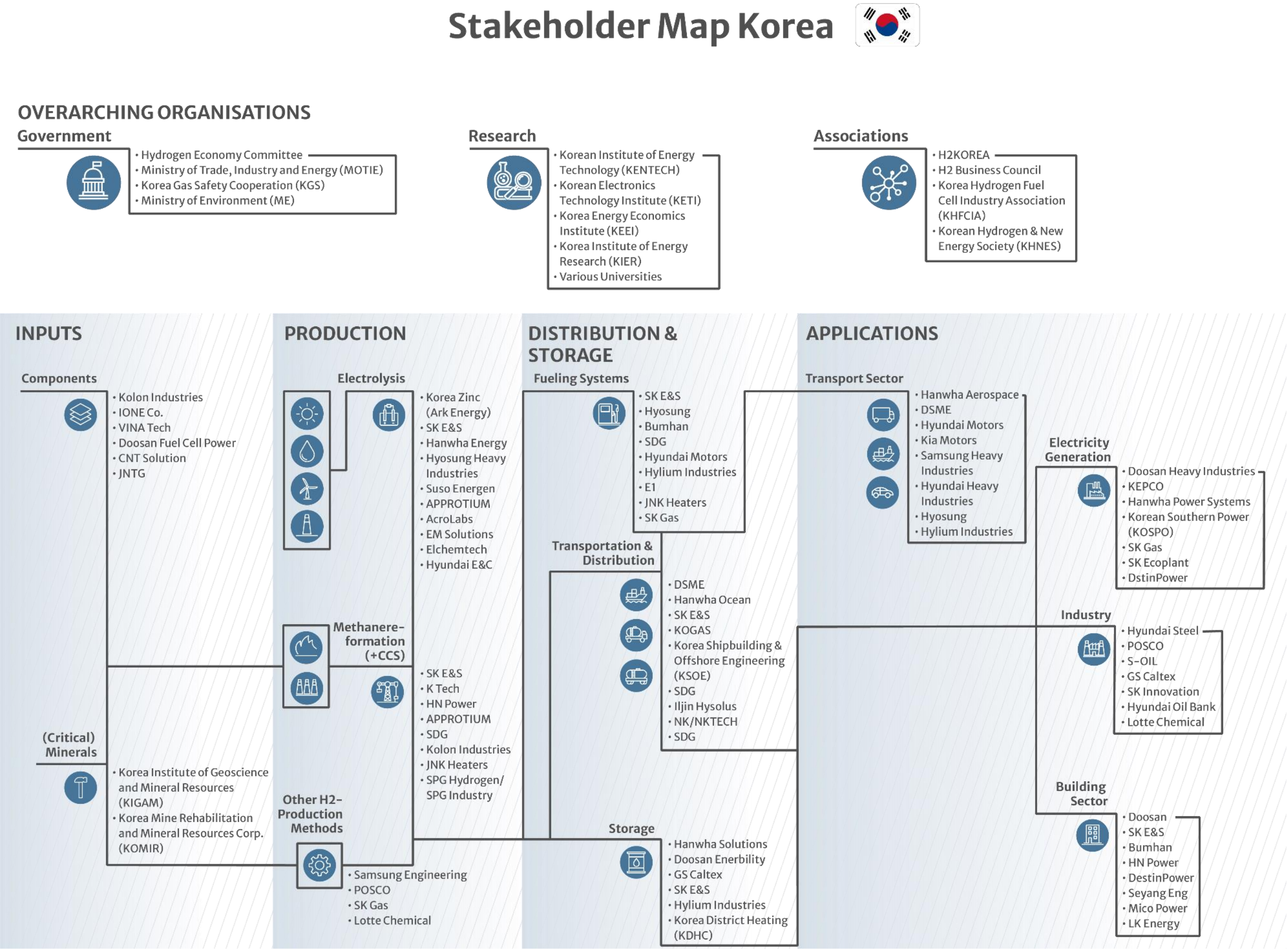
Korean companies are also active in integrating hydrogen-powered appliances into the electricity sector. In a cooperation of POSCO Energy and Doosan Fuel Cell for a power plant of Korean Southern Power [KOSPO] in Incheon, the then largest hydrogen fuel cell power plant generating electricity for 250,000 households annually, was opened in 2021 (Fuel Cells Works 2021). In 2023, Korea was the first country globally to pass the threshold of 1 GW installed fuel cell capacity for power generation. This is roughly double and almost triple of the installed capacity in the US and Japan, respectively. However, many countries view fuel cell power generation as a back-up option to deal with the intermittency of renewables, whereas Korea sees hydrogen-powered electricity generation as one of the mainstays of its future energy system. While the milestone referenced above seems to indicate increased momentum around the technology, yearly capacity additions and industry scepticism rather point to a lack of thereof (Hydrogen Insight 2024h).

Similar to Japan, Korean politics and companies also see co-firing of hydrogen and its derivatives as a means to reduce emissions from fossil-fuel power plants. Hanwha Impact has claimed a "world record" by blending almost 60% of hydrogen in an 80 MW gas turbine in a power plant near Seoul. However, critics have pointed out that the measure reduced CO_2 emissions by only 22% compared to running on fossil fuels alone, raising questions about the effectiveness of co-firing as a decarbonisation method (Hydrogen Insight 2023f).

Overview of Stakeholders

The following stakeholder map (Figure 9) provides an overview of Korean institutions and businesses active across the hydrogen value chain. Please note that the map does not represent a complete depiction of actors and that these were selected on the basis of desk research independently by the authors.

Figure 8: Overview of Stakholders Korea



Source: adelphi

4 Bilateral Collaborations

4.1 Australia - Germany

While energy exports from Australia to Germany have been limited in the past with most of Australia's energy exports going to Asia, renewable hydrogen and especially its derivatives present a new opportunity that some companies have already acted on. For instance, RWE and Australian developer H2U already signed a Memorandum of Understanding [MoU] in 2021 to develop global hydrogen trading, however, there have been no updates since (RWE 2021a). More concrete announcements followed in 2022: Fortescue wants to supply 100,000 tonnes (3.3 TWh) of hydrogen per year to Covestro, a subsidiary of Bayer (Covestro 2022). In March 2022, Fortescue signed another MoU, this time with E.ON on supply volumes of up to 5 Mt (166.9 TWh) by 2030 (E.ON 2022). From 2024 onwards, Fortescue wants to bring large quantities (250,000 tonnes per year) of green hydrogen and its derivatives (ammonia or CH_4) to Europe (Germany and the Netherlands); in a second step, other EU countries are also to be supplied. The envisaged quantities can play an important role for the security of energy supply in Germany and the EU (5 Mt correspond to about 1/3 of the imported natural gas from Russia) (Financial Times 2022b).To underpin this cooperation, Fortescue is currently in the process of investing around 100 Mio. AUD (62.2 Mio. EUR) in the development of Tree Energy Solutions' [TES] green hydrogen import terminal in Wilhelmshaven and acquiring 30% of the TES project company Deutsche Grüngas und Energieversorgung (Fortescue 2022). However, since Fortescue is a globally operating company, the hydrogen need not be imported from Australia but is more likely to originate from one of Fortescue's operations in countries such as Norway or Canada. Fortescue has also concluded an MoU with Deutsche Bahn on research cooperation concerning the use of green hydrogen and ammonia in rail transport as well as an MoU with Airbus to facilitate the exchange on the use of hydrogen in aviation (Airbus 2022; Deutsche Bahn 2022).

Meanwhile, Fortescue is also working closely with German companies in Australia to decarbonise its mining vehicle fleet. In Perth / Hazelmere, for instance, Fortescue collaborates with Liebherr to convert large mining vehicles to hydrogen, battery electric, and hybrid propulsion (Liebherr 2022).

There are many more companies engaged in building the German-Australian hydrogen ties. Major German companies, including thyssenkrupp, Linde, MAN, and Siemens, have established themselves in Australia and are strongly involved in local hydrogen operations (thyssenkrupp 2022; BOC Australia 2023; Australian Government 2023b). Most recently, a consortium of BOC, a Linde subsidiary, and ATCO has been among the successful companies selected by the government of South Australia to construct a large hydrogen power plant in Whyalla. The plant will comprise a 250 MW electrolyser, hydrogen storage for 3,600 tonnes of hydrogen and 200 MW of electricity generation capacity. Construction of the hydrogen power plant is scheduled for completion by early 2026 and receives 593 Mio. AUD (369.1 Mio. EUR) of funding from the SA government (Government of South Australia 2023).

These endeavours happen against the background of strong political cooperation between Germany and Australia. In 2021, the German-Australian Energy Partnership was established, within the framework of which a sub-working group on hydrogen regularly exchanges information, implements dialogue formats, and delegation visits take place. In addition to this, Germany and Australia also agreed on the Hydrogen Accord in 2021 with three initiatives:

1. Cooperation on the establishment of an innovation and technology incubator to promote hydrogen pilot projects (HyGATE), jointly funded by the DCCEEW and the German Federal Ministry of Education and Research [BMBF]. The four successful projects were announced in January 2023 (ARENA 2023).

2. Strengthening of industrial cooperation for bilateral demonstration projects with the aim of a German-Australian Hydrogen Hub, which could produce green hydrogen and derivatives using German technology in Australia.

3. Support for the development of bilateral hydrogen trade through an Australian procurement window under H2Global. This initiative is still subject to political discussions and legal reviews in both Germany and Australia (Australian Embassy Germany 2024; BMBF 2023).

The BMBF has also co-funded the cooperation of the bilateral hydrogen supply feasibility study "HySupply" with the Australian Government. The study included cooperation of a wide range of research and industry stakeholders on the opportunities and barriers to bilateral trade and has resulted in a range of publications and recommendations (acatech 2024; BMBF 2023).

Lastly, BMBF is also jointly funding the "TrHyHub" feasibility study with the Western Australian and Dutch Governments investigating the possibility of exporting renewable hydrogen from Western Australia to the Port of Rotterdam (Port of Rotterdam 2022).

4.2 Australia - Japan

Japan and Australia have close trade ties, particularly in the energy sector. Australia is responsible for the majority of supplies of LNG, coal, and iron ore and Japan is Australia's second largest export market as well as source of foreign direct investment (DFAT 2022). Therefore, Japanese and Australian companies have a long history of close cooperation in the energy sector and companies from both sides have naturally moved towards closer cooperation in the area of hydrogen in recent years (Australian Embassy Japan 2024). As already mentioned in Chapter 3.3., one of the largest cooperation projects is the Hydrogen Energy Supply Chain [HESC] project led by Kawasaki Heavy Industries [KHI] (in Japan referred to as HySTRA project). The consortium partners Electric Power Development [j-Power] and Sumitomo Corp will produce hydrogen via coal gasification using CCS in Gippsland, Victoria, while KHI and Iwatani will oversee the liquefaction, loading, transportation, and unloading of the hydrogen at the port of Kobe in Japan. The initial pilot project was completed in 2022 with the world's first shipment of liquid hydrogen via ship from Australia to Japan in February 2022 (Pekic 2022). The project has now entered its commercial demonstration phase (Liquefied Hydrogen Supply Chain Commercial Demonstration Project), which the Japanese government supports with 2.35 billion AUD (1.5 billion EUR)[23]. The project has the potential to produce and ship around 225,000 tonnes of liquid hydrogen per year (HESC 2024). Projects proponents suggest that the use of CCS technologies will reduce emissions by 1.8 Mt, however, given Australia's thus far unsuccessful history of CCU/S projects, there is a risk that HESC might rather add up to 3.8 Mt of emissions at full capacity (The Australia Institute 2022).

Meanwhile, the Japanese Sojitz corporation has announced its cooperation with the Australian power generator CS Energy in 2022 to produce green hydrogen from solar in Queensland, which is then to be supplied to Palau to serve as backup power sources in small fuel cells (Sojitz 2022). Rio Tinto and Sumitomo Corporation plan on building a green hydrogen production plant in Gladstone, Queensland, which is to become the world's first project using the hydrogen calcination technology. The project is co-funded by ARENA with a 32.1 Mio. AUD grant (20 Mio. EUR) and will consist of an onsite electrolyser, storage, and retrofit of a hydrogen-capable burner for one of the refinery's four calcinisers. Construction of the plant will commence in 2024 and Sumitomo will operate the plant supplying the hydrogen to Rio Tinto (Rio Tinto 2023). A consortium of Japanese Inpex, the Australian oil and gas major Santos, Scottish-based consultancy Xodus Group, and the national Australian research organisation CSIRO has been awarded 1 Mio. AUD (622,400 EUR) by the Australian government to run a feasibility study on the market potential of green and low-carbon hydrogen produced with renewables and fossil fuels with CCS in Darwin (INPEX 2023). Finally, the Australian Hazer Group has signed an agreement with Japanese Chubu Electric Power Company and Chiyoda Corporation. The three companies seek to determine the feasibility of employing Hazer's technology using methane feedstocks to produce hydrogen while capturing carbon in the form of solid graphite, a technology originally developed by the University of Western Australia and subsequently bought by Hazer Group, in Japan's Chubu region. The MoU is non-binding but hopes to establish a Project Development Plan to enable the construction of a production facility in Japan by the late 2020s. The aim is to produce 50,000 to 100,000 tonnes of hydrogen per year (Chubu Electric Power 2023).

Additionally, the Japanese and Australian governments have created political fora and institutions to further support their countries' cooperation on hydrogen. In 2020, the Japan-Australia Joint Statement of Cooperation on Hydrogen and Fuel Cells was signed on the side-lines of the Japan-Australia Ministerial Economic Dialogue. While the agreement is not binding, it nevertheless serves as a "shared

[23] The funding was allocated by the Japanese government to Japan Suiso Energy, Iwatani Corporation and ENEOS in 2021. The money stems from the government's Green Innovation Fund (GIF). On March 6, 2023, Japan Suiso Energy decided to allocate the money to the HESC project (HESC 2023).

commitment to deploying hydrogen as a utility-scale source of energy" (HESC 2020; KWM 2020). This was followed in 2021 by the Japan-Australia Partnership on Decarbonisation through Technology, a collaboration aimed at jointly facilitating the achievement of net zero by supporting the development of necessary technological innovations and their cost-parity with existing technologies. Focus areas are low-carbon hydrogen as well as lower emissions liquid natural gas production, transport, and use; carbon capture, utilisation and storage; carbon recycling; and low emissions steel and iron ore (DCCEEW 2021a; Ministers for the Department of Industry, Science and Resources 2021b). To advance progress in low-carbon hydrogen technologies, the Australia-Japan Clean Hydrogen Partnership was signed in January 2022, which formalises Japan's participation in the first round of the 150 Mio. AUD (93.4 Mio. EUR) Australian Clean Hydrogen Trade Program [ACHTP] (ARENA 2022; Ministers for the Department of Industry, Science and Resources 2022).

4.3 Australia - Korea

Korea and Australia have a long-standing relationship in the trade of energy and resources, with Australia acting as a reliable resource and energy supplier, and Korea being a reliable off-taker of Australian supplies. To date, Korea is the third largest market for Australian resources and energy exports after China and Japan, worth 23 billion AUD (14.3 billion EUR) in 2020-2021. In turn, Australia was the single largest provider of gas and coal imports into Korea in 2022, supplying 22% and 44% of overall imports, respectively (Yonhap News Agency 2023). In December 2021, the two countries established a Low and Zero Emissions Technology Partnership with the goal to jointly invest 50 Mio. AUD each (31.1 Mio. EUR) in hydrogen supply networks, the development of CCS and storing technologies as well as low-carbon steel. The partnership will be steered by a newly established working group within the pre-existing Joint Committee for Energy and Mineral Resources Consultations and Cooperation [JCEM] (Korea Joongang Daily 2021; DCCEEW 2021b; Ministers for the Department of Industry, Science and Resources 2021a).

Bowen and Springer (2022) suggest that the cooperation of Korean and Australian companies in the hydrogen market could follow a similar approach as cooperation in the energy sector more broadly. Here, Korean companies have been able to negotiate long-term supply contracts and to establish minority investment relationships. Accordingly, in 2019, H2Korea and the Australian Hydrogen Council [AHC] signed an MoU to set up a working group to enable regular exchange on hydrogen topics of mutual interest (Bowen and Springer 2022).

In fact, businesses are already actively pursuing joint projects. Korea Zinc's subsidiary Ark Energy is building the SunHQ Hydrogen Hub in Queensland. The plan is to install an electrolyser at a zinc refinery of Sun Metals, another subsidiary of Korea Zinc. The hydrogen produced is supposed to be used as diesel replacement. The long-term goal is to also export the hydrogen to Korea. For this purpose, Ark Energy has signed an MoU with the Port of Townsville to conduct a feasibility study. The project has received 5 Mio. AUD (3.1 Mio. EUR) in funding from the government of Queensland, 3 Mio. AUD (1.9 Mio. EUR) from the Australian government and an investment commitment of up to 12.5 Mio. AUD (7.8 Mio. EUR) from the CEFC (CSIRO 2024b). In 2021 and 2022, POSCO, Korea's largest steel-making company, signed decarbonisation and low-emissions partnerships with BHP to share research in hydrogen-based direct reduction technology, FMG for general cooperation in the area of hydrogen, Rio Tinto to conduct joint research into low-carbon emissions steel value chains, Roy Hill for a shift towards hydrogen-based steel production, and Origin Energy to enable the supply of hydrogen to Korea (Bowen & Springer 2022). POSCO's relationship with FMG is designed as a circular one: FMG will be providing iron ore to POSCO, which the steelmaker will send back in the form of steel destined for use in FMG's renewable energy projects, which in turn will provide green hydrogen and its derivatives to the Korean company (PV Magazine 2021). Moreover, POSCO has been granted land in the Pilbara region by the WA government to construct a plant where iron ore will be refined into hot briquetted iron [HBI] and subsequently be shipped to POSCO's steel plants in Korea. It is now working on a pre-feasibility study with French energy generator Engie to determine whether the plant can be powered by hydrogen (Engie 2023). Overall, POSCO plans to invest 40 billion AUD (24.9 billion EUR) in Australia by 2040 of which 28 billion AUD (17.4 billion EUR) will be dedicated to the manufacturing of hydrogen and 12 billion AUD (7.5 billion EUR) to the production of green steel. The goal is to produce 1 Mt of hydrogen by 2040 (POSCO 2022). Also, in 2021, the Korean SK Group announced its investment of 1.4 billion USD (1.3 billion EUR) in Australian gas fields to, inter alia, enable the production of blue hydrogen using CCU/S technologies (Bowen & Springer 2022). Australian companies are also active in Korea, for instance, Woodside cooperates with a number of Korean companies to realise the HyStation project, which will develop and manage refuelling stations for public hydrogen buses in Korea (Woodside 2021).

4.4 Germany – Japan

During inter-governmental consultations in March 2023, headed by Prime Minister Kishida and German Chancellor Scholz, the two countries have agreed to intensify their cooperation in the field of clean energy deployment, the ramp-up of a low-carbon hydrogen economy, and various other energy transition-related fields of action (S&P Global Commodity Insights 2023). Hydrogen has become an important focal topic within the two countries' energy cooperation. The Working Group "Hydrogen" of the Japanese-German Energy Partnership, which was established between the BMWK and METI in 2019, is dedicated to low-carbon hydrogen-related aspects of the energy transition. It is the platform for exchanges on hydrogen related policies between both ministries and it facilitates stakeholder dialogues on topics ranging from certification to the build-up of import infrastructure as well as instruments for the international market ramp-up (Japanese-German Energy Partnership 2024).

Following discussion between METI and BMWK within the Energy Partnership, the aforementioned H2Global Foundation has intensified contacts with the Japanese side. As a result of this, MoUs on knowledge transfer regarding the establishment of hydrogen supply chains have been signed in early 2024 and the cooperation was further deepened with an addendum in June of this year. H2Global and JOGMEC will deepen their cooperation in the framework of the working group "Hydrogen" of the Japanese-German Energy Partnership, focusing on key topics such as hydrogen regulation, technology, and supply chains. H2Global and the Tokyo Metropolitan Government signed a separate MoU to promote cooperation and the exchange of information on topics such as trading and logistics, and the development of hydrogen exchanges and related activities (JOGMEC 05.02.2024; HTT Tokyo; H2Global 02.02.2024).

The public Japanese Bank for International Cooperation [JBIC] and its German counterpart KfW IPEX have cooperated on international energy projects before (KfW IPEX-Bank 2021) and may well cooperate on hydrogen projects in the future. Japan's NEDO and Germany's NOW GmbH have signed an MoU on cooperative activities already in 2010 and have since carried out various exchange formats in order to advance mutual learning about mainly technological and infrastructure-related hydrogen developments (NOW GmbH 2024b).

Japanese and German companies cooperate in many economic sectors and hydrogen is no exception to the intertwined nature of both countries' economies. RWE and Kawasaki Heavy Industries are currently implementing a joint project in Lingen, Germany, at the end of which a hydrogen-powered gas turbine with the generation capacity of 34 MW is going to flexibly provide electricity to the German grid (RWE 2021b). Japanese know-how on hydrogen-powered turbines is thereby helping with the decarbonization of RWE's power plants (DWIH Tokyo 2022). Japanese utility JERA, German energy company EnBW and VNG AG have recently partnered to conduct a feasibility study for a large-scale ammonia cracker in the port of Rostock, Germany (EnBW 2023). Further, JERA and Mitsubishi Corporation have invested in Hydrogenious LOHC, located in Southern Germany, which develops storage and transportation infrastructure solutions for the hydrogen economy (Hydrogenious LOHC Technologies 2024).

German companies are active in hydrogen-related activities Japan as well. Siemens Energy's Japanese subsidiary and Toray Industries are partnering in a PEM electrolysis project supported by METI and NEDO (Siemens Energy 2021). In August 2023, Enapter has announced a partnership with Enoah Inc. for the distribution of its AEM electrolysers to Japanese customers (Enapter 2023a). Further German electrolyser producers, like ThyssenKrupp Nucera and Bosch, are also active on the Japanese market.

Japanese and German research, public, and private actors are further developing joint projects to advance research and development on all parts of the hydrogen value chain. In a cooperative project between TU Braunschweig and Yamanashi University, the Japanese-German Green Hydrogen Material Laboratory has been established at the end of 2023. The project is intended to serve as an incubator for material innovation around the production of green hydrogen and is receiving funding from the German Federal Ministry of Education and Research [BMBF] (Technical University Braunschweig 2023). Ruhr Universität Bochum and Osaka University have initiated a joint H2 Lab, which is conducting research on the potential of biohydrogen production (Ruhr University Bochum 2024). Another example of research collaboration containing an actor of the private sector is Asahi Kasai Europe's demonstration of a chlor-alkali electrolysis project in Herten, Germany, that was supported by NRW.INVEST and the Energy Agency NRW, two economic development agencies of the Federal State (H2 Netzwerk Ruhr 2018).

4.5 Germany – Korea

As two heavily industrialised countries and projected future importers of low-carbon hydrogen, Germany and Korea both have undertaken measures to increase exchange on their hydrogen policies in recent years. In 2019, the Korean-German Energy Partnership was established between the BMWK and MOTIE. The working group "New Green Energy Technologies" within the Energy Partnership has hydrogen as an important focus topic and is the platform for respective exchanges and discussions on policies as well as the initiation of joint activities like expert workshops (Korean-German Energy Partnership 2024). Supported by BMBF, BMWK, and MOTIE and organized by a wide range of institutions, the two countries also hold an annual bilateral hydrogen conference. The conference's 4th rendition in October 2023 featured 200 participants from political and research institutions and companies active in the field and discussed recent developments along the entire clean hydrogen value chain (Fraunhofer Representative Office Korea 2023).

Besides governmental cooperation the private sector is cooperating on many levels with regards to the establishment of hydrogen value chains. Hanwha's German venture Hanwha Q Cells, one of the biggest global manufacturers of photovoltaic cells is supplying many of the companies planned green hydrogen production sites with the necessary amounts of clean electricity to power its electrolysers (Hanwha 2022). Enapter has been assigned a hydrogen pilot project supported by MOTIE on Jeju Island. The German company will deliver to advance the island's hydrogen ecosystem (Enapter 2023a). In 2021, Linde and Hyosung Heavy Industries have initiated Linde Hydrogen Energy, a joint venture, designed to carry out hydrogen projects. The first flagship project, a hydrogen liquifying plant located in Ulsan, Korea, with an annual production capacity of 13,000 t of liquid H_2, has begun operation in 2023 (Korea Certification 2021). In November 2023, Hyundai Engineering and Construction [E&C] and RWE have signed an MoU to jointly develop offshore wind and green hydrogen projects in Korea. They plan to leverage their combined expertise in joint projects in the future (RWE 2023). On the associations level, H2Korea and Deutsche Wasserstoff und Brennstoffzellen Verband [DWV] have signed an MoU on advancing the hydrogen economy through joint exchange formats on all levels of the value chain (H2 News 2024). Hyundai Motor is a shareholder of H2 MOBILITY, a German venture established to advance hydrogen infrastructure in Germany. The company receives funding from the German Federal Ministry for Digital and Transport [BMDV] and the European Commission (NOW GmbH 2021). Siemens Energy and Korea Gas Corporation [KOGAS] have started a strategic partnership in 2021 with the aim of expanding their green hydrogen production capacities and thereby advancing Korea's climate neutrality ambitions (Siemens Energy 2021a).

German and Korean research and public institutions as well as private actors are actively engaging in joint hydrogen research projects. On the side-lines of the 3rd bilateral Hydrogen Conference in 2022, Fraunhofer IMWS and Korea Institute of Energy Technology [KENTECH] have signed a contract sealing the establishment of the Fraunhofer Innovation Platform for Hydrogen Energy at KENTECH. The platform is intended to develop technological solutions for all parts of the hydrogen value chain, with both sides profiting from the other institution's research focus, respectively (Fraunhofer IMWS 2022). German public entity Bundesanstalt für Materialforschung und- prüfung [BAM] is conducting cooperative research with Korea Gas Safety Corporation and Korea Electronics Technology Institute [KETI] funded by MOTIE on safety issues around hydrogen fuelling stations (Wang and Perez 2022). BAM is further conducting a research project funded by BMBF called H2Safe_Collaboration, which plans to analyse hydrogen applications in urban contexts among other things (Wang and Perez 2022).

4.6 Japan – Korea

Japan and Korea face long-standing political disagreements, leading to a relatively cold political relationship, which has only recently begun to thaw. On the other hand, the economic relationship between both countries has always been significant, due to their close proximity and industrial similarities. They are each other's fourth and fifth largest trading partners, respectively (WITS 2021a, 2021b). This is also true for the energy field, with Korea, as an intermediary, being one of the largest oil exporters to Japan.

The recent improvement of political relations has, however, also improved business ties – for example with Keidanren, Japan's leading business federation announcing plans to establish a joint scholarship fund with South Korean businesses (Brookings 2023). A 2023 director level meeting between Japan's METI and Korea's MOTIE signalled a closer cooperation on hydrogen at ministerial level. In the meeting, both sides exchanged best practices on their efforts for establishing respective hydrogen economies and agreed to better leverage shared expertise in the future (H2 Energy News 2023). In November 2023, Prime Minister Kishida and President Yoon unveiled a plan to cooperate on the procurement of clean hydrogen and ammonia through their governmental financial institutions in order to reduce the costs of imports (Hydrogen Insight 2023g). Following the announcements, civil society actors and academics have criticized the two countries' focus on hydrogen for decarbonisation, pointing to efficiency concerns and the risks of locking-in fossil infrastructure (Oil Change International 2023). In a Director General level meeting in February 2024 between METI and MOTIE, the two sides agreed to cooperate further around the establishment of hydrogen markets and to set up a 'Japan-Korea Hydrogen and its derivatives such as ammonia Cooperation Dialogue' (METI 2024c).

Already in June 2023, Korean Gas Safety [KGS] and the High Pressure Gas Safety Institute of Japan [KHK] have conducted a meeting discussing hydrogen safety issues and preventive measures for accidents, further signalling closer official cooperation between the two countries (MOTIE 2023a). On the associations level, H2KOREA has signed an agreement with the Japan Hydrogen Association [JH2A] to support bilateral cooperation between the hydrogen businesses in both countries. JH2A also joined the Global Hydrogen Industry Association through H2KOREA, which further underlines their close cooperation (H2 News 2024). In December 2023, Korea National Oil Corporation [KNOC] agreed to increase exchange and cooperation on energy security, CCS, and hydrogen/ammonia business with Japan's JOGMEC (Business Post).

Individual companies have also improved their ties, for example Japanese Suimoto signed an MoU with Korean LOTTE Chemical on cooperation on hydrogen and ammonia for decarbonisation (Sumitomo Corporation 2022). LOTTE has also signed an MoU with Japanese Itochu Company on hydrogen and ammonia infrastructure development (Lotte Chemical). In early 2024, HD Korea Shipbuilding & Offshore Engineering [HD KSOE] signed an MoU with Hyundai Glovis (Korea), Woodside Energy (Australia), and Mitsui O.S.K. Lines (Japan) to develop a value chain for the maritime transportation of liquefied hydrogen (Business Post). The beforementioned examples of joint private sector projects are a sign of more frequent cooperation, as the two countries are looking to manifest their role in the establishment of international hydrogen value chains.

5 Suggestions for Quadrilateral Cooperation Opportunities and Conclusion

The preceding chapters have shown that each of the four countries has unique as well as overlapping strengths across the hydrogen value chain. It has also become apparent that multiple bilateral cooperation activities are already under way. However, scaling-up the hydrogen economy and creating a global hydrogen market will require moving from predominantly bilateral cooperation towards a web of interactions, where groups of countries collaborate and trade with each other. As outlined by Ansari and Pepe (2023), the gradual multilateralisation of the hydrogen market offers multiple advantages including "specialisation and innovation spillovers" (p. 19), which in turn accelerate the much-needed technological progress, the reduction of market power asymmetries, where suppliers alone can set the trading conditions, reduced dependencies, and lower transaction costs. For Germany, Japan, and Korea, specifically, collaboration can mitigate competition for hydrogen supplies and instead establish trading patterns beneficial to all three countries, strengthening their overall position in the market (Fraunhofer ISI 2024). For Australia, collaborating with three of the biggest hydrogen importers and hydrogen-technology front-runners offers substantial business opportunities, not merely with regards to supply contracts but also in terms of the transfer of know-how and technologies. The following will highlight the most suitable topics and subsequently approaches for quadrilateral cooperation between the countries.

5.1 Topics of Cooperation

Collaboration on the **transportation of hydrogen** appears as a natural field of cooperation, as each of the four countries either seeks to export (Australia) or import (Germany, Japan, and Korea) hydrogen in the near future. As outlined in chapter 2.4 this is an area where innovation is still very much needed, so R&D cooperation can serve as an important foundation. However, it is crucial to also be action-oriented to encourage the concretisation of projects. Japan and Korea are leaders in the design and construction of hydrogen transport vessels. Bringing together representatives from respective companies with port authorities in Australia and Germany can help identify the required adjustments to the port infrastructure. At the same time, port authorities and shipping companies from all countries can exchange their experiences and determine areas of collaboration. The issue of fuel bunkering could bring in additional countries and partners, including from Singapore, which is at a strategic location on trade routes from Australia.

The question of **hydrogen safety** is closely related to the issue of (transport) infrastructure. It is a relatively nascent issue but is poised to become increasingly significant as the hydrogen economy continues to scale up. Consequently, there is a growing need for collaboration among port authorities, infrastructure developers, and policymakers globally to exchange insights and strategies on hydrogen safety. Establishing a coordinated approach, possibly through the formulation of standards, to delineate responsibilities for safety provisions at various points along the trading route up to the consumption centres could prove beneficial. Clarity on safety is a prerequisite for the implementation of projects to prevent harm to workers, the public, and the environment and to ensure social license. Quadrilateral cooperation on this topic can build upon existing initiatives and projects in Japan, Korea, and Germany as well as the ongoing collaboration between German and Korean authorities and Japanese and Korean entities.

Speaking of the implementation of projects, the **bankability of hydrogen projects** is another topic relevant to all four countries. While Australia is the frontrunner in terms of project announcements (see chapter 3.1), industry players are increasingly raising the issue of bankability. Since the hydrogen economy is nascent and practical experiences are scarce, key risks relating to construction, technology, operations, and the future market are rated as high. Consequently, many projects struggle to secure the necessary financing to reach FID. With Germany, Japan, and Korea having their own production goals and a keen interest in realising imports from Australia, exploring ways to mitigate risks and foster investments is of mutual interest. For instance, public and private finance institutions and banks from all four countries, such as the German KfW, the Australian CEFC, Japan's JBIC, and Korean KDB could join forces to devise support options and scale up financial support for the hydrogen market ramp-up.

Meanwhile, the Australian Council for Clean Energy and Energy Efficiency Council have launched the campaign "Careers for Net Zero" to encourage more people to move into energy transition related jobs. The availability of workers in the hydrogen economy and other issues related to **hydrogen workforce development** will be decisive across the entire value chain. Policy-makers from all four countries may exchange their respective approaches to this and might want to consider setting up exchange programmes for workers to benefit from each other's strengths.

Lastly, blue hydrogen, the production of which involves the use of **CCU/S technologies**, is increasingly regarded as a bridging technology until green hydrogen becomes more economically competitive. Hence, this is an issue that will be of high relevance in the near-term. Acknowledging this reality, even Germany, who has always been rather hesitant towards the usage of CCU/S technologies, has developed a carbon management strategy to regulate the handling of unavoidable or difficult to avoid residual emissions, and allows for the import of blue hydrogen, even though funding still clearly concentrates on green hydrogen. To ensure transparency and the responsible application of CCU/S technologies, creating an open dialogue and robust policy framework between the four countries on this issue can be useful.

In the field of applications, **hydrogen in the electricity sector** promises to be a fruitful subject for deeper cooperation. From a policy perspective, South Australia has recently kick-started the process for the construction of a hydrogen power plant in Whyalla (see chapter 3.1) by selecting the implementing partners, one of which is BOC, a subsidiary of German company Linde. Meanwhile, Germany foresees a key role for H_2-ready power plants in its newly announced power plant safety act. Korea plans to commercialise electricity generation from hydrogen and ammonia by 2027 and has introduced the world's first hydrogen power generation bidding market (see chapter 3.4). Japan has set quotas for co-firing of NH_3 and the Japanese companies Kawasaki and IHI have already developed turbines that can be used with 100% hydrogen (see chapter 3.3). Policy makers from all four countries can therefore benefit from exchanging early experiences. Technically, companies from all countries are working on improving existing technologies and innovating new ones to answer to the goals set by their countries politically. Again, knowledge exchange and B2B networking can foster partnerships and potentially speed-up innovation processes.

The production of steel, prospectively **green iron and steel**, is a key application for hydrogen. Today, Australia is the greatest iron ore producer globally, with its exports continuing to grow (Feitz et al. 2023). Meanwhile, Japan, Korea, and Germany are the 3rd, 5th, and 8th largest producers of steel globally. With more and more steel companies committing to the decarbonisation of their production processes and a growing interest in the production of green steel, German, Japanese, and Korean companies have a keen interest in the greening of Australia's iron ore production. Meanwhile, scope 3 (i.e. downstream emissions) are increasingly accounted for and Europe has adopted the Carbon Border Adjustment Mechanism [CBAM], so that Australian mining businesses develop an interest in both the reduction of their direct and indirect emissions (scope 1, 2, and 3). This mutual interest and dependency create a fruitful ground for a deepening of the cooperation between mining businesses in Australia and steel producers in Germany, Japan, and Korea. Understanding each other's ambitions and needs can contribute to a smoother transition. For instance, greener steel production methods work more efficiently if the ores have less impurities (BCG Global 2022). And mining companies can benefit from technological inputs to decarbonise their processes, including efficiency measures, clean fuels, and sustainable drivetrains (McKinsey & Company 2021).

However, as outlined in chapter 3.1, Feitz et al. (2023) found that iron ore production sites in Australia are also very well suited to the production of green hydrogen themselves. Hence, a co-location of hydrogen production capacities, iron ore mines, iron production, and potentially even steel factories is beneficial and feasible. Australian companies might therefore want to consider moving towards value-added exports in the form of green steel. At the same time, the Australian market might be attractive for German, Japanese, and Korean companies. Importing or producing green iron and potentially even steel might be more economical in the long-term than transporting sustainable iron ore and green hydrogen across the globe. Relevant agreements and collaborations can be set up early now so that companies from each country can benefit from each other's expertise and strong consortia can be formed. Since green steel will remain more expensive than conventional steel for the time being, policy-makers from the four countries could align their incentive structures and start joint funding initiatives. While any shifts in the steel value chain need to be carefully considered, they might offer new, futureproof business models, where being among the first-movers offers great opportunities for the countries and businesses involved (see also Fraunhofer ISI 2024).

5.2 Formats for Cooperation

Germany-APAC Hydrogen Leaders Forum

Given that Australia, Germany, Japan, and Korea are leaders in their own right at specific points of the hydrogen value chain, this study would like to suggest the setting-up of a **Germany-APAC Hydrogen Leaders Forum**. Australia accounts for 30% of all planned hydrogen projects by 2030 today, while Germany, Japan, and Korea are among the handful of countries, who will become major hydrogen importers. Consequently, the four countries will be relevant players in the global hydrogen economy and are in a position to actively shape developments together.

The forum could be held as a one-time, high-level political and economic forum or even help institutionalise regular exchanges among all four countries on topics named in the chapter above, ranging from the transport of hydrogen and bankability to green steel, to the extent that this is desired by the countries. Since the identified cooperation potentials span the entire value chain, one possible and ambitious endeavour for the Leaders Forum may be the **joint establishment of a flagship project** involving companies from all countries, starting with the provision of raw materials and components and moving onto the employment of electrolysis technologies, transport infrastructure, and resulting in a final application of hydrogen. This would offer a powerful demonstration of the feasibility of multilateral cooperation in global hydrogen production and trade as well as the commitment from all four countries to jointly realise projects that are of mutual benefit.

Workshops and Roundtables

As outlined above, the move towards the **production of green steel** is a multi-faceted and complex endeavour. A series of online workshops could be organised to do justice to this complexity and to give each stage of the transformation process sufficient time and attention. Participants from industry could be complemented by government representatives to ensure the exchange of information between stakeholders. An online format is particularly suitable here, although the possibility of individual site visits following certain workshops could be considered. Topics can include, for instance, the decarbonisation of the Australian mining sector, the EU’s CBAM and its implications for the mining and steel sector, technological and economic advances towards the production of green steel in all four countries, etc.

All four countries would like to use hydrogen in the **electricity sector**, albeit to varying extents. In an online workshop, policy-makers and relevant industry actors from all countries could present their status quo and future roadmaps as well as discuss each other’s approaches, the extent to which the usage of hydrogen in the power sector is desirable and feasible, and ask questions.

Japanese and Korean companies are already early investors in projects in Australia but are not always the sole off-taker. Hence, there might be opportunities to explore for German technology providers and off-takers to join in **specific projects**. Potentially in a roundtable format, whether conducted in person or online, facilitated discussions could aim at forming project consortia and, ideally, signing MoUs. These agreements would ensure that Australia benefits from the expertise of German, Japanese, and Korean companies, while concurrently allowing companies from these nations to establish a foothold in the Australian market.

5.3 Conclusion

Overall, this study shows that there is a keen interest and activity in the development of a hydrogen market in Australia, Germany, Japan, and Korea. Low-carbon and particularly green hydrogen will be absolutely critical to the decarbonisation efforts of the four countries. As the global hydrogen market is still in its nascency and time pressure is high, it makes sense to choose a collaborative approach where all countries contribute according to their strengths and comparative advantages. In the case of Australia, Germany, Japan, and Korea, the countries' expertise is distributed across the entire value chain, making multilateral cooperation particularly promising. Australia is strong in the mining sector and positioning itself as a renewable energy powerhouse. Paired with its export credentials and existing infrastructure, this makes Australia a promising hydrogen producer and exporter. While Germany, Japan, and Korea have ambitions to produce some hydrogen themselves, high demand, particularly from their large industrial sectors, will make them net importers of hydrogen and its derivatives. Meanwhile, all three importers offer innovative inputs at different locales of the value chain. Germany is one of the world's leading producers and innovators of components and technologies (especially electrolysis). Korea and Japan are frontrunners in the development of shipping and other transport solutions as well as of fuels cells and the application of hydrogen in power plants.

This study also shows that the four countries have already recognised each other's strengths and have established bilateral economic and political cooperation activities. However, a strong global hydrogen economy must quickly move beyond bilateral collaboration to ensure that countries meet their decarbonisation targets and the Paris temperature goal is reached. To this end, this study proposes quadrilateral cooperation opportunities. At the centre of this is a "Germany-APAC Hydrogen Leaders Forum" to address urgent issues such as the transport, bankability, and safety of hydrogen. This would be an opportunity for the four countries to pool common interests and develop shared positions, thus increasing their leverage on global developments and accelerating the ramp-up of the global hydrogen market.

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