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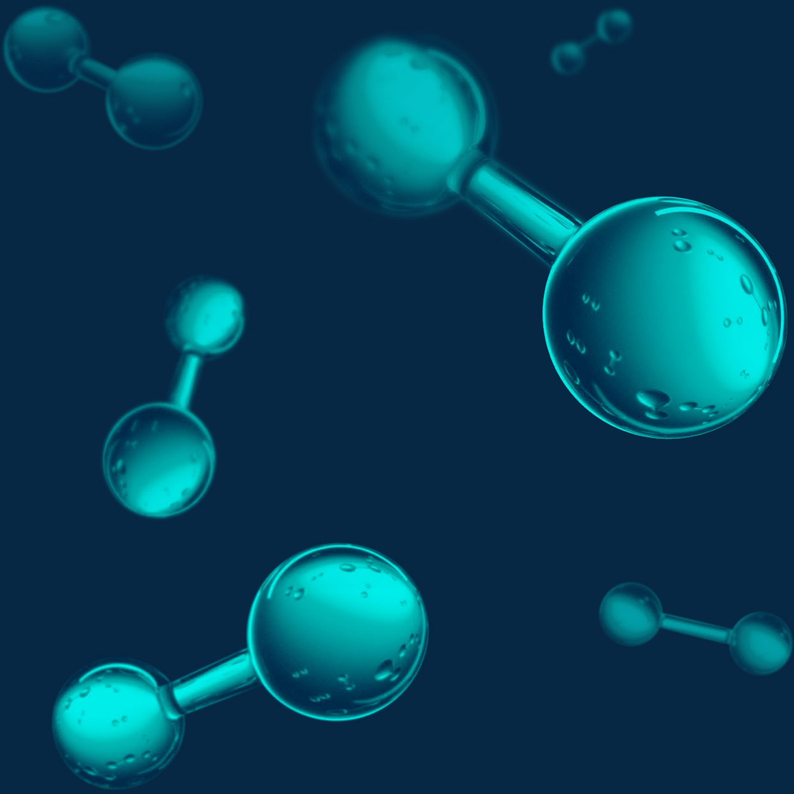
REGIONAL PROGRAMME
AUSTRALIA AND THE PACIFIC

# The Era of Hydrogen Economies

## *Shared Interests by Australia, Germany and Japan*

Edited by Eva U Wagner

VOLUME 6 / 2021



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## Vision and Worldwide Work

The Konrad Adenauer Stiftung (KAS) is a political foundation of Germany, with the vision to promote international dialogue, sustainable development, good governance, capacity building, regional integration and enhance understanding of the key drivers of global developments. It is named after the first Chancellor (Prime Minister) of the Federal Republic of Germany, Konrad Adenauer whose name represents the democratic rebuilding of Germany, the anchoring of German foreign policy in a trans-Atlantic community of values, the vision of European unity, and Germany's orientation towards a social market economy. Currently KAS is present in around 120 countries, with over 100 offices on six continents. With our worldwide networks and long-term partner structures, we aim to contribute to knowledge exchange and policy development in line with our values and goals.

## Our Work in Australia and the Pacific

As current global developments - such as a volatile security environment – underscore the common interests of Europe and Australia, KAS' Regional Programme for Australia and the Pacific seeks to foster durable collaboration through dialogue among parliamentarians, representatives of government departments and leading academic/think tank experts, as well as political analysis and consultancy. For the European Union in general and Germany in particular, dialogues with Australia and New Zealand are of special relevance due to our history of strong bilateral and regional relations. Given our shared values and common interests in shaping the rules-based order, there are manifold opportunities for this partnership. Our programmes are dedicated to collaboration and knowledge-sharing to strengthen our collective resilience and ability to find solutions to the pressing problems of our time.

## The Era of Hydrogen Economies

### Shared Interests by Australia, Germany and Japan

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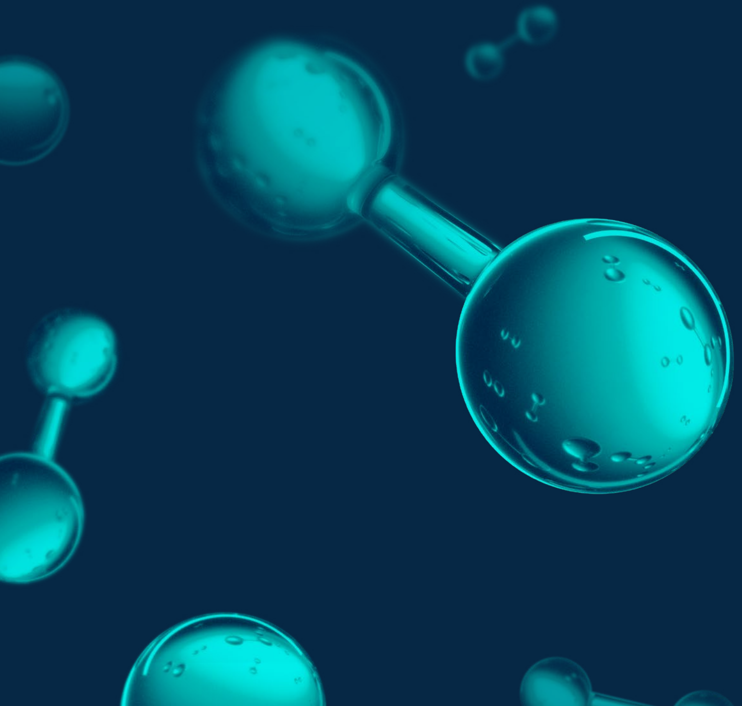


# Foreword

Dear Readers,

I am pleased to say that Konrad Adenauer Stiftung's Regional Programme Australia and the Pacific (KAS Australia) and the European Cluster for Climate, Energy and Resource Security (EUCERS) at the University in Bonn have been able to organise their annual energy dialogue again this year. We started the first dialogue in 2018 between Australia and Germany and have developed it into a trilateral dialogue between Australia, Germany and Japan this year. The 2021 KAS EUCERS Energy Dialogue focusses on the emerging hydrogen economies in these countries and seeks to identify shared interests. More and more countries consider hydrogen as part of the solution to decarbonise their economies. And, whilst Germany and Japan are likely to depend on the import of hydrogen to do so, Australia has the potential to become a leading hydrogen producer and exporter. In the first virtual seminar, impulse statements were followed by a lively discussion and raised core issues of future hydrogen economies, including green versus clean hydrogen, the role of carbon capture and storage technology, and the certification of hydrogen to enable global trade. The discussion clarified some of the challenges on the way to decarbonisation in which hydrogen will play a crucial role. But plenty of challenges remain in all three countries, including the certification of hydrogen, which will be discussed in a second virtual seminar, presumably to be held in November this year. There is a "window of opportunities" for Australia, Japan and Germany – a window KAS Australia would like to keep open and let fresh ideas in.

I would like to take this opportunity to thank cordially the experts in the Trialogue, and authors of this publication, for their valuable contributions to the ongoing debate. We look forward to continuing this platform, be it in cooperation with our local partners to date, namely ANU's Centre for Climate and Energy Policy (ANU CCEP), the University of Tokyo and the German-Australian Hydrogen Alliance or new cooperation partners, and hope that a personal encounter will be possible again next year.

**Dr Peter Hefele**

Director Asia and the Pacific
Berlin, July 2021

INTRODUCTION

# Trilateral Dialogue for Hydrogen – Australia, Germany and Japan

Llewelyn Hughes

## About the Author

***Dr Llewelyn Hughes*** is an Associate Professor at the ANU's Crawford School of Public Policy. In his academic work Llewelyn is interested in how public policies affect, and are affected by, energy markets. He is currently investigating how and why energy policies are changing in response to the problem of climate change, with a particular focus on the Asia-Pacific region. An ongoing project examines how the rise of Global Value Chains affect the ability of governments to promote green growth industries. He received a Ph.D. from the Massachusetts Institute of Technology (MIT), and holds a Masters' degree from the University of Tokyo. Llewelyn is trained as a simultaneous and consecutive interpreter in the Japanese language, and is a citizen of Australia, New Zealand and Great Britain.

**National low carbon energy transitions can become interdependent and affect industrial development pathways. Policies developed in one country or jurisdiction affect policy choices made elsewhere, and support the development of supply chains that cross national borders.**

The cross-border dimensions in establishing new energy industries is illustrated by Australia's liquefied natural gas (LNG) export industry, which was established on the basis of long term supply contracts with customers predominantly in Japan. Another canonical case is the decision by the German Government to subsidise deployment of renewable energy installations at large scale through a feed in tariff. Other countries have transferred the lessons of Germany's policy to their own markets. Germany's success also led to substantial investments within China in solar photovoltaic manufacturing capabilities by companies, and this has been a crucial factor contributing to falling costs of the technology, with global benefits (Meckling and Hughes 2018).

Australia, Germany and Japan are now taking the lead in a nascent international market for hydrogen. National hydrogen strategies released in each country are designed to spur the development of hydrogen and related infrastructure domestically. National strategies also directly reference policy choices being made elsewhere, and envision an important role for cross-border trade and investment through supply chain development.

A key question is what governance arrangements are appropriate to underpin the development of a global market, while ensuring the increased role for hydrogen to support rapid deep decarbonisation. The three country briefs attached herein offer perspectives on the shared interests of the three countries with regards to hydrogen market development.

Australia, Germany and Japan are natural partners in collaborating on developing governance arrangements for the hydrogen sector, notwithstanding competitive elements between them, because of the complementarities in their national hydrogen strategies. Most notably, Germany and Japan identify imports as playing an important role in the development of their hydrogen economies, while Australia identifies itself as a crucial exporter of hydrogen and associated vectors such as ammonia.

The three country briefs highlight a number of common themes that provide a platform for deepening discussion around collaboration in the development of a global market for hydrogen.

### 1. Early Stage Market Development

The briefs document how a feasibility study, and demonstration projects, are underway between Australia, Germany and Japan, with the aim of spurring the development of supply chains between hydrogen importers and exporters. Australia and Germany have launched a joint feasibility study to assess the costs and scalability of green hydrogen trade between those countries. Japan and

Australia have a number of demonstration projects under development.

These developments help set the stage for testing different technologies and reducing production costs. Transport technologies are a key theme in the briefs. Japan, for example, notably identifies not only of ammonia, but also liquefied hydrogen and methylcyclohexane (MCH), as potential enablers of trade in hydrogen.

Given this, it is useful to enable information about the performance of different production technologies, transport options and associated costs as well as greenhouse gas emissions outcomes. Whilst some details are likely to be commercial in confidence, governments, and market participants, share an interest in enabling the scaling up of low emissions hydrogen so that it can compete with fossil fuels.

## 2. Hydrogen and Deep Decarbonisation

An important question highlighted across the briefs is what role hydrogen is likely to play in deep decarbonisation. Analysis such as that by the International Energy Agency (2021) suggest a potentially very large role especially in industry and transport. Direct electrification has been found to be a solution in a wide range of diverse industrial processes considered difficult to decarbonise (Madeddu *et al*, 2020). The scale of the role for hydrogen will thus depend on its cost competitiveness. In addition, the country briefs commonly identify the importance of ensuring that a developing hydrogen market supports decarbonisation.

The country briefs are unified on the importance of ensuring that the emissions associated with the provision of hydrogen is properly quantified and accounted for through an international certification framework. The briefs suggest there is substantial scope to engage on the question of certification collaboratively across the three countries, as well as the appropriate balance between ensuring hydrogen supports rapid decarbonisation, and the need to create an industry at scale.

In addition, the Japan country brief highlights that there remain substantial technical questions to be solved traversing hydrogen production, transportation, and end-use technologies. In addition, as is pointed out, there are fundamental questions about whether hydrogen and associated vectors, produced using fossil fuels coupled with carbon capture and sequestration is sufficiently low emissions, low cost and scalable to see it play a significant role in scaling up the industry. There is thus likely to be substantial scope for international collaboration not only in technology-related research and development, but also in techno-economic pathways that examine the feasibility of hydrogen as a core component in rapid decarbonisation.

Australia, Germany, and Japan are natural partners in leading the development of a market for hydrogen that supports rapid and deep decarbonisation globally. The issues identified through these country briefs offer a platform for beginning discussions about how to spur further collaboration.

ANALYSIS 1

# Australia

Llewelyn Hughes, Frank Jotzo, Thomas Longden

### About the Authors

***Dr Llewelyn Hughes*** is an Associate Professor at the ANU's Crawford School of Public Policy. In his academic work Llewelyn is interested in how public policies affect, and are affected by, energy markets. He is currently investigating how and why energy policies are changing in response to the problem of climate change, with a particular focus on the Asia-Pacific region. An ongoing project examines how the rise of Global Value Chains affect the ability of governments to promote green growth industries.  He received a Ph.D. from the Massachusetts Institute of Technology (MIT), and holds a Masters' degree from the University of Tokyo. Llewelyn is trained as a simultaneous and consecutive interpreter in the Japanese language, and is a citizen of Australia, New Zealand and Great Britain.

***Prof Frank Jotzo*** is the Head of Energy, Institute for Climate, Energy & Disaster Solutions at the Australian National University. His research includes policy instruments for emissions reductions, international climate change policy, decarbonisation strategies, and economic aspects of the energy transition – including the prospect of international trade in clean fuels. Frank Jotzo is a lead author with the Intergovernmental Panel on Climate Change and is joint editor-in-chief of the academic journal Climate Policy. He has advised national and state governments. He tweets @frankjotzo.

***Dr Thomas Longden*** is a Fellow working on the ANU Grand Challenge – Zero-Carbon Energy for the Asia-Pacific. He is based at the Crawford School of Public Policy. Before joining ANU in 2019, Dr Longden worked at the University of Technology Sydney, Macquarie University, and Fondazione Eni Enrico Mattei (FEEM). His work on energy, applied econometrics, and technological change has been published in leading international journals (including Climatic Change, Energy, Technological Forecasting and Social Change, Energy Policy and Health Economics).

National strategies released by governments globally, including in Australia, Japan and Germany as well as the European Union, offer roadmaps for the development and deployment of a hydrogen industry at scale. Roadmaps are useful because they can help to mobilise resources, and help create certainty about governments' commitment to particular technology choices. They can also help create a market niche within which hydrogen technologies are able to develop even when they are uncompetitive relative to more emissions intensive technologies (McDowall, 2012).

The focus of many national hydrogen strategies is on domestic uses of hydrogen (in the transport, industrial or power sectors). In contrast, Australia's National Hydrogen Strategy is explicitly international in scope. It specifically mentions the development of Japan's National Hydrogen Strategy, and identifies hydrogen exports as an important economic opportunity. A key policy approach to realise Australia's export potential is the creation of hydrogen hubs and to use policy to help early stage development. Large-scale exports to trading partners in the Asia-Pacific region is identified as an important indicator of success.

Companies are also laying the ground work for the development of supply chains between Australia, Germany and Japan. Japan's National Hydrogen Strategy envisages the development of a supply chain for hydrogen and associated vectors within this decade. A number of demonstration projects are already under development and, under the leadership of National Energy Resources Australia (NERA), a series of hydrogen technology clusters will support hydrogen supply chain development under the Hydrogen Technology Cluster Australia (H2TCA) initiative. In the case of Germany and Australia, the German Ministry for Academy and the Australian Department of Foreign Affairs and Trade have combined to commission a feasibility study ('HySupply'), looking at the costs and technical challenges associated with establishing a supply chain between the two countries.

**2020 Measures of success for being a major global player**

Source: Commonwealth of Australia (2019)

| | 2030 Measures of Success |
|---|---|
| Hydrogen Exports | We are among the top three exporters of hydrogen to Asian markets |
| Investor confidence | Australia is seen as a destination of choice for international investors in hydrogen.<br>We have major offtake or supply chain agreements in place with importing countries |
| Hydrogen capability | We have demonstrated our hydrogen capability in all links of the supply chain |

**Australian Hydrogen Technology Cluster Network**

Source: National Energy Resources Australia

## Hydrogen Technology Cluster Australia Technology Hubs

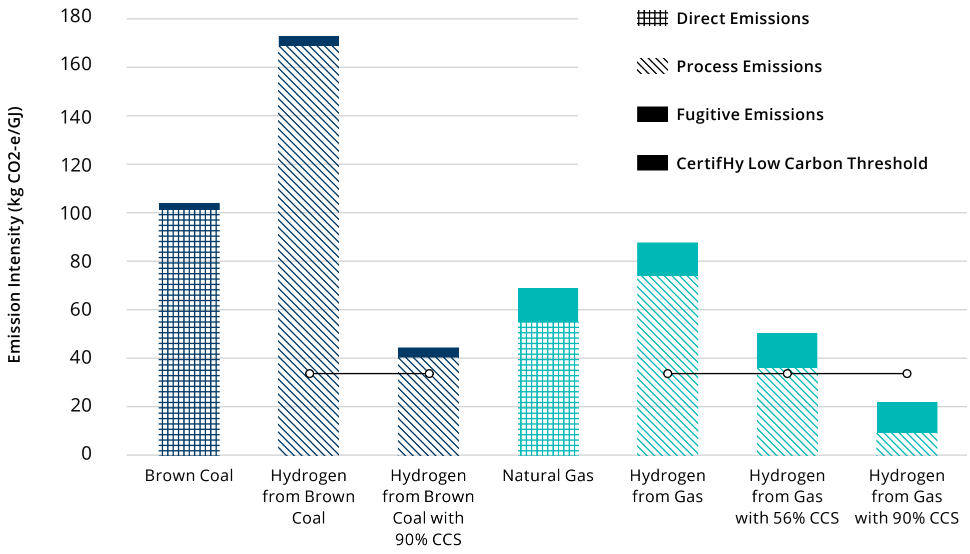
These are welcome developments. With the capacity for producing huge amounts of low-cost renewable energy, Australia is well-placed to become a powerhouse in supplying low carbon hydrogen globally. And the three countries have a shared interest in ensuring that low emissions hydrogen industries develop at the scale and pace required to help reach net zero emissions globally by the middle of the century. This will be crucial to improvements in the capital costs of electrolysers.

Shared Challenges in the Low Carbon Hydrogen Transition

The interdependence of policy development within the three countries highlights some important shared challenges around embedded emissions, and industry scale up.

## Shared Challenge 1: Low Carbon

The hydrogen strategies released by Australia, Germany and Japan envision a long-term goal of deploying hydrogen and associated vectors at scale in support of decarbonisation, and in support of the widely adopted goal of reaching net zero emissions by mid-century. The emission intensity associated with the production of different types of hydrogen is recognised as varying significantly (Longden *et al*, 2021). The figure below presents a comparison of the emission intensity of hydrogen produced from coal and gas with and without carbon capture-and-storage, with the direct emissions from the combustion of the fossil fuels for an equivalent amount of energy. The salient fact is that hydrogen from fossil fuels is generally associated with significant amounts of residual greenhouse gas emissions, even at high rates of carbon capture.



Source: Longden *et al* 2021

Only hydrogen produced from gas with a high capture rate is below the European CertifHy Guarantee of Origin scheme low carbon threshold. At present emission intensive technologies dominate the production of hydrogen globally, centred on steam methane reforming (SMR).

Emission intensity of hydrogen production processes and different fossil fuels.

There are different approaches in national strategies towards the emissions from hydrogen production. Some indicate that in the long run it is crucial that end use demand for hydrogen is supplied using low carbon hydrogen. Others, however, imply that it may be beneficial to enable scale up of hydrogen use on the demand side by allowing for cheaper but more emission intensive technologies, such as SMR. In an alternative view it makes more sense to invest in zero-carbon hydrogen via electrolysis powered by renewable energy from the start as this will minimise emissions and help to drive down costs of electrolysis.

Governing these different approaches is crucial to a successful deployment of low carbon hydrogen. In an analysis of a supply chain between Australia and Japan using hydrogen, for example, we found that there is no benefit on a supply chain basis associated with Australia exporting ammonia to Japan if this is done using business as usual SMR technology to produce hydrogen, matched with the Haber-Bosch process to produce ammonia (Stocks *et al*, 2020).

Thus, it is important to govern the emissions embedded in hydrogen and ammonia. One approach is to enable consumers to differentiate between the level of emissions embedded in different hydrogen products. This does not solve the problem of renewable ammonia being costlier, but it does allow consumers to make informed purchasing choices.

Schemes under development in each of these countries recognise the utility of enabling end users to choose between hydrogen with different levels of embedded emissions. The approaches that are being developed differ, which raises the question of mutual recognition or the harmonisation of hydrogen certification.

The need for harmonisation is a common issue in the area of standards and certification (White et.al. 2021). Energy efficiency standards are typically domestic in nature, for example, and not readily recognised internationally. Given that the expectation is that there will be substantial trade and cross-border investment in hydrogen, and the leading roles Australia, Germany and Japan play in the developing global hydrogen economy, there is an important opportunity to coordinate standards and certification in order to facilitate trade between different jurisdictions as seamlessly as possible.

## Shared Challenge 2: Scaling Up

A crucial driver of the declines in unit costs that we have seen, and of low carbon technologies such as solar photovoltaics, wind power, and batteries, is the deployment of these technologies at scale. Recognising this, Australia, Germany (and the European Commission) and Japan have released long-term targets and timetables designed to provide greater certainty to businesses domestically so that it makes sense for them to invest in hydrogen production capacity. In addition, Australia and Germany are undertaking a feasibility study to assess the costs and technology constraints that may exist in developing a supply chain between the two countries, and Australia and Japan have a number of demonstration projects under development, which can be used to assess costs and technology constraints prior to commercialisation.

Each of these efforts are testing techno-economic pathways to scaling up hydrogen and associated vectors. They will produce important knowledge about technical feasibility, and environmental and economic costs. Australia, Germany, and Japan have an interest in ensuring the lessons of this work is shared. Beyond this, the three countries also have an interest in sharing information about technical, economic, and environmental progress and challenges in potential end-use sectors identified in their national strategies.

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ANALYSIS 2

# Germany

Friedbert Pflueger

## About the Author

**Professor Dr Friedbert Pflueger** is the Director of the European Cluster of Climate, Energy and Resource Security (EUCERS) at the Center for Advanced Security, Strategic and Intergration Studies (CASSIS), University of Bonn. He is Managing Partner of Bingmann Pflueger International GmbH, Berlin.

Prof Pflueger is also (non-resident) senior fellow at the Atlantic Council's Global Energy Centre, Washington D.C. and Senior Advisor to the World Energy Council's Global Gas Centre, Geneva. He sits on the Advisory Board of Zukunft Gas and the Institute for Climate Protection, Energy and Mobility (IKEM). He is member of the newly established German-Russian Business Council.

Prof Pflueger has studied Political Science, State Law and Business at the Universities of Goettingen, Bonn and Harvard. For eight years he has served as speechwriter and press secretary to former German President Richard von Weizsaecker. Prof Pflueger was a Member of the German Bundestag from 1990-2006, Chairman of the Bundestag's Committee on the Affairs of the European Union (1998-2004) and Deputy Minister of Defence in the first Merkel Government.

## German opportunities and goals

Germany is heavily dependent on energy imports. And the Government has set three ambitious energy transition goals of greenhouse gas reductions, more renewable energies and higher energy efficiency. Hydrogen is widely seen as part of the solution, which has the necessary characteristics (incl being a storable energy carrier) to help meet the German climate target of reducing CO2 emissions by 95 % in 2050. Hence, the German Government set and published its National Hydrogen Strategy in June 2020. The Strategy outlines the role of hydrogen both as a low carbon energy carrier and as industrial feedstock. The German Strategy not only envisages hydrogen to decarbonise the industrial processes but also **as a means to accelerate the domestic supplier industry** by financially supporting research, innovation and pilot projects. Major German technology companies such as Siemens and Thyssenkrupp are global market leaders in electrolysis technology already today.

But to be able to meet the additional demand of hydrogen required by 2030 and by 2050 in order to decarbonise the industrial, heating and energy sectors, Germany needs to build up large-scale hydrogen production, use and application. The Strategy sees a liquid European hydrogen market as a requisite to be able to cater to the foreseeable hydrogen supply gap in Germany. However, taking industrial application as well as the aviation, heavy transport and heating sectors into account, hydrogen demand in the EU is expected to rise to over 40 million tons by 2050. Domestic production is expected to reach merely 25 million tons a year. **Germany will remain a major energy importer as it is today and must build up new import strategies since it cannot rely on the EU to cover its supply.**

Regarding the different production pathways (colours) of hydrogen, the German Strategy focusses on carbon-free (green) hydrogen produced by electrolysis based on renewable energy as the only sustainable production pathway for the long term. However, blue and turquoise hydrogen will also be tradable in Germany and are so-called "technologies to bridge the gap". These production ways are carbon neutral and can even be carbon positive as they use CCUS technologies to store the released CO2 or capture it in the methane pyrolysis production. To effectively and efficiently trade carbon neutral hydrogen of all colours internationally, the need for an **internationally recognised standardisation and certification system is indispensable**.

The Government has already begun to expand partnerships with existing energy suppliers such as Australia by including hydrogen and launched strategic technical partnerships with worldwide hydrogen pioneers such as Japan. Between Germany and Japan opportunities overlap to some extent, even though strategies may differ. Australia as a potential large producer and exporter can export to both countries. And while Germany will need to import hydrogen in the future, it is also suited as a strategic technology, standardisation and certification partner within the energy trialogue with Australia and Japan.

### Shared interest 1: scale

Born out of the existing German-Australian energy cooperation and to support the hydrogen market rollout, the two governments launched the joint feasibility study “HySupply” to evaluate the production of green hydrogen in Australia and its transport by ship to Germany. Funded by the German Ministry of Research and coordinated by the German Academy of Science and Engineering (Acatech) and the Federation of German Industries, its aim is to map out business models that favour a long-term hydrogen partnership and to scale up a sustainable transport system for both countries. Particularly, companies in the steel and chemical sectors will soon need climate-neutral hydrogen in large quantities in order to serve their share of the climate targets. Thyssenkrupp and BASF are both on board the German-Australian project. Siemens Energy is also participating in “HySupply” and already supplying electrolysers to Australia. Thyssenkrupp is not only a potential large-scale customer for green hydrogen, but also a supplier of electrolysers. The company is constructing the production facilities for the production of green ammonia in Port Lincoln in Southern Australia.

The predicted growth of the Australian hydrogen production could open up extensive market opportunities for German companies in the field of renewable energy generation, electrolysis, transport and storage of hydrogen, as well as for products and services related to hydrogen applications. Besides the abovementioned companies, others such as Enercon, WestWind Energy, NewEn, Pro Ventum International, ibvogt, BayWa, Wirsol, and innogy are supporting Australia’s expansion of wind and solar capacities.

In order to help strengthen the export character, **joint lighthouse projects of sufficient size should be launched so that hydrogen transport and import technologies and learnings can be tested and costs of production can be reduced and then scaled**. Both Germany and Japan - even though they have less favourable conditions for productions - are aiming at large shares of domestic green hydrogen production. Projects developing new technologies for hydrogen production, for use and storage, especially innovative solution approaches for transport (*eg* LOHC technologies, ammonia) over long distances should be made eligible for additional state funding.

### Shared interest 2: technology cooperation & investment

Importing energy sources is no new concept for Germany. Already today, 70% of German primary energy consumption is imported. Countries with many more hours of sunlight and strong winds could be able to supply the needed quantities of green hydrogen more efficiently. For that reason, existing bilateral energy partnerships include joint studies and pilot projects. For instance, expanding the partnership with Russia with a view to Russia’s potential to transport hydrogen via the Nord Stream 2 pipeline. Or with Norway with its developing industry of CCUS technologies. New partnerships, such as the ones with Morocco and Ukraine, are in the making. For supply in the long term and technology cooperation, not only the MENA region, but also Australia and Japan are viable. Decisive criteria for hydrogen trade are production and transport costs, suitable political and economic conditions, the availability of skilled workers, political interest in the development of hydrogen value chains and investment security. In Australia’s case the often used argument that the locally produced hydrogen could rather be used domestically is irrelevant due to the sheer amount the country will be producing.

But for sustainable and competitive hydrogen trade to make sense between Australia and Germany (or the EU), **transport technologies must improve**. According to the Energy Economics Institute of the University of Cologne, the highest costs are linked to transport by ship compared to green hydrogen that is locally produced or transported through converted natural gas pipelines. The high energy input required for liquefaction before transport must be lowered. At the present time and in the mid-term, it is more plausible that Australian hydrogen will be exported to Asia and the Pacific region, while European demand is met by own production and by imports from closer regions such as North Africa or the Middle East. However, it is in Germany’s interest for Australia to develop its production of hydrogen sooner rather than later. On the one hand, this can boost the technological learning curve and economies of scale worldwide. On the other hand, it can meet expected demand from Asia and the Pacific, which will tend to depress market prices for hydrogen from the Middle East which, in turn, would serve Europe.

The German energy company RWE is pushing forward the development of German-Australian hydrogen trade. The aim of the company’s trading subsidiary RWE Supply & Trading is to import green hydrogen produced in Australia to Europe in the form of ammonia or synthetic methane. RWE’s entry into hydrogen trading represents an **extension of its existing trading relationships** (including LNG trading) with Australia.

Of particular interest to German companies is the fact that **Japan often follows different paths than Europe**. For example, the country does not only focus on fuel cell passenger cars, while Europe prefers battery-powered electric cars. Japan also wants to use hydrogen and ammonia in power generation as well as in the heating market. In addition, unlike the EU, Japan is focussing not merely on green hydrogen but on blue hydrogen, which is split off from fossil fuels, with the CO2 being stored. Technological cooperation needs to be expanded in the areas of hydrogen application in the heating and transport sectors. Hydrogen is also an important topic in the German-Japanese energy partnership, which was initiated by the ministries of economics of both countries. A joint study on the role of hydrogen in both countries was the first result. Such an energy partnership concentrated on hydrogen is an excellent opportunity for countries to exchange information on research and development. While Europe has only recently started to take hydrogen seriously, Japanese corporations have been investing massively for years to create a global market and exportable technology for the gas by 2030.

### Shared interest 3: low carbon transition

Another main shared interest is the definition of standards and certification procedures. Australia has already made progress in developing technical standards. Japan is discussing a certification scheme to test hydrogen sources from ammonia to water in one of Japan’s regions.

Technical standards are an important prerequisite for the large-scale application of green hydrogen in all three countries. They ensure efficient global trade in hydrogen by reaching international harmonisation, *eg* for pressure levels, purities and pipeline transport. But they must be accompanied by sustainability standards.

Sustainability standards ensure that emission reductions in Germany through the import and use of hydrogen do not lead to increased emissions in the countries of origin, and that the environmental impacts arising from the hydrogen value chain (production, conversion, storage, transport, distribution and use) remain within acceptable limits. The most common criteria applied in different certification schemes relate to the

1. reduction of life-cycle greenhouse gases,
2. dilemma in the case of green hydrogen production, where conflicts of use arise about when to use the renewable energy as a power source and when to convert it to hydrogen - especially in countries such as Germany and Japan where renewable power generation is limited - and
3. water consumption, land requirements, and possibly socioeconomic and developmental impacts.

When defining concrete requirements and thresholds for certification, the appropriate balance is key. **Only hydrogen with clear climate advantages over conventional energy carriers should be eligible for certification. At the same time, the aim is to avoid barriers to hydrogen market development caused by overly strict requirements.**

In terms of sustainability standards, it would make sense to strive for a common definition of carbon-free and low carbon hydrogen. For all three countries these standards will likely play an important role in establishing international markets. In defining standards for carbon-free and low carbon hydrogen, issues such as guarantees of origin and environmental and social standards for renewable energy generation, water desalination and electrolysis will play a role. Especially with Australia, as probably one of the largest hydrogen exporting countries of the future, a common definition of low carbon hydrogen would be very relevant. Issues such as the limits or carbon intensity of hydrogen, the definition of the limits of life cycle analysis, the consideration of methane leaks or the eligibility of nuclear based electrolysers play a role.

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ANALYSIS 3

# Japan

**Masakazu Sugiyama**

**Masakazu Sugiyama** is a Professor at the Research Center for Advanced Science and Technology (RCAST), The University of Tokyo. He received the B.E., M.S., and Ph.D. degrees in Chemical Systems Engineering, all from the University of Tokyo, Japan, in 1995, 1997, and 2000, respectively. In 2000, he became a Research Associate at the Department of Chemical System Engineering, the University of Tokyo. In 2002, he joined the Department of Electronic Engineering as a Lecturer. He became an Associate Professor in 2005. In 2016, he was promoted to a full professor and then moved to RCAST in 2017.

His major research topics are high-efficiency photovoltaic (PV) devices using the nano-epitaxial structures of III-V compound semiconductors. He is a recognised leader in the sustainable conversion of solar energy to next-generation fuels through use of leading-edge photovoltaics and compound semiconductors. More recently, he has demonstrated the highest level of infield solar conversion efficiency using electrolysis to produce hydrogen from water. He organises a Social Cooperation Research Unit “A Global Network of Renewable Fuels” and serves as a hydrogen envoy of Queensland state government, Australia. In 2020, he was appointed as a programme manager of the Japanese MOOMSHOT programme, aiming to realise $CO_2$ capture and conversion to chemical feedstocks driven by renewable electricity. He has authored and coauthored 290 refereed journal publications and 505 international conference papers.

## Japanese opportunities and goals

Last year, the Japanese Government declared the goal of carbon neutrality by 2050. For the realisation of this target, the Ministry of Economy, Trade and Industry (METI) issued a "Green Growth Strategy Through Achieving Carbon Neutrality in 2050" last December in collaboration with related ministries and agencies. This Strategy is an industrial policy to achieve the challenging goal of carbon neutrality by 2050 and aims toward a positive cycle of both economic growth and environmental protection. In the Strategy, decarbonisation of the power sector is regarded as the major premise. Approximately 40% of $CO_2$ emissions in Japan derive from the generation of electricity. Boosting the installed capacity of renewable electricity sources such as solar and wind is regarded to be the primary course of action for the decarbonisation of electricity. Hydrogen is positioned as decarbonised fuel for adjustable electricity generation and the source of high-temperature heat for industrial applications, as well as fuel for transportation. The Strategy emphasizes the need for the creation of new industries for boosting decarbonisation. The following industries are expected to grow between 2030 and 2050: offshore wind power generation, fuel ammonia (burners for power generation) and hydrogen (turbines for power generation, steel making using hydrogen, carrier vessel, mobility power by either fuel cells or hydrogen engine, and water electrolysers).

In order to boost the transition to decarbonised energy sources by fostering new industry, the Japanese Government created a fund in an unprecedented scale of two trillion yen, and continues to support enterprises that attempt ambitious innovation for the next ten years. Existing research and development funded by the Government will be expanded, such as the benchmark of hydrogen for fuel in thermal power plants, hydrogen carrier technology, and hydrogen production from renewable electricity using water electrolysers.

### Shared interest 1: Scenario for carbon neutrality with renewables and hydrogen

Towards the carbon neutrality target, the electrical power demand in 2050 is expected to increase by 30-50% compared with the current demand level by facilitating electrification in the industrial, transportation and household sectors, resulting in an annual power generation of 1300~1500 TWh. 50 ~ 60% of this amount (650 ~ 900 TWh) is expected to be generated by renewables. In 2020, approximately 200 TWh was generated by renewables, however, drastic expansion of renewable power generation capacity is mandatory to meet the goal in 2050. Limitation of land area available for solar and wind power generation imposes a severe impediment to such massive penetration of renewables. Offshore wind power generation is therefore regarded as a key technology. The Japanese Government will continue to pursue a capacity of 10 GW by 2030 and 30-45GW, including floating offshore wind, by 2040. Another severe constraint for the penetration of renewable power generation is the intermittency of the stability of the power grid. Japan's electricity grid is not connected to those of its neighbouring countries, and adjustable power generation sources are essential to keep the balance between the demand and supply of electricity. Decarbonisation of thermal power plants, which is almost the only adjustable power generation source with substantial power generation capacity, is therefore the key for the supply of $CO_2$-free electricity.

In the Green Growth Strategy, the major route for decarbonising thermal power generation is carbon capture and storage (CCS), which will be applied to 30 ~ 40% of the total power generation. Hydrogen (or ammonia) fuelling for thermal power generation is expected to provide 10% of the total power generation, which needs 6.6 ~ 7.6 million tons of hydrogen. However, the capacity of CCS, or annual $CO_2$ disposal by CCS, is subject of debate in Japan. Japan's 2017 Basic Hydrogen Strategy expected 10 million tons of hydrogen used in 2050, corresponding to a power generation of approximately 200 TWh using hydrogen as fuel. The technology for power generation fuelled by hydrogen and ammonia is still in the stage of development and demonstration. Their use will depend on the state of establishment of technology and industry, and a fraction in power generation much greater than 10% will be mandatory for successful decarbonisation of electricity in Japan.

### Shared interest 2: Scaling up the production of $CO_2$-free hydrogen

Other than the use in power generation, transportation with commercial vehicles such as long-haul trucks, the electrification of which is difficult, is one of the areas in transportation field where hydrogen utilisation is expected. A potential domestic hydrogen demand of ca 6 million tons per year is anticipated. In addition, there is great demand in the steel industry. If coal, currently used as reduction agent of iron ore, would be replaced by hydrogen as a reducing reagent in the steelmaking sector, a large amount of $CO_2$-free hydrogen would be needed. The potential domestic hydrogen demand is ca 7 million tons per year, with 100% hydrogen reduction steelmaking still to be technically established.

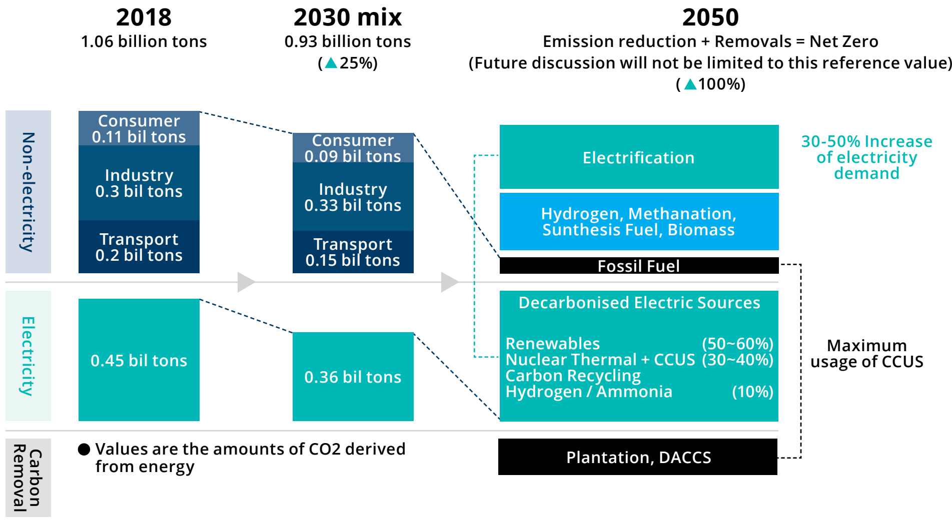

Figure 1 A scenario for the carbon neutrality goal in 2050
(cited from Japan's Green Growth Strategy Through Achieving Carbon Neutrality in 2050, December 2020, METI, Japan)

The demand for hydrogen in the above-mentioned sectors, thermal power generation, transportation and material manufacturing, is expected to amount to approximately 20 million tons/year by 2050, with a cost of 20 yen/Nm$^3$ (approximately 0.20 USD/Nm$^3$). If this amount of hydrogen is produced solely by water electrolysis, 1000 TWh of electricity is necessary, which approximately corresponds to the annual total power generation in Japan. This value exceeds the amount of total renewable power generation in Japan in 2050 (650 ~ 900 TWh) predicted by the Green Growth Strategy. To illustrate geographical constraints for hydrogen production by 20 million tons/year using renewable energy, let us simply assume 1000 TWh of power generation by solar panels. Considering solar irradiance in Japan, a solar generation capacity of 900 GW is necessary which is larger than the cumulative installation of solar panels in an entire world. The necessary land area is approximately 100 sq km, which is hardly available in Japan. This is in accordance with the preference of offshore wind power generation in Japan's Green Growth Strategy, which puts less emphasis on the on-land renewable power generation in Japan. On the other hand, 1000 TWh is available and affordable in Australia with 85 sq km. The shortage in flat land area for renewable power generation in Japan requires the import of hydrogen from overseas countries. One alternative is to produce hydrogen powered by offshore wind in the sea area around Japan. However, this option needs consideration of hydrogen costs compared with the case of importing hydrogen from abroad.

The condition of isolated islands prevents Japan from importing hydrogen from overseas countries through pipelines. Therefore, the Government has been supporting technology development and verification of marine transportation technology and infrastructure using liquefied hydrogen and MCH (Methylcyclohexane). As a result, Japan has the world-leading technology for hydrogen carriers, highlighted by the world's first liquefied hydrogen carrier ship.

Japan's Hydrogen Strategy has put lower priority on the source of hydrogen than the expansion of hydrogen utilisation and carrier technologies. So far, greater emphasis has been on the volume and cost of hydrogen, irrespectively of the origin of hydrogen. Needless to mention that there is concern about the impact of hydrogen on the reduction of total $CO_2$ emission, and both blue hydrogen and blue ammonia from fossil resources coupled with CCS have been expected to serve as the initial tool to facilitate transition from infrastructures to the ones using $CO_2$-free fuel. This is based on the belief that green hydrogen is far more expensive and the lead-time for its commercialisation is long. However, there is a fundamental concern about (1) the supply capacity of blue hydrogen: how much major CCS sites can absorb $CO_2$ annually, and (2) the $CO_2$ footprint associated with CCS. Unless there is a clear answer to these concerns, green hydrogen will be the only choice for the massive supply of hydrogen to meet the demand in Japan and the rest of the world. This fundamental discussion is still at a very early stage.

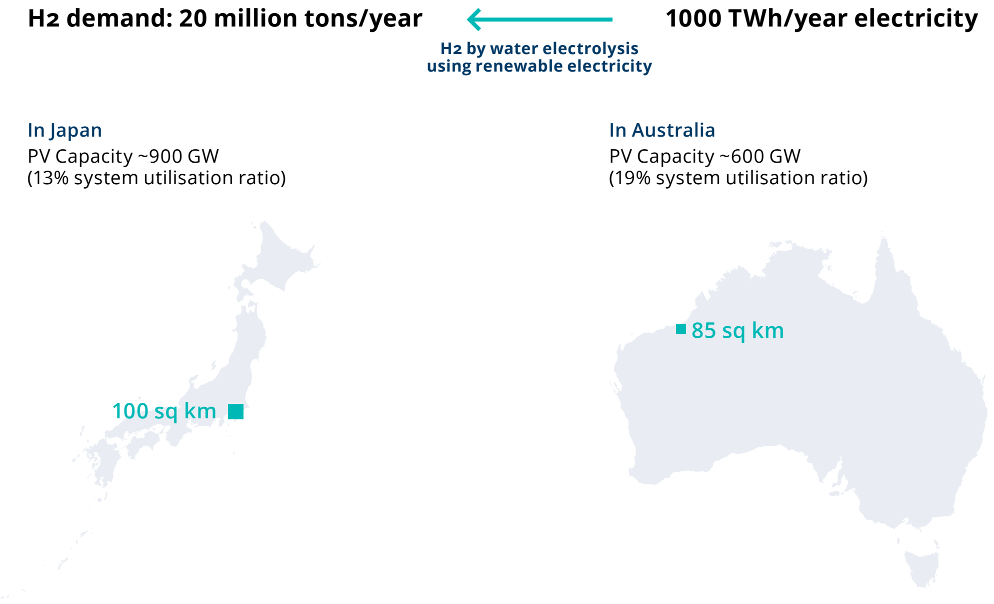

**Figure 2** The land area which is necessary for renewable hydrogen production of 20 million tons/year using solar panels, the cases in Japan and in Australia.

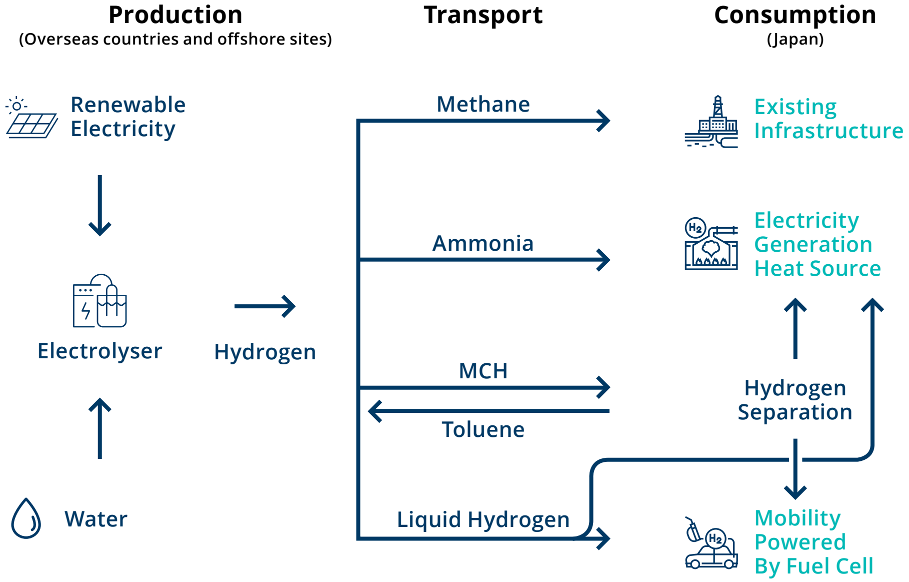

**Figure 3** Future supply chain of green hydrogen to Japan.

### Shared interest 3: Further technological development for $CO_2$-free fuel (ammonia and hydrogen)

#### Ammonia fuelling for thermal power generation

$CO_2$ emission is reduced by 20% by co-firing of 20% ammonia (calorie-based) at one thermal power plant, therefore, if 20% co-firing is implemented at all coal-fired thermal power plants in Japanese major power companies, $CO_2$ emissions by domestic electric power sector will be reduced by about 10%. Annual global production of ammonia is about 200 million tons worldwide, most of which is used as fertiliser and locally consumed. In the future, if 20% co-firing with ammonia is implemented for thermal power, ca 0.5 million tons of ammonia will be required annually for one plant (1 GW). To implement 20% co-firing at every thermal power plant in Japan, approximately 20 million tons of ammonia will be required, which is comparable to the current world trade volume. Formation of fuel ammonia supply chains separate from the one for conventional ammonia becomes an issue. It is of crucial importance for the decarbonisation of electricity that such ammonia for fuelling thermal power generation is $CO_2$ free, because the existing ammonia production uses natural gas as a source of hydrogen and is never $CO_2$ free. Therefore, this issue is related the production of hydrogen.

#### Hydrogen carriers: liquefaction and Methylcyclohexane (MCH)

Although liquefied hydrogen, Methylcyclohexane (MCH) and ammonia have been intensively developed by public funding, gas carrier's transportation and receiving systems have not yet been widely established. Furthermore, importing low cost next-generation energy in large quantities would require securing resources overseas and developing ports of shipment, in addition to developing domestic infrastructure. Furthermore, there is a concern for inconsistency of regulations between countries, which needs to be overcome through international collaboration.

#### Hydrogen production by water electrolysis with renewable power

Owing to cost reduction of renewable energy and water electrolysers, it is anticipated that, in 2050, the costs of hydrogen from renewable sources will be lower than those from fossil fuel coupled with CCS. To meet the intermittency of renewable electricity, adjustability in the power input to electrolysers is of primary importance. Furthermore, the capacity of renewable power generation for hydrogen production will far exceed the existing grid capacity for the electricity supply to local communities when a large amount of hydrogen production, in the order of 10 million tons annually, is implemented, especially in areas with very small populations and abundant land area. Local electricity grids with gigawatt-scale capacity will be necessary which simply connect intermittent power sources with electrolysers. In such a situation, an issue will be how to keep the baseload electricity required to maintain electrolysers. In order to reduce hydrogen costs, the use of batteries needs to be minimised. Another fundamental concern is the use of rare metals in conventional electrolysers. The use of platinum and iridium needs to be minimised while accepting water in nearly neutral pH conditions. There is a huge demand for technological development which encourages international collaboration for research and development.

#### Certification of CO2 footprint on hydrogen

Although Japan has given green hydrogen less priority than the European countries and Australia, there emerges an increasing concern about the $CO_2$ footprint of hydrogen. Quantification and certification of this value is an issue which needs an international framework. Pioneers of hydrogen in Japan are always watching the relevant momentum in the world and are eager to participate in the discussion.

### References

**Japan's** Green Growth Strategy Through Achieving Carbon Neutrality in 2050, December 2020, METI, Japan (www.meti.go.jp/english/press/2020/pdf/1225_001b.pdf)

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**Publisher**

Konrad Adenauer Stiftung (Australia) Limited
Regional Programme Australia and the Pacific

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Tel: +61 2 6154 9322

www.kas.de/australia

**ISSN**

Periscope – Occasional Analysis Paper Series #6 (July 2021).
ISSN 2652-6484 (Online)

**Design, Layout and Typeset**

Swell Design Group

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Australia, Germany and Japan are now taking the lead in a nascent international market for hydrogen. National hydrogen strategies released in each country are designed to spur the development of hydrogen and related infrastructure domestically. National strategies also directly reference policy choices being made elsewhere, and envision an important role for cross-border trade and investment through supply chain development.

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