Perception of the Implementation of a Hydrogen Economy in Asia-Pacific: An Expert Survey

Regional Project Energy Security and Climate Change Asia-Pacific (RECAP)

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Foreword

The importance of hydrogen as an energy carrier, which allows to store electricity from various sources of renewable energies and transport it over a long distance, is more and more recognized in major parts of the global industry. All over the world there are efforts to develop the potential of a hydrogen economy to achieve climate-neutral targets. In the EU, for example, hydrogen is seen as essential for securing future climate-neutral energy supply. The EU is mobilizing extensive financial resources for this. Individual EU member states such as Germany are also promoting the hydrogen sector with their own national programs and international partnerships. With regard to Asia, Germany can already refer to hydrogen cooperations with selected countries. The focus of theses cooperations is on possible hydrogen trading relationships, the development of common economic framework conditions and the exchange in the field of research and development of corresponding technologies.

In Asia itself, the first countries are already beginning to build hydrogen infrastructure for production, storage, transport and use. There the importance of hydrogen for the challenges of decarbonization is recognized and is developed according to the national frameworks. Globally, the development of a hydrogen economy in Asia is of particular importance. Nowhere in the world is the demand for energy increasing so rapidly and nowhere are more fossil fuels being consumed. If the energy carrier hydrogen succeeds here, then path dependencies in the energy industry that have grown over decades could possibly be overcome and the prerequisites for a climate-neutral energy supply could be developed. This survey reflects the perceptions of Asian energy professionals from nine different countries (Australia, China, India, Indonesia, Japan, South Korea, Malaysia, Thailand and Singapore) on the state of the hydrogen economy. I wish you an interesting reading.

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1 Executive Summary

This report summarises the perception of expert insights on the expectations, concerns, and barriers to local hydrogen implementation in nine major countries in Asia-Pacific (APAC) — Australia, China, India, Indonesia, Japan, Malaysia, Singapore, South Korea, and Thailand. These countries represent the nine largest economies by GDP in APAC and are highly representative of the APAC region. Meanwhile, these countries' ongoing innovative and varying degree of hydrogen development is of great reference value for the EU to consider. Konrad Adenauer Foundation's Regional Project Energy Security and Climate Change Asia-Pacific has commissioned IPSOS to conduct 57 pilot and in-depth expert interviews with experts from each of the nine countries, with a minimum of six interviews in each country. The interviews were conducted via internet calls between December 2021 and April 2022. On average, the interviews lasted for approximately 60 minutes.

We asked the experts about: the hydrogen development in their country of expertise; projects or initiatives they have been involved in; how they perceive the current status, speed, and direction of the local hydrogen development; what the barriers and supportive factors are to the local hydrogen development; where they see the hydrogen economy development going in the coming future; and suggestions for development acceleration.

The experts generally agree that their country of interest is making progress in advancing hydrogen economy development, with common goals to decarbonise different sectors, reduce energy dependency on fossil fuel imports, and drive domestic economies by creating new job opportunities. Meanwhile, many of the experts perceive that their countries are only at the early stage of hydrogen adoption as the hydrogen economy concept is relatively nascent in APAC, except in Japan. And to effectively drive hydrogen development, the experts believe that official direction from the national level is fundamental, while most APAC hydrogen economies are now stymied by the high cost of clean hydrogen production and lack of infrastructure for transportation and storage.

In the future, experts believe that hydrogen will be mainstream energy in a decade or more in many of the nine APAC countries. In particular, many countries have been putting efforts into lowering the cost of hydrogen deployment along the value chain and increasing the supply of green hydrogen. The experts foresee that hydrogen will be vastly adopted in the mobility, power, industrial, and non-industrial gas sectors when the cost is lowered to a more reasonable level for end-users.

To accelerate the local hydrogen development, all the experts agree that governments should provide more financial support to public and private entities as many perceive the current financial support as being insufficient. On top of government support, the experts suggest that different stakeholders should build strategic relationships to exchange opinions and technological know-how to facilitate the collaborative development of policies and initiatives.

Table 1 Summary of Country-specific Expert Insights

	Country-specific Expert Insights: Perception, Impacts and Mitigation
Australia	Australia is a regional raw material exporter that is now looking to produce and export hydrogen on a large scale. It has good infrastructure to use hydrogen to promote domestic decarbonization, among others in the transport and mining sectors. Coordination between the government and the private sector would have to be improved for this to happen.
China	China has the political will and the prerequisites, such as renewable energy and industrial manufacturing capacity, to become a leader in the hydrogen economy. The inadequate inter-province infrastructure and the availability of suitable technologies are currently perceived as the largest obstacles.
India	India has great potential for a domestic hydrogen economy, which could, among other things, contribute to climate protection through the use of green hydrogen and help improve energy security by reducing energy imports. However, experts are skeptical about how the existing hydrogen policy will be translated into effective measures.
Indonesia	Indonesia's climate policy could become a driver for the development of a domestic hydrogen economy, which could enable the export of hydrogen in the long term. The lack of a national hydrogen strategy is seen as an obstacle to develop corresponding infrastructures, especially given the diverse geographic conditions in Indonesia.
Japan	Japan is a forerunner in the implementation of a hydrogen economy and a leader in the development of corresponding technologies due to extensive early stage state support. However, current policies need to be adjusted to provide sufficient incentives for private sector investments in the hydrogen production.
Singapore	Singapore recognizes the importance of hydrogen as a key tool to decarbonize the economy. The existing gas infrastructure is seen as an advantage for the future use of hydrogen. However, the size of the country is seen as a natural constraint on a hydrogen economy market ramp-up.
South Korea	South Korea has good prerequisites for establishing an efficient hydrogen economy due to the technological capabilities of its big industrial companies. However, there are deficits in the implementation of national hydrogen strategies in terms of infrastructure and storage facilities.
Thailand	Thailand experts are seeing great potential for the use of hydrogen in the industrial, transport and heating sectors. However, the general perception is that the current priority of the government is expansion of renewable energies, e.g. in electric vehicles instead of hydrogen fuel cells.
Malaysia	Malaysia has the potential to become a hydrogen exporter in Southeast Asia in the long term. So far, however, the development of the hydrogen economy has only taken place at the provincial level. In addition, there is a lack of standards and regulations along the hydrogen value chain and sufficient state support.

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Introduction

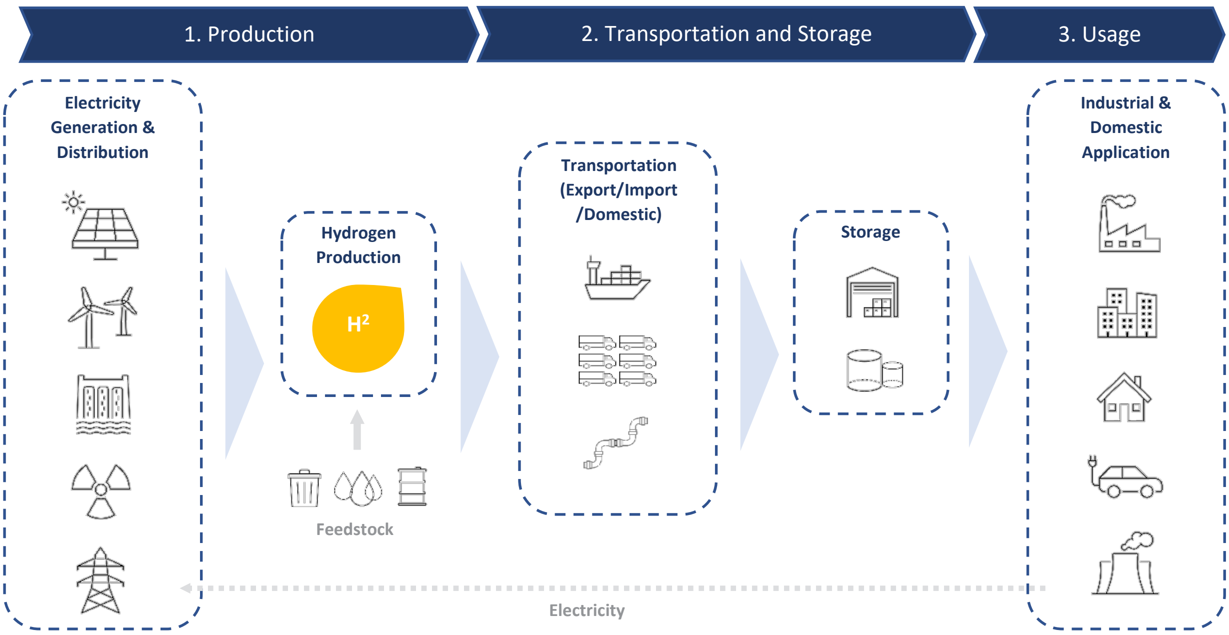
3.1 Hydrogen Economy

The hydrogen economy concept generally refers to using hydrogen as commercial fuel to replace fossil fuel in the empowering of social and economic activities. For instance, two of the most prevalent examples include hydrogen fuel cell electric vehicles (FCEVs) leveraging hydrogen instead of gasoline as a vehicle fuel and heating systems leveraging hydrogen instead of coal as a heating fuel.

The hydrogen economy comprises several stages within its value chain, namely production, transportation and storage, import and export, and usage. The value chain generally includes stakeholders such as government entities, international organisations, public corporations, private corporations, and end-users, where each stakeholder needs to play a vital role in the direction and pace of the development of the hydrogen economy. For instance, government entities could accelerate the development by issuing financial incentives, and private corporations could support the hydrogen economy by building specific infrastructure and developing applications which utilise hydrogen. However, there are several technical, social, and political barriers that each country must overcome to accelerate the development of the hydrogen economy.

The key activities on the supply side of the hydrogen economy include production, import, storage, and transportation of hydrogen, while those on the demand side of the hydrogen economy include export, industrial usage, and domestic usage of hydrogen.

Figure 1 Key Activities from Hydrogen Supply to Demand



3.1.1 Hydrogen Production

Hydrogen is not freely available in the environment, and it takes energy to extract hydrogen from hydrogen-containing compounds. The most frequently used hydrogen production methods are thermochemical processes that use heat and chemical reactions to release hydrogen from organic materials such as fossil fuels and biomass. Common examples of thermochemical processes employed for hydrogen production are steam methane reforming (SMR), coal gasification, and biomass gasification. Water electrolysis with renewable energy as a power source is widely used to produce hydrogen thereby eliminating carbon emissions. There are two main types of electrolysers: Akali-based electrolysers and Polymer Electrolyte Membrane (PEM)-based electrolysers. Akali-based electrolysers are not ideal for countries that depend mostly on wind and solar renewable energy sources due to the long restart time required upon interruption of the highly unstable renewable energy generation process. For example, clouds temporarily blocking the sunlight could halt hydrogen production and need a few minutes to restart the production with Akali-based electrolysers. On the other hand, PEM-based electrolysers are ideal for situations where higher flexibility is required and can restart within seconds after interruptions of the energy source.

Hydrogen is then transported to storage facilities and various secondary or tertiary application sites. As an energy source, hydrogen is generally more expensive than other energy sources, as it requires energy to extract hydrogen via various means. Mass production is needed to achieve economies of scale and reduce costs for clean hydrogen production. While there is no official hydrogen nomenclature, experts generally refer to "black", "brown", "grey", "blue", and "green" hydrogen, depending on how hydrogen is produced.

Table 2 Hydrogen Nomenclature and Production Methods

	Common Production Technology	Production Pathway
Brown/Black Hydrogen	Coal gasification	Produced using coal as feedstock, depending on the type of coal — bituminous (black) and lignite (brown)
Grey Hydrogen	Steam methane reforming	Produced using natural gas (methane) as feedstock
Blue Hydrogen	Steam methane reforming with CCUS[i] Coal gasification with CCUS	Produced either from "brown" or "grey" production methods coupled with CCUS
Green Hydrogen	Water electrolysis with renewable electricity Biomass gasification	Produced from zero-carbon sources and generated using renewable energy such as solar, wind, geothermal and hydroelectric power or from renewable sources such as waste biomass or biogas. Water electrolysis is the most established and common method to produce green hydrogen

i Carbon Capture, Utilisation and Storage (CCUS) include methods and technologies to remove carbon dioxide (CO_2) from the flue gas and from the atmosphere, followed by recycling of the CO_2 for utilisation and determining safe and permanent storage options.

3.1.2 Hydrogen Importing and Exporting

Besides producing hydrogen domestically, importing hydrogen is seen as a way to supplement domestic production by countries as importing could be more feasible, practical, and economical than domestic production in certain contexts due to various natural or technical constraints. Subsea transmission pipeline and seaborne transportation are two common options for volume transportation of hydrogen among countries, while each of the two options has its advantages over the other option depending on the scenario. Distance and volume are two major factors impacting the cost and efficiency of hydrogen imports. Many countries in APAC have established strategic partnerships on hydrogen imports with regional suppliers. These regional suppliers are countries with excess production capacity that may also have rich primary energy sources or could produce hydrogen at a cheaper cost. These hydrogen-producing countries will sell their excess supply to other hydrogen-deficit countries in the APAC region.

Japan and South Korea are perceived as two of APAC's largest hydrogen-importing countries. Driven by their increasing demand for hydrogen, their import volume could continue to increase in the future. In addition, hydrogen-importing countries aim to acquire cleaner hydrogen sources to meet their respective carbon reduction targets. On the other hand, Australia is currently perceived as the key hydrogen-exporting country in APAC because of its excess production capacity. It also aims to leverage its abundant renewable energy source to export more clean hydrogen across the APAC region.

3.1.3 Hydrogen Transportation and Storage

Hydrogen is normally transported in liquid or compressed gas form to maximise efficiency. Common hydrogen carriers are compressed gaseous hydrogen, liquified hydrogen, ammonia, methanol and liquid organic hydrogen carriers (LOHCs). Generally, a series of processes is needed to transform hydrogen into suitable physical or chemical forms for domestic and international transportation. Transporting hydrogen in the form of ammonia is considered the most mature technology available today due to its well-established usage in the fertiliser and chemical production industries. For most use cases, the reverse of the said processes would also be required to convert the transported hydrogen into a usable form.

Subsea transmission pipeline and seaborne transportation are the two common options for regional transportation. While a subsea transmission pipeline is generally a more efficient option for hydrogen imports and exports in transmission volume, construction requires huge capital expenditure upfront and involves certain safety considerations. Therefore, not many countries are currently importing or exporting hydrogen through pipelines. As a substitution, seaborne transportation is more common for inter-country trading of hydrogen. Also, shipments could be even more economical than pipeline transmissions if hydrogen is imported or exported between countries over long distances. For domestic transportation of hydrogen, tube trailers are commonly deployed for their higher accessibility to remote areas. However, the volume carried by tube trailers is relatively low, especially when compared to the use of pipelines. Nevertheless, a tube trailer is still the most prevalent option for domestic hydrogen transportation, especially for countries that are still conservative regarding hydrogen deployment, as it requires less capital investment than building pipeline infrastructure.

Hydrogen storage also requires investments in infrastructure and related technologies. Hydrogen storage in gaseous form typically requires high-pressure tanks, while hydrogen storage in liquid form requires cryogenic temperatures due to hydrogen's extremely low boiling point at normal atmospheric pressure of -253 degrees Celsius. Hydrogen can also be stored on the surface of solids or within solids but this is less common. While it is technically feasible to transform existing natural gas storage facilities into hydrogen storage facilities, the existing facilities would require substantial investment in retrofitting.

Hydrogen transportation and storage require extensive technology and infrastructure investments, limiting the pace and scale of development for some developing hydrogen economies. In addition, most countries are paying careful attention to the safety concerns of hydrogen due to its dangerous and explosive nature. As such, local governments often set rules and regulations to facilitate a safe hydrogen transportation and storage distance from residential areas — which may also impact the pace and scale of hydrogen deployment.

3.1.4 Hydrogen Applications

Hydrogen is mainly used in the industrial sector as a chemical catalyst and energy source replacement for different industry sectors. The industrial sector is currently the dominant sector for hydrogen usage in many countries. Hydrogen is a commonly used element as a chemical catalyst in oil refineries, ammonia production, methanol production, steel production and high-tech electronics. Besides usage as a chemical catalyst, hydrogen also has numerous applications across various sectors to replace traditional fossil fuels. For example, hydrogen can also be used as a feedstock for electricity generation. For instance, hydrogen and ammonia can be used as the fuel for gas turbines in power generation.

Moreover, hydrogen is a prevalent option as an energy carrier for storing renewable energy and providing energy to stationary fuel cell power systems while off-grid. In some developed hydrogen economies, hydrogen adoption can also be extended to home appliances, such as blending into the existing natural gas network and directly using hydrogen boilers. Finally, the mobility sector is one of the most promising sectors that are leveraging hydrogen. FCEVs are being deployed across the region to replace mainly Liquefied Natural Gas (LNG) or diesel-powered vehicles to cut their carbon footprint. At the same time, the competitiveness of FCEVs depends on fuel cell costs and the maturity of hydrogen refuelling station (HRS) networks. Commercial vehicles such as trucks and buses are often prioritised to reduce the delivery price of hydrogen.

Hydrogen can be categorised into pure hydrogen and non-pure hydrogen. Pure hydrogen has 99.999 per cent purity and is typically used for FCEV propulsion. As all FCEV HRSs are required to use 99.999 per cent pure hydrogen, non-pure hydrogen such as hydrogen refined from blue ammonia and methylcyclohexane (MCH) cannot be utilised at the stations. Non-pure hydrogen is generally reserved for power plants or as factory-grade fuel.

3.2 Hydrogen Strategy

The European Union (EU) is perceived as one of the world's largest hydrogen production and consumption entities. Given its similar history of hydrogen consumption to that of APAC countries and its substantial potential to deploy clean hydrogen, it serves as a meaningful reference framework comparison for APAC country-level evaluation. While the EU has issued a bundling hydrogen strategy to promote the production capacities for green hydrogen, the situation in the EU is similar to that of the APAC countries. The implementation of policies requires the active involvement of legislators and private stakeholders at the national level.

On a par with many APAC countries, the production and application of hydrogen in the EU are not novel, and the concept of clean hydrogen does not have a long history either. The EU currently uses approximately 339 TWh of hydrogen annually, with refineries, fertiliser production, and the chemical industry constituting most of the total consumption. To date, about 95 per cent of EU hydrogen is "grey hydrogen", the production of which is done via steam methane reforming and, to a lower extent, autothermal reforming (ATR).[1] The European Commission has recognised the potential to decarbonise the hydrogen segment and therefore identifies clean hydrogen as a key area for achieving carbon neutrality in the "European Green Deal" realised in late 2019.[2] Following such release, the EU issued a specific hydrogen strategy — "Hydrogen Strategy for a Climate-neutral Europe" in 2020 — as a roadmap to scale up its green hydrogen production. Four pillars have been put forward to support the transformation in the short, medium, and long term — (i) Fostering investments, (ii) Boosting supply and demand, (iii) Creating a supportive framework, and (iv) Promoting research and innovation.[3] While the strategy is designed at the EU level, the implementation still largely depends on member states' willingness to devote time and resources. Some member states have issued hydrogen strategies or related development goals, showing certain differentiations in their ambition and focus. With the roadmap only rolled out in 2020, the development in the EU is not particularly advanced compared to some countries in APAC.

While the production and application of hydrogen are not nascent among the nine APAC countries discussed in the report, it was not until recently that some of the countries released their national hydrogen strategies. Japan, the country with the longest history of hydrogen development among the nine countries, released its national hydrogen strategy in 2017, and it was the first national hydrogen strategy published across the globe. South Korea and Australia are also relatively advanced in their hydrogen development within the APAC region. They published their national hydrogen roadmap in 2019 to facilitate further development of both supply and demand-side activities. India and China have subsequently released their respective hydrogen strategies, while Indonesia, Malaysia, Singapore, and Thailand are yet to formulate or finalise their strategies for publication.

Like many European countries, all of the nine APAC countries are mainly producing grey or brown hydrogen domestically and starting to realise the necessity to decarbonise the industry by migrating towards the production of blue or green hydrogen. Therefore, most of the nine countries have included the development of green or blue hydrogen production in their national planning. Nevertheless, every country exhibits a different level of ambition depending on its current production capability and investment budget. For instance, China aims to increase its domestic clean hydrogen production to reduce its dependency on foreign energy sources. Australia, which is more mature in regard to hydrogen production technology, is also looking to export hydrogen to other countries after satisfying its domestic demand. To equip it with the capability of transporting hydrogen overseas, Australia is also focusing on developing hydrogen transportation infrastructure and technologies.

Fuel cell technology is frequently mentioned in the five published hydrogen roadmaps among various hydrogen applications. In particular, these countries all display a certain level of interest in developing the value chain along FCEV in their countries, hoping to increase transportation efficiency and decarbonise their mobility sectors. Apart from fuel cell technology, they have also set targets to decarbonise their power, industrial, and other sectors through hydrogen deployment.

As Japan, South Korea, and Australia released their national hydrogen roadmap earlier than other APAC countries and even the EU, their hydrogen development is perceived to be more advanced at the current state, with more notable projects being rolled out. Compared to other APAC countries and the EU, they are more advanced in their construction of hydrogen ecosystems, such as South Korea expanding its HRS networks in the country and Japanese automobile manufacturers maintaining their existing FCEV production streams. On the other hand, while business sectors in Indonesia, Malaysia, Singapore and Thailand are still awaiting official directions from their authorities, projects carried out in these countries have generally been of a relatively small scale to minimise investment risk. Nonetheless, relevant authorities in these APAC countries have supported the Research and Development (R&D) and implementation of pilot projects with grants and subsidies. With the inauguration of hydrogen development in multiple countries across APAC, it is expected to result in a synergy that could accelerate the hydrogen development of the entire region.

4

Methods

Methods

The Regional Project Energy Security and Climate Change APAC (RECAP) of the Konrad Adenauer Foundation (KAS) commissioned IPSOS Asia Limited (IPSOS), an independent international research and consulting agency, to conduct a study on the state of hydrogen development in APAC that the EU community can potentially reference for its implementations. This research focuses on the nine major countries in APAC — Australia, China, India, Indonesia, Japan, Malaysia, Singapore, South Korea, and Thailand and aims to provide expert insights on the expectations, concerns, and barriers to their local implementations. These countries represent the nine largest economies by GDP in APAC, with a combined population of approximately 3.4 billion people or 44 per cent of the world's population,[4] and were chosen as representative of the APAC region with distinctive importance. The ongoing hydrogen development in these countries is of great reference value that the EU community can learn from.

The report is based on both qualitative and quantitative data collected from a combination of in-depth interviews with experts and desk research, respectively. IPSOS selected expert interview respondents, independently of KAS, based on the respondents' expertise and knowledge of the topic as a whole and the project experience that each respondent possesses. Respondents were selected from academia, private or state-owned corporations, private institutions, government, and non-governmental organisations. The expert interviews were conducted in a semi-structured format as it allows a degree of freedom to explain the reasons or logic behind actions for a more comprehensive investigation and prompts experts to share their project experience with a more proactive approach. Objective data presented and facts provided by the experts in this report were collected and confirmed through extensive desk research. Perceptions of and suggestions for development were mainly compiled from expert opinions and expertise. To maintain data integrity and advocate free opinion sharing, the respondents were all anonymised as a form of confidentiality. The interviews were conducted via internet calls between December 2021 and April 2022. On average, the interviews lasted for approximately 60 minutes.

A minimum of six open-ended, semi-structured interviews in each of the nine countries and additional pilot interviews, resulting in a total of 57 interviews, were conducted. The respondents involved in local or regional hydrogen development projects or policymaking of their country with more than five years of related work experience were targeted. In some cases, comments made by the experts have been summarised, synthesised, and reworded for clarity and precision, while best efforts were made to preserve the original meaning, intention, and presentation of information. Answers or statements with unclear meaning are not included to maintain the integrity of the interpretations. We have included references from reliable sources whenever appropriate for qualitative information and quantitative numbers, with independently verifiable statistics.

The information and opinions provided by the selected experts lay the foundation for the text of this report. While expert opinions are accumulated from years of experience that are hard to quantify and combined with personal experience and subjective opinions, it is important to recognise the limitations of the information provided. This report serves to complement and suggest recent development and population perceptions among the industries, rather than present systematically acquired expert knowledge. With its qualitative nature, the data gathered in the expert opinion interviews may be subsequently added to or disputed by other experts and/or future published research. Facilitators during the process could also inject personal biases or cause misinterpretations, resulting in a loss of true meaning despite the best professional efforts being made to guard against bias. Despite this, diverse opinions and insights remain protected and fully embraced in this context. English is used as a medium of reporting. However, it is noteworthy to highlight that many experts were not native to the English language. While some of the interviews were carried out in foreign local languages, lost-in-translation issues should be taken into account. This situation may indirectly cause misinterpretation of the indicated meaning or an unintentional shift in the advocated focus. Regardless of this, the expert interviews provided a vital gateway to obtain first-hand and most up-to-date data on the development status and generate great value for the research.

5

Australia

5.1 Overview

Table 3 Australia Hydrogen Development Overview

OVERVIEW OF AUSTRALIA	
Key Background Information	- The government published Australia's National Hydrogen Strategy in 2019, outlining the roadmap and collaborative framework between the federal government, state governments, industry players and research institutes. - Australia is looking to build on existing trading routes to include hydrogen transportation hubs with a target export value of up to AUD 10.0 billion per year by 2040. - Australia has also initiated many notable supply-side and export projects. It also focuses on using hydrogen for land and air transportation and has launched numerous heavy-duty and long-range vehicle initiatives. - Australia's LNG infrastructure owners have started investing in trial projects blending green hydrogen with natural gas in existing gas pipelines.
Key Expert Insights	- There are four key pillars in future hydrogen development: export, long-haul transportation, decarbonisation of mines using hydrogen, and blending hydrogen into the gas network. - Australia aims to become one of the prominent regional players in exporting hydrogen to Singapore and China, but the market will likely become more competitive over time. - There is multi-level and active involvement of industry stakeholders and government support to accelerate Australia's hydrogen ecosystem's development, but more coordination may be required between government entities and among industry players. - Without proper and sustained funding and subsidies, many companies are struggling to justify the investment spent as marginal returns are low at the current technology level. - Australia will focus on building strategic relationships and ensuring sufficient financial support as critical actions in developing the hydrogen industry.

5.2 Background

5.2.1 Overall Hydrogen Landscape

In 2019, the government published Australia's National Hydrogen Strategy, outlining the roadmap and collaborative framework between the federal government, state governments, industry players and research institutes. The strategy sets Australia's vision for a clean, innovative, and safe hydrogen economy and becoming a major global player in this field by 2030. According to the National Strategy, development is divided into two stages. From now to 2025, the objective is to create, test and prove a comprehensive supply chain to demonstrate Australia's capability and strength in hydrogen production. From 2025 onward, Australia will more aggressively launch large-scale commercial activation. Instead of achieving decarbonisation and diversifying energy supply like other Asian countries, the National Strategy vision is to foster economic growth by exporting green hydrogen and creating job opportunities generating AUD 11.0 billion a year in GDP and 8,000 jobs by 2050.[5] In 2021, the public investment allocated on hydrogen exceeding AUD 1.3 billion (USD 0.9 billion), and the estimated green hydrogen market size was USD 22.9 million in 2021.[6,7]

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) set a roadmap with commercial, policy, research, and social priorities across various hydrogen use cases. In May 2021, the CSIRO launched a new AUD 68.0 million Hydrogen Industry Mission initiating over 100 projects.[8] These projects included creating a hydrogen knowledge centre to promote hydrogen projects and industry development in Australia, developing demonstration projects that illustrate the viability of the hydrogen value chain, and investing in hydrogen-related emergent technology with the private sector. Meanwhile, Australia's Technology Investment RoadMap was also drafted as a strategy to accelerate the development and commercialisation of low emission technologies with eight stages in the roadmap, setting the future vision to balance the overall investment portfolio and assessing technological investments.[9] The Australian Renewable Energy Agency (ARENA), another independent agency of the Australian federal government, also funded a total of AUD 1.8 billion over 600 energy-related projects, of which 36 are hydrogen-related projects with AUD 69.8 million.[10,11] With renewable hydrogen today costing between AUD 6.0/kg and AUD 9.0/kg, The Australian Government's Low Emissions Technology Statement aims to reduce the hydrogen cost to AUD 2.0/kg in 2030 and further reduce it to AUD 1.0/kg by 2050.[9]

Australia is actively seeking to capitalise on its high-volume export of raw materials built on existing solid trading routes via large-scale hydrogen transportation hubs. The export value of hydrogen can possibly reach AUD 10.0 billion per year by 2040.[12] Australia has been developing a bilateral agreement with Germany, Japan, and South Korea to establish a hydrogen supply chain for export.[6] As part of this bilateral agreement, a total wind and solar capacity of 15.0 GW to 17.5 GW would be required to meet the projected 3.5 million metric tons of green hydrogen demand for export in 2030.[13] In addition to the bilateral trading agreement, CSIRO also launched the USD 5.0 million Hydrogen R&D International Collaboration Programme to foster collaboration between industry and researchers in Australia and overseas. Nevertheless, Australia is facing strong export competition from countries such as Norway, Iceland, the USA, the Middle East and North Africa. It is estimated that Australia's share of global hydrogen export was 9.1 per cent in 2020 and will further drop to 3.6 per cent by 2040.[14]

5.2.2 Hydrogen Supply Landscape

The hub model is Australia's key approach to creating large-scale clean hydrogen at an early stage. The approach is to develop clusters of large-scale demand by aggregating various uses of hydrogen into one area, such as ports, cities, or remote areas. These supply hubs are also complemented by other early initiatives to use hydrogen in transportation, industry, and gas distribution networks and integrate hydrogen technologies into electrical systems to enhance reliability. As of September 2021, the federal government announced seven potential locations for clean hydrogen hubs. These potential locations include Belly Bay in Tasmania, the Pilbara in Western Australia, Gladstone in Queensland, La Trobe Valley in Victoria, the Eyre Peninsula in South Australia, Hunter Valley in New South Wales and Darwin in the Northern Territory. To accelerate the development of hydrogen hubs, the Minister for Energy and Emissions Reduction has launched an AUD 464.0 million grant programme to progress feasibility and design work.[15] In addition, the National Energy Resources Australia (NERA), a federally funded not-for-profit organisation, also formed a network of 18 hydrogen clusters across Australia to accelerate the development of hydrogen equipment, technology, and expertise.

Australia has initiated many notable supply-side projects in support of the development of the hydrogen industry. For example, a project has been initiated by Woodside Energy in Bell Bay, Tasmania where the electrolyser with a natural capacity limit of 500 MW without transmission upgrade was built to take advantage of the windy environment.[16] Projects such as the Bell Bay wind power project have provided substantial employment opportunities for the local green energy industry in Tasmania. In Western Australia, the Murchison renewable hydrogen project can build a 5,000 MW wind and solar farm and transmit electricity directly to the electrolysers within the port, aiming for export to the Asian market.[17] In other projects, over 200,000 hectares of land have been earmarked to support the development of wind and solar power, with around 15.0 GW connecting to electrolysers with an exclusive port facility only for the hydrogen producers to transport hydrogen.[18] One of the experts also shared that one of the projects aims to introduce hydrogen buses on the Australian island. As the island is not connected to the mainland electricity grid, a solar farm and a wind farm have been built to power the electrolyser in the station, making the hydrogen price more competitive than the cost of diesel.

The development of the hydrogen economy is also active in Victoria. In Gippsland, both semi-government groups and non-government institutes are engaged in a number of hydrogen energy projects with government support. For example, on the application side, long-haul hydrogen trucks and buses are planned to be run in Gippsland on a trial basis. Furthermore, a significant milestone was also achieved in Victoria as part of Australia's hydrogen export strategy in 2021. Specifically, the Hydrogen Energy Supply Chain Project (HESC) successfully produced liquefied hydrogen from Latrobe Valley coal in Victoria for export. The HESC project has become the first to produce, liquefy, and transport liquid hydrogen by sea to the international market.[19,20]

5.2.3 Hydrogen Demand Landscape

According to the National Hydrogen Roadmap, the significant types of hydrogen utilisation are heat, export, static electricity, industrial feedstock, and hydrogen-fuelled transportation. The high cost of green hydrogen is one of the major factors that has limited the adoption of hydrogen. According to some estimates on the cost of hydrogen compared to conventional energy solutions, hydrogen will only be competitive at the production cost of USD 1.6/kg to USD 2.3/kg in 2030 for most road transportation applications and hydrogen feedstock for industry.[21]

Australia is developing ten export trading projects to export hydrogen in liquefied or ammonia form to meet the demand from other countries.[6] Japan was the first and major hydrogen trading partner for Australia. As part of this partnership, Australia sent the world's first shipment of liquified hydrogen to Japan in Feb 2022.[22] In addition, Origin Energy, an Australian energy company, has collaborated with Japan's Kawasaki Heavy Industries Ltd (KHI) on a 300 MW export project to produce 36,500 metric tons of green liquid hydrogen per annum using renewable energy and sustainable water.[23] Furthermore, the Asian Renewable Energy Hub (AREH) has also developed a project leveraging more than 26 GW of wind and solar energy to produce green ammonia for Japan as low carbon shipping fuel and industrial feedstock.[24] Within Australia, the Western Australian government has been especially proactive in proposing two hydrogen hubs in the Mid West to speed up the export of hydrogen in support of Australia's ambitions to lead the global hydrogen export market.[25]

Australia's Federal, State, and Territory Governments have a shared vision of hydrogen as a fuel option for land and air transportation and have taken various initiatives to deploy hydrogen vehicles, particularly for heavy-duty and long-range applications. For example, the Victoria government has developed its zero-emission vehicle roadmap to launch zero-emission vehicles supported by government policies focusing on the energy system transition and energy infrastructure planning.[26] In addition, the Queensland government has also trialled five Hyundai Nexo FCEVs with the hydrogen manufactured by BOC Gas.[27] The Australian government is also looking to leverage hydrogen fuel in public transportation vehicles, signified by introducing more hydrogen buses in the public transportation sector. For example, True Green has reached an agreement with the New South Wales government to introduce 200 hydrogen buses in Australia.[28] Another company H2X, a start-up involved in hydrogen vehicle manufacturing, plans to build fuel cell electric vehicles in Gippsland, Victoria.[29]

In February 2021, the Federal Government took additional steps to articulate the zero-emission vehicle roadmap by releasing the "Future Fuels Strategy" discussion paper, recognising investment in hydrogen refuelling infrastructure as a priority initiative. Three public HRSs have been built in Brisbane, Melbourne, and Canberra supporting Hyundai and Toyota's hydrogen car fleet trial. It was also revealed that HRSs are currently being built in Karachi and the southwest regions of Western Australia. According to another of the experts, the blue energy garden project in the Mid West and one project in Rottnest Island are working on domestic HRSs.

With some states setting the target of having about 10 per cent hydrogen in gas pipelines by 2030, Australia's private gas distribution asset owners have started investing in trial projects which blend green hydrogen with natural gas in existing gas pipelines.[30,31]

Australia's gas pipeline and network owners have already invested AUD 180.0 million in projects that involve pure hydrogen to reduce carbon emissions.[32] For example, the Hyp SA project, operated by the Australian Gas Infrastructure Group (AGIG), plans to blend about 5 per cent green hydrogen into its gas distribution network to more than 700 homes in a suburb of Adelaide in South Australia.[32] Moreover, safety measures are also being implemented, including the safety standards in pipeline transmission and downstream pipeline modification.

Players on the supply side have also been working actively along the value chain to drive the demand for hydrogen. For example, ATCO has a partnership with a number of mining companies to set up applications for using hydrogen fuel cells for power generation and blending hydrogen into reciprocating engines. As part of the project, ATCO installed electrolysers on a remote mining site to produce hydrogen on site instead of transporting hydrogen using tube trailers from its production facility 600–700 km away.[33] In addition, ATCO has also partnered with Caterpillar, Cummins and Rolls Royce power systems to develop ways to leverage existing spark-ignited technology to build hydrogen engines for power generation.

5.3 Expert Insights: Perception of Hydrogen Development

The experts generally perceive four key pillars in future hydrogen development: export, long-haul transportation, decarbonisation of mines using hydrogen, and blending hydrogen into the gas network. In addition, experts also believe that there are concerted efforts in the national and state strategies to create large-scale demand. Finally, the experts also believe that the use of hydrogen in long-haul trucking utility vehicles and the blending of hydrogen into the gas network have accelerated in Australia, but the decarbonisation of mines, industrial feedstock, and export have been comparatively slower.

The experts commend Australia's national strategy, yet more momentum is needed to accelerate the implementation. The experts comment that the states' plans have been put into early trials, removing regulatory barriers. However, the experts believe that it is hard to justify if the national strategy's implementation is progressing well as many projects still require government funding in order to be financially viable and investible. Another of the experts mentioned that the government is prudent in minimising massive investments when the technologies are underused and considered non-competitive over the short run. It is anticipated that only large corporations, such as Toyota and ATCO, can proceed with their investment in Australian hydrogen energy projects. To draw support from the government, the expert suggested that corporations demonstrate to the government the opportunities that can be created for the country, including economic development, employment and business opportunities. In addition, some of the experts also perceive Western Australia as more proactive and competitive in hydrogen development compared to other regions in Australia. The faster pace of development in Western Australia is supported mainly by the region's richness in renewable energy sources and the West-Australian Government's supportive stance in creating local demand and allocating resources for manufacturing technologies.

The experts have also witnessed how energy companies and mining companies struggle with the existing business model and therefore seek to adopt hydrogen into their line of business. According to the experts, the most prominent question is whether hydrogen and green ammonia can replace the conventional oil and gas markets cost-effectively. Currently, traditional energy companies are trying to replicate what they did in gas and oil exploration and seek ways to minimise hydrogen production costs by selecting the best location with sufficient renewable energy to generate electricity at the lowest price. The experts revealed that mining companies are also seeking to transform from conventional sources to the use of hydrogen, in part addressing the environmental and sustainability-related concerns. For example, there have been numerous environmental concerns with regard to coal mining in Gippsland and mining companies have been forced to shut down due to political pressure over environmental concerns. Mining companies have been seeking ways to adopt renewable energy and investing in solar and wind farm projects to mitigate some of the environmental concerns.[34] The experts believe that traditional companies are still on the learning curve in relation to adopting hydrogen into their business models. Projects are running at enormous budget levels, as the inter-industrial personnel and technological shifting directly from the conventional energy industry to the hydrogen energy industry are not as effective as expected.[35]

The experts are optimistic that Australia will become one of the prominent regional players in exporting hydrogen to Singapore and China, yet the market will likely become more competitive over time. One of the experts pointed out that Australia can export hydrogen cost-efficiently to countries requiring hydrogen imports to supplement domestic production and support local demand. For example, countries such as Singapore and China have historically expressed interest in commodities and hydrogen from Australia. However, for the export to be competitive, domestic capability and scalable export initiatives are needed to reduce the costs to about USD 2.0/kg for the project to be competitive in the Asian export market.

“ A country involved in hydrogen export has to have enough land, position, and time. A project roadmap demonstrates how the country can have a minimal opportunity for three GW to be seen as a project that will compete globally in the export markets. ”
— General Manager

The experts also believe that countries like Germany and China can industrialise green hydrogen production technology and create large-scale and cost-efficient electrolysers to reduce costs. Meanwhile, some large solar farms will be under development in the Middle East and South America, generating electricity at an average cost of USD 0.015/kWh. But according to one of the experts, Australia can only generate significant wind and solar energy at an average cost of USD 0.03/kWh. Besides the cost of green hydrogen production, discussions on alternative ways of efficiently exporting hydrogen are still in progress. The expert pointed out that export companies such as Sumitomo and Woodside are researching ways to effectively transport and export hydrogen. However, there is no alignment on the most suitable way yet. The expert also suggested that Canada, England, and Scotland have the shortest routes to Asia with control of the supply chain to Asia. Australia will be competitive only when the cost of hydrogen is as low as AUD 1.0/kg.

5.4 Expert Insights: Supporting Factors for Hydrogen Development

The experts believe that the active involvement of external and internal stakeholders and the government's support have accelerated the hydrogen ecosystem's development in Australia. Externally, countries such as Japan, South Korea, and Singapore have begun developing and supporting projects by allowing their sovereign wealth funds to invest in large-scale port infrastructure overseas or companies which export hydrogen to their respective countries. In addition, one of the experts also observed that many joint ventures or start-ups are currently focusing on hydrogen-related development in Western Australia, where these companies could provide a more independent operation without the limitation of a traditional company. Furthermore, the government is also developing joint ventures with private enterprises to produce stand-alone power systems in the renewable energy area.

> **“I think there'll be two joint ventures. I was just involved in the Australian Defence Force Future fuels study and looked at how they could look at hydrogen and other alternative fuels for their defence. And part of that was quite a lot of joint ventures with local companies to shore up supply.” — Business Development Executive**

The Australian government has also played a supportive role in amending related laws and regulations. One of the experts explained that the government has amended the offshore petroleum and greenhouse gas storage act (OPGGS) to allow carbon storage in underground reservoirs in support of the production of blue hydrogen. The government has also completed a review of the national gas law to remove the unnecessary regulatory barriers and improve the consistency of rules across jurisdictions.[26] Following the government's action, Standards Australia has set up a technical committee to facilitate the development of national hydrogen standards. In addition to Standards Australia, Safework Australia also develops safety standards for workers.[26]

Several of the experts agree that Western Australia is a region that is ideal for hydrogen development due to the region's rich natural resources and positive government support. As Western Australia is rich in offshore wind and solar resources, the experts expect Western Australia to be an area with unspoiled human and natural resources exploitation for renewable resources, particularly in the southwest region. Leveraging this competitive advantage, the Western Australia government has been supporting the allocation of land to build the necessary infrastructure and the related environmental, safety and regulatory approvals. According to one of the experts' understanding, the Western Australian government is working hard to attract R&D and manufacturing companies to support the hydrogen industry and create local demand.

Besides building conventional storage facilities, new technologies such as new trailers capable of transportation and long-term storage of hydrogen are also under development. According to one of the experts, some trailers are manufactured and tested to carry 800 kg of hydrogen thus being capable of transporting hydrogen to injection points. Such trailers can replace expensive storage facilities with equivalent high safety standards as these trailers are kept in locked laydown areas. Meanwhile, one of the experts highlighted that R&D is underway to create portable hydrogen generators that can be installed at the back of cars to generate hydrogen fuel during long road trips to reduce recharging times. These portable generators can operate between 5, 20, 50, and 100 kW instead of 2 MW for existing hydrogen generators. While this technology is currently on the roads and highways, the expert believes that hydrogen generator development is crucial to shortening the recharging time for future hydrogen energy implementation. Lastly, the expert also estimates that liquid forms such as liquid hydrogen, liquid ammonia, and liquefied organic hydrogen will be the primary forms of hydrogen transportation as they are much more effective and much safer even if the cost is higher than that of current technology. As the industry is experienced in natural gas liquefaction, the experts believe that the shipping industry is ready for carrying liquefied hydrogen at scale.

5.5 Expert Insights: Barriers to Hydrogen Development

The experts suggest that improper funding for projects and excessive participation of players in the industry dilute the industry's sophistication and hinder development. It has been suggested that not all investments make significant contributions to hydrogen development in Australia. Many funded hydrogen energy projects are creating insignificant contributions to the development of the industry. One of the experts highlighted that businesses often use the "hydrogen" buzzword to attract investors. The expert also mentioned that some engineering companies may exaggerate their experience in the sector, reducing the effectiveness of invested capital. Another of the experts also believed that the participation of a vast number of players is hindering the creation of large-scale projects. For example, companies may proactively try to connect with many interested parties but still not find the right partners for their projects.

The experts highlight that many big corporations are struggling to justify the investment spent on hydrogen projects as the marginal returns are low at the current technology level. Even though corporate executives may envision replacing existing energy sources with hydrogen, many of the projects remain in the pilot stage since it is difficult to justify the economics of such changes to the board and shareholders. The experts highlight that it is hard to develop large-scale projects without the ability to estimate the potential demand which these projects will generate accurately. For example, the high cost of HRSs and electrolysers could be underwritten if there are domestic strategies and related targets to increase the utilisation of HRSs in the FCEV sector. To build investors' confidence, one of the experts suggested building up the infrastructure city by city to assess the economic viability instead of focusing on larger deployments. Another of the experts also cautioned that industry stakeholders should align on the use of green hydrogen instead of investing valuable capital in blue hydrogen projects. However, this may be unrealistic and not feasible due to creating additional barriers for the industry as the focus on green hydrogen increases the cost gap. The required scale of such a facility to produce green hydrogen would only create additional commercial risks and discourage the development of the hydrogen industry in the short term.

The high cost of hydrogen production continues to be the core barrier to hydrogen development in Australia. With the high capital expenditure on electrolysers, companies cannot see a total return on their investment for five years, particularly without an off-taker. Renewable energy makes up about 54 per cent of producing hydrogen, and the transmission operators would also charge a high price for infrastructure, further driving up overall hydrogen prices. Meanwhile, even though electricity prices in some regions may be lower because of the open market mechanism, the demand may outstrip supply when many hydrogen projects go live, driving up prices. To tackle the challenge in the cost of electricity, the experts suggested that the only way for hydrogen producers to maintain low electricity costs is to develop their own renewable energy resources and keep costs below AUD 2.0 cents/kWh.

Some of the experts also highlighted the conflicting regulations and the cost of pipeline modification as the key challenges in leveraging existing natural gas pipelines for hydrogen transportation. Even the National Hydrogen Strategy suggests that blending around 10 per cent hydrogen into natural gas could be done in most existing infrastructure, experts believe that the current safety regulations and technical standards are still insufficient of supporting the injection of hydrogen into existing gas pipelines. Meanwhile, due to the cost of infrastructure modification, both the pipeline owners and customers are not prepared to absorb the cost. One of the experts also suggested that it would be challenging to implement a pilot project on a large scale since there are insufficient customers at the other end. The expert also suggested that pipeline owners are not incentivised to carry out hydrogen-related modifications without the government's financial support and compensation.

5.6 Expert Insights: Future of Hydrogen Development

Several of the experts believe that the APAC region can play a crucial role in the emerging hydrogen economy, given that governments are supportive in terms of financial subsidisation. A successful and sustainable hydrogen economy in one country can inspire confidence in other APAC countries, as the ongoing projects in Singapore, Vietnam, Indonesia, and Malaysia are not mature. One of the experts also insisted that the key to promoting hydrogen energy in APAC is demonstrating the economic feasibility of the hydrogen economy in the current projects to other countries and establishing a model for countries to follow.

More new entrants are expected to join the hydrogen industry, and hydrogen will be the dominant energy by 2030, with excess hydrogen that could be extended to decarbonise other industrial processes such as the steel industry. It has been suggested that 2025 will be a critical milestone for hydrogen development in Australia as most of the projects will be mature, including the plan to export hydrogen, which will be ready to be implemented from 2025 to 2030. The experts further point out that 2022 could be the last call for new entrants to join the industry, as it will be difficult to break into the hydrogen industry in 2030 when all prominent players have established themselves in the value chain. One of the experts further suggested that when the hydrogen industry becomes mature, the use of hydrogen could be expanded into other segments, such as producing green steel in Australia and exporting it to other countries.

The production cost for green hydrogen will continue to decline with the large-scale production of electrolysers. One of the experts expects the price of large electrolysers to continue to decrease with the reduced shared cost of sensors, tubing and cabling in the system of a bigger stacker. Large-scale production will allow industrialisation with cheap materials in the supply chain and higher efficiencies in production. However, even with the reduced cost of electrolysers and the commercialisation of export initiatives, the experts believe that the price of hydrogen will likely remain above AUD 2.0/kg over the next five years. To a certain extent, some of the experts believe that the goal of AUD 2.0/kg is too uncertain for the industry as the cost of hydrogen varies according to different end applications. One of the experts suggested that more specific supply volume and price targets are needed to encourage the industry stakeholders to participate more actively in the hydrogen value chain.

The price of hydrogen fuel cells is expected to decrease over time, but a robust hydrogen refuelling network must be in place for FCEV to proliferate in Australia. According to one of the experts, the cost of a fuel cell for a hydrogen bus has decreased from about AUD 200,000 two years ago to less than AUD 60,000 today. The experts believe that the current best solution is to study different ways to improve efficiency, for example, how fuel cells work with products other than hydrogen.[ii] Yet the underdevelopment of the refuelling network has resulted in a reluctance on the part of OEMs like Toyota to push for cars with hydrogen fuel cells. The experts anticipate that two to three years are needed to have enough HRSs installed and supplied with enough hydrogen.

5.7 Expert Insights: Actions to Accelerate Hydrogen Development

The experts recommend that Australia focus on building strategic relationships with international partners as a critical step in developing the hydrogen industry. The experts suggest that creating a successful hydrogen business is not simply about products but also collaborative relationships with the customers throughout the hydrogen lifecycle

ii The typical power for a hydrogen-based bus fuel cell is about 60 to 80 kilowatt.

from production to application. One of the experts suggested an example that his company had employed several commercialisation managers working in Japan, South Korea, Europe and the US to help develop customer relationships and obtain helpful information from other corporations. These long-term strategic relationships will enable Australia to compete internationally by creating long-term bilateral strategic relationships from day one.

The experts also gave the reminder that the government must ensure that the policy frameworks are supported by sufficient capital investment and complementary policies to support hydrogen projects. Given that there is no certainty of tenure under the land leasing by the government, more comprehensive policies could be implemented to address the remaining unresolved leasing issues. In addition, the government could also act as an equity participant in some projects to help build investor confidence at the early stage of these project developments. By bearing a higher level of risks and providing commercial finances, the government could aid more businesses that may be otherwise unable to cope with capital investment requirements to initiate or sustain their hydrogen projects. Finally, the Australian state governments could also create better business environments with sufficient infrastructure to establish and facilitate international relationships and grow their networks. The experts further suggest that the Western Australian government could consider building the port infrastructure to accommodate the inflow of users and create an environment where other projects could be introduced. The experts suggest that these port infrastructure developments could also appeal to multinational corporations like Copenhagen Infrastructure Partners, BP, and other businesses of various scales.

Innovative incentives and financial leasing products for hydrogen-related equipment could increase the scale of deployment and reduce equipment costs over the longer term. The experts suggest that government, financial institutions and equipment manufacturing companies could potentially work together to introduce leasing of hydrogen equipment such as storage tanks and electrolysers to attract businesses into the segment and lower the financial-related entry barriers. For example, many mining companies prefer not to generate their own electricity and contract independent power providers to charge them for electricity according to their usage. The experts suggest that the independent power providers could upgrade their equipment and offer to lease electrolyser to mining companies working together with financial institutions.

6

China

6.1 Overview

Table 4 China Hydrogen Market Overview

OVERVIEW OF CHINA	
Key Background Information	The Chinese government has established clear goals and objectives and has established several roadmaps and plans related to hydrogen and renewable energy development since 2016. China has always been heavily dependent on foreign energy sources and key related technologies. However, the national strategic plans advocate increasing domestic production while reducing import dependency on energy and related key products and technologies. Many players in China currently focus on the hydrogen industry, with top Chinese SOEs leading the overall hydrogen production segment. However, the green hydrogen production segment comprises new entrants, private enterprises and SOEs. China has been experiencing high growth in hydrogen development since Secretary Xi announced the Chinese carbon-neutral target and is on track to switch to mostly green hydrogen production by 2030.
Key Expert Insights	The one-party system and Chinese Communist Party's (CCP) ability to quickly establish multi-level policies and abundance of funding help drive the industry's accelerated development. China has an extensive range of natural resources with immense potential to support the scale-up of hydrogen production capacity for nationwide adoption. China's hydrogen development is constrained by a lack of inter-province infrastructure and limitations in storage technology, recharging infrastructure, and FCEV application. However, it is quickly catching up, and China will likely become APAC's manufacturing hub for hydrogen production and renewable energy equipment. China will focus on increasing its green hydrogen production, leveraging its advantage in renewable energy and focusing on R&D efforts to resolve domestic manufacturing limitations of hydrogen equipment.

6.2 Background

6.2.1 Overall Hydrogen Landscape

The Chinese government has established clear goals and objectives via various policies and has established several roadmaps and plans related to hydrogen and renewable energy development since 2016. For example, the National Energy Administration of China established the "Energy Technology Innovation Plan of Action (2016–2030)" roadmap in 2016, which included hydrogen development as part of the national strategy for the first time.[36] More recently, Secretary Xi also announced China's plan for carbon emission reduction by establishing "Carbon Peaking and Carbon Neutrality Goals" in 2020.[37] Furthermore, the 13th and 14th Five Year Plans have also clearly outlined that green hydrogen development has been deemed a top priority in achieving "green development"[iii] over the long run.[38,39] In addition, provincial and city-level hydrogen projects are also being carried out under various local governments' hydrogen roadmaps led by State-Owned-Enterprises (SOEs).

China has always been heavily dependent on foreign energy sources and key related technologies. However, the national strategic plans such as the "Made in China 2025" and "Hydrogen Industry Development Plans (2021–2035)" advocate increasing domestic production while reducing import dependency on energy and related key products and technologies.[40,41] As part of the implementation of this vision, leading SOEs in the energy industry have carried out numerous domestic hydrogen production projects across various provinces. The Made-in-China industrial policies also included manufacturing "power generation equipment" for hydrogen production and producing "green energy" such as green hydrogen. Furthermore, China is also focusing on manufacturing "green vehicles". FCEVs using clean fuels are prioritised as an industrial goal to meet the transition to green transportation. With the implementation of these initiatives, China is also aiming to position itself as APAC's leading renewable energy equipment provider in products such as electrolysers for green hydrogen production.

6.2.2 Hydrogen Supply Landscape

China aims to become a self-sufficient hydrogen economy focusing on increasing domestic production capabilities while minimising imports. As outlined in "Made in China 2025" and "Hydrogen Industry Development Plans (2021–2035)" policies, hydrogen production has been targeted as one of the contemporary industrial goals to achieve energy independence from foreign suppliers as well as from fossil fuels.[42,43] While China has a relatively large hydrogen production capacity of around 3,300 million metric tons as of 2021, China is currently heavily reliant on grey and brown hydrogen production with minimal green hydrogen production.[41] Currently, brown hydrogen is widely adopted in China, with related production capabilities available across all 31 Chinese provinces supported by domestic manufacturing production equipment and China's large coal reserves.[44] On the other hand, green hydrogen production is only at an early experimental stage and is of a relatively small scale due to the high costs of renewable energy. In 2019, hydrogen production using renewable energy sources only constituted about 1 per cent of the total hydrogen production in China, which is less than the world's average of 4 per cent.[45] Today, these early-stage green hydrogen projects are mainly led by large SOEs using electrolysis production methods. However, blue hydrogen production is notably missing in China because the CCUS technology is still in the very early R&D stage in China, and the government policy preference is on focusing on green hydrogen production rather than blue hydrogen production technologies.[46]

There is currently a mix of players in China focusing on the hydrogen production segment. Top Chinese SOEs such as CNOOC, PetroChina, and Sinopec are leading the hydrogen production segment in China, in which there are only a few new entrants. The grey/brown hydrogen production segment is

iii Defined as "green, low-carbon and circular development in China's ongoing anti-pollution fight to achieve its carbon peak and neutrality goals" by the Chinese government, according to the 14th five-year plan.

highly saturated, comprising various large-scale SOE-led projects. An example of these large-scale projects is the Ningdong Energy and Chemical Base in Yinchuan of Ningxia.[47] The Ningdong Energy and Chemical Base is an industrial park producing grey hydrogen with its rich fossil fuel resources. The hydrogen produced facilitates Yinchuan's position as an industrial centre and a transportation hub with multiple HRSs supporting transportation from western to eastern China.

Compared to the brown hydrogen production segment, the green hydrogen production segment comprises new entrants, private enterprises and SOEs. The new entrants and private enterprises generally focus on the R&D and manufacturing of electrolysis equipment capable of green hydrogen production. There is also a mix of large-scale private enterprises, such as Sungrow and Longi Green Energy, and smaller-scale equipment providers, such as Tianjin Mainland Hydrogen Equipment, focusing on the green hydrogen production equipment segment. However, most large-scale experimental green hydrogen production projects are still SOE-led. For instance, Sinopec started construction on a green hydrogen production plant in Kuqa of Xinjiang in 2021.[48] The project utilises electrolysis technology with its 1 GW photovoltaic capacity to supply the region. This new green hydrogen plant will supply nearby chemical factories and is expected to replace about one-tenth of the current brown hydrogen demand in the region. Another noticeable green hydrogen project was built in Zhangjiakou of Hebei to demonstrate the feasibility of an all-in-one supply-and-storage green hydrogen solution to promote hydrogen development in 2020.[49] The project was recently commissioned to support the 2022 Winter Olympics Games and highlighted China's ability to leverage its green renewables resources in locations such as Zhangjiakou with its wind power.[50]

China has historically been limited to short-distance hydrogen gas transportation, constrained by a lack of inter-province infrastructure and technology limitations for long-distance transportation. The distance limitation is mainly due to the high cost and coordination required for constructing a pipeline capable of transporting pure hydrogen gas. Without sufficient inter-province pipeline infrastructure, hydrogen supply can only be transported over short distances and in limited quantities. Furthermore, land-based transportation of hydrogen is mainly due to regulatory and technological reasons. For example, hydrogen transportation in a solid metal form is only in the experimental stage in China, and it is rarely used due to its high cost and additional reheating process to extract the hydrogen. In addition, hydrogen transportation for commercial purposes can only be carried out in compressed gas form since only military entities were permitted to transport liquified hydrogen before November 2021.[51] However, hydrogen transportation in gas form is only limited to facilities near the production location due to energy loss issues in gas form. From a technology perspective, Chinese-made equipment is also currently behind other developed hydrogen economies, such as Japan, South Korea, and the US. For instance, Chinese-made pressure vessels are only available at a lower tank capacity of less than 70 Mpa, limited by China's technical manufacturing capability. [52] In addition, with only a few reputable manufacturers in China, hydrogen storage tanks are comparably high in price. The Chinese manufacturers have proactively worked with foreign businesses to import more advanced technology to address the manufacturing capability gap. For example, CIMC Enric has been working with Hexagon Purus to import Norwegian's advanced manufacturing technology.[53] Lastly, Chinese-made storage tanks are available only in limited quantities with long waiting queues for delivery. These factors are unfavourable for China's hydrogen adoption as these tanks are essential for hydrogen vehicles and HRSs to store compressed hydrogen gas.

In addition to addressing the limited supply and high price of hydrogen storage tanks, China has been working toward improving the hydrogen transportation infrastructure by initiating a number of small-scale pilot projects to establish new fixate hydrogen infrastructure. For example, Sinopec has built several short-distance pipelines focusing on hydrogen transportation, with one project from Luoyang to Jiyang covering 25 km and another project from Baling to Changling covering 42 km.[54,55] In addition, CNPC also commissioned a project to construct a hydrogen pipeline covering 145 km in June 2021 in Hubei.[56] The Dingzhou-to-Gaobeidian pipeline will help facilitate the hydrogen supply in Hubei province. Despite being the longest hydrogen pipeline in China, the Dingzhou-to-Gaobeidian pipeline will only serve Hubei province and not cross into other provinces.

6.2.3 Hydrogen Demand Landscape

China has significant hydrogen consumption with a relatively high potential for a number of vertical-specific demand applications such as FCEVs, home heating systems, and energy generation. Most of China's hydrogen is consumed as part of various industrial processes. As one of the world's largest manufacturing centres, China requires a stable hydrogen supply for its sizeable chemical production industry. For example, hydrogen is used as a catalyst in the agriculture and chemical production industries to produce ammonia, methanol, urea fertiliser, and the oil refinery industry to facilitate chemical reactions. This industrial hydrogen is produced via natural gas or coal, and the industry is looking to transition from using grey hydrogen to green hydrogen. Aside from industrial usage, hydrogen heating initiatives have been deployed as demonstration projects in a number of provinces. For example, a demonstration project testing the feasibility of hydrogen-powered home uses was launched in Hunan in 2020.[57] The Hunan project demonstrated the use of fuel cells through distributed energy generation to provide electricity for heating and lighting for homes. In addition, another demonstration project was launched in November 2021 with collaboration between CIMC Enric and Panasonic which aims to produce electricity and heating through the application of combined heat and power (CHP) technology[iv] in China.[58] Besides providing electricity for heating and home use, hydrogen has been heavily promoted in FCEVs to reduce carbon emissions in the automotive and transportation industry. Despite the focus, FCEV adoption is relatively low in the private vehicle sector, with more progress in the public bus or heavily weighted logistic vehicle segments. As of 2020, only about 7,000 hydrogen FCEVs were deployed in China to replace fossil fuel-powered vehicles.[59]

In China, the national government and local governments are the key stakeholders determining the demand-side development. The Chinese government has been involved in multiple hydrogen-related projects to support the usage of hydrogen FCEVs. During the 2022 Winter Olympics, 710 hydrogen fuel-cell buses were deployed on the Olympics campus to promote the application and viability of hydrogen fuel cell-enabled public transportation buses in daily life.[60] Besides event-focused demonstration, the Guangdong Foshan government deployed over 1,000 hydrogen fuel-cell buses and 460 logistic trucks across over 88 public transportation routes to transform Foshan city into the most evolved "hydrogen city" in China.[61] While the national and local governments are driving hydrogen application-related initiatives, market players such as SOEs and other new entrants from the energy sector are also leading the development. For example, Sinopec built China's first oil-and-hydrogen recharging station in Foshan, and Baowu has been adopting hydrogen for its iron and steel production plant in different regions of China.[62,63]

The Chinese government has shown no sign of increasing or turning to export among all existing roadmaps and hydrogen plans. With low production, high domestic consumption, and the lack of established inter-country transportation infrastructure pipelines, China is not focusing on exporting its scarce supply of hydrogen. With the rapid development of hydrogen FCEVs and high industrial chemical demand, the Chinese government has ordered and envisioned the domestic production supply to focus on serving the surging domestic market instead of exporting.

iv Combined heat and power (CHP) technology is applied to take use of the otherwise-wasted heat and thermal energy from hydrogen production to drive a gas or steam turbine-powered generator for heating purposes and electricity generation.

6.3 Expert Insights: Perception of Hydrogen Development

The experts highlight that China has been experiencing exponential growth in the country's hydrogen development since 2020 after Secretary Xi announced the Chinese carbon-neutral target. The experts believe that China's hydrogen development is on track to switch to mostly green hydrogen production by 2030, as announced in the 2020 New York UN meeting to achieve carbon neutrality by 2060.[37] Many experts opine that the "Carbon Peaking and Carbon Neutrality Goals" policy published in 2020 was the main reason contributing to the acceleration and rapid development of China's hydrogen industry into 2030. With the announcement of emission goals in the policy, the development of green hydrogen has become one of the top national priorities in the energy sector to reduce carbon emissions from fossil fuels in China. In addition, several other related green hydrogen policies, such as "the Guiding Opinions on Energy-related Work in 2021" and "Hydrogen Industry Development Plans (2021–2035)", were also announced to support the overall national vision.[64,41] The experts working in the green hydrogen production sector also agree with the government on its plan to transit from brown hydrogen production to green hydrogen production. It is perceived that the transition will support China's industrial and transportation development using green hydrogen as the main hydrogen supply.

In comparison to other developed hydrogen economies, the experts perceive that hydrogen development in China is only in its early stage and is lagging in storage technology, recharging infrastructure, and FCEV application. In particular, the experts recognise that China is behind other developed hydrogen economies such as the European countries or Japan on both the supply side and demand side of the hydrogen economy. The experts describe the existing value chain as underdeveloped, with some parts not sufficiently mature to support China's hydrogen development, especially in regard to hydrogen storage and recharging from a supply-side perspective. Technologies required in these areas are mostly imported, making the adoption expensive or only limited to a low-demand situation. Therefore, balancing the economic return and cost of construction on both supply-side infrastructure and demand-side application deployment is the biggest challenge. Furthermore, the experts also highlight that China has to develop its hydrogen FCEV adoption model as foreign operation models cannot be adopted explicitly due to China's higher population density, large geography and higher recharging demand in urban areas. This special condition makes China unsuitable for adoption of the same kind of recharging facilities or equipment used in foreign countries as China needs equipment with higher charging speed and storage capacity to meet the intensive demand.

The experts perceive China as becoming APAC's manufacturing hub for hydrogen production equipment and related renewable energy equipment such as electrolysers. Today, China is a major player in hydrogen production equipment with less demanding requirements and is still facing difficulties in mass-production equipment for some technologies, such as PEM electrolyser or hydrogen storage tanks of over 70 Mpa. China has gradually increased its influence within APAC by taking up more market share in the equipment manufacturing market for green hydrogen production, such as photovoltaic equipment and Alkali electrolysers. For example, China has been a major photovoltaic equipment supplier, contributing to over 70 per cent of the world's photovoltaics equipment in 2021.[65] Regionally, China has already sold over USD 1.5 billion worth of photovoltaic equipment to Japan, nearly USD 1.0 billion to Australia, and over USD 0.6 billion to India in 2020.[66]

“ The green hydrogen sector in China will enter a phase of exponential growth with the application of electrolysis to produce clean and green hydrogen in 2030. But for now, we are only in the early stage for green hydrogen. According to the Chinese government's roadmap, China has set a goal to lower the price of green hydrogen to a range similar to that of natural gas by 2023. And we are all trying to achieve that. ” — Strategic Manager

Table 5 Highlighted Hydrogen-related Policies Announced by the Chinese Government

Timeline	Policy Title	Main Takeaways	Department
Mar 2016	13th Five-Year Plan[38]	Systemically develop fuel-cell vehicles and the hydrogen economy	CCP
Jun 2016	Innovation Action Plan of Energy Technological Revolution (2016–2030)[36]	First time being included in the national energy strategy	National Development and Reform Commission, National Energy Administration
Mar 2019	2019 Government Work Report[67]	Promote the construction of hydrogen infrastructure	The State Council
Early–Mid 2020	Nanhai: City District Development Plan for Hydrogen (2020–2035)[68] Guangzhou: City Development Plan for Hydrogen (2019–2030)[69] Tianjin: City Development Plan for Hydrogen (2020–2022)[70]	Local hydrogen development roadmaps with subsidies	City-level Local Governments
Sept 2020	Carbon Peaking and Carbon Neutrality[37]	Carbon emission goal	The State Council
Late 2020	Dalian: City Development Plan for Hydrogen (2020–2035)[71] Lu'An: City Development Plan for Hydrogen (2020–2025)[72] Qingdao: Development Plan for Hydrogen (2020–2030)[73] Shandong: Development Plan for Hydrogen (2020–2030)[74] Sichuan: Development Plan for Hydrogen (2021–2025)[75]	Local hydrogen development roadmaps with subsidies	City-level and Province-level Local Governments
Mar 2021	14th Five-Year Plan[39]	Achieve green development	CCP
Late 2021	Shanghai: Policies on Supporting the Fuel-Cell Vehicles Industry[76] Shenzhen: City Development Plan for Hydrogen (2021–2025)[77]	Local hydrogen development roadmaps with subsidies	City-level Local Governments
Mar 2022	Hydrogen Industry Development Plans (2021–2035)[41]	Official hydrogen roadmap and envisioned direction	National Development and Reform Commission

6.4 Expert Insights: Supporting Factors for Hydrogen Development

The experts generally perceive that the one-party system and the CCP's ability to establish multi-level policies have been conducive to the development of hydrogen in China. Under the one-party system, the CCP is responsible for guiding the direction of industry development. The Chinese government possesses strong governance influence over economic activities through its tight policy alignment culture amongst the national, provincial, and city-level governments and their policy directions. After the CCP established hydrogen development as a national priority, the experts also noticed that many provincial-level and city-level governments had also demonstrated their adherence to national priorities through various policies and initiatives. For example, over 20 province-level governments have established hydrogen plans or roadmaps with 15 of these provinces specifying at least eight and sometimes up to 20 ongoing projects to support the CCP's vision since 2019. The experts reason that the quick response from local governments is the most important factor supporting hydrogen development in China.

The experts opine that one of the key supporting factors for hydrogen development is the unique tendency for Chinese businesses, especially SOEs, always to follow the established national policy and government visions. Specifically, Chinese companies in the hydrogen-related sectors often carry out demonstration projects systemically aligned with national policies and visions to facilitate future nationwide adoption. Many of the experts notice that large companies and SOEs often launch initiatives related to the proposed policies, even if some of these policies may not have clear and concrete developmental frameworks due to SOEs' corporate mandates. In addition, SOEs are often the main contractors for most pilot projects. The experts further highlight that SOEs often serve as a 'lighthouse' signalling business trends aligning with top party officials' views and directions. SOEs in the hydrogen sectors often have a strong bond and communication channel with the government agencies and enjoy special financial and non-financial incentives from the local governments. With strong support from the CCP, SOEs often carry out demonstration projects even at a budget deficit to lower the fixed and variable costs of new technologies over the long run. This approach is often more cost and time-efficient when the industry players approach industry development under a unified development direction.

> **“ Secretary Xi announced the Carbon Peaking and Carbon Neutrality Goals in 2020. Business enterprises such as PetroChina and Sinopec must lead and help achieve the goals. The target year for carbon neutrality in China is 2060. Like Baofeng, a large chemical production company in China, and other large Chinese enterprises, these companies also target to achieve carbon neutrality by 2040. Other large businesses such as PetroChina, Sinopec, and Baowu Steel, must achieve the carbon neutrality goal by 2050. Some of these businesses are state-owned enterprises or central enterprises, and they must lead and support the government. ” — Strategic Manager**

Besides government policies and SOE support, the availability of generous monetary subsidies is also a key factor in attracting new entrants and driving the development of the hydrogen industry in China. For instance, local governments often provide additional support, including easing government approvals and special subsidies to facilitate project development. For example, Shanghai introduced a subsidy scheme for FCEV manufacturers and operators of licensed HRSs in 2021 to promote hydrogen FCEV adoption.[76] In addition, Puyang city of Henan also launched a policy in 2021 to subsidise new entrants 10 per cent of their investment when they invest more than RMB 30 million in hydrogen-related industries.[78] Under this lucrative financial and regulatory environment, many demonstrational and experimental projects from small to middle-sized new entrants are being carried out to facilitate the implementation speed of hydrogen adoption.

On top of government and business influence, China also possesses an extensive range of natural resources with immense potential to support the scaling up of hydrogen production capacity for nationwide adoption. Those of the experts working in the energy industry reasoned that China has already been producing hydrogen using its huge reserve of coals. In 2020, China recorded the highest production of coal globally, accounting for over half of the world's yearly supply.[79] This stable and large coal production has also historically been the preferred method of producing hydrogen in China. On top of that, the experts believe that China's vast renewable resources for electricity generation will continue to be scaled up, supporting the transition to green hydrogen. An example of a large-scale renewable source is wind power. For example, China ranked number one in wind power production capacity, accounting for approximately 37.8 per cent of the global capacity in 2020.[80] This large amount of renewable energy can be utilised for green hydrogen production. Furthermore, energy experts also suggest that China has the potential for further renewable electricity production growth to support large-scale green hydrogen production by increasing the amount of renewable energy production sites in the desert and rural provinces such as Xinjiang and Inner Mongolia using photovoltaic and wind power.[81]

6.5 Expert Insights: Barriers to Hydrogen Development

The experts believe that the time-consuming decision process of complex hydrogen initiatives is limiting the pace of some hydrogen projects' development in China. The preparation work of hydrogen projects is highly time-consuming as complicated organisational decisions are usually involved. Furthermore, multiple partners along the value chain may also need to be included in decision-making processes. Compared to traditional energy projects with long-established project experience, hydrogen is still a developing sector in China, and the projects are typically highly complex. In particular, most foreign multi-national companies (MNCs) require feasibility studies and financial modelling to be conducted in the early stages in support of decision-making to avoid uncertainties and manage risks. Foreign businesses often utilise more comprehensive decision-making processes, while Chinese SOEs are more willing to invest in projects that align with the national goals. Therefore, many local Chinese projects involving foreign MNCs and more advanced technologies require relatively lengthy preparation. The experts conclude that such complex decision-making procedures are more likely to prevent the efficient implementation of risky projects.

Aside from cost concerns, the experts highlight that any hydrogen policies implemented in China would need to consider inter-province coordination. Unlike traditional energy sources, which already have well-established developmental frameworks and policies, mature infrastructure, and technology, hydrogen applications require a much higher level of coordination amongst all levels of government and stakeholders along the industry value chain. For example, hydrogen infrastructure such as HRSs and policies such as safety precautions and regulations for FCEVs is required across all industry touchpoints to facilitate widespread adoption. The experts perceive that inter-province cooperation is not proactively facilitated. As a result, hydrogen-related initiatives are often limited locally, as manifested via the different stages of development across cities and regions. For instance, inter-region pipelines or large-scale infrastructure are only permitted among SOEs or local governments which are capable of mobilising the required resources.

The experts also opine that the hydrogen infrastructure in China is unable to cover the vast landscape or meet the long-distance or inter-province hydrogen transportation requirements. As the world's third-largest country as ranked by area, China has 31 provinces, and all possess different types of business landscapes and natural resources.[82] The regional differences must be considered when establishing infrastructure linking up the hydrogen production and end-use locations. For instance, northern China is rich in natural resources and excessive hydrogen production, while southern China has high industrial demand, sophisticated supportive policies, but insufficient hydrogen supply. Hydrogen produced in northern China, such as Ningxia and Inner Mongolia, will need to find a transportation mode to supply southern China to support the HRS infrastructure in China. However, the current infrastructure is still immature to meet the current growth requirements. For example, there are presently no long-distance pipelines of over 500 km connecting different provinces in China.[v] Without long-distance pipelines, other approaches to domestic transportation of hydrogen would be required. However, due to technical constraints, the distance over which hydrogen gas can be transported using trucks is limited. Liquid hydrogen transportation was only recently allowed by introducing the "Technique Requirement on Storage and Transportation of Liquid Hydrogen" in November 2021.[51] These factors combined have resulted in high hydrogen transportation costs within China. The combination of high hydrogen transportation costs and limited travel distance has made it difficult to link up hydrogen supply and demand across eastern and western China and northern and southern China. For example, Foshan of the Guangdong province in southern China suffered from an insufficient supply of hydrogen in 2020, with only one-third of its hydrogen-power FCEVs operating for public transportation due to the shortage.[61]

The experts also suggest that the "made-in-China" technology along the hydrogen value chain lags behind foreign countries and limits China's hydrogen production efficiency and domestic distribution. For example, China can only commercially manufacture Akali-based electrolysers currently instead of the more efficient PEM electrolysers.[83] While Chinese-made Akali-based electrolysers are low-priced options, these electrolysers are not the most efficient due to China's dependence on wind and solar sources. While the PEM-based electrolysers are more suitable for China, these electrolysers must be imported from foreign producers. The inability to manufacture the more efficient and more suitable PEM-based electrolysers domestically results in increased implementation costs and ultimately limits China's ability to implement green hydrogen production on a large scale. Another example of a "made-in-China" technology limitation is storage tank technology. Chinese storage tanks are mostly limited to 35 MPa in the commercial sector, which is lower than the 70 MPa international hydrogen storage tank standard. These higher pressured storage tanks are produced as prototypes in small quantities and have only been available in pilot projects such as the Zhangjiakou project for the 2022 Winter Olympics.[84] Until China can domestically manufacture and commercialise hydrogen storage tanks to these higher standards, China's target for FCEV adoption on a large scale will be limited.

"As wind power and photovoltaic energy are unstable, the volatility of these renewable power supplies is much higher than traditional fossil fuel sources. China is mostly still using Alkali-based electrolysers with these unstable renewable energy sources. The reflexibility of this type of electrolyser is low and cannot be rebooted immediately after a production halt. For example, a random cloud could cover the sun thereby interrupting solar power and stopping hydrogen generation. Alkali-based electrolysers would require a long time to reboot. Therefore, the efficiency of using Alkali electrolysers for green hydrogen production is not very high. The PEM-based electrolysers offer higher flexibility and low reboot times. However, China currently has to import these electrolysers from other countries." — Strategic Manager

v The longest pipeline in China is currently under construction covering 145 km in the Hebei Province.[46]

6.6 Expert Insights: Future of Hydrogen Development

The experts forecast that hydrogen development in China will continue to focus on increasing its green hydrogen production using electrolysis technology by leveraging China's advantage in renewable energy. The experts suggest that since green hydrogen has been identified as a development goal by the National Development and Reform Commission and listed in several strategic plans, more green hydrogen-related policies are expected over the coming few years.[36,38,39,40,41] For example, more lucrative government subsidies and strategic goals for archiving hydrogen-related milestones may be announced at the national and provincial levels to help facilitate green hydrogen production and FCEV adoption across China. As outlined in the hydrogen strategic plans, the experts highlight that China will mainly focus on green production with renewable energy in the future and will slowly phase out coal-based hydrogen production. More green hydrogen production projects are also expected to commence as many of these initiatives are already outlined in many city-level hydrogen roadmaps. The experts also notice that traditional energy companies are already taking the lead in green hydrogen production. Under this transformation, the experts forecast that China will complete the total transformation to systematic clean hydrogen production by 2050.

> **“ It is expected that large-scale green hydrogen production will be in the north-western part of China. The production will first supply industrial usage, especially to replace the brown hydrogen and hydrogen produced with natural gas. In the future, the developments will likely be located in places such as Xinjiang and Inner Mongolia since these regions have an abundance of renewable energy sources. ” — Strategic Manager**

The experts anticipate that with the promising domestic green hydrogen production outlined by the hydrogen roadmaps, China will be able to decarbonise its industrial and mobility sectors with expanded FCEV adoptions. The experts highlight that even though the current adoption rate and coverage for hydrogen FCEVs are minor, the adoption could expand significantly. As part of the transportation transformation, green hydrogen will fuel parts of China's public transportation systems, such as buses and logistic trucks. In 2020, the Chinese General Office of the State Council launched a roadmap, “New-Energy Vehicle Industry Development Plan (2021–2035)”, which focused on improving fuel cell technology and paved the way for enhancing the Hydrogen Recharging Station (HRS) infrastructure.[85] The “Hydrogen Industry Development Plans (2021–2035)” published in March 2022 also set the goal for China to deploy approximately 50,000 FCEVs in total by 2025.[41] In addition, China is also expected to transform its chemical industrial sector by replacing brown and grey hydrogen with green hydrogen in various production processes.

The experts predict significant technological improvements in production, transportation and storage technologies that will further facilitate green hydrogen development for China. The experts suggest that upcoming advancements in domestic technology with the increased focus on R&D and imported technology from foreign developed hydrogen economies will be the key drivers. For example, the transportation of liquid hydrogen is expected to dominate transportation approaches and replace hydrogen gas transportation within five years for short-distance and long-distance transportation with the recent revision of the civic applications after introducing “Technique Requirement on Storage and Transportation of Liquid Hydrogen” in 2021.[51] Since liquid hydrogen can be compressed into a very small volume in a stable and safe form, liquid hydrogen is more convenient and efficient for transporting over a long distance than hydrogen gas. In addition, with the ongoing R&D initiatives from SOEs such as State Power Investment Corporation (SPIC) and Sinopec on manufacturing PEM-based electrolysers, the experts predict that the domestic production of green hydrogen using the more efficient electrolysis technology will eventually replace grey/brown hydrogen production using fossil fuels.[86,87]

6.7 Expert Insights: Actions to Accelerate Hydrogen Development

The Chinese government should establish an enhanced framework to facilitate the coordinated development of hydrogen policies and initiatives across China. The Chinese government has acknowledged the issue of incoherence among regional policies and expected progress. The latest hydrogen industry strategic plan has recently tried to address this gap. Based on the assessment of each province's resource landscape and current development status outlined in the Hydrogen Industry Development Plans (2021–2035), the Chinese government plans to establish a coordinated system for hydrogen development to facilitate and lead national-level large-scale hydrogen development, especially in infrastructure construction across China.[41] The experts agree with the government's response and recognition of the need for supplemental assessment and evaluation of the inter-province projects from the government side. The government and the coordination system further suggested that it could help track and monitor the progress of significant projects for continuous improvement opportunities.

The experts suggest that Chinese energy companies should take advantage of China's diverse natural renewable resources to produce low-cost renewable electricity for green hydrogen production. As the cost of renewable electricity is the most important factor in determining the cost of green hydrogen in China, a lower cost of electricity will reduce the price of green hydrogen. China has access to many sources of renewable energy. For example, southwestern China provinces, such as Sichuan and Yunan, have abundant hydropower supply at a low cost.[88,89] In addition, there is also much potential to leverage photovoltaic power in northern regions such as Ningxia and the Gobi Desert, where low-cost solar electricity can be generated to support hydrogen production.[81] Furthermore, the experts suggest that China may take reference from some European countries and study the feasibility of producing hydrogen offshore using on-sea wind power on a large scale. The offshore production can construct a pure hydrogen gas pipeline connecting the facilities directly to use sites for direct usage to raise the transportation efficiency. This approach can be a promising approach to the renewable energy industry for China as it possesses a long coastline and can support the demand in the coastal regions.

> **“Southern China is more developed and has higher electricity consumption. However, southern China does not have sizable hydro or wind energy production. The hydroelectric power plant at the Three Gorges could not sufficiently meet the hydrogen demand. In terms of solar power, southern China is mostly rainy in the summer, and the intensity of the sunlight is not high enough for efficient solar power generation. Therefore, southern China is not a suitable place to produce green hydrogen. In contrast, western China could produce green hydrogen more efficiently. For example, Ningxia is already producing hydrogen with solar power, and the Sichuan province is leveraging hydroelectric power to produce hydrogen.” — General Manager**

To improve the current technological limitations on green hydrogen production and storage, the experts point out that China needs to focus more efforts on R&D to resolve domestic manufacturing limitations of hydrogen equipment such as PEM-based electrolysers and high-pressure hydrogen storage tanks. Domestic manufactured electrolysers are currently limited to the less efficient Alkali-based electrolysers that are prone to interruptions and long restart times as well as renewable energy input instability. However, importing the more efficient foreign PEM-based electrolysers on a large scale is not cost-effective. The ability to manufacture the more efficient electrolysers is vital to support the cost-effective deployment of green hydrogen production capability on a large scale in China. The experts also suggest that electric grids for renewable electricity storage be deployed to support 24/7 hydrogen production. Particularly for photovoltaic energy production, energy can be stored on the installed grid during daylight hours when the production rate is high and output at a fixed rate during night time when production is halted. Regarding storage, the experts suggest that the government could facilitate the application of 70 MPa hydrogen storage tanks in FCEVs to replace the common 35 MPa one for higher efficiency. A handful of companies, such as Sinoma Science & Technology and Beijing Tianhai, have already succeeded in manufacturing prototypes of 70 MPa storage tanks. FCEVs will be more fuel-efficient and cover a longer distance at a lower cost with more efficient storage tanks.[52]

To foster a supportive hydrogen industry environment and help SMEs (Small and Medium-sized Enterprises) integrate into the Chinese hydrogen community, the experts suggest that the Chinese government help the community establish an open, standardised community platform to assist SMEs with their R&D projects. One of the experts suggested that the hydrogen business sector in China should establish either a new national industry association or an extension of the existing hydrogen alliances under the government agencies' lead to facilitate integration and knowledge exchange. These meaningful exchanges are often able to speed up local R&D. Furthermore, another of the experts also believes that it is important for SMEs to be integrated with large enterprises in such an association. This integration would help promote a helpful and inclusive community in building a healthy hydrogen business ecosystem in China. One of the experts also suggested that the Chinese government should also provide more assistance and encourage SMEs to integrate among big enterprises in their R&D projects. For instance, the government should promote an industry culture where SMEs act as individual innovators helping SOEs on R&D projects.

7

Indonesia

7.1 Overview

Table 6 Indonesia Hydrogen Market Overview

OVERVIEW OF INDONESIA	
Key Background Information	• Indonesia currently has no clear national hydrogen strategy established, while its national vision on environmental sustainability and zero-emission aspirations have promoted hydrogen development in the country to a certain extent. • Indonesia has been producing hydrogen for various purposes, including power generation, transportation, and refining. However, hydrogen is mainly produced as a by-product and the supply is still low. Blue and green hydrogen only account for a small proportion. • The demand for hydrogen is yet to be fully established in Indonesia, where it is widely used in various industrial sectors and only to a lesser extent in the power sector.
Key Expert Insights	• Indonesia's hydrogen market is still at the early development stage, and its overall development is lagging behind the other countries in the APAC, such as Japan, South Korea, and Australia. • The lack of concrete policies and a hydrogen roadmap hinders Indonesia's hydrogen development and related incentives to boost private investments in the field. • The immature production technology and insufficient hydrogen infrastructure pose barriers to producing, transporting and storing hydrogen in a financially viable way, especially given Indonesia's diverse geography. • However, clear government support for renewable energy is a potential driver of the hydrogen economy in the country, as this indicates the government's attention to the deployment of cleaner energy. • Indonesia's utilisation of hydrogen in the mobility and power sectors will increase in the future. It can also develop itself as a hydrogen exporter within the APAC region in the longer term, given its geographical proximity to many Southeast Asian countries.

7.2 Background

7.2.1 Overall Hydrogen Landscape

Indonesia does not have a clear national hydrogen strategy with no distinct roadmap or beneficial policies to support the development of hydrogen industries. As of December 2021, Indonesia had only established a mandate RUEN[vi] outlining the regulation for hydrogen use for transportation. The plan was issued in 2017, proposing a strategy to utilise new energy sources in liquified form, namely liquefied coal and hydrogen, for the transportation industry from 2016 to 2050.[90] In 2010, the Ministry of Energy and Mineral Resources (MEMR) of the Republic of Indonesia came up with a strategy to meet RUEN's 23 per cent renewable energy mix target by 2025 by developing roadmaps for each technology.[91] However, detailed plans under the mandate are still being developed, with no significant programmes initiated nor related plans published by the government as of December 2021.

In terms of national regulations, there is a national standard related to hydrogen application in Indonesia. The Indonesia National Standard (SNI) RSNI3 7928:2013 was formulated to regulate hydrogen fuel safety and security. The standard outlines (i) the restriction on the use of hydrogen, (ii) safety requirements for the use of hydrogen and liquified hydrogen, (iii) properties, mitigation and risk control, and (iv) providing specific guidance on the application of hydrogen in the hydrogen fuel industry in Indonesia. Nevertheless, save for this National Standard RSNI3 7928:2013, there is no other national regulation regulating the production or use of hydrogen in other sectors in Indonesia.

While there is no clear national hydrogen strategy currently established in Indonesia, its national vision on environmental sustainability and zero-emission aspirations, to a certain extent, have promoted hydrogen development in Indonesia. In 2015, the government of Indonesia pledged to reduce emissions from 2020 to 2030 by a target range of 29 per cent[vii] to 41 per cent[viii] against the 2030 business-as-usual scenario. This renewed pledge increases the committed target from the 2010 pledge of 26 per cent.[92] In order to achieve the target, the development of renewable energy sources as a national policy directive has been established accordingly. According to Government Regulation No. 79/2014 on National Energy Policy, new and renewable energy should account for at least 23 per cent in 2025 and at least 31 per cent in 2050 in the primary energy supply mix among the other energy sources such as oil and coal.[93] The policy directive in promoting the use of new and renewable energy provides an opportunity to showcase the importance of hydrogen as an alternative and complementary energy source.

7.2.2 Hydrogen Supply Landscape

Indonesia has been producing hydrogen for various purposes, including power generation, transportation, and refining. However, the supply of hydrogen is still low, as it is usually produced as a by-product in Indonesia in sectors such as the chemical industry to produce chlorine. Furthermore, most hydrogen produced in Indonesia is grey or brown hydrogen. Blue and green hydrogen only account for a small share in Indonesia. Key suppliers of hydrogen in Indonesia are Brenntag, Evonik, PT Peroksida Indonesia Pratama, Air Liquide, and Samator. While the current hydrogen supply is still low in Indonesia,

vi National Energy General Plan of Indonesia

vii An unconditional reduction refers to a definite commitment to the reduction of GHG emissions. The commitment will be implemented through effective land use and spatial planning, sustaining forest management which includes social forestry programmes, restoring the functions of degraded ecosystems including wetland ecosystems, improved agricultural productivity, energy conservation and the promotion of clean and renewable energy sources and improved waste management.

viii A conditional reduction refers to targeting a reduction of GHG emissions. The actual level of reduction is subject to the availability of international support for finance, technology transfer and development and capacity building.

Pertamina, an SOE in the energy sector, is actively developing green and blue hydrogen. For instance, studies and trials on green hydrogen are being carried out in the Ulubelu geothermal working area, which Pertamina Geothermal Energy manages. The company has announced a pilot project to produce green hydrogen in Indonesia, with the production capacity targeting a daily production of 100 kg. The project will start in 2023 with a budget of approximately USD 3 to 5 million.[94] The project is expected to be a proof of concept for replacing conventional hydrogen production processes, such as using natural gas as feedstock and further reducing the carbon footprint in hydrogen production.

HDF Energy, a French-based power generation company, introduced hydrogen to power generation in Indonesia and received positive feedback from the public. HDF Energy plans to develop Indonesia's first renewable-hydrogen combined power plant in 2024 on Sumba Island, East Nusa Tenggara Province. HDF Energy plans to develop a power plant called Renewstable, a technology that combines Solar PV and wind power to generate electricity with a capacity of 7 to 8 MW during the day, with some portion of the electricity stored in batteries. The rest of the electricity will be used to produce hydrogen using electrolysis. The batteries and the hydrogen fuel cells will work simultaneously to produce electricity at night. The total amount of investment for the project is approximately USD 70 million.[95] Financiers support the project intending to address challenges in Eastern Indonesia that heavily rely on diesel power generation and assist the government's vision of decarbonising the power sector.

7.2.3 Hydrogen Demand Landscape

The demand for hydrogen is yet to be fully established in Indonesia, where it is widely used in various industrial sectors and only to a lesser extent in the energy sector. Today, hydrogen used in the industrial sectors is used primarily in fertiliser manufacturing, refinery and chemical sectors. The largest hydrogen consumption in Indonesia is the oil and gas industry. The petrochemical industry is the second-largest hydrogen consumer, followed by the oleochemical industry and other industries.

The industrial application of hydrogen has gradually become more popular. PT Pupuk Indonesia (Persero), a state-owned enterprise in the fertiliser sector in Indonesia, formed a collaboration with Pertamina NRE in August 2021, exploring the opportunities of utilising clean hydrogen as a raw material to commercialise green ammonia and blue ammonia in Indonesia.[96]

Substantial demand for hydrogen used in the energy sector is still not established currently as the cost of using hydrogen is still far more expensive than that of using other alternative resources. Over the next three to five years, the demand for hydrogen is also expected to increase in the energy sector driven by SOEs such as Pertamina and several foreign private companies such as HDF Energy. Pertamina NRE is making an energy transition in line with the Grand Energy Strategy, transitioning from reliance on fossil-based energy to renewable energy sources. The energy transition target set by Pertamina aims to increase the energy mix of new and renewable energy by 10.2 GW power generating capacity, including 5.7 GW gasification power plant, 3.4 GW renewable energy such as solar energy, bioenergy, hydro and wind power plants, and 1.1 GW of geothermal energy in 2026.[97] With Indonesia's national target to install 250 MW of mixed energy or new renewable energy in 2025 to meet RUEN's 23 per cent renewable energy mix, it is expected that clean energy, including hydrogen, will be used further in Indonesia.

Moreover, joint research conducted between the government and private companies is observed in Indonesia. For example, the Assessment and Application of Technology Agency of Indonesia with Toshiba Energy Systems & Solutions Corporation (TESS) signed an agreement pact to begin their joint research to assess and develop the H2One™ system in Indonesia. The H2One™ system is an autonomous off-grid hydrogen energy system based on renewable energy and uses hydrogen as a fuel for power generation.[98] This research aims to build up a distributed energy supply system in the remote and off-grid areas in Indonesia using hydrogen power storage technology, promoting the application of hydrogen in the energy sector in Indonesia.

7.3 Expert Insights: Perception of Hydrogen Development

The majority of the experts consider that the hydrogen market in Indonesia is still in its early development stage, and its overall development is lagging behind the other countries in APAC, such as Japan, South Korea, and Australia. The main perceived reason contributing to the slower development is that the price of using hydrogen is still far from competitive compared to other alternative resources. The supply and demand for hydrogen in the Indonesian economy are yet to be established. In Indonesia, hydrogen is considered an expensive resource which discourages businesses from producing and utilising it. Even though the general public in the country has a consensus that hydrogen is a greener energy source, affordable prices still have a higher priority than environmental sustainability in commercialising hydrogen.

> **“ There is no clear development nor roadmap for hydrogen (in the country). We have prospects in that area [hydrogen economy], but there has not been such a massive development, so it is still in the development stage. ” – Director**

The experts agree that the Indonesian government has published no specific policy nor clear roadmap regarding hydrogen usage, hindering hydrogen development and related incentives to boost private investments in the field. The lack of government policies have resulted in insufficient investments in infrastructure and technology and, ultimately, high costs of producing hydrogen. As a result, there is inadequate investment in hydrogen-related infrastructure, such as hydrogen transportation and storage in Indonesia. The lack of policy and a clear roadmap have ultimately affected hydrogen storage and transportation feasibility and efficiency. Besides, the technologies in the hydrogen field are less mature than in other countries, resulting in a higher cost of production. As such, slower development of the hydrogen market is observed in Indonesia.

The experts also suggest that the high transportation costs limit the current development of hydrogen exports in Indonesia. While the transformation of gaseous hydrogen into liquified hydrogen before cross-border transportation requires substantial investment in building the necessary facilities, the demand for hydrogen from overseas is not huge enough to justify the investment as the international hydrogen supply chain is still relatively nascent. Besides, the experts perceive that Indonesia’s amount of hydrogen excess is currently not significant enough for scalable exports. As a result, the experts believe that Indonesia is unlikely to become a notable hydrogen-exporting country in the near term, given the constraints.

7.4 Expert Insights: Supporting Factors for Hydrogen Development

The experts perceive that international banks’ financial support has facilitated the setting up of projects in Indonesia. For instance, the Asian Development Bank (ADB) has approved a USD 150 million loan for a facility to encourage public and private funds to invest in green infrastructure projects in Indonesia. The new fund called the “Sustainable Development Goals Indonesia One-Green Finance Facility” (SIO-GFF) aims to finance at least ten projects, of which at least 70 per cent by value will be green infrastructure projects.[99] With support from international commercial banks, Indonesia has more resources for conducting initial research on hydrogen production and related technologies, intending to eventually lower the production and transportation costs for the commercialisation of hydrogen in Indonesia.

The experts also believe that Indonesia’s technological advancement has increased hydrogen transportation and storage safety, promoting hydrogen development in Indonesia. For instance, the refinery sector has seen technological advancements in transportation and storage safety over the past ten years. High-pressure gas storage tubes are deployed where the hydrogen is stored to avoid gas leakage. The technological advancement in hydrogen transportation and storage has become a supporting factor driving the hydrogen development in Indonesia as hydrogen is becoming easier to use and apply to the downstream sectors.

> **“There has even been a technology change over the last ten years. It has been developed and is getting better. The technology from before the 80s is still prone to work accidents in terms of its safety. But the technology after 2000 is better.” — Production Officer**

Some of the experts suggest that clear government support for renewable energy and hydrogen development is a driver of the hydrogen economy in the country. While hydrogen development is still nascent in the country, the experts suggest that there are signs of government support that could accelerate hydrogen development. In particular, the current administration issued two regulations in 2021 to facilitate the growth of renewable energy in the short term and until the end of the decade.[100] To a certain extent, the supportive actions toward renewable energy indicate the government's attention to the deployment of cleaner energy. While the production of green hydrogen requires energy input from renewable energy sources, the renewable energy sector could also promote the production and application of green hydrogen in Indonesia.

7.5 Expert Insights: Barriers to Hydrogen Development

The experts agree that the lack of government policy is a major barrier to Indonesia's hydrogen development. The Indonesian hydrogen development roadmap is unclear as it lacks specific policies and guidelines on hydrogen development and applications. The Indonesian government is currently developing a national hydrogen roadmap with research academies. However, concrete policies or incentives have not been fully established and launched. Besides, Indonesia's possible applications and usages have not been set clearly by the government thereby introducing perceived risks from the business communities. For instance, one of the experts shared that the government currently does not have a clear direction on the role of hydrogen in the energy system nor clear ideas on possible hydrogen application in Indonesia. The expert opines that without a clear roadmap and comprehensive planning on hydrogen development, sector-specific policies or regulations cannot be rolled out accordingly.

> **“When it comes to hydrogen itself, there does not seem to be any direction regarding policymaking by the government. It is unclear whether the government has a concrete plan for using hydrogen yet, for whom, and when it will be used. So, it is natural that the government has not formulated clear policies or regulations in this area yet.” — Researcher**

Moreover, the experts suggest that financial incentives such as subsidies and tax reductions are still lacking, which could drive further research and initial investment from the private sector. According to the Indonesia Clean Energy Outlook published by the Institute for Essential Services Reform (IESR), a lack of investment in renewable energy signals a lack of investors' confidence in Indonesia.91 Investors have generally been discouraged by the poor incentives offered by existing regulations and government policies.

The experts also highlight that the insufficient hydrogen infrastructure poses a barrier to transporting and storing hydrogen in a financially viable way, especially given Indonesia's diverse geography. Indonesia currently does not have a well-built gas pipeline network to transport hydrogen. Hydrogen suppliers have to use tube trailers to transport hydrogen across the country, which costs more than a gas pipeline network. Besides, island-formed Indonesia also poses a geographical limitation and, therefore, increases the difficulty and capital requirements of building a pipeline system among the islands in the country. As infrastructure requires time and capital to develop, the insufficient hydrogen infrastructure is expected to pose a barrier to Indonesia's hydrogen development in the short to medium term.

“ The cost of hydrogen is still high as the infrastructure itself is also challenging. For example, the demand for hydrogen will be concentrated in one or two islands, such as Java, Bali, or Sumatra. We have to connect the supply and demand by setting up a network to distribute or transport the hydrogen from the source to the demand sites. ” – Officer

The immature hydrogen production technology is considered by the experts to be another barrier hindering the development of hydrogen, resulting in the high cost of production and limited application deployments. While this is a common issue across the APAC region that causes hydrogen not to be as price-competitive as other energy sources, Indonesia's situation is considered worse, given the lack of government incentives and insufficient infrastructure. The cost of production is still too high for hydrogen to be fully commercialised for domestic usage. According to their latest research, the expert reveals that Indonesia is still seeing economic failure of the proliferation of domestic hydrogen applications due to the high production costs. For example, one of the experts revealed that the application of grey hydrogen has not been fully commercialised successfully in Indonesia's power and mobility sector, and the cost of green hydrogen currently is more expensive.

7.6 Expert Insights: Future of Hydrogen Development

Indonesia is a large market for manufacturing and transportation. Hydrogen, produced via green sources, can play a pivotal role in supporting Indonesia's objective of massively reducing carbon emissions, which will be a significant achievement in terms of environmental sustainability.

The experts believe that the utilisation of hydrogen in the mobility and energy sectors will increase in the future. The experts generally believe that the best way to establish a viable and affordable hydrogen market in Indonesia is to initially increase the utilisation of hydrogen in the energy and mobility sectors. The focus on energy and mobility sectors also follows Indonesia's national vision of developing cleaner and sustainable energy resources and reducing the emission of greenhouse gases (GHG) to decarbonise the energy and mobility sectors. Once the initial demand for hydrogen is formed, the production and related infrastructure investments would come into operation, providing a foundation and further driving hydrogen development. The initial hydrogen demand would, in turn, increase the economies of scale and lower the hydrogen production costs thereby increasing the financial viability and adoption for other sectors. Eventually, hydrogen in Indonesia will become a commercially viable resource that is more profitable from a business perspective. In fact, according to estimates by ERIA, Indonesia has the potential to have the highest demand in the Association of Southeast Asian Nations (ASEAN) by 2040.[101]

“ I foresee hydrogen being implemented in various sectors in the upcoming years. Applications with the highest potentials are automotive, power generation and refineries. ” – Production Officer

Furthermore, the experts predict that there will be a faster pace of development in hydrogen in Indonesia over the next five to ten years, given that the private sectors will initiate more research and projects. Private companies will continue to increase their presence within Indonesia's hydrogen economy. For instance, one of the experts revealed that HDF Energy has plans to initiate at least 20 hydrogen-related projects in Eastern Indonesia to accelerate the overall development in Indonesia. As estimated by one of the experts, it will take five to eight years for hydrogen to become a substantial commodity in Indonesia, thereby driving the price to a sufficiently low level to be a viable alternative energy source.

While progress is still expected to be made in Indonesia's hydrogen development over the next five to ten years, the experts believe that

Indonesia will only be a follower within the APAC region over the short term. Leading countries such as Japan, South Korea, and Australia will lead the development as they have been highly involved in hydrogen development and have constantly been encouraging hydrogen deployment in their countries. Driven by the massive demand for hydrogen in these leading countries, the experts suggest that Indonesia can develop itself as a hydrogen exporter within the APAC region in the future, given its geographical proximity to many Southeast Asian countries, either exporting green or grey hydrogen.

7.7 Expert Insights: Actions to Accelerate Hydrogen Development

To accelerate the hydrogen development in Indonesia, all the experts suggest that a comprehensive set of government policies has to be rolled out by the Indonesian government as soon as possible. It should include a clear roadmap and direction on hydrogen development and supportive policies or regulations to guide hydrogen production and utilisation in different sectors. For example, roadmaps should be coupled with targeted and sufficient financial incentives such as subsidies and tax reductions to promote business development and investments in hydrogen.

> **“It would be so much better if there were investment from the government to promote hydrogen production and application. This could, in turn, benefit the Indonesian economy. The government should also provide certain incentives to the business sector to facilitate hydrogen deployment.” — Production Officer**

The experts also suggest that it is important for the Indonesian government to play a key supportive role to help establish a stable demand and supply model for the hydrogen market. The additional government support could be accomplished by promoting clean energy and focusing on reducing national GHG emissions in Indonesia. An example of such required policies is the Carbon Tax which will be effective in April 2022.[102] The Carbon Tax is deemed a supportive policy driving the development of hydrogen as it could increase the awareness of clean energy and the opportunity cost of not converting from fossil fuels to cleaner energy, such as hydrogen.

Apart from clear and supportive government policies, more research and pilot initiatives are also deemed necessary to increase the technology development in Indonesia and bring down the cost of hydrogen production. The experts generally believe that conducting research and pilot initiatives will facilitate the development of hydrogen production technology and, as a result, increase production efficiency and reduce production costs. One of the experts also suggested that Indonesia should develop in the field of hydrogen purification and liquification to facilitate the transportation of hydrogen within the country and even across the border in the future. As an illustration, the expert pointed out that hydrogen could be transported to further locations from production sites more efficiently if purified and liquified near the origin of production. Hence, they are confident that conducting more research and pilot projects is a way to accelerate hydrogen development in Indonesia.

8

India

8.1 Overview

Table 7 India Hydrogen Market Overview

OVERVIEW OF INDIA	
Key Background Information	The Prime Minister announced the National Hydrogen Energy Mission (NHM) and drew up a roadmap in August 2021. The government has set an ambitious target along with extensive investment. In 2022, the NHM identified pilot projects, infrastructure, supply chain, R&D, regulations, and public outreach as broad activities for investment. Most of the six million metric tonnes of hydrogen produced in India in 2021 was produced through SMR by key players. Green hydrogen development is still at an early stage, and there is currently no significant hydrogen storage or distribution in India. India's hydrogen demand is driven mostly by demand from industrial and refinery processes. The government has been proactively supporting the development of hydrogen use in the mobility sector with focused policies.
Key Expert Insights	Hydrogen is still at an early stage in the energy sector. India's hydrogen usage is highly limited to petrochemicals, fertilisers and a few industries. The development of the hydrogen mission can serve multiple purposes and eventually enable India to achieve energy independence and security. The high demand from the energy, industrial, and mobility sectors is key to fostering India's hydrogen economy development. The government has also played a vital role in supporting collaboration in research to drive hydrogen development and is looking for opportunities to promote private sector involvement. Research has been limited due to the lack of funding to develop related technology and implement the necessary HRS infrastructure. The development of hydrogen could be slower than anticipated as there is much paperwork and the government often delays approvals. Significant adoption of hydrogen might not materialise in the mobility sector for 10 to 15 years due to the lack of investments, but FCEVs could be deployed in specific mobility niches. The government should consider targeting one industry segment over the short term while enforcing hydrogen for industrial purposes to educate the public on the benefit of green hydrogen in reducing the carbon footprint over the long term.

8.2 Background

8.2.1 Overall Hydrogen Landscape

The Indian government announced a plan for hydrogen development that was objectified to achieve its emission goals under the Paris Agreement and reduce the dependence on imported fossil fuels in 2020.[103,104] In 2020, the Indian government announced a plan of developing 175 GW of renewable energy capacity by 2022.[104] Furthermore, the Prime Minister also announced the NHM and drew up a roadmap in August 2021 to use hydrogen as an energy source in the short and long term.

According to the NHM, hydrogen demand is estimated to increase from six metric tonnes in 2021 to 28 metric tonnes by 2050.[105] The government aims to increase demand by focusing on industry sectors to either expand in existing sectors, such as fertilisers and refineries or grow into new sectors, such as steel. The NHM also proposes making it mandatory for fertiliser plants and oil refineries to purchase green hydrogen to reduce the nation's dependence on fossil fuels. The NHM will also focus on producing green hydrogen to develop India into a global hub for green hydrogen. To actualise the NHM, the government agency, the Ministry of New and Renewable Energy (MNRE), is now in charge of policymaking, hydrogen-related research, and green hydrogen projects in India.

In February 2022, the Prime Minister announced the first part of the NHM, aiming to boost the production of green hydrogen and ammonia with renewable energy and develop India into a green hydrogen global hub to export 5 million metric tonnes of green hydrogen by 2030.[106,107,108] The policy allows companies that manufacture green hydrogen and ammonia to install renewable energy generating plants without transmission costs until 2025. These green hydrogen and ammonia manufacturers can 'store' the unconsumed renewable electricity to the grid for up to 30 days at no cost and take it back when required. Green hydrogen and ammonia manufacturers are also allowed to set up bunkers near ports for hydrogen storage to export or consume hydrogen as shipping fuel, with the land provided by the respective port authorities. Lastly, the government will also set up manufacturing zones focusing specifically on green hydrogen production zones to create the necessary clustering effect.

The government has set an ambitious target along with extensive investment. In 2022, the NHM identified pilot projects, infrastructure, supply chain, R&D, regulations, and public outreach as broad activities for investment with a proposed financial outlay of INR 8 billion (or USD 107.1 million) over the next three years. For example, INR 250 million (or USD 3.4 million) was allocated from the Union Budget 2021–2022 for the R&D in hydrogen energy.[109] In its first year, the NHM will also focus primarily on funding pilot projects and experimental initiatives in the industry sector. On the application side, Indian Public Sector Undertakings (PSUs), such as Indian Oil and NTPC, and private companies such as Mahindra & Mahindra (M&M), are leading the charge in bringing fuel cell buses to the roads.

The green hydrogen development in India is currently at a very nascent stage. According to the experts' information, 98 per cent of the hydrogen produced is grey hydrogen, and 2 per cent is a mix of blue and green hydrogen. The government has ambitious plans to convert 5 per cent of grey hydrogen to green hydrogen by 2024 and 15 per cent over the next five years. To raise the production capacity for green hydrogen, the government aims to extend the production-linked incentive (PLI) scheme to support the indigenisation of electrolysers, and the initiative will target the establishment of 10 GW of domestic manufacturing capacity for green hydrogen starting from 2024.[110,111] The government aims to bring down the cost of green hydrogen to USD 1/kg.[112]

8.2.2 Hydrogen Supply Landscape

Most of the six million metric tonnes of hydrogen produced in India in 2021 was produced through the SMR process by key players such as Praxair India Private Limited, Linde India Limited, INOX Air Products, Bhuruka Gases Limited, Air Liquide India, Aditya Birla Chemicals (India) Limited., Gujarat

Alkalies and Chemicals Limited, DCW Limited (DCW), TATA Chemicals Limited, and GHCL Limited. To some small extent, hydrogen is also produced as a by-product in some industries in India. For example, Chemfab Alkalis Limited's production of 2.9 million tonnes of caustic soda produces about 83,000 tonnes of hydrogen.[113,114]

Green hydrogen development is still at an early stage, and green hydrogen production in India is typically about three times more expensive than blue hydrogen. According to the industry body, India H2 Alliance (IH2A), India will require an estimated USD 15 billion in public and private funding to set up a 15 GW capacity green hydrogen electrolyser by 2030.[115] This electrolyser capacity is expected to produce 3 million metric tonnes of green hydrogen, and 30 GW of renewable energy is required for the production.[115] However, due to the captive consumption nature of the hydrogen, in most cases, hydrogen is produced within the manufacturing facility, and there is currently no significant hydrogen storage or distribution in India. India does not have any distribution pipeline for hydrogen, and the government has emphasised developing the pipeline for hydrogen transportation in the future.

Most of the significant green hydrogen initiatives are being led by PSUs as the NHS focuses on green hydrogen as the solution to the growing need for fossil fuels in the country. For example, National Thermal Power Corporation Limited (NTPC) was the first state-owned company awarded India's first green hydrogen microgrid project at its Simhadri plant in Andhra Pradesh.[116] NTPC has also recently announced its plan to develop 60 GW of renewables capacity by 2032.[117] Besides the pilot project in its Vindhyachal unit, which aims to produce hydrogen at around USD 2.8 to 3/kg, the company is also proactively planning for the future with plans to set up a 4,750 MW solar energy park at the Rann of Kutch and generate green hydrogen on a commercial scale from the park, and its first green hydrogen fuelling station is in Leh, Ladakh.[118] In addition, GAIL Gas Limited, a state-owned natural gas corporation, plans to build India's largest green hydrogen plant to supplement its natural gas business. The company has finalised at least two production sites for green hydrogen production, including one at Vijaipur in Madhya Pradesh, with a production capacity of 10 MW.[119] PSUs in the oil and gas and refinery sectors, such as Indian Oil Corporation Limited (IOC) and Bharat Petroleum Corporation (BPCL), have also started green hydrogen production initiatives. For example, IOC has announced plans to build a green hydrogen plant at the Mathura and Panipat refineries, targeting to convert at least 10 per cent of the hydrogen usage to green sources by 2024.[120] Meanwhile, the company is also setting up a plant to manufacture green hydrogen at its Jorhat oil field in Assam.[121] Finally, BPCL, a Mumbai-based oil and gas corporation under the ownership of the Ministry of Petroleum and Natural Gas, Government of India, with two large refineries in Kochi and Mumbai, has cooperated with Bhabha Atomic Research Centre (BARC) to scale up alkali-based electrolyser technology for green hydrogen production.[122]

The private sector companies in India have also made commitments to green hydrogen production. For example, the operator of the world's largest oil refining complex, Reliance Industries Limited (RIL), has announced its plans to become a net carbon-zero company by 2035.[123] The company plans to redesign a Rs 30,000-crore plant that converts petroleum coke into synthesis gas to produce blue hydrogen at USD 1.2 to 1.5/kg.[124] Meanwhile, RIL also plans to invest INR 600 billion to build a 5000-acre green energy complex in Jamnagar to produce green hydrogen. In addition, Larsen & Toubro (L&T) plans to spend between INR 10 billion and INR 50 billion on renewable energy to achieve net carbon zero by 2040. The company has announced the setting up of a green hydrogen plant at the Hazira complex in 2022, supporting internal needs.[125] Another renewable energy company, GreenKo, has formed an agreement with John Cockerill, a Belgian manufacturer of alkaline electrolysers, to develop green hydrogen electrolysers in India jointly. The partnership will facilitate the production of the lowest-cost green hydrogen by enabling the supply of electrolysers at scale in India by 2022.[126] The company also plans to build green ammonia export facilities, producing hydrogen at the rate of up to one metric tonne per annum by 2025 and a 2 GW electrolyser is required.[127] Finally, the Adani Group has also announced a USD 20 billion investment in renewable energy generation, component manufacturing, transmission and distribution over the next decade.[128]

8.2.3 Hydrogen Demand Landscape

According to one of the experts, India's hydrogen demand is approximately 6 to 6.7 million tonnes per year, driven mostly by demand from industrial and refinery processes. The demands from industrial and refinery use account for over 90 per cent of the hydrogen demand in India. Material production processes such as producing basic chemicals such as ammonia for fertilisers and methanol account for almost 60 per cent of all demand. Oil and steel product refinery accounts for 20 to 30 per cent of the hydrogen demand and the petrochemicals sector accounts for the remaining consumption. To achieve competitive prices for green hydrogen in the market, MNRE is considering aggregating demand from different sectors and consolidating bids for green hydrogen and ammonia procurement through designated implementing agencies.

The Indian government has been proactively supporting the development of hydrogen use in the mobility sector with focused policies. In 2016, the Ministry of Road Transport & Highways issued a notification for hydrogen to be an automotive fuel. The ministry allowed up to an 18 per cent blend of Hydrogen CNG (H-CNG) as an automotive fuel in September 2020.[129] In the latest NHM, the government has also proposed a USD 8 billion scheme to incentivise companies to build electric and hydrogen fuel-powered vehicles to meet their clean mobility targets for 2030 with a robust base for manufacturing zero-emission vehicles (ZEVs).[130] There have been numerous FCEVs tested under different government-supported initiatives. For example, Tata Motors, in collaboration with the Indian Space Research Organization (ISRO) and Indian Oil Corporation Limited (IOCL) developed six fuel cell buses in 2019.[131] Subsequently, IOCL is procuring 15 hydrogen-powered buses with on-site hydrogen production for its Faridabad R&D centre.[132] In addition, around 50 hydrogen-enriched compressed natural gas CNG (H-CNG) buses are under testing in Delhi by Indian Oil Corporation Limited in collaboration with the Government of National Capital Territory (NCT) of Delhi.[133] Finally, NTPC is working on a pilot project to operate ten hydrogen fuel cell electric buses and vehicles in Leh and Delhi.[134]

Large companies such as M&M and Hyundai have also been very active in developing FCEVs. For example, M&M has developed 15 hydrogen-fuelled 3-wheelers and two hydrogen-fuelled internal combustion engine buses in collaboration with the Indian Institutes of Technology (IIT) Delhi.[135] In addition, Hyundai is seeking to place its first fuel cell NEXO SUV in India by 2022 and plans on building the required hydrogen infrastructure to support the vehicles near Delhi.[136]

8.3 Expert Insights: Perception of Hydrogen Development

The experts believe that hydrogen is still at an early stage of entering the energy sector in India, and hydrogen usage is highly limited to petrochemicals, fertilisers and a selected few industries. India is currently the world's third-largest consumer of oil, and the import of oil and natural gas accounted for almost 25 per cent of India's overall imports in 2020.[137] To reduce carbon emissions, government and non-government funding agencies are engaged in R&D projects on hydrogen production, storage, utilisation, power generation, and transportation applications. The experts believe that advancements in science and technology will make hydrogen a cheaper fuel in the future.

> **“ India is not energy independent, and the country spends over INR 1.2 million on importing energy. We need to become energy independent before 100 years of independence are completed. National Hydrogen Mission aims to cut down carbon emissions and increase the use of renewable sources of energy while aligning India's efforts with global best practices in technology, policy, and regulation. ” — Head of Operation**

One of the experts perceives that the development of the hydrogen mission can serve multiple purposes and eventually enable India's energy independence and security. The government has taken serious steps to become energy independent by 2047, with green hydrogen as one of the key options for replacing fossil fuels. Besides, the experts also believe that integrating different renewable energy resources, reducing the reliance on imports, addressing climate change, and achieving decarbonisation in other sectors are all key objectives aligned with the NTS. One of the experts further commented that even though the NHS announced the focus on industrial decarbonisation, there is also huge potential in the mobility sector as a direct replacement for fossil fuels that the government is targeting. In addition, shipping and aviation have limited low-carbon fuel options and could represent an opportunity for hydrogen-based fuels.

The experts believe that the government aims to achieve 80 per cent green hydrogen by 2050 after releasing its hydrogen mission policy in 2021. As of December 2021, around six large Indian private companies have shown interest in investing in the hydrogen field despite a lack of public awareness. Even though the hydrogen policy launched in 2007 was not well executed, one of the experts from the energy sector observes that the government is still confident in achieving the present targets.

> **“If you speak of the current state with respect to green hydrogen, it is still very early as the first national hydrogen mission was in 2007. Unfortunately, none of the policy's objectives have been met to date. In 2021 the second national hydrogen plan was released, and the government is positive about achieving the targets set out in the plan.” — Head of Operation**

On the export front, the experts believe that India has the potential to be a price-competitive green hydrogen exporter as India will be able to produce cheap renewable energy domestically. India has been investing in renewable energy for the last seven to eight years, and with inexpensive renewable power, the output cost of producing hydrogen will also be reduced and be cost-competitive in the global market. Once India becomes self-reliant in regard to energy, export will be an option to consider.

8.4 Expert Insights: Supporting Factors for Hydrogen Development

The experts perceive the high demand for energy and hydrogen and the drive for FCEV adoption as key factors in fostering India's hydrogen economy development. India's current hydrogen demand is over six million metric tonnes from the industrial and refinery sectors. The experts reaffirm the government's objective of reducing the dependence on fossil fuels across these industries and extending beyond other industries such as transportation. One of the experts believes that hydrogen can provide linkages between energy supply and demand in a centralised and decentralised manner, resulting in higher flexibility in the overall energy system. Hydrogen can be used for small- to large-scale applications and short- to long-term storage to meet the seasonal or daily supply and demand imbalance. For example, hydrogen can provide energy in rural places with limited or no access to the grid. Yet, as intermittency is the major barrier to achieving the ambitious targets of greater renewable deployment, the experts suggest that energy storage is an inevitable part of the energy system.

The government has played a vital role in supporting collaboration in research to drive hydrogen development and is looking for opportunities to promote private sector involvement. According to the experts, the Department of Science and Technology works with most research agencies, particularly getting clearances from the government departments and setting up advisory panels for hydrogen projects. The Department of Science and Technology is also working on at least eight to 10 hydrogen-related projects in storage, transportation, and production with research agencies and academia in India. The focuses of these projects include reducing the dependence on imported fossil fuels, reducing the carbon footprint in the country, integrating renewable energy, and decarbonising different sectors. Most of these projects are expected to complete and yield results within 6 to 24 months. Furthermore, the Indian government has also waived the transmission fee to encourage large corporations to manufacture green hydrogen. According to one of the experts, depending on corporations' responses, the Indian government will evaluate the possibility of extending the waiver after 2030. In addition, MNRE has been taking an active role in facilitating hydrogen production in India. For example, MNRE is looking to establish a single portal for all statutory clearances and permissions required for the manufacturing, transportation, storage and distribution of green hydrogen and ammonia. The committed clearance period will be shortened to within 30 days from the date of application.[138] Furthermore, MNRE also plans to waive the goods and services tax (GST) for domestically manufactured electrolysers for five years to further the hydrogen development in India.[139]

One of the experts further suggested that domestic technological intellectual properties in renewable energy resources could be a supporting factor in lowering the cost of renewable energy production. According to one of the experts from the academic sector, India has one of the lowest solar PV generation costs globally through a reverse auction mechanism. The breakthrough allows India to produce the lowest cost of solar PV generation, which stands at INR 2.0 per kWh compared to most current installations of INR 2.5 per kWh to INR 4 per kWh.[140] The expert believes that India has the potential to bring down the cost of green hydrogen by using low-cost renewable, domestically made solar technologies.

8.5 Expert Insights: Barriers to Hydrogen Development

The experts from different sectors agree that research is limited due to the lack of funding to develop related technology and implement the necessary HRS infrastructure and the government has allocated only INR 250 million (about USD 3 million) to MNRE's hydrogen-related R&D budget for the next five years.[141] Meanwhile, there is very limited technology in the mobility sector, and most companies are focusing on the electric vehicle segment for transportation. According to one of the experts from the energy department, very few auto OEMs besides the large entities such as Mahindra & Mahindra, Tata, and TVS are working on hydrogen fuel cell prototypes. The automotive OEMs are delaying the research since the required infrastructure for hydrogen fuel cells has not been developed well in the country. Currently, the focus on hydrogen fuel cells is limited, and most of the projects are still in the prototyping stage, requiring better technology and designs to attract customers. One of the experts suggests that hydrogen players are currently looking for better technology partners to accelerate the development.

The lack of distribution and storage infrastructure is also a key barrier to mass hydrogen distribution and adoption, especially for FCEVs. The experts believe that most hydrogen is currently produced near the consumption site or within the plant, with very limited infrastructure supporting manufacturing, distribution, and storage. Currently, hydrogen transportation is highly dependent on gas transported using trucks. The other major bottleneck in the hydrogen pathway is compact, efficient, conformable, cost-effective, and safe hydrogen storage. Until the hydrogen transportation and storage issues have been addressed, it will be difficult for FCEVs to proliferate, and the distance from the production sites will generally limit where hydrogen can be used.

The high-cost differential of utilising hydrogen compared to traditional fossil fuels is a barrier in the mobility sector. Besides the high cost of developing the required comprehensive HRS infrastructure to support FCEVs, the cost of hydrogen is three to four times more expensive when compared to fossil fuel. One of the experts suggested that the cost of grey hydrogen produced through fossil fuel is INR 300 to 400 (about USD 4 to 5), and hydrogen will only be competitive when the cost is down to roughly USD 2/kg. Furthermore, FCEVs remain more expensive than traditional vehicles in India because automotive manufacturers are generally hesitant to manufacture FCEVs on a large scale. The cost differentials would make it difficult for significant adoption in the mobility sector unless the hydrogen cost can be reduced to be competitive with fossil fuel. As a result, besides the various demonstration projects in limited geographic settings, high adoption of FCEVs will be challenging until these problems are addressed.

Finally, one of the experts also pointed out that the development of hydrogen could be slower than anticipated as there is much paperwork and the government often delays approvals. For example, setting up a new company could take up to 15 to 18 approval certificates from different departments across the government. Most of the projects related to the manufacturing of electrolysers are still on paper without significant progress being made. Yet, the experts witness the improvement from the current government as it has a single-window clearance procedure to speed up the process.

8.6 Expert Insights: Future of Hydrogen Development

The experts expect that the government and private sectors will contribute to the hydrogen economy differently. For the industrial sector, petrochemical, fertiliser and oil companies will be focusing on converting grey hydrogen into green hydrogen over the next five years. For many of these companies, it is expected that they will add supplemental green hydrogen capacity on site using either solar or wind energy in the short to medium term. Large enterprises and PSUs will likely take on scaling up of the centralised production plants by leveraging their experiences gained through the current ongoing demonstration projects. Furthermore, one of the experts further predicts that within the next ten years, the government will invest or work through the PSUs to set up the required distribution infrastructure and gas pipeline in at least the top 10 cities of the country by 2030.

The experts suggest that significant adoption of hydrogen might not materialise in the mobility sector for 10 to 15 years due to the lack of investments, but FCEVs could be deployed in specific mobility niches. One of the experts estimates that it would likely take a long time to develop the mobility sector as companies prefer to invest in electric technology instead of hydrogen fuel cell technologies for the mobility sector. The investment preference is mainly due to the government's focus and support of BEV infrastructure, such as building HRSs and supporting battery manufacturing. However, the expert further suggested that hydrogen's role in the mobility sector lies in the heavy-duty, long-distance mobility segments as hydrogen vehicles can outperform EV trucks given FCEVs' higher fuel longevity and shorter refilling time. In addition, the expert also further suggested that hydrogen could also power 3-wheelers and passenger vehicles as the refuelling time is significantly shorter than equivalent BEVs.

8.7 Expert Insights: Actions to Accelerate Hydrogen Development

In the short term, one of the experts pointed out that the government should target one industry segment at a time, and after it has succeeded, learning and adjustment can be conveyed to other industrial sectors for better development. For example, the government should focus on either the petrochemical or fertiliser industry first and start imposing policies on the usage of green hydrogen. One of the experts from the government further specified a short-term goal of achieving 15 per cent green hydrogen usage in the industrial sector by 2030. On the other hand, one of the experts from the industry association suggested that the government provide more funding for R&D on hydrogen technologies.

Over the long term, one of the experts suggested enforcing hydrogen for industrial purposes to educate the public on the benefit of green hydrogen in reducing the carbon footprint. The expert suggested that the industries should make a mandatory rule to use only green hydrogen. Once the use of green hydrogen achieves at least 50 per cent in the industrial segment, the government should also focus on the mobility sector and promote the benefit of hydrogen over fossil fuels.

More subsidies and FDIs can accelerate the building of the hydrogen facilities and accelerate technology development. One of the experts suggested that adequate subsidies for new investments in the hydrogen sector and FDI investments should be provided. The funding can be allocated to R&D activity for joint ventures and facilitating the needed technology transfer from other countries. These subsidies could supplement any private investments to support infrastructure building, such as HRSs and pipeline infrastructure.

Seeking other technological partners is required to shorten the technological gap with existing companies. One of the experts suggested that there is also a technology gap with current companies, and they have to look for better technology partners, such as the Gulf Cooperation Council countries (GCC). The GCC countries have invested heavily in hydrogen energy and have abundant resources for renewable energy products. Some of the experts suggested that India could strengthen its partnerships with the GCC countries in the R&D of hydrogen production, storage, and transportation. For example, the government or companies can work with the United Arab Emirates (UAE) on green hydrogen mobility and fuel cells,[ix] Kuwait on hydrogen storage technology and Qatar on academic research on clean energy, including hydrogen technology. In addition, given that India is identified as one of the potential export countries, importing blue or green ammonia from GCC countries can accelerate the adoption of green hydrogen.

ix Private companies including Marubeni Corporation, Hyundai, Toyota and Airquide started working with government bodies including Dubai's Roads and Transport Authority (RTA) to run feasibility studies as well as hydrogen bus pilot schemes.

9

Japan

9.1 Overview

Table 8 Japan Hydrogen Market Overview

OVERVIEW OF JAPAN	
Key Background Information	• The Japanese government has fully sponsored and led the development of hydrogen technologies through the Ministry of Economy, Trade and Industry (METI) since 1970, but it was not until 2017 that the country officially formulated its national hydrogen strategy. • Japan's reliance on grey hydrogen is inevitable in the short term, but it is slowly shifting its source of hydrogen from fossil fuels and nuclear to renewable energy. Japan started importing liquid hydrogen from Australia in early 2022 to mitigate the need for pure hydrogen. • Japan focuses on decarbonising the mobility sector with hydrogen deployment. As of December 2020, there were 162 HRSs, approximately 3,800 FCEVs, 99 fuel cell-operated buses, and roughly 250 hydrogen forklifts currently in operation.
Key Expert Insights	• Hydrogen development in Japan is already at its implementation stage, where consumer and commercial usage is the country's major focus. The Japanese government has been very open to listening to industry needs, researching basic technologies, and mitigating risks and costs. • Japan's hydrogen initiatives and policies are very advanced compared to the rest of the world. According to global statistics, Japan has the highest number of HRSs globally. • With the Japanese economy recovering slowly, some supply-side corporations have taken advantage of the system to profit from government funding rather than making additional investments in hydrogen, highlighting the potential insufficiency in governance and monitoring. • The country's exportation of FCEVs will continue to fuel the R&D efforts of hydrogen fuel engines in Japan and their overseas joint venture partners. • The Japanese government should consider adjusting its funding and subsidy policies toward hydrogen-related supply-side projects as the current policies are incapable of incentivising additional investments and development from the private sector.

9.2 Background

9.2.1 Overall Hydrogen Landscape

Japan started its development of hydrogen storage and fuel cell technologies in the mid-1970s, and the country has continued to seek ways to decarbonise its economy ever since. The Japanese government has fully sponsored and led the development of hydrogen technologies through the METI since 1970, but it was not until 2017 that the country officially formulated the world's first national hydrogen strategy. The formulation of the national hydrogen strategy aimed to propel the country from the R&D stage into the actualization and implementation of hydrogen technologies in Japan.

With the roadmap to achieve net-zero carbon emissions for the country by 2050, the strategy outlines three key milestones to reach decarbonisation. Japan made specific commitments under the United Nations Climate Change Convention to reduce GHG emissions by 26 per cent from 2013 levels by 2030, to promote the development of innovative technologies by 2050 that enable Japan to contribute to the reduction in accumulated atmospheric CO_2 globally to "Beyond Zero", and finally, to set Japan to achieve net-zero GHG emissions by 2050.[142] As of the completion of this report, while Japan's pace of development of hydrogen-related technologies is on schedule from the demand perspective, the supply side lacks a fluid supply chain to meet demands, thus hindering the development of hydrogen usage implementation for consumers.

As of December 2021, approximately 4,200 FCEVs were operating in Japan, with a gradual slowdown in additional adoption.[142] The domestic demand for FCEVs, to a certain extent, has been bottlenecked by the limited supply of hydrogen for HRSs. The limited hydrogen supply resulted in a situation where not all HRSs had enough fuel for additional consumer vehicle operation, discouraging consumers from purchasing FCEVs. The low subsidy amount for consumer FCEVs compared to commercial FCEVs for companies and manufacturers further discourages consumers from adopting FCEVs.[143] Unable to resolve the supply-side problem in the short term, the Japanese government's current focus is on exporting FCEVs and has set it as one of the key objectives of Japan's hydrogen roadmap. Despite the deployment of over 330,000 household hydrogen energy generators and storage units called ENEFARMS[x] installed for consumer usage, the pace of hydrogen implementation will still require additional policies to support day-to-day adoption.[142]

The country's forward-thinking goal to achieve net-zero carbon emissions within the next 30 years may not be easily achievable as Japan's economy has been heavily affected by the COVID-19 situation over the past two years. Many hydrogen supply-side companies, such as ENEOS, had been in distress due to the energy market fluctuations with the crude oil price decline in 2020, making them reluctant to make additional investments in the hydrogen economy.[144,145] Some supply-side companies rely heavily on full government subsidies to maintain revenues and profits without a proper roadmap or relevant investments to build supply chains. Although this policy to fully commit to hydrogen-related projects successfully pushed companies to build the necessary infrastructure, it does not benefit the greater need to form viable business models for future supply chains.

x ENEFARM (Residential Fuel Cells) is a hot water supply and warm water heating system that also enables households to generate power on their own. The system generates power through a chemical reaction by combining hydrogen extracted from Liquefied petroleum gas (LPG) or city gas with oxygen in the air and utilises the generated heat to supply hot water and heating.

Table 9 Japan Current Hydrogen Deployment Situation and Future Targets[142]

	Current Situation (As of December 2020)	Target by 2030	Target by 2050
Supply Production	Hydrogen derived from Fossil fuel (By-product hydrogen, natural gas reforming)	Establishment of the international hydrogen supply chain and increase of production efficiency within Japan	Full utilisation of a CO_2-free hydrogen supply chain
Production Amount	Over 200 tonnes	300,000 tonnes (via commercial supply chain)	10,000,000 tonnes
Pricing	JPY 100/Nm^3	JPY 30/Nm^3	JPY 20/Nm^3
Production Costs	N/A (Initial Development Stage)	JPY 17/kWh	JPY 12/kWh
No. of Stations	162+	900+	Effectively replaces Gas Station
No. of FCEVs	3,800+	800,000+	Fully replaces all fossil fuel vehicles to utilise FC stacks via cost reduction and/or conversion
No. of FC Buses	99+	1,200+	
No. of FC Forklifts	250+	10,000+	
No. of ENEFARM	330,000+	5,300,000+	Replaces all household energy systems

9.2.2 Hydrogen Supply Landscape

Japan's hydrogen supply is generally separated into three different sources: domestic green and grey hydrogen production, overseas import of liquid green pure hydrogen, and chemical conversion of non-pure hydrogen. While the Japanese government sees reliance on grey hydrogen as inevitable in the short term, the country is slowly shifting its source of hydrogen from fossil fuels and nuclear to renewable energy. Reduction of hydrogen production costs is one of its major goals. Overall advancements are underway to reduce the cost from about JPY 100 per cubic metre (Nm^3) in 2020 to JPY 30/Nm^3 by 2030 and below JPY 20/Nm^3 by 2050.[142]

Due to the lack of natural resources in the country for green hydrogen production, there have not been many breakthroughs in development. To tackle this issue, the Japanese government opened up a major hydrogen research complex based in Fukushima Prefecture near the site of the Fukushima nuclear accident. The Fukushima Hydrogen Energy Research Field (FH2R), which opened in March 2020, utilises 20 MW solar power generation on a 0.18 km^2 site to electrolyse water in a 10 MW-class hydrogen production unit and is one of the world's largest green hydrogen production facilities. The facility is also responsible for various experiments to identify the optimal operation control technologies.[146]

The current hydrogen domestic production is mainly split into four methods to supply the country with enough hydrogen that FCEVs rely on. First is water electrolysis via electricity generated from other means such as nuclear energy, with key players being Asahi Kasei, Hitachi Zosen, Toray, Hydrogenics (Canada), Thyssenkrupp (Germany), and Nel (Norway), ITM Power (UK), and Siemens Energy (Germany). Second is SMR, with notable companies such as Mitsubishi Heavy Industries, Mitsubishi Kakoki, Hitachi HRI, IWATANI and Osaka Gas involved. Third is major players such as IWATANI and Obayashi utilising electrolysis via biomass fuels from forestry resources and wastes created with high-temperature waste furnaces.

Finally, there is hydrogen production via gaseous by-products from steel factories and chlor-alkali electrolysis, such as Asahi Kasei, Daiso Engineering, and AGC.[147]

For overseas import of liquid green hydrogen, the Japanese government has fully funded the Suiso Frontier Project, the world's first liquid hydrogen transport tanker built by Kawasaki Heavy Industry and owned by the CO_2-free Hydrogen Energy Supply-chain Technology Research Association (HySTRA). According to Kawasaki's official data, the tanker is installed with a 1,250 m^3 vacuum-insulated, double-shell-structure liquefied hydrogen storage tank manufactured by Harima Works, and is capable of transporting liquefied hydrogen at 1/800 of its original gas-state volume, cooled to 253 degrees Celsius, safely and in large quantities over long distances by sea.[148] This tanker has recently started operating at full capacity and transporting liquid hydrogen fuel from Australia, its maiden voyage being in January 2022. As of 2021, only France and Japan possess technologies for shipping pure liquid hydrogen, and only Japan can ship in large quantities.[149] However, it is notable that Suiso Frontier's engine operates on diesel-electric propulsion. In the future, the Japanese government and Kawasaki aim to create new transport ships that can operate solely on hydrogen. However, as the current technology will only allow tankers to operate with ammonia hydrogen engines, which have limited operating distance, they can only operate with local shipments rather than international.

In addition, the import of liquid hydrogen from Australia started in January 2022 to mitigate the need for pure hydrogen in Japan. The Hydrogen Energy Supply Chain project (HESC), which the Australian and Japanese governments have funded, produced the brown hydrogen being shipped to Japan at a newly constructed gasification plant. The project was led by Kawasaki Heavy Industry, Electric Power Development, IWATANI, Marubeni, Sumitomo Corp., and AGL Energy (Australia).[142] Even with the combined domestic production of pure hydrogen fuel, the demand to supply additional FCEV operations will require supply-side players to make additional efforts to bolster R&D to reduce the pricing of pure hydrogen fuel.

For non-pure hydrogen fuel, two major fuels are imported from overseas, mainly blue and grey ammonia and MCH. In 2020, ITOCHU successfully made the first blue ammonia import from India to Japan at a roughly 20 per cent premium to regular grey ammonia. The amount, though not substantial, was about 50 tonnes, but the company is seeking to increase its annual shipment from Saudi Arabia and India to 100 tonnes in 2022 with further increases. Blue ammonia is currently used as an agricultural fertiliser rather than hydrogen production, but it is possible to use the same material for power generation. JERA, a power company, expects to source about 40,000 metric tonnes of ammonia in the next four years for grey ammonia.[150] Japan currently imports about 20 per cent of its grey ammonia from Malaysia and Indonesia.[151] Chemical conversion of non-pure hydrogen from liquid MCH is another common method of non-pure hydrogen production in Japan.[xi] ENEOS is the current leader in Japan for MCH and relies on overseas production from Australia and Brunei to create the fuel.[152] Due to the lack of wind and solar power in Japan, it is difficult to replicate the MCH production process in Japan. Therefore, ENEOS hopes to increase production, mainly via a mix of wind and solar power in Australia and hydropower in New Zealand. Unfortunately, despite MCH production being mostly green, the ships for its logistics operate on fossil fuel. Additionally, ENEOS is considering purchasing excess production of blue hydrogen created by Petronas in Malaysia and shipping it over to Japan. It is also notable that the refinement of ammonia to pure hydrogen fuel is yet to be developed in Japan.

9.2.3 Hydrogen Demand Landscape

As of 2020, there were 162 HRSs, approximately 3,800 FCEVs in operation, 99 fuel cell operated buses, and roughly 250 hydrogen forklifts currently

xi MCH is produced from toluene and hydrogen, which can be safely and economically stored, and transported. Both toluene and MCH are maintained in a liquid state at ambient temperatures and pressures, thus making it an easier alternative to liquid pure hydrogen.

in operation.[153] HRSs are concentrated in four regions: 60 stations in Tokyo's Kanto region, 49 stations in Aichi Prefecture, where Toyota Automobile operates, 23 stations in Osaka's Kansai region, and 30 stations in Fukuoka's Kyushu region.[144] The combination of HRSs has provided a refuelling chain for FCEV trucks to operate in these regions;large players, such as ENEOS, operate roughly half of the 180 HRSs in Japan; other major operators include IWATANI, Tokyo Gas, and Idemitsu.

Regarding consumer FCEVs, there are approximately 3,800 vehicles in operation across Japan. The consumer FCEV, Mirai, manufactured by Toyota, is one of the first mid-sized fuel cell-powered automobiles to be mass-produced and sold worldwide in 2014. The Mirai has accounted for over 14,000 units out of the 40,000 FCEVs sold globally as of June 2021.[154] There are currently only two models of consumer FCEVs publicly available in select markets, namely the Toyota Mirai and the Hyundai Nexo, which were first sold in 2018. The Honda Clarity, also produced in Japan, was produced between 2016 and 2021 and was subsequently discontinued. Honda currently has two vehicle models produced utilising General Motors's JV technologies, which will be sold under the Honda brand and the Acura brand in North America.[155] The demand for fuel cell commercial vehicles has remained low over the years in Japan due to insufficient coverage of the refuelling infrastructure.[156] To further push consumer adoption of FCEVs, the government has increased its subsidy amount up to JPY 1.3 million to match conventional gasoline automobile pricing.[143]

Regarding public transportation, Toyota has developed its first FCEV bus, SORA. This single-decker bus is equipped with an electric motor powered by hydrogen fuel cells, developed in cooperation with Hino Motors. The bus was put into operation in 2018, with more than 100 buses currently operating in the public transportation system in the Kanto region supporting the 2021 Olympic and Paralympic Games.[157] There are currently more than 250 hybrid and fuel cell-powered forklifts operating across the country for commercial use, with most of those forklifts produced by Toyota.

For commercial and industrial use of non-pure hydrogen fuel, power plants are now conducting actual ammonia mixture with conventional coal at a 20/80 ratio. This government initiative with JERA and IHI aims to lower coal usage and effectively lower GHG emissions.[158] The Japanese government will spend JPY 27.9 billion on subsidies for two demonstration projects to burn at least 50 per cent ammonia produced from hydrogen with coal at power plants by 2029.[159] It will take some time for corporations' R&D to develop a plant that can burn 100 per cent ammonia. The plan is to slowly increase the mixture ratio through experimentation as conventional power plants cannot burn pure ammonia. Future modification for ammonia-based power plants is also in the plans. However, it is notable that foreign experts of the Hydrogen Science Coalition commented that the USD 392.0 million plan by the Japanese government is a wasteful greenwash as the fuel will be five times more costly than other economies. While a tonne of green ammonia requires 14.38 MWh to produce, it only generates the equivalent of 5.16 MWh when burned, which reduces to 1.96 MWh in a coal-fired power plant when presuming a steam turbine generator efficiency of 38 per cent, making it an incredibly inefficient method to produce electricity.[160] In addition, as there are large energy costs involved in making ammonia and turning it back into hydrogen, there is yet to be any actual usage of grey or blue ammonia in Japan for hydrogen chemical conversion as of this moment.[161] For MCH-produced hydrogen fuel, with government funding from NEDO, ENEOS has been trying to push for the utilisation of MCH produced hydrogen at power plants, steel plants, and chemical plants within the Kanto region for the past two years but has been unsuccessful. The company has been unable to agree with its potential clients the covering of the costs of building the necessary pipelines to deliver the hydrogen fuel. The existing infrastructure cannot directly utilise MCH-produced hydrogen gas; thus, new pipelines and facilities are needed.

ITOCHU ENEX has developed a hydrogen-propelled hot water supply and warm water heating system called the ENEFARM to generate power for household hydrogen fuel usage. This system generates power using the opposite principle to water electrolysis with hydrogen extracted from LPG or city gas. Electricity is later generated by reacting this hydrogen with oxygen in the air. As the chemical reaction also produces heat at the same time, this heat is used to supply hot water. Unfortunately, despite its efficiency, the system is still partially reliant on fossil fuels and can only be a transitional solution to the country's green initiatives. The current installation of each ENEFARM costs roughly JPY 1.11 million per unit with a 70 to 80 per cent subsidy to lower consumer pricing down to roughly JPY 300 to 400 thousand per household. Currently, there are over 330,000 units installed across Japan, and it is targeted to reach 8 million units by 2030.[153] With the help of the Japanese government, researchers are looking to create a more efficient unit in the future with the aid of solar power generation.

9.3 Expert Insights: Perception of Hydrogen Development

With a 30-year head start in hydrogen technology research, development in Japan is already at its implementation stage, where consumer and commercial usage is the country's major focus. The experts agree that the Japanese government has been very forward-thinking. It has been very open to listening to industry needs over the past 20 years, researching basic technologies and mitigating risks and costs. The government also facilitated consortiums and connected corporations with similar interests to focus on certain research areas with the necessary governmental and financial support.

However, with the Japanese economy recovering slowly, some supply-side corporations took advantage of the system to profit from government funding rather than making additional investments in hydrogen. Some of the experts commented that since the government also played a key role in establishing the current hydrogen refuelling infrastructure, the cost of building HRSs was 100 per cent funded by the government. These companies have benefited from building the infrastructure but made little to no effort in making additional investments or strategic implementations to operate the business.

“ The government funds all hydrogen-related projects up to 100 per cent for most large corporations willing to participate in the CO_2-free initiative, effectively making the business risk-free. This action inevitably removes companies' incentives to properly develop the business or related technologies but focus on directly profiting from the government funding. ” — Professor

One of the experts stated that with the help of Japan's METI, hydrogen technology has been able to develop in Japan slowly, but from 1990 to 2020, there were no significant innovative breakthroughs, and the country is still using 30-year-old technology. Despite the demand-side ecosystem having made additional effort to advance, the supply-side ecosystem has not been able to advance at a similar pace.

Most of the experts agree that the halt in both supply chain and technological development on the supply side subsequently delayed the implementation of hydrogen technology on the demand side. With difficulty providing enough pure liquid hydrogen to support additional FCEV operations or adoption, the Japanese government is trying to increase hydrogen supply via hydrogen import, which is unfortunately still in its infancy. Toyota and Hino are currently working on a large-capacity high-pressure hydrogen tank and a 25-tonne FC truck with a targeted cruising range of around 600 km.[162] According to one of the experts' comment, if the country can increase the number of HRSs up to 900 to 1,000 by 2030, plans for long-distance commercial EV utilisation may be possible. However, as of this moment, hybrid vehicles remain more efficient overall, whereas FCEVs are more efficient for urban commercial use or public transportation.

The experts mentioned that Japan Aerospace Exploration Agency (JAXA) has been properly utilising and developing new hydrogen-related technologies jointly with Nissan and has successfully developed advanced hydrogen storage technology and many other utilisation systems, including a new “circulative renewable energy system” to provide oxygen, hydrogen, and electricity to human outposts on space missions to the moon and a new lunar rover prototype.[163]

9.4 Expert Insights: Supporting Factors for Hydrogen Development

With strong government backing, all of the experts agree that Japan’s hydrogen initiatives and policies are far more advanced compared to the rest of the world. According to global statistics, Japan has the highest number of HRSs globally.[164] With over 162 stations scattered across the country, most stations were built entirely with government funding.[144] However, many of the experts commented that development of the supply chain is still in progress despite proper infrastructure being created on schedule for FCEV refuelling. To resolve this pure hydrogen fuel shortage, importing liquid hydrogen from Australia and other countries is one of the key elements in the government’s plans, but it is still based on grey hydrogen produced outside of Japan, which is not ideal for the long term. Some of the experts stated that the companies involved in the project are slowly moving towards green hydrogen production in Australia, but the process will take years to complete and hopefully be completed by the 2030 mark.

> **“ The Japanese government is showing equivalent if not more support for ammonia import and utilisation instead of hydrogen. It aims to at least import 50 million tonnes by 2050 as a commitment to ammonia usage. The direct use of ammonia as a burning fuel at power plants and ease of logistics make it ideal as a form of imported fuel. ” — Department Head**

From the government’s perspective, ammonia is also a form of hydrogen fuel. With both strategies working in parallel, resources may become less focused on specific aspects of hydrogen supply development. However, it is also notable that green ammonia technology is yet to be developed globally, making it less ideal for the CO_2-free initiative.

9.5 Expert Insights: Barriers to Hydrogen Development

Despite the country’s general direction toward suspending and lowering nuclear power usage after the 2011 Fukushima Power Plant incident, the government still relies on nuclear power to generate and cover 40 per cent to 50 per cent of its hydrogen fuel demand. As the production of pure hydrogen through electrolysis is only roughly 50 per cent, its efficiency is questionable, and it would be far more efficient just directly to use the electricity to power EVs. As the technology cannot directly create hydrogen fuel from nuclear plants, this production direction makes it more plausible to support direct EV rather than FCEV usage.

For non-domestically produced hydrogen fuels such as MCH and liquified hydrogen, the experts commented that dependence on imports is not sustainable due to the expensive costs. The energy consumption in maintaining the low temperatures during the transportation is costly and requires highly technical equipment. In addition, other countries are starting to display signs of disapproval toward polluting their own country to create a so-called “green economy” for Japan. According to the IEA’s report on Japan, 90 per cent of the country’s energy is still reliant on imported fossil fuels.[156] The goal to truly create a zero-carbon economy requires green natural resources that Japan sorely lacks. One of the experts clearly stated that just converting over to hydrogen fuel does not necessarily make the country carbon-free if the hydrogen is produced from fossil fuels. Therefore, alternatives such as wind, water, and geothermal energy generation also need to be considered as part of Japan’s future energy mix. Despite the FCCJ’s supportive stance on importing hydrogen from Australia, some of the experts are not happy with the overall business model, as Australia’s hydrogen supply is also created from fossil fuel, making it non-carbon free.

“ The Japanese government’s decision to shut down nuclear plants only makes the power production situation more difficult. ” — Director

In terms of investments in R&D for hydrogen technologies, one of the experts stated that demand-side corporations such as General Motors, Nissan, and Toyota have spent billions and are continuing to develop related technologies. In contrast, the Japanese supply-side companies have not spent as much nor displayed equivalent commitment in this aspect. Certain hydrogen refuelling stations continuously operate at low capacity as they cannot acquire sufficient fuel from sources. The lack of business model development for the supply side has severely disrupted the advancement where the supply companies are not working together to fulfil pure hydrogen demands.

Domestic production of pure hydrogen fuel remains one of the biggest hurdles that the Japanese government seeks to overcome. Although carbon-free production of hydrogen in Fukushima is currently in the works via solar energy, commercialisation of this production is still far from complete due to low involvement from corporations. The experts understand the dilemma of Japan’s lack of natural resources but prefer the country and industry to make more effort to make the country energy independent. One of the experts commented that the Japanese government is throwing a lot of resources and money into research and production, making many companies dependent on such money for profits, creating structural risks for the country.

9.6 Expert Insights: Future of Hydrogen Development

Although Japan is still the leading country in hydrogen development across the globe, its hydrogen-related supply-side technology development remains slow. The main reason is the lack of forward-moving incentives and policies for supply-side corporations to perform the necessary R&D.

“ Corporates in both Europe and the APAC region are highly interested in obtaining the latest hydrogen technologies my company offers. We are currently in talks with various investors overseas. With the R&D funding and interests from overseas parties, I expect a faster pace of development outside of Japan rather than within the country. ” — CEO

Some of the experts noted that once these overseas companies obtain the necessary hydrogen technology from Japan, they plan to build the necessary applications and infrastructure independently rather than invest in Japan to keep the R&D within its borders. As these technologies are not restricted from import, the experts worry that they may eventually close the gap between Japan’s hydrogen technology advancements and other countries.

The experts agree that the country’s exportation of FCEVs will continue to fuel the R&D efforts of hydrogen fuel engines in both Japan and their overseas joint venture partners on the automobile front. The mass production of fuel cells will be further expanded to accommodate Japan’s FCEV productions. With that said, some of the experts are quite worried that the lack of pure hydrogen supply will greatly hinder the adoption of FCEVs in Japan.

Some of the experts suggest that CCUS technology is currently gathering attention in Japan and that this technology may be able to create new changes in Japan’s industrial production and aid the country’s carbon-neutral emission objectives. The government is currently working on new CCUS initiatives, with a clear outline and roadmap established and outlined in June 2019, targeting to commercialise and lower the cost of utilisation by 2030.[165] Asahi Kasei Co., Limited was one of the first companies in the world to produce polycarbonate resin from CO_2 commercially in 2002. In 2016, this licensed technology accounted for 16 per cent of the approximately 4.8 million tonnes of global polycarbonate production. The company is currently piloting a new CO_2 polycarbonate and polyurethane manufacturing process to achieve energy savings across the manufacturing process using hydrogen. Additionally, the Japanese government's ultimate plan is to use the captured carbon with hydrogen to chemically recreate conventional fuel products such as diesel, gasoline, BTX, DME, etc.[166]

9.7 Expert Insights: Actions to Accelerate Hydrogen Development

Some of the experts commented that the Japanese government should adjust its funding and subsidy policies toward hydrogen-related supply-side projects as the current policies are incapable of incentivising additional investments and development from the private sector. By adjusting the use of government funding and adding restrictive requirements for corporations, the private sector will be forced to figure out ways to increase the efficiency of current infrastructure and bolster profitable business models. On the policy creation side, one of experts suggested that similar to the recent new policy to allow electric companies to sell both natural gas and electricity at the same time, the same freedom can also apply to energy production, as the current laws are restricting non-electric companies in the generation of energy due to licensing restrictions. The added competition will revitalise the supply side, establish new business models, and improve the supply chain.

The government can subsidise the conversion of gas stations into HRSs to increase the number of available HRSs and pave the way for additional consumer adoption of FCEVs. As every existing gas station needs to renew its equipment every 20 to 30 years, one of the experts commented that it is plausible to retrofit the existing gasoline equipment as hydrogen refuelling equipment, costing roughly USD 2 million each. However, another of the experts also commented that since the equipment is a lot more expensive, gas companies may not have sufficient incentive to join the cause in the short term. These companies are also concerned about losing their gasoline market shares as the country moves toward EVs and FCEVs. The availability of government subsidies may address some of the companies' concerns and ease the transition from fossil-fuelled power vehicles to FCEVs.

Japan could consider a wider mix of renewable energy sources in addition to solar and wind to support its domestic hydrogen production. With the lack of common green natural resources, one of the experts suggested that Japan's strong reliance on solar and wind power may become a bottleneck for the country, and additional new renewable energy resources such as geothermal energy should also be considered. He also commented that for power plant operators, if the Japanese government can provide an additional cashback or subsidy policy based on electricity created with hydrogen, it will provide the necessary incentives for companies to inject more investments.

> **“ IDEMITSU is currently the largest geothermal power plant operator, while ENEOS also operates one facility in the Kyushu region. If these facilities can be further developed into efficient power plants for hydrogen production, it would greatly increase the options for green sustainable energies. ” — CEO**

Another of the experts suggested that one way to resolve the general need for fossil fuel resources is for more consumers to install solar panels and ENEFARM units to decentralise and minimise the need for nuclear, ammonia and MCH power plants. Additional subsidies from the government will help with higher consumer adoption of household ENEFARM and solar panel unit installation.

10

South Korea

10.1 Overview

Table 10 South Korea Hydrogen Market Overview

OVERVIEW OF SOUTH KOREA	
Key Background Information	• South Korea released its Hydrogen Economy Roadmap on 17 January 2019, highlighting energy and mobility as two key development sectors. It aims to create a comprehensive hydrogen ecosystem by 2040. • To support the implementation of the roadmap, the Hydrogen Economy Committee was established to formulate new government policies on hydrogen development. Fundings and regulations were rolled out, subsequently supporting the country's hydrogen development. • Most hydrogen in South Korea is currently obtained from refining and petrochemical processes in three large-scale petrochemical complexes in Ulsan, Yeosu and Daesan. Compared to other APAC countries, South Korea's hydrogen economy is relatively mature, attracting local and foreign investments from the public and private sectors. • South Korea seeks to become a leader in the global fuel cell market, especially in the manufacturing and utilisation of stationary fuel cells and FCEVs. Power and mobility sectors are being prioritised in the fostering of the development of South Korea's hydrogen economy.
Key Expert Insights	• South Korea is still laying down the groundwork for realising its hydrogen roadmap for achieving carbon neutrality and energy independence, while its development is skewing towards the mobility and power sectors as planned. • Most hydrogen produced in South Korea is still by-product hydrogen. Therefore, production is mainly restricted to areas near steel mills or petrochemical complexes. • The technology of storing a large amount of hydrogen is still novel in South Korea, and there is no major hydrogen storage facility in the country currently. The lack of hydrogen infrastructure is the main barrier to South Korea's hydrogen development. • Water electrolysis and overseas imports are perceived to have been introduced to obtain clean hydrogen in the future and reduce reliance on by-product hydrogen. • South Korea could lead the hydrogen fuel cell power generation market in APAC due to its relatively well-established fuel cell industry among APAC countries.

10.2 Background

10.2.1 Overall Hydrogen Landscape

Envisioning the creation of a comprehensive hydrogen ecosystem by 2040, South Korea released its Hydrogen Economy Roadmap on 17 January 2019, highlighting two key development sectors — energy and mobility. The South Korean government considers that hydrogen development will foster growth in multiple industries as hydrogen will become more economically viable over the coming decade, and is forecast to undergo about a 50 per cent decrease in the total cost of ownership,[xii] according to an estimate by the Hydrogen Council in its "Path to hydrogen competitiveness: a cost perspective" report.[167] Equipped with world-class fuel cell generation technologies, South Korea aims to produce 15 GW of electricity from fuel cells by 2040, 8 GW for domestic use and 7 GW for export.[168] According to the roadmap, the government plans to establish a fixed price system for power generated from fuel cells to encourage nationwide energy transition. South Korea aspires to become the global market leader in FCEVs. It targets to produce 6.2 million hydrogen FCEVs by 2040, 3.3 million of which are for export.[169] In this regard, in 2018 the government committed KRW 2.34 billion to facilitate cooperation between public and private sectors in accelerating the local production of FCEVs.[170] The roadmap also anticipates imports of green hydrogen by 2030, and studying the possibility of supplying liquified hydrogen through existing LNG pipelines.

To support the implementation of the roadmap, the Hydrogen Economy Committee has been established to formulate new government policies on hydrogen development. In October 2019, the "hydrogen-powered cities' initiative" was announced, revealing candidate cities for building hydrogen R&D hubs. Three cities will receive KRW 29.0 billion funding to develop green hydrogen production systems and fuelling infrastructure.[171] Furthermore, the Hydrogen Economic Promotion and Hydrogen Safety Management Law was enacted on 4 February 2021, serving as the overarching legal framework for the government's efforts to promote the hydrogen economy. It supports hydrogen-focused companies via R&D subsidies, loans, and tax exemptions. Most importantly, it eliminates the regulatory blind spot in hydrogen safety. Safety has to be assured in technological safety at both the design and completion stages.

The private sector is also actively involved in hydrogen R&D and related initiatives, aligning with the government's hydrogen vision. South Korea's 15 leading companies established a hydrogen business council in September 2021 to invest in hydrogen projects to support growth in the global hydrogen market. Key industry players in the council include SK group from the supply side, South Korea's largest LNG provider, and Doosan Group from the demand side, one of the leading stationary fuel cell technology developers.

10.2.2 Hydrogen Supply Landscape

South Korea is one of the world's largest energy importers and a net hydrogen importer due to insufficient domestic natural energy resources. Most hydrogen in the country is currently obtained from refining and petrochemical processes in three large-scale petrochemical complexes in Ulsan, Yeosu and Daesan. These by-product gases are cleaned through pressure swing adsorption (PSA) and distributed through pipelines or tube trailers to customers. A small proportion of hydrogen is also produced from natural gas through SMR. SMR is seen as a bridging technology for South Korea's ultimate transition to green hydrogen.

To reach carbon neutrality, South Korea aims to produce three million metric tonnes of green hydrogen and import 22.9 million metric tonnes of hydrogen from overseas per year by 2050.[172] The government's key strategy for rolling out hydrogen infrastructure is to build a 'hub-and-spoke' network where hydrogen will be transported to nearby storage stations from a centralised production site. It is envisioned that the existing LNG supply network could be utilised for establishing a nationwide hydrogen production and supply system as it is

xii Total cost of ownership defines the total costs incurred by a consumer over the lifetime of using an application, including capital, operating, and financial costs.

readily stable and economically viable. To promote hydrogen use, the government also hopes to stabilise the average hydrogen cost to KRW 3,500.0/kg by 2030.[172] In terms of hydrogen import, in June 2019 South Korea entered into a Memorandum of Understanding with Norway to develop ships that are capable of transporting liquified hydrogen.[173] These developments support South Korea's aim to leverage its legacies as a heavily gas-dependent country by increasing hydrogen production and overseas import.

Compared to other APAC countries, South Korea's hydrogen economy is relatively mature, attracting local and foreign investments from the public and private sectors. Key players from the supply side can be classified into three groups: hydrogen suppliers, electrolysis companies and gas equipment suppliers. The largest hydrogen supplier is Deokyang, producing 150,000 Nm^3/h of hydrogen and accounting for 50.1 per cent of the market share.[174] Global-renowned industrial gas companies, Air Liquide and Linde, rank third and sixth in the domestic market. In 2021, Air Liquide signed an agreement with SK E&S, South Korea's largest renewable energy operator, to supply 90 metric tonnes of liquid hydrogen per day by constructing a new hydrogen liquefaction plant in South Korea.[175] Linde also entered into a joint venture with Hyosung to build the world's largest liquid hydrogen production facility in Ulsan.[176] In addition, South Korean natural gas utility company Korea Gas Corporation has also announced its 2030 hydrogen targets to construct 25 hydrogen production plants and more than 700 km of hydrogen pipelines.[168] Apart from domestic production projects, South Korea's renowned steel manufacturing company, POSCO, has also revealed its plan to build a hydrogen terminal separately from the Korea Gas Corporation to bring hydrogen in the form of ammonia from overseas. POSCO believes that the project will create a "hydrogen-centric change in the logistics industry" as a large-diameter piping system will be established, enabling large-scale hydrogen supply.[177] Although most of these projects are still in the initial stage, they are paving the way for South Korea to become a leading hydrogen economy.

10.2.3 Hydrogen Demand Landscape

South Korea seeks to become a leader in the global fuel cell market, especially in the manufacturing and utilisation of stationary fuel cells and FCEVs. Power and mobility sectors are being prioritised in fostering the development of South Korea's hydrogen economy. In 2021, the installed capacity of stationary fuel cells in South Korea was 620 MW, equating to about 0.5 per cent of the country's installed capacity for electricity generation in 2020. Among the installed capacity of stationary fuel cells, 605 MW was for electricity generation, and 15 MW was for buildings usage.[178] While stationary fuel cells are yet to be fuelled by hydrogen and are entirely fuelled by natural gas, hydrogen could serve as the ideal replacement for natural gas as the feedstock of the fuel cell generators for central power generation and home use. The fuel cell market for power generation in South Korea emerged in 2012 after the government launched the Renewable Portfolio Standard (RPS). The RPS has supported the deployment of large-scale stationary fuel cells as it requires power plants with a power generation capacity of 500 MW or more to increase their power generation from renewable energy sources. This strategy prompted the establishment of the world's first fuel cell power plant in Incheon, inside the South Korea Southeast Power Plant. The 79.0 MW-class power plant was put into operation in October 2021, providing electricity to up to 250,000 households per year.[179] The government sees stationary fuel cells as an opportunity for energy exports, targeting 7 GW of exports by 2040.[168]

The government has also invested heavily in the development of hydrogen mobility. In 2018, it committed USD 2.3 billion to establishing a public-private hydrogen vehicle industry till 2022.[170] Along with that, South Korea's hydrogen roadmap calls for the increase of HRSs from 34 in 2020 to 310 by 2022 and 1,200 by 2040.[168] Substantial government support has made South Korea a pioneer of FCEV technology, with over 10,000 FCEVs on the road in 2020, doubling the national stock of 2019.[180] As of January 2022, there were 112 HRSs in the country with plans to build 660 HRSs by 2030.[178] In addition, the government identified three cities as hydrogen pilot cities — Ulsan, Ansan and Wanju — for testing the application of hydrogen in transportation, industry, and space heating, with the aim to achieve the goal of powering 10 per cent of its cities with hydrogen by 2030 as stated in the roadmap.[180] For instance, Ulsan focuses on hydrogen production from local petrochemical complexes to refuel FCEVs and power buildings. All these schemes underpin the government's efforts to develop a hydrogen ecosystem.

The government's vision is backed by key industrial stakeholders, power companies, mobility OEMs and fuel cell companies. Five South Korean conglomerates, including Hyosung, Hyundai Motors, SK Group and POSCO from the demand side, have planned to invest USD 38 billion in hydrogen technology by 2030.[181] Hyundai Motors Group, the first company to commercially produce FCEVs globally, has also announced the production of 500,000 hydrogen vehicles and 200,000 other fuel cell systems for power plants, ships and trains by 2030 in its FCEV Vision.[182] Doosan Fuel Cell, accounting for 80 per cent of the domestic fuel cell market share, invested in Hanwha Energy's completed 50 MW hydrogen-based fuel cell power plant.[182] Furthermore, fuel cell technology in ships and submarines has been transferred to buildings and mobility applications. For instance, a domestic fuel cell company, Bumhan Pure Cell, is expanding its submarine fuel cell technology to commercialise civil fuel cells.[183] Apart from hydrogen FCEVs, hydrogen-powered ships and trams are also under development. The South Korean Register of Shipping has set up a research centre to study the capabilities of hydrogen ship technology, thereby supporting the sustainable growth of South Korea's shipbuilding industry. The first HRS for trams will be built by 2022, and mass production of hydrogen trams is expected to begin in 2024.[184] It is estimated that the overall demand for hydrogen in South Korea will increase to 5.4 million tonnes a year in 2040.[168]

10.3 Expert Insights: Perception of Hydrogen Development

The experts believe that South Korea is still laying down the groundwork for realising its hydrogen roadmap for achieving carbon neutrality and energy independence, and the country's hydrogen development is perceived to focus mainly on the mobility and power sectors. Several of the experts mentioned that many companies in South Korea are gradually working towards zero carbon emissions to fulfil their social responsibilities and maintain competitiveness through hydrogen deployment. For instance, one of the experts suggested that POSCO, the world's fifth-largest steel producer, aims to reduce its CO_2 emissions by 20 per cent by 2030 and 50 per cent by 2040, with zero emissions by 2050.[185] POSCO has been exploring possibilities to deploy cleaner energies such as hydrogen to avoid European carbon tax for its goods to be exported to Europe. The experts also suggested that advancing in the hydrogen industry would help establish South Korea's independence in the energy market and safeguard its energy security, as most of its energy is imported to South Korea in the form of natural gas and crude oil. The experts find the development progress slow despite the inducements, especially in production, storage, and transportation. Although hydrogen has already been applied in some industries, the scale is still insignificant. One of the experts revealed that most of the hydrogen in South Korea is still collected as a by-product of petrochemical processes. Hence, the transition of the hydrogen supply method from by-product hydrogen to natural gas-based hydrogen is lagging. Another of the experts estimates that South Korea will only be able to produce, store and transport hydrogen on a small scale by 2030. The experts have further observed an imbalanced development in the hydrogen economy from the demand side as the government mainly focuses on mobility and power sectors. In particular, the experts believe that South Korea is aspiring to become a global leader in the fuel cell market. Therefore, policies and resources are skewing towards the two sectors, leaving other sectors with insufficient support.

“ In particular, the focus in South Korea is on the automobile industry. That is what the government talks the most about, with the work focused on FCEVs, and Hyundai Motor is the most active in this area. Automobiles are what we can easily see the results of, so the government wants to nurture the FCEV market. However, the government rarely discusses hydrogen in the context of other sectors. ” — Lead Chemist

The experts generally consider the government's policies and regulations on hydrogen-related issues to be immature, hindering full-scale hydrogen strategy implementation. To begin with, some of the experts suggested that the legal definition of 'clean hydrogen' is still unsettled, putting a pause on many hydrogen production projects as companies fear that the hydrogen they produce does not meet the government's standard. One of the experts argued that the government's indecisiveness has stirred up many political debates that are slowing down industry development. Regulations concerning hydrogen safety are also absent. Besides, insufficient government support provides little incentive for companies to invest in hydrogen. While the government believes that the hydrogen production ecosystem should be the priority, companies desire to secure users before making significant investments. Furthermore, the experts also indicated that ordinary consumers do not understand why there is a need to switch to hydrogen. Although the roadmap has been established, the experts expressed doubts that it was being implemented effectively and on a large scale.

According to the experts, South Korea has engaged in various international collaborations to explore import opportunities and new technologies, as the country is aspiring to become the global transportation hub for hydrogen. Although hydrogen deployment in South Korea appears to be a relatively closed-loop system in production and consumption, the country is also studying import feasibilities with countries in various regions. The experts observe that South Korea targets to import 22.9 million metric tonnes of green hydrogen annually from overseas markets by 2050.[172] To this end, in 2021 South Korea signed a letter of intent with Australia to promote a mutually beneficial hydrogen import and export partnership.[186] Apart from Australia, South Korea is also considering importing hydrogen from Middle Eastern countries.

Moreover, South Korean businesses have also established technological cooperation partnerships with various international corporations. The experts highlighted that a state-owned gas company, Korea Gas Corporation, signed a non-binding agreement with Austrian LNG producer, Woodside, to study a green hydrogen project's technical and commercial feasibility. The agreement will help the identification of different hydrogen production options and supply chains.[187] Located at the centre of East Asia, surrounded by China, Japan and the Russian Far East, the experts believe that South Korea could take the lead in hydrogen-related maritime transportation, transporting hydrogen from Australia to South Korea and distributing it to different parts of the world. Shell, a multinational oil and gas company, has teamed up with Doosan Fuel Cell and Korea Shipbuilding and Offshore Engineering to modify fuel cells for marine applications.[188] Hence, the experts trust that South Korea is seeking multiple pathways to expand its hydrogen industry.

10.4 Expert Insights: Supporting Factors for Hydrogen Development

The experts believe that collective efforts from the public and private sectors have been pushing hydrogen development forward. They perceive that the government has taken tangible actions to support its ambitions, such as dedicated large funding to foster hydrogen development, especially in power generation and transportation areas, as potential drivers of South Korea's economy. The government also increased its spending by approximately 40 per cent from 2020 to 2021, to KRW 701.9 million in developing the hydrogen economy.[180] In addition, the government has introduced new subsidies for the mobility sector to purchase 624 hydrogen buses, which will be in service by the end of 2025.[189] The experts also perceive that the private sector has been putting effort into supporting hydrogen development in support of the government's actions. For instance, Hyundai Motor has offered a KRW 10 million bulk-purchase discount on each fuel cell bus.[189] SOEs have also collaborated with local and foreign industry players to establish a hydrogen value chain. For example, Korea Gas Corporation (KOGAS), one of the world's largest LNG operators, formed a partnership in 2021 with the country's top oil refiner, GS Caltex, to build a liquefaction plant at one of the KOGAS LNG terminals.[190] KOGAS is also collaborating with Siemens, a global pioneer in electrical engineering, to study green hydrogen production and hydrogen turbine power generation.[191] Many of the experts mentioned the Hydrogen Council, which 15 leading domestic corporations established to support South Korea's hydrogen ecosystem's healthy and balanced growth. They also perceive that many private companies have formed alliances among themselves to reduce their risk of investing in the hydrogen field, as the return on investment is still uncertain to some extent. The experts believe that public and private investments underpin South Korea's efforts to become a global hydrogen leader.

The experts perceive that South Korea's existing demand for natural gas and comprehensive natural gas infrastructure is a key supporting factor in the development of hydrogen. One of the experts revealed that natural gas in South Korea is mostly used as a fossil fuel instead of a feedstock to produce blue hydrogen. However, KOGAS has tremendous bargaining power to lead the energy transformation in South Korea owing to its mature domestic natural gas infrastructure. As it is technically feasible to leverage existing natural gas infrastructure to transport and store hydrogen, KOGAS's natural gas infrastructure could be a steppingstone for South Korea to develop its hydrogen value chain extensively. One of the experts believes that South Korea has better infrastructure than other countries for supporting the development of fuel cell power as the largest electric utility in South Korea. For instance, Korea Electric Power Corporation (KEPCO) has a strong national grid that makes connecting power lines easy.

“ South Korea has better infrastructure than other countries. For instance, KEPCO has a comprehensive national power grid, so it is easier to draw fuel and connect power lines [for the power generation with fuel cell technology]. ” — Manager

10.5 Expert Insights: Barriers to Hydrogen Development

The experts generally perceive that immature production technologies and insufficient infrastructure have hindered the overall hydrogen development in South Korea, especially for green and blue hydrogen. The experts revealed that South Korea's electrolysis facilities, which generally involve wind and solar power, have not been commercialised. Potential technologies such as PEM-based electrolysis are still being studied for demonstration purposes only. While wind and solar power alone cannot meet the production targets for 2030 and 2050 set by the roadmap, other renewable sources such as biomass technology are also considered underdeveloped in South Korea. As a result, South Korea's ability to produce 100 per cent green hydrogen domestically is low, considering the immature production technologies. Blue hydrogen is more eco-friendly than grey hydrogen, serving as a transitional fuel. However, the experts commented that the production of blue hydrogen is also limited in South Korea as there are insufficient facilities for collecting CO_2.

Some of the experts mentioned that industry players from the mobility sector are holding back on large-scale investments in FCEVs due to uncertainties over government devotion to the industry. One of the experts criticised the government for sometimes perhaps refusing to support some hydrogen projects if it does not recognise their immediate potential. The fear of lacking government support, to a certain extent, has led many ambitious small and medium-sized companies to take on only smaller, less ambitious research projects. Particularly in the mobility sector, one of the experts argued that the government has not invested enough to bring down the price of hydrogen buses. The expert stated that the standard price of a hydrogen bus could be more than double the price of a CNG bus. Therefore, industry players generally have low motivations to purchase hydrogen buses without sufficient financial support from the government. Moreover, the experts commented that the number of established HRSs in the country is insufficient to support hydrogen fuel's potential demand and geographical coverage requirements. The inadequate HRS infrastructure is, to a certain extent, also due to the insufficient financial aid from the government to help improve the economies of scale, which is leading to high installation costs and uncertain profitability of HRS investments. Inadequate refuelling facilities infrastructure combined with a low number of FCEVs has created a vicious cycle that hinders private investments in hydrogen utilisation for the mobility sector.

> **“The government needs to replace 10,000 domestic buses with hydrogen buses. The budget for next year has only budgeted enough to replace a few hundred buses. Even if you have the budget for a couple of hundred hydrogen buses, it would still require sufficient HRSs to be effective.” — Project manager**

Some larger mobility corporations also hesitate to invest heavily in hydrogen as they do not have enough interest in developing hydrogen vehicles. Mobility corporations sometimes question FCEVs' energy conversion efficiency, as there will always be unconditional energy loss in converting hydrogen to electricity. This subject is particularly apparent when compared to traditional EVs. Since world-renowned mobility companies are doubtful about hydrogen vehicles, the general public in South Korea is even less interested in acquiring FCEVs. While many of the experts mentioned that the concept of FCEVs is more applicable to commercial vehicles, the experts believe that the price of FCEVs nowadays is still uncompetitive due to the low demand.

A number of the experts also consider that citizens' opposition and passive local government support have been hindering South Korea's hydrogen development. One of the experts mentioned that although hydrogen production technologies and systems have been sufficiently proven safe for more than a decade, the public is still sceptical about fuel cell technology. With residents opposing the construction of a hydrogen liquefaction plant or a HRS, local governments could not grant the licence to commence the projects. The experts also suggested that oppositions make it almost impossible to proceed with any projects if a residential complex or a school is near the project site. While there was no procedure such as deliberation or opinion collection in advance during the licensing stage before 2019, the Ministry of Trade, Industry and Energy now requires fuel cell companies to collect opinions from residents before approval is given. The experts believe that this has made commencing a hydrogen project even more difficult.

10.6 Expert Insights: Future of Hydrogen Development

The experts believe that hydrogen will continue to be one of the key strategic industries in South Korea, driven by the mobility and power sectors. They also perceive that South Korea's hydrogen development focuses mainly on industrial processes and transportation projects. In the mobility sector, one of the experts believes that FCEVs will have a competitive edge over their competitors with improved technology in the coming years. Customers who are interested in low-emission vehicles will be attracted. Apart from major developments in mobility and power sectors, the experts suggested that there is also a growing trend in diversifying hydrogen usage. Another of the experts also shares his observation that South Korea has been diversifying hydrogen usage to various sectors by leveraging its advantage in fuel cell technology. In the public sector, the government envisions commercialising hydrogen-powered trams as the next generation of eco-friendly urban transportation by 2023. According to the Korea Energy Economics Institute (KEEI), South Korea's hydrogen economy was worth KRW 14.1 trillion in 2020 and is predicted to reach KRW 26.8 trillion by 2030.[174] South Korea is also embarking on a huge capital investment drive to build on its early achievements in fuel cell development. Several of the experts also mentioned the then-upcoming presidential election as a potential factor affecting the industry's growth. According to a press release, the newly elected president, Yoon Suk Yeol, previously announced his commitment to invest in clean hydrogen. He also stated that he would include hydrogen production technology as a national strategic technology. In particular, he expressed his intention to transition to a decarbonised industrial structure, focusing on developing the hydrogen industry, and the main investment destination is hydrogen production and liquefaction technology and facilities.[192] In light of this, the development of the hydrogen industry is expected to continue to receive the current government's support.

To diversify the hydrogen supply portfolio, water electrolysis and overseas imports are perceived to be a key clean hydrogen supply in the future. One of the experts believes that electrolysis and overseas imports would be the most feasible and effective ways for South Korea to realise carbon neutrality with hydrogen, while the ratio for by-product hydrogen would also gradually decline. The expert predicts that LNG-reformed hydrogen will still account for a portion of South Korea's hydrogen production until 2040 but will probably be reduced to only around one-fifth of the country's total hydrogen supply by then. But as an importing country, the experts suggest that South Korea would have to increase its capacity and capability to handle significant hydrogen imports by comprehensively developing its transportation and storage systems. It is anticipated that transforming by-product hydrogen to fully green hydrogen could take more than a decade.

The experts perceive that South Korea will be one of the leading countries with China and Japan in developing APAC's hydrogen economy, particularly in the hydrogen fuel cell power generation market. The experts also believe that China will be the biggest demand market in APAC as many SOEs are investing heavily in hydrogen to support goals set by the government. Japan and South Korea are perceived to be very advanced in fuel cell technology, led by strong companies such as Toyota and Hyundai. Although Japan excels in the chemical field, South Korea's petrochemical and materials industries are also developing quickly with intensive investment from private corporations. Furthermore, the experts are confident that South Korea could be far ahead of China and Japan in regard to hydrogen fuel cell technology. Once the industry becomes mature, the manpower and R&D strategies will be concentrated on hydrogen production, storage and distribution, completing the hydrogen value chain and complementing one another. Therefore, the entire hydrogen ecosystem will be fully commercialised in South Korea over the coming years.

“Whilst by-product hydrogen will not disappear, the ratio will decrease. New areas such as water electrolysis and overseas imports will be added. That is how Australia will obtain clean hydrogen or ingredients containing enough hydrogen to extract clean hydrogen, such as ammonia. I think that it would take at least 20 years until it starts to be meaningful (achieving carbon neutrality).” — Manager

10.7 Expert Insights: Actions to Accelerate Hydrogen Development

While collective efforts have been seen, some of the experts perceive that strengthening collaboration between the government, private sector, and local authorities could further facilitate hydrogen development in South Korea. They believe that hydrogen initiatives and programmes would map out easier and smoother if the government and company leaders invest in these projects jointly. One of the experts mentioned the case of HyNet, a joint venture established by 13 leading companies and headed by KOGAS, as a successful example of a government-led hydrogen initiative to roll out a HRS network.[xiii,193] At the regional level, the experts suggest that local governments should actively promote the use of hydrogen in their cities. One of the experts pointed out that while some regions, such as the Gyeonggi Province, have a certain amount of HRSs, some regions, such as the Gangwon Province, have none. Therefore, the experts suggest that local governments should initiate more local projects to stimulate the hydrogen economy. Hence, policymakers should work closer together with private companies and local authorities to achieve the goals set by the roadmap.

“ To stimulate the hydrogen economy, a national power generation project or the promotion of local projects should be carried out. If we want to utilise the HRSs as quickly as we build them, it would be better if it was accompanied by balanced regional development. ” — Manager

The experts also opined that the government should consider allocating subsidies to articulate the specific needs of hydrogen suppliers and users. Some of the experts suggest that the government should subsidise more R&D projects related to power generation using hydrogen to achieve economic feasibility similar to LNG gas turbines or coal-fired power plants. According to one of the experts, the power generation cost of hydrogen is still higher than that in coal-fired power plants or LNG gas turbine power plants when calculating LCOE[xiv] with the current investment cost. Through conducting more R&D activities, hydrogen power generation technologies will become more mature and thus undergo a reduction in the production cost. In addition, the experts also believe that subsequent financial support from the government is essential for green hydrogen production, as the production cost of green hydrogen is inevitably much higher than that of most non-renewable hydrogen. For the existing HRSs subsidy scheme, the experts believe that the government should consider funding the construction and operation as the demand for HRSs is still low. To reduce public opposition to the construction of hydrogen facilities, one of the experts also suggested that the government could provide benefits to neighbourhoods affected by such construction. The experts perceive that the private sector would be more encouraged to participate in the hydrogen economy if the government could address the above issues, primarily through financial aid.

xiii The Hydrogen Energy Network (HyNet) was established in 2019 with an initial investment of USD 119 million to expand the fleet of HRSs from about two dozen HRSs in 2019 to 310 by 2022 and 1,200 by 2040.

xiv The levellised cost of energy (LCOE), also referred to as the levellised cost of electricity or the levellised energy cost (LEC), is a measurement used to assess and compare alternative methods of energy production. The LCOE of an energy-generating asset can be thought of as the average total cost of building and operating the asset per unit of total electricity generated over an assumed lifetime.

11

Malaysia

11.1 Overview

Table 11 Malaysia Hydrogen Market Overview

OVERVIEW OF MALAYSIA	
Key Background Information	Malaysia does not have a hydrogen roadmap announced and is at the very early stage of developing its hydrogen economy, and the Sarawak state is currently the only state in Malaysia proactively pursuing hydrogen development. Malaysia's hydrogen production mainly focuses on brown and grey hydrogen production, as green hydrogen production is only available at the experimental stage with a few producers while it is still developing its transportation and storage capabilities by partnering with foreign companies. Malaysia is trailing behind in the use of FCEVs for public transportation in Sarawak and is also investing and exploring opportunities in innovative and green applications, with intensive R&D in progress in hydrogen fuel cell applications, heating, and power generation.
Key Expert Insights	Hydrogen projects are limited to small-scale proof-of-concept or regional projects to attract more foreign investments but are expected to become a major exporter in Southeast Asia. The experts are sceptical about the current hydrogen development status and speed because of the slow responses from the government due to political uncertainties. Malaysia does not have sufficient hydrogen technical talents to support and lead long-term development, while the hydrogen adoption needs to overcome the tropical climate. The government should establish firm standards and regulations across all touchpoints in the hydrogen value chain to create a more regulated and systematic hydrogen economy while offering more grants, tax incentives, and subsidies.

11.2 Background

11.2.1 Overall Hydrogen Landscape

Malaysia is at the very early stage of developing its hydrogen economy, and it has yet to launch an official national hydrogen strategic plan. The National Science Academy introduced "the Blueprint for Fuel Cell Industries in Malaysia" in 2017 as guiding objectives and suggested strategies for the hydrogen industry but without any quantified targets or official policies.[194] The blueprint reviewed Malaysia's hydrogen development in 2017 and envisioned the need to overcome three main challenges of developing a hydrogen ecosystem: the lack of hydrogen infrastructure, a small domestic market for fuel cell applications, and the low cost-effective Malaysian fuel cell technology.

Following the blueprint, the Ministry of Science, Technology and Innovation (MOSTI) has also commissioned the "Hydrogen Economy Technology Roadmap (HETR)", but it was postponed from its November 2021 announcement without a date of publication.[195] While the HETR drafting is still in progress, there has been no further indication of when it will be announced. Under short-, medium-, and long-term goals, the proposed roadmap strives to improve all touchpoints across the hydrogen value chain. According to the experts, Malaysia plans to become a major hydrogen exporter in the APAC region and improve hydrogen-related technologies in production, transportation, and storage in the short term. Over the medium term, Malaysia plans to utilise hydrogen for power generation as an energy carrier and transition to blue hydrogen production. Over the long term, Malaysia aims to develop its hydrogen economy with an extensive range of hydrogen applications such as mobility, manufacturing, and agriculture to reduce its carbon emissions.

Under the government's proposed directions, Malaysian scholars and researchers have proactively contributed to enhancing domestic research capability. The enhancements were encouraged by the proposed objectives. For example, in 2017 researchers from the Fuel Cell Institute at Universiti Kebangsaan Malaysia (UKM) and researchers from other universities created a national-level hydrogen association, the Malaysian Association of Hydrogen Energy (MAHE).[196]

Malaysia is in the process of assessing viable hydrogen economy models based on other successful hydrogen-developed economies. Malaysia is currently searching to find the most suitable model from other developed hydrogen economies as the blueprint for its supply and demand-side hydrogen adoptions to facilitate hydrogen development. For example, the safety precautions and layout of current hydrogen infrastructure are directly replicated from foreign developed hydrogen economies such as Denmark, Japan, and Scotland for HRS, transportation, and hydrogen storage. But with a very different tropical rainforest climate, most models are not suitable for application directly in Malaysia.

At this early stage of development, Sarawak is currently the only state in Malaysia proactively pursuing hydrogen development. Sarawak is the only one out of the 13 Malaysian states proactively pursuing hydrogen development. The state is located on the northwest coast of the island of Borneo supported by its rich hydropower resources. With access to hydroelectric power and already-established renewable energy production infrastructure such as hydroelectric plants and dams, the municipality of Sarawak introduced the local "Hydrogen Energy Roadmap (2005–2030)" in 2005 with a focus on realising hydrogen storage, deployment of FCEV public transportation, and establishing hydrogen transport infrastructure for global export by 2020.[197,198] However, as of December 2021, while Sarawak has progressed according to the state's plan, it missed the pre-set hydrogen development targets for 2020. As of December 2021, FCEV buses have only been deployed on a limited scale in Sarawak, with no major hydrogen infrastructure built for storage or transportation.

11.2.2 Hydrogen Supply Landscape

Malaysia is extending its hydrogen production capacity locally with a final target to phase out brown and grey hydrogen production and replace it with green hydrogen. Blue hydrogen and green hydrogen production are noticeably absent. Blue hydrogen is unavailable due to the lack of CCUS technology, while green hydrogen production is only available at the experimental stage, with only a few producers.

Malaysia's hydrogen production mainly focuses on brown and grey hydrogen production, but investments have been made focusing on blue hydrogen and the CCUS technology over the next ten years. Regarding brown/grey hydrogen production, the market is currently occupied by a handful of traditional energy SOEs such as Tenaga Nasional Berhad (TNB), Petronas and a few private energy companies such as Shell Malaysia and Sarawak Energy Berhad (SEB). To meet the carbon neutrality target set in the Paris Agreement, Malaysian energy SOEs have been investing in R&D in relation to CCUS technology to transition from the current brown and grey hydrogen production to blue as a medium-term objective over the next ten years. For example, Petronas signed a joint study and collaboration agreement (JSCA) with Shell to study and research CCUS applications in selected locations offshore of Sarawak, and it has deployed a CCUS project in Sarawak at the Kasawari natural gas field.[199,200] The initiative aims to extend its application to other Malaysian states to support the clean hydrogen transition. TNB, the largest energy company in Malaysia and an SOE, in 2021 also announced its intention to accelerate investment in the research and development of CCUS technology.[201]

Green hydrogen production is only available in pilot projects with a few producers at the experimental stage. These green hydrogen production sites are mostly concentrated in Sarawak. However, the deployed electrolysers and the related technical expertise are mostly imported from foreign partners. As Malaysia's largest green hydrogen producer, SEB is now producing green hydrogen through electrolysis at a small scale in its integrated hydrogen production plant, serving the HRS for FCEVs in Kuching.[202] The facility was built in 2019 in partnership with Linde Group's hydrogen division, Linde Hydrogen. The project demonstrated and contributed to the continuous study of how hydrogen production, transportation, and storage infrastructure operate in a tropical environment. In addition, the electrolysers used in SEB are imported from Hydrogenics, a Belgian electrolysis equipment manufacturer with operations in Malaysia. Besides equipment, the technical experts leading the green hydrogen production are recruited from Europe since Malaysia does not have local expertise.

Malaysia is still developing its transportation and storage capabilities, but it is currently partnering with foreign companies to import technologies and talents while investing in more advanced and innovative approaches. Currently, Malaysia can carry out short- and long-distance hydrogen transportation, but only in small quantities and at a high cost due to the lack of hydrogen transportation infrastructure and safety regulations. Malaysia has extensive experience transporting hydrogen in liquid form because of hydrogen uses in heavy industries. Malaysia already possesses the necessary expertise for using cryogenics to transport liquid hydrogen. Today, hydrogen is commonly transported by hydrogen tube trailers in gaseous form. Both liquid and gaseous hydrogen transportation are expensive because additional compressor tools are needed to compress the hydrogen compounds. While there has been a plan to build hydrogen transportation infrastructure outlined in 2017's Hydrogen Fuel Cell Blueprint, no significant pipelines have been constructed to date.[194] Instead, Malaysian energy companies are researching the feasibility of utilising its fossil fuel infrastructure for hydrogen transportation. For instance, Petronas has signed a Memorandum of Understanding (MoU) with ENEOS to study the feasibility of transporting hydrogen in liquid form over long distances by leveraging existing oil and petrochemical infrastructure.[203] On top of that, one of the experts also shared that Petronas has studied the feasibility of transporting hydrogen in existing natural gas pipelines with a mix of up to 20 per cent of hydrogen. In addition, Malaysia is partnering with foreign companies to acquire their expertise but is still relying on foreign hydrogen expert teams for maintenance and technical support. For example, SEB is working with Linde Hydrogen under a partnership to import their hydrogen storage tanks, and the project relies on

Linde's expert team.[204] To advance the development of hydrogen transportation and storage for nationwide adoption, Malaysian energy companies and SMEs are working to explore opportunities in transporting hydrogen through different stable carriers in various forms. For example, SEB is referencing Singapore and researching the transportation of hydrogen via ammonia or in the form of liquid methylcyclohexane (MCH), which can be safely and economically stored and transported.[203] In addition, Galaxy FCT, a small Malaysian start-up specialised in hydrogen technology, is testing the transportation of hydrogen in solid form as sodium borohydride (NaBH4) while the hydrogen gas is released at the point of end-use via hydrolysis.[205] This innovative method claims to be more cost-effective and safer than current gas or liquid form transportation with only a few simple operating procedures.

11.2.3 Hydrogen Demand Landscape

Malaysia is trailing behind in the use of FCEVs for public transportation in Sarawak and is limited to serving a small range of users, while more HRSs in Sarawak are under construction to support FCEV adoption. Currently, only Sarawak has deployed FCEVs as a proof of concept as backed by SOEs while other Malaysian states have yet to follow. This FCEV transportation system in Sarawak was funded by the municipality authority and run by Sarawak Metro, a subsidiary of the Sarawak Economic Development Corporation (SEDC).[206] FCEV buses were purchased on a trial operation basis to develop a clean transportation system in the future and prove that FCEVs can operate in a tropical climate. With only a handful of daily routes and free to ride, these hydrogen buses are designed for tourism purposes to take tourists around the areas and are limited to within the downtown area of Kuching and Damai.[207] Furthermore, the buses are only available in a few districts since their operation in 2020 though routes are being expanded to cover more nearby cities.[208] In addition to deploying FCEVs, the SEDC is also proactively working with Malaysian energy companies to establish more HRSs in Sarawak. For instance, Petroleum Sarawak Berhad (PETROS), a Malaysian SOE, has constructed Malaysia's first multi-fuel HRS in Darul Hana of Sarawak and is expected to support the Sarawak FCEVs with its high-speed charging facilities.[209,210] On top of that, the construction of five more HRSs is already scheduled in nearby districts such as Batu Kawah, Sibu, and Sri Aman to support Kuching's FCEV public transportation system.[210]

Malaysia is also investing and exploring opportunities in innovative and green applications, with intensive R&D in progress related to hydrogen fuel cell applications, heating, and power generation. Currently, there is significant R&D participation from universities, scholars and researchers on fuel cell application in Malaysia, especially FCEVs. For example, UKM has researched and developed a few fuel cell products with its Fuel Cell Institute. In March 2022, UKM successfully developed a FCEV buggy and SUVs that utilise hydrogen fuel cells, and were specially engineered for adaptation to Malaysia's tropical climate.[211] These hydrogen hybrid vehicles are equipped with humidifiers and water coolers to overcome the humid and hot weather throughout the year. In addition to FCEVs, hydrogen fuel cells have been pioneered for drones in Malaysia and utilise hydrogen fuel cells' advantages of longer flying range and flight time.[212] Pulsar-UAV is experimenting with drones to automate the fertilisation process and manage plantations for Malaysia's agriculture industries.[213] Aside from the mobility and agricultural sectors, the Malaysian government has also identified the potential to use hydrogen for home heating and power generation in off-grid areas. Hydrogen has not been used for either heating or as an energy carrier commercially or in any significant pilots. This sector is identified as the main medium-term goal in the official HETR and is expected to bring in more investment and research after the roadmap is published.

11.3 Expert Insights: Perception of Hydrogen Development

The experts notice that most hydrogen production and demand-side projects are limited to small-scale proof-of-concept or regional projects to attract more foreign investments and commercialise new hydrogen applications. In Malaysia, most hydrogen-related small-scale innovative projects are carried out as a proof of concept to show the government and investors that Malaysia has the potential for a hydrogen economy and can overcome the technical barrier caused by the tropical climate. The experts reason that these pilot projects are launched in the hope of attracting foreign investments and funding for carrying out large-scale projects down the line. For example, innovative hydrogen technology projects such as the hydrogen transportation project using $NaBH_4$ and fuel cell drone projects are only available in a few working prototypes.[205,213] In addition, the experts perceive the Sarawak projects, such as the green production and hydrogen buses, as successful pilot demonstrations for other states to follow and attract foreign investment into Malaysia. The hydrogen projects in Sarawak are yet to be considered sufficient for decarbonising both the industrial and mobility sectors.

The experts are sceptical about the current hydrogen development status and speed because of the slow responses from the Malaysian government in regard to mapping out the hydrogen development direction due to political uncertainties. At present, the Malaysian government aims to systematically plan the hydrogen development by providing an official national-level Malaysian roadmap to support SMEs and facilitate the growth of the overall hydrogen economy in Malaysia. Despite the hype over the upcoming roadmap, the draft is still in progress after suffering from delays by the government's consultants, NanoMalaysia, due to the ongoing Malaysian Political Crisis[xv] since 2020.[214,215] The experts acknowledge that several unpublished hydrogen-related policies were delayed and pulled from the initial schedule during the political uncertainties. Nevertheless, the experts foresee that the eventual release of the roadmap will effectively help unite the development directions on hydrogen production and applications with its proposed short-, medium-, and long-term goals.

Malaysia is envisioned to drive economic growth with hydrogen development, while the experts see that most pilot projects only aim to yield investment returns but not reduce carbon emissions. Those of the experts who work as hydrogen policy consultants believe that hydrogen development is the new industrial revolution to drive Malaysia's economic growth in the long run. For instance, one of the main themes for the upcoming hydrogen roadmap is "Wealth Creation via Carbon Neutrality by 2050" while constantly emphasising the promising potential return on hydrogen export opportunities. One of the respondents who is a green hydrogen production expert expressed his concerns that the energy industry is treating green hydrogen only as a sales pitch while most pilot projects are only focusing on money and potential rewards for the short term. The experts also agree that the hydrogen development in Malaysia is highly reward-oriented, which may delay green hydrogen production development as the business sector currently lacks the motivation to reduce its carbon footprint with the underdeveloped local hydrogen market and low adoption rate.

The experts perceive that Malaysia aims to become a major exporter and supplier of hydrogen to other high-demand countries in Southeast Asia but is still in the early stage. As an economy that relies heavily on fossil fuel production and export trade, Malaysia wants to stretch its fuel product line to hydrogen with its well-developed trading network.[216] Those of the experts who work as hydrogen policy consultants highlighted Malaysia's potential to supply hydrogen to high-demand hydrogen economies such as Japan, Singapore, and South Korea, which prefer to import hydrogen due to their high domestic production costs or limited renewable energy. Those respondents who are energy industry experts also notice that the energy industry is utilising its well-established trade relationship with other hydrogen-developed economies to develop hydrogen-related technology for production and pilot projects under partnerships.

xv The Malaysian Political Crisis has endured since 2020 caused by the change of party support among members in the 14th Parliament of Malaysia. Up until April 2022, two successive coalition governments had been dissolved with two Prime Ministers having resigned amid the political instability.

“ Malaysia will position itself as a key hydrogen player in the Asia Pacific region. Malaysia is a potential hydrogen exporter in Southeast Asia to fulfil the hydrogen demands in the Asian Pacific region. And we are now considering potential export destinations in a few targeted countries. So the countries that we are targeting are Japan, South Korea, and China, which are potentially the main importers of hydrogen. And the APAC region's consumption of hydrogen will be worth billions as estimated in 2050. ” — Policy Consultant

11.4 Expert Insights: Supporting Factors for Hydrogen Development

The experts perceive that Malaysia possesses enormous potential for increasing its green hydrogen production with its well-established hydroelectricity infrastructure and grey hydrogen production along with its mature natural gas production. Hydropower plays an increasingly crucial role in Malaysia's renewable energy balance with several well-established hydroelectric facilities across West and East Malaysia. The experts highlight that green hydrogen producers, such as SEB and the Elquator Group, are taking advantage of Sarawak's several waterfalls and mountain ranges in the rainforest areas to generate affordable hydroelectricity for producing green hydrogen through water electrolysis. In addition, hydropower is primed to become one of the main renewable energy sources in Malaysia in the future with expanding capacity. In 2018, hydroelectricity was the largest renewable energy source produced in Malaysia, contributing 5.7 per cent among all other fuel types, quadrupling from 1.4 per cent in 1998.[217] Furthermore, TNB, as the main energy producer in Peninsular Malaysia, has an installed hydroelectric capacity of 2,556.5 MW, while SEB had 3,458.1 MW in Sarawak as of 2019.[217] The experts perceive Malaysia's hydropower capacity as “more than enough” for green hydrogen production despite not being a large renewable energy producer compared to other APAC countries. In addition to renewable energy, Malaysia possesses one of the world's largest natural gas reserves for grey hydrogen production. Finally, as APAC's biggest LNG exporter and the world's fifth with approximately 32.8 billion cubic metres of export volume in 2020, Malaysia's rich natural gas reserve of 79.5 trillion standard cubic feet can fully support the acceleration of grey hydrogen production.[217]

The experts see Malaysia's geographic location as advantageous for expanding its hydrogen export trade to nearby SEA economies with its well-developed LNG transportation infrastructure. Those of the experts who work as hydrogen policy consultants believe that Malaysia has a favourable strategic location in Southeast Asia, enabling transportation through convenient and direct channels to most energy trade partners, such as Japan and South Korea. With its history of exporting LNG, Malaysia owns several LNG export terminals, such as the Tiga Malaysia LNG Terminal and MLNG Satu LNG Liquefaction Terminal in Sarawak.[218,219,220] The experts pointed out that Malaysia can also take full advantage of the available infrastructure to export liquefied hydrogen via cargo ships. Furthermore, Malaysia aims to support its neighbour, Singapore, with few natural resources for clean hydrogen production. Only separated by the Straits of Johor, Malaysia and Singapore are connected through two bridges so that hydrogen transportation can efficiently use tube trailers without any inter-country hydrogen pipeline.

“ We see competition (over exporting hydrogen), but one of the strategic advantages that we have in Malaysia is being closer to end-users who have demand for hydrogen but not sufficient production capabilities. Malaysia is strategically located within the SEA region, where it can export to places of high demand, such as Japan, South Korea, Singapore, etc., while in most cases, leveraging existing infrastructure. ” — Senior Engineer

11.5 Expert Insights: Future of Hydrogen Development

With the ongoing investment in R&D, Malaysia is expected to see technological advancement in its green hydrogen production to decarbonise the mobility sector by making hydrogen prices more affordable to end-users. Committed to reaching carbon neutrality by 2050, many Malaysian energy companies are proactively looking to leverage technology to increase green hydrogen production to decarbonise the energy sector. Aside from the various R&D initiatives, SEB is also working with Petronas to study leveraging other countries' business cases to bring down the current production costs of Sarawak's green hydrogen production.[221] Those respondents who were energy experts shared that the industry is now focusing on increasing the efficiency of the imported electrolyser and lowering the cost of renewable electricity by taking advantage of Malaysia's cheap renewable energy. They expect that the lower production cost will boost hydrogen adoption as the high price is the main roadblock for nationwide application in Malaysia.

Despite decarbonising the mobility and electricity sectors as key objectives, hydrogen applications such as FCEVs and electricity generation are expected to remain medium- to long-term goals with gradual rising adoption. The experts believe that Malaysia will experience an increase in hydrogen usage for power generation in remote off-grid locations such as West Malaysia or Central Malaysia in 15 to 20 years, under the facilitation of the upcoming hydrogen roadmap. On the other hand, FCEV adoption is expected to grow within a few years, but the vehicles will still be imported instead of being made in Malaysia. After successfully overcoming the tropical weather with Sarawak's hydrogen buses in 2021, the experts forecast that Malaysia will accelerate the deployment of more FCEVs for public transportation at a mild and steady pace. All the experts agree that most FCEVs will still rely on imports as Malaysian manufacturers have not announced any FCEV major production lines to date.

The experts also forecast that Malaysia is more prominent in supporting APAC's hydrogen development with increasing exports to high demand countries. With more mature production technology for electrolysis and renewables, the production cost is predicted to become more competitive in the APAC hydrogen export market. The experts believe that Malaysia's export trade will start to flourish after this technical breakthrough is achieved. In addition, the experts also anticipate that Malaysia will start enhancing its transportation and storage technology for long-distance transportation when the hydrogen export price is competitive.

Malaysia is trying to cultivate more local hydrogen industry experts by establishing more research facilities and learning from foreign experts in developed hydrogen economies to solve the hydrogen talent shortage. Currently, Malaysia is still depending on foreign talents as there are insufficient local experts to support Malaysia's development. Some of the experts are optimistic that this situation will improve soon. One of the experts has noticed some positive changes over the last decade. For example, the number of Malaysian hydrogen experts has been growing, and Malaysians are proactively learning from foreign experts based on their experiences in developing hydrogen economies. On top of that, Malaysia has been expanding its R&D facilities, such as the Fuel Cell Institute in UKM and the Centre of Hydrogen Energy in Universiti Teknologi Malaysia (UTM).[222,223] Furthermore, the unexpected COVID pandemic has pushed forward Malaysia's schedule to train its local expertise due to difficulties in importing talents.

> **“Hydrogen experts are growing in number. Back 15 years ago, we had to rely mostly on German experts. Our company used to require a German mechanical PhD engineer to come to our facility to conduct a technical audit and train us on how to build our devices. Hydrogen experts used to be very scarce in Malaysia. There were no experts in Malaysia until the local university like UKM started the Fuel Cell Institute, headed by Prof Kamarulzaman.” — Founder**

11.6 Expert Insights: Barriers to Hydrogen Development

The experts see the stagnated hydrogen-related technological advancement in transportation and storage, CCUS, and green hydrogen production as the main barriers limiting the speed of hydrogen adoption in Malaysia. Currently, transporting hydrogen in either gas or liquid form is still highly costly without major infrastructure specialised in hydrogen transportation, and transportation in solid form is not yet commercialised. The experts explain that most equipment such as compressor tools for compressing hydrogen compounds and storage tanks for HRS and FCEVs are all imported from China or European countries, thereby increasing the transportation and storage costs. Furthermore, all the experts agree that the technology for blue and green hydrogen is not sufficient to transform Malaysia's current grey production to blue or green at the moment. The respondents who were energy experts shared that CCUS projects in Malaysia have just started and are not yet used for hydrogen production but only for the natural gas sector. For example, energy companies have only started R&D and signed MoU with foreign partners, such as ExxonMobil and JAPEX, since 2021.[224,225] Meanwhile, green hydrogen production using the electrolysis technology is limited in Sarawak to using high-cost imported electrolysers. The high production cost has restrained Malaysia's current hydrogen production capacity.

Apart from technological limitations, the experts reason that the lack of regulation and a law system for transportation, storage, and applications from the Malaysian government constrain hydrogen development on both supply and demand sides. Those of the experts in the fuel cell industry pointed out that the absence of a standardised certification and licensing system is discouraging foreign investors from investing in Malaysia's hydrogen-related innovative projects, such as in FCEVs or fuel cell applications. The underdeveloped market in the hydrogen sector is hindering Malaysian SMEs, which often depend on foreign investments to scale up their products beyond the prototyping stage. In addition, the experts find the current hydrogen-related certification and licence policy hard to follow as no single authority is responsible for hydrogen-related operations. Furthermore, Malaysia has yet to establish a set of national-level hydrogen safety standards on hydrogen production, transportation, and storage. While the policymakers and advisors are aware of the urgent need for regulation, the government has decided not to develop Malaysia's version of safety laws but to follow other countries' standards instead. Some of the experts expressed concerns that such standards may not suit Malaysia's tropical climate.

> **"When we start selling hydrogen and fuel cells, these products' safety needs to be certified for end-users. Therefore, they need to go through SIRIM (Standard and Industrial Research Institute of Malaysia). But as we know, they have zero hydrogen experience. So this is a problem. Because of this, we cannot sell our products overseas or to nations that are hydrogen ready in regard to both regulation, the law and policy. I think that the minimum the government can do is at least set the standards for commercial hydrogen and fuel cells. Otherwise, this is a hindrance." — Founder**

Malaysia does not have sufficient hydrogen technical talents to support and lead long-term development, while some of the experts reasoned that the conservative Malaysian education system is inducive to this. Since the beginning of hydrogen development in early 2005 in Sarawak, Malaysia has always relied on foreign companies' experts for the deployment and maintenance of each section across the supply chain. This approach is often seen as more cost-effective and efficient by energy companies that value short-term results. But under the impacts of COVID-19, several hydrogen maintenance works and hydrogen production projects have been affected and delayed as foreign experts could not travel to Malaysia under the stricter border controls. The experts criticised the approach of relying on recruiting talents from overseas. However, the experts also further highlighted that the local hydrogen talent pool does not meet the demand for engineering skillsets, and recruiting talents from overseas is the only possible short-term solution. A respondent who was an energy expert explained that the conservative education system does not help train future engineers for hydrogen development. Specifically, the experts described Malaysia's education system as not being highly regulated as teaching quality is not standardised at the national level. As a result, many engineer graduates may not be properly equipped with the necessary technical skillsets and knowledge to follow the instructions of foreign hydrogen experts.

Malaysia has a tropical climate located in the equatorial region, which may affect the operation of FCEVs and other fuel cell applications. Malaysia has rainfalls for at least 250 days in most regions each year, while in Kuala Lumpur it rains for more than 287 days.[226,227] Also, with an average temperature of 25.9 degrees Celsius and remaining hot and humid throughout all seasons, those respondents who were FCEV experts explained that engineers must consider the tropical and rainy weather when designing any fuel cell products.[228] From the experts' project experience, Malaysia's HRS infrastructure currently uses the UK's layout, which may not suit Malaysia's tropical climate while additional measures or equipment are required. For example, a cooler is required to reduce the refilling duration due to the hot weather. For instance, extra equipment such as coolers is deployed in Sarawak's HRS system while humidifiers are installed in the FCEVs' layout. The experts anticipate that this issue will become more prominent and need to be systematically measured and assessed when FCEV adoption is extended to other states.

11.7 Expert Insights: Actions to Accelerate Hydrogen Development

To advance hydrogen-related technology with local hydrogen innovation, the government should establish firm standards and regulations across all touchpoints in the hydrogen value chain to create a more regulated and systematic hydrogen economy for foreign investment. From the experts' experience, many hydrogen-related start-ups and SMEs are currently showcasing their products and services as prototypes to demonstrate and attract foreign investment to commercialise their offerings and expand production lines. However, many of the experts perceive Malaysia as less competitive in maintaining a lucrative business environment at the moment. Therefore, the experts agree that there is an urgent need to establish hydrogen-related standards and regulations in Malaysia to facilitate trade on fuel cell applications and smoothen work partnerships with other countries when the laws are clear and well-defined. For example, it has been suggested that hydrogen transportation and storage safety standards should be clearly defined and established as soon as possible because of hydrogen's hazardous properties. On top of that, the licensing authorities responsible for hydrogen application should be listed clearly. Standardisation would also help reduce risks for businesses and investors, which would result in attracting additional foreign investments to help expand the hydrogen economy in Malaysia.

To further support local hydrogen innovation and SMEs, the experts suggest that the government should offer grants, tax incentives, and subsidies for hydrogen projects while opening up the local carbon credit trading system could attract investment in green hydrogen-related technology. Envisioned as a new industrial goal, the experts encourage the government to solidify grants and subsidies to make Malaysia more attractive to foreign investors. In Malaysia, both hydrogen policy consultants and experts perceive that foreign investment is more important than local investment for project implementation for unknown reasons. On top of bringing in investment, the grants, tax incentives, and subsidies will help mitigate part of the business risk from SMEs, as many are perceived to be in the seed or early start-up stage and are in desperate need of financial assistance. The experts reason that hydrogen-related business is perceived as risky with uncertain returns because of Malaysia's current delayed hydrogen development and related roadmap, and no major support from the government or any authorities in regard to regulating and uniting the industry. Therefore, a respondent who was an energy expert suggested that the government should consider establishing a carbon credit trading system for carbon credit trading[xvi] to encourage energy companies to invest more in green hydrogen-related technology.

“ The main idea behind this hydrogen economy is to bring foreign investments into the country while being facilitated by Malaysia’s pioneer status and tax incentives. But we do realise that it is a very capital-intensive initiative. The laws from the government need to act as some facilitation to make the country attractive to foreign investors. It is also important to look at subsidies currently being applied to petrol and diesel sectors, and study the possibility of shifting these subsidies towards hydrogen. ” — Hydrogen Policy Consultant

Aside from drawing in more investment, the experts believe that building a local expert pool with independent R&D and technical capability will help solve the shortage of access to experts in the long run. As most hydrogen talents are now recruited from overseas for the short term, the experts believe that energy companies should take on a proactive role of filling and strengthening Malaysia’s hydrogen talent pool beside the current research institutes. For example, the business sector should invest more resources in engineering schools and hydrogen-related research. In addition, energy businesses can utilise their networks and resources to hire foreign hydrogen experts to train potential engineers for hydrogen projects locally instead of depending on foreign experts. Over the long run, the experts are confident that Malaysia has shown great potential to nurture a pool of hydrogen experts with its new generation.

xvi Up to April 2022, there is currently no existing carbon credit trading market or system in Malaysia as many energy producers are acting as Independent Power Producers (IPP) and running on Power Purchase Agreements (PPAs) to supply power for power utility companies. Under the PPAs, the carbon credit is counted as Gross National Product instead, and the energy producers cannot trade them for reward.

12

Singapore

12.1 Overview

Table 12 Singapore Hydrogen Market Overview

OVERVIEW OF SINGAPORE	
Key Background Information	• Singapore has not released a specific hydrogen roadmap but launched the Singapore Green Plan 2030 in February 2021 to set concrete targets for long-term net-zero emissions by 2030. • Singapore is still searching for its position in the global hydrogen market, awaiting the emergence of a successful hydrogen economic model. Public and private stakeholders are constantly conducting R&D and pilot projects. • Singapore is currently a net importer of hydrogen, while the scale of imports is perceived to be small. Most of the hydrogen produced domestically is grey hydrogen from SMR for industrial usage. • Non-industrial gas and industrial sectors are two major sectors requiring hydrogen for their everyday operations in Singapore. The power, mobility, and maritime sectors have a high potential to deploy hydrogen but do not have immediate demand.
Key Expert Insights	• The government sees hydrogen as one of the crucial aspects of Singapore's energy transformation. It has realised the necessity to promote the use of hydrogen as a solution to reach the carbon reduction target and further upgrade its core industries. • Singapore is still at its very early stage of hydrogen development apart from the industrial sector, especially for green and blue hydrogen. The overall scale of consumption is not large as perceived. • Singapore only has relatively small-scale hydrogen transportation and storage infrastructure, but it is still feasible to transform into a hydrogen economy with its well-established gas power system for its mature deployment of LNG. • Singapore's relatively small economy is a barrier to the country in regard to creating economies of scale for hydrogen usage, making it difficult to develop hydrogen extensively in different industry verticals. • Nevertheless, with the private sector's continuous effort to build hydrogen business prototypes, the power industry, the non-industrial gas industry, and the marine industry are perceived to be the most immediate segments to deploy hydrogen to a large extent. • Hydrogen could be utilised to decarbonise the bunkering sector in Singapore as the country is one of the largest bunkering hubs worldwide.

12.2 Background

12.2.1 Overall Hydrogen Landscape

Singapore is still searching for its position in the global hydrogen market, awaiting the emergence of a successful hydrogen economic model. The Singapore Government launched the Singapore Green Plan 2030 in February 2021 to set concrete targets for long-term net-zero emissions by 2030.[229] Energy Reset, one of the key pillars, stresses the importance of sustainable fuels to increase energy efficiency and lower Singapore's carbon footprint. As a country that employs little renewable energy, Singapore believes that low-carbon hydrogen and the combination of CCUS will play a prominent role in its transition to a green economy. Commissioned by the National Climate Change Secretariat (NCCS), Singapore Economic Development Board (EDB) and Energy Market Authority (EMA), KBR, Inc and Argus published the Study of Hydrogen Imports and Downstream Applications for Singapore, analysing potential hydrogen import sources and deployment pathways.[230] In October 2021, SGD 55 million was awarded to 12 research, development and demonstration projects on low-carbon energy technology under the Low-Carbon Energy Research Funding Initiative (LCER FI), supporting the Singapore Green Plan 2030.[231]

Hydrogen has been explored in four major projects concerning better efficiency and lower cost for hydrogen-related processes. The first project aims to develop robust ammonia-cracking technologies. The second project attempts to minimise hydrogen leakage and optimise hydrogen purity sensors for downstream hydrogen use. The third project studies pyrolysis for hydrogen and carbon nanotube production. The last one focuses on MCH as a LOHC for building a minimum-cost supply chain network in Singapore. Commercial execution was yet to be observed from the four aforementioned hydrogen-related projects in Singapore as of late 2021.

Singapore is also expanding its international network to build a regional hydrogen value chain. In July 2019, Singapore signed an agreement with New Zealand to jointly research the production and deployment of low-carbon hydrogen.[232] In 2021, Singapore began its partnership with Australia, investing USD 30 million in developing low emission fuels and corresponding technologies, including clean hydrogen for emission reduction in maritime and port operations.[233] Aspiring to become Asia's carbon trading hub, Singapore promotes the use of hydrogen and clean ammonia in maritime and port operations by employing the venture's low emissions solutions.

12.2.2 Hydrogen Supply Landscape

Singapore is currently a net importer of hydrogen, despite having substantial domestic production for its industrial sector. Its oil refining industry, for instance, is recognised as one of the world's largest and is one of the top hydrogen consumers of the city-state. With grey hydrogen being widely adopted in the industrial sector, SMR is Singapore's primary hydrogen production technology. Air Liquide and Linde are identified as Singapore's two major hydrogen producers. There is no significant amount of green hydrogen produced within Singapore. The lack of green hydrogen is mainly because Singapore does not have enough land to set up water electrolysis leveraging renewable electricity. Blue hydrogen is also absent from domestic production as CCUS technology is still yet to see prevalent deployment in the region. A Singapore-based company is currently constructing two of the first-ever commercial green hydrogen production plants in Singapore utilising biomass gasification technology. They could start operation as soon as the end of 2022.

Although Singapore is a net importer of hydrogen, the scale of imports is perceived to be small due to the lack of domestic and regional mature transportation infrastructure. The first reason for such a small-scale import is that the technology for transporting hydrogen is still not very established across the region, if not worldwide. The lack of large-scale, cost-effective transportation infrastructure has further driven up the total import price of hydrogen. Furthermore, the safe transportation and storage of hydrogen domestically are also challenging. Singapore is a small country with residential areas crammed in with industrial areas. The transport of imported hydrogen within the country could be challenging because tube trailers carrying hydrogen are likely to travel near residential areas and pose potential threats to residents. Singapore currently lacks the infrastructure for storing and transporting hydrogen, such as hydrogen pipelines and large-scale storage tanks. Hydrogen is primarily transported through surface vehicles, such as tube trailers and cruise ships. Large-scale imports of hydrogen are still in the discussion stage, with many revisions of proposals being presented and reviewed.

Singapore has been focusing its research efforts on producing and importing sustainable and affordable hydrogen. The Semakau Project, under the Renewable Energy Integration Demonstrator (REIDS) programme, is the first of its kind — a full-cycle non-commercial pilot project, testing the hydrogen power-to-power system and microgrids for the transition towards a green hydrogen economy.[234] Other stakeholders from the private sector, such as City Gas and Sembcorp Industries, are actively studying the feasibility of importing hydrogen. For instance, they entered an MoU with PSA Corporation Limited, Jurong Port Pte Limited, Singapore LNG Corporation Pte Limited, Chiyoda Corporation, and Mitsubishi Corporation to explore Singapore's hydrogen import and utilisation business models.[235] Global gas corporation, Air Liquide, is also looking into green hydrogen by developing electrolysis and the CCUS technologies in Singapore. On top of the efforts from the private sector, the National Climate Change Secretariat, Prime Minister's Office, put forward a study in 2020 together with KBR to study the potential of importing hydrogen from countries including Australia, New Zealand and Malaysia.[230]

12.2.3 Hydrogen Demand Landscape

There are already various sectors in Singapore that require hydrogen for their everyday operation. Two significant examples would be the non-industrial gas sector and the industrial sector — piped town gas that is supplied to domestic and non-domestic end users, produced by City Gas, already contains 43 vol per cent to 65 vol per cent hydrogen.[230] Also, hydrogen is a crucial feedstock for Singapore's oil refining and petrochemical industries. These sectors have been relying mainly on the grey hydrogen produced domestically or imported hydrogen to a smaller extent, while other sectors, such as the power sector, the mobility sector, and the maritime sectors, do not have an immediate demand for hydrogen. However, market players from these sectors are gearing up for the transition to a hybrid ecosystem, with hydrogen being an essential element to reduce the carbon footprint and increase operational efficiency for their respective industries. While 95 per cent of the country's electricity is currently generated through burning natural gas, the power sector could be one of the largest hydrogen consumers in the country by blending hydrogen with natural gas as a feedstock for combustion turbines.[236] Besides, hydrogen FCEVs could also disrupt the mobility sector, especially for commercial vehicles that do not prefer long charging hours as required by battery EVs. With the excessive hydrogen demand for the existing and potential applications, Singapore is perceived as a hydrogen-deficit country with no significant hydrogen exported to other countries.

Market players from the demand side involve both local and international players, while established stakeholders from the demand side are mostly local players, such as City Gas, Sembcorp and Singapore LNG Corporation. For instance, City Gas has blended up to 65 per cent of hydrogen into its town gas system.[230] Multinational corporations are also actively involved in hydrogen-related pilot projects and testbed demonstrations. For instance, Keppel Offshore & Marine's Floating Living Lab, a floating barge with LNG bunkering facilities for harbour craft and small vessels, will be powered by Wärtsilä engines operating on gas containing up to 25 per cent of hydrogen.[237] Global energy group, Shell plc, is also working with Wärtsilä to study the use of hydrogen fuel cells for ships in Singapore.[238] A report compiled by KBR has investigated different downstream applications for hydrogen of different forms such as compressed gaseous hydrogen, liquefied hydrogen, ammonia, liquid organic hydrogen carriers and methanol. It highlights the high-potential downstream sectors, including power, mobility and marine.[230]

12.3 Expert Insights: Perception of Hydrogen Development

The experts agree that while the Singaporean government has not released any roadmap specifically for the country's hydrogen development, the government sees hydrogen as one of the crucial aspects of Singapore's energy transformation. Most of the experts perceive that their respective governments have realised the necessity to promote the use of hydrogen as a solution to reach the carbon reduction target committed to in the Paris Agreement and further upgrade their core industries, such as the bunkering industry. Also, one of the experts believes that the development of hydrogen could diversify the country's reliance on imported energy from its existing trading partners. In the near future, the experts believe that Singapore should position itself as not just a solution developer of hydrogen but also reinforce its role as a hydrogen trading centre by utilising its geographical advantage and experience in commodities and energy trading.

The experts from Singapore also perceive that apart from the industrial sector, Singapore is still at its very early stage of hydrogen development, especially for green and blue hydrogen. Besides feasibility studies pushed forward by the National Climate Change Secretariat, Singapore Economic Development Board and Energy Market Authority, there are only a small number of small-scale pilot and non-commercial projects in progress within Singapore. Nevertheless, the experts from the private sector have been actively giving impetus to developing cleaner hydrogen. Constructive discussions and business collaborations on hydrogen are becoming vigorous, and technology companies from foreign countries are also involved in various discussions and projects.

Although Singapore's industrial sector has a history of utilising grey hydrogen, the overall scale of consumption is not as large as perceived. As the hydrogen facilities were only designed for industrial use, they are not sufficient to accommodate higher demand if other sectors also migrate to hydrogen simultaneously. The experts from Singapore generally believe that the country has not developed a comprehensive supply chain for hydrogen. Infrastructure for the transportation and storage of hydrogen is lacking, which would be a roadblock to the development of hydrogen in the region. The experts also mention that Singapore has yet to publish its hydrogen roadmap, nor has it officially implemented the recommendations from the feasibility studies in real-life practice because the government is still waiting for a successful model of a hydrogen economy. The experts believe that the Singaporean government is observing first-movers such as Japan, South Korea and Australia and hope to replicate their success.

> **“The thing is that hydrogen is still at a very early stage. As far as I know, the Singaporean government, the EMA, and the EDB paid a company to conduct a study on the application of hydrogen and imports for Singapore. Several Japanese companies also signed the MoUs on this initiative. One of them was signed by Chiyoda Corporation, Mitsubishi Corporation and SEMBCORP. They were commissioned to look at how to utilise hydrogen as a green source of energy in Singapore.” — Energy Business Director**

Singapore, however, could face more challenges when developing green hydrogen due to the limited land supply in the country. The most common technique of producing green hydrogen worldwide is still electrolysis using renewable electricity such as solar power or wind power. But on the other hand, Singapore does not have sufficient flatland to set up solar power or wind power compared to countries such as China and Australia, making the technology not very effective in its context. The experts speculate that the limited land supply in such a small country would limit its ability to produce green hydrogen domestically.

12.4 Expert Insights: Supporting Factors for Hydrogen Development

Some of the experts suggest that even though Singapore only has relatively small-scale hydrogen specific transportation and storage infrastructure, it is still feasible for Singapore to transform into a hydrogen economy with its well-established gas power system for its mature deployment of liquified natural gas. The experts generally consider that the technology required to deploy LNG is relatable to that of hydrogen if it is to be reallocated for hydrogen usage and other hydrogen derivatives. Therefore, it is not unfeasible for existing market players, especially in the power sector, to leverage their LNG technology and facilities to expand their capabilities to focus on hydrogen deployment. Nevertheless, the existing LNG facilities would still need extra effort to be input into their redesign and retrofitting.

> **“The LNG is likely the closest technology compared to hydrogen, liquid hydrogen or other hydrogen derivatives, so this is advantageous to the hydrogen development in Singapore. It is just the size and magnitude of the industrial challenge; it is still relatively doable.” — Senior Vice President**

The experts also consider that the ongoing green hydrogen-related pilot projects across various industries have been instrumental in inaugurating the relatively novel segment. Various of the experts confirmed that while the discussion on hydrogen utilisation in the country had only started by around 2020, each has been involved in some pilot projects and testbeds, respectively, with the main purpose of assessing the feasibility of hydrogen deployment in different industries and scenarios. Disclosable projects such as the floating living lab project, Singapore's first utility project, aim to develop a floating lab running on a hydrogen-enabled engine.[237] It would act as a reference for hydrogen usage in the bunkering industry in Singapore. One supply-side project that one of the experts has been involved in is producing affordable carbon-negative hydrogen through gasification.[239] This project is also deemed to become an important benchmark for the hydrogen industry once the construction is completed and operation begins. Stakeholders from many industries have started to recognise the potential of hydrogen in fulfilling their social responsibility of decarbonisation or even improving their operational efficiency. After both the supply and demand for hydrogen are secured, per the experts' conjecture, the value chain of the hydrogen economy will be set in motion and accelerate going forward.

12.5 Expert Insights: Barriers to Hydrogen Development

The experts believe that the higher cost of hydrogen compared to traditional energy sources constitutes the major barrier to hydrogen development, preventing the increase of its usage in multiple industries in Singapore and worldwide. Particularly in Singapore, the power sector is one of the largest potential hydrogen users as hydrogen is the most readily available energy replacement for natural gas for decarbonising the country's industries. However, industry players are currently hesitant to employ hydrogen, and natural gas continues to be the dominant fuel for price competitiveness reasons. One of the experts suggested that the electricity cost in producing grey hydrogen could be more than double that of natural gas, while the electricity cost in producing green hydrogen could be ten times that of the cost of natural gas for equivalent application. The cost difference is too significant for industry players to substitute natural gas with hydrogen. Many of the experts also suggested that the carbon tax in Singapore is too low to cover the price premium for purchasing hydrogen, so many companies would rather pay the tax than transition to the more expensive hydrogen option. Singapore's current carbon tax rate is SGD 5/tCO_2e, much lower than most European countries.[240] The European Union levied its carbon tax rate at an average of EUR 55.9/tCO_2e in 2021, which was over 17 times higher than in Singapore.[241] Hence, industries in Singapore are less eager to adopt hydrogen as an alternative energy source.

Apart from the cost factor, the experts also suggest that Singapore's relatively small economy is a barrier to the country in creating economies of scale in regard to hydrogen usage, making it difficult for the country to develop hydrogen extensively in different industry verticals. Some of the experts perceive that even if Singapore's hydrogen market is fully developed, its size and scale will not be comparable to other leading hydrogen economies such as Japan and South Korea, owing to its relatively low level of local demand. For example, Singapore's power sector scale in terms of total electricity consumption was 50.1 TWh in 2020, only approximately 1.1 per cent of that of Japan and approximately 9.8 per cent of that of South Korea.[242] Moreover, there were only about 974,000 motor vehicles in Singapore in 2020,[243] compared to South Korea's vehicle market, with approximately 24.4 million in 2020.[244] Hence, the experts believe that Singapore's hydrogen development is governed by its small economy.

" Singapore is a very small market. There will be no demand (for hydrogen) in a very small market. And it is also about economies of scale - you are not going to do it for just a small project. Economies of scale would be needed. Economies of scale are what bring the cost down. Singapore is small, yet the government wants to do it. " — Energy Business Director

While possessing adequate hydrogen infrastructure to transport and store hydrogen is one of the fundamental requisites for the development of hydrogen in a country on a full scale, some of the experts are concerned that there are insufficient relevant facilities in Singapore and that the industry players in Singapore might yet need to master the technology of hydrogen transportation and storage. One of the experts revealed that the ammonia storage infrastructure is underdeveloped in Singapore, with only one ammonia storage tank in the city-state. Another of the experts also commented that not many manufacturers in Singapore are capable of producing liquid hydrogen containers up to international standards. With limited support from the government, the experts consider that industry players from the supply side have to build their transportation and storage infrastructure at their own expense.

12.6 Expert Insights: Future of Hydrogen Development

With the private sector's continuous effort to build hydrogen business prototypes, the experts generally believe that the country's demand for hydrogen will emerge across different industries. In contrast, the domestic hydrogen supply will soon be insufficient to meet the increasing demand. In particular, the experts presume that the power industry, the non-industrial gas industry, and the marine industry will be the most immediate segments to deploy hydrogen to a large extent in Singapore. It is technically feasible for power plants in Singapore to increase their hydrogen usage as an energy feedstock after specific retrofitting. It is also possible to increase the hydrogen ratio for some non-industrial gas in the country, such as town gas. Industry players have carried out actions in both sectors as perceived by various of the experts.

" All the power generation companies like SEMBCORP are talking to upstream equipment manufacturers like General Electric, Siemens and Mitsubishi on the blending of hydrogen. " — Business Development Manager

Many of the experts also believe that hydrogen can be utilised to decarbonise the bunkering sector in Singapore as the country is one of the largest bunkering hubs worldwide. In 2021, Singapore's bunkering sector ranked first worldwide in recorded bunker sales volume.[245] As it could become a massive market for hydrogen once hydrogen is deployed in the bunkering sector, many of the experts trust that decarbonising the bunkering sector would be a major direction for Singapore's hydrogen development. While the experts perceive that domestic hydrogen production on a large scale would still be a challenge for Singapore in the short term, the city-state will remain a net hydrogen importer in the foreseeable future. Particularly the production of green hydrogen, one of the experts suggested that there could be a fundamental shift of production technology in Singapore, if not in the APAC, from electrolysis to biomass gasification.

Gasification plants, unlike electrolysers, are decentralised and can be built anywhere close to hydrogen demand. The experts also suggest that with the adoption of the decentralised model, Singapore could overcome its shortcomings in hydrogen transportation infrastructure. It could be a disruptive technology not only in Singapore but also in other countries with similar settings.

Moreover, the experts generally perceive that Singapore is actively learning from leading hydrogen economies such as Japan and South Korea and is proactively analysing its possible role in the global hydrogen value chain. While Singapore's hydrogen development is lagging behind that of some leading countries, and no national hydrogen roadmap has been rolled out by the officials to date, the experts have reached little consensus on Singapore's projected timeline and its role in hydrogen development in the APAC. Nevertheless, many of the experts perceive that the Singaporean government has been learning from some first movers in APAC and hopes to apply some successful business models within Singapore. As discussed, Singaporean officials signed an agreement with New Zealand in 2019 and subsequently partnered with Australia in 2020 to research the deployment of low-carbon hydrogen and to develop low-emission technologies.[246,247] With Singapore's small economy and its efficient governmental style, it has been establishing pilot projects of its own by referencing successful cases in other countries. Singapore can also promote hydrogen usage effectively in the future once it has identified a profitable role in the global and regional hydrogen value chain. Nevertheless, the experts believe that the government will not invest extensively in hydrogen at this stage before other major economies have achieved proven successes, as Singapore would require international collaboration to achieve economies of scale for its deployment of hydrogen.

12.7 Expert Insights: Actions to Accelerate Hydrogen Development

The experts believe that more financial and regulatory support from the government is essential to create sufficient incentives for players in the private sector to commercialise hydrogen usage. The experts suggest that while collaborations within the private sector have created certain momentum for the country's hydrogen development, its pace still largely depends on the extent of government support. With the high cost of hydrogen deployment being one of the biggest hurdles, the experts generally suggest that the Singaporean government should provide more subsidies and grants to relevant industry players to reduce their capital and operational expenditure needed for the transition. Direct investments should also be made to support the country's hydrogen transportation and storage infrastructure. The experts trust that financial aid is the most direct and practical way to encourage industry players to construct the country's hydrogen economy.

> **“ We need the government entities to come together, roll out and mandate certain policies and strategies that say we want this to happen, and encourage that and support that with funding and grants and subsidies so that industry is encouraged. ” — Founder of Company**

Various of the experts also mentioned supportive policies and education about the benefits of hydrogen as the key actions that Singapore could undertake to further promote hydrogen implementation on a larger scale. One of the experts suggested that the government could devise new traffic regulations for hydrogen transportation on the road, especially for the main island, as the current traffic regulation imposes restrictions on hydrogen transportation, which could hinder the country's hydrogen development to a further extent. In terms of education, the experts believe that education should target both industry players and the general public, as it could be challenging for either side to move towards hydrogen utilisation if the other side is not well aware of the reasons and potential benefits of deploying hydrogen as the country's future energy source.

13

Thailand

13.1 Overview

Table 13 Thailand Hydrogen Market Overview

OVERVIEW OF THAILAND	
Key Background Information	The hydrogen industry in Thailand is still in the early stage of development since five energy plans were introduced in 2015 to accelerate Thailand's development of low-carbon energy consumption. There are currently small-scale green hydrogen production, large-scale grey hydrogen production, and by-product hydrogen production from industrial processes in Thailand. Hydrogen is mainly used in the industrial sector for iron smelting, petrochemical refinement, chips production, and glass production while MNCs and domestic private companies have proactively invested in fuel cell technology in a collaborative effort to drive FCEV adoption.
Key Expert Insights	The government is making steady progress in achieving carbon neutrality by adopting hydrogen, and private corporations will play a more important role in driving the hydrogen economy. Government policy is in favour of EVs instead of FCEVs, and regulation and public education are urged to increase the public confidence in FCEVs. The hydrogen industry value chain and associated technology are not mature compared to renewable energy sources. The lack of a clear national strategy, roadmap, and regulation hinder the hydrogen development while the high upfront investment and production costs remain a key barrier to green hydrogen adoption in Thailand. Hydrogen demand will increase in Thailand's industrial, transportation, and heating sectors and will take around five to ten years to address the cost barriers related to green hydrogen production. The government should consider investing in carbon capture infrastructure to encourage the development of a hydrogen ecosystem with blue hydrogen and private organisations to invest on R&D to lead the hydrogen development.

13.2 Background

13.2.1 Overall Hydrogen Landscape

The hydrogen industry in Thailand is still in the early stage of development, with Bangkok Industrial Gas (BIG) as the single largest grey hydrogen producer. According to the latest information from the Department of Alternative Energy Development and Efficiency (DEDE) in 2019, there is no record of green hydrogen production in Thailand.[248]

In 2015, Thailand's Ministry of Energy integrated five energy plans, namely Power Development Plan (PDP), Efficiency Plan (EEP), the Alternative Energy Development Plan (AEDP), the oil plan and the gas plan, into a single Thailand Integrated Energy Blueprint 2015–2036 (TIEB). The new energy strategic plan TIEB was released to accelerate Thailand's development to align with the global trend of low-carbon energy consumption across different industries. While the Energy Policy and Planning Office (EPPO) is responsible for drafting the plan, the direction of the plan follows the framework approved by the National Energy Policy Council.

The TIEB defines the application of renewable energy as one of the core strategies. The Thai government aims to increase the use of renewable energy to 30 per cent of total energy consumption in electricity generation, heating, industrial feedstock and transportation by 2036.[249] The Thai government targets to put Thailand forward as a green and clean country to achieve carbon neutrality by 2070, with GHG intensity reducing from 24 metric tonnes per million THB to 15.2 metric tonnes per million THB.[250]

According to the Alternative Energy Development Plan (AEDP) under the TIEB 2015–2036, hydrogen is not the top priority of the TIEB. The energy consumption target of hydrogen and bio-oil outlined in the AEDP is set at 10 ktoe for the mobility sector, approximately only 0.05 per cent of Thailand's total planned renewable energy consumption.[251]

13.2.2 Hydrogen Supply Landscape

There are currently three types of hydrogen generation-related project types in Thailand: smaller-scale green hydrogen production, large-scale grey hydrogen production, and by-product hydrogen production from industrial processes.

Lam Takhong Wind Hydrogen Hybrid Project and the Phi Suea House Project are two of the more notable small-scale demonstration projects that focus on using renewable resources to produce green hydrogen in Thailand. The Lam Takhong Wind Hydrogen Hybrid Project was announced by The Electricity Generating Authority of Thailand (EGAT) in 2016. The EGAT aimed to develop a wind hydrogen hybrid system combined with fuel cells to enhance the capability of surplus power generation from wind turbines. The system can produce hydrogen with approximately 4.6 million units of electricity per year.[252] In 2017, the Phi Suea House in Chiang Mai was built and powered entirely by a solar-hydrogen system that provides 24-hour, year-round access to clean energy for fou residential homes. The demonstration project was co-developed by the EGAT and electrolyser manufacturer Enapter and is the world's first solar-hydrogen multi-building with 100 per cent self-sustaining capability.[253,254] In this demonstration project, photovoltaic panels are mounted on the rooftops to generate electricity during the day with excess energy stored in lead-acid battery packs, and the rest is used to produce hydrogen via electrolysis. The hydrogen is then stored in fuel cells for use to convert into electricity during the evenings.

Large-scale grey hydrogen-related projects such as BIG's hydrogen plants are generally focused on supporting Thailand's manufacturing industry. While the first BIG hydrogen plant was built in 2013, BIG established the second hydrogen plant in Map Ta Phut in Rayong in 2018 to serve the rising demand from the transportation and industrial sectors in the Eastern Economic Corridor (EEC). The new hydrogen plant aims to produce 12,000 metric tonnes of hydrogen a year at a productivity rate of 15,000 Nm^3/hr with commercial operations in 2019.[255] While both plans still use fossil fuels to produce hydrogen, this project aligns with the government's policy of promoting hydrogen as alternative energy to replace fossil fuels for the mobility sector.

13.2.3 Hydrogen Demand Landscape

Today, hydrogen is mainly used in the industrial sector for iron smelting, petrochemical refinement, chips production, and glass production in Thailand. Hydrogen consumption in Thailand was 33.3 million metric tonnes in 2020, and it is expected to grow at a CAGR of 5.7 per cent until 2031.[256] For example, hydrogen is used to improve fuel quality to comply with Euro 4 and Euro 5 standards. Hydrogen is also used for iron smelting and petroleum refinement to remove the sulphur through hydrocracking. In addition, hydrogen application is also extended to food production such as the hydrogeneration of fat and oil.

Multinational and domestic private companies have proactively invested in fuel cell technology in a collaborative effort to drive FCEV adoption in Thailand. For example, FEV, a German energy company, established a subsidiary in Thailand to support the mobility sector in regard to developing vehicles, engines, and electric drives — including batteries and hydrogen fuel cells.[257] BIG also cooperated with Toyota Motor Thailand to develop FCEVs and set transportation safety standards to ensure the vehicles' reliability and enhance customer confidence in the technology.[258] Furthermore, PTT Public Company Limited has also partnered with the public and private sectors and established the Hydrogen Thailand Group to promote green hydrogen as new alternative energy to drive new demand.

13.3 Expert Insights: Perception of Hydrogen Development

While hydrogen is still a missing piece in the latest renewable energy blueprint, the experts revealed that the government is making steady progress in achieving carbon neutrality by adopting hydrogen. The experts also believe that private corporations will play a more important role in driving the hydrogen economy.

The experts also suggest that the hydrogen industry value chain and associated technology are not mature compared to renewable energy sources such as solar, wind, and biomass. The experts suggest that while the Thai Government is interested in furthering hydrogen development, hydrogen will not be a sole focus for Thailand, given that the Thai government wants an energy source with high stability. However, hydrogen is still one of the major alternative energy options which can support Thailand's goals of clean energy and reducing CO_2 emissions. For example, the Energy Policy and Planning Office (EPPO) sees hydrogen as potential alternative energy from a technical perspective. The EPPO is actively investigating how much hydrogen-related focus should be put into the TIEB. More importantly, one of the experts believes that while hydrogen is one of the key options for Thailand to achieve carbon neutrality, the current production of grey hydrogen is not the solution. It has been further suggested that blue hydrogen would be one of the options for carbon neutrality once the Thai government solidifies its policy and investment direction to implement CCUS infrastructure.

> **"Hydrogen has been widely used in Thailand's petrochemical industry. Notable companies such as PTT and IRPC use by-product hydrocarbon and steam reforming to produce [grey] hydrogen. Since carbon dioxide is produced during hydrogen production using biomass, by-product hydrogen production is not conducive to achieving carbon neutrality." — Division Chief**

While the new national hydrogen development plans will be released later this year, hydrogen's positioning among the renewable energy options has not been clearly defined. According to the latest updates from one of the experts, the EPPO has assigned the Energy Research Institute, Chulalongkorn University and Chiang Mai University to draft a hydrogen usage roadmap, and the plan is still under revision. An updated version will be launched this year. The experts believe that it is essential for Thailand to identify its unique advantages in producing biogas, ethanol, and green hydrogen instead of following other countries' policies and initiatives.

13.4 Expert Insights: Supporting Factors for Hydrogen Development

The experts believe that Thailand can develop into a self-sustaining hydrogen economy with large potential demand and sufficient capacity for hydrogen. While the government is launching a policy to accelerate the development and implementation of EVs in the mobility sector, the experts also perceive the deployment of FCEVs as the key driver of the hydrogen economy in Thailand.

One of the experts believes that Thailand has sufficient knowledge in producing, storing, and transporting hydrogen as hydrogen has been produced using fossil fuels in large quantities for use in industrial processes for over 20 years. These industrial demands have enabled Thailand to build sufficient capacity to produce grey hydrogen domestically, eliminating the need for hydrogen imports. The experts believe that the upcoming green tax policy will reinforce the importance of decarbonisation strategies for the industrialisation processes in the manufacturing sector.[259] The green tax policy could entice businesses to assess the need for decarbonisation and drive the adoption of green hydrogen or blue hydrogen as alternative sources to reduce the carbon tax burden.

Although the government currently focuses on developing BEVs due to the technological maturity and sophistication and lower battery cost, the experts believe that the focus on EV adoption would still benefit FCEV and hydrogen development. For instance, the Thai government recently released new incentives in 2022 for the automotive manufacturing industry as part of its ambitious plan to transform 50 per cent of all new vehicles manufactured in Thailand into EVs by 2030.[260] In addition, In addition, the government has been considering carbon emission tax on a passenger car to stimulate EVs development.[261] The experts believe that the support could trigger the deployment of renewable energy in the mobility sector in the long term, with Japan as a reference for Thailand in regard to developing policies to accelerate FCEV domestic development. Furthermore, even with government policy and related roadmap announcements, private investments and corporations are seeking more guaranteed demand and profit. The experts suggest that the government could also consider drafting FCEV-related regulations and investing in HRSs themselves to boost confidence and demand for FCEVs.

13.5 Expert Insights: Barriers to Hydrogen Development

The experts agree that the lack of a roadmap and regulation makes it difficult for the private sector to adopt green hydrogen. Also, with a limited budget in research and social consumers' interest readiness in FCEVs, the policy and consumer needs favour EVs instead of FCEVs. While the cost of hydrogen production continues to be the key barrier to hydrogen development, the cost of transportation and storage will remain high in the short term due to technology constraints.

All the experts opine that the lack of a clear national strategy along with a comprehensive hydrogen development roadmap and supportive policies hinders the hydrogen development in Thailand. One of the experts revealed that the EPPO will promote hydrogen as new alternative energy and launch a draft of the hydrogen plan in late 2022. However, based on the expert's understanding, no further implementation strategy is being planned yet. The expert also believes that the private sector has been hesitant to invest in hydrogen-related technology and related initiatives without a clear roadmap and concise targets. He believes that the private sector will interpret the existence of a clear roadmap with concise implementation targets as a signal for private sector investments. Another of the experts also opined that while there is a clear policy on EV adoption and incentives, the current plans lack clarity on the positioning and development direction for FCEVs and the related infrastructure. It has further been suggested that clear commitments from the government are important to help drive private sector investments and build consumer confidence in FCEVs, thereby driving adoption. One of the experts also further suggested that many Thai people are neither aware of nor accept FCEVs as they are concerned about the law, regulation, and safety, drawing parallel references from their negative perception of nuclear energy.

The high upfront investment and production costs remain the key barrier to green hydrogen adoption in Thailand. The production chain, including electrolyser, transportation and storage, makes green hydrogen uncompetitive compared to grey hydrogen or traditional energy sources. Producing green hydrogen using renewable energy such as solar and wind power is two to three times more expensive than conventional (grey) hydrogen production costs. While lower-cost hydrogen production using renewable energy could be produced in remote areas at a lower cost, hydrogen transportation from such remote areas could still be a key barrier. For instance, compressors and systems required to compress and liquefy hydrogen are expensive, with very few European manufacturers who can manufacture them. The experts are not supportive of the government's investment in green hydrogen as the investment will end up spent on the high cost of renewable energy consumed by the hydrogen producer.

13.6 Expert Insight: Future of Hydrogen Development

The experts generally believe that hydrogen demand will increase in Thailand's industrial, transportation, and heating sectors. According to the AEDP, the combined hydrogen and bio-oil renewable energy consumption target of 10 ktoe has been set for heating and transportation purposes.[262] The proposed target accounts for approximately 0.05 per cent of the total planned renewable energy by 2036. It is also estimated that the demand for hydrogen in the industrial sector and transportation will continue to increase.[263]

The experts expect it to take about five to ten years to address the cost barriers related to green hydrogen production. For example, one of the experts revealed that the EGAT is currently investigating new carbon capture technologies leveraging renewable energy such as solar, wind, and different hydrogen feedstock such as water, biomass, and biogas to produce blue and green hydrogen. One of the experts further suggests that Thailand could leverage its comparative advantage in biofuel to produce green hydrogen more cost-effectively. Thailand has set an aggressive target of achieving 30 per cent of its power generation from renewables led by biofuels by 2036.[264]

While the experts suggest that building a robust green hydrogen production ecosystem could be challenging and will take time, blue hydrogen could be a low-cost alternative to achieve net-zero emissions. The experts agree that blue hydrogen is produced from the same source as grey hydrogen, requiring incremental upgrades to existing facilities, resulting in a lower entry cost to invest in blue hydrogen infrastructure than green hydrogen. However, the experts also suggested that certain technological barriers in CCUS need to be overcome — for instance, Thailand's land subsurface and sea subsurface are not suitable for storing gas.

13.7 Expert Insights: Actions to Accelerate Hydrogen Development

The experts urge both the government and private organisations to take a more active role in driving demand and public confidence toward hydrogen development. Those of the experts from both the private and public sectors understand that any governmental subsidies will be limited and have to be allocated to various sectors. However, there are alternative approaches to increasing demands and investments. One of the experts referenced Toyota as an example. Although Toyota's sales have been low in Thailand, promoting the hydrogen-fuelled Mirai[xvii] allows Toyota to help Thailand promote FCEVs as alternatives to traditional combustion vehicles and enable Toyota to develop a differentiated positioning and gain market share

xvii Toyota's FCEV

early. Another of the experts also urged the development of standards and safety regulations on FCEVs to build up the public's confidence in using hydrogen and drive the potential demand.

The experts suggest that the private sector should focus on investment and research to accelerate and lead the hydrogen development in Thailand. For example, the EGAT is planning a project with Tokyo Electric Power Company (TEPCO) to replace steam with hydrogen produced from surplus renewable energy for heating production plants. The experts believe that these projects could accelerate hydrogen development by promoting hydrogen efficiency and safety to facilitate and promote hydrogen as an alternative energy source.

The government could invest in carbon capture infrastructure to encourage the development of a hydrogen ecosystem with blue hydrogen to reduce the environmental impacts. One of the experts suggested that as the production of green hydrogen will likely remain high in the near future, it is important to focus on building an overall hydrogen ecosystem as the priority. It is important to ensure that the hydrogen ecosystem can leverage hydrogen produced from renewable sources as the end objective, with the use of CCUS as an interim step to encourage the overall ecosystem development while waiting for the green hydrogen production technology and ecosystem to become more competitive.

14

Expert Insights Conclusion

The perceptions, supporting factors, barriers, future and implementation actions of the nine APAC countries discussed in the report vary to a certain extent, depending on each country's current status, the direction of development, specific advantages and constraints, and the background of the experts. While country-specific discussions are mentioned in respective country sections, there are some shared opinions across the nine countries for various reasons, such as their similarity in the development stage, geographical proximity, and shared nature of hydrogen. These opinions and factors are worth highlighting in the conclusion section to show the general progress, characteristics, setbacks and prospects of hydrogen development across the nine countries in APAC.

14.1 Perceptions

The experts generally perceive that country leaders are making progress in promoting hydrogen development in their countries, with shared targets to decarbonise their countries, reduce energy dependency on fossil fuel imports, and even drive domestic economies. In fact, the hydrogen economy concept is relatively nascent in APAC except for Japan, as it released its national hydrogen strategy about half a decade ago. Therefore, many of the experts suggest that their countries are only at the early stage of deploying hydrogen extensively in industry verticals. Nevertheless, many of them notice their governments' efforts to inaugurate the development of hydrogen sectors in their respective countries with various measures and incentives, as hydrogen is generally seen as one solution to decarbonise their countries. Using hydrogen to power their respective domestic economies may reduce their reliance on traditional energy imports such as fossil fuels. Moreover, some of the experts believe that the construction, maintenance, and operation of hydrogen facilities will create enormous job opportunities, thereby stimulating domestic economies. While each of the nine countries discussed in the report has a different vision and target investment in hydrogen, each country is progressing at its own pace and is focusing on different stages of its hydrogen development.

To effectively drive the development of hydrogen in a country, the experts believe that the official direction from a national level is of fundamental importance. When discussing the speed of hydrogen development in their respective countries, many of the experts correlate the presence of national strategies with the country's hydrogen deployment progress and efficiency. For instance, some of the experts believe that hydrogen-related collaborations within the private sector are more effective if the government has mapped out the directions and targeted segments for hydrogen development in the country. Also, the presence of national hydrogen roadmaps reduces the risk of investments in hydrogen technology and infrastructure, which facilitates investments from both the public and private sectors. In light of this, countries that have not released their specific hydrogen roadmaps, namely Indonesia, Malaysia, Singapore, and Thailand, are generally perceived to have slower hydrogen development among the nine APAC countries.

14.2 Supporting Factors

Despite the fact that some countries have yet to publish their specific hydrogen strategies, all national governments of the nine APAC countries discussed in the report have been supportive of their country's hydrogen development to a certain extent. For instance, with the Japanese government and the South Korean government's support of FCEV development, these two countries have been extending their HRS infrastructure to multiple regions within their respective countries. Even for some countries that are perceived to be lagging behind in terms of development status, such as Singapore, India and Indonesia, their national governments have been providing financial support to local R&Ds and pilot projects to foster technical advancements. In addition, the experts have also noticed that some national governments have been facilitating collaboration within and between the private and public sectors, which is instrumental to the hydrogen development in the APAC region.

The experts also believe that having well-established natural gas infrastructure could be advantageous to some countries as the infrastructure could be retrofitted for hydrogen-related applications. According to the experts, countries such as South Korea and Singapore have mature transportation pipelines for natural gas, and it is technically feasible for these transportation networks to be reallocated for hydrogen transportation. The same concept also applies to storage facilities, that is, natural gas storage tanks can be converted to store hydrogen after specific retrofitting. In light of this, these countries would be more efficient in domestic hydrogen transportation and storage if they were to transform their existing natural gas infrastructure for hydrogen applications. As a result, hydrogen deployment in these countries, such as South Korea and Singapore, could require lower capital investment upfront.

14.3 Barriers

The experts perceive that the high cost of producing, supplying and developing hydrogen as mainstream energy is the biggest hurdle for all the nine countries. From the production perspective, while hydrogen has been produced by many of these nine APAC countries since a few decades ago, the hydrogen produced has mainly been for specific industrial use cases. When compared to the cost of fossil fuel, producing hydrogen is much more expensive. Particularly for green and blue hydrogen, the cost of producing hydrogen with zero-carbon emissions is even higher, which incurs an unreasonably high price for end-users. Hence, all countries are researching ways to reduce the cost of producing hydrogen.

On top of that, hydrogen's domestic transportation and storage are also costly as many countries lack specific infrastructure. For instance, the experts from countries such as India, Indonesia, and Thailand suggested that they currently lack specific infrastructure and technology for hydrogen transportation and storage. As a result, these countries are currently using less efficient methods to transport and store hydrogen, which implies a higher cost. Such a high cost of supplying hydrogen, bundled with the high cost of production, has made it difficult for hydrogen to penetrate industry verticals as a general fuel in many countries. While R&D is fundamental for technological advancement and to reduce the cost of hydrogen deployment, some of the experts shared their observation in some countries that there are insufficient financial incentives to drive the expensive R&D initiatives for the private sector.

While the high cost of hydrogen deployment is a shared hurdle across the nine APAC countries, some countries also find it challenging to advance in the hydrogen economy with insufficient support from the government. Many of the experts suggest that the government in their respective countries is relatively passive in formulating supportive policies and regulations and providing financial incentives to the private sector. Unclear, outdated and unfavourable policies and regulations for hydrogen development still exist in some countries, and these could discourage private sectors' involvement. An example across a few countries would be the lack of safety standards to articulate the use of hydrogen. Besides, as most of the experts agree that their countries are still at the early stage of hydrogen development, it is almost essential for private corporations to have financial incentives from the governments to justify their early involvement in the hydrogen economy. Given that some country leaders are yet to commit to deploying hydrogen in their countries fully, financial support from these governments is perceived to be limited. Hence, hydrogen deployment in these countries would be even harder without sufficient support from the government.

14.4 Future

As hydrogen-related technologies constantly advance along with the continuous investments in R&Ds and trial projects, the experts believe that hydrogen will be mainstream energy in a decade or more in many of the nine APAC countries. Many countries have been putting efforts into lowering the cost of hydrogen deployment along the value chain by researching and investing in hydrogen production, transportation, storage, and application technologies. Hence, the experts are convinced that the cost of deploying hydrogen across the APAC would be reduced to an acceptable level, and it would be competitive with other conventional energy such as fossil fuels in the near future. In particular, the supply of green hydrogen would focus on the nine APAC countries after the demand for hydrogen in these countries is consolidated. The experts believe that the advent of cheaper and cleaner hydrogen would be a factor in phasing out traditional carbon-containing fuels in APAC. Domestic production is expected to scale up in many of the nine APAC countries. For countries expected to have a shortage in domestic production, the experts suggest that they would increase imports to accommodate their excess demand.

The experts also suggest that hydrogen will be widely adopted and utilised in many industry verticals, and some of these nine APAC countries could lead the pack in different use cases. For instance, many of the experts believe that hydrogen will be vastly adopted in their countries' mobility, power, industrial and non-industrial gas sectors after the cost of deploying hydrogen is reduced to an acceptable level. Specifically, many countries have shown interest in decarbonising their mobility sectors by introducing FCEVs. But while the maturity of hydrogen technology varies among these APAC countries, some countries with a solid track record of applying fuel cell technologies, such as Japan and South Korea, are expected to enjoy their first-mover advantages in FCEV deployments. In this case, Japan and South Korea could take up a larger share of FCEV production within the APAC and take the lead in other fuel cell applications.

14.5 Implementation Actions

With the high cost of hydrogen deployment being the biggest barrier to hydrogen development, all the experts agree that the governments of the nine APAC countries should provide more financial support to public and private entities to foster hydrogen development. Although some of the experts notice that their countries have been devoted to hydrogen development to a large extent, they perceive that the financial support from their government is still insufficient to break even the cost premium of deploying hydrogen in many sectors. The experts suggest that apart from directly investing in hydrogen infrastructure, their governments should also consider providing funds, grants, subsidies, or tax reductions to encourage technological advancements and the construction of infrastructure and create a certain amount of public awareness to educate the general public. The experts believe that sufficient financial support is crucial to creating enough momentum for hydrogen deployment across different sectors in their countries.

In order to create synergy between government support and the private sector in the nine APAC countries, the experts believe that different stakeholders should build strategic relationships with each other to exchange opinions and technologies. Some of the experts suggest that to enable the governments to have a better understanding of the current policy constraints on the private sectors, the government and the private entities could collectively build a communication platform to facilitate the coordinated development of policies and initiatives. Besides, private entities are suggested to create hydrogen communities and develop strategic partnerships with foreign players and players from different industries. For such, players could share industry knowledge and technologies that could benefit the entire hydrogen community.

Abbreviations

Abbreviations	Description
ADB	Asian Development Bank
AEDP	Alternative Energy Development Plan
AGIG	Australian Gas Infrastructure Group
AREH	Asian Renewable Energy Hub
ARENA	Australian Renewable Energy Agency
ASEAN	Association of Southeast Asian Nations
ATR	Autothermal Reforming
BIG	Bangkok Industrial Gas
BPCL	Bharat Petroleum Corporation
CCP	Chinese Communist Party
CCUS	Carbon Capture, Utilisation and Storage
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEDE	Department of Alternative Energy Development and Efficiency
EDB	Singapore Economic Development Board
EEC	Eastern Economic Corridor
EEP	Efficiency Plan
EGAT	Electricity Generating Authority of Thailand
EMA	Energy Market Authority
EPPO	Energy Policy and Planning Office
EU	European Union
EV	Electronic Vehicle
FCEV	Hydrogen Fuel Cell Electric Vehicle
FH2R	Fukushima Hydrogen Energy Research Field
GCC	Gulf Cooperation Council Countries
GHG	Greenhouse Gas
H-CNG	Hydrogen CNG
HESC	Hydrogen Energy Supply Chain
HESC	Hydrogen Energy Supply Chain Project
HETR	Hydrogen Economy Technology Roadmap
HRS	Hydrogen Refuelling Station
HySTRA	Hydrogen Energy Supply-Chain Technology Research Association
IESR	Institute for Essential Services Reform
IIT	Indian Institutes of Technology
IOC	Indian Oil Corporation Limited
IPP	Independent Power Producers
ISRO	Indian Space Research Organization
JAXA	Japan Aerospace Exploration Agency
JSCA	Joint Study and Collaboration Agreement
KAS	Konrad Adenauer Foundation
KEEI	Korea Energy Economics Institute
KEPCO	Korea Electric Power Corporation
KHI	Kawasaki Heavy Industries Limited

KOGAS	Korea Gas Corporation
L&T	Larsen & Toubro
LCER FI	Low-Carbon Energy Research Funding Initiative
LNG	Liquefied Natural Gas
LOHC	Liquid Organic Hydrogen Carrier
M&M	Mahindra & Mahindra
MAHE	Malaysian Association of Hydrogen Energy
MCH	Methylcyclohexane
MEMR	Ministry of Energy and Mineral Resources
METI	Minister of Economy, Trade and Industry
MNC	Multi-National Company
MNRE	Ministry of New and Renewable Energy
MOSTI	Ministry of Science, Technology and Innovation
MoU	Memorandum of Understanding
NaBH4	Sodium Borohydride
NCCS	National Climate Change Secretariat
NCT	National Capital Territory
NERA	National Energy Resources Australia
NHM	National Hydrogen Energy Mission
NSW	New South Wales Government
NTPC	National Thermal Power Corporation Limited
OPGGS	Offshore Petroleum and Greenhouse Gas Storage Act
PDP	Power Development Plan
PEM	Polymer Electrolyte Membrane
Persero	Pt Pupuk Indonesia
PETROS	Petroleum Sarawak Berhad
PLI	Production-Linked Incentive
PPA	Power Purchase Agreement
PSA	Pressure Swing Adsorption
PSU	Indian Public Sector Undertaking
R&D	Research and Development
RECAP	Regional Project Energy Security and Climate Change APAC
REIDS	Renewable Energy Integration Demonstrator
RPS	Renewable Portfolio Standard
SEB	Sarawak Energy Berhad
SEDC	Sarawak Economic Development Corporation
SIO-GFF	Sustainable Development Goals Indonesia One-Green Finance Facility
SIRIM	Standard and Industrial Research Institute of Malaysia
SME	Small and Medium-Sized Enterprise
SMR	Steam Methane Reforming
SNI	Indonesia National Standard
SOE	State-Owned Enterprise
SPIC	State Power Investment Corporation
TEPCO	Tokyo Electric Power Company
TESS	Toshiba Energy Systems & Solutions Corporation
TNB	Tenaga Nasional Berhad
UAE	United Arab Emirates
UKM	Universiti Kebangsaan Malaysia
UTM	Universiti Teknologi Malaysia
ZEV	Zero-Emission Vehicle

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