The Hydrogen Revolution in APAC

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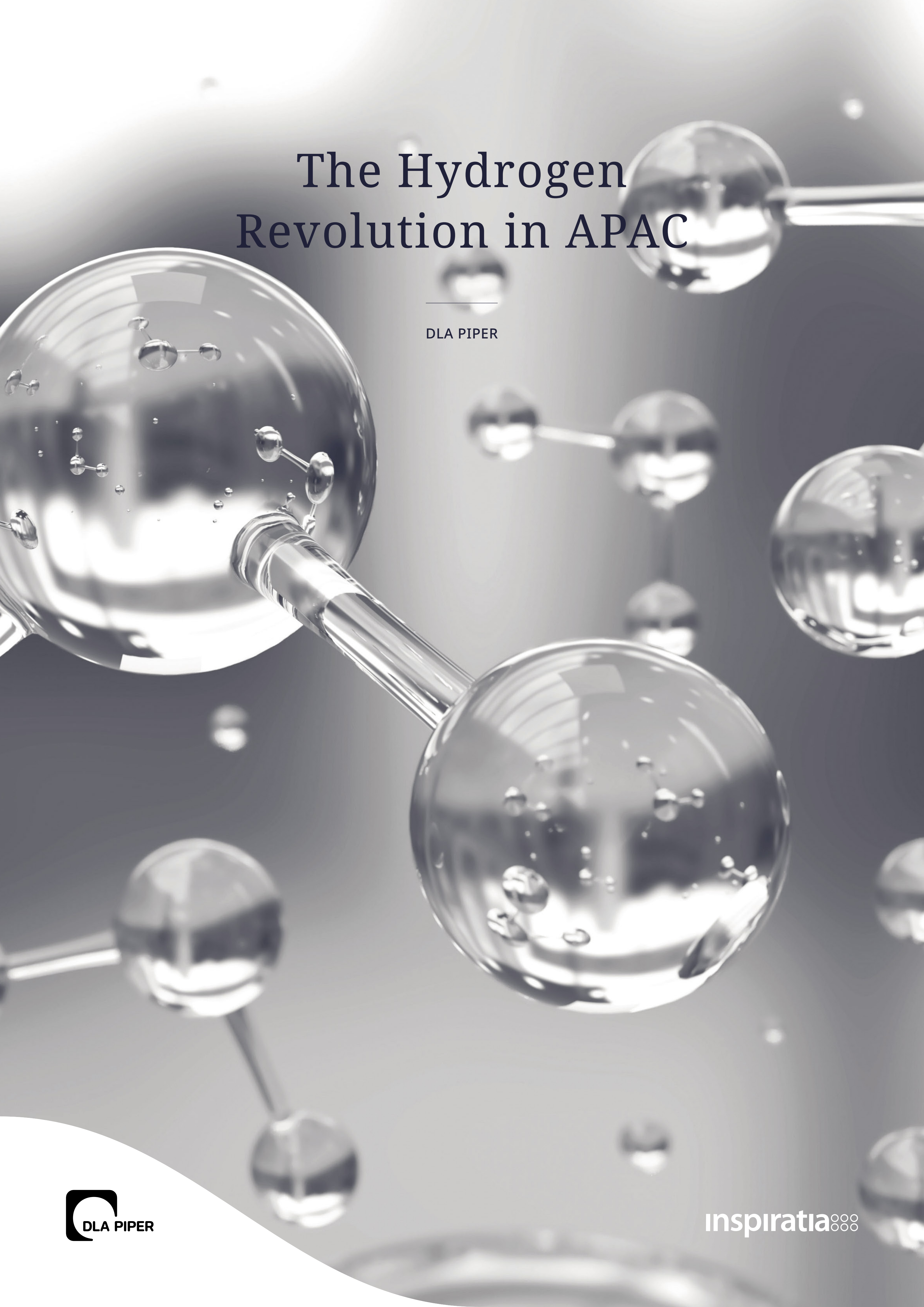

Contents

Foreword

There will be no single solution to the well-documented climate crisis. Major industrial nations must look to a range of options to reduce their carbon emissions and meet their various environmental targets. Of the many emerging solutions, hydrogen will have a significant part to play in our sustainable future as an efficient and clean energy carrier that can be utilised in new applications but also integrated into existing industrial processes in place of fossil fuels. (e.g. as a clean, alternative feedstock) and implementation as a sustainable fuel alternative.

Hydrogen is already having, and will continue to have, a significant impact in the Asia-Pacific (**APAC**) region – the opportunity is already being embraced by Australia, Japan and the Republic of Korea in particular. Hydrogen offers the APAC region a practical option to reduce carbon emissions and fossil fuel dependency. Further, investment into domestic hydrogen applications (such as stationary applications and fuel cell electric vehicles (**FCEVs**)) will serve as a catalyst for the creation of ambitious regulatory frameworks for hydrogen across the region. This, in turn, can support sufficient production and demand to provide the backbone for the global hydrogen supply chain.

What is particularly striking about hydrogen in APAC region is the scale, scope and diversity of opportunity that it presents. Whilst diversity of opportunity has a downside (notably the dilution of effort resulting from a relative lack of collaboration between different jurisdictions who are placing focus on different aspects of hydrogen's obvious potential) it is likely to be the foundation for a multi-jurisdictional hydrogen success story. The broad, pan-region drive toward the use of hydrogen and the development of related technologies across a range of sectors, combined with increased demand (motivated in no small part by climate related considerations) will all serve to reduce production cost and facilitate adoption.

This report seeks to achieve an understanding of the scale and potential of hydrogen in the APAC region by examining what has been done and the ambitions of the Australian, Japanese and the Republic of Korea jurisdictions for their hydrogen future.

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1. Introduction

Overview of Hydrogen

Hydrogen is the most abundant element in the universe. On earth, hydrogen only occurs naturally in compounds formed with other elements including in oxygen to form water (H_2O) and carbon to form hydrocarbons which are found in fossil fuels such as natural gas (predominately methane (CH_4)), coal and petroleum.

Hydrogen has several unique characteristics that are crucial for its role in the global response for reducing carbon emissions and fossil fuel dependency. Firstly, it is an energy carrier (as opposed to an energy source) – this means hydrogen transports energy in a usable form from one point to another. As an energy carrier, hydrogen shares several characteristics with electricity including the following:

- hydrogen must be produced from another substance, for example by separating hydrogen from fossil fuels or water (discussed further **below**);
- hydrogen can be produced in a variety of different ways and has multiple applications; and
- hydrogen production can generate carbon dioxide (CO_2) when produced using fossil fuels.

Secondly, unlike electricity, hydrogen is a chemical energy carrier composed of molecules (i.e. rather than only electrons). This feature means hydrogen can be stored and transported in a stable way, stored for long periods (e.g. if transported by sea) and integrated into existing infrastructure and business models that previously leveraged fossil fuels (e.g. transportation through existing natural gas pipelines). Hydrogen can also be combined with carbon or nitrogen to make hydrogen-based fuels or used as an industry feedstock.

Thirdly, hydrogen also has the highest energy content of any fuel by mass (approx. three times greater than gasoline and twice that of natural gas).[1] As a result hydrogen can, depending on its production method, be more energy efficient by mass than other fuel alternatives. Therefore, hydrogen is viewed as an attractive transport fuel. Notwithstanding its potential potency as an energy carrier, at present it takes more energy to produce hydrogen than the fuel by-product provides when converted into energy. Like all energy carriers, hydrogen encounters efficiency losses at each stage in the supply chain. Following production, transportation, storage and conversion to electricity the delivered output can be below 30% of the initial electricity input. Consequently, existing production methods can sometimes result in hydrogen being less efficient as an energy carrier than electricity or natural gas. It is important to note, however, that hydrogen efficiency is context specific – for example, the International Energy Agency (**IEA**) estimates that a hydrogen fuel cell in a FCEV operates at approximately 60% efficiency compared to a gasoline internal combustion engine that operates at approximately 20% efficiency. Further, it is likely that efficiency will improve with developments in production, storage, transportation and conversion technologies.

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[1] Hydrogen also has the lowest energy content by volume (approximately four times less than gasoline).

History of Use

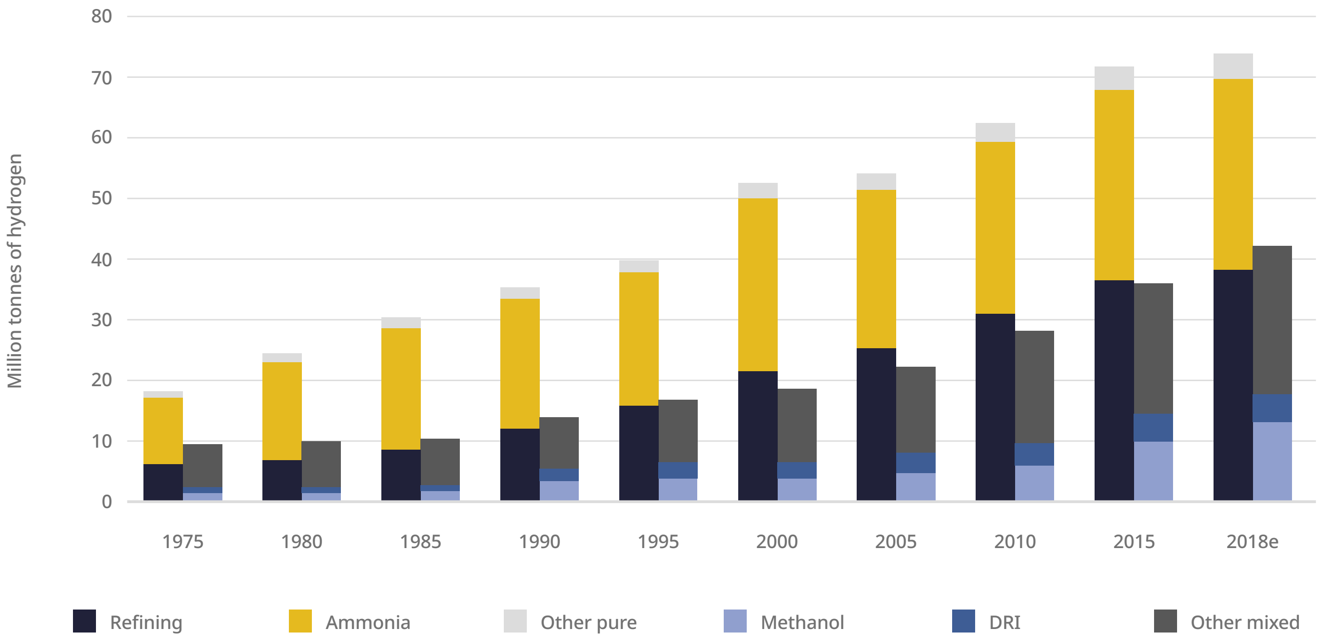
The industrial usage of hydrogen is not new or novel. Early attempts to use hydrogen as a fuel trace back to the 1800s and the first demonstrations of water electrolysis and fuel cells, and the use of hydrogen in the first internal combustion engine. Through the 18th and 19th centuries hydrogen was used in airships before eventually being the fuel source that sent humanity to the moon in the 1960s (primarily due to it being a low weight fuel source).

Interest in hydrogen as an alternative fuel source piqued in the 1970s because of rising oil prices, petroleum shortages and growing concerns regarding air pollution. Through the 1990s the growing focus on climate change stimulated increased research into hydrogen, carbon capture and storage (**CCS**) technology, renewable energy and transport. However, decreasing oil prices through the remainder of the decade reduced mainstream support for hydrogen projects. In the early 2000s climate change and 'peak oil' concerns drove renewed focus on hydrogen fuel. Despite the reinvigorated momentum the interest in hydrogen waned again due to a combination of factors, including uncertainty surrounding climate policy, developments in electric vehicles (which required less infrastructure investment than FCEVs) and a reduction in concerns over oil scarcity.

After a long journey, the hydrogen revolution has begun with support from the highest levels internationally and across sectors. With technological improvements foreshadowing reduced production costs and increased support globally for addressing climate change the case for hydrogen as an energy source has never been stronger. What is also changing is the hydrogen demand, which has more than tripled since 1975 and continues to rise.

Figure 1: Global annual demand for hydrogen since 1975

Source: IEA, "The Future of Hydrogen" (2019)[2]



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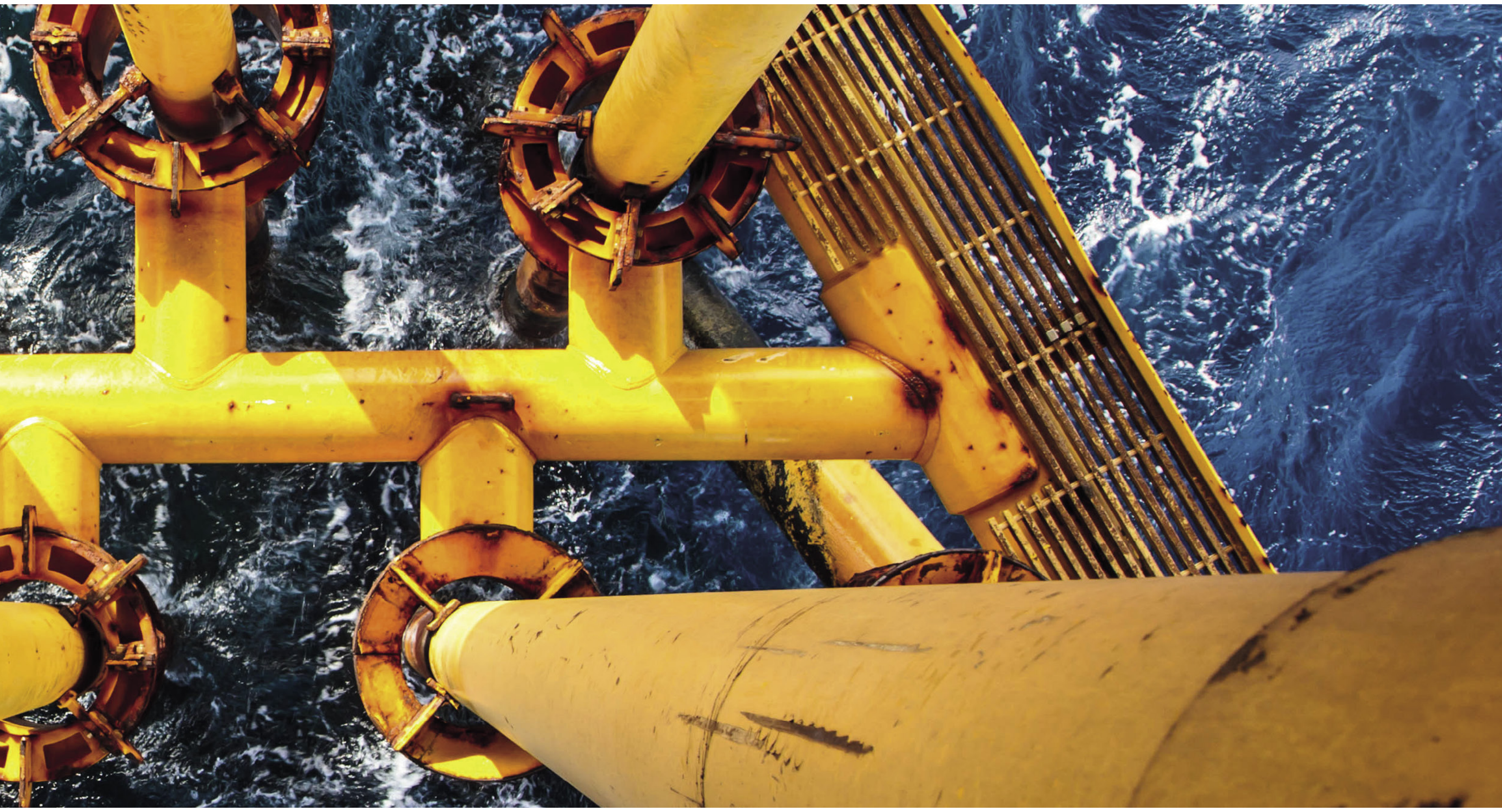
[2] The full report is available from: https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf

In 2020, the IEA estimated that demand for pure hydrogen was around 70 million tonnes per year (**Mt/yr**) – almost all of it being supplied from fossil fuels (i.e. 6% of global natural gas and 2% of global coal going to hydrogen production). The increasing hydrogen demand is largely attributed to new industries such as FCEVs, traditionally carbon-based industries seeking to decarbonise (e.g. steel and cement production) and an increased demand for cleaner forms of energy. The interest in hydrogen as a clean energy source is supported by the ability for hydrogen to be used without, depending on the production method, significant air pollution and produced using a diverse range of low-carbon materials. Outside the energy context, hydrogen is also used extensively as part of industrial processes such as refining petroleum, treating metals, and in the agricultural sector by combining hydrogen with nitrogen to produce ammonia (NH_3) for fertilisers.

Despite the increase in demand there remains some roadblocks that exist which will slow the transition from fossil fuels to hydrogen fuel. These include:

- insufficient existing infrastructure to support the transition to hydrogen-based business models;
- current high costs associated with most forms of production;
- the absence of universal regulatory standards;
- low production capabilities and expertise; and
- a need for commercial-scale storage and transportation methods to facilitate a consumer market.

APAC countries are beginning to address these issues as part of the early-stage development of a promising hydrogen market throughout the region. Where a solution cannot be reached by a single nation, innovation will occur through cooperation at the national level. Significant opportunities will come from cross-border hydrogen trading, international collaboration on policies and investment, and the development of a thriving FCEV consumer market.



Hydrogen Production

The increased use of hydrogen is important for the development of the global hydrogen market. However, not all types hydrogen will contribute equally in the strive for cleaner renewable energy. Importantly, there are multiple types of hydrogen, each varying in its 'cleanness' depending on the production method used. These include:

1. Brown Hydrogen – produced through a thermochemical reaction called coal gasification in which coal, oxygen and water vapor are combined at high temperature producing hydrogen gas (H_2), water and a number of carbon-based by-products (i.e. carbon monoxide, carbon dioxide and natural gas). Production of brown hydrogen creates significant amounts of CO_2 by-product (approx. 19Mt of CO_2, twice the amount generated by green hydrogen production). On its own, the significant CO_2 by-product reduces the viability of brown hydrogen as a clean and sustainable energy source. However, the unsustainability can be mitigated through the implementation of pollution controls that efficiently remove the carbon by-products from the gasification stream. An example of carbon pollution controls is CCS technology which captures, transports and stores CO_2 emissions underground. The adoption of CCS technology will be crucial for coal-rich countries that intend to rely on brown hydrogen production in the early stages of the hydrogen revolution in order to support infrastructure development.

2. Grey/Blue Hydrogen – produced using natural gas steam methane reforming (**SMR**).[3] SMR processes involve introducing a high pressure mixture of steam and methane gas to a catalyst at high temperature to produce CO_2 and hydrogen gas (H_2). The SMR process has generally preferable environmental credentials compared with brown hydrogen production. However, it still generates significant CO_2 emissions unless implemented in conjunction with CCS technology (i.e. blue hydrogen production). The ability to retrofit CCS technology to SMR processes and capture a significant proportion of the emissions (particularly as costs decrease) may increase the viability of SMR hydrogen production. Where natural gas is cheap, and CO_2 storage is available, SMR production coupled with CCS technology will offer a low-cost, at-scale source of production.

[3] The term 'blue hydrogen' is used to describe hydrogen produced through natural gas steam methane reforming used in combination with CCS technology. Hydrogen produced through this method without CCS technology is referred to as 'grey hydrogen'.

3. Green Hydrogen – produced using electrolysis, the process of using electricity to separate hydrogen from the oxygen in water. Green hydrogen production is the key to providing the most environmentally sustainable hydrogen solution. However, for production to be truly 'green' the source of the electricity must be renewable (e.g. solar-, wind- or hydroelectricity) which is the largest single cost component for on-site production of green hydrogen. Even with reductions in renewable power costs, green hydrogen is still approximately 2-3 times more expensive to produce than blue hydrogen. In addition to lower electricity costs, viable green hydrogen production requires a reduction in the cost of electrolysis facilities. Unlocking pathways to reduced green hydrogen production costs is a key challenge for all regions who see hydrogen as a component of their drive for environmentally sustainable energy production.

Notwithstanding the merits and limitations of each hydrogen type, local conditions will largely dictate the kind of hydrogen production pursued in a particular jurisdiction. This is particularly relevant for the APAC region given the breadth of markets each displaying varying characteristics. In the short-term, APAC countries with plentiful coal supplies will focus on producing brown hydrogen as a cost-effective, early step towards cleaner energy. However, this is can only be a stepping stone. As hydrogen also offers the region a practical option to cut carbon emissions, there will be a push from policymakers to encourage hydrogen production from coal combined with CCS in countries like Australia, China and India (rather than simply expanding power generation from clean energy sources). As technology advances and production costs decrease, APAC countries positioning themselves as hydrogen producers will likely seek to incrementally transition to cleaner production methods (i.e. blue and green hydrogen).

2. Overview of Hydrogen Policy Developments and Implementation in the APAC Region

Local Level Policy Developments in the APAC Region

After a series of false starts (discussed **above**), the APAC hydrogen revolution began to accelerate in 2014 with the release of the Strategic Roadmap for Hydrogen and Fuel Cells by the Japanese Ministry of Economy, Trade and Industry (**METI**) (later iterations of the strategy have been released in 2016 and 2019). This roadmap acknowledged hydrogen as a low-carbon energy carrier with the capacity to help the country reduce CO_2 emissions and strengthen energy security.

The next major step forward was the formation of the Hydrogen Council in 2017 – a global, CEO-led Organisation featuring 123 corporate members from across multiple sectors that comprise the entire hydrogen value chain. The aim of the Hydrogen Council is to encourage the use of hydrogen as part of the transition to clean energy and decarbonization.

In December 2017 the Japanese Ministerial Council on Renewable Energy, Hydrogen and Related Issues published its "Basic Hydrogen Strategy" (**Basic Strategy**). The goal was to formulate a strategy to underpin Japan's hydrogen-related policies to encourage unity in the government's pursuit of being a "world-leading hydrogen-based society". The Basic Strategy outlines Japan's 2050 hydrogen visions while also setting out setting out an "action plan to accomplish the visions by 2030". It also sets the national targets for reducing hydrogen costs through cross-ministry policies ranging from hydrogen production to utilization.

Following Japan's lead, the Council of Australian Governments Energy Council established a Hydrogen Working Group as part of setting the nation's vision for a "clean, innovative, safe and competitive hydrogen industry". The aim was to develop a national hydrogen strategy that could cement Australia as a major player in the global hydrogen industry by 2030. This came to pass in November 2019 with the release of the Australian National Hydrogen Strategy (**Australian Strategy**). The country began taking its first steps towards implementing this strategy in December 2019 when the Australian Renewable Energy Agency (**ARENA**) supported the foundation of ATCO Group's Clean Energy Innovation Hub (**CEIH**) – a hub designed to generate green hydrogen through electrolysis-based hydrogen production and storage.

Initial policy and project developments at the APAC regional level also seek to secure hydrogen's place as a prominent part of energy systems in the coming years (discussed further **below**). For example, in September 2019 the Australian government signed a letter of intent with the Korean Ministry of Trade, Industry and Energy to develop "joint cooperation projects in the hydrogen field" with a view to "[drawing] up a specific hydrogen implementation plan by 2030". Similarly, in January 2020 the Australian Department of Agriculture, Water and Environment and Japanese METI released a Joint Statement of Cooperation on Hydrogen and Fuel Cells acknowledging the importance of national cooperation to shape hydrogen policy development.

The Need for Cooperation at the Regional Level

Notwithstanding early signs of a developing market, one of the key weaknesses of the APAC region's hydrogen approach has been the lack of regional collaboration. What is needed is regional policy development and supply chain implementation on a collaborative, multilateral basis. A pilot example of bilateral cooperation in the hydrogen space is the recent transaction between Brunei and Japan. In 2019 the Brunei and the Japanese Advanced Hydrogen Energy Chain Association for Technology Development (**AHEAD**) launched the world's first international hydrogen supply chain. The arrangement involves the transportation of hydrogen from Muara Port, converted into methylcyclohexane (i.e. a "liquid organic hydrogen carrier" that remains in a liquid state at ambient temperature and pressure), from the resource-rich Brunei to Japan where it is converted back into hydrogen gas and toluene (i.e. a hydrocarbon). The hydrogen gas is supplied to customers while the toluene is transported back to Brunei where it is reused to transport more hydrogen to Japan. This transaction represents an early, but significant, step in developing the international commercial hydrogen supply chain. The arrangement also demonstrates, to those involved, the viability of hydrogen transportation on a large scale.

"On a technical level, production, transport, and storage technologies have been proven, enabling us to establish the supply chain,"

says Osamu Ikeda from the Hydrogen Supply Chain Development Department of Chiyoda Corporation (one of the companies working on the project Japan-Brunei project).

When looking to Southeast Asia, there remains a general lack of formal government initiatives and plans to adopt hydrogen as a key part of the region's energy supply. However, in November 2020 the Association of Southeast Asian Nations (**ASEAN**) presented its Plan of Action for Energy Cooperation (**APAEC**) Phase II (covering the years 2021–2025). One of the APAEC's intentions was to encourage the promotion of technologies such as hydrogen and energy storage with a view to this feeding through to government policies in the bloc's member states. Countries in the ASEAN bloc, such as Indonesia, the Philippines, Singapore, Malaysia, and Thailand, will need to assess ways to develop domestic hydrogen industries for both energy and transport applications. While established fossil fuel sectors and the growing renewables will lend themselves towards multiple forms of hydrogen generation, the region has significant work to do to catch up with both other jurisdictions within Asia.

"ASEAN is a great platform where countries can get together to have a common budget, a common set of rules and regulation, and policy enablers to promote the hydrogen economy, but it just hasn't yet been achieved,"

says DLA Piper Partner Vincent Seah,

"Singapore is developed and most other ASEAN countries like the idea but don't have the money or financial support to give to projects. So at a regional level, it will help if countries band together and do something collectively."

Fostering inter-governmental collaboration in the transactional sense is, by itself, insufficient. As noted above, there is also a need for the development of a comprehensive regulatory framework to support the growth of a sustainable hydrogen market. As with the existing carbon-based gas markets, for the hydrogen supply-chain to flourish there is a need for operational, technical and safety standardization. Even more critical is the adoption of clear and consistent regulations and guidance to govern the exportation, transportation and storage of hydrogen to facilitate cross-border trade.

"The best support is a regulatory framework that is consistent with lasting power. A structure that does not change frequently, so it gives companies enough time to execute. The clearer the guidance the further [the industry] can go,"

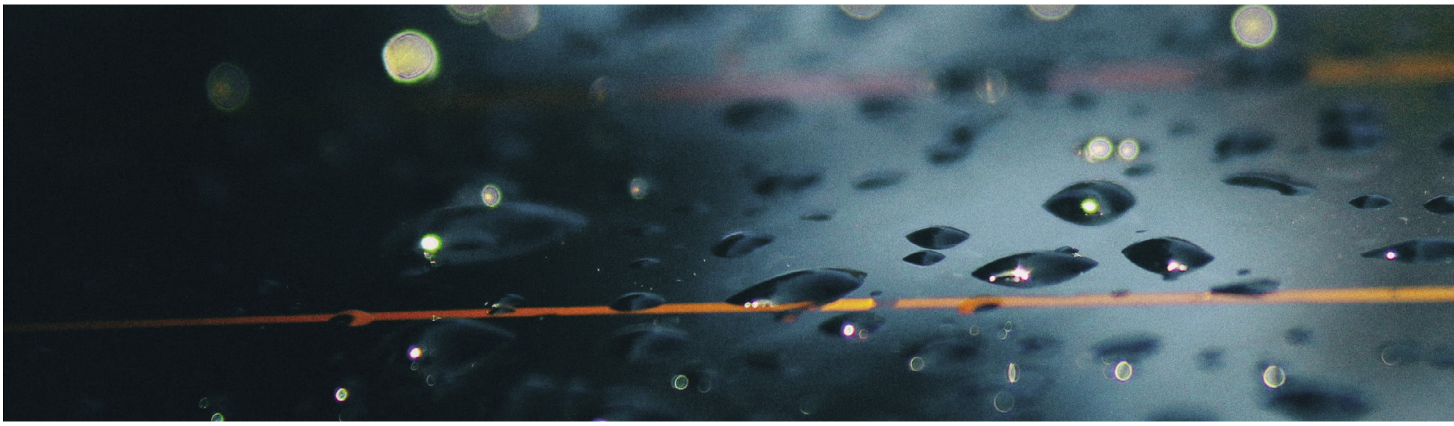
says Alfred Wong, Managing Director of Asia Pacific at Ballard Power Systems.

The creation of a healthy hydrogen market in the APAC region will also require cooperation between companies and other bodies (e.g. trade groups). For example, in 2019 the Asia Pacific Hydrogen Association (**APAC Hydrogen Association**) was created in Singapore by companies from the renewable energy sector as a regional platform to coordinate international policy development, research, and communications to support members´ development. Creating a broad range of holistic partnerships will support the hydrogen market so that it may permeate several industries and use

cases. Critically, through joined-up thinking in multiple parts of the ecosystem, a stable and reliable landscape can be created in which projects can prosper and costs reduced.

The potential for a diverse hydrogen market to develop across APAC economies was mapped out in a recent study published by the Economic Research Institute for ASEAN and East Asia (**ERIA**) in December 2020. ERIA predicted that with widespread adoption in several industries, hydrogen costs will more than halve by 2040. Additionally, it considered that Indonesia, the Philippines, Malaysia, Australia, New Zealand, and Brunei (each located on islands or individual continental landmasses) would become stand-out hubs for implementing hydrogen storage industries. Although there are no clear supply and demand patterns in the APAC hydrogen market there are still high expectations for establishing a regional market and innovative applications (particularly considering the region's focus on mobility applications, manufacturing capacity, and geographies with abundant natural resources). Indeed, progress is being made within the region to develop wider and more diversified applications for hydrogen-based power generation systems both on and off the grid. For example, in 2019 Singapore Power Group (**SP Group**) developed the first green hydrogen-powered building in Southeast Asia. The technology used in the project was Toshiba's H2One system – a system that produces and stores green hydrogen which can later be used in fuel. Building on this platform in Singapore, Toshiba sees potential for similar applications in countries like Indonesia and the Philippines.

Outside the APAC context, governments around the globe have recognized the unprecedented momentum in the hydrogen sector and implemented a growing number of tangible policies to further support the deployment of hydrogen-based solutions. This includes announcements from the Clean Energy Ministerial Forum, a high-level collaborative body featuring the leading economies and greenhouse gas emitters, setting a target to deploy 10 million FCEVs globally by 2030 (a fourfold increase on the 2018 target). Projects have also been announced for China, Japan, the Republic of Korea and the US to build 10,000 FCEV hydrogen refuelling stations by 2030. The action of these governments has set in motion a series of solutions for the challenges that face the successful development of substantial hydrogen industries in each market of the APAC region. But there will need to be further refinement of strategies, suitable policy and regulatory frameworks set up, incentives for investment, support for research, and increased exposure to consumers, among other points, to fully realize these ambitions.



Early-Stage Implementation of Hydrogen Polices in APAC Jurisdictions

As noted above, local conditions will largely dictate the kind of hydrogen strategy pursued in a particular jurisdiction. Generally speaking, Singapore and Japan are known to be among the countries seeking to encourage hydrogen use whilst relying on a combination of importation and production. For example, in addition to importation initiatives (like the Japan-Brunei supply chain) the Japanese government is also pursuing green hydrogen production as a future core component of its energy transition. A 2019 Fuji Keizai market assessment predicted that some JPY400 billion (USD3.74 billion) is being invested into the country's hydrogen industry in the years leading up to 2030 (although not all of it necessarily in low-carbon production).

Meanwhile, Australia and New Zealand will focus on the development of exportation hubs in combination with blue and green hydrogen production. Other nations like the Republic of Korea and China are likely to focus on manufacturing and exporting hydrogen technology applications, particularly in the transport sector, betting on FCEVs to facilitate the introduction of hydrogen technologies into the region.

On the Republic of Korea's position within international hydrogen trade, Kim Ki-hyun, CEO at Iljin Composites, says,

"As Korea wants to export [hydrogen] applications, so the government wants to import infrastructure technology. Most capex on production and transport of hydrogen is coming from abroad whereas we are currently exporting light-duty vehicles to Europe and California."

Regardless of the strategies pursued across the region, the reduction of hydrogen production costs will have a significant impact on investor interest. Relevantly, the Hydrogen Council has predicted that green hydrogen production will fall by approximately 60% by 2030. Consequently, APAC countries acknowledge that clean hydrogen is the long-term objective – for example, Asia´s electrolyzer capacity is estimated to reach 10GW over the coming decade.[4] In addition to lower production costs, distributed applications like mobility will benefit from a decrease in delivery costs.

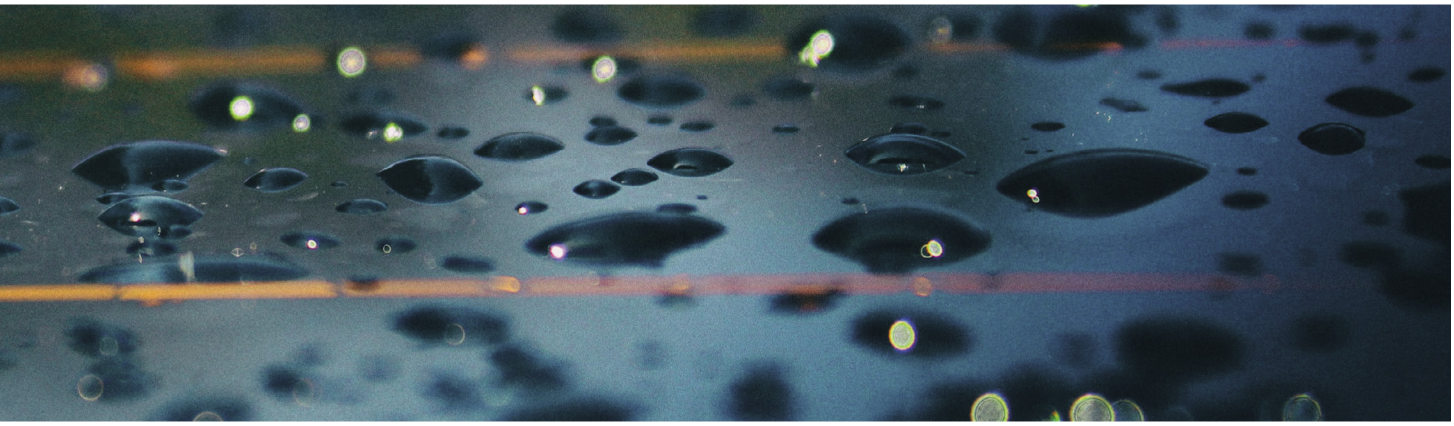
With a serious advance in scale, hydrogen delivery costs should decrease by 70% over the next decade, meaning the delivery of hydrogen could fall to between USD4.50/kg and USD6/kg.[5] However, the development of a sustainable hydrogen industry will be contingent on improved costs throughout the whole supply chain, development of the required infrastructure and improved safety practices. As with any other industry, economies of scale will produce results in these areas, particularly with regards to falling costs.

"Today, renewable hydrogen is expensive; that is why the role of governments should come in place at a domestic and regional level. I think one of the key issues in the energy transition is to keep the electricity affordable, so hydrogen becomes the promise to keep energy affordable,"

says Peter De Neef, Regional Representative Asia-Pacific / Global Solutions & Partnerships in the Hydrogen Business Unit at Engie.

4 Fitch Solutions Country Risk & Industry Research, 2020

5 Hydrogen Council, "Path to hydrogen competitiveness: A cost perspective", 2020



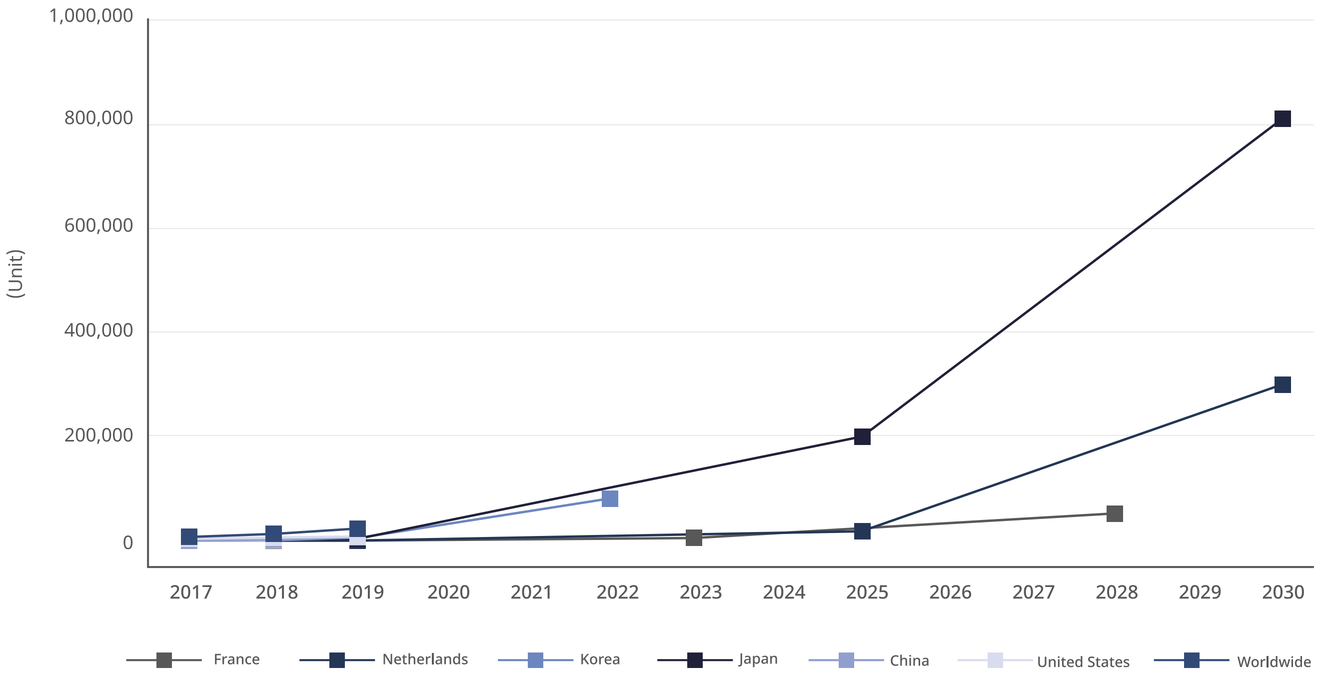
The Role of FCEVs in the APAC Hydrogen Revolution

The personal FCEV market is poised to break out from being a niche product to establishing itself in areas in which it can flourish. According to the IEA FCEVs represent just 0.5% of low-carbon vehicles sale. However, the FCEV market is an area experiencing significant growth. 2019 was a bumper year for FCEVs, with the worldwide operating fleet almost doubling to 25,210 vehicles. Despite many of the companies most active in the supply of these vehicles hailing from Asia (the growth in the FCEV market has primarily been led by Asian manufacturers such as Toyota and Hyundai), the US is currently the largest market, with a trio of APAC countries following behind: China, Japan and the Republic of Korea.

Despite the worldwide fleet of FCEVs only being in the tens of thousands (Figure 2), developed economies feel optimistic towards future vehicle production and adoption. To reflect this optimism, several FCEVs manufacturing countries in 2020 announced a range of ambitious targets. By 2030 Japan expects to sell over 810,000 FCEVs domestically. Looking even further to the future, Japan's Prime Minister announced in a January 2021 speech in the Diet that he wants electrified vehicles, including FCEVs, to make up 100% of Japan's new car sales by 2035. This will translate to an annual growth rate of over 2,100% for the next decade, compared to the 3,700 FCEVs sold in the last six years to date.

Figure 2: Fuel cell electric vehicle deployment (2017-2019), and national targets for selected countries

Source: IEA (2020)



The Republic of Korea has been more cautious with its forecasting – the nation expects to sell 81,000 FCEVs, while installing 310 refuelling stations and 1.5GW stationary fuel cell power plants by 2022.

Although China has not announced an FCEV national target for the next decade, the transport sector is predicted to be an essential breakthrough for the Chinese hydrogen market. Currently, there are over 7,000 FCEVs being driven on Chinese roads. Additionally, China has positioned itself as a leader in terms of fuel cell buses (approx. 97% of global stock) and trucks (approx. 98%) through the implementation of FCEV-supportive policies. However, the Chinese Hydrogen Alliance estimates further growth predicting that 360,000 FCEVs will be sold in China domestically by 2030 – 7% of total commercial vehicle sales. Further, FCEVs domestic sales were predicted to reach 1.6 million by 2050 – 37% of total sales for commercial vehicles. With respect to passenger vehicle sales, the market share of FCEVs will remain at 3% by 2030 and grow to 14% by 2050. To support the significant increase in FCEVs it has been hydrogen demand in the Chinese transport sector will be 24.58 million tonnes by 2050 – 19% of total energy consumption in transport. The hydrogen energy consumption in freight transportation accounts for up to 70% of total hydrogen demand in the transport sector, meaning that it will be the main driving force behind increased overall hydrogen demand.

Following these estimations, Alfred Wong, APAC Managing Director of Asia Pacific at Ballard Power Systems, comments about Ballard's position in the Chinese market and what Ballard expects in the short-term.

"In China, at a vehicle level, we have around 6,800 vehicles registered. At this point, with respect to refuelling stations, there are around 60 refuelling stations in service, but we expect this number to grow up to 200 by the end of 2021."

The growth in FCEVs also requires an increase in the prevalence of fuel sources. In 2019 the number of hydrogen refuelling stations installed across the world increased by over 20% (approx. 470 in existence by the end of 2019). Japan leads the way with almost a quarter of the world total, followed by Germany and the US. While 2019 was slow year for US refuelling stations (only one new site opened), Japan, Germany and the Republic of Korea each pushed forward by each adding between 10 and 20 new refuelling facilities to their nationwide portfolios.

Notwithstanding the potential for FCEV growth in the APAC market, there are still sizeable investment, development and infrastructure hurdles to negotiate for both personal and commercial vehicles. Compared with direct competitors (e.g. battery electric vehicles) both FCEV uptake and the installation of necessary infrastructure lag in the APAC region. On one hand, the development of refuelling infrastructure for fuel cell cars is not as advanced as the charging infrastructure for electric vehicles. In contrast, hydrogen cars typically have a significantly longer range between charges than battery electric cars.

However, whether hydrogen cars can become a viable alternative mode of transport remains to be seen. Due to the currently high production cost green hydrogen does not have a price advantage compared to fossil-fuels-based generated hydrogen (i.e. brown, grey and blue hydrogen). Keeping in mind green hydrogen as the long-term target, in the short-term, the main goal is to encourage users to switch to FCEVs and household fuel cells to expand the demand for low-carbon hydrogen. When the scale of the low-carbon hydrogen market grows, and most solar PV and wind power can achieve grid parity, then the goal of mass utilization of green hydrogen will eventually be achieved.

Alfred Wong, APAC Managing Director of Asia Pacific at Ballard Power Systems, comments about the barriers to the mass adoption of FCEVs.

“From our perspective, we don’t see safety as a barrier for mass production of FCEVs and refuelling station development. The real focus is on how to create awareness and incentivize people with the best standards to manage hydrogen-based applications.”

The Future of Hydrogen Trade in the APAC Region up to 2030

Major APAC economic powerhouses such as Japan, the Republic of Korea and China are currently leading in developing applications for hydrogen. Each leader is expected to continue to push forward on multiple fronts in the run-up to 2030 (as seen in Figure 3).

Currently, these three countries mainly target transport as a venue for hydrogen use. However, Japan and the Republic of Korea are also exploring stationary applications. According to the IEA, the installation of 300MW of stationary hydrogen use in 2019 has resulted in the Republic of Korea positioning itself as a market leader. The nation is also showing no signs of slowing by targeting continued growth to reach 3.5GW of total capacity. All three nations also see hydrogen as a way to confront environmental issues while developing local industries and energy self-sufficiency.

Australia plans to capitalize on its position as a high-volume exporter of raw materials and build on strong existing trade routes. The country is seeking to exploit its plentiful renewable resources through the development of large-scale power generation hubs which will prominently feature hydrogen production – chiefly of the green variety – for export to Southeast Asia and perhaps beyond. Additionally, through the utilization of CCS capabilities, it can retool its large coal mining sector to fuel low carbon hydrogen generation. The increased hydrogen output from both renewables and coal-powered production could capture a sizeable portion of increased demand from major regional import economies like the Republic of Korea, Singapore, and Japan to create a multi-billion-dollar industry for Australia.

> ***“The establishment, development and growth of a number of Australia’s export industries including iron ore and LNG have been built off the back of investment partnerships and long-term offtake contracts with Asian customers, so these are the jurisdictions that Australia is looking to partner with to assist with the growth of their hydrogen industry,”***

says DLA Piper Partner Tom Fotheringham.

Figure 3: APAC Region Hydrogen Demand and Supply based on 2030 National and Regional Roadmaps

Sources: IEA, “The Future of Hydrogen” (2019); Commonwealth of Australia (2018), “Hydrogen for Australia’s Future”; Ministerial Council on Renewable Energy, Hydrogen and Related Issues (2017), Basic Hydrogen Strategy; Venture Taranaki (2019), Hydrogen Taranaki Roadmap.

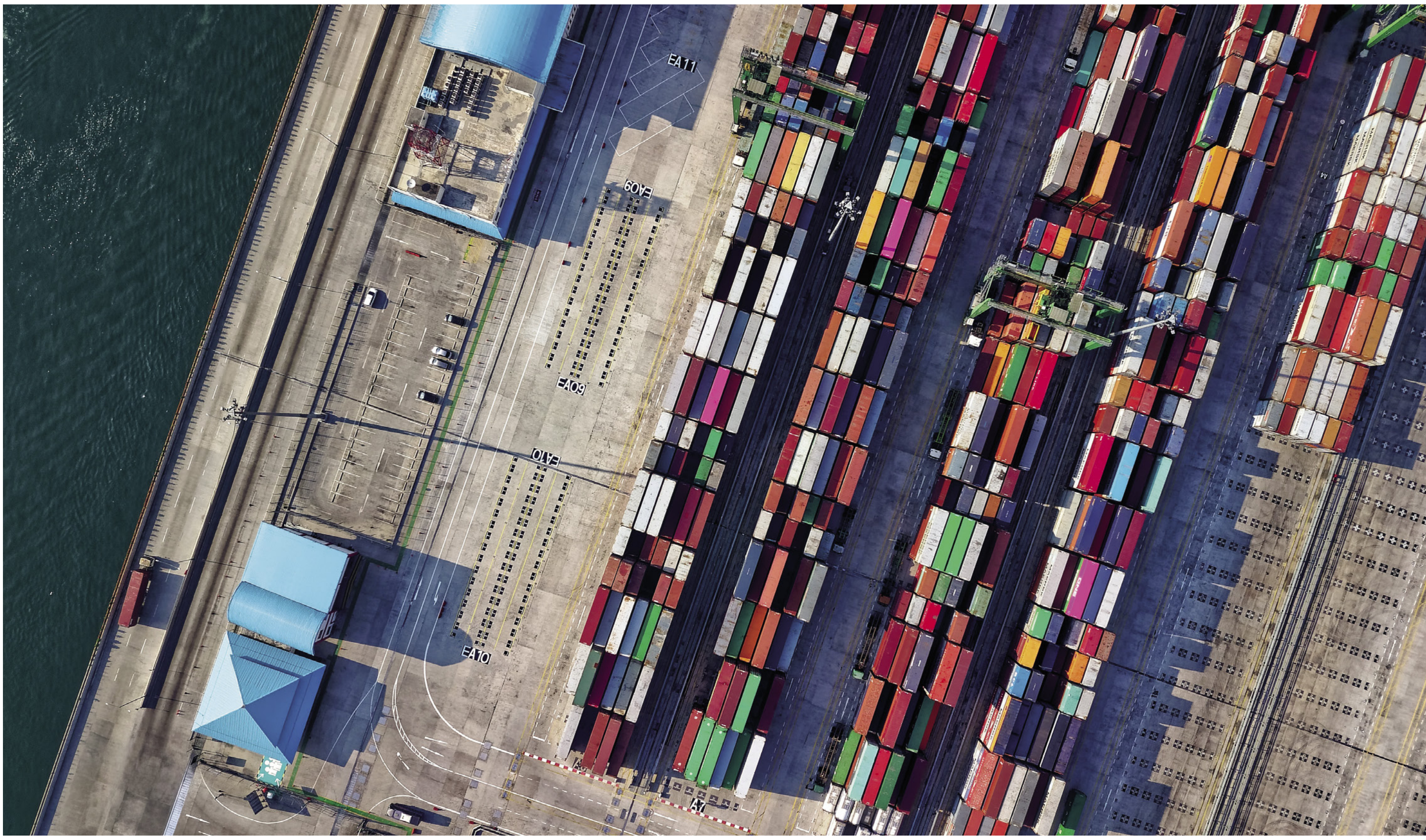
COUNTRY	2030 TARGET				NOTES
	Hydrogen flow (MtH_2/yr)	Transport (thousand vehicles)	Power generation (GW)	Residential (million homes)	
AUSTRALIA	0.5	–	–	–	Australia´s strategy is likely to be led by exports.
CHINA	0.2	1,000 (cars)	–	–	China´s strategy focused on matching domestic supply and demand.
JAPAN	0.3	800 (cars) 1.2 (buses)	1	5.3	Demand mostly for power generation. Demand from transport is around 0.15 MtH_2/year and expected to be satisfied domestically.
NEW ZEALAND (TARANAKI REGION)	0.7	–	–	–	Taranaki proposes exporting around 0.3 MtH_2 (0.5-1 GW), or 40% of production.
REPUBLIC OF KOREA	0.2	630 (cars) 150 (trucks)	3.5	–	The target for power is for fuel cells, not necessarily hydrogen.

Nation Profile: Australia

Recently, the Australian Federal Government has prioritized low-carbon hydrogen technologies to:

- significantly reduce greenhouse gas emissions to meet the country's Paris Agreement targets;
- facilitate the reliable integration of renewable energy into the electricity grid on the east coast (which is increasingly reliant on solar and wind generation); and
- decrease Australia's reliance on imported fuels, while simultaneously leveraging investment in the sector in order to generate new jobs as part of a larger strategy to become a major clean hydrogen exporter.

The Australian Strategy estimates that about 11% of Australia (approx. 872,000 square kilometers) could be highly suitable for renewable hydrogen production utilizing, wind or hydropower generation (i.e. green hydrogen). Further, a significant portion of the production-viable land (approx. 3% or 262,000 square kilometres) is also located near coastal water sources, which (together with waste water) may provide a feasible and socially acceptable water source for hydrogen production. Australia is also well placed to produce low-carbon hydrogen from coal and natural gas using CCS technologies (i.e. blue hydrogen). The export of low-carbon hydrogen produced in Australia is widely considered a huge economic opportunity, with estimates suggesting it could be worth up to AUD10 billion/year by 2040.



Like the Federal Government, Australia's States and Territory Governments have supported specific hydrogen projects. Further, some states and territories have released their own individual emission targets and hydrogen strategies that focus on activities that make use of their local resources and expertise. For example, Tasmania has an abundance of wind power generation and freshwater storage capacity. The state intends to leverage these natural resources through a focus on green hydrogen production through electrolysis. State-owned Hydro Tasmania, Tasmania's predominant electricity generator, estimates that the cost of locally produced renewable hydrogen could be 10-15% lower than the production of hydrogen using power supplied by the electricity grid, and up to 30% lower than off-grid variable renewables. Favourable costing estimates have been attributed to Tasmania's high electrolyzer utilization supported by a combination of predominately wind power and capacity firming hydropower relative to the electrolyzer utilization achievable in other Australian jurisdictions (i.e. which have wind and solar generation but limited firming).

In contrast to Tasmania, several Australian States rely heavily on natural gas or coal as their predominant source of energy generation. New South Wales (23% of Australia's coal resources) and Queensland (63%) are both planning, in the short-term, to produce low-carbon hydrogen using CCS. However, both states plan, in the long-term, to switch to renewable energy sources for hydrogen production. The requirement to transition from high- to low-carbon hydrogen production is necessary as it will take longer to develop the required infrastructure for production at scale.

"At the moment, Australian States are competing for the opportunity to become Australia´s major hydrogen exporter. Ultimately, Australia plans to become a renewable export superpower and hydrogen is one of those potential vehicles,"

says Ben McGarry, Global Service Leader for Future Energy at Aurecon.

National Hydrogen Roadmap and Hydrogen Industry Mission

The Commonwealth Scientific and Industrial Research Organisation (**CSIRO**) – a government agency responsible for scientific research and development – first published its National Hydrogen Roadmap (**Australian Roadmap**) in 2018 as a demonstration of what developments in several areas would be required to build a full hydrogen economy in Australia. Specifically, the Australian Roadmap considered actions that needed to be taken to support business cases, tighten up policy and regulation, incentivize research & development, and increase knowledge of the industry among the wider public.

The Australian Roadmap outlines the necessary steps for the country to take over the coming years that would positively influence hydrogen investment decisions by government and industry participants. Additionally, the roadmap highlights research that may lead to sustainable growth of the hydrogen industry as a whole. It also identifies the barriers that currently exist to the formation of a self-sufficient hydrogen industry, including a lack of infrastructure, and details of how policy interventions can serve to address these roadblocks.

The Australian Roadmap details a list of commercial, policy, R&D, and social priorities for the coming years, across various hydrogen use cases, including transport, industry, export, power, heat, and synthetic fuels. Key initiatives include the stimulation of hydrogen demand through new policy frameworks, adopting a renewables-style Guarantees of Origin scheme (discussed **below**), incentivizing grid firming services from electrolyzers, and opening up existing segments to the use of hydrogen in their operations, such as industrial feedstocks or in gas networks.

In May 2021 the CSIRO launched its new Hydrogen Industry Mission to support the transition to hydrogen by driving down the cost of hydrogen production to less than AUD2/kg (i.e. "H2 under USD2", a key government priority), increasing fuel affordability and positioning Australia as a major exporter by 2030. The Hydrogen Industry Mission involves more than 100 projects, worth approx. AUD68 million, being rolled out over the next five years by the CSIRO and several partners (e.g. ARENA, Fortescue Metals Group, Toyota, Hyundai). The Hydrogen Industry Mission will focus on:

- the creation of a Hydrogen Knowledge Centre to promote projects and industry developments in the Australian hydrogen market;
- commissioning feasibility and strategy studies that will form the basis of advice to the Australian government, industry and community;
- developing demonstration projects that illustrate the viability of hydrogen value chains; and
- investing in emergent science, including commercialization of new hydrogen technologies through the CSIRO's partnership with Fortescue Metal Groups.

The CSIRO achieved a key milestone in the Hydrogen Industry Mission in July 2021 with the launch of the AUD5 million Hydrogen Research, Development and Demonstration International Collaboration Program. The program will facilitate collaboration between Australian and international research Organisations to support the grown of the domestic hydrogen research and development community while also fostering internal partnerships with participating countries.

Australia's National Hydrogen Strategy

As noted above, the Australian Strategy was adopted in 2019 with unanimous endorsement by the Council of Australian Governments (the nation's primary intergovernmental forum, now replaced by the National Cabinet in response to the COVID-19 pandemic). The Australian Strategy seeks to coordinate the various actions of Australian governments in seeking to capture the hydrogen opportunity.

Constitutionally, Australia's States and Territories play the dominant role in governing the traditional mineral and petroleum industries. However, export and customs issues, in addition to the implementation of international environmental conventions, is generally a power of the Federal Government. Given the export-focused strategy for hydrogen, Australia's States, Territories and the Federal Government have come together to provide an integrated approach with strong Federal oversight.

Early steps for implementing the Australian Strategy are focused on creating and proving Australia's clean hydrogen supply chains, building cost-competitive production capacity and encouraging global markets to emerge in line with mutual interests. The Australian Strategy also identifies Australia as having significant competitive advantages for developing a substantial hydrogen export industry. The nation is rich in all the natural resources required for hydrogen production, has a demonstrated track record in building large scale energy industries and is a trusted energy supplier to the Asian market.

In addition to establishing Australia as a global hydrogen powerhouse, the Australian Strategy identifies opportunities for building domestic hydrogen demand, including using clean hydrogen for industrial feedstocks and heating, blending of hydrogen in gas networks and using hydrogen for long-distance heavy-duty transport and the development of associated refuelling infrastructure.

Another key element of the Australian strategy is the creation hydrogen hubs – regions of hydrogen user co-location. These hubs will be pilot projects that make use of economies of scale by developing hydrogen generation stations, end-user operations and facilities. Hub utilisation will significantly reduce expense and complexity of supply chains, transport logistics and infrastructure. Once completed, these hubs will provide the additional benefit of making future project development easier and the deployment of proven technologies into the market more readily scalable. Projects supported by the Australian Government are often developed in partnership with the private sector and focus on a variety of innovative applications and technologies, including chemical feedstocks, heating, electricity, and FCEVs.

Several federal funding initiatives have been announced to support the implementation of the Australian Strategy. In April 2019 ARENA announced the Renewable Hydrogen Development Funding Round (**Hydrogen Funding Round**) of up to AUD70 million to fund two or more large-scale hydrogen production projects. The funding round was expected to play a significant role in the Australian Government's goal of reaching a price of at, or under, AUD2/kg of hydrogen. In May 2021 it was announced that the Australian Government, through ARENA, had conditionally approved AUD103 million (increased from AUD70 million) in funding for three commercial-scale renewable hydrogen projects as part of the Hydrogen Funding Round. With the funding, ARENA hopes for Australia to become home to some of the largest hydrogen electrolysers in the world. AUD300 million has also been made available through the Clean Energy Financing Corporation's Advancing Hydrogen Fund to provide debt and/or equity financing for eligible hydrogen production and exportation projects, domestic hydrogen supply chains (e.g. exportation infrastructure) and hydrogen hubs.

Funding has also been made available by several Australian States and Territories. For example, in June 2021 the Queensland Government announced as part of its COVID-19 Economic Recovery Plan AUD2 billion would be invested as part of the Queensland Renewable Energy and Hydrogen Jobs Fund. This investment is intended to support the development of Queensland's resource sector to deliver on the state's 2030 50% renewable energy target, whilst also positioning Queensland to capitalise on the emerging hydrogen market. Similarly, the Tasmanian Government has developed a AUD20 million Renewable Hydrogen Fund as part of the state's 2020 Renewable Hydrogen Action Plan.

In June 2021 the Australian Government released for consultation a discussion paper outlining a proposed Hydrogen Guarantee of Origin certification scheme (**GO Scheme**). The GO Scheme is one of the priority strategic action items outlined the Australian Strategy. The Australian Government has acknowledged that for the country to position itself as a major exporter it will be necessary to develop a standardisation framework to provide a consistent and accurate approach for tracing key attributes associated with hydrogen production (particularly the hydrogen's carbon footprint). This will enable countries importing hydrogen to accurately compare product from different countries and provide importers access to all the information needed to guide purchasing decisions. The consultation period ended in July 2021.

Production and Export

The Australian Strategy projects global demand for hydrogen to be between 72 and 76 Mt/yr by 2030, and between 100 and 300 Mt/yr by 2050. The variability in these projections stems from unknown factors such as adoption rates of hydrogen as a fuel source in various countries.

The Hydrogen Council predicts that the global market for hydrogen will grow to about USD2.5 trillion by 2050; Australia estimates that it will be able to capture approximately USD5.7 billion in 1.3Mt of exported hydrogen by 2040. Australia will be able to realize this return by capturing early market share, investing in developing new technologies, and implementing small-scale projects with plans and infrastructure in place to ramp up production as demand increases for low hydrogen in the future, and for green hydrogen in particular. The country will also be looking to leverage its existing export infrastructure to gain a foothold in all aspects of the hydrogen supply chain. For example, in July 2021 the Western Australian Government announced as part of its State Infrastructure Strategy a target for securing 12% of the global hydrogen export market by 2030.

Many companies have begun to invest in pilot projects, with additional funding being provided by the Government through grants that are available for projects contributing to a reduction in greenhouse gas emissions and development of a carbon-neutral economy (discussed **above**). One such early-stage, but potentially long-term, project is the Pilbara Hydrogen Hub in Western Australia under development by Engie and Norwegian chemicals company Yara International. The scheme, which was partly funded by ARENA, commenced in early 2019 and completed a feasibility study in late 2020. The scheme maps out the development of a large-scale facility over stages during the next decade and more.

“Back in February 2019, we looked to Australia where Yara has facilities. That’s already before all the hype started in Australia. We have already locked in a forward-looking customer like Yara, so we are way ahead compared to many other projects in Australia that came into existence,”

says Peter De Neef, Regional Representative Asia-Pacific/ Global Solutions & Partnerships in the Hydrogen Business Unit at Engie.

"The collaboration between Engie and Yara is very strong, complementary. It is heavily focused on renewable hydrogen."

The Pilbara project was initially designed to exploit the significant renewable energy potential in the area to help give a decarbonisation option to Yara's local fertilizer plant using electrolyzers for green hydrogen production. However, it may have wider ramifications. While the Pilbara project is starting with a 10MW electrolyzer and adjoining solar park to power it, the project could reach up to 2GW of renewables-powered hydrogen production by 2030. As the scale increases in Pilbara, export markets in Japan, and elsewhere across Asia, will come firmly into view. Hydrogen produced at the Pilbara project will then be able to leverage established exportation chains out of the nearby Port of Dampier. A further tantalising feature of the Pilbara project for investors considering the hydrogen sector is that it could be one of the first schemes to feature project finance. Although it is by no means a certainty, it could demonstrate signs of interest from an 'unproven technology-averse' financial sector that will be needed to fund the hydrogen revolution. The project is in the process of obtaining environmental approval from the Federal Government.

"The plan is to get the banks on board. The problem for banks is they are averse to new technology until it's proven,"

says DLA Piper Partner Vincent Seah.

"In a gas-fired power plant, for example, you need 30,000 running hours before they put their money behind it, and it's the same for hydrogen. The financing, in a way, hampers the application of hydrogen in blending and more of the innovative stuff, that's going to be even more challenging to finance as opposed to green ammonia."

Another Western Australian project in the works that is heavily focused on using hydrogen to produce agricultural fertilizers is Strike Energy's Geraldton-based Project Haber – a 1.4Mt/yr urea production facility to be build near Geraldton, in mid-west Western Australia. The natural gas specialist plans to convert methane into ammonia which will then be combined with a mixture of blue and green hydrogen to produce urea. Project Haber is project to replace Australia's AUD1+ billion reliance on fertiliser imports by creating a local, low carbon production source. A feasibility study has been completed and the company's search for expressions of interest for fertiliser offtake agreements closed in May 2021. Strike plans to undertake a competitive process to identify project and equity partners to fund Project Haber's equity requirements in Q4 2021. The company is targeting completion of engineering studies in 2022 and looking to commence construction in 2023.

"Strike is looking to use its gas endowment to enable Australia's hydrogen future,"

says Strike Energy Managing Director and CEO, Stuart Nicholls.

"Apart from minimizing our carbon footprint from the natural gas through the consumption of the CO_2 in the urea manufacturing process, the plant will actually be the largest hydrogen and ammonia consuming facility in Australia, and will be co-located with 900MW of renewable energy that already exists. There are about half a dozen demonstration and semi-commercial hydrogen projects floated by various energy proponents in the immediate region, and we are building a facility that can actually enable the sale of all of the hydrogen that is developed by these companies, including Strike."

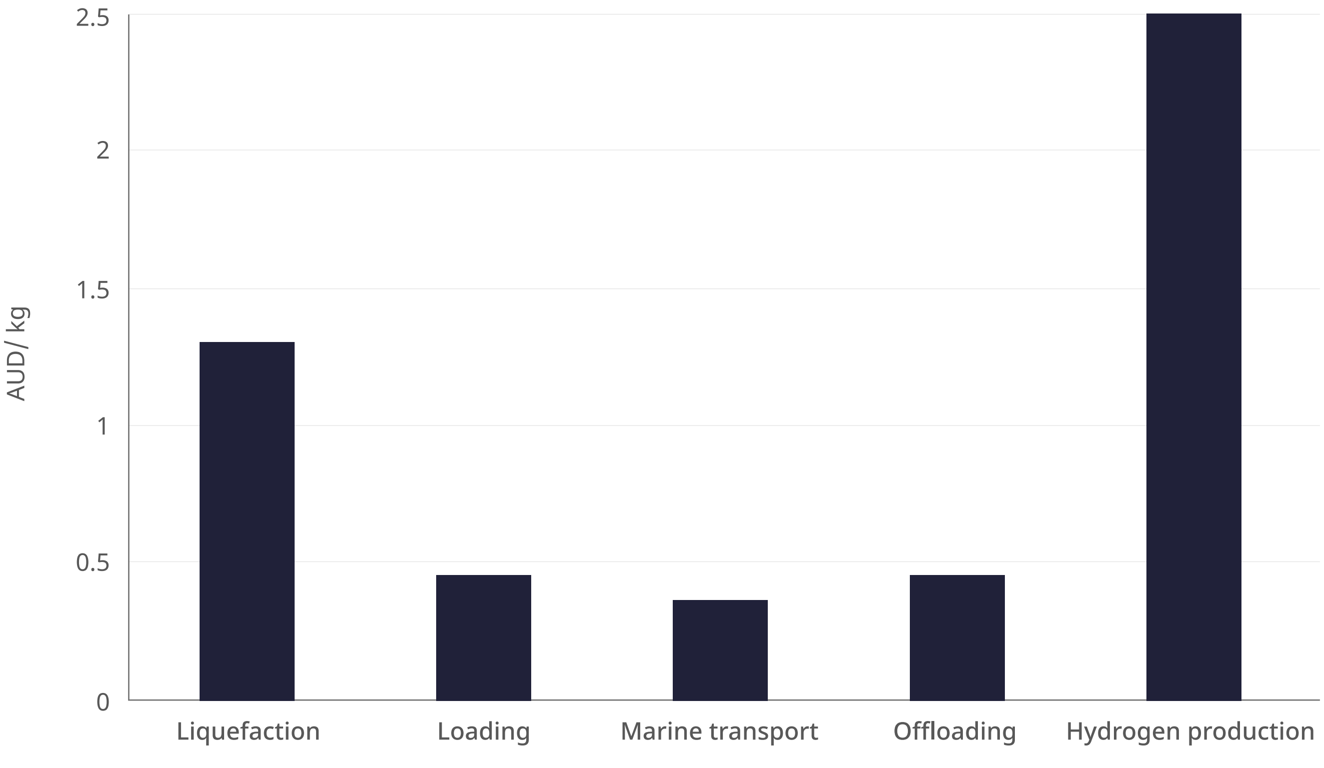
Australia is also looking to invest in innovative projects that capture the whole supply chain. A key example in its early stages is the Hydrogen Energy Supply Chain (**HESC**) Project, a world's first, full-scale hydrogen supply chain. The HESC Project is being developed in two phases. The pilot phase will produce hydrogen from coal at AGL's newly constructed Loy Yang Complex using the coal gasification process (i.e. brown hydrogen). The hydrogen gas is then transported to a 'first-of-its-kind' liquefaction and loading termination at the Port of Hastings where it is loaded onto special purpose liquid hydrogen transport carriers bound for Japan. The hydrogen produced from the project's pilot phase will not utilise CCS technology due to the low emissions from the small amount of hydrogen being produced. However, the decision to implement CCS technology to produce cleaner hydrogen will be assessed as part of the commercialisation decision-making phase. In March 2021 it was announced that the HESC Project pilot phase had commenced operations.

The HESC Project, which required an initial investment of AUD500 million (USD344 million) to develop the production facilities, is being backed by Japan's government and several domestic companies. Some 5,000 tonnes of hydrogen and 18,000 tonnes of ammonia per annum are expected to be produced by the project. The decision to transition into full commercial operation is due to be made sometime within between 2020 to 2030, with operations targeted for the 2030s (depending on the success of the pilot phase and outcome of various operational and commercial considerations).

As demonstrated above, Australia has started its hydrogen journey with a diverse portfolio of projects targeted at proving the viability of the international supply chain and the demand for domestic hydrogen use. In doing so, Australia has positioned itself to be ready to scale up its low-carbon hydrogen production quickly enough to meet global demand as it increases, capturing early market share. These projects will also serve to provide the building blocks for the policies and regulations which will be required to safely implement hydrogen use on a widespread scale.

Figure 4: Delivered cost in AUD/Kg of liquefied hydrogen to Japan — 2025 figures from the CSIRO Roadmap

Source: CSIRO, based on data from the National Hydrogen Roadmap (2018); inspiratia



Heat and Gas Distribution Systems

The Australian Strategy identifies the blending of clean hydrogen with natural gas as a means to stimulate early hydrogen demand growth. The National Roadmap identifies, however, that a clear policy signal from government would be required to achieve this. The call for action is due to combustion of hydrogen for the purpose of heating being unlikely to compete with natural gas on a commercial basis before 2030. The introduction of state and territory zero-emission targets may provide that impetus. Relevantly, the Australian Capital Territory has targeted zero-emissions by 2045. In 2020 the Federal Government also removed the requirement for gas connections in new suburbs and committed to establishing a timeline for phasing out existing gas connections.

In September 2020, the Western Australian Government issued a global expressions of interest process for the Oakajee Strategic Industrial Area Renewable Hydrogen project (the call for expressions of interest has since closed). The scheme will seek to exploit the potential for wind and solar in the region to power clean hydrogen production and tie that into local industrial sites. Offtakers could include metal refineries, ammonia producers and the transport sector. The region has an advanced mining sector an extensive international export network that both provide synergies for hydrogen production.

"When I think about the Oakajee project, economic stimulation of this particular hub is driving that, in addition to the geographic location and economies of scale. The project is a very good example of all of those coming together,"

says DLA Piper Partner Alyson Eather.

Meanwhile, several private gas distribution asset owners in Australia are investing in trial projects that blend clean hydrogen with natural gas transported in existing gas pipelines. The goal is to ultimately displace natural gas with 100% hydrogen. Others in the space are trialling the storage of hydrogen on existing gas pipelines to provide capacity firming for renewable generation. The rationale for investment is, in both cases, identifying a means to extend the economic life of existing distribution pipeline assets and avoiding asset stranding that will inevitably result from the phase-out of natural gas.

Another project designed to demonstrate the use of renewable hydrogen blended with the existing natural gas network is the Hydrogen Park South Australia Project (**SA Hydrogen Park**). Developed by the Australian Gas Infrastructure Group (**AGIG**), the SA Hydrogen Park will produce hydrogen using a 1.25MW solar-powered electrolyzer which will then be mixed into the natural gas network at a concentration of 5%. While this mix is extremely conservative, and international testing has shown that it is safe to blend as much as 20% or more into many existing gas grids, the Australian Government is choosing to do its own thorough testing before more significant implementation. Consequently, the Government has only approved projects with a concentration of up to 10% – targeting a switch to 100% in the long-term after significant safety testing. Significant testing was conducted prior to the SA Hydrogen Park's project approval to ensure the safety of the planned system.

Current data suggests that consumer costs will not be significantly affected by a switch to a hydrogen-natural gas blend. For the SA Hydrogen Park, and similar projects, consumers will be unlikely to notice the difference once the switch has been made. This will be instrumental when scaling up pilot projects for widespread deployment. However, a move to 100% displacement of natural gas with hydrogen will likely require an upgrade to existing appliances and possibly to distribution pipelines.

Gas pipeline owner Jemena is currently running the Jemena Western Sydney Green Gas Project (**Jemena Project**) – the country's largest power-to-gas trial which will convert renewable power generation into hydrogen gas. The project also intends to demonstrate how existing gas pipeline infrastructure can be used to store excess renewable energy. The AUD15 million project is being co-funded by Jemena and ARENA.

The Jemena Project will produce green hydrogen for use in powering 250 homes and supplying a hydrogen vehicle refuelling station. The hydrogen will be generated through electrolysis – with a 500MW capacity – using wind and solar energy. This green hydrogen will be stored in Jemena's existing gas pipeline network, reducing the timeline and development costs by utilizing existing infrastructure. If successful, the Jemena Project will be expanded across the New South Wales gas network and support refuelling for public and private hydrogen transport. Jemena has signed a memorandum of understanding with Coregas and Hyundai to support Hyundai's hydrogen vehicle fleet.

Frank Tudor, Managing Director of Jemena, says of the Western Sydney Green Gas Project,

> *“In the future, Australians will need to decide what to do with excess renewable energy on very windy or very sunny days. Jemena’s Western Sydney Green Gas Project will demonstrate how existing gas pipeline technology can store excess renewable energy for weeks and months, making it more efficient than batteries which can only store excess renewable energy for minutes or hours.”*

In February 2021 APA Group, the owner and operator of a 15,000km natural gas pipeline network running all across mainland Australia, announced a landmark hydrogen pilot project under its Pathfinder Program (an initiative to leverage emergent energy solutions). The pilot project is aimed at enabling the conversion of 43km of pipeline in Western Australia into a 100% hydrogen transmission pipeline. APA Group is targeting completion of the testing and research phase by the end of 2022.

Despite the potential benefits of leveraging existing natural gas infrastructure for hydrogen gas deployment, research has identified potential pipeline safety and longevity issues arising from the use of hydrogen in the existing high-pressure gas transmission networks. Australian governments will not support the blending of hydrogen on existing gas transmission systems until evidence establishes that hydrogen embrittlement issues can be safely overcome. Even where the system has been proven safe, there will still ultimately be issues around resolving potential liabilities that arise from the system’s operationalisation.

> *“As with most new technologies and supply chains, a key question is who will be liable in the event that the expectations of the safe blending of hydrogen do not play out as expected (e.g. what if there is an unintended consequence on the longevity of households gas cook-tops?). The government will need to be satisfied that this a sufficiently low risk before it provides regulatory support and backing to hydrogen blending,”*

says DLA Piper Partner Tom Fotheringham.

Carbon Capture and Storage

In 2018 Australia was the second-largest coal exporter in the world (second only to Indonesia). The country exports approximately two-thirds of its total raw materials used for energy production. Nevertheless, the scale of the Australian coal industry is so significant that there is ample opportunity for its use within a future domestic hydrogen industry. However, the ongoing sustainability of leveraging Australia's coal deposits for hydrogen production necessitates sizeable investment in CCS technology. Interest from international partners in projects like HESC Project suggests CCS hydrogen may be an acceptable option in some export markets for achieving their decarbonisation objectives.

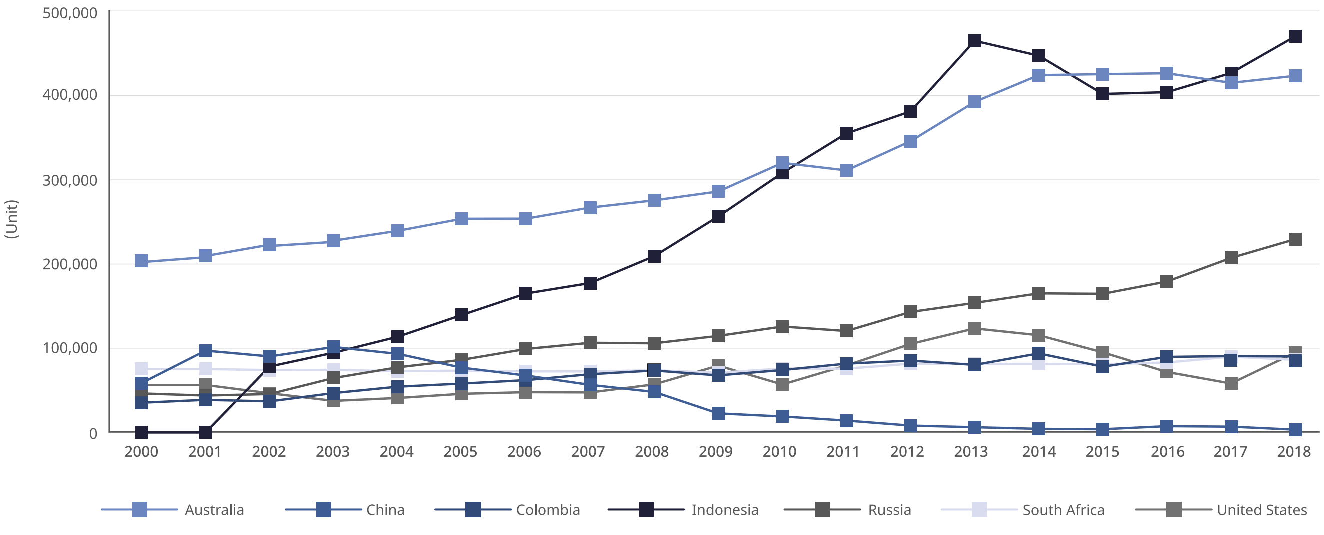
The Australian Government is known for wanting to leverage its existing strong coal and natural gas industries and not neglect their potential to produce vast quantities of hydrogen. For example, in 2020 the Australian Government passed a legislative package the amended the Offshore Petroleum and Greenhouse Gas Storage Act 2006 (Cth) (**OPGGS Act**; i.e. Australia's existing offshore oil & gas legislation) to allow carbon storage that would support using these natural resources for hydrogen production. This will naturally need to be done alongside the use of CCS technology fitted to hydrogen production facilities. Nevertheless, this demonstrates that the country will not be jumping wholesale ahead to purely green hydrogen production for some time.

The best areas for hydrogen production supported by CCS technology would be close to coal or gas sources and CO_2 subsurface storage. The National Strategy has identified the following areas for CCS-based hydrogen production activities that satisfy these two requirements, in addition to the need for pipeline access and water availability:

- the Carnarvon Basin;
- off-shore Western Australia;
- the Gippsland Basin in off-shore Victoria;
- onshore regions near the Cooper Basin in Queensland and South Australia; and
- the Surat Basin in Queensland.

Figure 5: Coal export by country, 2000-2018

Source: US Energy Information Administration, International Energy Statistics (2019)



The 2020 OPGGS Act amendments allow for the storage of CO_2 in underground reservoirs. This will enable to commencement of projects like CarbonNet – a pathfinder scheme funded by the Australian and Victorian Governments that aims to establish a commercial-scale carbon transportation and storage system in Gippsland, Victoria. By providing this system, CarbonNet aims to "[provide] a safe, competitive, flexible solution for Victoria to manage its future carbon emissions from industrial sources" (including hydrogen production). With an initial investment of AUD95.2 million, the CarbontNet operations involve drilling to obtain rock samples at the storage site (i.e. to assess its suitability for injecting carbon) and above the storage site (i.e. to test its impermeability to ensure the carbon will not leak back into the atmosphere). The results of these tests will determine the site's suitability as a carbon storage location. The captured carbon dioxide will be transported from various projects in Victoria's Latrobe valley via a pipeline. If the Victorian Government is satisfied with the CarbonNet project, then the proposed operational timeline is final investment decision in 2024 and operationalisation by 2030.

Hydrogen for Transport

The transport sector is Australia's largest end-user of energy. As noted above, hydrogen has the highest energy content of any fuel by mass. Consequently, hydrogen-based fuel cells carry more energy than the equivalent weight of batteries resulting it an economically viable alternative for powering buses, trucks and ships carrying heavy loads and travelling long distances. To leverage this utility, Australia's Federal, State and Territory Governments have a shared vision of hydrogen as a fuel option for land and air transport (particularly for heavy-duty and long-range applications). In February 2021 the Federal Government took additional steps to outline this vision by releasing the "Future Fuels Strategy" discussion paper. Relevantly, the discussion paper recognises investment in hydrogen refuelling infrastructure as a priority initiative. To realise this objective, the Government has co-invested AUD71.9 million to support the rollout of electric charging and hydrogen refuelling infrastructure through the Future Fuels Fund. In terms of hydrogen rollout, the Australian Government has stated it will cooperate with industry stakeholders and state governments to co-invest in demonstration hydrogen refuelling stations (consistent with the hydrogen transport approach in the Australian Strategy). Consultation for this rollout is scheduled for the second half of 2021.

One strategy Australian government bodies are using to encourage a transition to hydrogen fuel is demonstrated by the hydrogen refuelling station at Fyshwick in Canberra (which the ACT Government will use to fuel a fleet of 20 new Hyundai Nexo vehicles). The project, developed in partnership by ActewAGL and renewables developer Neoen, commenced operations in March 2021 after its initial 2020 opening date was delayed due to COVID-19 restrictions. Relevantly, the hydrogen will be produced by renewable energy power electrolyzers located at Neoen's Hornsdale Wind Farm and its neighboring, and now-expanded, 150MW Hornsdale Power Reserve battery (built by Tesla). In May 2021 the Fyshwick refuelling stating received an official zero carbon certification from the Smart Energy Council (the peak Australian body for solar, storage and smart energy). The refuelling stating is only the second in the world to receive certification, behind another hydrogen station in Belgium.

Other similar facilities are expected to follow across the country, including the Jemena Project in Sydney which will deliver renewable hydrogen to Hyundai at its Macquarie Parker headquarters. Meanwhile, Toyota is developing a similar scheme at its Altona site in Victoria which will ultimately produce green hydrogen for both transport and stationary applications. A commercial-scale hydrogen vehicle refuelling station will sit at the heart of the project (which will also feature an education center, solar photovoltaic system and battery storage). Toyota and Hyundai, the latter of which intends to develop similar facilities in Western and South Australia, will then aim to push ahead with expanding their infrastructure offering in Australia to support a market for their hydrogen vehicles.

Australian governments are also looking to leverage hydrogen fuel for use in commercial-sized vehicles like busses. The push by state governments for zero emission public transport options has led to a partnership between TrueGreen and Chinese manufacturer Foton Global. The partnership will initially import hydrogen fueled buses into Australia with the long-term intention of building these buses locally at a facility in Moss Vale, New South Wales. Similarly, the University of Queensland has announced that it will add two hydrogen fuel cell buses to its fleet by 2022 with support from the Queensland Government's Hydrogen Industry Development Fund. These busses will be fueled by hydrogen produced through electrolysis using renewable power from the University's Gatton solar farm. Notwithstanding the suitability for hydrogen-based public transport, there is still some progress required to make them venues for the widespread use of hydrogen vehicles.

"You can see from a public policy perspective how clean energy sources for things like public transport would be politically very attractive. The question is, how do you do that as a price point where the technology is not quite there,"

says DLA Piper Partner Alyson Eather.

"So the regulatory push in relation to pushing that as a policy, it'd be a highly regulated product. I would have thought there's a fair bit of work to be done to make that financially feasible."

Nation Profile: Japan

National Energy Security and Importation

As noted above, Japan was the first country to adopt a comprehensive hydrogen strategy when it adopted the Basic Strategy in 2017. This national plan aims to achieve cost parity with petroleum in the transport sector as well as LNG used in power generation. It accounts for all aspects of the nation's hydrogen adoption, including retail and shipping, production, and supply chain. In July 2021 the Japanese METI continued to iterate on the nation's hydrogen strategy by releasing a draft Strategic Energy Plan. The draft plan foreshadows the transition to renewable energy at a greater rate than previously expected – outlining that Japan will target 36% to 38% renewable energy power generation by 2030 (including 1% hydrogen/ammonia power generation). The new target is a significant increase from the current goal of 22% to 24% renewable power generation by 2030.

In terms of energy security, Japan is primarily reliant on imports from the Middle East for roughly 87% of the nation's oil supply. Further, the country also sources approximately 94% of its total energy supply from imported fossil fuels. In contrast, only 2% of its vehicles are currently running on alternative fuels or electricity.

> *"Japan's highly successful economy and industrial growth is reliant on importation of energy resources, particularly fossil fuels. Japan is a densely populated country and therefore has limits on the amount of land it can commit to renewable energy sources. Additionally, given that Japan is an island, there is limited opportunity to import green electricity through submarine power cables or hydrogen through gas pipelines. Therefore, there is an increased focus by Japan on the importation of green energy sources such as hydrogen, particularly if they wish to achieve a net-zero target by 2050,"*

says DLA Piper Partner Tom Fotheringham.

Japan has already begun to investigate possible hydrogen import options. As noted above, in 2019 Japan and Brunei launched an international hydrogen supply chain involving the importation of a "liquid organic hydrogen carrier" to Japan. In March 2021 ENEOS Energy entered a memorandum of understanding with Saudi Arabian Oil Company (**Aramco**) to investigate establishing a blue hydrogen and blue ammonia supply chain. As part of the arrangement, ENEOS and Aramco intend to assess the viability of liquid hydrogen carriers (e.g. ammonia and methylcyclohexane) for importation from Saudi Arabia to Japan. Japan is also investigating the development of hydrogen importation and storage infrastructure at the Muroran and Onahama ports.

This importation demand has been exacerbated by the closure of the country's nuclear fleet following the 2011 Great East Japan Earthquake and the resulting tsunami which caused the Fukushima nuclear disaster. Japan's response to the disaster, in combination with the country's longstanding low levels of raw materials, leave it with the second-lowest energy self-sufficiency rate amongst Organisation for Economic Co-operation and Development member countries. In 2017 Japan committed to a greenhouse gas emissions reduction target of 26% below its 2013 emissions level by 2030 as part of the Paris Climate Agreement. More recently, in October 2020 the Japanese Prime minister declared that the country was targeting net zero greenhouse gas emissions by 2050 (a target common amongst many of Japan's developed economy peers).

> *"To promote decarbonisation and renewable energy, Japan needs to introduce hydrogen. However, Japan is not able to produce hydrogen in large volumes domestically, so we have no choice but to import the hydrogen,"*

says Osamu Ikeda from the Hydrogen Supply Chain Department of Chiyoda Corporation.

Like many of its international peers, Japan has yet to achieve a mature hydrogen sector and is currently subsidizing much of the hydrogen activity that exists within its borders. However, the nation has set a goal to reduce the current hydrogen retail price of JPY100/normal cubic metre (**Nm^3**) to JPY30/Nm^3 (USD0.28/Nm^3) by 2030 and JPY20/Nm^3 (USD0.18/Nm^3) over the longer-term (a target has not been specified, however, 2050 has been alluded to). The Japanese METI is also targeting self-sufficiency for the hydrogen industry, in terms of monetary support, by 2030. It is only once hydrogen becomes economically viable, which according to METI, is JPY20/Nm^3, that the Japanese government will add additional focus on its emissions-free production.

One of the hurdles standing in the way of reducing retail prices is the initial production costs. Due to the infancy of hydrogen production, and the role of exportation in Japan's hydrogen strategy, the nation will have to navigate early-stage high production costs. For example, the fact that hydrogen imported from Australian hydrogen will be produced from lignite (i.e. not a green source) necessitates production in combination with CCS technology. This results in increased production costs that will need to be borne by the importer. However, the increased cost means a reduction in the price gap between different hydrogen sources. Therefore, domestic production of green hydrogen may become at least competitive on a nearer timescale than initially was anticipated by most. Peter De Neef, Regional Representative Asia-Pacific / Global Solutions & Partnerships in the Hydrogen Business Unit at Engie, has appraised the costs associated with green hydrogen. On this, he says,

> *"Renewable electricity is the main cost of renewable hydrogen, and then its capex is the electrolyzer and equipment. That is the part that has more potential for cost reduction. Whilst for niche markets like FCEVs, we can expect to have parity with diesel mobility in a few years' time from now."*

According to the report, "Japan's Hydrogen Strategy and Its Economic and Geopolitical Implications" from the Institut francais des relations internationales (**Ifri**)[6] in 2018, Japan aims to develop supply chain networks of zero-emissions and low-cost hydrogen. Its domestic companies have begun to participate in international projects to progress in this area in places like Norway and Saudi Arabia. For this purpose, liquid hydrogen, methyl-hydrohexane, compressed hydrogen and ammonia are among the most feasible options. With regards to the latter option, Saudi Aramco has begun producing ammonia from natural gas, capturing the carbon through CCS and then exporting it to markets including Japan, and the state-owned oil company regards this as a key pillar of its bid to reduce its carbon footprint. While the 40 tons of ammonia that has so far been shipped to Japan was part of a pathfinder mission, Aramco views Japan as a natural longer-term customer for its ammonia.

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6 Monica Nagashima, "Japan's Hydrogen Strategy and Its Economic and Geopolitical Implications" from the Institut francais des relations internationales, Ifri, October 2018.

Figure 6: Japan's Targets for the Hydrogen Economy

Source: METI Hydrogen Roadmap 2014, Hydrogen Strategy (2017); "Japan's Hydrogen Strategy and Its Economic and Geopolitical Implications", the Institut francais des relations internationales (Ifri) (2018); inspiratia (2020)

	PRESENT		2020 TARGET		2030 TARGET			
	Scale	Cost	Scale	Cost	Scale	Cost	Long term (After 2050)	Reference Data
SUPPLY	Hydrogen derived from fossil fuels without CCS technology (industrial by-product, natural gas reforming)				Develop international hydrogen supply chains and domestic production from renewables.		Zero carbon H2 with CCS technology and renewables	
END USE								
POWER GENERATION	200 tonne/ year	Approx. USD10/ kg (Price at fueling stations)	4,000 tonne	N.A.	300,000 tonne	USD3/ kg	5-10 million tonne, USD2/ kg	Annual LNG import 85 million tonne
MOBILITY								
FUELING STATIONS	100	Construction cost: USD 4.5-5.4 million Annual operating cost USD 450,000	160	Competitive without subsidies in second half 2020	900	N.A.	Replacing gasoline stations	31,500 gasoline stations Construction cost USD $630,000-720,000
FUEL CELL VEHICLES	2,000	Toyota Mirai USD 66,000	40,000	Competitive without subsidies in second half 2020	800,000	N.A.	Replacing gasoline cars	62 million Passenger cars
FC BUSES	Approx. 2 buses	Approx. USD900,000	100	N.A.	1,200	N.A.	Large FC vehicles	
FORKLIFTS	40 forklifts	N.A.	500	N.A.	10,000	N.A.	Large FC vehicles	
HOME FUEL CELLS	220,000	Rough cost estimate of Ene-farm. Approx. USD11,000	N.A.	Competitive in early 2020	5.3 million	N.A.	Replacing conventional residential energy systems	53 million households in Japan Cost of conventional heat and power systems USD 5,400-6,300

Production, Storage, Transportation and Distribution

In the short-term, hydrogen in Japan is expected to be produced domestically as a by-product of the refining and steam reforming of fossil fuels. In the long-term, Japan's commercialization strategy is to mass-produce hydrogen from low-cost, unused energy using CCS technology as well as cheap renewable energy sources.

Despite this strategy, Japan is already at the forefront of the clean hydrogen production. Since 2019, the Japanese government had spent more than USD16 billion on hydrogen research and development since the 2011 disaster at the Fukushima nuclear plant. One of the products of this investment, the Fukushima Hydrogen Energy Research Field project, was completed in March 2020 becoming the world's largest green hydrogen production plant powered by solar when it comes online from Spring 2021. With a potential maximum capacity of 10MW, the plant will be able to produce up to 2,000 Nm^3/h (averaging 1,200 Nm^3/h), which is enough to power at least 150 homes or 560 FCEVs. Toshiba Energy Systems and Solutions Corp. are leading the project's development and Asahi Kasei is acting as technology provider.

In March 2021 Japanese energy company ENEOS and engineer Chiyoda announced another project that will help the government drive down hydrogen production costs. The project will involve construction of a solar powered green hydrogen plant that will leverage proprietary electrolysis technology with the aim of reducing costs from JPY1,100/kg to JPY330/kg by 2030, and eventually JPY220/kg. The partnership is looking to Australia and other locations as a site for the project's construction.

However, as noted above, Japan's hydrogen strategy looks to leverage all aspects of the supply chain, including storage and transportation (notwithstanding the resourcing issues the nation faces). In June 2020 Kawasaki Heavy Industries announced it would start selling a hydrogen liquefier.[7] In addition, the company has several hydrogen related tanks and storage containers specifically designed for containing liquified hydrogen. Kawasaki's asset portfolio includes the world's first liquified hydrogen carrier, Suiso Frontier, a 380 foot vessel with 1,250m^3 storage capacity that will be used to export hydrogen from Australia back to Japan.

Kawasaki is also a member of the consortium developing the Australian-based HESC Project (discussed **above**) which aims to produce liquid hydrogen in the Latrobe Valley, Victoria for exportation back to Japan. If the project is successful, the parties will aim for large-scale commercialization in 2030 which is projected to involve annual production of 225,000 tonnes of hydrogen. Other Japanese consortium participants include Marubeni Corp, J-Power Systems, and Iwatani Corp. Relevantly, Australian brown hydrogen currently costs JPY29.8/Nm^3 (USD0.27/Nm^3).

[7] Liquefaction of gas hydrogen into a liquid state (condensation). The liquefaction of gases uses various compressions to achieve high pressures and very low temperatures.

Hydrogen Fuel and FCEVs

In March 2019 the Japanese Council for a Strategy for Hydrogen and Fuel Cells released its revised Strategic Roadmap for Hydrogen and Fuel Cells (**Strategic Roadmap**; the 2019 iteration was published following the release of the Basic Strategy in 2017 and Japan's Fifth Strategic Energy Plan in 2018). According to the Strategic Roadmap, the Japanese government is aiming to increase the number of hydrogen refuelling stations to 900 in 2030 through technology development and deregulation aimed at decreasing construction and management costs of hydrogen stations.

Market research company Fuji Keizai has similarly estimated an increase in hydrogen refuelling infrastructure to meet the increased demand for domestic hydrogen. The market researcher has predicted more than 1,300 hydrogen refuelling stations being built in Japan by 2030 (a more than 10-fold increase). Fuji Keizawa cites expected growth in the Japanese hydrogen market to approximately JPY408.5 billion by 2030 (representing more than 50-fold growth from current levels).

"Currently, there are not enough fuel cell vehicles on the road for hydrogen stations to be economically feasible. In addition to the acceleration of technology development, government support and market mechanisms are essential to build out the infrastructure and to increase the number of fuel cell vehicles on the road. Discussion between industry players and the Japanese government is ongoing,"

adds Osamu Ikeda from Chiyoda Corporation.

However, according to the Association of Hydrogen Supply and Utilization Technology (**HySUT**) a significant reduction in costs will be needed before there can be improvements in the availability of hydrogen refuelling infrastructure. Building out a supply chain at scale will be a crucial component of achieving this. Further, supply chain development must be supported by the implementation of harmonized standards and practices across the hydrogen sector. If this aspirations can be put into practice, then the shorter manufacturing times it would make possible would be highly advantageous and provide benefits to any group involved in the industry at any point right along the supply chain. Japan's government is overhauling its regulations to make gains in this area. As noted above, the Japanese government has already been taking regulatory steps to facilitate growth in refuelling infrastructure. In 2018 METI began to relax fire safety regulations that made it difficult to build hydrogen refuelling stations. The ministry's changes now allow the siting of hydrogen facilities in locations already host to traditional petrol stations for cars, creating potential value for existing operators.

A correlative of the increase in demand for hydrogen fuel infrastructure is an increase in adoption of FCEVs. Japanese companies are currently world-leaders in the development of hydrogen fuel cell vehicles. Specifically, by the end of 2018 Toyota and Honda were producing one quarter of all FCEVs around the world. At the end of 2020, approximately 4,600 FCEVs were sold. According to the Fuji Keizai study, FCEVs in Japan are predicted to increase to 636,900; by 2030 the vast majority being cars. In May 2021, Toyota announced that it plans to sell an aggregate of two million battery electric vehicles (**BEVs**) and FCEVs in 2030.

One issue with respect to hydrogen vehicle production is the cost. The Japanese government's hydrogen strategy forecasts that the difference in list price between a new hybrid car and a new fuel cell car will decline to JPY0.7 million over the next five years, down from approximately JPY3 million today. Meanwhile, electricity produced by hydrogen fuel cells is currently around twice as expensive as producing it via conventional methods at around JPY40/kWh. The hydrogen fuel market in Japan should expand substantially from JPY7.3 billion in 2018 to JPY408.5 billion by 2030, according to projections by Fuji Keizai.

"Japan has a big advantage in terms of technology development, but more collaboration is needed for market and business creation, both on domestic and on international levels,"

concludes Osamu Ikeda from Chiyoda Corporation.

Developments in the Japanese FCEV space are also progressing in several areas outside the use in personal vehicles. For example, Toyota has been developing its SimpleFuel hydrogen production modules which are powered by photovoltaics for use with forklift trucks. Toyota states that each module will be able to fully refuel up to eight forklifts every day and predicts a spike in demand for this kind of FCEV in the logistics sector. Additionally, Toyota has recently released the second generation of its Mirai fuel-cell car (i.e. the first hydrogen car to hit the mainstream consumer market). The new model has three tanks – one more than the first generation – which hold its hydrogen fuel. According to the carmaker, the additional fuel tank results in a full-tank range of 850km.

Meanwhile, Japan's largest rolling stock operator, East Japan Railway Company (**JR East**), has partnered with Hitachi and Toyota to develop a hybrid fuel cell and lithium-ion battery powered locomotive. JR East will invest approximately JPY4 billion to develop the train as a steppingstone to start testing by Q1 2022 and bring it to market by 2024.

In the residential market, Panasonic has rolled out a product called "Ene Farm" which will make fuel cells available for use in domestic settings. The company claims to have reached a point where the Ene Farm business model will not require any government support whatsoever, opening up the option of exports around the world as a result. In 2020 Toshiba began offering its equivalent hydrogen fuel cell product H2OneTM for use in the commercial sector (for example, targeting larger buildings). The company is supplying the product to brewery giant Asahi Breweries as well as other business users.

Additional testing of hydrogen use cases are being conducted by Tohoku Electric Power and Toshiba at the hydrogen production plant in Namie, Fukushima Prefecture. The two companies are working on methods to make hydrogen a viable option as fuel in the power generation sector. The scheme intends to generate and store approximately 900 tonnes of hydrogen per annum.

Notwithstanding increased public and private investment in the sector, the Japanese government understands that public acceptance of hydrogen is crucial. To facilitate acceptance, Tokyo has deployed 100 fuel cell buses as the official transportation of the 2021 Olympic Games. That will be in addition to 500 Toyota Mirai cars – the world's first commercial hydrogen vehicle – which will ferry athletes and VIPs around the city during the games. Further, hydrogen sourced from Fukushima will be used to provide energy for the athletes' Olympic Village in a demonstration of the all-round potential of hydrogen as an energy carrier.

Nation Profile: The Republic of Korea

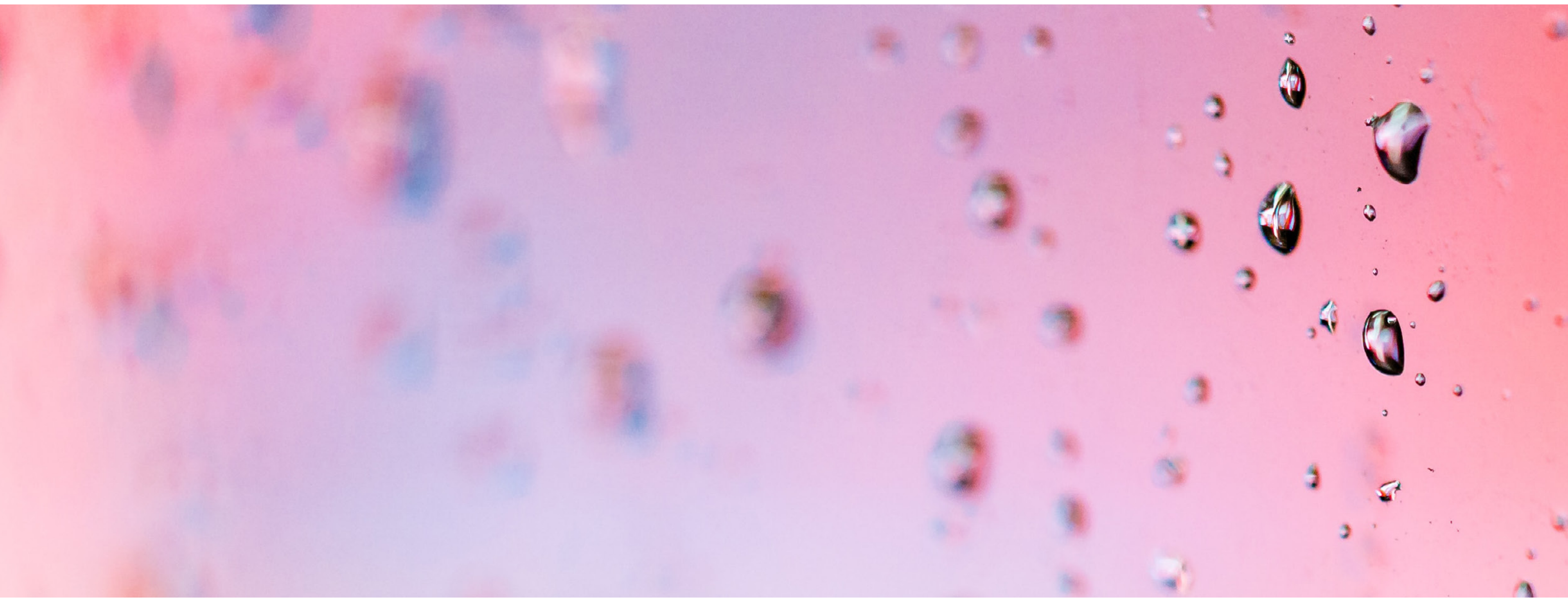
National Production, Importation and Development Strategies

The Republic of Korea is a global leader in the push to develop an integrated hydrogen economy as part of a path to decarbonization. The world´s first commercial FCEV – the Tucson ix35 – was launched by Korean automotive manufacturer Hyundai in 2013. In 2015, POSCO Energy, the largest private energy group in the country, developed the then-largest fuel cell manufacturing facility in the world. In 2018, ideas around how hydrogen could be used to boost the Korean economy began to crystalize within the country's government.

In June 2018, the Republic of Korea's Ministry of Trade, Industry and Energy announced a KRW2.6 trillion package until 2022 to support public and private sector cooperation to accelerate the development of the country's FCEV industry. Following that initiative, in 2019 the government published the "Hydrogen Economy Roadmap of Korea" and "National Roadmap of Hydrogen Technology Development" (together, **Korean Roadmaps**). The Korean Roadmaps contain the nation's FCEV and hydrogen targets for the years running up to 2040. To further build on those plans, in February 2020 the National Assembly of Korea passed the "Hydrogen Law" (discussed **below**) to set out the framework under which projects would be developed and what government support would look like (including provisions for hydrogen equipment safety regulations, certification and the role of government bodies). The Hydrogen Law took effect in February 2021.

In terms of the targets, the Korean Roadmap is aiming for 6.2 million FCEVs manufactured by 2040, with 3.3 million of these exported and the remainder for domestic consumption. By 2040 the target for fuel cell power generation is 15GW, including 7GW for export, with 2.1GW for buildings in the form of stationary fuel cells. The nation's strategy also stipulates that FCEVs will replace some 80,000 taxis and 40,000 buses by 2040, as well as 30,000 trucks. Financial subsidies have also been implemented to encourage the transition to FCEVs. For example, the Korean Government is contributing half the list price of a standard new hydrogen car (e.g. between KRW32.5 million and KRW36 million).

At present, the Republic of Korea´s hydrogen strategy is behind others in terms of decarbonization credentials. This is due to the nation's reliance on petrochemical plants or natural gas reforming without CCS technology to upscale hydrogen production. Further, the strategy fails to incorporate green hydrogen for use in the industrial sector. The combined hydrogen production in the Republic of Korea´s three principal petrochemical clusters is around 2 million tonnes. These production facilities have been strategically located in regions with correlatively high hydrogen demand. It follows that any growth plans for this industry will result in a steady climb in hydrogen demand. The Korean government predicts that this growth will help the nation's hydrogen demand rise to 0.47 million tonnes by 2022, 1.94 million tonnes by 2030, and 5.26 million tonnes by 2040.



> *"Korea is a heavily gas-dependent country. Green hydrogen is the ultimate source-target, but blue hydrogen is inevitable. At the moment, everybody is trying to minimize the costs and addressing the challenge of deploying new infrastructure. So, every player is trying to leverage existing legacies,"*

says Kim Ki-hyun, CEO of Korean industrial Iljin Composites.

Although green hydrogen is the long-term goal, there is ambiguity as to the steps that will be taken by Korean government and industry to achieve this overarching ambition. However, what is clear is that there is a significant short-term role to play for hydrogen production from natural gas. Peter De Neef, Regional Representative Asia-Pacific / Global Solutions & Partnerships at the Hydrogen Business Unit at Engie, outlines that the initial approach to start a green hydrogen economy would be to inject hydrogen into industrial chemical assets,

> ***"Hydrogen is a powerful element to decarbonize heavy industry and mobility applications, for instance, refineries, chemical sector and ammonia. Actually, any substance that already has hydrogen in it can benefit from renewable hydrogen production."***

Figure 7: The Republic of Korea´s Targets for Hydrogen Storage and Transportation

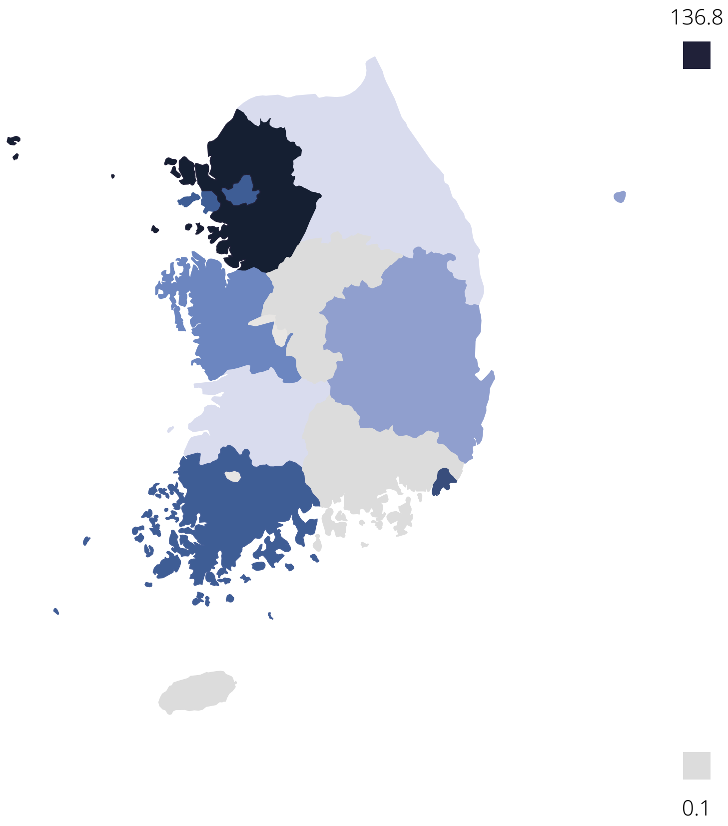
Source: "Hydrogen Economy Roadmap of Korea", Ministry of Trade, Industry and Energy (2019)

	PRESENT	2022	2030
TUBE TRAILERS	500	Large-scale gas storage and transportation	Liquefaction and liquid and solid hydrogen storage and transportation
PIPELINE	200km	Establish hydrogen pipelines near sources of by-product hydrogen production (Ulsan, Yeosun, and Daesan)	Consider the construction of high-pressure hydrogen pipelines nationwide
CORE ISSUES	–	Establish base of supply centered on demand	Establish supply infrastructure nationwide

Generally, the Republic of Korea's renewable energy plans dictate that its energy mix will be 20% clean by 2030. The nation will then target a 30%-35% energy mix by 2040. As in many other countries, there is a limit to how much of this can be achieved by electrification of energy demand. Consequently, hydrogen can also have a distinct role to play in this plan.

Figure 8: Fuel Cell Power Generation (MW) per province of the Republic of Korea

Source: "Hydrogen Korean Economy Roadmap", Ministry of Trade, Industry and Energy (2019)



PROVINCE	SERIES1
GYEONGGI	136.8
CHUNGCHEONGNAM-DO	10.2
JEOLLABUK-DO	0.5
JEOLLANAM-DO	25.4
GANGWON-DO	0.1
GYEONGSANGBUK-DO	2.4
SEOUL	42.0
INCHEON	38.6
DAEGU	11.2
ULSAN	2.8
BUSAN	37.6

SECTOR	MW	PLACES
TOTAL POWER GENERATION	307.6	41
HOMES/BUILDINGS	7.05	3,167

In the power sector, the country's largest utility provider, Korea Electric Power (**KEPCO**), announced plans to progress green hydrogen and power-to-gas demonstration projects alongside local authorities in Jeollanam-do and Naju City in 2019. These plans illustrate the types of projects leading operators in the space are beginning to explore. However, renewable electricity production in the Republic of Korea is amongst the costliest in the world. According to a 2018 study by the Korea Energy Economics Institute, typical solar and onshore wind costs are between USD10 and 12 cents/kWh. Importantly, the IEA estimates renewable electricity costs need to be USD1 to 4 cent/kWh with full load hours of 3,000 to 6,000 hours per annum before green hydrogen production using electrolysis can compete with SMR with CCS. Therefore, there is a long way to go in the Republic of Korea before this section of the market can stand on its own.

The Republic of Korea is also eying the potential hydrogen import market developing in the APAC region and globally. For example, in June 2019 the Republic of Korea and Norway entered a memorandum of understanding to develop ships for liquefied hydrogen transportation. The aim of the partnership is to overcome some of the problems associated with liquid hydrogen transportation, including by developing new technology necessary for safe exportation.

"We have gas infrastructure in place as Korea is one of the biggest LNG import countries. We don't have the natural resources, so we will import green hydrogen. The Korean government will judge if it is better to import gas and reform it or import green hydrogen from Australia, for instance,"

says Kim Ki-hyun, CEO at Iljin Composites.

The Australian relationship will, like in other markets across the region, prove crucial in the coming years. The public-private partnership H2Korea has already signed a memorandum with the Australian Hydrogen Council to foster collaboration on hydrogen-related issues, exchange information and facilitate the development and deployment of emerging hydrogen technologies. This memorandum is in addition to other bilateral projects between the two countries which include a green hydrogen pilot scheme jointly developed by Australia's Woodside Petroleum and Korean LNG import specialist Kogas. More recently, in June 2021 the Australian Prime Minister and South Korean President agreed at the annual G-7 summit to expand the two nation's economic cooperation in relation to low-carbon technologies such as hydrogen production.

Notwithstanding the environmental benefits associated with the hydrogen transition, the Republic of Korea is looking to hydrogen primarily to encourage economic growth. This contrasts the strategy of other developed economies that see hydrogen as a tool to decarbonize. The Republic of Korea does, however, currently have less ambitious climate reduction targets than many of its peers. At present, only a 37% cut in greenhouse gas emissions (beneath a "business-as-usual" level) by 2030 has been. Therefore, the immediate requirement to use hydrogen to decarbonize the nation's more resilient industries (as is envisaged by many) does not yet exist.

The Korean government has acknowledged that the economic growth targeted cannot come without significant emissions attached. Consequently, the country has begun to look at an economic agenda for growth with hydrogen as the driving force. In February 2020, the Republic of Korea´s National Assembly passed the Hydrogen Economy Promotion and Hydrogen Safety Management Law (i.e. the "Hydrogen Law"). This law, which took effect in February 2021, takes a number of steps to further the nation's hydrogen agenda including through the implantation of government industry subsidies and the establishment of the "Hydrogen Economic Committee". The Hydrogen Economic Committee will serve to oversee the implementation of the hydrogen economy and issues relating to industry, promotion, distribution and safety.

It is expected that this new law will assist in transitioning the Republic of Korea to a green hydrogen industry. Currently, the government is targeting 70% of the country's hydrogen demand being achieved through low-carbon hydrogen by 2040 (either produced locally from renewables or imported). However, implicit in that target is the fact that a sizeable minority of Korean hydrogen consumption will be of the grey variety for some years to come.

Snapshots of Other APAC Region Profiles

China

Hydrogen demand in China is massive. In 2019 China produced 36% (approx. 20 million tonnes) of the 55 million tonnes of hydrogen produced globally. Further, the Chinese Hydrogen Alliance has predicted that domestic hydrogen demand will reach 36 million tonnes by 2030 and 58 million tonnes by 2050 (accounting for 5% and 10% of the total energy consumption, respectively).

Currently, 97% of the total Chinese hydrogen production mainly depends on fossil fuels and on industrial by-product. In order to achieve the long-term goal of being a major green hydrogen producer, the Chinese government hopes to increase the share of green hydrogen supply to 15% by 2030, 45% by 2040, and 70% by 2050.

In March 2021 the Chinese National People's Congress adopted the country's 14th Five-Year Plan (**Five-Year Plan**). The Five-Year Plan sets out the nation's economic and social targets for the period between 2021 to 2025, including a binding target for cumulatively reducing CO_2 emissions by 18% per unit of GDP. Transitioning the nation's economy to include development of emerging 'new energy automobile' technology (e.g. FCEVs) is another key pillar of the Five-Year Plan that supports the October 2020-adopted 'New Energy Automobile Industry Development Plan' for 2021 to 2035. Similar five-year plans aimed at accelerating the development of the emerging automotive industry have been adopted by various Chinese provincial governments (e.g. Beijing, Shanghai, Guandong Province). The implementation of these plans is already starting to be seen – in the first five months of 2021, 35 government subsidised FCEV and hydrogen refuelling projects have been commissioned worth approximately CNY110 billion (approx. USD17 billion).

China has yet to adopt a national hydrogen industry plan (although the strategy drafting process has begun). However, the hydrogen push is being seen at the provincial level in several government plans for 2021 to 2025. These plans cover several hydrogen-related topics, including development of large-scale grey and green hydrogen production facilities and fuel cell infrastructure projects. Therefore, it is expected that the Chinese government´s strategic plan for hydrogen energy will, to some extent, target self-sufficiency. Consequently, the Chinese economy is expected to import less hydrogen than other markets like Japan and the Republic of Korea. It is also likely that hydrogen will receive greater focus in China as part of the President's September 2020 pledge that the nation will reach carbon neutrality by 2060.

India

The majority of India's hydrogen is produced through SMR (i.e. blue / grey hydrogen). The country has yet to make a breakthrough in terms of fully developing large-scale pathfinder projects. However, it is encouraging research and development of hydrogen applications, storage, and production. To support this push, in April 2021 the Indian Government:

- announced it would be spending USD200 million over the next five to seven years invigorate the development of India's hydrogen market; and
- requested a number of its state-owned energy assets to commission seven pilot hydrogen production plants before the end of the 2021 financial year. Subsequently, in July 2021 government owned IndianOil announcement that it would begin construction on a green hydrogen production facility at its Mathura refinery.

This drive is also starting to see progress in the private sector. For example, in March 2021 Fusion Fuel Green and BGR Systems announced of a partnership for the development of green hydrogen production projects in India. Once an initial, solar-based production facility has been developed in Tamil Nadu the partnership will look to develop larger projects in the region.

In addition to production projects, Indian universities Banaras Hindu University and IIT Dehli have partnered with Mahindra & Mahindra to develop hydrogen-fueled combustion engines. Further, two hydrogen refuelling stations have been established at the Indian Oil R&D Centre and the National Institute of Solar Energy.

According to New Delhi-based 'The Energy and Resources Institute', there is potential to scale up hydrogen use in India up to ten-fold by 2050. This suggests policymakers will have to push carbon-capture technologies that encourage production of hydrogen from coal. This was demonstrated in a November 2020 announcement made by India's president that the nation was poised to launch a "Hydrogen Energy Mission in 2021-2020 for generating hydrogen from green power sources". In 2020, Reliance Industries announced plans to embrace hydrogen in its efforts toward making itself a net-carbon zero firm by 2035.

New Zealand

In 2019 the New Zealand Ministry of Business, Innovation & Employment released the green paper, "A Vision for Hydrogen in New Zealand" (**NZ Green Paper**). The NZ Green Paper was the product of public and industry consultation on the issues and opportunities associated with incorporating a hydrogen economy into the nation's renewable energy strategy. The report served as the initial outline for New Zealand's renewable energy pathway carbon-neutral status by 2050.

The next stage of New Zealand's strategy is to develop a hydrogen roadmap that explores the issues that need to be addressed for wider hydrogen use within the community and the steps to resolve those issues. The government has commissioned strategic adviser Castalia to prepare a model of possible scenarios for New Zealand's future hydrogen economy. The model will inform whether New Zealand's role will be as exporter, importer or producer (which will ultimately depend on relative electricity prices in competitor nations).

Hydrogen is already starting to play a major role in supporting New Zealand's carbon-neutral transition. In March 2021 Firstgas Group announced a plan to decarbonize New Zealand's natural gas pipeline network using hydrogen. From 2030, hydrogen gas will be blended into the North Island's gas network. The Group is targeting 100% conversion to a hydrogen-based gas network by 2050. The transition will be supported by biogas (i.e. gas produced from waste products) and bioLPG (i.e. propane produced from plant and vegetable waste products). The country is also home to a number of proposed and existing hydrogen production facilities (e.g. Port of Auckland hydrogen production and refuelling facility, Tauropaki Trust geothermal green hydrogen production project) and FCEV-based projects (e.g. the NEXO fuel cell powertrain, FCEV passenger busses for South Island tourism).

New Zealand has also begun fostering international hydrogen partnerships in the APAC region. In October 2018 the country signed a Memorandum of Co-operation on Hydrogen with Japan. The agreement will encourage the governments, industrial stakeholders and research institutes of both countries to collaborate in the hydrogen space. Further, in November 2019 New Zealand and the Republic of Korea signed a letter of intent to investigate the feasibility of developing a green liquid hydrogen supply chain, underpinned by hydrogen produced in New Zealand (using renewable electricity) and exported to Korea for domestic distribution.

About inspiratia

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