Asia-Pacific
Economic Cooperation

Final Report

Assessing Existing and Planned Hydrogen Infrastructure to Facilitate Widespread Hydrogen Use in the APEC Region

APEC Energy Working Group
October 2023

Assessing Existing and Planned Hydrogen Infrastructure to Facilitate Widespread Hydrogen Use in the APEC Region

Final Report

APEC Energy Working Group

October 2023

APEC Project: EWG 01 2021A

Produced by

Arthur D. Little
1 Raffles Place
#32-02A One Raffles Place
Singapore 048616
Website: www.adlittle.com/en

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

APEC#223-RE-01.12

Table of contents

1. Executive Summary 8

2. Introduction 15

3. Summary of methodology 18

4. The global state of hydrogen 20

4.1 Overview of the hydrogen economy 20

4.2 Trends in global hydrogen supply and demand 21

4.3 Hydrogen transportation overview 23

4.4 Hydrogen technology development 29

4.5 Potential barriers to developing hydrogen ecosystem 30

5. State of hydrogen infrastructure in APEC 32

5.1 Hydrogen infrastructure readiness framework 32

5.2 Readiness assessment 34

6. Selected case studies in APEC economies 45

6.1 Australia 45

6.2 Canada 46

6.3 Chile 48

6.4 China 51

6.5 Japan 52

6.6 Korea 55

6.7 Singapore 56

6.8 The United States 58

7. Strategic and policy recommendations 62

7.1 The archetypes 62

7.2 Case studies for each archetype 64

7.3 Initiatives for archetypes 67

7.4 What initiatives can APEC undertake? 68

8. Appendix 71

8.1 Economy profiles (in order of APEC Guidelines) 71

8.2 Webinar conducted on 30 March 2023 93

References and sources 96

List of figures and tables

List of figures

Figure 1: Archetypes within the hydrogen economy ... 10
Figure 2: Potential cross-economy initiatives that can be facilitated by APEC ... 11
Figure 3: CertifHY certification process ... 13
Figure 4: Types of hydrogen ... 15
Figure 5: Hydrogen derivatives use cases ... 16
Figure 6: Domestic hydrogen strategy overview ... 20
Figure 7: Hydrogen economy and value chain ... 20
Figure 8: Global hydrogen supply and demand (2020-2050) ... 21
Figure 9: Regional hydrogen supply geared for export by end-product derivatives: Count of assets ... 24
Figure 10: Ammonia cracking schematics ... 26
Figure 11: Ammonia cracking research projects in Singapore ... 28
Figure 12: Hydrogen infrastructure readiness framework ... 32
Figure 13: Canadian players across the hydrogen value chain ... 47
Figure 14: Hydrogen/fuel cell projects and initiatives in different Canadian provinces ... 48
Figure 15: The layout of the Haru Oni Plant ... 49
Figure 16: Korea's partnership model for hydrogen development ... 56
Figure 17: Singapore & Rotterdam Green Shipping Corridor – the world's longest green corridor ... 57
Figure 18: The United States regional network model for H2Hubs ... 60
Figure 19: Archetypes within the hydrogen economy ... 62
Figure 20: Potential cross-economy initiatives that can be facilitated by APEC ... 68
Figure 21: CertifHY certification process ... 69
Figure 22: Webinar turnout and statistics ... 93
Figure 23: Webinar outcomes and feedback from participants ... 94

List of tables

Table 1: Summary of infrastructure readiness among APEC economies ... 9
Table 2: Hydrogen energy carriers summary ... 23
Table 3: Centralized and decentralized cracking ... 25
Table 4: Selected global ammonia cracking projects ... 27
Table 5: Main hydrogen production technologies ... 29
Table 6: Hydrogen infrastructure readiness framework – sub-factors or metrics ... 32
Table 7: Hydrogen infrastructure readiness framework – factor weights ... 33
Table 8: Summary of infrastructure readiness among APEC economies ... 35
Table 9: Economy assessments based on readiness scores ... 36
Table 10: Case studies of selected policies by archetype ... 64
Table 11: Webinar feedback and discussion points ... 94

Glossary and definitions

AEL:	Alkaline electrolysis
AEMEL:	Anion exchange membrane electrolysis
AGIG:	Australia Gas Infrastructure Group
AHEAD:	Advanced Hydrogen Energy Chain Association for Technology Development
ARIES:	Advanced Research on Integrated Energy Systems
ART:	Autonomous Rail Rapid Transit
A*STAR:	The Agency for Science, Technology and Research
ATR:	Autothermal reformer
BLT:	Build lease transfer
Bn:	Billion
CAS:	Chinese Academy of Sciences
CAGR:	Compound annual growth rate
CAPEX:	Capital expenditure
CCGT:	Combined cycle gas turbine
CCUS:	Carbon capture, utilization, and storage
CHPS:	Clean Hydrogen Energy Portfolio Standard
CO2:	Carbon dioxide
CSIRO:	Commonwealth Scientific and Industrial Research Organization
DoE:	Department of Energy
ETS:	Emissions trading system
EV:	Electric vehicle
FCV:	Fuel cell vehicle
FFI:	Fortescue Future Industries
GHG:	Greenhouse gases
GO:	Guarantee of Origin
G2G:	Government to government
HEREM:	International Symposium on Hydrogen Energy, Renewable Energy and Materials
HPS:	Hydrogen portfolio standard
HRS:	Hydrogen refueling station
HTEL:	High-temperature solid oxide electrolysis
HyMARC:	Hydrogen Materials Advanced Research Consortium
HyNet:	Hydrogen Energy Network
H2:	Hydrogen

H2Hubs:	Regional Clean Hydrogen Hubs
H2TCA:	Hydrogen Technology Cluster Australia
ICE:	Internal combustion engine
IIJA:	Infrastructure Investment and Jobs Act
IPHE:	International Partnership for Hydrogen and Fuel Cells in the Economy
IRA:	Inflation Reduction Act
ITRI:	Industrial Technology Research Institute
JETP:	Just Energy Transition Partnership
K:	Thousand
Kt:	Thousand ton
LCER:	Low Carbon Energy Research
LNG:	Liquefied natural gas
MAS:	Monetary Authority of Singapore
MCH:	Methylcyclohexane
MDA:	Master Development Agreement
METI:	Ministry of Economy, Trade and Industry
Mn:	Million
MOLIT:	Ministry of Land, Infrastructure and Transport
MoU:	Memorandum of understanding
MOTIE:	Ministry of Trade, Industry and Energy
MPA:	Maritime and Port Authority of Singapore
Mt:	Million ton
NEDO:	New Energy and Industrial Technology Development Organization
OPEX:	Operating expense
Pa/Pd:	Per annum/Per day
PDP:	Power development plan
PEM:	Proton exchange membrane
PEMEL:	Polymer electrolyte membrane electrolysis
PSA:	Pressure swing adsorption
R(D)&D:	Research (and demonstration) and development
RPS:	Renewable Portfolio Standard
SMR:	Steam methane reformer
SOE:	State-owned enterprise
Tn:	Trillion
V-LEEP:	Viet Nam Low Emission Energy Program

1. Executive Summary

1. Executive Summary

This report has been developed to support a discussion on assessing existing and planned hydrogen infrastructure to facilitate widespread hydrogen use in the APEC region. **Note that this report was prepared between January 2023 and March 2023, and any data and information are reflective of that time period.**

This report comes at a crucial time given that hydrogen has become a key alternative energy source to decarbonize various sectors such as transportation, chemicals, power, etc. While the transition to clean hydrogen is underway, it is not yet competitive enough to be scaled up and is facing many challenges such as cost reduction, transport and storage option availability, and safety concerns.

Many of these challenges could be alleviated by the timely buildout of key hydrogen infrastructure across the value chain connecting supply and demand.

Selected Results and Findings

A key step of this study was to understand the hydrogen infrastructure readiness across the 21 APEC economies. This would support a tailored economy-level strategy to ensure hydrogen development.

For each APEC economy, five factors were assessed to determine hydrogen infrastructure readiness – three factors associated with the hydrogen value chain and two supporting enablers:

- **Hydrogen value chain factors**: Supply, transportation, local demand
- **Supporting enablers**: Policy and regulation, technology

A summary of the results are shown below, and the detailed methodology and assessment can be found in **Section 5.**

Table 1: Summary of infrastructure readiness among APEC economies

	Overall infrastructure readiness level	Factors				
		Supply (S)	Transpor-tation (Tr)	Local demand (D)	Policy and regulation (P&R)	Technology (Te)
Australia						
Brunei Darussalam						
Canada						
Chile						
China						
Hong Kong, China						
Indonesia						
Japan						
Korea						
Malaysia						
Mexico						
New Zealand						
Papua New Guinea						
Peru						
The Philippines						
The Russian Federation						
Singapore						
Chinese Taipei						
Thailand						
The United States						
Viet Nam						

0% of assessment score 100% of assessment score

Economies can essentially be mapped into four quadrants as illustrated in ***Figure 1***. This allows for a targeted set of strategies and policies. For instance, the set of initiatives for an economy in the advanced stage of fulfilling the supply role in the value chain would be vastly different from that of a nascent counterpart. As part of this study, we have identified four archetypes into which economies could fit.

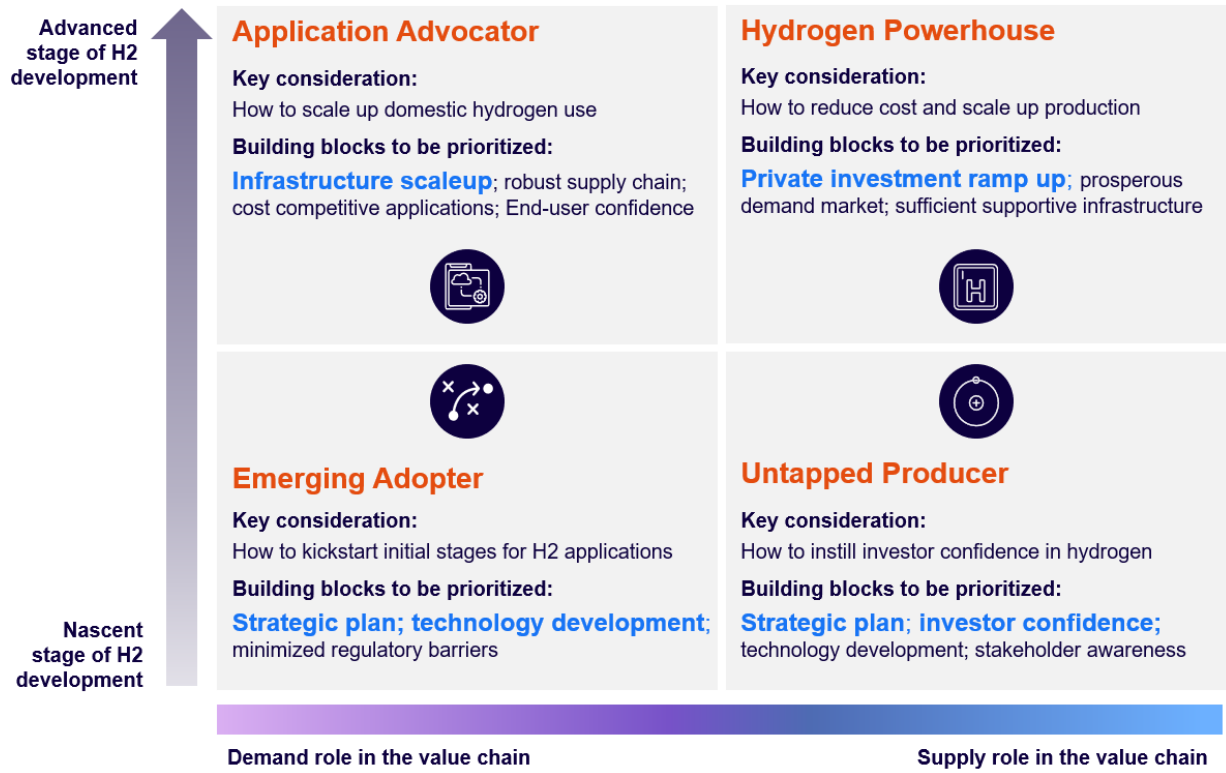


Figure 1: Archetypes within the hydrogen economy

While more details can be found in **Section 7**, the set of strategies and policies each economy can undertake is as such:

For **"Application Advocators"** looking to scale up infrastructure, policy-makers first need to encourage private participation. This will enable them to accelerate the scale-up of infrastructure and lay the foundation for a robust hydrogen economy. Secondly, promoting public spending is key to allaying significant CAPEX (for example, repurposing natural gas pipelines and creating ammonia-receiving terminals) and OPEX requirements (such as hydrogen fuel prices). Therefore, policies need to be enacted to allow public capital to flow freely into network expansion. Lastly, providing comprehensive regulations for gas composition and hydrogen content will limit ambiguity and uncertainty, specifically for hydrogen transport. To unlock the global supply chain in the long run, policy-makers from these economies might need to pioneer international standards for the transport of green hydrogen and related products. For example, consideration must be given to safety, pipeline integrity, and fuel specifications that will facilitate cross-border trading of hydrogen.

For **"Hydrogen Powerhouses"** looking to ramp up investments, policy-makers first need to alleviate investment risks given that projects may not be able to break even or overcome coordination market failures. Long-term commitment needs to come from authorities through regulations and cover risks in both capital investments and operations. In addition, policy-makers can propose to improve policies for electrolyzers, possibly through lowering corporate, business, and sales taxes on green hydrogen to improve the rate of return on projects. Secondly, accelerating finance for clean hydrogen projects is paramount, and this can come in many forms. For instance, governments have used long-tenor contracts for differences (CFDs) to make up the difference between green hydrogen and its gray counterparts. Other diverse instruments can also be used to cater to businesses with different needs and concerns, such as tax credits, direct and debt investments, and regulated returns.

For **"Emerging Adopters"** looking to boost technology development, policy-makers need to first encourage SMEs and start-ups to enter the hydrogen economy, given its role as a strong force in application and market-oriented innovation, which will lay the foundation for a robust, dynamic hydrogen economy. Secondly, leveraging international collaboration is key to accessing mature technology, thereby jumpstarting R&D initiatives and industry adoptions. Lastly, providing a clear signal for application prioritization by leveraging hydrogen in high-value applications effectively will provide direction for use cases in industry investment and effort.

For **"Untapped Producers"** looking to create investor confidence, policy-makers need to first encourage government support. The government is best positioned to coordinate resources and achieve breakthroughs in hydrogen production set-up and operations. It also provides a business case reference for future investments by validating the economy's hydrogen potential and operational feasibility. Secondly, leveraging international collaborations should be viewed as a key priority. International collaborations could accelerate the development of technology and capital. For example, Just Energy Transition Partnerships (JETPs) could assist developing economies greatly with their hydrogen ambitions. Lastly, policy-makers could leverage the network and resources of state-owned enterprises (SOEs) in hydrogen developments. SOEs are dominant across many industries in emerging markets, and by engaging SOEs, policy-makers can drive acceleration in research, economies of scale, and overall investor confidence in hydrogen developments.

Additionally, for **"Emerging Adopters"** and **"Untapped Producers"**, a strategic plan through a hydrogen strategy will convey a clear vision for the role of hydrogen, as well as clear targets for short-term and long-term development. Policy-makers also should ensure hydrogen is embedded in overarching policy framework and surrounding policies such as gas legislation, while support initiatives on related infrastructure, such as grid capacity, are also necessary. Additionally, facilitating private and public partnerships will serve as an information exchange platform to align interests, reduce risks, and incentivize transition at an early stage of development.

As shown in ***Figure 2***, APEC has a crucial role to play in facilitating some of the initiatives given it's role as an inter-governmental forum for its 21 member economies.

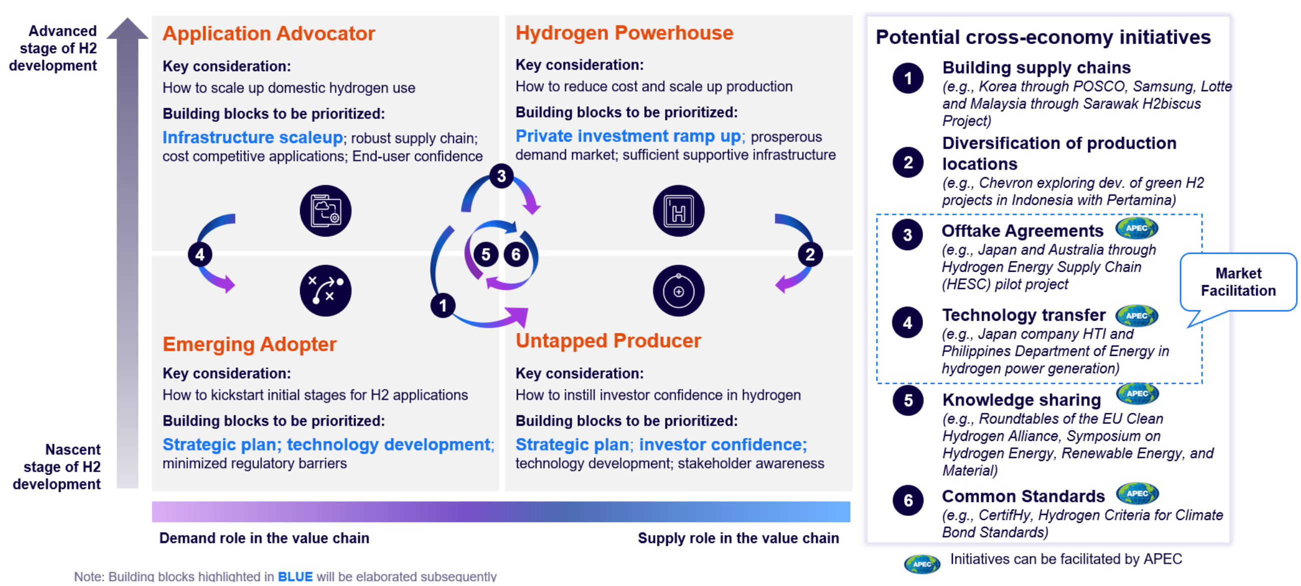


Figure 2: Potential cross-economy initiatives that can be facilitated by APEC

APEC could facilitate three key initiatives.

1. APEC can **ensure market facilitation** to promote partnerships among selected APEC member economies to build a sustainable hydrogen economy and support the carbon neutrality strategy within APEC. Market facilitation could take the form of offtake agreements between advanced economies in the demand and supply role in the value chain and technology transfer between economies in the demand role, but at different stages of hydrogen development.

   <u>Facilitation of offtake agreements:</u> We see this initiative as part of the European Clean Hydrogen Alliance. A list of 840 hydrogen projects was published in November 2021 to facilitate offtake agreements and create integrated hydrogen value chains. Inclusion in the alliance project pipeline does not convey any direct financial or regulatory advantage, and also does not award any financing to projects. Similarly, the Africa Green Hydrogen Alliance launched in May 2022 aims to accelerate and improve market development by refining project development, procurement, and financing models. Therefore, we suggest that APEC launches and monitors an APEC hydrogen project pipeline to facilitate trade and investment.

   <u>Technology transfer:</u> We see a similar initiative in the European Clean Hydrogen Alliance, in which an electrolyzer partnership was established in 2022 to promote hydrogen technology transfer and material availability to meet the manufacturing capacity in Europe by 2025. The Africa Green Hydrogen Alliance also emphasizes technology development through sharing technical insights and capabilities across RD&D. Therefore, APEC can consider an APEC Hydrogen Partnership focused on technology transfer and development, linking manufacturers, key material suppliers, and policy-makers.

2. APEC could **facilitate knowledge sharing** between economies to enhance collective intelligence and cooperation, potentially through roundtables. These have already shown instances of success. For example, the Roundtables of Europe Clean Hydrogen Alliance was set up in November 2020 to promote hydrogen development and address hydrogen issues and barriers. Six roundtables were launched in 2021, spanning themes across hydrogen production, distribution, and usage in the industrial, mobility, and energy sectors. The roundtables also spawned working groups for hydrogen research, with two papers presented in 2021 and a paper on hydrogen standards to be presented in 2023. Another example of a successful roundtable is the symposium of International Hydrogen Energy, Renewable Energy, and Materials (HEREM), which was set up by the International Energy and Environmental Research Institute in 2015 to present research results in the respective fields. To date, it has opened internal discussion forums in 2015–2016 in China, launched a symposium to discuss 13 topics spanning hydrogen and related energy and materials in 2017–2019 in Thailand, conducted virtual conferences in 2020–2022, and recently announced a hybrid event in October 2023 in Thailand. Another outstanding instance is the Center for Hydrogen Safety (CHS) established by the American Institute of Chemical Engineers (AIChE) as a global non-profit organization dedicated to promoting hydrogen safety and best practices worldwide. Not only does it support the safe handling and use of hydrogen across applications in the energy transition, but it also provides a common communication platform with a global scope to ensure safety information, guidance and expertise to stakeholders. To date, the CHS has conducted numerous conferences, webinars, courses and training to push hydrogen safety codes and standards. Building on these examples, we suggest that APEC boosts specific knowledge-sharing sessions for main hydrogen themes, such as infrastructure, technology, and policy, and if resources are available, also consider newsletters to ensure constant sharing of information.

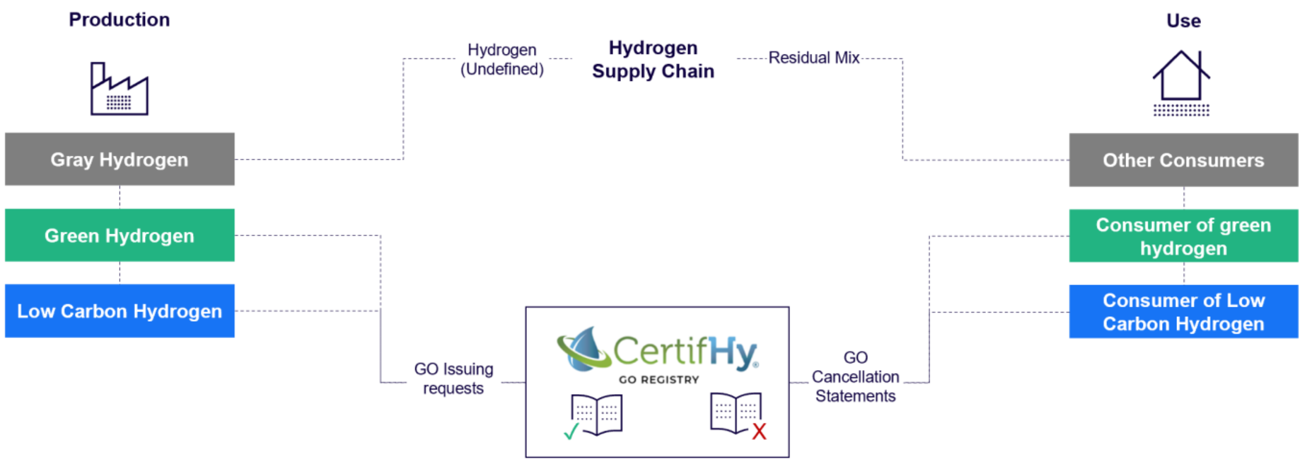


Figure 3: CertifHY certification process

3. APEC could consider **developing standards** such as a guarantee of origin (GO) certification scheme, which would show customers that a unit of energy is aligned with a scheme's criteria. One such example is CertifHy, which was started in 2014 to advance production, procurement, and use of hydrogen. To qualify as "green hydrogen" under CertifHy and attain the certificate, hydrogen must be produced using renewable energy sources and have a carbon footprint of less than 36.4gCO2e/MJ. At the moment, CertifHy is applicable within the EU region and only certifies hydrogen gas production but not hydrogen derivatives. Therefore, APEC could create the infrastructure for a common hydrogen standard with the extension of low-carbon hydrogen certification to hydrogen derivatives across the APEC region. However, it needs to consider that while this would allow APEC to ensure alignment to serve each economy, governance efforts would be challenging to coordinate across member economies. Alternatively, APEC could push for adoption of an international low-carbon standard, which would have lower barriers to implementation but could face issues in driving adoption from all member economies.

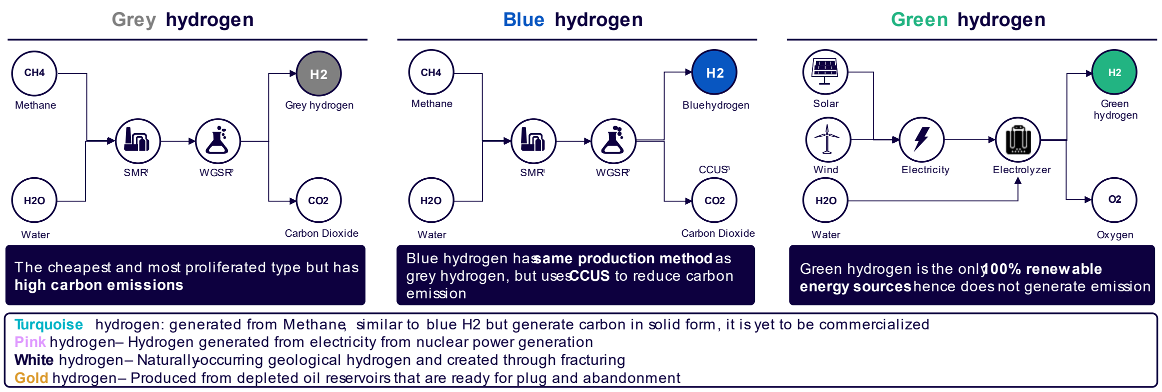
2. Introduction

2. Introduction

Climate change is becoming one of the most pressing challenges globally. At the 2015 COP21 in Paris, economies reached an agreement to limit global warming to 2 degrees Celsius above pre-industrial levels. In recent years, spurred by various climate-related external events, economies have accelerated the pace to net zero to limit the temperature increase to 1.5 degrees Celsius by the end of this century. To achieve this target, drastic carbon emission reduction is needed – emission needs to peak in 2025 and reach net zero by 2050. We are seeing economies pledging net zero by 2050, with some aiming for as early as 2030.

Hydrogen has become a key alternative energy source to carbon neutrality. As a high-intensity, low-carbon energy carrier, hydrogen is seen as an integral part of many economy's energy systems with a key role in decarbonizing end uses; it will facilitate energy transition as well as ensure energy security. Hydrogen has various applications in transportation– producing low-carbon materials, fuels, and chemicals and generating electricity and heat. One example its use in hard-to-abate and carbon-intensive industries where electrification is difficult to implement, such as steel and cement.

The transition to clean hydrogen is under way. Hydrogen can be produced through various processes, with carbon emissions ranging from unabated to zero. However, approximately 98 percent of hydrogen produced globally is from fossil fuels. Clean hydrogen, including green and blue hydrogen (as illustrated in ***Figure 4***), is increasingly sought after to realize true low-emission energy consumption.



Note: 1) Steam methane reformer 2) Water gas shift reaction 3) Carbon capture, utilization, storage 4) Renewable electricity
Source: Deloitte, Arthur D. Little analysis

Figure 4: Types of hydrogen

Clean hydrogen is not yet competitive enough to be scaled up, especially green hydrogen. Clean hydrogen is still in the nascent stage, facing challenges such as cost reduction, transport and storage option availability, and safety concerns. Green hydrogen is currently three times the cost of gray hydrogen. Further cost reductions in renewable electricity generation, electrolyzers, battery technology, and other electricity storage options are needed for green hydrogen to have uptake at a larger scale.

E-Fuel production relies on extracting hydrogen through an electrolysis process. This involves breaking down water (such as seawater from desalination plants) into its elemental components of hydrogen and oxygen. Electricity is used during this process and subsequent production stages. In the next step, the hydrogen is combined with carbon dioxide (CO2) captured from the atmosphere using methods like Fischer-Tropsch synthesis. This fusion results in the creation of E-Fuel, a liquid energy carrier. By using a catalyst and subjecting it to high pressure, the hydrogen chemically bonds with the CO2. As electricity is converted into a synthetic liquid that is easily storable and transportable, this procedure is known as a power-to-liquid process.

The increasing popularity of hydrogen technology suggests the potential for a global market in green hydrogen derivatives. For example, green ammonia can be employed in the production of sustainable fertilizers, aiding in the decarbonization of food supply chains and boosting agricultural efficiency. Similarly, green methanol can serve as a low-carbon liquid fuel, showing promise in reducing the carbon emissions of industries with high pollution levels, such as maritime transport. This broader utilization of green hydrogen derivatives has the potential to yield significant environmental advantages, as illustrated in the Figure below.

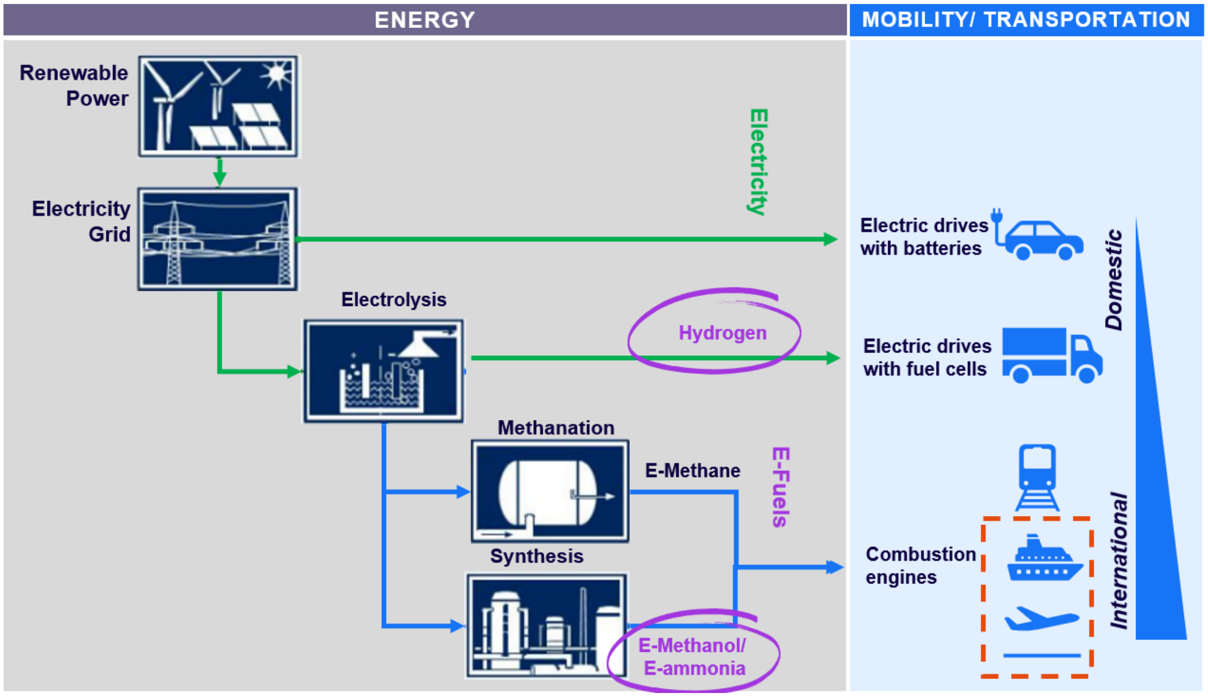


Figure 5: Hydrogen derivatives use cases

Infrastructure readiness is important for scaling up the hydrogen economy. In a complex and interdependent hydrogen ecosystem, energy use transition would rely on infrastructure development in production, transport, and demand, along with cross-cutting support from policy, regulation, and technology. Overall infrastructure underpins economies' readiness to foster a hydrogen economy. **Assessing and understanding existing and planned infrastructure facilitates widespread hydrogen use and an affordable, reliable, resilient, and sustainable energy supply.**

The objective of this work is to enhance region stakeholders' knowledge of existing hydrogen infrastructure. This knowledge will aid policy and investment decisions on maintaining and/or expanding existing fossil-based hydrogen infrastructure and developing new infrastructure based on green hydrogen.

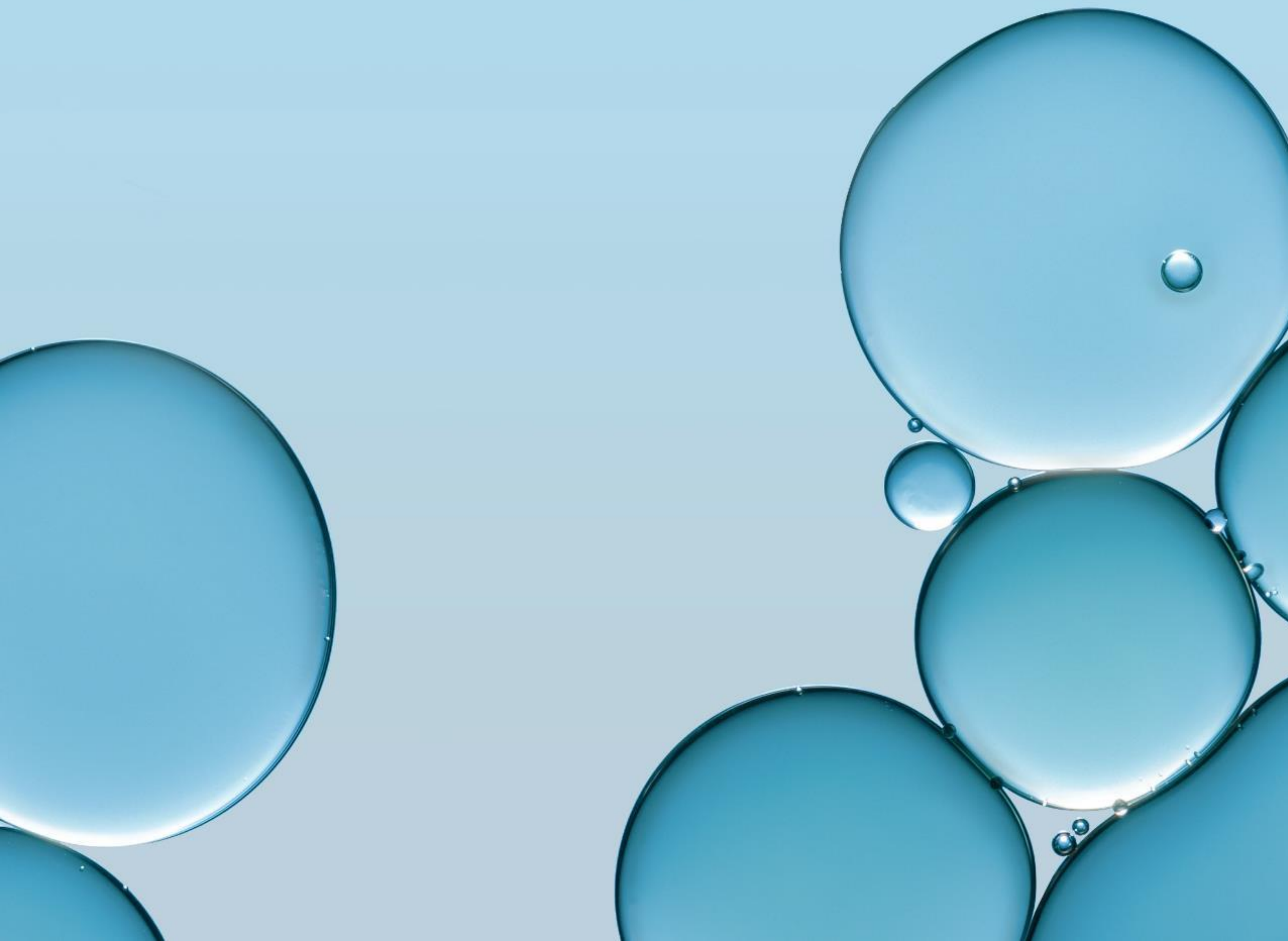
3. Summary of methodology

3. Summary of methodology

The following methodology was adopted for the preparation of this report:

1. **Market analysis**: A high-level global hydrogen market analysis was conducted to gain an overview of the hydrogen market on the global landscape:
    - Market size (demand and supply), including trends and key drivers
    - Key players and collaborative activities across the hydrogen value chain
    - High-level technology scans that are relevant to hydrogen production
    - Potential barriers to developing a hydrogen economy and related initiatives.
2. **Overall infrastructure readiness assessment**: Detailed assessment was conducted on hydrogen infrastructure readiness across the 21 APEC economies using our infrastructure readiness framework, as elaborated in ***Section 5.1****.* The assessment consisted of the following steps:
    - Develop infrastructure readiness framework factors, with sub-factors/metrics for each
    - Develop the measurement methodology and weights for each of the sub-factors/metrics
    - Conduct research to assess each APEC economy across the infrastructure readiness framework factors and sub-factors/metrics
    - Deduce the factor level and sub-factor/metric level score of infrastructure readiness for each APEC economy
    - Deduce the overall infrastructure readiness score for each APEC economy.
3. **Best practices from APEC economies**: Following the overall readiness assessment, data on each APEC economy's hydrogen infrastructure readiness were triangulated from Arthur D. Little infrastructure assessment and publicly available reports on hydrogen development and readiness. Best practices from APEC economies were selected considering the economy's stage of overall hydrogen infrastructure readiness, diversity of initiatives across the hydrogen value chain, and relevance and replicability of best practices across APEC economies. Infrastructure readiness assessments were elaborated on for the selected economies, along with highlighted initiatives within the economies.
4. **Strategic and policy recommendations**: Based on the stage of hydrogen development and role in the hydrogen value chain, archetypes were developed. High-level strategic and policy recommendations for the archetypes were synthesized to facilitate economies in developing relevant pillars (supply or demand) in the hydrogen economy. General recommendations for APEC were also developed to create an enabling environment for hydrogen development in the region.
5. **APEC workshop**: A webinar was conducted with participants from the Energy Working Group from APEC economies to seek feedback for the methodology, assessment, and recommendation in this report, and to facilitate discussion on hydrogen development within the APEC region.

4. The global state of hydrogen



4. The global state of hydrogen

4.1 Overview of the hydrogen economy

Hydrogen is gaining global traction as a key enabler of the global energy transition

Figure 6: Domestic hydrogen strategy overview

In light of the pressing challenges posed by climate change, net zero initiatives and energy transition are being prioritized across economies. Hydrogen is gaining global attention due to its unique role as a clean energy carrier that can store large volumes of energy and be transported over long distances. At COP27, the Planning for Climate Commission was launched to speed up planning and approvals for deployment of green hydrogen and renewables. Globally, at least 88 economies are pushing for or already have hydrogen policies. As seen in ***Figure 6***, 10 APEC economies have developed hydrogen strategies or released drafts, with many pioneering globally. Japan was the first economy worldwide to release a hydrogen strategy.

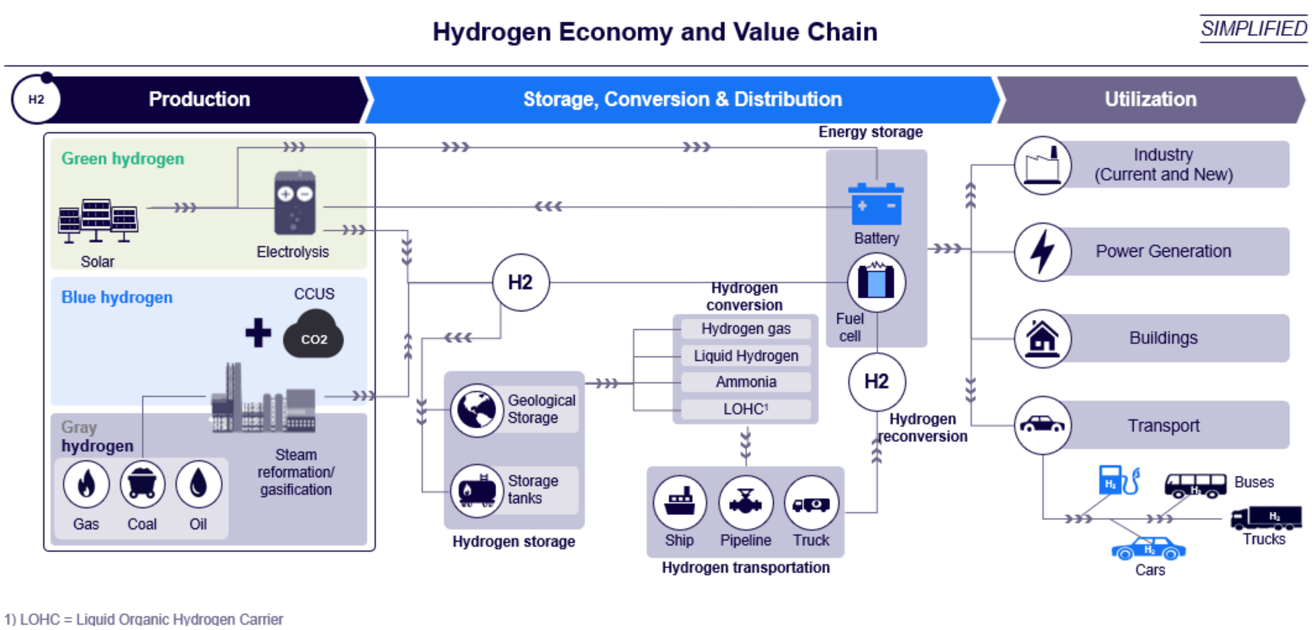


Figure 7: Hydrogen economy and value chain

The hydrogen ecosystem shows its potential in facilitating renewable energy transition, energy distribution and storage, and end-use carbon neutrality. As illustrated in ***Figure 7***, hydrogen can be produced from various energy sources, including renewables and fossil fuels. Hydrogen produced from these energy sources can be stored in various forms and subsequently transported for carbon-free energy consumption in industry, power generation, buildings, and transport. Energy from hydrogen can also be stored through a battery or fuel cell at an interim stage. To illustrate, green hydrogen produced using renewable energy can be stored and act as a buffer for renewable energy production in load management. Meanwhile, it can replace carbon-emitting gas boilers and be consumed in building heating and cooling through stationary fuel cells, with zero greenhouse gas emissions.

4.2 Trends in global hydrogen supply and demand

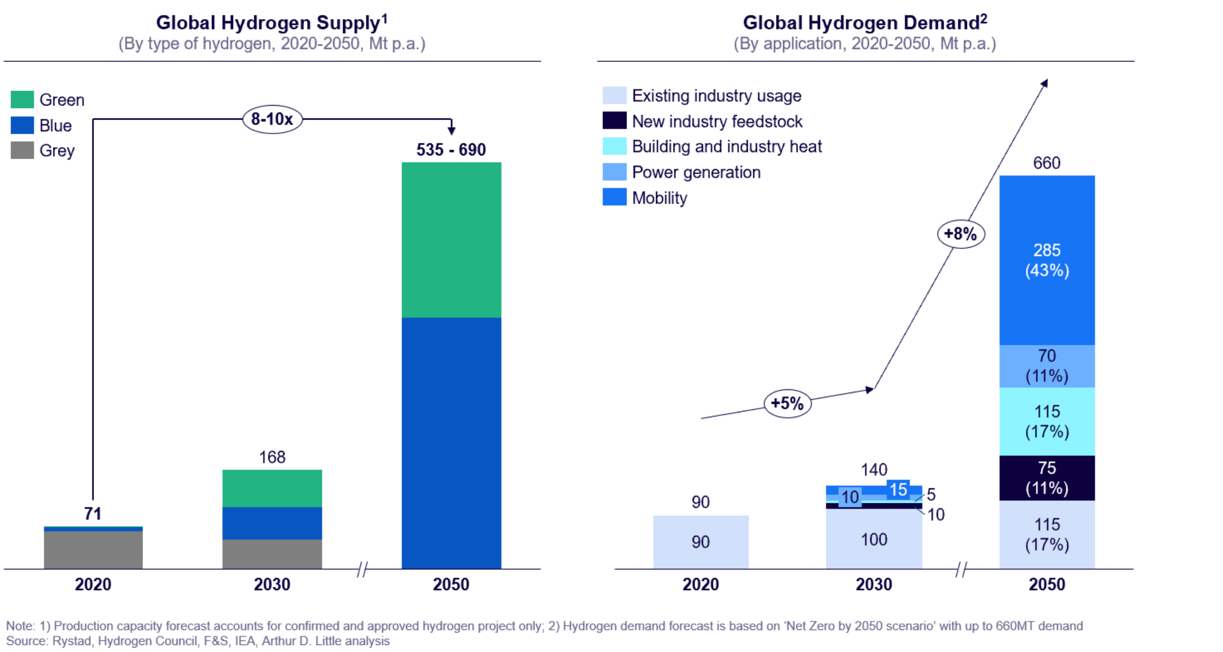


Figure 8: Global hydrogen supply and demand (2020-2050)

Hydrogen supply and demand are expected to grow significantly given a push from a few key drivers

As hydrogen becomes the focus of many economies' energy plans, the global hydrogen supply is expected to surge in the coming years. By 2030, global hydrogen production is expected to grow by eight to 10 times that in 2020. Clean hydrogen, mainly green and blue hydrogen, will be the main driver in the growth, while gray hydrogen, currently the main type of hydrogen, will decrease in the coming years. This is in line with the global carbon neutrality vision and effort to reduce the cost of clean hydrogen and scale up production. Green hydrogen is expected to scale up significantly by 2030, when it is estimated to be cost competitive with gray hydrogen.

On the demand side, hydrogen is forecast to experience a quick ramp-up after 2030 at a CAGR of eight percent, reaching total demand of 660Mtpa. by 2050. The demand will be largely driven by applications in industry feedstock, as well as fuel cell applications in mobility, power generation, and heating.

Four drivers for growth of hydrogen supply and demand will be explored.

1. **Cost-effectiveness** will play a key role in the proliferation of hydrogen. For example, in the mobility sector, the price of both hydrogen-related fuels and hydrogen vehicles will need to decrease significantly to incentivize end users to switch from traditional ICE or even battery EVs to FCVs.

2. **Infrastructure** is essential in the ramp-up. Facilities need to be developed and upgraded to support hydrogen production and transportation. Examples include green and resilient grids, pipelines, tanks, and refueling stations. The availability of infrastructure will largely affect investor sentiments in production investment, as well as the end-user willingness to adopt hydrogen applications.

3. Equally important is the safety of those infrastructures and end users' perceptions of them. Therefore, government plays a crucial role in setting standards and regulations, as well as educating the public. **Government support** is vital in hydrogen development, and not limited to safety topics. Other key initiatives include incentivizing the uptake of clean hydrogen and penalizing other carbon-emitting energy sources. Examples include a tax credit for clean hydrogen production and a carbon tax.
4. The hydrogen ecosystem is complex and interdependent. Production scale-up will require hydrogen use to be proliferated, and hydrogen supply will be essential to support the demand ramp-up. Therefore, **cross-sectoral investment coordination and collaboration** play a key role in hydrogen economy development.

Global consortia are being formed to support the supply and demand of hydrogen development

Considering the nascent stage of hydrogen development and the interdependency of hydrogen supply and demand, we are seeing a lot of global collaborations in the APEC economies. We are seeing energy giants collaborate **to scale up clean hydrogen production**, such as the Western green energy hub in Australia. This is the largest production plant announced to date (March 2023) according to Rystad, a collaboration among four parties headquartered in three different economies (Australia; Singapore; UK). Partnerships have been formed **to jumpstart production** in economies. Vietnamese local energy company Total Green has partnered with ThyssenKrupp to initiate the economy's first green hydrogen production plant in Tra Vinh province. Consortia have been established **to match supply potential and demand**. Korean industrial giants have formed alliances and initiated the H2biscus project in Sarawak, Malaysia to exploit hydropower potential and supply hydrogen and derivatives to Korea, where hydrogen is in high demand.

Green hydrogen is the most attractive segment due to its low CO2 footprint, while blue hydrogen could be an interim solution before 2030 when cost for green hydrogen is high

Green hydrogen is deemed the most sustainable hydrogen, as the production would not produce any GHG. Although blue hydrogen leverages CCUS technology to offset its carbon emission, GHG is still produced along the way. The European Union, one of the frontrunners in pushing net zero regulation, is considering constraining the definition of clean hydrogen to show a clear preference for green hydrogen (Delegated Act). With the increasing share of renewable energy in the energy mix, green hydrogen production will have the opportunity to scale up. At the same time, technological advancement, especially in electrolyzer cost reduction and efficiency ramp-up, also makes green hydrogen cost competitive with blue hydrogen.

However, it is still important to develop blue hydrogen as an interim solution. Considering the current challenge in green hydrogen, including high cost, lack of availability, and large investment needed, blue hydrogen would be an immediate solution to enable quick wins in achieving carbon neutrality. Besides building new plants, one way could be by retrofitting, given the technology readiness for blue hydrogen, the existing scale of grey hydrogen production, and use and high investment being made in CCUS technology. In addition, blue hydrogen offers the potential of solving current downstream hydrogen challenges to transport and applications, enabling the transition toward green hydrogen in the future.

4.3 Hydrogen transportation overview

Certain regions globally have high demand for hydrogen and often have difficulties accommodating large scale production, especially given the need for significant amounts of renewable energy and advanced electrolysis infrastructure, which necessitate specific conditions and ample space.

For instance, Europe has substantial demand for green hydrogen but faces complexities in achieving large-scale production due in part to the limited renewable energy production potential. Australia; Chile; USA and Middle East are regions well-suited for renewable energy production, with large projects within the green hydrogen space.

This uneven distribution of renewable energy and electrolyzers globally makes the international transportation of hydrogen important for a global green hydrogen economy.

While hydrogen pipelines and trucks are suitable for shorter distances, large quantities and longer distances require alternative techniques. liquified hydrogen, ammonia, and LOHCs (liquid organic hydrogen carriers) are three energy carriers being explored, which vary across several dimensions, as shown in ***Table 2.***

Table 2: Hydrogen energy carriers summary

Hydrogen carrier methods	Transport cost (USD/kg)	Emissions (Ton CO2 / ton H2)	High-level safety	TRL (Technological readiness level)
Liquefied hydrogen	**Highest** 2025: 2.8 2030: 2.6 2035: 1.7	**Highest** 2020: 7.3 2050: 5.1	**Higher risk**	**TRL 5-7** Low TRL for storage and transport Pilot trials are being conducted
Ammonia	**High** 2025: 2.4 2030: 2.5 2035: 1.9	**High** 2020: 5.1 2050: 3.93	**Higher risk** Increased risk due to corrosive nature and high toxicity	**TRL 6-7** Expected commercialization by 2025
LOHC	**Low** 2025: 2.2 2030: 2.3 2035: 1.6	**Moderate** 2020: 2.6 2050: 2.6	**Lower risk**	**TRL 5-7** Expected commercialization by 2025; R&D on dehydrogenation catalyst efficiency and purity of hydrogen liberated

Among the three energy carriers, ammonia is likely the favored export derivative in the coming years. From ***Figure 9*,** a count of assets shows ammonia is likely to be leading across several regions, including Africa, North America, Asia, and Middle East.

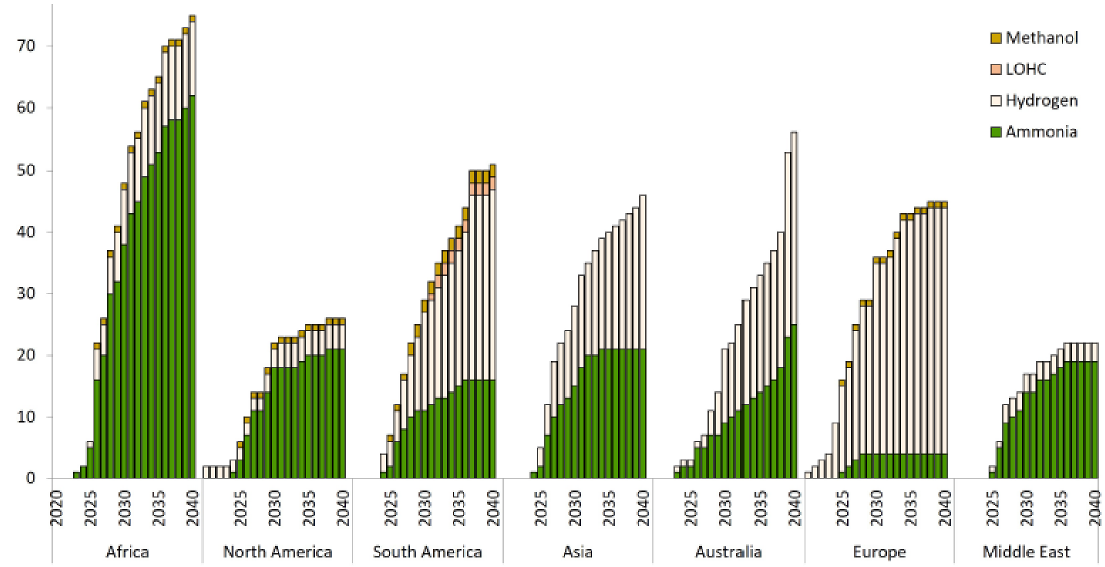


Figure 9: Regional hydrogen supply geared for export by end-product derivatives: Count of assets

There are three main advantages being discussed with respect to using ammonia as a hydrogen carrier:

1. **Ammonia is flexible, and its adoption has potential to achieve carbon neutrality**. Blue and green ammonia has the potential to replace gray ammonia or other fossil fuels in existing industries and offers opportunities for growth in new sectors. Ammonia is attractive due to its ability to be co-fired with thermal coal for power generation. Within APEC, several Japanese companies have initiated such pilot projects. For instance, IHI and JERA are trialing ammonia co-firing at the Hekinan coal plant, located on the Chita peninsula, while other Japanese companies are aiming to export this technology to Indonesia and Malaysia to support the carbon neutrality goals of the power generation sector. Similarly, Korea has announced plans to blend ammonia into its thermal plants, substituting 20 percent of its coal use.

2. **Energy density makes transportation of hydrogen efficient.** Ammonia has a higher energy density at 12.7MJ/L than liquid hydrogen at 8.5MJ/L. Furthermore ammonia can be stored at a much less energy intensive -33 degrees Celsius. These factors result in ammonia requiring far fewer ships to transport the same amount of energy, aiding its cost competitiveness.

3. **Ammonia is already a traded global commodity with existing supply chains and synthesis technology.** Ammonia is used around the world as fertilizer, with seaborne trade in ammonia currently around 20Mtpa, representing 10 percent of global ammonia production. This means ammonia already has the benefits of global transportation and storage infrastructure, giving cost advantages.

Despite the advantages in existing supply chains, the process of cracking ammonia back to hydrogen is still relatively new, expensive, and not energy efficient. Ammonia cracking process is achieved via reacting ammonia gas with heterogenous catalyst under high pressure and temperature to obtain nitrogen and hydrogen gas. The product gas are subsequently purified via pressure swing adsorption process to separate out the hydrogen product gas.

There are two main ammonia cracking technology – centralized cracking and decentralized cracking, with elaboration shown in ***Table 3.***

Table 3: Centralized and decentralized cracking

	Definition	Advantage	Disadvantage
Centralized cracking	Ammonia fed through ammonia cracker at a central location and product hydrogen gas transported through pipeline to end users such as power plant or industry	• Reduces the safety risks associated with handling ammonia • Lower cost per unit hydrogen due to economies of scale	• Lack of RD&D focused on centralised cracking and lack of commercial scale projects • Significant CAPEX required to set up centralised cracking infrastructure
Decentralized cracking	Ammonia is transported as liquid ammonia through tankers or pipeline where it is cracked, at the customers site, using a small reactor.	• Integration of the reaction and separation process steps lower operating temperatures • A simplistic design with significantly lower number of operating units	• Only applicable to smaller scales • Toxic ammonia has to be transported and stored in various locations • Increase in ammonia storage in Singapore required

For large hydrogen requirements, technologies suitable for centralized cracking will need to be pursued.

The schematics of centralized ammonia cracking is shown in ***Figure 10,***

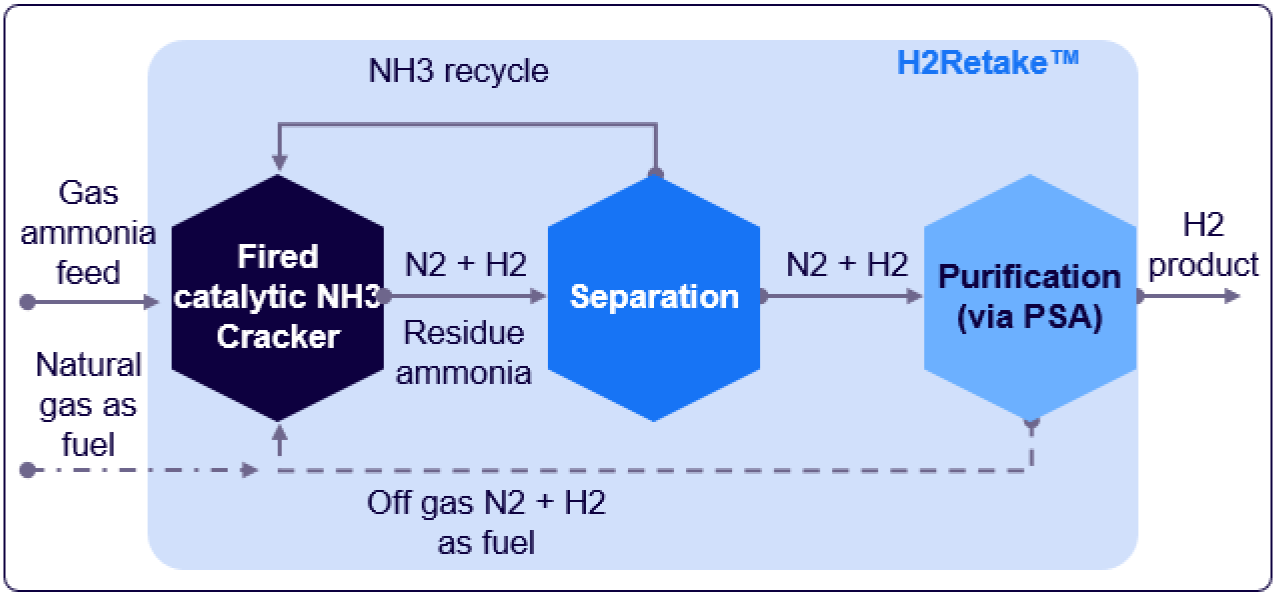


Figure 10: Ammonia cracking schematics

Currently, process conditions are as follows:

- 30 to 50barg
- 850 to 1,000 degrees Celsius
- 5 to 500Mtpd

In terms of catalyst development, iron and nickel based catalyst are currently being used depending on temperature requirement, with a ~97% conversion efficiency from NH3 to H2. There are currently significant ongoing catalyst optimization research (e.g., catalysts, supports, promoters) and cheap and robust separation technologies are being developed.

Some recent developments include Saudi Aramco partnering with King Abdullah University of Science and Technology and Linde Engineering to develop a new generation of cracking catalyst, while recent testing of Ruthenium-based catalysts have shown significant ammonia conversion ratio as compared to nickel-based catalysts.

Major research and projects for ammonia cracking are concentrated in Europe and Middle East, with catalyst licensors taking the lead. ***Table 4*** shows a selection of some notable global ammonia cracking projects, which are mostly either in the conceptual or FEED stage.

Table 4: Selected global ammonia cracking projects

	Key Players	Description
1	Haldor Topsoe	• MOU to explore green ammonia and hydrogen technologies • Tech provider: **Haldor Topsoe** for cracking catalyst technology
2	Siemens Energy-led consortium	• Developing ammonia cracker prototype delivering 0.2Mtpd H2 • Tech provider**: Fortescue Future Industries** for cracking catalyst technology, **Siemens** for cracking facility
3	Air Products	• Developing ammonia cracking facility for the NEOM green hydrogen project in Saudi Arabia • Tech provider: **Air Products** for cracking facility
4	Port of Rotterdam and partners	• Feasibility study for ammonia cracking facility (delivering 1Mt H2 per year) • Tech provider: **Fluor Corporation** for ammonia cracking facility
5	Uniper	• Developing ammonia cracking facility (delivering 295Kt of H2 per year) • Tech provider: **Undisclosed**
6	Linde Engineering and Aramco	• Agreement to jointly test new ammonia cracking catalyst with demonstration plant in Germany • Tech provider: **Aramco** for cracking catalyst technology, **Linde** for ammonia cracking facility
7	Johnson-Matthey and DOOSAN Enerbility	• MOU on cooperation for ammonia cracking • Tech provider: **Johnson-Matthey** for cracking facility and cracking catalyst technology
8	ThyssenKrupp Uhde and ADNOC	• MOU to develop commercial-scale ammonia cracking plants globally • Tech provider: ThyssenKrupp Uhde for cracking facility

Among APEC economies, there are some ammonia cracking development. In Singapore, there are several ongoing developments, all of which are still in an early research or conceptual level.

There are two research projects by various organizations as shown in ***Figure 11.***

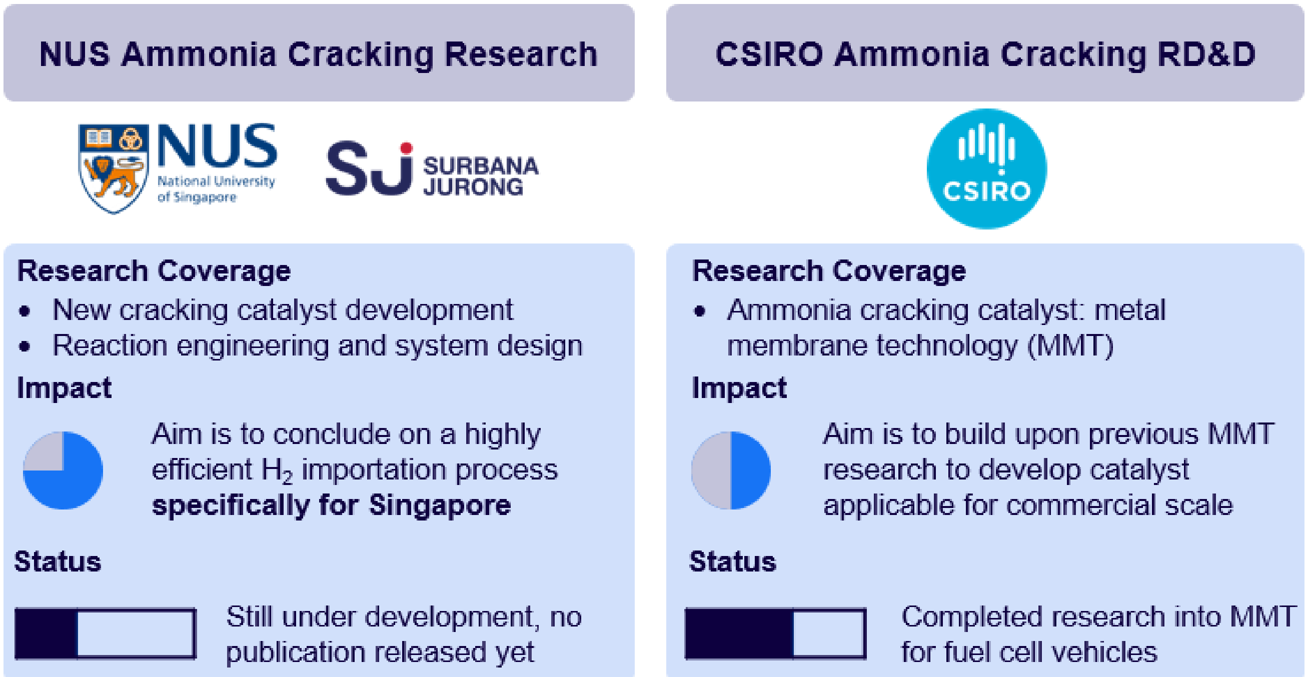


Figure 11: Ammonia cracking research projects in Singapore

Additionally, there are studies conducted by potential suppliers:

- Keppel infrastructure is currently undertaking a feasibility study for ammonia cracking technology and has mentioned that it will require government support to commercialize
- Air Products is currently examining commercial and technical feasibility of ammonia cracking and have not concluded if they will pursue commercialization.

4.4 Hydrogen technology development

Table 5: Main hydrogen production technologies

Types of hydrogen	Technologies	Description
Gray hydrogen	Coal gasification	Combusting air and coal to generate CO2 to react with coal, with a key output of CO that reacts with steam to generate hydrogen
	Steam methane reformer (SMR)	Using steam to generate chemical reactions with hydrocarbon gas and generate hydrogen, CO2, and CO, and use pressure swing adsorption (PSA) to separate hydrogen from other gases
	Autothermal reformer (ATR)	Mixture of SMR and partial oxidation by adding oxygen with hydrocarbon gas to the steam to generate hydrogen
Blue hydrogen	Coal gasification + CCU/S	Coal gasification process with carbon capture systems to capture CO2 from syngas
	Steam methane reformer (SMR) + CCU/S	SMR process with carbon capture systems to capture CO2 from one of the following gases, including flue gas, syngas, and tail gas
	Autothermal reformer (ATR) + CCU/S	ATR process with carbon capture systems to capture CO2 from flue gas, syngas, or tail gas
Green hydrogen	Alkaline electrolysis (AEL)	Operates in a liquid electrolyte solution of potassium hydroxide or sodium hydroxide, with a zirconium dioxide diaphragm to separate hydrogen
	Polymer electrolyte membrane electrolysis (PEMEL)	Operates in pure H2O (water), separated by a solid polymer electrolyte membrane that conducts protons
	High-temperature solid oxide electrolysis (HTEL)	Splits steam into hydrogen and oxygen, where the anode and cathode are separated by a solid oxide/ceramic membrane
	Anion exchange membrane electrolysis (AEMEL)	Separated by transition metal catalysts, which are cheaper material than the solid polymer electrolyte membrane in PEMEL
	Solid oxide electrolysis cells (SOEC)	Converts steam and/or carbon dioxide directly into hydrogen gas, featuring higher conversion efficiency

As listed in ***Table 5***, a few technologies are in development for different types of hydrogen. Gray hydrogen is mainly produced using coal gasification, SMR, or ATR, while blue hydrogen uses the same production methods, with an additional carbon capture system to capture CO2 from the process. Among these three main technologies, ATR appears to be the most accepted production method for blue hydrogen, as it allows for easier and more economic CO2 capture. However, compared to ATR, SMR has been more widely used in gray hydrogen. Therefore, older projects usually retrofit SMR plants with carbon capture systems, while ATR is more popular in new investments.

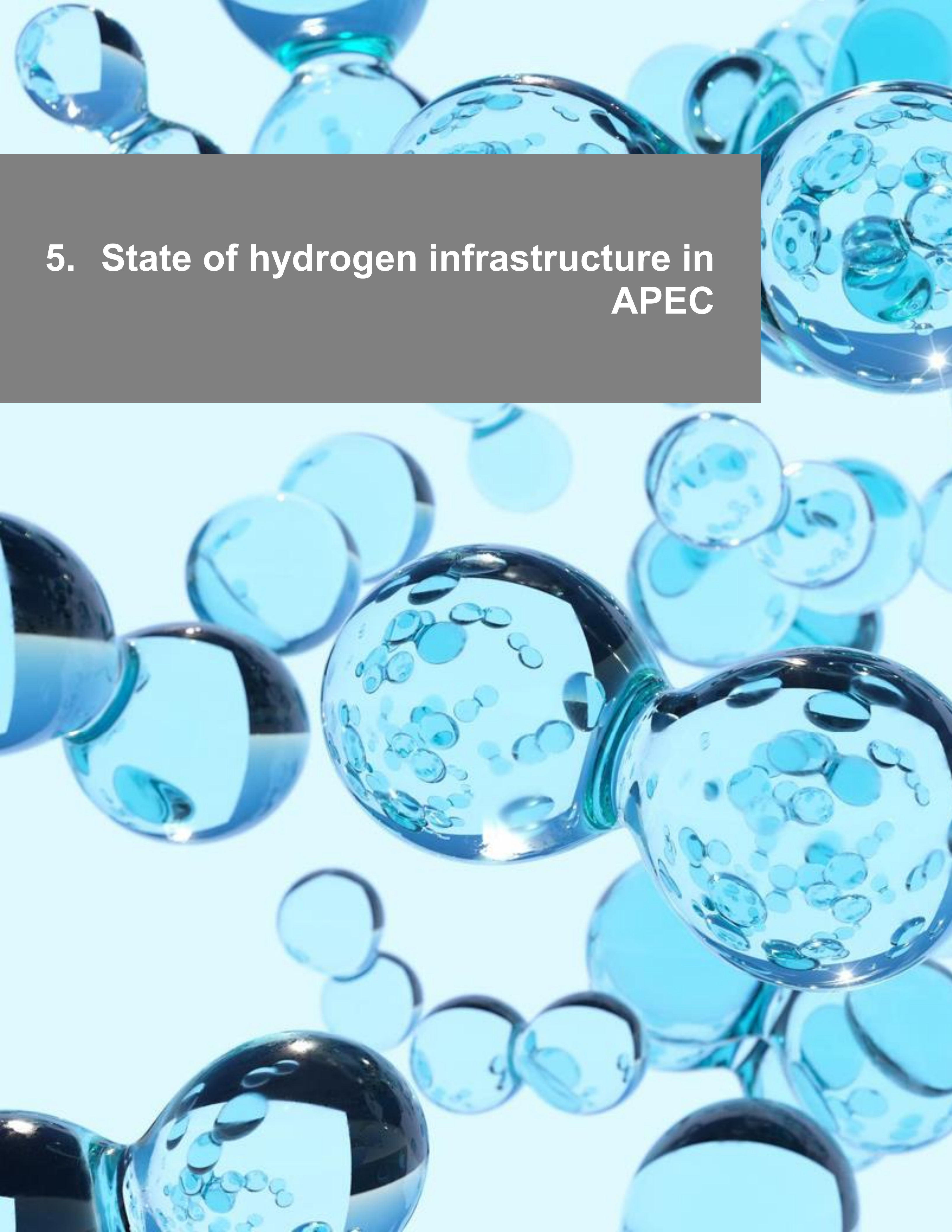
Green hydrogen production is produce through four main technologies, of which AEL is the most mature, having many years of experience. However, the other newer technologies have demonstrated superior characteristics over AEL. PEMEL has the highest hydrogen production rate, HTEL uses the least energy in production, and AEMEL faces the lowest technical barrier. It is still unclear which technology will win in the long run.

Meanwhile, other types of hydrogen, including pink, gold, and white hydrogen, are produced from nuclear-powered electricity, depleted oil reservoirs, and extracting naturally occurring hydrogen, respectively. However, their usage is not popular in the market as of now.

4.5 Potential barriers to developing hydrogen ecosystem

1. **Lack of infrastructure:** Available infrastructure to support the production, transportation, and storage of hydrogen is limited. This could heavily constrain scaling up on both the supply and demand sides. For example, fuel cell vehicle uptake will go hand-in-hand with the ramp-up of hydrogen refueling stations. An underlying challenge in infrastructure scale-up is that most carry very high cost to operate and maintain safety. For example, according to European Hydrogen Backbone, pipeline OPEX could amount to USD3.6 Bn per year. The high cost would affect the cost competitiveness and, consequently, the adoption rate. Apart from direct financial support, an initiative taken by many economies (such as the Australia; Canada; Korea; The United States) to address this challenge, especially in transport infrastructure, is to establish regional hydrogen hubs. The aim is to establish hydrogen production close to its end users, thus minimizing the cost of infrastructure construction and operation. With more available and less costly infrastructure, the hydrogen ecosystem can jumpstart and bypass huge infrastructure-related investments.
2. **High upfront capital investment:** Large capital outlay is common across the hydrogen value chain. Examples include electrolyzers (production); compressors, storage tanks, and underground caverns (storage); and trucks and pipelines (transport). According to IEA, in 2022, CAPEX required for electrolyzers could range from USD500/kWe to USD5,600/kWe depending on the technology. As an illustration, China is planning to reach 100GW of capacity by 2030. Given the large amount requirement, investments may enter the "valley of death" and not be bankable if demand is lacking or market coordination fails, especially in the initial stage of a project. This high risk may cause many potential investors to stay on the fence. Many governments have been trying to mitigate risks through loans, direct investments, and tax incentives. Examples include Australia's Clean Energy Finance Corporation and the United States' Inflation Reduction Act (IRA).
3. **Safety concerns:** The low ignition point of hydrogen has raised concerns about the risk of explosions. Furthermore, the hydrogen flame is invisible to the naked eye, colorless and odorless, making fires and leaks difficult to detect. However, given the nascency of hydrogen technologies, stability and durability could still be improved. For example, fuel is not yet durable, therefore, car accidents could cause explosions due to deformation. As these concerns are crucial challenges for hydrogen scale-up, economies are taking initiatives in R&D for hydrogen safety. A study funded by the Singapore Low Carbon Energy Research (LCER) Program is developing hydrogen leakage and purity sensors for downstream hydrogen use. Authorities will also need to consider developing safety standards and processes to regulate the safe production, transport, storage, and use of hydrogen.
4. **Limited awareness:** End users are often not aware of hydrogen as a clean energy carrier. In a 2019 survey conducted by the World Economic Forum through social media, 31.4 percent of the respondents believed hydrogen was dangerous. Many potential market participants, including consumers, businesses, and the government, still have concerns over the safety of hydrogen use, and thus are reluctant to adopt hydrogen applications. Therefore, end-user education is crucial for economies aiming to leverage hydrogen for domestic carbon neutrality. For example, promoting national understanding is included in the Basic Hydrogen Strategy in Japan. Communication with citizens, regional governments, and business operators is encouraged, together with information-sharing conferences.
5. **Competition with substitutes:** As an energy storage system hydrogen is a less mature, more costly technology with less available infrastructure than lithium-ion batteries. However, it could be more suitable as a long-duration energy storage (more than four hours), especially for hybrid energy storage systems (HESS); Long-duration energy storage (LDES) with hydrogen is typically easier and cheaper scale up, with little geographical limits and the ability to support longer time imbalances (for example, in the grid system). In contrast, lithium-ion batteries are more costly to scale up and could provide limited duration for energy storage. Therefore, hydrogen could potentially be a better fit for energy storage in remote areas. Therefore, hydrogen development could be prioritized in end uses for which hydrogen's advantages can be better utilized, especially in the early stages when the technology is developing and costs are high.
6. **Geopolitical risk:** If the majority of hydrogen is supplied by Middle Eastern and African states (such as Qatar, Saudi Arabia, and Morocco), regions such as Europe would simply trade dependency on Russian gas for a reliance on other economies, bringing potential risk.

5. State of hydrogen infrastructure in APEC



5. State of hydrogen infrastructure in APEC

5.1 Hydrogen infrastructure readiness framework

5.1.1 The framework

The infrastructure readiness framework in this report is illustrated in ***Figure 12***. For each APEC economy, five factors are to be assessed to determine hydrogen infrastructure readiness –three factors associated with the hydrogen value chain and two supporting enablers.

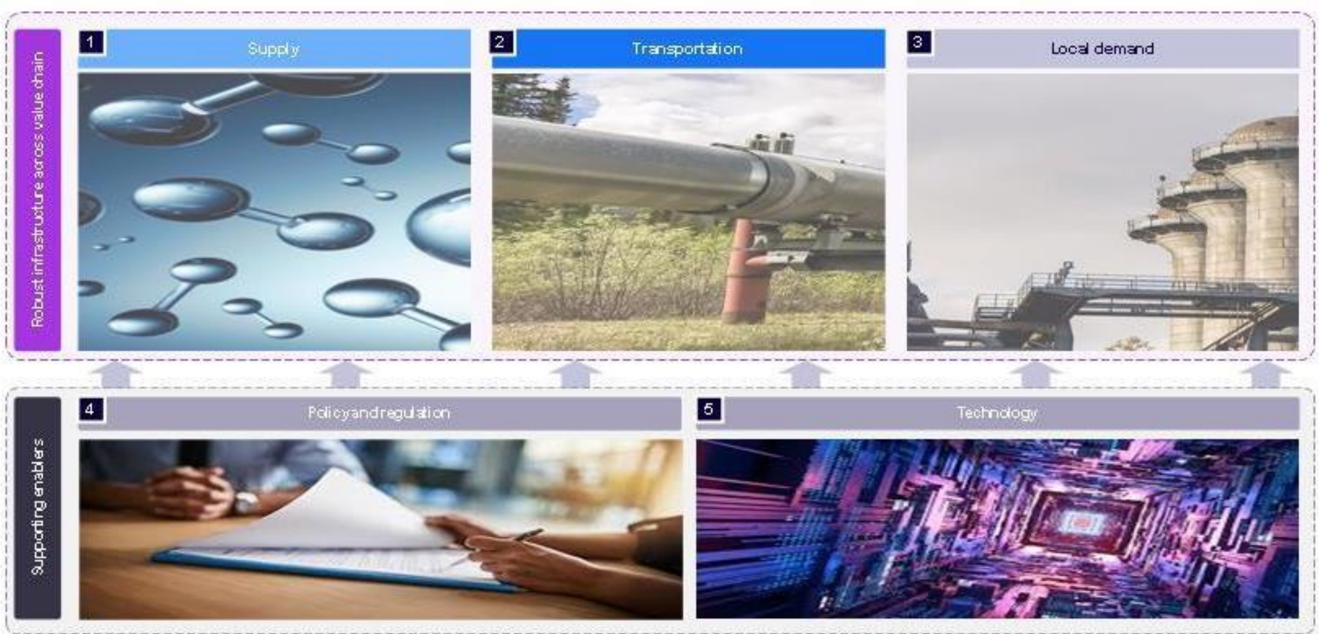


Figure 12: Hydrogen infrastructure readiness framework

5.1.2 Sub-factors and metrics

The five factors in the framework will be further broken down into sub-factors, as illustrated in ***Table 6*** to ensure that the evaluation framework is holistic and covers all key bases.

Table 6: Hydrogen infrastructure readiness framework – sub-factors or metrics

Factors	Sub-factors/metrics	Rationale
Supply	Current hydrogen production capacity	Indicates the current readiness level of hydrogen production
	Future hydrogen production capacity	Indicates the economy's ambition for hydrogen production
	Planned pipeline of hydrogen projects	Indicates the economy's future readiness and commitment to producing hydrogen
Transportation	Length of gas pipeline infrastructure	Indicates the economy's readiness to transport hydrogen through pipelines
	No. of liquefaction and regasification plants	Indicates the economy's readiness to support the transport of hydrogen by sea
	Presence of ammonia-cracking facilities	Indicates the economy's readiness to support the transport of hydrogen by sea

Factors	Sub-factors/metrics	Rationale
Local demand	Current hydrogen demand	Indicates current readiness level of hydrogen demand
	Future hydrogen demand	Indicates the economy's ambition for hydrogen as a low-carbon source
Policy and regulation	Carbon-neutral strategy, targets and timeline	Indicates the economy's readiness to push for carbon reduction where hydrogen could be a driving force
	Domestic hydrogen strategy, targets and implementation roadmap	Indicates the economy's readiness to develop its hydrogen economy
	Subsidies and tax incentives	Indicates the economy's readiness to incentivize hydrogen development by private/public players
	Presence of a carbon market (e.g., carbon taxes, ETS)	Indicates the economy's readiness to complement the development of a hydrogen economy
Technology	Stage of hydrogen technology implementation[1]	Indicates the economy's maturity of technology implementation
	No. of start-ups involved in hydrogen	Indicates the economy's readiness to support hydrogen technology development
	Existence of Triple-Helix networks for R&D (networks where the public sector, private sector and academia collaborate)	Indicates the economy's readiness and commitment to supporting hydrogen technology development

5.1.3 Indexing and weights

The mentioned factors and corresponding subfactors and metrics are assigned weights to provide an overall assessment of the infrastructure readiness of the economies, as illustrated in ***Table 7***. The weights are assigned according to the representativeness of overall readiness for hydrogen infrastructure. Given the nascency of a hydrogen economy, policy and regulations are a better measure of readiness than technology, hence, a higher weight is assigned.

For comparison purposes, the assessment result of each sub-factor and metric are indexed to their maximum possible score in that metric.

Table 7: Hydrogen infrastructure readiness framework – factor weights

Factors	Sub-factors/metrics	Sub-factor weights	Factor weights
Supply	Current hydrogen production capacity	6.7%	20%
	Future hydrogen production capacity	6.7%	
	Planned pipeline of hydrogen projects	6.7%	
Transportation	Length of gas pipeline infrastructure	6.7%	20%

[1] Hydrogen technology throughout the spectrum of production (PEM, alkaline), transportation (LOCH, MCH) and end application (advanced fuel cell, co-firing, steelmaking, etc.) are investigated. Points are assigned based on the stage of implementation of the most mature technology in the economy.

Factors	Sub-factors/metrics	Sub-factor weights	Factor weights
	No. of liquefaction and regasification plants	6.7%	
	Presence of ammonia-cracking facilities	6.7%	
Local demand	Current hydrogen demand	10%	20%
	Future hydrogen demand	10%	
Policy and regulation	Carbon-neutral strategy, targets and timeline	7.5%	30%
	Domestic hydrogen strategy, targets, and implementation roadmap	7.5%	
	Subsidies and tax incentives	7.5%	
	Presence of a carbon market (e.g., carbon taxes, ETS)	7.5%	
Technology	Scale of technology cooperations	3.3%	10%
	No. of start-ups involved in hydrogen	3.3%	
	Existence of Triple-Helix networks for R&D (networks in which the public sector, private sector, and academia collaborate)	3.3%	

5.2 Readiness assessment

5.2.1 Infrastructure readiness overview

Based on the framework, below is the summary of each APEC economy across the five factors of the infrastructure assessment framework, as seen in ***Table 8***.

Table 8: Summary of infrastructure readiness among APEC economies

	Overall infrastructure readiness level	Factors				
		Supply (S)	Transpor-tation (Tr)	Local demand (D)	Policy and regulation (P&R)	Technology (Te)
Australia						
Brunei Darussalam						
Canada						
Chile						
China						
Hong Kong, China						
Indonesia						
Japan						
Korea						
Malaysia						
Mexico						
New Zealand						
Papua New Guinea						
Peru						
The Philippines						
The Russian Federation						
Singapore						
Chinese Taipei						
Thailand						
The United States						
Viet Nam						

0% of assessment score — 100% of assessment score

5.2.2 Economy assessments based on readiness scores

Table 9: Economy assessments based on readiness scores

Economy	Assessment	
Australia	S	Australia currently has clean hydrogen production capacity of approximately 0.4Ktpa. It has approximately 108 hydrogen projects in the pipeline, with an estimated capacity of 2Mt clean hydrogen by 2030.
	Tr	Gas pipeline coverage is adequate across the economy. Australia has 12 liquefication plants and no regasification plants. A small demonstration of an ammonia-cracking fuel system was seen in 2018, while larger-scale plans are yet to be observed.
	D	Local demand is currently limited. Feedstock to ammonia plants and oil refineries will be the primary driver before 2040.
	P&R	Australia's hydrogen development is strongly backed by decarbonization plans, hydrogen strategy, and extensive hydrogen-targeted subsidies. The carbon market is also in place to complement the hydrogen market activities.
	Te	Australia aggressively promotes R&D and partnerships for hydrogen technology; hence, it has many projects in the planning/development phase. Sixty-seven start-ups are involved in the hydrogen space, with more than 10 consortia.
Brunei Darussalam	S	Brunei Darussalam currently produces gray hydrogen, with no clean hydrogen project identified.
	Tr	It has one liquefaction plant, which is neither a regasification plant nor an ammonia-cracking facility.
	D	The demand will mostly be driven by power generation and transport, and is expected to scale up after 2035.
	P&R	Brunei Darussalam has published a decarbonization strategy. However, it does not have a hydrogen strategy and incentives yet. The economy is researching carbon pricing mechanisms.
	Te	The economy has a demonstration project for MCH hydrogen shipment to Japan, but neither a start-up nor a Triple-Helix consortium in the hydrogen space.
Canada	S	Canada currently has three blue hydrogen and two green hydrogen projects in operation, with 20 clean hydrogen projects in the pipeline. The current capacity of clean hydrogen is 0.88Mt, with an estimated capacity of 2.9Mt by 2030.

Economy	Assessment	
	Tr	Canada has well-established natural gas systems, with one regasification plant. Moreover, AmmPower has demonstrated ammonia cracking technology for fuel cell generator.
	D	Demand is mostly driven by power generation, with hydrogen supplying 30 percent of the economy's power demand, and strong demand in the industrial, transport, and heating sectors as well.
	P&R	Canada has an economy-wide decarbonization and hydrogen strategy. Regional ETS and the carbon tax are also available to support hydrogen development.
	Te	Technologies such as electrolysis, CCUS, ammonia cracking, and fuel cell are operational. Approximately 100 start-ups involved in the hydrogen sap, as well as Triple-Helix networks for R&D, such as the Canadian Hydrogen and Fuel Cell Association.
Chile	S	Chile currently has no large-scale hydrogen production, although it has more than 60 hydrogen projects in the pipeline, with an estimated clean hydrogen production capacity of 1.3Mt by 2030.
	Tr	Chile has a regional gas infrastructure and two regasification terminals. It does not have liquefication or ammonia-cracking facilities.
	D	Oil refineries and ammonia are expected to be the first hydrogen adopters. Heavy-duty trucking organizations could become the largest consumers.
	P&R	Chile has economy-wide decarbonization and hydrogen strategies, with extensive hydrogen subsidies. The carbon market is also in place to encourage hydrogen development.
	Te	Chile has several projects at the pilot stage and six start-ups involved in the hydrogen space, as well as ASDIT, a Triple-Helix consortium.
China	S	China is the largest gray hydrogen producer. However, it has 120 green hydrogen projects at different stages of development. The current capacity of clean hydrogen is 0.5Mtpa, with an expected capacity of 7.7Mt by 2030.
	Tr	China emphasizes gas pipeline development, with a 110,000km gas/hydrogen pipeline. It has 22 regasification terminals and no large-scale ammonia-cracking facilities.
	D	Hydrogen is used mostly in transport and industry. For transport, China rolled out the world's first hydrogen train in December 2022. For industry, demand mostly comes from chemicals.
	P&R	China has a long-term carbon neutrality strategy, a long-term hydrogen development plan, and provincial hydrogen policies. A funding scheme for R&D hydrogen technology and infrastructure has been developed.
	Te	China is a leader in alkaline electrolyzer and shows interest in CCUS deployment. More than 140 start-ups are involved in the hydrogen space, with the presence of the China Hydrogen Alliance for hydrogen development.
Hong Kong, China	S	Hong Kong, China has a limited landscape for hydrogen production. Hence, Hong Kong, China would rely on hydrogen imports.

Economy	Assessment	
	Tr	Hong Kong, China has an existing gas pipeline used for gas import from China (currently only for natural gas), and a regional town gas pipeline. It has no liquefication, regasification, or ammonia-cracking facilities.
	D	Hong Kong, China has released the Hong Kong Roadmap on Popularization of Electric Vehicles, Clean Air Plan for Hong Kong 2035, and Hong Kong's Climate Action Plan 2050 which lay the foundation for hydrogen adoption. There are currently several applications of hydrogen trial projects including the Hydrogen Fuel Cell bus by Citybus and Wisdom, which have been assessed by the Working Group with agreement in principle granted.
	P&R	China has released the first medium to long-term plan on development of hydrogen energy in March 2022. There is also hydrogen project funding under other funding programs including the New Energy Transport Fund. Additionally, the new international carbon marketplace Core Climate launched in October 2022 will help develop the hydrogen economy in Hong Kong, China.
	Te	Hydrogen is being planned for use in trials of hydrogen fuel cell buses. No triple-helix consortiums observed yet.
Indonesia	S	Indonesia currently produces gray hydrogen. It has four projects in the pipeline, and the estimated capacity for clean hydrogen is 0.12Mt by 2030.
	Tr	Indonesia has an adequate natural gas pipeline network, three liquefaction and six regasification plants, and no ammonia-cracking facility.
	D	Demand is driven by the power generation, transport (rail, maritime and aviation), and industrial (steel and cement) sectors.
	P&R	Indonesia has published a decarbonization strategy. However, it does not have a hydrogen strategy and incentives. The statutory carbon tax is scheduled to be implemented.
	Te	Hydrogen technologies in Indonesia are mostly in the pilot stage. However, it has three start-ups in the hydrogen space and a collaboration between government and academia.
Japan	S	Japan has 28 projects in the pipeline. The current production capacity of clean hydrogen is 1.8Ktpa, with an estimated capacity of 2.69Kt by 2030.
	Tr	Japan has adequate gas pipeline coverage, as well as 28 liquefication and regasification plants. It also has an operational ammonia-cracking facility for Saudi Arabia ammonia import.
	D	Demand is driven by the power generation, mobility, and industrial sectors.
	P&R	Japan has a subsidy for the hydrogen supply network and FCV purchase. Regional ETS and carbon tax are in place to support hydrogen development.
	Te	The technology is available in power generation and mobility. 40 start-ups are active in the hydrogen space, as well as the Namie Town transport consortium.

Economy	Assessment	
Korea	S	Korea's expected production capacity for clean hydrogen is expected to be 1Mtpa by 2030, with imports of 1.96Mtpa from 2030.
	Tr	Korea has seven regasification plants, with three ammonia-cracking facilities in development.
	D	The demand is primarily driven by FCEV and large-scale FC stationary power generation. It can also come from the chemicals and manufacturing sectors.
	P&R	Korea has published a hydrogen strategy with legislation on hydrogen development. It has subsidies for hydrogen applications, including mobility. ETS is in force for emission reduction.
	Te	The technology in is operational in power generation and mobility. 60 start-ups are active in the hydrogen space, with strong involvement of the private sector (Hyundai, SK, POSCO, etc).
Malaysia	S	Malaysia has a pilot project in Sarawak, with minimal hydrogen-powered buses and ART vehicles. It has large-scale projects in the pipeline, but the numbers of projects remain small. The estimated capacity for clean hydrogen is 0.5Mt in 2030.
	Tr	Malaysia has six liquefaction plants, two regasification plants, and no ammonia-cracking facility.
	D	Hydrogen is mostly used in Sarawak for hydrogen-powered vehicles. A portion of 7Ktpa from the H2biscus project will be consumed locally. Hydrogen will be used in the transport, industrial, and manufacturing sectors in the future.
	P&R	Malaysia has published a decarbonization strategy and hydrogen energy roadmap for 2005–2030. It also has introduced voluntary carbon market exchange. However, it does not have a hydrogen strategy and incentives.
	Te	The technology is mostly in the pilot stage. No start-ups are involved in the hydrogen space, but collaborations between the public and academia have been initiated.
Mexico	S	Mexico currently produces gray hydrogen. It has four production projects in the pipeline, with an estimated 670MW electrolysis by 2030.
	Tr	Mexico has adequate gas pipeline infrastructure and four regasification terminals. It has neither a liquefication plant nor an ammonia-cracking facility.
	D	Strong hydrogen demand exists for mining and industrial use. Mexico has vast potential for the hydrogen mobility sector in 2050.
	P&R	Mexico has a decarbonization goal. Although SMH, a private consortium has published a proposed domestic hydrogen plan, the economy does not have a domestic hydrogen policy. However, ETS has been implemented to support hydrogen development.
	Te	Mexico has long-standing R&D in hydrogen technology, but it lacks knowledge transfer to commercialization.

Economy	Assessment	
New Zealand	S	New Zealand currently operates the Halcyon project (0.12Kt capacity) and the BOC project for use in steel manufacturing and other projects. It has 11 projects in the pipeline and an estimated capacity of 0.27Mt clean hydrogen in 2030.
	Tr	New Zealand has adequate gas pipeline coverage especially throughout the North Island, and has conducted a feasibility study on a hydrogen pipeline to develop hydrogen transport infrastructure. It has a liquefication and regasification plant in Port Taranaki, while Hiringa Energy is developing hydrogen refuelling stations in the North Island and trucking and fuel supply company HW Richardson is developing refuelling stations in the South Island. Furthermore, it has a project to develop green ammonia to use in the Ballance site for lower-carbon urea in fertiliser production, and to partially supply Hiringa's refuelling network.
	D	Some local demand from steel production (0.6MW onsite electrolyser) and for fuel for various transport trial applications, supplied from NZ Steel and a 1.25MW electrolysis facility in Taupo.
	P&R	New Zealand has a decarbonization plan and ETS in place. It released an Interim Hydrogen Roadmap in August 2023, and is developing a final Hydrogen Roadmap for publication in 2024 alongside the New Zealand Energy Strategy. Targeted funding includes a green hydrogen consumption rebate scheme that is in development, a clean heavy vehicle grant scheme that is in development, and a transport demonstration trial fund that has already funded several hydrogen transport trials across FCEV trucks and buses, along with dual fuel hydrogen diesel truck conversions.
	Te	The technology is available due to the Halcyon project in operation. It has four start-ups involved in the hydrogen space, with the New Zealand Hydrogen Council operating as an industry-led body that engages public, private, and academia. Additionally, Fabrum, a company based in Christchurch, works with Clean Power Hydrogen (CPH2) to supply membrane-free Liquid Hydrogen Systems. The benefits include prolonged operating life, reduction in maintenance cost, and avoidance of rare earth catalytic metals, unlike that of a PEM system.
Papua New Guinea	S	Papua New Guinea does not currently produce green hydrogen, but it has green hydrogen projects in the pipeline by FFI.
	Tr	Papua New Guinea has limited gas pipeline coverage and one liquefaction terminal. However, it does not have a regasification plant or ammonia-cracking facility.
	D	Papua New Guinea has unclear policy in hydrogen use and no sign of ideation or testing of hydrogen applications. However, demand is expected to be driven by the industrial, transport, and power sector.
	P&R	Papua New Guinea has an economy-wide decarbonization strategy, target, and plan. However, it has neither a hydrogen strategy nor carbon pricing initiatives.

Economy	Assessment	
	Te	The technology is in the conceptual stage for green hydrogen production. No start-ups are involved in the hydrogen space, and no Triple-Helix partnerships have been formed.
Peru	S	Peru has less than five projects in the pipeline. The expected capacity for clean hydrogen is 0.173Mt in 2030, from the current capacity of 0.0043Mt.
	Tr	Peru has 729km of gas/hydrogen pipeline infrastructure. It has one liquefaction plant and no ammonia-cracking facility.
	D	The demand is mostly from the mining, industrial, and transport sectors.
	P&R	NDC and ENCC2050 announce have announced a decarbonization strategy. Even though Peru does not have an domestic hydrogen strategy, the private H2 Peru has proposed a roadmap and signed a cooperation agreement with the ministry to develop green hydrogen.
	Te	Electrolyzer is available. Peru has no start-ups involved in the hydrogen space, but a collaboration has been established between the industry alliance and ministry.
The Philippines	S	The Philippines produces large amounts of gray hydrogen.
	Tr	The Philippines has 504km of gas/hydrogen pipeline infrastructure and three regasification terminals under construction.
	D	Demand is driven by the power generation, industrial, and transport sectors.
	P&R	The Philippines does not have a net zero target and domestic hydrogen strategy, but a GHG reduction emission mandate is in place. It offers incentives to renewable energy developers.
	Te	Electrolyzer is available, and few start-ups are involved in the hydrogen space. The DoE signed an MoU with Japanese and Australian firms for hydrogen research.
The Russian Federation	S	The Russian Federation currently produces gray hydrogen and has five blue hydrogen projects in the pipeline. It has an expected capacity for clean hydrogen of 0.39Mt by 2030.
	Tr	The Russian Federation has one of the largest gas supply systems in the world. It has two liquefaction plants and one regasification plant; however, it does not have an ammonia-cracking facility.
	D	Policy for intended domestic hydrogen application is unclear. However, demand is driven by the industrial and transport sectors.
	P&R	The Russian Federation has published a decarbonization and hydrogen strategy with hydrogen-targeted funding initiatives. However, the carbon tax is in discussion.
	Te	A feasibility study has been undertaken for hydrogen production. The Russian Federation has 13 start-ups involved in the hydrogen space and a working group engaging ministries and industry players.

Economy	Assessment	
Singapore	S	Singapore currently produces gray hydrogen. It has four production projects in the pipeline, but no clear future production capacity.
	Tr	Singapore has well established natural gas infrastructure and one regasification plant. Ammonia-cracking technology is under RD&D.
	D	Hydrogen is used in the power sector; maritime and aviation fuel in transport; and industrial feedstock in the chemical sector .
	P&R	Singapore has published a decarbonization plan, hydrogen strategy, and carbon tax. The government sets funding for low-carbon energy research initiatives, and A*STAR, MAS, and SET provide funding for hydrogen projects.
	Te	Twelve start-ups are involved in the hydrogen space, and multiple consortia engage universities and research institutes.
Chinese Taipei	S	Chinese Taipei has a plant to produce hydrogen on a small scale. It has one production project in the pipeline and an estimated capacity of 4Kt clean hydrogen in 2030.
	Tr	Chinese Taipei has two regasification plants, but neither a liquefication plant nor an ammonia-cracking facility.
	D	Demand is driven by industrials and power generation, with a greater focus on hydrogen power generation before 2030 (approximately 900MW of demand).
	P&R	Chinese Taipei has an economy-wide decarbonization and hydrogen roadmap, with targeted funding for hydrogen development. The carbon tax will be released in 2023.
	Te	Chinese Taipei has had long-standing R&D in fuel cell technology since 1993, and has operational applications and supply chains in fuel cell back-up power. Eight start-ups are involved in hydrogen, and partnerships have been established between public and private as well as academia and private.
Thailand	S	Thailand currently operates one green hydrogen plant with a production capacity of 0.08Ktpa. It has less than 10 projects in the pipeline, and the estimated capacity for clean hydrogen is 0.03Mt by 2030.
	Tr	Thailand has adequate gas pipeline coverage and two regasification plants. However, it has no liquefication plant or ammonia-cracking facility.
	D	Development in hydrogen fuel cell mobility is increasing.
	P&R	Thailand has a decarbonization strategy, ETS, and carbon market. It does not have a domestic hydrogen policy, but has published incentives for hydrogen production and related activities.
	Te	The technology has only been implemented in small-scale and experimental projects. Few start-ups are involved in the hydrogen space, and a Thailand Hydrogen Group has been established to promote hydrogen development.

Economy	Assessment	
The United States	S	The United States mostly produces gray hydrogen. However, it has 68 clean hydrogen projects in the pipeline. The current production capacity for clean hydrogen is 1.78Mtpa as of 2022, with an expected capacity of 10Mt by 2036.
	Tr	The United States has adequate infrastructure, with 1,600 miles of hydrogen pipeline. It has 18 liquefication and 10 regasification plants, with patented ammonia-cracking technology.
	D	Demand is mostly driven by the industrial sector. Hydrogen demand is estimated to by 10Mt in 2036, with huge potential in mobility (long-haul trucking) and chemicals.
	P&R	The United States has strong policy support in decarbonization and hydrogen, with a USD9.5 Bn public monetary commitment. Regional ETS is in place to support hydrogen development.
	Te	The technology is developed and operational. Approximately 650 start-ups are involved in the hydrogen space, as well as a Triple-Helix collaboration including H2@Scale and MachH2.
Viet Nam	S	Viet Nam currently has no green hydrogen production and less than 10 projects in the pipeline.
	Tr	Viet Nam has adequate gas pipeline coverage and regasification terminals under development (LNG to power projects). It has neither a liquefication plant nor an ammonia-cracking facility.
	D	Even though Viet Nam's policy for promoting hydrogen as an energy source is unclear, it has potential to replace natural gas with hydrogen in 2050.
	P&R	Viet Nam has no domestic hydrogen policy, but has included hydrogen in PDP VIII in a discussion. ETS is in discussion for emission reduction.
	Te	Viet Nam has limited hydrogen development, largely relying on foreign investment and partnerships for technology. It has no start-ups involved in the hydrogen space.

6. Selected case studies in APEC economies

6. Selected case studies in APEC economies

Out of 21 APEC economies, we selected the eight with relatively high scores in infrastructure readiness and diverse ranges of practices and learnings across the hydrogen value chain.

6.1 Australia

Australia is well positioned for clean hydrogen export due to abundant solar and wind energy sources. It expects to achieve clean hydrogen production costs of USD1.36–2.72/kg, which will be some of the most competitive in the world. As an economy with a large-scale energy sector, established infrastructure, and good regulation, Australia has approximately 108 projects in the pipeline, with an estimated capacity of 2Mt hydrogen by 2030. Thanks to adequate gas pipeline coverage and a strong track record in energy export, Australia can leverage its established transport infrastructure and experience to build a foundation for hydrogen export. To facilitate hydrogen development, the Australian government has been active in accelerating both demand and supply of hydrogen. Australia has established hydrogen hubs in different states for multi-use in industry and export, while partnering with other economies such as the Netherlands, Germany, and Japan to cooperate on hydrogen technology R&D for emission reduction and cost optimization. Moreover, the Australian government demonstrates strong support through funding and collaboration. It has allocated more than USD2 Bn for hydrogen projects at the central and state level. More importantly, National Energy Resources Australia has implemented a domestic hydrogen transition to drive industry collaboration by building a hydrogen technology cluster. Australia is on track to become a hydrogen exporter with, estimated export of 500+Kt to East Asia by 2030.

Practice 1: Australia fosters both domestic and international partnership for trading and technology development, through initiatives including hubs and cooperation MoUs

As states and territories have different capabilities and resources, Australia promotes domestic partnerships to build up hydrogen hubs, serving growing local demand for the industrial, mobility, and heating sectors. It can also lay a strong foundation for hydrogen export in the future. The government has invested AUD526 Mn (USD 357.9 Mn) in support to develop regional hydrogen hubs across states. For example, in 2022 the federal government announced a fund of USD47 Mn to support the Pilbara Hydrogen Hub in Western Australia, with a range of local and international players to produce green hydrogen and green ammonia. During the same period, the Tasmanian government formed a consortium of five state-owned enterprises to build the Tasmanian Green Hydrogen Hub with a fund of USD47 Mn, serving domestic use in the short term (2022–2024) and the export market in the long term (beyond 2024). The South Australian government has sought to establish Port Bonython Hydrogen Hub in South Australia, with a fund of USD47 Mn to build on its existing infrastructure and resources, producing green hydrogen and its derivatives for export in 2021. The government has selected seven projects to support the development of a hydrogen export hub, with involvement from international corporates from Australia, Japan and Canada. The Port of Newcastle is working with Macquarie Green Investment Group on a feasibility study for the Port of Newcastle Hydrogen Hub in New South Wales with a fund of USD27 Mn. The study, which assesses the technical and commercial viability of renewable hydrogen and ammonia production, is underpinned by a 40MW electrolyzer with potential scale-up to 1GW and production of 150Kt hydrogen per annum.

Since Australia aims to achieve net zero emissions by 2050 through a technology-based approach, it facilitates overseas partnerships to focus on R&D hydrogen technology innovation for lowering GHG emission and production costs. The government has allocated USD565.8 Mn to advance overseas collaborations to boost the development of low-emissions technologies and support the goals of Australia's Technology Investment Roadmap. Australia has already announced partnerships with other economies, such as Japan, Singapore, Germany, and the Netherlands, to advance low-emissions technology innovation.

- In January 2020, Australia partnered with Japan to support technologies, including clean hydrogen and ammonia, CCUS, and lower emissions products (LNG, steel, iron ore). For example, Japan's Osaka Gas participated in an Australian hydrogen project that used a unique electrolyzer to produce green hydrogen.
- In March 2020, Australia collaborated with Singapore on a low-emission maritime initiative to co-invest USD20 Mn in pilots and projects to trial the use of low-emissions technologies. For example, Singapore's GIC secured a stake in major Australian hydrogen projects to promote green hydrogen hubs.

- In June 2021, Australia worked with Germany on the hydrogen accord to promote the HyGATE Program, with a combined investment of approximately USD87 Mn for RD&D projects along the hydrogen supply chain. For instance, Australia's Vast Solar collaborated with Germany's Fichtner GmbH to develop a 10MW electrolyzer for green hydrogen.
- In January 2023, Australia signed MoU with the Netherlands on hydrogen cooperation to support the development of a renewable hydrogen supply chain from Australia to Europe. The MoU covers topics related to hydrogen technology, hydrogen trade policy and standards, supply chain development, and government policies for hydrogen regulation. For instance, Tasmania partnered with the Port of Rotterdam to conduct a feasibility study of green hydrogen export from Bell Bay to the Port of Rotterdam.

Practice 2: Australian government implements Hydrogen Technology Cluster to drive industry collaboration toward hydrogen development

National Energy Resource Australia has partnered with governments and industry to form Hydrogen Technology Cluster Australia (H2TCA) – a network of hydrogen technology clusters to facilitate cooperation and action alignment across the economy to push hydrogen development forward. Moreover, H2TCA expedites rapid development of the hydrogen supply chain and drives market activation, establishing a global identity for Australian hydrogen technology and expertise. It also helps build skills, capability, and commercialization opportunities in the emerging hydrogen industry.

Australia currently has 18 hydrogen technology clusters with a connection of more than 500 organizations across eight states. For example, Perth and Peel Hydrogen Technology Cluster which is located in Western Australia focuses on supply chain activation, innovation and technology development. Clayton Hydrogen Technology Cluster which is located in Victoria partners with ARENA2036 (Germany) to accelerate the development of an Australia-Germany hydrogen industry. More importantly, these clusters work on technologies to promote hydrogen development.

6.2 Canada

Canada is a large-scale hydrogen producer aided by advanced technology. It owns abundant renewable energy sources, with more than 98.6GW as of 2021 for green hydrogen production. It also has great natural resources with advanced CCUS technology to manufacture blue hydrogen. Moreover, the economy has advanced technologies for hydrogen development. It leads in fuel cell system, electrolyzer, and fueling application technology, with established companies across the hydrogen value chain, such as Proton Technologies (hydrogen production), Ballard Power (fuel cell systems), and Hydrogenics (hydrogen production and fuel cell products). In addition, Canada implements different strategies at economy-wide and international levels to push green hydrogen development forward. At the economy-wide level, Canada promotes "regional blueprints" to help its provinces develop hydrogen hubs. At the international level, Canada signed an agreement with Germany to export hydrogen to Europe by 2025. Canada is expected become one of the largest hydrogen producers and exporters with innovative technology, creating more than 350,000 sector jobs by 2050.

Practice 1: Canada has developed world-class hydrogen technologies and infrastructure across the value chain to serve domestic demands

Canada has played an indispensable role in the development of hydrogen production technology, storage, and distribution equipment. Moreover, Canada is well known for its hydrogen and fuel cell technologies because of early investment in RD&D and clean technology development for more than 40 years. It achieved the first patent for electrolysis technology in 1915, as well as the first breakthrough in proton exchange membrane (PEM) fuel cell power density in the early 1990s to prove the viable technology for transportation applications. For instance, Canadian fuel cell technology has been deployed in more than half of the fuel cell buses around the world, demonstrating its world-class hydrogen technology. In addition, Canada is strengthening its technology position by developing technologies across the value chain to reduce hydrogen costs and serve local demands and export markets in the future. It has more than 100 established fuel cell companies spanning the value chain, generating more than 2,100 job opportunities within the economy and revenue of over CAD200 Mn (USD 147 Mn).

Figure 13: Canadian players across the hydrogen value chain

These corporates are not only helping Canada achieve its ambitious goal of becoming a leading hydrogen technology developer, but also supporting the economy in building a sustainable hydrogen economy.

More importantly, the hydrogen sector invests large amounts of funding to keep Canadian companies at the forefront of innovation. The private sector spent up to USD66Mn on hydrogen research projects in 2017. In addition, Canada's Ministry of Natural Resources launched a clean fuel fund in June 2021 to grow the production of clean fuels, such as hydrogen, renewable diesel, and synthetic fuel. It also announced up to USD587 Mn in project funding to advance Canada's clean fuels in November 2022.

Practice 2: Canada promotes "regional blueprints" to build comprehensive hydrogen hubs, serving local demands and future exports

Based on the economic and geographical characteristics of different provinces, Canada has implemented a province-level strategy and roadmap to push the development of hydrogen forward. For example, British Columbia became the first Canadian province to release a hydrogen strategy in July 2021, which identifies how this province will promote, provide incentives for, and support the development of hydrogen production, use, and export over the next 10 years and beyond. Alberta developed a hydrogen roadmap as a key part to build a lower-emission energy future, and identifies blue hydrogen as a key growth area to develop its hydrogen economy. Ontario developed a low-carbon hydrogen plan to accelerate and sustain a low-carbon region. Quebec introduced a green hydrogen and bioenergy strategy to develop a framework and environment that boost the production, distribution, and use of green hydrogen and bioenergy. In addition, these provinces have implemented hydrogen and fuel cell projects and initiatives to realize their goals.

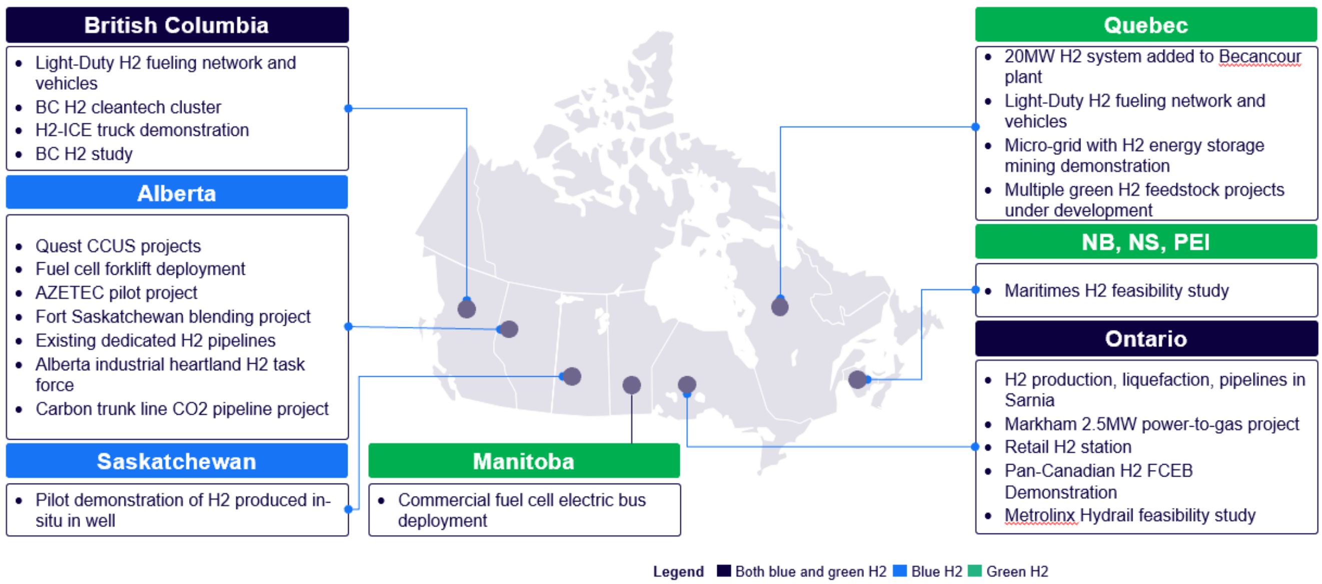


Figure 14: Hydrogen/fuel cell projects and initiatives in different Canadian provinces

Different provinces develop different types of hydrogen to promote a low-carbon hydrogen economy. While Manitoba, Quebec, and Maritime Provinces (NB, NS, PEI) strive to develop green hydrogen, Alberta and Saskatchewan prioritize producing blue hydrogen. British Columbia and Ontario focus on developing both green hydrogen and blue hydrogen.

6.3 Chile

Chile will be a global hydrogen powerhouse with the cheapest hydrogen cost. Due to its favorable geological position and abundant renewable resources – solar in the North and wind in the South, Chile is expected to produce the cheapest clean hydrogen at USD1.3–1.4/kg by 2030, compared to Australia (USD1.7) and China (USD2.2). As a proving ground for green hydrogen development, Chile has been an ideal destination for the first few hydrogen projects of big corporates such as Engie and Air Liquide, as well as implementing more than 60 hydrogen projects of its own. More notable are its outstanding private-sector partnerships, namely, the Haru Oni plant (HIF, Siemens, Porsche) and HyEx project (Engie, Enaex). Furthermore, the Chilean government shows strong public support through funding, regulation, and cooperation. The government has pledged USD50 Mn in funding to six economy-wide green hydrogen projects. It is also working on key areas to develop all-aspect legislation to push green hydrogen development. In addition, Chile has signed an MoU with Singapore for clean hydrogen technology and the Port of Rotterdam for green hydrogen export. Thanks to cost leadership in hydrogen production, Chile will become one of the largest exporters of green hydrogen and its derivatives, with 25GW electrolysis capacity and USD25 Bn export revenue by 2030.

Practice 1: Chile leverages bilateral agreements to promote private-sector partnerships for green hydrogen development

Acknowledging its ideal location for green hydrogen production, Chile has facilitated private-sector partnerships through free trade agreements to advance the hydrogen economy. It has more than 60 hydrogen projects, collaborating with international corporates to further enhance green hydrogen production. One of the prominent examples is the Haru Oni plant – the world's first industrial facility for carbon-neutral fuel in Southern Chile to decarbonize the transport sector and serve the export market.

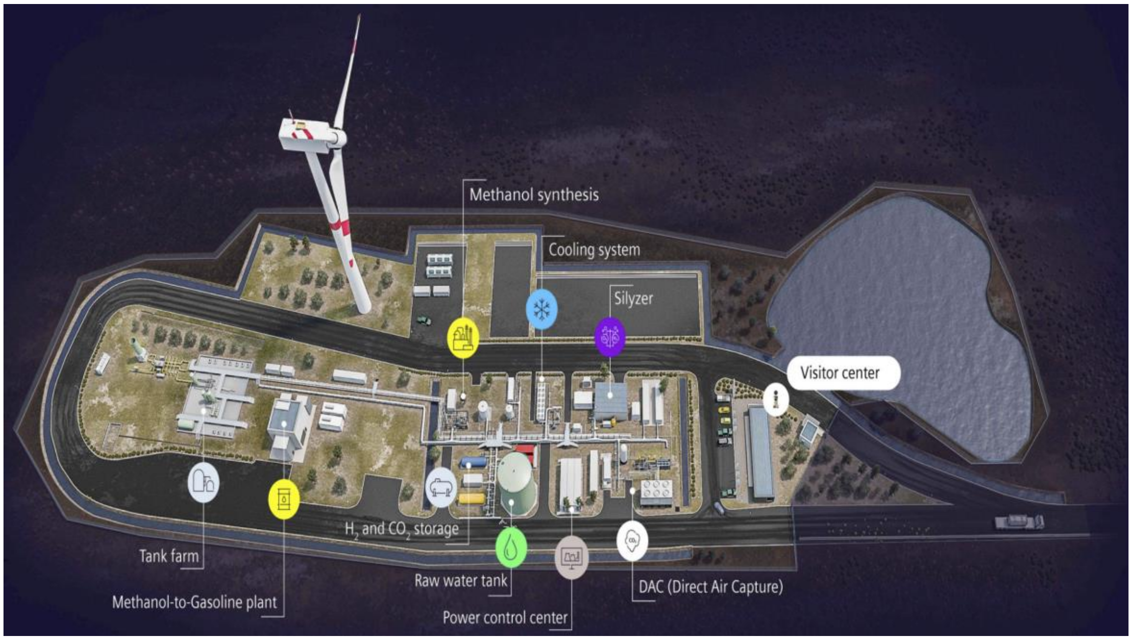


Figure 15: The layout of the Haru Oni Plant

The Haru Oni plant officially opened on 20 December2022. It is the first hydrogen project to have received USD8.7 Mn from the German government, a total investment of USD74 Mn. The plant produces green hydrogen via electrolysis using wind energy. Besides, it captures CO2 from the atmosphere and uses a process of synthesis to combine the CO2 and hydrogen to produce e-fuels, including carbon-neutral methanol (e-methanol); carbon-neutral gasoline (e-gasoline); and carbon-neutral Liquefied Gas (eLG). The plant aims to decarbonize the transportation sector through e-fuel which can be used to power cars, trucks, ships or aircraft.

In the pilot phase, the plant was expected to produce 130,000 liters of e-fuel per year until 2023. For this stage, Porsche would use the e-fuel for its Porsche Experience Centers and the Porsche Mobil 1 Super Cup. In the first phase, it is projected to increase 55Mn e-fuel liters per year by 2025. Approximately two years later, the capacity is expected to be 550 Mn e-fuel liters per year, which will show a strong commitment to energy transition in Chile, Europe, and around the world.

HIF Global is the lead developer of the Haru Oni plant, with more than eight years of studies for e-fuel development in Chile. Other partners comprise:

- Enel Green Power: an Italian partner that produces wind power and green hydrogen.
- ENAP: the Chilean state-owned energy company, which supports infrastructure and logistics.
- Siemens Energy: a Germany energy partner that is responsible for plant design and technology integration; it also supplies its electrolyzer and the wind turbine from Siemens Gamesa.
- Empresas Gasco: a Chile-based company that provides research and development for the production of synthetic gas.
- ExxonMobil: an American multinational corporation that provides the plant with methanol-to-gasoline (MtG) technology.

The Haru Oni plant is an eminent example of a case study in Chile. First, Chile leverages abundant wind resources in its southern region to produce green hydrogen. Second, it locates the plant in a strategic area near the port of Punta Arenas for exports. Third, it cooperates with other economies, such as Germany, to attract investment and co-develop hydrogen projects.

Practice 2: Chile aims to develop all-aspect legislation to push the demand and supply of green hydrogen

Chile released its National Green Hydrogen Strategy in 2020 to produce the world's cheapest green hydrogen by 2030, and to make the economy one of the top three exporters by 2040. Specifically, its vision for 2030 includes becoming the top exporter of green hydrogen and derivatives (USD2.5 Bn per annum), offering the cheapest green hydrogen on the planet (less than USD1.5/kg), and leading production via electrolysis (25GW). To achieve such goals, Chile has been working on three aspects to develop its green hydrogen economy.

- Supply: The government focuses on regulation and permits to provide transparent and harmonized standards that enable early hydrogen projects and production acceleration. Chile aims to reduce market uncertainty to boost green hydrogen projects, as well as lessen the complexity around new projects to boost green hydrogen production. In the current state, it defines economic and tax instruments, develops green hydrogen bylaws for applications, and defines green hydrogen legislation. In the future plan, it will evaluate other relevant gaps in regulations and permits that inhibit effective project execution, while assessing existing best practices.
- Demand: The government works through domestic markets and partnerships to unlock the mining sector and overseas demand. Chile aspires to boost internal demand for decarbonization and capture external demand fast to position the economy as the most competitive supplier. In the current stage, it generates public-private agreements for hydrogen usage in the mining sector, is developing a transition plan with ENAP to enable hydrogen utilization in refineries, and signs offtake agreements with big markets such as the European Union, Asia, and North America. In the future plan, it will define additional support mechanisms to foster exports and attract consortia, which will bring international demand to foster vertical integration across green hydrogen production.
- Infrastructure: The government enhances the local value in developing hydrogen infrastructure and capabilities. Chile strives to equip local territories with the potential to capture value throughout the green hydrogen production value chain. In the current state, it defines infrastructure for hydrogen hubs and gaps in large-scale manufacturing, and promotes hydrogen application in remote areas. In the future plan, it will detail value-capture initiatives for local suppliers alongside the productive value chain.

Although Chile’s regulatory situation for green hydrogen is at a nascent stage, the government is working with policy-makers to build a comprehensive framework, which is expected to roll out soon.

Practice 3: Chile has proposed a financing scheme under the National Hydrogen Strategy to provide funding for green hydrogen development

Chile has mentioned the financing and incentives under the supply side of the national green hydrogen strategy for promoting early-stage projects and closing the cost gap to enhance scale. The key initiatives in progress include attracting bilateral financing and development banking for green hydrogen production, establishing certification of origin for hydrogen quality validation, and launching a USD50 Mn funding round for scalable green hydrogen projects. In the future, it will establish additional initiatives to reduce financing costs for green hydrogen projects.

Specifically, Chile’s economic development agency, CORFO, has chosen six projects that will receive USD50 Mn in funding to advance the development of an economy-wide green hydrogen industry. The projects are located throughout Chile and across diverse industries.

- Faro del Sur: A project located in Magallanes (Southern Chile) and developed by Enel Green Power to produce 25Kt of green hydrogen per year through wind energy and the installation of 240MW of electrolyzers. The green hydrogen is expected to be sold to HIF Chile, which will produce e-fuels for export to Europe. The project has been awarded USD16.9 Mn.
- Antofagasta Mining Energy Renewable (AMER): An initiative from Air Liquide in Antofagasta (Northern Chile) will produce 60Kt of e-methanol per year from installation of an 80MW electrolyzer and renewable energy via green hydrogen and CO2 capture. The project has been awarded USD11.8 Mn.
- HyEx: A project led by Engie in Antofagasta will produce 3.2Kt of green hydrogen per year with a 26MW industrial pilot-scale plant. This green hydrogen will be supplied to the explosives company Enaex for green ammonia production. The project has been awarded USD9.5 Mn.
- Hidrógeno Verde Bahía Quintero: An initiative led by natural gas company GNL Quintero will produce the first large-scale green hydrogen plant, with expected capacity of 430t of green hydrogen per year from 10MW electrolyzer in Valparaiso (Central Chile). The project has been awarded USD5.7 Mn.

- H2V CAP: A project from the mining company CAP aims to produce 1.55kt of green hydrogen from a 20MW electrolyzer in Biobío (Central Chile). The project has been awarded USD3.6 Mn.
- HyPro Aconcagua: A project from German engineering company Linde GmbH in Valparaiso plans to replace part of its current gray hydrogen production at the Aconcagua refinery with 3Kt of green hydrogen per year from a 20MW electrolyzer. The project is awarded USD2.4 Mn.

The six projects, which each have at least 10MW capacity commencing by 2025, are expected to attract a total of USD1 Bn in investment and develop an electrolyzer capacity of 388MW that will produce more than 45Kt of green hydrogen annually.

6.4 China

China is one of the global leaders in green hydrogen production. The government will allocate almost 25 percent of its renewable energy to hydrogen over the next five years, much higher than the 5–10 percent in Europe, Australia and Chile. China is accelerating hydrogen development through major SOEs, paving the way for hydrogen production and active collaboration with international players. Moreover, it is the dominant force in electrolyzer technology, aiming to ramp up electrolysis capacity to 100GW by 2030. More than 40 percent of electrolyzers made today come from China, so the economy can leverage its expertise, resources, and cost leadership strategy for export. In addition, China shows active development in hydrogen transportation and technology. It allocated 52 percent of its project funding to this area during 2018–2020. The government also supports hydrogen transport for high energy-consuming provinces and cities by providing local policies. Hence, China will emerge as a green hydrogen powerhouse by implementing technology cost leadership in green hydrogen and adopting a cost leadership strategy in technology development through government-level funding. Foreign economies can benefit from joining China’s growing industry through R&D cooperation and standard setting.

Practice 1: China establishes cost leadership in electrolyzers to support domestic demand and exports, aided by both the public and private sectors

Beyond vast renewable energy resources, China focuses on reducing electrolyzer costs so it can achieve one of the most competitive hydrogen prices in the world. As China has already accounted for one-third of global manufacturing capacity, it can manufacture all key parts with few exceptions, such as hydrogen valves, and domestic manufacturers are price competitive. However, according to MERICS, they are not yet on par with international standards in terms of efficiency and reliability for large systems. Thus, the public and private sectors have offered various measures and initiatives to support the growth of electrolyzers. This will allow Chinese electrolyzer manufacturers to scale up, refine their technologies, and become more cost competitive.

For public sectors, measures such as R&D funding, research collaboration, and financial market support aid hydrogen technology development. R&D funding for hydrogen has been increasing since 2015, and the investment increased sixfold between 2018 and 2019 (International Energy Agency and Mission Innovation). Among China’s R&D funding, the National Key R&D Programs (NKPs) are the largest for applied technology and the second-largest channel for public R&D funding. The government has announced 66 NKP projects focusing on hydrogen technologies since 2016, with a total estimated value of USD250–720 Mn. Out of 66 NKPs, 14 focus on green hydrogen technologies, with a combined estimated value of USD58–180 Mn. These projects encourage R&D into alkaline and proton-exchange membrane (PEM) electrolyzer technologies to advance the cost, efficiency, power, and scalability of hydrogen production. Besides that, the Ministry of Science and Technology has provided USD78 Mn in R&D funding under “Renewable Energy and Hydrogen Energy Technology” to enhance hydrogen technologies and production. The funding stream will be allocated with a balanced distribution between upstream production and downstream applications. For research collaboration, many research institutes that participate in State Key Laboratories play an important role in hydrogen technology development.

For example, the lab at the Dalian Institute of Chemical Physics, part of the Chinese Academy of Science (CAS) developed a new catalyst that is used for highly efficient alkaline electrolysis. Since the government controls or funds the majority of China’s leading green hydrogen innovators, such as public universities, the CAS, and SOEs, they aim to promote the domestic innovation ecosystem through collaboration among universities, local companies and international enterprises. The CAS acts as a central point to collaborate with research institutes for green hydrogen technologies, and partners with corporates for green hydrogen patents. For instance, the Technical Institute of Physics and Chemistry, part of the CAS, conducts research for electrocatalytic hydrogen evolution reaction (HER) as an efficient method to produce green hydrogen. The CAS has worked with corporates such as PetroChina, Boeing, and Shell to create multiple patent families. For financial market support, the People's Bank of China offers green loans with a low-interest rate (1.75 percent green interest rate versus 3.85 percent 1Y loan prime rate) to clean hydrogen projects, helping corporates invest in hydrogen technologies. Hydrogen start-ups are also encouraged to be listed in the Shanghai and Shenzhen stock exchanges for easier capital raising.

For the private sector, there are initiatives such as investment for capacity building and partnerships for technology advancement. For capacity investment, State Power Investment Corporation (SPIC), China's largest state-owned power company, announced that it would invest of USD1.45 Bn in a project to develop high-end PEM equipment, including a manufacturing base with an annual output of 40GW. Longi Green Energy Technology Company, a Chinese solar manufacturer, ramped up its production of electrolyzers in 2021 to drive down the cost. Belgium's Cockerill Jingli Hydrogen partners with the Dalian Institute of Chemical Physics to develop electrolysis technology and works with China's Huaneng Group to produce the world's first 1,300 normal cubic meters per hour alkaline electrolyzer. United Statesfirm Sinopec Cummins teamed up with China Sinopec to form a 50/50 joint venture to promote Cummins' PEM electrolysis technology in China with a plant of 1GW capacity by 2028.

Establishing electrolyzer cost leadership supports China in increasing domestic green hydrogen production because the economy is looking to replace imported parts with domestic alternatives, as well as achieve the low cost of green hydrogen at USD2.4/kg by 2030 by ramping up capacity to 100GW. Moreover, it can position China as a global electrolyzer exporter. For instance, PERIC Hydrogen Technologies and Shandong Saikesaisi Hydrogen Energy have already started exporting electrolyzers to other markets.

Practice 2: Local governments issue local policies with a high level of guidance from the central government to push the development of hydrogen in transport

China issued a "Medium and Long-term Plan for Hydrogen Energy Industry Development (2021–2035)" in March 2022 to develop and implement hydrogen usage. The domestic hydrogen strategy will focus on general industry development first and green hydrogen second after 2030. It prefers the state-capitalist approach of depending on local governments, R&D centers, and SOEs to develop an industry around strategic policy targets. Although China's economy-wide targets are conservative, local governments are actively driving hydrogen development. Specifically, they issue local policies to boost hydrogen development in transport.

More than 20 local governments mentioned hydrogen in their fourteenth Five-Year Plans, and over 50 cities have issued 201 policies related to hydrogen and fuel cells to grow their local hydrogen industry. Nearly all provinces and cities that have issued hydrogen policies have focused on FCVs. Four provinces and cities, Beijing, Shanghai, Hebei, and Shandong, plan to have 40,000 FCVs by 2025. Some hydrogen fuel cell vehicle clusters have formed, with advanced regions having adopted FCVs and potentially influencing adjacent areas. These developed areas will leverage established industries to expand across the hydrogen value chain. For instance, Shanghai plans to consolidate its success in FC batteries, FCV manufacturing, and testing while exploring opportunities in hydrogen storage.

Central government provides strategic guidance for provinces to push hydrogen in transport forward, with the target of 50K FCVs on streets by 2025. It encourages infrastructure buildout, including production, transport, storage, and refueling stations for faster adoption of FCVs. It advances demonstration projects and promotes innovation in core technology, collaboration, and education to enhance the deployment of FCVs. In addition, the central government offers funding to support growth of FCVs via a program that provides reward incentives for city clusters that industrialize core FC technologies. It offers a reward of up to USD250 Mn for local governments that meet target achievements, rather than providing subsidies, which avoids reliance on subsidies and promoting cooperation and innovation.

6.5 Japan

Japan fosters the global hydrogen supply chain. For decarbonization purposes, Japan aspires to establish an "S+3E" (Safety, Energy security, Economic efficiency, and Environmental sustainability) hydrogen society, and has made significant progress in hydrogen application. It has commenced its demonstrated operation of a hydrogen plant in Fujuyoshida to serve households with power generation and energy security. For automotive, it invests in hydrogen mobility and leverages automobile capability to advance hydrogen transport. In addition, it facilitates global partnerships to build a global hydrogen supply chain. Because it lacks resources for hydrogen production, Japan has imported an estimated 5–10Mt of hydrogen for power generation in the future. Through this, it has forged international partnerships with economies such as Germany, France, and Canada and established infrastructure to secure a stable global supply. Besides, Japan establishes Asia Zero Emission Community (AZEC) to build hydrogen and ammonia supply chains especially in the Indo-Pacific region. In return, Japan aims to be an exporter of hydrogen products. Thanks to technological advancement, it can export technologies such as fuel cells and CCUS to other markets. It also has wide-ranging participation among its residents and industries to improve the global hydrogen economy. With hydrogen demand in transport, power, and industrial applications growing, Japan will be a major importer backed by international agreements and import infrastructure.

Practice 1: Japan plans to ramp up domestic hydrogen demand via public funding, stakeholder engagement, and supply chain development

Japan has increased local hydrogen consumption via three key measures – direct government funding, collaboration enhancement, and establishment of a robust hydrogen supply network. For direct government funding, the Japanese government has developed a Green Innovation Fund at the level of JPY2 Tn (USD14.7 Bn) as part of the New Energy and Industrial Technology Development Organization (NEDO). It provides tremendous support for up to 10 years for R&D projects, demonstration and social implementation projects from "green" companies with ambitious goals. Specifically, the government has allocated JPY370 Bn (USD2.7 Bn) from the Green Innovation Fund for two projects to push hydrogen R&D and use over the next 10 years. One involves up to JPY300 Bn (USD2.2 bn) to increase demand for clean fuel and create a large-scale hydrogen supply chain. The other JPY70 Bn (USD500 Mn) project aims to develop a sizable, cost-efficient hydrogen production system through water electrolysis using renewable electricity. These were the first projects announced by the government in 2021 to support hydrogen R&D and use from Green Innovation Fund. It has planned to announce more potential projects in the near future.

In addition, the Ministry of Economy, Trade and Industry (METI) offered to fund approximately USD591 Mn for green hydrogen development, with more than 60 percent of used in the downstream application in 2021. For collaboration fostering, 11 private Japanese companies formed the Hydrogen Utilization Study Group in Chubu in March 2020 to increase hydrogen demand and build a sustainable supply chain for hydrogen utilization in the Chubu region. These 11 companies worked together to conduct cross-sectional studies focusing on hydrogen demand and import infrastructure in Chubu, driving the regional consumption of hydrogen. To decarbonize the transport sector, the METI established the Mobility Hydrogen Public-Private Conference in 2022 for the public and private sectors, suppliers and consumers to develop a shared future vision and policies for hydrogen application in commercial mobility.

To ensure a robust hydrogen supply network establishment, Japan leverages international trade agreements with other economies. For instance, it signed a trade agreement with Saudi Arabia for ammonia import, and with Australia for liquefied hydrogen import. Moreover, it could receive direct funding support for international hydrogen transport projects to facilitate hydrogen development. For example, its Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD) launched its pilot project to bring hydrogen from Brunei Darussalam to Tokyo Bay to power gas turbines for power generation with financial support from NEDO.

With this support, Japan is driving domestic hydrogen consumption in various sectors and critical progress in hydrogen applications.

1. **Transportation:**
   - Toyota launched the first hydrogen FCV, Mirai, in 2014.
   - 162 hydrogen stations were established by 2021.
2. **Power generation:**
   - Toyota launched the first hydrogen FCV, Mirai, in 2014.
   - 162 hydrogen stations were built by 2021.
3. **Heat use:**
   - Under the Ene-Farm initiative, 300,000 units of residential fuel cells have been installed.

4. **Industrial processes:**

- Nippon Steel plans to start making iron produced using hydrogen.

Practice 2: Japan partners with industry players and governments, both domestically and internationally, to secure a supply of cheap hydrogen or derived compounds

As a hydrogen importer, Japan leverages international trade agreements to collaborate with other governments and their industries so it can guarantee procurement of cheap hydrogen or its derivatives. Currently, it has 28 projects in the pipeline. Below are some of its prominent projects illustrating global partnerships in the private and public sectors:

- Fukushima Hydrogen Energy Research Field: A project led by a consortium of Japanese companies (Toshiba, Iwatani, Asahi Kasei, and Tohoku Electric Power), located in Fukushima (Japan) with a capacity of 900t of green hydrogen per year and is funded by NEDO. The project was launched in 2018 and piloted in 2020.
- Brunei MCH pilot: A project led by a consortium of Japanese companies (AHEAD, Mitsui, NYK Line, Chiyoda, and Mitsubishi) with the support of the Japanese and Brunei governments, located in Brunei Darussalam, has a capacity of 210Mt of gray hydrogen per year and is funded by NEDO. The project was launched in 2017 and piloted in 2020.
- Hydrogen Energy Supply Chain (HESC): A project led by a consortium of Japanese (Kawasaki, Iwatani, Sumitomo and J-Power) and international companies (France's HySTRA and Australia's AGL), located in Australia, has a capacity of 225Kt of blue hydrogen per year and is funded 80 percent by NEDO and 20 percent by Australian governments (USD340 Mn). The project was launched in 2018 and piloted in 2022.
- Saudi Blue Ammonia Pilot: A project led by a consortium of Japanese companies (IEE Japan, Mitsubishi, UBE, JGC) and a Saudi Arabian enterprise (Aramco), located in Saudi Arabia, has a capacity of 40t of blue ammonia per year and is supported by the Japanese and Saudi Arabian governments. The project was launched in 2019 and piloted in 2020.
- Indonesia Blue Ammonia Pilot: A project led by Japanese companies (Jogmec and Mitsubishi) and an Indonesian enterprise and university (Panca Amara Utama and Institute Teknologi Bandung) is located in Indonesia to produce blue ammonia. The project was launched in 2021, and the pilot stage will be announced soon.

6.6 Korea

Korea will be a global net hydrogen importer. Due to restricted natural resources for clean hydrogen production, it will increase local demand to 2.9Mt hydrogen by 2030. In addition, its domestic hydrogen roadmap reports its reliance on offshore production to boost hydrogen development. It is also planning to build hydrogen pipelines and ammonia facilities to support hydrogen import. Additionally, Korea aims to be a leader in hydrogen downstream applications, as this is its key focus in hydrogen strategy, especially in FCVs, refueling stations, and stationary hydrogen power plants. In 2021, Korea was the largest seller of hydrogen vehicles, which indicates its strong application in transportation. Furthermore, Korea has established strong collaboration across the public and private sectors. It has a strong engagement of private players as domestic consortia. Internationally, it facilitates G2G cooperation to accelerate hydrogen development. It will emerge as a leader in hydrogen use in transportation and power generation, an exporter of downstream application technology, and a global player in overseas markets.

Practice 1: Korea is advanced in fuel cell technology with government support and effort from the private sector

Korea has strong targets for hydrogen usage. For consumption, it aims to reach at 5.26Mt per year in 2040 from 130Kt per year in 2022. For the transportation sector, it has set its 2040 FCEV target to nearly 3Mn, including 2.9Mn domestically produced FCEVs, 30K fuel cell trucks, and 40K fuel cell buses. In 2020, Korea was the world’s leader in FCEV installation, with over 10K FCEVs on the road, thereby doubling the economy-wide stock from 2019. To maintain its dominating position in fuel cell technology, Korea has implemented four key areas to enable fuel cell applications – subsidy, funding, pilot cities, and policy and regulation.

For subsidy, the central and local authorities provide USD288.7 Mn for hydrogen vehicles, which potentially halves the purchase price. For example, the end-user price for the Hyundai NEXO is KRW30 Mn, compared to the original price of KRW70 Mn, thanks to the central subsidy of KRW22.5 Mn and local subsidy of KRW10–20 Mn. In addition, the governments offer other incentives, including a 50 percent reduction of toll charges, free or reduced parking fees, and tax breaks, directly driving the FCEV adoption rate and advancing FC technology deployment.

For funding, the public and private sectors are putting tremendous effort into development of a hydrogen supply chain and hydrogen technology. The government has introduced Korea’s New Deal as one of its key pillars for the economy’s carbon neutrality push, with USD15.8 Bn in funding for hydrogen mobility. This is backed by huge Korean industrial companies, including auto manufacturers such as Hyundai Motors Group, whose own FCEV vision for 2030 is accompanied by investment plans of USD5.8 Bn. The Korea H2 Business Summit, established by 15 of Korea’s leading conglomerates, launched a fund of KRW500 Bn (USD385 Mn) in 2022 to build a hydrogen value chain and promote commercialization of hydrogen technology. In addition, The Hydrogen Energy Network (HyNet) was established as a consortium of 13 of Korea’s leading industrial companies in 2019 with an investment of KRW135 Bn (USD104 Mn) for hydrogen refueling station (HRS) constructions and operations; this expanded the number of HRSs from 24 in 2019 to 100 in 2022, as well as the use of fuel cell technology.

For pilot cities, the Ministry of Land, Infrastructure, and Transport (MOLIT) announced that three cities (Ansan, Ulsan, and Wanju-Jeonju) would be the Hydrogen Pilot City in 2019, responsible for testing hydrogen application in transportation, industry, and space heating in 2022. These pilot cities are the first to operate hydrogen vehicles, such as hydrogen buses and taxies, with Ulsan as a free trade zone for hydrogen mobility.

For policy and recommendation, the government passed its Hydrogen Law in 2020 to build a sustainable hydrogen economy, including advancement of hydrogen technology. Furthermore, the government introduced the Renewable Portfolio Standard (RPS) to incentivize fuel cell power generation through renewable energy certificates in 2012. Further, the Ministry of Trade, Industry and Energy (MOTIE) proposed separating hydrogen from RPS to establish the Clean Hydrogen Energy Portfolio Standard (CHPS) and an economy-wide clean hydrogen certificate scheme in 2022, emphasizing the importance of hydrogen in the economy. Finally, the Korea H2 Business Summit provides policy recommendations for the government to bolster support for hydrogen technology and mitigate regulations for new technology development.

Practice 2: Korea is active in collaborations across sectors, both domestically and internationally, to advance the hydrogen economy

Besides introducing a domestic hydrogen roadmap, legislation, and funding, Korea actively local and international partnerships to further advance the hydrogen economy.

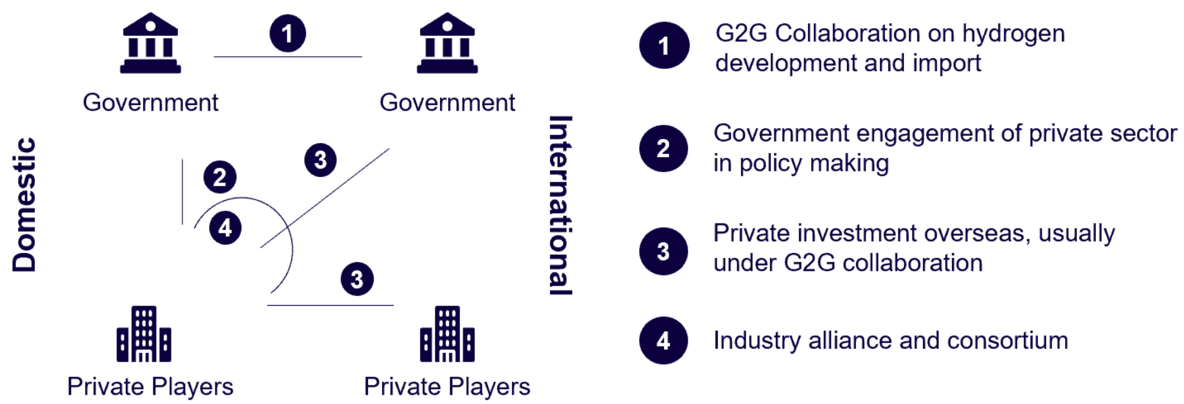


Figure 16: Korea's partnership model for hydrogen development

The case studies for each type of partnership are illustrated in the following:

1. Government to government (G2G) collaboration on hydrogen development and import: Korea partnered with Australia to establish the Low and Zero Emissions Technology Partnership in 2021 to advance technologies, push trade systems for hydrogen suppliers, and develop low-emissions products (steel and iron ore).
2. Government engagement of the private sector in policy-making: H2 Korea is a public-private consultative body that builds a connection between government institutes (35 government agencies) and private players (96 companies) to enhance policy-making, systems, and distribution of hydrogen led by private sectors.
3. Private investment overseas, usually under G2G collaboration: Three Korean companies (Korea Electric Power Corporation, Samsung C&T, and Korea Western Power) cooperated with the UAE's Petrolyn Chemie to build a USD1 Bn green hydrogen and ammonia production plant in the UAE in 2022, with a capacity of 0.2Mt of green ammonia per year.
4. Industry alliance and consortium: The Korea H2 Business Summit, built by a consortium of 17 leading Korean conglomerates, launched a fund of USD385 Mn in 2022 for the hydrogen value chain and technology. It also facilitates discussion of hydrogen industry challenges and provides policy recommendations.

6.7 Singapore

Singapore has been researching ammonia-cracking technology to enhance its positioning as a global transport hub. It has partnered with Australia's CSIRO to increase research and development in science and innovation, driving hydrogen technology development. In addition, the Maritime and Port Authority of Singapore (MPA) promotes maritime decarbonization and ammonia use for power generation and bunkering. In December 2022, the MPA and Energy Market Authority called for an expression of interest to build, own, and operate low, zero low, or zero-carbon power generation and bunkering solutions in Jurong Island. Singapore has also conducted many feasibility studies and discussed hydrogen legislation to advise the transition toward bunkering.

Singapore is also an early advocate for hydrogen development. Despite releasing the national hydrogen strategy in late 2022, it has applied efforts and resources to support hydrogen development. It has dedicated public funding hydrogen projects – for example, USD96 Mn in funding under Low Carbon Energy Research (LCER) phase II. For public private partnership funding, Centre for Hydrogen Innovations was established with support from Temasek and NUS to enhance hydrogen technology R&D. Finally, Singapore has leveraged international partnerships to build a sustainable hydrogen economy. It has collaborated with foreign corporates for domestic hydrogen transition because of the nascent stage of hydrogen. It also has built international partnerships with economies such as Australia; Chile; New Zealand as a basis for future positioning as a facilitator of global hydrogen. Singapore will become the trendsetter in maritime decarbonization in Southeast Asia by leveraging its existing position as a transport hub and continuing its dedicated R&D investment. It will also be a green hydrogen importer with its sea fleet infrastructure and technology.

Practice 1: Singapore has collaborated with Rotterdam to establish the "Singapore – Rotterdam Green Shipping Corridor" to decarbonize the maritime and shipping industry

To realize its dream of trendsetting in green maritime, the Port Authority of Singapore partnered with the Port of Rotterdam to build the first Green and Digital Shipping Corridor.

Figure 17: Singapore & Rotterdam Green Shipping Corridor – the world's longest green corridor

The port authorities for each port aim to inspire others to follow their lead, while seeking to expand on the concept of green shipping corridors first introduced at COP26. In addition, they want to optimize maritime efficiency and safety and the transparent flow of goods by supporting the use of digitalization. More importantly, they aim to decarbonize the maritime and shipping industry through hydrogen infrastructure development and increasing the use of sustainable alternative fuels. This project will help raise investment confidence, attract green financing, and kick-start joint bunkering pilots and trials for digitalization.

The Singapore & Rotterdam Green Shipping Corridor serves as a valuable platform to pilot ideas that can be scaled up for more sustainable international shipping. It also helps address challenges regarding alternative fuels, such as costs, availability, and safety. To enable the first sustainable vessels to sail on the route by 2027, it will bring together key members (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping and the Global Centre for Maritime Decarbonization), the port operator (the Digital Container Shipping Association), shippers (CMA CGM, Maersk, MSC, and Ocean Network Express), fuel suppliers (BP and Shell), and standards (the Digital Container Shipping Association) to transition towards low and zero-carbon alternative fuels.

Practice 2: Singapore has offered a wide range of funding mechanisms and initiatives to support hydrogen development

The public and private sectors have introduced various funding initiatives to advance the development of hydrogen. Public funding has five initiatives, while public private partnership funding has only two.

- Low Carbon Energy Research (public funding): A multi-agency initiative (involving A*STAR, EDB, EMA, NCCS, and NRF) aims to develop low-carbon energy projects including hydrogen and CCUS to support decarbonization strategy. The first grant of USD42 Mn was issued in 2021, and the second grant of USD96 Mn will be issued soon.

- Research, Innovation and Enterprise Plant 2025 (public funding): An initiative led by NRF supports companies in establishing their RD&D activities in low-carbon energy technologies in Singapore. A budget of approximately USD19 Bn has been dedicated – USD5.4 Bn for capability development at universities and A*STAR Research Institute, USD4.8 Bn for mission-oriented research, USD3.9 Bn for innovation capabilities and entrepreneurial talent, USD2.8 Bn for new program support, and USD1.6 Bn for postgraduate programs and talent development.
- Green Finance Action Plan (public funding): An initiative led by MAS aims to develop green finance solutions and markets, as well as build international collaboration for green finance with a green investment program of USD2 Bn.
- Enterprise Sustainability Program (public funding): a program developed by Enterprise Singapore helps SMEs develop capabilities in sustainability with funding of approximately USD134 Mn over four years.
- Industry Alignment Fund (public funding): The programs led by A*STAR support transfer of capabilities, IP, and technologies to industry applications to achieve tangible economic impact.
- Centre for Hydrogen Innovation (public private partnership funding): The Centre established by NUS and Temasek Holdings strives to develop breakthrough technology to make hydrogen commercially available with funding of USD19 Mn.
- The SgEC consortium (public private partnership funding): a partnership founded by NTU, NUS, and Exxon Mobil leads several core research projects in science and engineering with undisclosed funding. It also facilitates member-directed projects defined by industry members and undertaken with research partners.

6.8 The United States

The United States is the key enabler of the global energy transition to hydrogen. It is pursuing a low-cost strategy as a backbone for the hydrogen economy. The United States Department of Energy (DoE) has introduced many plans and initiatives to support hydrogen development and cost reduction. Besides that, the government facilitates cooperation in R&D and scale-up to further drive down hydrogen cost. Beyond the low-cost strategy, the United States focuses on connecting supply and demand through infrastructure buildout and regional hydrogen hubs. It can leverage its well-established energy infrastructure to develop hydrogen infrastructure. It is also establishing regional hydrogen hubs to not only connect large-scale production plants with customers, but also decrease hydrogen costs. Because of this, the United States is a global advocate for hydrogen transition. For international collaboration, it has joined the International Partnership for Hydrogen and Fuel Cells (IPHE) in the Economy to partner with other economies in terms of policy, production, and trading. In support of the program, it participates in the Just Energy Transition Partnership (JETP) to help finance the energy transition in developing economies. It will be the key player in the global hydrogen ecosystem, with a strong domestic hydrogen economy as well as technology export and international collaboration. It will manufacture and use approximately 49.2Mt of clean hydrogen in 2050, generating USD750 Bn in revenue and 3.4 Mn jobs.

Practice 1: Hydrogen cost reduction in the United States is supported by several public policies and incentives

As hydrogen plays an important role in energy transition, The United States has made a significant investment in clean hydrogen through a wide range of policies and initiatives, namely H2@Scale, Hydrogen Shot Goal, the Infrastructure Investment and Jobs Act (IIJA), and the Inflation Reduction Act (IRA). In 2016, The United States DoE launched the H2@Scale initiative to connect stakeholders and advance affordable hydrogen value development (production, transport, storage, and utilization) to enable decarbonization and revenue opportunities across various sectors. It facilitates cooperative agreements for USD750 thousand to USD5 Mn per project, each lasting three to four years.

The H2@Scale initiative has more than 20 projects, and the selected projects can leverage the Advanced Research on Integrated Energy Systems (ARIES) platform to enable integration of hydrogen technologies in future energy systems. In addition, it can support up to 80 percent of total project costs and help drive down hydrogen costs. In June 2021, the United States DoE launched the Hydrogen Shot initiative with a fund of USD400 Mn to reduce the cost of clean hydrogen by 80 percent to USD1/kg in one decade (“1 1 1”). It is also building a framework and foundation for clean hydrogen deployment in the American Jobs Plan, including support for demonstration projects. Achieving Hydrogen Shot goals will increase clean hydrogen use at by least five times, generate USD140 Bn in revenues and 700 thousand jobs in 2030, and reduce carbon dioxide emission by 16 percent in 2050. In November 2021, the government introduced the Infrastructure Investment and Jobs Act (IIJA) with a fund of USD8 Bn to develop clean hydrogen hubs, supporting clean hydrogen production, processing, delivery, storage, and end use. In addition, USD1.5 Bn in funding will be used for clean hydrogen manufacturing and advancing recycling RD&D, which will help decrease the cost of hydrogen through scale. In August 2022, the government presented the IRA with a fund of USD369 Bn for renewable and green energy projects in the form of a tax credit, increasing domestic manufacturing capacity and jumpstarting R&D and commercialization of technologies such as CCUS and clean hydrogen.

For clean hydrogen, the “45V” tax credit took effect for products sold after December 2022, with support of up to USD3/kg of clean hydrogen based on carbon intensity (up to 10 years) and an investment tax credit of up to 30 percent can be claimed for eligible technologies. Thus, the IRA will have a positive impact on clean hydrogen – the price of clean hydrogen (USD0.4/kg) will be 30 percent cheaper than that of gray hydrogen (USD1–1.5/kg) by 2030, and investors can earn 23 percent returns if they sell green hydrogen at the price equal to the cheapest blue hydrogen.

Practice 2: Technology breakthroughs and scale-ups through collaborations push down hydrogen prices from production to delivery

The United States has facilitated clean hydrogen collaborations for technology breakthroughs and scale-up to reduce hydrogen cost:

- H2New: An initiative from the DoE with the participation of nine national labs aims to make large-scale electrolyzers that produce hydrogen from electricity and water. For example, it targets cost gains from scaling up processes for Membrane Electrode Assemblies (MEA).
- CRADA H2@Scale: An initiative from the DoE with the participation of national labs and industry players and USD8 Mn in funding aims to advance the affordable hydrogen value chain. For example, it produces low-cost hydrogen through Methane Pyrolysis at less than USD2/kg.
- APEP: An initiative from the University of California Irvine with industry partners aims to enhance the development and deployment of sustainable power generation, energy conversion, and hydrogen. For example, it has the first power-to-gas hydrogen pipeline injection project in the US.
- Wilbarger County Green Hydrogen: A partnership between Air Products and AES with USD4 Bn in funding aims to build a mega-scale renewable power to hydrogen project as the US's largest green hydrogen production plant.

Practice 3: The United States connects supply and demand through infrastructure buildout and regional hydrogen networks

Besides issuing policies and initiatives to support hydrogen production and utilization, the United States continues to scale up infrastructure and introduce a hydrogen network, matching supply with demand. In terms of infrastructure scale-up, it has a well-established and significant infrastructure already in place for transport and pipeline. For transport, it has more than 1,600 miles of dedicated hydrogen pipelines and a robust network of approximately 3Mn miles of natural gas pipelines, and has had success in testing hydrogen blend-in gas pipelines. It also has 18 liquefaction plants and 10 regasification plants. For storage, the United States has the world's largest hydrogen storage vessel in Kennedy Space Center and has established the Hydrogen Materials Advanced Research Consortium (HyMARC, a consortium of five national laboratories - Sandia National Laboratories, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Lawrence Livermore National Laboratory, and Lawrence Berkeley National Laboratory) to facilitate discovery of new storage materials and carriers. It also has three massive geological caverns. For the regional hydrogen network, the United States aims to create at least four regional clean hydrogen hubs (H2Hubs) for clean hydrogen development. The hub should co-locate clean hydrogen production with multiple end uses and accelerate the use of clean hydrogen by creating a network of producers, consumers, and local connective infrastructure.

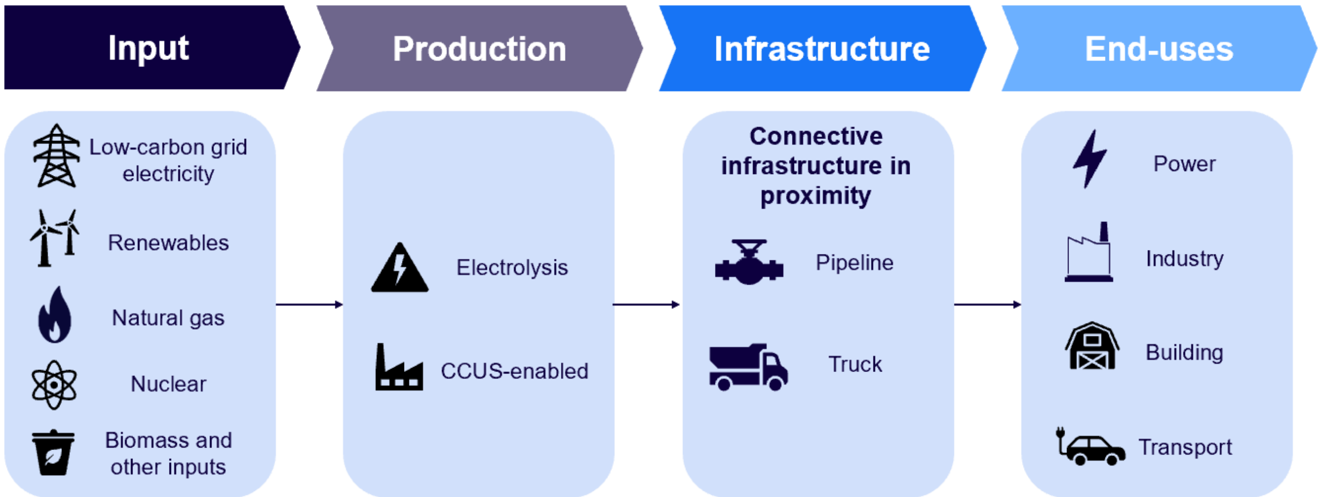


Figure 18: The United States regional network model for H2Hubs

The regional network model aims to promote low-cost hydrogen, foster infrastructure, replicate demonstration, avoid stranded assets, and benefit communities. Therefore, the government has implemented key enabling initiatives to support the regional network model through public funding of USD8 Bn for H2Hubs (under IIJA), the clear guideline for clean hydrogen production standards, and 50/50 private investment requirements.

Practice 4: The United States is active in elevating global hydrogen development through international collaborations, especially in supporting developing economies

As a global advocate for hydrogen development, the United States has formed global partnerships and international support programs with other economies to not only support itself, but also assist developing economies. The United States is one of the founding members of the IPHE, together with the European Commission and 22 other economies, which was established in 2003 to facilitate information sharing, government RD&D, and collaboration fostering. It also pledged during Tokyo Green Transformation week in 2022 to ramp up global clean hydrogen production to 90Mt by 2030, along with other 20 economies (including Germany and Australia), to emphasize its seriousness about clean hydrogen development. For its international support program, the United States takes part in JETP to provide financing for energy transition in developing economies such as South Africa, Indonesia, and Viet Nam. Specifically, it has provided USD20 Mn in grants and technical support and USD1 Bn in commercial loans to South Africa for energy transition, including hydrogen development. Moreover, the United States partnered with Viet Nam to launch USD36 Mn in funding for the Viet Nam Low Emission Energy Program II (V-LEEP II) in 2022, which builds on the success of V-LEEP I in 2015–2022 to speed up Viet Nam's transition to clean energy. This project includes a seminar on the important role of hydrogen in energy transition, encouraging Viet Nam to deploy clean hydrogen in the future.

7. Strategic and policy recommendations

7. Strategic and policy recommendations

This section outlines the insights and options for economies to develop their hydrogen economy and the role of APEC in enabling that development.

7.1 The archetypes

To ensure a targeted strategy, economies first need to determine their role in the value chain and stage of hydrogen development. For instance, the set of initiatives for an economy in the advanced stage of fulfilling the supply role in the value chain would be vastly different from that of a nascent counterpart. We have identified four archetypes into which economies could fit. (See ***Figure 19***.)

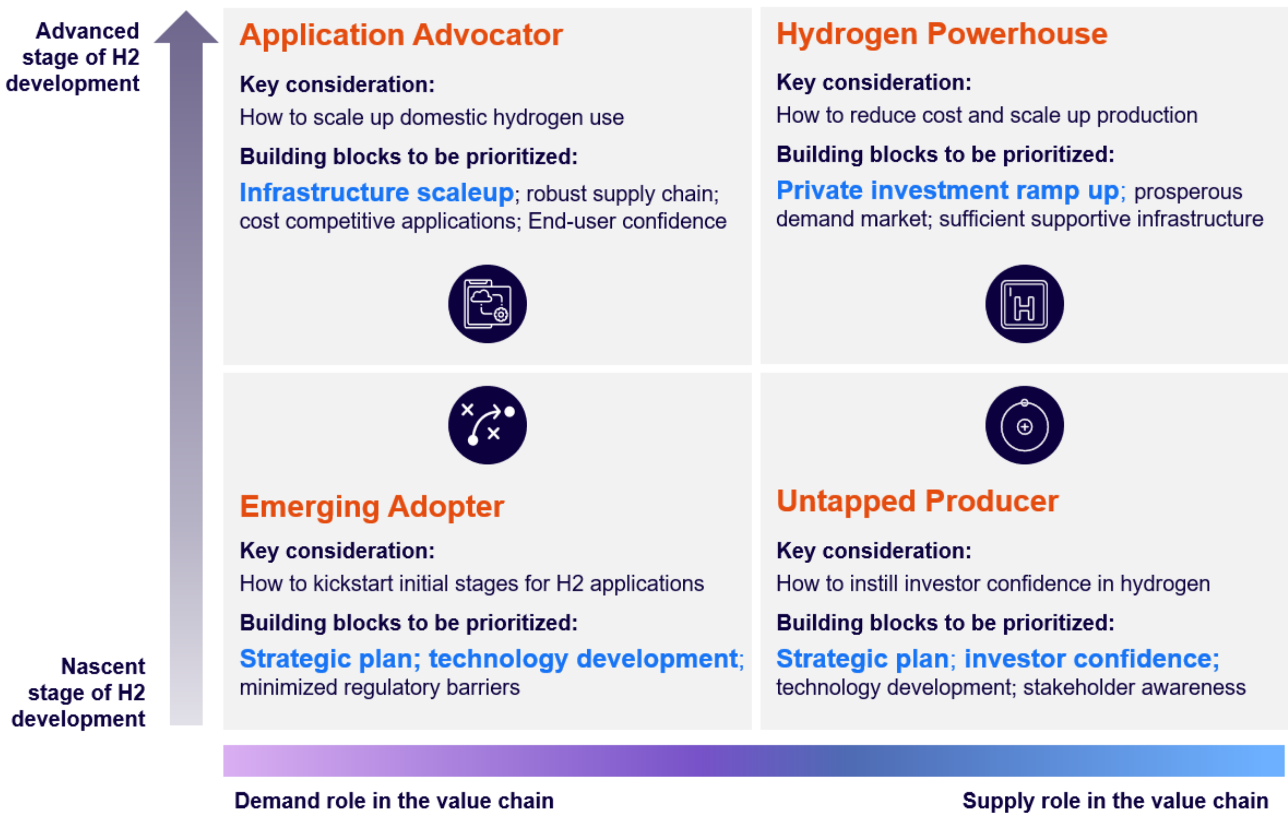


Figure 19: Archetypes within the hydrogen economy

The **"Application Advocators"** are economies that fulfill the demand role in the value chain and are currently at an advanced stage of hydrogen development. These economies have been kickstarting their domestic market for hydrogen for some time, perhaps through hydrogen-powered vehicles or power plants. The next phase will be to focus on initiatives to scale up domestic hydrogen use. To do so, they must emphasize infrastructure scale, a robust supply chain, cost-competitive applications, and end-use confidence. We have identified scaling up infrastructure as one of the priority levers, planning the infrastructure of the future is important, just like with power grid planning. Planning will allow these economies to ascertain the need for investment in new hydrogen pipelines, as well as compression stations and pressure regulators for repurposing existing pipelines.

Advanced demand economies are already implementing widespread infrastructure planning and development, as is evident from Europe's recent launch of the European Hydrogen Backbone initiative to foster market competition, security of supply, and security and demand. If APEC economies can enable scaling up of infrastructure, it will serve as the backbone for widespread hydrogen adoption, ultimately enabling end use at scale, boosting producer confidence, and improving market efficiency.

The **“Hydrogen Powerhouse”** archetype includes economies that are fulfilling the supply role in the value chain and currently at an advanced stage of hydrogen development. To solidify their position as leading players, these economies will need to shift their focus to reducing costs and scaling up production. We have identified ramping up of private investments as one of the priority levers. While these economies likely have domestic hydrogen strategies and projects in the pipeline, they must make significant investments in scale-up to achieve the next phase of growth, and the focus should be on catalyzing private investment. In particular, they must consider promoting innovation, efficiency gains, and developments in electrolyzer manufacturing within the private sector, a key component in green hydrogen.

This is especially important due to the large levels of investment required for hydrogen, which means public capital is typically insufficient to make hydrogen mainstream. Therefore, with a combination of public and private capital, economies can achieve a boost in innovation and, more importantly, market-driven resource allocation for projects.

The **“Emerging Adopters”** are economies fulfilling the demand role in the value chain and are currently at a nascent stage of hydrogen development. These economies likely do not have large hydrogen production potential and could rely on imports to meet hydrogen demand. As such, their focus is on kickstarting the initial stages for hydrogen applications to aid their transition into becoming an “Application Advocator.” To do so, the first step is to establish a clear strategic plan. This will define the target and timeline, and illustrate the interplay with other energy initiatives. Concurrently, economies will need to prioritize driving economies of scale for hydrogen technology, such as fuel cells, flexible energy storage, combined heat and power generation, and hydrogen propulsion for vehicles, which will enable cost-competitive use cases in their respective sectors. This can be achieved by fostering collaboration between the public, private, and academic sectors. In the long run, economies could export these technologies.

The **“Untapped Producers”** are economies fulfilling the supply role in the value chain and are currently at a nascent stage of hydrogen development. These economies could have large green hydrogen potential through ample renewable resources such as wind, solar, or hydro, which would give them the opportunity to be hydrogen exporters. Despite the renewable resources, these economies could still be in the process of energy transition though electrification of buildings, industry, and transport, and thus also need to be aware of the principle of renewable energy. This means that in the case of other productive uses for the electricity generated from renewable sources, such electricity must not be used to produce green hydrogen. With the overall carbon neutrality of the economy still in the works, pushing hydrogen development will require these economies to instill investor confidence in carbon neutrality efforts and hydrogen ambitions. Investor confidence will create a spade of projects across hydrogen production, creating positive signals for other investors, both domestic and foreign.

7.2 Case studies for each archetype

We have selected several case studies in ***Table 10*** from various APEC economies to inspire potential initiatives depending on their archetype.

Table 10: Case studies of selected policies by archetype

Relevant Archetype (Priority building block)	**Case study**	**Goal**	**Initiative**	**Results**
Application Advocators (scaling up of infrastructure)	Financial support for hydrogen refueling stations (HRS)	Provide financial relief for HRS builders and operators to encourage HRS expansion and facilitate fuel cell vehicle (FCV) adoption	• Fifty percent CAPEX subsidy for private HRS consortium called HyNet • Subsidize operators 70 percent of the difference between the hydrogen fuel price and the breakeven price • Build lease transfer (BLT) model in discussion	Growth from 14 HRS in 2018 to 162 HRS in 2022, with more than 60 built by HyNet
	South Australia legislative reform to support hydrogen blending	Provide regulation ground for hydrogen transport using natural gas pipelines	• In 2021, hydrogen and its derivatives were defined as a regulated substance in the Petroleum and Geothermal Energy Regulations 2013, allowing for transport in natural gas transmission pipelines	Australia Gas Infrastructure Group (AGIG) Hydrogen Park South Australia has been supplying 700 houses with five percent hydrogen blending since 2021, the most advanced in Australia
Hydrogen Powerhouses (investment ramp-up)	The Inflation Reduction Act (IRA) provides tax credits for hydrogen production	Provide financial incentives to curb the cost challenges in producing and using clean hydrogen	• 45V Clean hydrogen credit – supports up to USD3/kg of clean hydrogen for production and up to 30 percent investment tax credit • Other forms of credits, including carbon capture credits and clean electricity credits, are also applicable to blue and green hydrogen-related activities	Clean hydrogen is forecast to be 30 percent cheaper than gray hydrogen by 2030
	Clean Energy Finance Corporation (CEFC)	Filling the market gap by providing financing to hydrogen projects through investment	• The CEFC Advancing Hydrogen Fund is aiming to invest up to USD204 Mn in projects through debt and equity finance • Other financing activities include debt market, asset finance and other funds	Three transactions have been made from 2021 to 2022, totaling USD15.6 Mn in commitment

Relevant Archetype (Priority building block)	**Case study**	**Goal**	**Initiative**	**Results**
Emerging Adopter (technology development)	Low Carbon Energy Research (LCER) Program	Provide funding and collaboration support for innovation through multi-agency initiatives by the Economic Development Board, Energy Market Authority, A*STAR, National Council of Social Service, and National Research Foundation	• Phase 1: three-year funding of USD42 Mn from 2021; Phase 2: proposed USD96 Mn funding, with hydrogen a key research area • One project explores an efficient ammonia-cracking process through collaboration between the National University of Singapore and Surbana Jurong Infrastructure	Four projects have been funded in Phase 1 • Ammonia cracking • Miniature hydrogen leakage and purity sensors • Methane pyrolysis • Liquid organic hydrogen carrier technology
	HTI-Philippines Ministry of Energy partnership for hydrogen power generation	Leverage international technology progress to springboard hydrogen adoption in the prioritized use case of power generation	• MoE signed a collaboration agreement with Japanese company HTI to explore opportunities of using hydrogen for power generation in the Philippines, with HTI bringing technologies and engineers to jumpstart R&D initiatives	While too early to determine the result of the partnership, it could serve as a springboard for future collaboration
Untapped Producer (investor confidence)	Sumatera plant by the Pertamina partnership with Keppel and Chevron	Jumpstart large-scale green hydrogen production with a state-owned enterprise in the lead, leveraging collaborations with international partners	• State-owned energy giant Pertamina signed an MoU with Keppel (Singapore) and Chevron (US) to build the first large-scale green hydrogen plant in Sumatera	Marks the first large-scale production with 120Kt of capacity across two phases
	Haru Oni plant by Empresa Nacional del Petróleo (ENAP) and international private players	Push hydrogen production with support from ENAP (40 percent ownership), Andes Mining and Energy (40 percent ownership), and Enel and Siemens (10 percent ownership each), with HFI as the developer	• In 2020, Chile SOE ENAP was one of the major partners leading one of Chile's first green hydrogen productions (Methanol), in which Porsche was an off taker for mobility fuel in Germany after operation in 2022	E-fuel capacity of 130,000 liters in 2022 and expected to scale up to 550 Mn liters by 2023

Relevant Archetype (Priority building block)	**Case study**	**Goal**	**Initiative**	**Results**
Emerging Adopter and Untapped Producer (strategic plan)	EU Hydrogen Strategy	Signal commitment and provide direction and foresight through stakeholder engagements, such as workshops, public consultations, and public-private partnerships	• Initiatives across the value chain. For supply, use of lifecycle CO2 thresholds, certifications, and adoption of tenders. For infrastructure, gas market legislation reform and repurposing of gas infrastructure. For demand, revisions to the emissions trading scheme, “carbon contract for differences,” and quotes for green hydrogen • Enablers of the value chain. For investment, REACT-EU. For R&D, focus on electrolyzers. For the international dimension, focus on partnerships with other regions and international consortia	Signify long-term commitment to economies, develop Europe as a unified entity for hydrogen

7.3 Initiatives for archetypes

These case studies highlight several imperatives for policy-makers across the various archetypes.

For **“Application Advocators”** looking to scale up infrastructure, policy-makers first need to encourage private participation. This will enable them to accelerate the scale-up of infrastructure and lay the foundation for a robust hydrogen economy. Secondly, promoting public spending is key to allaying significant CAPEX (for example, repurposing natural gas pipelines and creating ammonia-receiving terminals) and OPEX requirements (such as hydrogen fuel prices). Therefore, policies need to be enacted to allow public capital to flow freely into network expansion. Lastly, providing comprehensive regulations for gas composition and hydrogen content will limit ambiguity and uncertainty, specifically for hydrogen transport. To unlock the global supply chain in the long run, policy-makers from these economies might need to pioneer international standards for the transport of green hydrogen and related products. For example, consideration must be given to safety, pipeline integrity, and fuel specifications that will facilitate cross-border trading of hydrogen.

For **“Hydrogen Powerhouses”** looking to ramp up investments, policy-makers first need to alleviate investment risks given that projects may not be able to break even or overcome coordination market failures. Long-term commitment needs to come from authorities through regulations and cover risks in both capital investments and operations. In addition, policy-makers can propose to improve policies for electrolyzers, possibly through lowering corporate, business, and sales taxes on green hydrogen to improve the rate of return on projects. Secondly, accelerating finance for clean hydrogen projects is paramount, and this can come in my forms. For instance, governments have used long-tenor contracts for differences (CFDs) to make up the difference between green hydrogen and its gray counterparts. Other diverse instruments can also be used to cater to businesses with different needs and concerns, such as tax credits, direct and debt investments, and regulated returns.

For **“Emerging Adopters”** looking to boost technology development, policy-makers need to first encourage SMEs and start-ups to enter the hydrogen economy, given its role as a strong force in application and market-oriented innovation, which will lay the foundation for a robust, dynamic hydrogen economy. Secondly, leveraging international collaboration is key to accessing mature technology, thereby jumpstarting R&D initiatives and industry adoptions. Lastly, providing a clear signal for application prioritization by leveraging hydrogen in high-value applications effectively will provide direction for use cases in industry investment and effort.

For **“Untapped Producers”** looking to create investor confidence, policy-makers need to first encourage government support. The government is best positioned to coordinate resources and achieve breakthroughs in hydrogen production set-up and operations. It also provides a business case reference for future investments by validating the economy’s hydrogen potential and operational feasibility. Secondly, leveraging international collaborations should be viewed as a key priority. International collaborations could accelerate the development of technology and capital. For example, Just Energy Transition Partnerships (JETPs) could assist developing economies greatly with their hydrogen ambitions. Lastly, policy-makers could leverage the network and resources of state-owned enterprises (SOEs) in hydrogen developments. SOEs are dominant across many industries in emerging markets, and by engaging SOEs, policy-makers can drive acceleration in research, economies of scale, and overall investor confidence in hydrogen developments.

Additionally, for **“Emerging Adopters”** and **“Untapped Producers”**, a strategic plan through a hydrogen strategy will convey a clear vision for the role of hydrogen, as well as clear targets for short-term and long-term development. Policy-makers also should ensure hydrogen is embedded in overarching policy framework and surrounding policies such as gas legislation, while support initiatives on related infrastructure, such as grid capacity, are also necessary. Additionally, facilitating private and public partnerships will serve as an information exchange platform to align interests, reduce risks, and incentivize transition at an early stage of development.

7.4 What initiatives can APEC undertake?

Several potential cross-economy initiatives can occur between these archetypes. Given APEC's role as an inter-governmental forum for its 21 member economies, it has an opportunity to facilitate some of these initiatives.

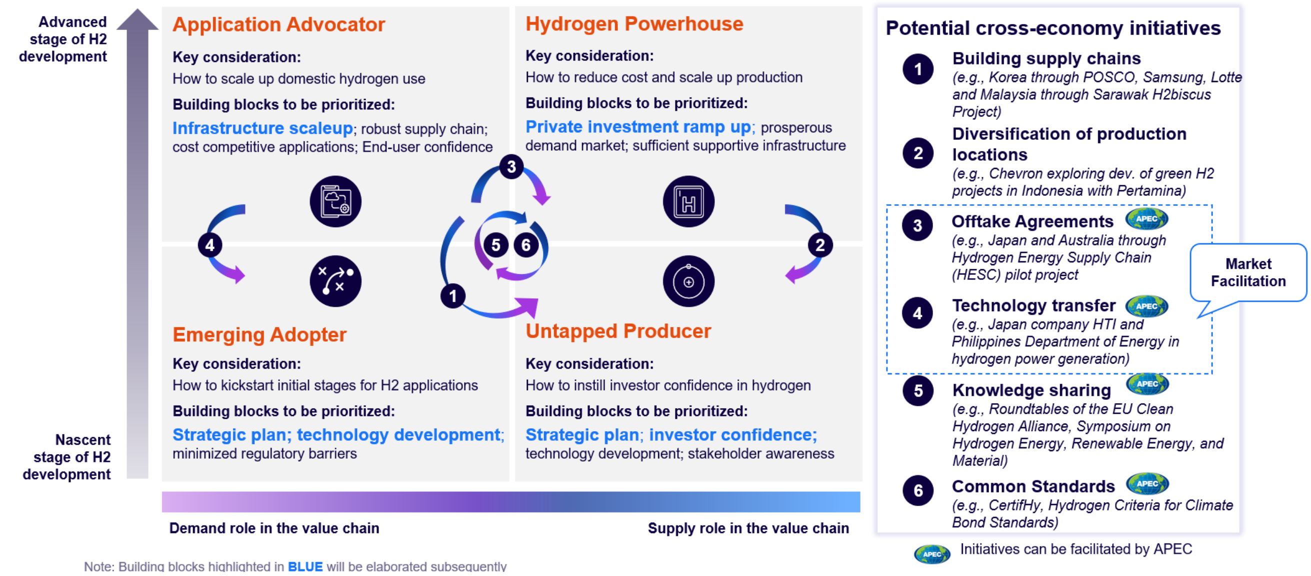


Figure 20: Potential cross-economy initiatives that can be facilitated by APEC

As shown in ***Figure 20***, APEC could facilitate three key initiatives.

4. APEC can **ensure market facilitation** to promote partnerships among selected APEC member economies to build a sustainable hydrogen economy and support the carbon neutrality strategy within APEC. Market facilitation could take the form of offtake agreements between advanced economies in the demand and supply role in the value chain and technology transfer between economies in the demand role, but at different stages of hydrogen development.

   Facilitation of offtake agreements: We see this initiative as part of the European Clean Hydrogen Alliance. A list of 840 hydrogen projects was published in November 2021 to facilitate offtake agreements and create integrated hydrogen value chains. Inclusion in the alliance project pipeline does not convey any direct financial or regulatory advantage, and also does not award any financing to projects. Similarly, the Africa Green Hydrogen Alliance launched in May 2022 aims to accelerate and improve market development by refining project development, procurement, and financing models. Therefore, we suggest that APEC launches and monitors an APEC hydrogen project pipeline to facilitate trade and investment.

   Technology transfer: We see a similar initiative in the European Clean Hydrogen Alliance, in which an electrolyzer partnership was established in 2022 to promote hydrogen technology transfer and material availability to meet the manufacturing capacity in Europe by 2025. The Africa Green Hydrogen Alliance also emphasizes technology development through sharing technical insights and capabilities across RD&D. Therefore, APEC can consider an APEC Hydrogen Partnership focused on technology transfer and development, linking manufacturers, key material suppliers, and policy-makers.

5. APEC could **facilitate knowledge sharing** between economies to enhance collective intelligence and cooperation, potentially through roundtables. These have already shown instances of success. For example, the Roundtables of Europe Clean Hydrogen Alliance was set up in November 2020 to promote hydrogen development and address hydrogen issues and barriers. Six roundtables were launched in 2021, spanning themes across hydrogen production, distribution, and usage in the industrial, mobility, and energy sectors. The roundtables also spawned working groups for hydrogen research, with two papers presented in 2021 and a paper on hydrogen standards to be presented in 2023. Another example of a successful roundtable is the symposium of International Hydrogen Energy, Renewable Energy, and Materials (HEREM), which was set up by the International Energy and Environmental Research Institute in 2015 to present research results in the respective fields. To date, it has opened internal discussion forums in 2015–2016 in China, launched

a symposium to discuss 13 topics spanning hydrogen and related energy and materials in 2017–2019 in Thailand, conducted virtual conferences in 2020–2022, and recently announced a hybrid event in October 2023 in Thailand. Another outstanding instance is the Center for Hydrogen Safety (CHS) established by the American Institute of Chemical Engineers (AIChE) as a global non-profit organization dedicated to promoting hydrogen safety and best practices worldwide. Not only does it support the safe handling and use of hydrogen across applications in the energy transition, but it also provides a common communication platform with a global scope to ensure safety information, guidance and expertise to stakeholders. To date, the CHS has conducted numerous conferences, webinars, courses and training to push hydrogen safety codes and standards. Building on these examples, we suggest that APEC boosts specific knowledge-sharing sessions for main hydrogen themes, such as infrastructure, technology, and policy, and if resources are available, also consider newsletters to ensure constant sharing of information.

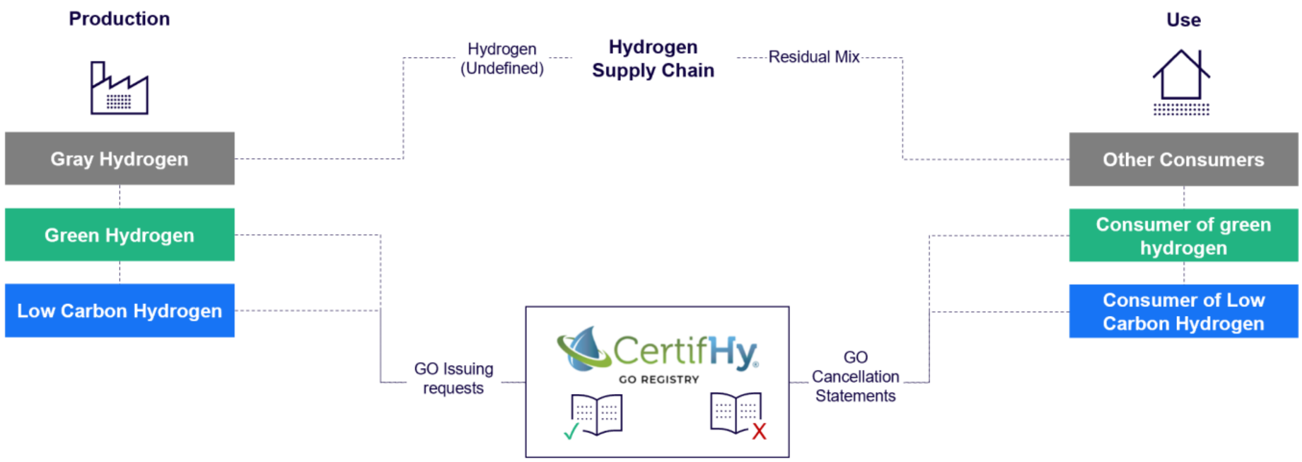


Figure 21: CertifHY certification process

6. APEC could consider **developing standards** such as a guarantee of origin (GO) certification scheme, which would show customers that a unit of energy is aligned with a scheme's criteria. One such example is CertifHy, which was started in 2014 to advance production, procurement, and use of hydrogen. To qualify as "green hydrogen" under CertifHy and attain the certificate, hydrogen must be produced using renewable energy sources and have a carbon footprint of less than 36.4gCO2e/MJ. At the moment, CertifHy is applicable within the EU region and only certifies hydrogen gas production but not hydrogen derivatives. Therefore, APEC could create the infrastructure for a common hydrogen standard with the extension of low-carbon hydrogen certification to hydrogen derivatives across the APEC region. However, it needs to consider that while this would allow APEC to ensure alignment to serve each economy, governance efforts would be challenging to coordinate across member economies. Alternatively, APEC could push for adoption of an international low-carbon standard, which would have lower barriers to implementation but could face issues in driving adoption from all member economies.

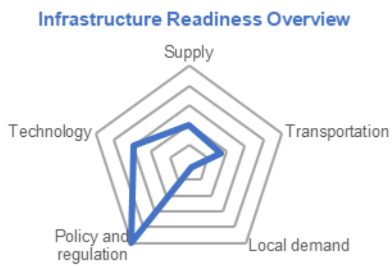
8. Appendix

8. Appendix

8.1 Economy profiles (in order of APEC Guidelines)

Australia: Prominent green H2 exporter through collaborations

Current capacity **0.0002***Mt/yr*	Future (2030) capacity **2***Mt/yr*
Current demand 0*Mt/yr*	**Future (2030) demand 0.86***Mt/yr*
Domestic hydrogen policy in place?	✓



Supply

- Currently most captive hydrogen production
- ~108 projects in the pipeline
- Estimated capacity of 2Mt by 2030

Transportation

- Adequate gas pipeline area coverage
- 12 liquefication plants and no regasification plant
- Small CSIRO plants produce hydrogen from ammonia, with a larger-scale plant in development

Local demand

- Existing feedstock will be the primary demand before 2040
- Blended gas is expected to take up 10 percent of hydrogen demand by 2050

Policy and regulation

- Strong support from decarbonization plans, hydrogen strategy, and extensive hydrogen targets subsidies
- Carbon market in place

Technology

- Many projects in the planning/development stage
- 67 start-ups in hydrogen
- More than 10 consortia

Strong position for hydrogen export

Australia is known for its richness of renewable resources, especially solar and wind energy. Coupled with vast land and water resources, an estimated 11 percent of Australia is suitable for hydrogen production. The abundant reserve in fossil fuel and geological conditions for CCUS makes Australia a strong producer of blue hydrogen as well. Clean hydrogen production costs are expected to be AUD2 (USD1.36) – AUD 4 (USD2.72)/kg, some of the cheapest globally. The scaling potential of production in Australia could lower the electrolyzing cost even further. Moreover, Australia has a large-scale energy industry, with established infrastructure, talent, and a regulatory environment. Australia is home to two of the top 10 hydrogen developers globally, FFI and Elixir Energy. It currently has around 108 projects in the pipeline, totaling to 2Mt in clean hydrogen capacity by 2030. An established track record in energy export to Asia also lays a foundation for hydrogen export. Currently, hydrogen and ammonia export by sea to Japan is under development, under projects including HESC and HySTRA.

Ministry-driven collaborations across sectors and borders

The Australian government has been active in pushing hydrogen demand and supply scale-up forward. One of its strategic initiatives is to establish hydrogen hubs in different states by matching large-scale demand and supply to springboard industry scale-up. One example is the announcement to develop a hydrogen hub for multi-use industry and export at Port Bonython, SA, engaging industry players from Australia (FFI, Origin, etc.), Japan (Chiyoda, Mitsubishi, etc.), and Canada (AMP energy). Internationally, it has partnerships in hydrogen technology collaboration with the Netherlands, Germany, Singapore, and Japan.

Strong government support through funding and collaboration

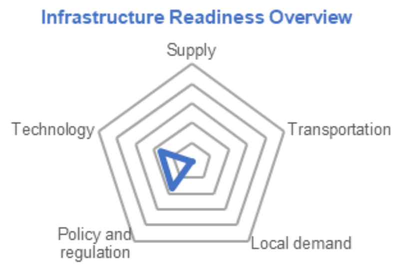
Australia has allocated more than AUD3 Bn (USD2.04 Bn) to fund applicable hydrogen projects at the central level, through dedicated funds such as the Advancing Hydrogen Fund or agencies such as ARENA and NERA, while funding is also available at the state level. Western Australia has a renewable hydrogen strategy fund that is an AUD80 Mn (USD54.44 Mn) commitment. Collaboration to encourage domestic transition has also been facilitated by NERA to support SMEs in building hydrogen capacity and drive industry collaboration by forming an industry-led hydrogen cluster.

The future of hydrogen in Australia

Australia is on track to become one of the largest hydrogen exporters, with offerings ranging from blue hydrogen to green ammonia. The strong export infrastructure and established relationship will allow for export to major hydrogen importing economies, with estimated export to East Asia at over 500Kt by 2030.

Brunei Darussalam: Early advocate in H2 transportation

Current capacity	Future (2030) capacity
0*Mt/yr*	**N/A**
Current demand	**Future (2030) demand**
0*Mt/yr*	**0.01***Mt/yr*
Domestic hydrogen policy In place?	x



Supply

- Gray hydrogen production currently
- No clean hydrogen projects identified

Transportation

- 1 liquefaction plant
- No regasification and ammonia-cracking facility

Local demand

- Mostly in power generation and transport, expected scale-up after 2035

Policy and regulation

- Published decarbonization strategy
- No hydrogen strategy and incentives
- In the process of researching the carbon pricing mechanism

Technology

- Demonstration project of MCH hydrogen shipment to Japan
- No start-ups and Triple-helix consortium in hydrogen

Blue hydrogen export potential

Brunei Darussalam had a large reserve of natural gas encompassing 9.5 trillion cubic feet as of 2017, together with flaring from the existing gas operation, which provides 2.12Mt of hydrogen potential. Of this potential, 90 percent comes from small and medium-sized gas farms that are mostly undiscovered. Brunei Darussalam announced an investigation into CCUS technology as early as 2020. Shell announced plans for a feasibility study on carbon storage in Brunei Darussalam in late 2022. However, while renewable energy contributes 0.27Mt of potential green hydrogen, the opportunity is limited due to land size. Domestically, hydrogen will most likely be used in the transport and power sector, at a total of 0.76Mt under the highest penetration scenario in 2040, according to an ERIA report. The surplus indicates export potential.

LNG export track record could facilitate hydrogen export

Brunei Darussalam has a track record of exporting LNG to Japan. Hence, it already has established infrastructure and relationships to develop hydrogen export for the Japan market. Similarly, Brunei Darussalam currently exports LNG to China; Korea; Chinese Taipei; and Thailand. Thus, it could potentially convert these LNG contracts to hydrogen export agreements.

An early advocate in hydrogen transport

Brunei Darussalam has been one of the earliest testers for hydrogen export. In 2020, led by the Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD), a Japanese hydrogen consortium, the first shipment of hydrogen with MCH was completed from Brunei Darussalam to Japan. Although utilizing the technology by Chiyoda in Japan, Brunei Darussalam has been tested for its export possibility to Japan. As a long-standing LNG exporter to big markets such as China; Korea; and Japan, Brunei Darussalam could leverage established facilities, routes, and relationships to enable hydrogen collaboration and transportation.

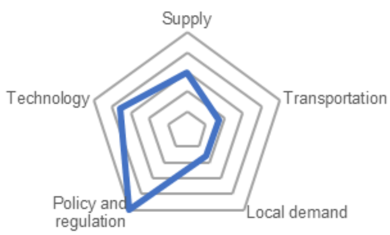
The future of hydrogen in Brunei Darussalam

Brunei Darussalam has the potential to be a blue hydrogen exporter with technology implementation and scale-up of hydrogen production and CCUS technology. It is expected to leverage its existing LNG export facilities and international agreements. However, clear prioritization and policy support are needed to foster a hydrogen economy that involves all stakeholders.

Canada: Large-scale producer aided by advanced technology

Current capacity 0.88*Mt/yr*	Future (2030) capacity 2.9*Mt/yr*
Current demand N/A	Future (2030) demand N/A
Domestic hydrogen policy in place?	✓

Infrastructure Readiness Overview



Supply

- 3 blue hydrogen and 2 green hydrogen projects are in operation
- ~20 projects in the pipeline
- Estimated capacity at 2.9Mt in 2030

Transportation

- Well-established natural gas system
- 1 regasification plant
- AmmPower ammonia-cracking demonstration

Local demand

- Power generation is a prominent demand, supplying 30% of the economy's power demand
- Applications in industrial, transport, and heating

Policy and regulation

- National decarbonization and hydrogen strategy
- Regional ETS and carbon tax

Technology

- Operational technology in electrolysis, CCUS, ammonia-cracking, and fuel cell
- ~100 start-ups involved in hydrogen
- Canadian Hydrogen and Fuel Cell Association (CHFCA)

Existing foundation for clean hydrogen production

Canada possesses vast potential for renewable energy resources as well as water, ideal for green hydrogen production. Canada had more than 98.6GW of renewable energy capacity in 2021, mostly from hydropower. A giga-scale green hydrogen project, Spirit of Scotia, with 500GW, is planned in Nova Scotia in 2022. In addition, as one of the largest producers of gray hydrogen, Canada has an opportunity to retrofit its existing production for blue hydrogen production. The opportunity is boosted by Canada's great natural potential and advanced technology in carbon capture, utilization, and storage (CCUS). As of 2021, Canada was hosting 20 percent of the world's operational large-scale CCUS projects. As a result, it is one of the earliest adopters of larger-scale blue hydrogen production, totaling 0.87Mt annual production with three operational projects. In the future, Canada is aims to be among the three largest producers of clean hydrogen (blue and green) globally, aiming for CAD1.5 (USD1.1) – CAD3.5 (USD2.58)/kg hydrogen by 2050.

Advanced technology for hydrogen development

Canada leads in technologies in fuel cell systems, electrolyzers, and fueling applications, with established companies with innovative hydrogen technologies spanning the value chain: Proton Technologies (hydrogen production), Ballard Power (fuel cell systems), and Hydrogenics (hydrogen production and fuel cell products). Canadian company Enhance Energy is behind the town of the current blue ammonia production site, providing CCUS solutions, while Hydrogenics is behind an operational on-site green hydrogen generator as part of an energy storage project. Despite government funding in clean energy innovations, the private sector is active in funding hydrogen research projects, with up to CAD65 Mn (USD47.9 Mn) in investment in 2020.

Different strategies for economy-wide and international levels

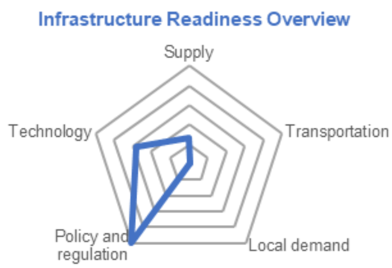
Canada has been encouraging "regional blueprints," allowing provinces and territories to leverage their own geographical and economical features while building complete value chain hubs. For example, oil and gas-prominent province Alberta is focusing on blue hydrogen, while Quebec focuses on decarbonization with hydrogen in industrial transition and synthetic fuel. On an international level, Canada signed an agreement with Germany to export hydrogen to Europe by 2025. Canada believes that, starting with self-sufficient hubs, the hubs will grow into an economy-wide hydrogen economy.

The future of hydrogen in Canada

Canada will grow to be one of the largest producers of hydrogen while continuing to innovate in hydrogen technology. Apart from export, hydrogen will be an integral part of the energy system, applied in power, industrial, transport, and heating and creating more than 350K sector jobs by 2050.

Chile: Propitious global hydrogen powerhouse

Current	Future (2030)
Current capacity 0.003*Mt/yr*	**Future (2030) capacity** 1.3*Mt/yr*
Current demand 0*Mt/yr*	**Future (2030) demand** 0.2*Mt/yr*
Domestic hydrogen policy in place?	✓



Supply

- Currently no hydrogen production at scale
- ~60 projects in the pipeline
- 1.3Mt production in 2030

Transportation

- Regional gas infrastructure
- No liquefication or ammonia-cracking facilities
- 2 regasification terminals

Local demand

- Oil refineries and ammonia as first adopters
- Heavy-duty trucking and mining haul trucking later become the largest consumers

Policy and Regulation

- National decarbonization and hydrogen policy
- Targeted funding for hydrogen
- Carbon tax in place

Technology

- Several projects at the pilot stage
- 6 start-ups involved in hydrogen
- Triple-helix consortium examples include ASDIT

Estimated cheapest hydrogen exports

With abundant renewable energy resources and an optimal geological position, Chile is estimated to have the potential for the cheapest hydrogen production and export. Chile has 1800+GW of solar, wind, and hydro energy potential, which could enable 160Mt of green hydrogen production at USD0.8–1.1/kg hydrogen by 2050. Chile is expected to have the lowest clean hydrogen production cost at USD1.3–1.4/kg by 2030, compared to Australia (USD1.7) and China (USD2.2). Besides that, transportation from Chile to Japan/Korea will also be cost competitive at USD2.2/kg hydrogen in 2030, compared to the cost from Australia of USD2.7/kg hydrogen. Similarly, the cost of export to the United States at USD1.9/kg hydrogen will be much cheaper than the cost of hydrogen from Mexico to the US, estimated to be USD2.57/kg hydrogen.

Proving ground for green hydrogen development

Given the vast potential, Chile has been the destination of the first few hydrogen projects for many companies (Enel, CWP, Engie, Air Liquide), with more than 60 hydrogen projects in the pipeline, while Engie itself has three projects in Chile. Engie and Enaex have started HyEx, a pilot project that produced 18Kt of green ammonia from solar energy in 2021. Meanwhile, a consortium of companies including HIF, Siemens, and Porsche are piloting project Haru Oni, the first industrial-scale plant producing synthetic climate-neutral fuel, which will be used by Porsche for its experience center in Germany. The projects include not only hydrogen production and synthetic fuels, but also applications in mining. CSIRO, Engie, and Mining 3 are also developing CAEX mining trucks with fuel cells. The project will facilitate hydrogen transition in the domestic market, as mining is one of the pillar industries.

Public support by funding, regulation and collaboration

With recognition of green hydrogen a key initiative in Chile, the government has signed an agreement to provide USD50 Mn in financing for the economy's first six hydrogen projects in 2021–2022, through Chile's Production Development Corporation (Corfo). Chile is also working on key areas to develop all-aspect legislation to push green hydrogen development. Internationally, an MoU has been signed with Singapore to collaborate on clean hydrogen technology, while an agreement has been made with the Port of Rotterdam for green hydrogen export to Europe.

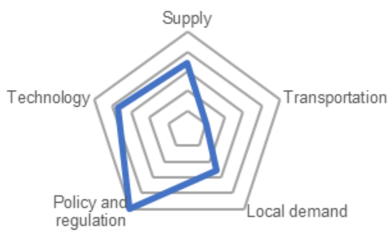
The future of hydrogen in Chile

With its cost leadership strategy in hydrogen production, Chile will become one of the biggest exporters of green hydrogen and derivatives, with 25GW of electrolysis capacity and generation of USD25 Bn in revenue in export in 2030. Hydrogen application in mobility, especially in heavy-duty trucks and mining haul trucking, will slowly be adopted before 2040, creating a USD3.6 Bn market in 2050.

China: Front liner in green H2 for exports and domestic use

Current capacity **0.5***Mt/yr*	**Future (2030) capacity** **7.7***Mt/yr*
Current demand **0.5***Mt/yr*	**Future (2030) demand** **7.7***Mt/yr*
Domestic hydrogen policy in place?	✓

Infrastructure Readiness Overview



Supply

- Currently the largest producer of gray hydrogen
- 120 green hydrogen projects at different stages of development

Transportation

- Large emphasis on gas pipelines
- 22 regasification terminals
- No large-scale development of ammonia cracking

Local demand

- Hydrogen is set to be used largely in transport and industry
- World's first hydrogen train rolled out in China in December 2022

Policy and regulation

- National and provincial green hydrogen strategies
- Funding scheme for R&D of hydrogen technology and infrastructure developed

Technology

- Leader in alkaline electrolyzer technology driven by SOEs
- Interest in CCUS deployment
- > 140 start-ups involved in hydrogen

Global leader in green hydrogen production

Almost 25 percent of new renewable power capacity deployed by China over the next five years will be allocated to green hydrogen production, compared to 5 to 10 percent in Europe, Australia, and Chile and 5 percent in the United States. Major SOEs are leading the way, with Sinopec aiming to produce more than 1Mt of green hydrogen from renewable energy sources by 2025. Sinopec is currently building the world's biggest plant for production of green hydrogen, amounting to 20Kt of green hydrogen a year upon completion in June 2023. An increasing number of international players have collaborated with China on green hydrogen development, including GIZ (German Ministry of Economic Affairs and Energy) and Agora Energiewende.

Dominant force in electrolyzer technology

According to the roadmap published by China Hydrogen Alliance, a government-supported industry group, China is aiming to reach 100GW of electrolyzer capacity by 2030. Considering there is only 1GW in operation and around 10GW planned today, it shows the likelihood of a massive ramping up of electrolysis capacity over the coming decade and beyond. Based on a study by BNEF, more than 40 percent of all electrolyzers made today come from China. While Chinese electrolyzers are not as efficient as their counterparts in the United States and Europe, it is less expensive, and Chinese companies are already starting to expand sales overseas by leveraging cost leadership strategy. Moreover, while Chinese companies have mostly produced "alkaline" electrolyzers up to this point, they are starting to develop PEM electrolyzers, encroaching on competitors in the United States and Europe. Longi Green Energy Technology Co., which is currently the world's largest solar equipment maker, set up a hydrogen unit to develop PEM products and expects that half of its sales will come from foreign markets in the next three years.

Active development in hydrogen technology and transportation

China has allocated a lot of funding to hydrogen-related R&D. Between 2018 and 2020, spending increased sixfold to surpass the United States and Europe combined. China has also awarded National Key R&D Programs, China's highest-level R&D funds, to 66 projects focused on hydrogen technologies. In addition, the government has provided local policies with high-level guidance to support hydrogen in transport for high energy-consuming provinces/cities.

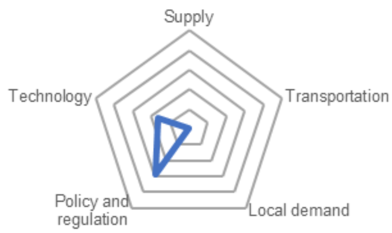
The future of hydrogen in China

China will emerge as a powerhouse in green hydrogen by adopting a cost leadership strategy in technology development through government-level funding. Foreign economies can benefit from participating in China's growing industry through collaboration on research and standard setting.

Hong Kong, China: Progressing in regulatory adaptation

Current capacity **0***Mt/yr*	**Future (2030) capacity** **0***Mt/yr*
Current demand **0***Mt/yr*	**Future (2030) demand** **N/A**
Domestic hydrogen policy in place?	✓

Infrastructure Readiness Overview



Supply

- Limited landscape for H2 production
- Hong Kong, China would rely on import of H2

Transportation

- Gas pipeline used for gas import from China, currently only for natural gas
- Regional town gas pipeline
- No liquefication, regasification, or ammonia-cracking facilities

Local demand

- Hong Kong Roadmap on Popularization of Electric Vehicles, Clean Air Plan for Hong Kong 2035 and Hong Kong's Climate Action Plan 2050 lay foundation for hydrogen
- Potential adoption in public transport

Policy and regulation

- China released first medium to long term plan on development of hydrogen energy in March 2022
- Hydrogen project funding under other funding programs including New Energy Transport Fund
- New international carbon marketplace Core Climate launched in October 2022

Technology

- Hydrogen is being planned for use in trials of hydrogen fuel cell buses
- No triple-helix consortium yet

Hong Kong, China will rely on hydrogen imports

Hong Kong, China has limited scale in land and high population density. Based on 2020 figures, Hong Kong, China imports its energy, mostly natural gas, which takes up 48 percent of the electricity fuel mix, followed by renewable energy and nuclear energy at 28 percent. However, only a small amount of renewable energy is produced locally. Hong Kong, China is actively studying the development and application of new sources, such as hydrogen, to achieve carbon neutrality before 2050. This includes the import of hydrogen for use as fuel to decarbonize its power sector and energy consumption.

Regional collaboration elevating hydrogen development

Hydrogen development in Hong Kong, China could leverage regional collaboration with China. To assist the transport trade to commence trials for hydrogen fuel transport technologies, the Government of Hong Kong, China has earmarked HKD200 Mn under the New Energy Transport Fund for subsidizing relevant costs of trial projects, such as construction or renting of hydrogen fuel cell vehicles, establishment of hydrogen refilling facilities and operating costs. To decarbonize public transport while tackling the challenge of hilly topography and long endurance, the first customized hydrogen-powered bus was developed by Citybus and Wisdom Motor Company.

Regulatory adjustment for hydrogen in progress

To keep pace with the development trend of hydrogen fuel cell adoption, the Government of Hong Kong, China set up the a working group called "Inter-departmental Working Group on Using Hydrogen as Fuel" in 2022 to coordinate preparation works of departments for using hydrogen as fuel locally, with a view to encourage adoption of hydrogen energy. This is especially important given there is no current comprehensive legislation governing the use of hydrogen as a fuel in Hong Kong, China. As such the Government plans to appoint a consultant in Q3 2023 to oversee legislative amendments.

The future of hydrogen in Hong Kong, China

Hydrogen is progressively gaining adoption in Hong Kong, China. The Chief Executive of Hong Kong, China Government has mentioned to commence trials of Hydrogen Fuel Cell double-deckers and heavy vehicles in 2023 and formulate the long-term strategies for the application of hydrogen energy in road transport by 2035. To date, several applications of hydrogen trial projects have been assessed by the Working Group with agreement in principle granted. Safety guidelines are also being developed for Hydrogen Fuel Cell vehicles and filling stations. Power companies are exploring the feasibility of blending natural gas and hydrogen for electricity generation. The Hong Kong SAR Government has set "net-zero electricity generation" as one of the decarbonization strategies in the Climate Action Plan 2050, aims to phase out coal for daily electricity generation in 2035, creating potential hydrogen opportunities.

Indonesia: Advancing with both blue and green hydrogen

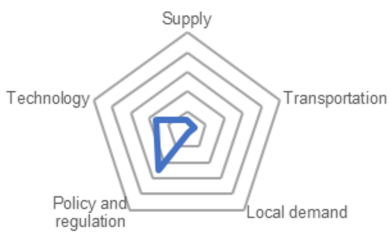
Current capacity
0*Mt/yr*

Current demand
0*Mt/yr*

Future (2030) capacity
0.12*Mt/yr*

Future (2030) demand
0.4*Mt/yr*

Domestic hydrogen policy in place?	x



Supply

- Gray hydrogen production currently
- ~4 projects in the pipeline
- Estimated 0.12Mt capacity in 2030

Transportation

- Adequate natural gas pipeline
- 3 liquefaction and 6 regasification plants
- No ammonia-cracking plant

Local demand

- Power generation
- Rail, maritime and aviation
- Industrial applications including steelmaking, cement

Policy and regulation

- Published decarbonization strategy
- No hydrogen strategy and incentives
- The statutory carbon tax was scheduled to be implemented

Technology

- Technology is mostly in the pilot stage
- 3 start-ups involved in hydrogen
- The consortium between academia and public

Hydrogen as a key in the decarbonization journey

As the fourth most populous economy, Indonesia is facing pressure in decarbonization, especially with the tightened emission goal ahead of COP27. Hydrogen is an important pathway for Indonesia's decarbonization, due to its huge unused renewable energy potential. Rich in solar and geothermal energy, Indonesia is only utilizing 0.3 percent of its renewable energy potential estimated at 3686GW. Using hydrogen to decarbonize its power sector is already of interest to the government. A collaboration was recently formed between the Japan government and MEMR for applying ammonia cofiring coal power plants. In the transport sector, the application is more likely in aviation, maritime, and rail, as battery-electric vehicles are more in focus at the moment. Indonesia state-own railway company KAI is partnering with ALSTOM, a French company, to develop hydrogen trains. meanwhile, in the industrial sector, there is an opportunity to decarbonize the steelmaking process as the parent company of the largest steelmaker in Indonesia, POSCO, based in Korea, is developing a hydrogen-powered steelmaking process.

Concurrent development of blue and green hydrogen

Indonesia is supporting the decarbonization plan with both blue and green hydrogen production. Endowed with rich renewable energy resources, Indonesia has vast potential in producing green hydrogen. The Indonesia's energy giant, Pertamina, has started planning for green hydrogen production plant construction in collaboration with Keppel and Chevron. Meanwhile, with a long-established history in natural gas and gray hydrogen production, as well as potential in carbon storage, blue hydrogen could be possible. Pertamina's oil and gas field is estimated to have a 1 Bn Mt carbon storage capacity. Pertamina has started a feasibility study on the commercialization of CCUS technology in South East Asia with Mitsui. However, the advancement still faces challenges in scaling up and reducing costs in Indonesia, especially when the end applications are not readily developed.

Natural gas transport facilities support hydrogen trade

Indonesia was one of the largest exporters of natural gas, through LNG terminals and pipelines to Malaysia and Singapore. Increasing domestic energy demand also brings energy import facilities such as regasification terminals. The established facility would lay a foundation for future hydrogen trade, regardless of the strategic direction.

The future of hydrogen in Indonesia

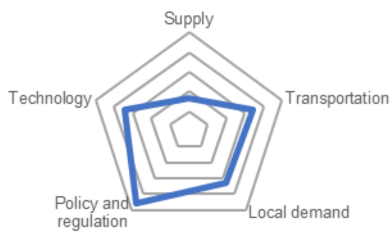
Indonesia will produce both green and blue hydrogen, totaling 0.12Mt in 2030. The hydrogen produced could be used for domestic consumption in power generation, rail, or steelmaking. Meanwhile, the established natural gas trade facilities also indicate potential to export or import depending on future development.

Japan: Fosterer of global hydrogen supply chain

Current	Future (2030)
Current capacity **0.001***Mt/yr*	**Future (2030) capacity** **0.003***Mt/yr*
Current demand **2***Mt/yr*	**Future (2030) demand** **3** *Mt/yr*

Domestic hydrogen policy in place? ✓

Infrastructure Readiness Overview



Supply

- No information on current hydrogen production
- ~28 projects in the pipeline

Transportation

- Adequate gas pipeline coverage
- 28 liquefication and regasification plants
- Operational ammonia-cracking facility from Saudi Arabia ammonia import

Local demand

- Strategic importance in power generation
- Heavily invested in mobility
- Largest demand from steelmaking in 2030

Policy and regulation

- One of the earliest to publish a hydrogen strategy
- Subsidy for hydrogen supply network
- Carbon tax and regional ETS

Technology

- Operational technology in power generation and mobility
- 40 start-ups in hydrogen
- Namie Town transport project consortium

Wide application indicates strong demand

For energy security and decarbonization reasons, Japan aims to build a hydrogen society, and remarkable progress in hydrogen application has been made. Aiming to use hydrogen as a power supply and energy security, Japan started the demonstrated operation of a pure hydrogen power plant in Fujiyoshida, generating 320KW of electricity to power 100 households. Japan has also been investing in hydrogen mobility, with more than 30 percent of the FY 21 MOE/METI budget invested in transport, amounting to more than JPY25 Bn (USD191 Mn). In 2014, Toyota launched the first hydrogen FCV, Mirai. By 2021, Japan had established the largest hydrogen network of 162 stations and 5,000 FCVs on the road. Overall, more than JPY7 Tn (USD53.2 Bn) in subsidies provided for hydrogen supply network in a decade.

Global partnership to establish global hydrogen supply chain

Constrained by the limited land area, Japan lacks suitable resources for hydrogen production, and most of the supply will come from overseas. As estimated in the Basic Hydrogen Strategy, for power generation alone, the annual import of hydrogen will be at 5–10Mt in the future. As a result, Japan has been active in establishing a stable global hydrogen supply chain. Several G2G partnerships have been established for technology collaboration and production plant building with Germany, France, the UAE, the Russian Federation, and Canada. Companies such as Iwatani, among others, are also partnering in setting up production plants overseas, including in Australia and New Zealand, to secure global supply. Meanwhile, hydrogen transport has been operational from Brunei Darussalam and Australia, along with a newly established Saudi Arabia import agreement. Japan is also active in driving international framework and standards, as one of the initiators for the Hydrogen Council.

Exporter of hydrogen products

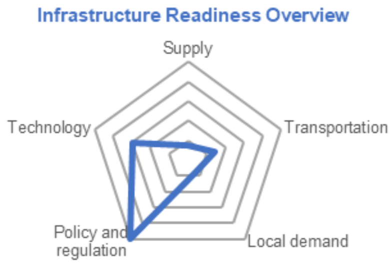
Leveraging the advancement, Japan has also aspired to be a key exporter of hydrogen products, including power stations, fuel cell vehicles, gas turbines, and CCUS technology. Among many hydrogen production construction collaborations, one other example is the Toyota FCV car-sharing pilot project in New Zealand. Besides that, Japan also has wide-ranging participation to boost the global hydrogen economy.

The future of hydrogen in Japan

Japan will establish a hydrogen society, balancing energy security, economic efficiency, environmental sustainability, and safety. Japan will have 800K FCVs by 2030, supported by more than 400 refueling stations. The power sector and steelmaking industry will be consuming more than 2Mt hydrogen by 2030. Most of the hydrogen will come from overseas supply supported by international agreements, transport, and storage infrastructure.

Korea: Elevating hydrogen downstream applications

Current capacity 0.001*Mt/yr*	Future (2030) capacity 1*Mt/yr*
Current demand 0.001*Mt/yr*	Future (2030) demand 2.9*Mt/yr*
Domestic hydrogen policy in place?	✓



Supply

- Currently no clean hydrogen capacity
- Future capacity of 1Mt
- Importing 1.96Mt clean hydrogen per year from 2030

Transportation

- Well-developed natural gas pipeline
- 7 regasification terminals
- Ammonia cracking in development

Local demand

- 2.9Mt expected demand in 2030
- Primarily driven by FCEV and large-scale FC stational power generation

Policy and regulation

- Decarbonization strategy, ETS system, and hydrogen roadmap in place
- Allocated subsidies to hydrogen applications

Technology

- Advanced development in FCEV
- ~60 hydrogen start-ups
- Strong involvement from the private-sector (Hyundai, SK, POSCO, etc.)

Global net importer of hydrogen

Korea aims to significantly scale up its domestic annual consumption to almost 2.9Mt by 2030, a portion of which will come from importing 1.96Mt of green hydrogen due to limited natural resources. In addition, the domestic hydrogen roadmap indicates that Korea relies on offshore production to promote the development of hydrogen. Korea has announced that it will build hydrogen pipelines and ammonia-receiving facilities.

Leader in hydrogen downstream applications

Korea's hydrogen strategy heavily focuses on developing downstream applications, especially in transportation, power generation, and industry, including FCEV, refueling stations, and stationary hydrogen power plants. Korea was the largest seller of hydrogen vehicles in 2021. Korea has announced up to KRW42.5 Mn (~USD33,575) in subsidy on hydrogen vehicle purchases, while the later established goal is to subsidize KRW365.5 Bn (~USD288.7 Mn) for hydrogen vehicles, boasting the third-largest public investment in hydrogen after Germany and Japan. Hyundai launched hydrogen-powered trucks in 2022, while HyNet, a joint venture backed by 13 companies, opened its 35th hydrogen refueling station.

Strong collaborator across public and private sectors

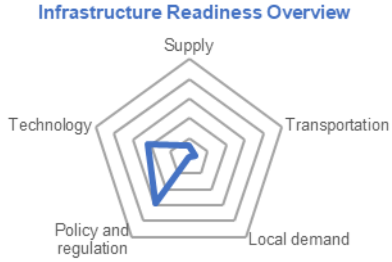
Korea has built strong collaborations both domestically and internationally, for establishing a resilient hydrogen supply chain, hydrogen R&D, and commercialization. Domestically, there are extensive collaborations across and among sectors in policy-making, R&D, and scaling. Examples include private-sector engagement in the hydrogen council and the Hyundai-led consortium of hydrogen equipment suppliers to operate hydrogen buses in Australia. International collaboration with Australia and Saudi Arabia is also announced for hydrogen development and supply, coupled with private-sector contracting between the economies. Moreover, Korea has been active in forging G2G collaborations, such as supply contracts with Malaysia and the UAE.

The future of hydrogen in Korea

Korea will lead hydrogen use in transportation and power generation, with ambitions to domestically produce 3 Mn FCEV and 70 thousand FC trucks and buses in 2040. Hydrogen supply chains will need to be further developed, along with core technology, investments in overseas production, and transportation infrastructure. Eventually, Korea is likely to emerge as a leading example of hydrogen use in downstream applications, simultaneously generating KRW43 Tn (~USD34 Bn) and 420 thousand jobs for Korea in the process.

Malaysia: Potential future green hydrogen producer

Current capacity	Future (2030) capacity
0*Mt/yr*	0.5*Mt/yr*
Current demand	**Future (2030) demand**
0*Mt/yr*	N/A
Domestic hydrogen policy in place?	x



Supply

- Minimal numbers of hydrogen-powered buses & ART vehicles
- Large projects in the pipeline
- Estimated 0.5Mt capacity in 2030

Transportation

- 6 liquefaction plants, 2 regasification plants
- No ammonia-cracking facility

Local demand

- Mostly hydrogen is used in Sarawak for hydrogen-powered vehicles
- A portion of 7,000 tons a year from the H2biscus project will be locally used

Policy and regulation

- Published decarbonization strategy
- No hydrogen strategy and incentives
- Introduced voluntary carbon market exchange

Technology

- Technology is mostly in the pilot stage
- No start-ups
- Collaboration between the public and academia

Green hydrogen export as a key focus in Sarawak

Sarawak aims to become the green hydrogen hub in Malaysia, with plans to start commercial hydrogen production and export by 2027. In October 2020, Malaysia's SEDC Energy signed an MoU with two Japanese companies (ENEOS and Sumitomo) to develop green hydrogen supply networks in Sarawak. In January 2022, it also signed an MoU with three Korean firms (Samsung Engineering, Lotte Chemical, and Posco Holdings) to build a green hydrogen and ammonia plant in Sarawak. In September 2022, these four companies signed an MoU with Malaysia's Sarawak Energy Berhad to study the supply of at least 900MW of hydro-based renewable energy for the plant. These partnerships position Sarawak not only as a key player in the global market, but also as an export hub to Japan and Korea.

State-owned players making moves

Malaysia's Petronas entered the hydrogen space in 2020 and formed several strategic partnerships with international and domestic companies to enhance its green hydrogen production capabilities and supply chain networks. In March 2021, it partnered with Japan's ENEOS to conduct a technical and feasibility study for commercial green hydrogen from a new hydro-powered electrolyzer facility. In March 2022, it signed an MoU with Korea's Samsung C&T to develop a blue or green hydrogen supply chain in Korea from its existing projects. In September 2022, it officially launched clean energy solutions provider Gentari to offer a wide range of renewable energy, hydrogen, and green mobility solutions for commercial, industrial, and retail customers. As a result, Petronas has contributed to establishing a hydrogen ecosystem while strengthening its competitive advantages.

Hydrogen as a fuel for transport

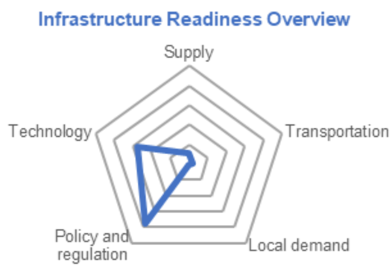
Hydrogen fuel cell has been prioritized for R&D, with a fund of MYR40 Mn (USD9.4 Mn) allocated to this from 1997 to 2013. A blueprint for fuel cell industries was introduced in 2017 to support the development of fuel cell technology and hydrogen infrastructure. NanoMalaysia has leveraged this opportunity to partner with Pulsar UAV to develop fuel cell drones in 2016, whereas Sarawak launched hydrogen-powered buses in 2020 and hydrogen fuel cell-powered ART vehicles in 2022.

The future of hydrogen in Malaysia

Malaysia aims at producing 0.5Mt hydrogen/year for exports before 2030. Thanks to initiatives driven by Sarawak and state-owned players' movements, Malaysia has built a good foundation for hydrogen. Although a hydrogen development roadmap has been announced, a legal framework for the hydrogen supply chain (production, transportation, storage, and utilization) is needed to boost utilization of hydrogen.

Mexico: Competitive hydrogen exporter to Europe and Asia

Current capacity	Future (2030) capacity
0*Mt/yr*	0.1*Mt/yr*
Current demand	**Future (2030) demand**
0*Mt/yr*	N/A
Domestic hydrogen policy in place?	x



Supply

- Currently all gray production
- ~4 production projects in the pipeline
- Estimated 670MW electrolysis by 2030

Transportation

- Adequate gas pipeline infrastructure
- No liquefication or ammonia-cracking facilities
- 4 Regasification terminals

Local demand

- Existing strong hydrogen demand in the mining and industrial use
- The vast potential of the hydrogen mobility sector in 2050

Policy and regulation

- Decarbonization goal
- No domestic hydrogen policy
- ETS implemented

Technology

- Long-standing R&D in hydrogen technology
- Lacking knowledge transfer to commercialization

Well-positioned for domestic consumption and export

Mexico has vast renewable energy capacity for green hydrogen production, with the second-largest solar energy sector in Latin America. While the renewable energy sites in the economy are located in proximity to the largest potential hydrogen consumers in the economy, Mexico is well positioned for domestic hydrogen consumption. Meanwhile, Mexico ranked second and third for LCOH export cost to Asia and Europe, respectively, after Chile and Morocco for Europe and Australia for Asia, at a price range of USD5.52~5.6/kg hydrogen.

Leveraging regional partnership

Mexico's development of hydrogen could leverage international partnerships in the private and public sectors. Currently, the main merchant hydrogen producers in Mexico are Air Liquide, Linde and Cryo-infra, most of which are international producers with capabilities and experience in green hydrogen overseas. Current hydrogen projects are initiated by foreign investors including HDF and Eni (under the company Dhamma Energy). On a government level, potential is indicated for collaboration between Mexico, the United States, and Canada on building the North American hydrogen market, specifying collaboration in R&D, safety codes and standards, and a green freight corridor.

SOEs have a role to play in clean hydrogen transition

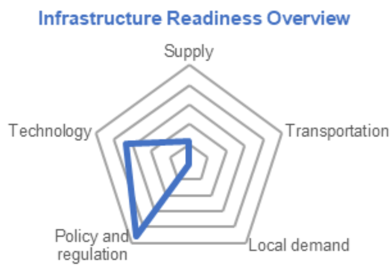
According to the GIZ report, Mexico state enterprises PEMEX (refinery, ammonia, syn-fuel) and CFE (grid injection, gas turbines) are estimated to be among the largest consumers of hydrogen in Mexico in 2030, before large-scale applications in mobility, with 5Kt annual demand under an NDC compliance scenario. The SOEs can potentially be the major players in the green hydrogen sector to decarbonize their supply chain and operation. Meanwhile, PEMEX is currently the largest producer and consumer of hydrogen in Mexico, mostly captive and gray. With the existing infrastructure and market, PEMEX has the opportunity to transition to clean hydrogen as one of the front runners in the market.

The future of hydrogen in Mexico

Leveraging low hydrogen production cost (USD2.55/kg in 2030) and geographical access to both the Atlantic and Pacific oceans, Mexico could export 60 thousand tons of green hydrogen by 2030, as estimated by GIZ. Domestically, green hydrogen will be widely adopted by SOEs including PEMEX and CFE, the mining industry, and close to 0.5 Mn buses and trucks by 2050.Overall, green hydrogen will create 90 thousand jobs and a USD5.7 Bn market in 2050.

New Zealand: Exporter utilizing renewable energy sources and infrastructure

Current	Future (2030)
Current capacity **0.0001***Mt/yr*	**Future (2030) capacity** **0.27***Mt/yr*
Current demand **0.0001***Mt/yr*	**Future (2030) demand** **0.1***Mt/yr*
Domestic hydrogen policy in place?	**Partial** – Interim Hydrogen Roadmap Published



Supply

- 2 projects (Halcyon with 0.12Kt capacity) and BOC project at Glenbrook Steel Mill
- ~11 projects in the pipeline

Transportation

- Adequate gas pipeline area coverage in the North Island
- Feasibility study on hydrogen pipeline
- A liquefication plant and regasification plant at Port Taranaki

Local demand

- Potential demand in 2035 between 179-600 kt depending on industrial feedstock conversion and speed/breadth of uptake
- Key opportunities in hard to abate sectors that support critical supply chains (heavy road, maritime, aviation), in industrial feedstock and e-chemical and sustainable fuel production

Policy and regulation

- Decarbonization plan and ETS in place
- Hydrogen strategy in development
- Funding targeting hydrogen projects

Technology

- ~4 start-ups in hydrogen
- New Zealand Hydrogen Council is an industry body with members across public, private, and academic stakeholders

Leveraging abundance in renewable energy resources

New Zealand has a high proportion of existing renewable generation in its electricity system. In 2022, renewable generation was 87 percent of total electricity production. Combined with considerable potential additional renewable electricity generation capacity, this presents a strong foundation for green hydrogen production.

Potential export leveraging existing infrastructure

There may be opportunities for New Zealand to export hydrogen or derivatives like ammonia and methanol. Meridian Energy have selected Australian company Woodside Energy as its preferred partner on a potential green hydrogen to ammonia plant targeted at export. One of the possible destinations could be Asia, especially Japan. New Zealand signed a Memorandum of Cooperation on hydrogen with Japan in 2018, which could be built upon for exporting agreements, and an Arrangement of Cooperation on low-carbon hydrogen with Singapore in 2021. Additionally, 2.4Mt of methanol is already exported from New Zealand annually, and 95 percent of this is exported to the Asia Pacific region. New Zealand could leverage the existing capacity and infrastructure for hydrogen transport after it has been liquefied to methanol.

Global partnership in R&D and commercialization

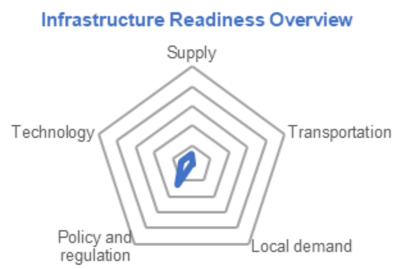
New Zealand has been engaging international private-sector players in its hydrogen development. Along with the Halcyon joint-venture between Tuaropaki Trust and with Japanese company Obayashi, New Zealand also hosts a feasibility study in partnership with Australian company Fortescue Future Industries (FFI) in producing green hydrogen for sustainable aviation fuel at the Marsden Point fuel import terminal. In transport, Hyundai has several pilot projects in hydrogen trucks and SUVs, and Toyota has a FCEV car-sharing scheme and worked with Team New Zealand to build a hydrogen fuel cell chase boat. In R&D development, a New Zealand-Germany Green Hydrogen Research programme has been formed between the New Zealand Ministry of Business, Innovation and Employment, and the German Federal Ministry for Education and Research.

The future of hydrogen in New Zealand

New Zealand published an Interim Hydrogen Roadmap in August 2023, and is planning to complete a final Hydrogen Roadmap alongside the New Zealand Energy Strategy in 2024. New Zealand has the potential to become one of the first large-scale producers of green hydrogen due to its established renewable energy infrastructure, potential for additional renewable generation and active private-sector collaborations. Domestically, key hydrogen uses are likely to be in industrial feedstocks and processes, and in heavy and long-distance transport across land, sea and aviation.

Papua New Guinea: Nascent yet promising producer

Current	Future (2030)
Current capacity 0*Mt/yr*	Future (2030) Capacity 0.12*Mt/yr*
Current demand 0*Mt/yr*	Future (2030) Demand N/A
Domestic hydrogen policy in place?	x



Supply

- Currently no green hydrogen production
- Green hydrogen projects in the pipeline by FFI

Transportation

- Limited gas pipeline coverage
- 1 liquefaction terminal
- No regasification or ammonia-cracking facilities

Local demand

- Unclear policy on hydrogen use
- No sign of ideation or testing of hydrogen applications

Policy and regulation

- National decarbonization strategy, target and plan
- No hydrogen strategy
- No carbon pricing initiatives

Technology

- Concept stage for green hydrogen production
- No start-ups in hydrogen

Currently powered by coal, energy transition in plan

Papua new guinea relied mostly on oil for energy supply as of 2020–2021 (50 percent), while electricity is mostly powered by hydropower (54 percent). The economy has laid down direction in its National Energy Policy to put a stronger emphasis on renewable energy, as the economy has an abundance of renewable energy resources, including hydropower and geothermal power, with a totaled potential of 25 thousand MW, while a large proportion of this is still unharnessed. The rich renewable resources and energy transition commitment indicate vast potential for green hydrogen production in Papua New Guinea. The Australian hydrogen project developer Fortescue Future Industry (FFI) estimated Papua New Guinea to have a hydrogen capacity potential of 2.3Mt per year.

Start of green hydrogen production

The Australian company Fortescue Future Industries (FFI) has signed a Master Development Agreement (MDA) to start a portfolio of hydrogen production from various renewable resources in Papua New Guinea, covering hydropower and geothermal power. The first-stage project is expected to be operating in 2030, producing 120Kt hydrogen per year. The output could potentially be taken by Total Energies in a broader talk of green energy offtake in PNG for power supply to its new LNG projects.

Building on global partnership in green transition

Papua New Guinea, together with Fiji, was one of Australia's partners for carbon offsets to participate in the Indo-Pacific carbon market launching low-emission projects. While a similar strategy in building international collaboration can be leveraged in promoting domestic energy transition, Papua New Guinea can use the partnership with FFI to increase the number of clean energy projects for domestic demand and export opportunities.

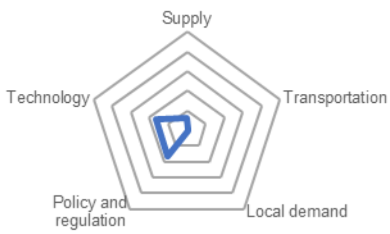
The future of hydrogen in Papua New Guinea

Papua New Guinea will be a local producer of green hydrogen by leveraging international support to harness unused renewable energy resources. Green hydrogen production could be developed at the same time as renewable energy expansion. The hydrogen produced could be utilized domestically to decarbonize the prominent mining and petroleum industry. Provided significant scale-up of production, potential also exists for export to economies with high hydrogen demand, including Japan and Korea, building on the current LNG export relationships.

Peru: Growing interests in hydrogen

Current capacity 0.0043*Mt/yr*	**Future (2030) capacity** 0.173*Mt/yr*
Current demand 0.0043 *Mt/yr*	**Future (2030) demand** 0.25*Mt/yr*
Domestic hydrogen policy in place?	x

Infrastructure Readiness Overview



Supply

- The current capacity is 0.0043Mt
- <5 projects in the pipeline
- Expected capacity at 0.173Mt by 2030

Transportation

- 729km length of gas/hydrogen pipeline infrastructure
- 1 liquefaction plant
- No ammonia-cracking facilities

Local demand

- The demand is driven by the mining, industrial and transport sectors.

Policy and regulation

- NDC & ENCC2050 announced for decarbonization strategy
- No domestic hydrogen strategy, but H2 Peru has proposed a roadmap and signed a cooperation agreement with Ministry to develop green hydrogen

Technology

- Electrolyzer is available
- No hydrogen start-up
- Collaboration between industry alliance and Ministry

Potential to export hydrogen

Rich in renewable energy resources, Peru is one of the Latin American economies that can produce low-cost hydrogen. According to the energy and mines Regulator Osinergmin, Peru produced up to 77,000MW in wind power and 70,000MW in hydroelectric energy in 2021. Besides that, the private Peruvian Hydrogen Association (H2 Peru) reports wind potential of 5kWh/m² along the northern coast and solar potential of 5kWh/m² on the southern coast. Enel Peru and Deloitte also identify that 81 percent of Peru's power generation could come from renewable sources by 2030 from 5 percent in 2022, of which 35 percent would be from solar and wind plants. Hence, Peru is abundant with renewable energy resources. In addition, hydrogen technology is in place in Peru, as the economy has been producing hydrogen by alkaline electrolyzer since 1965. Over the long term, a significant renewable energy supply and advanced technology will position Peru as an export hydrogen hub for other markets.

Growing interest in public and private sector

The hydrogen industry is emerging in Peru and is likely to develop over the coming decade due to its contribution to reducing 30 percent of carbon emissions by 2030. In March 2022, H2 Peru signed a cooperation agreement with the Ministry of Energy and Mines of Peru to jointly develop green hydrogen. Moreover, Peru lawmakers introduced bills to congress to promote green hydrogen production as part of the energy transition to reduce GHG emissions. Peruvian oil refineries have adopted carbon reduction strategies in their hydrogen facilities. For the public sector, the Talara Refinery, operated by NOC Petroperu, has established its hydrogen plant with Danish technology to make it more energy efficient. For the private sector, the Pampilla Refinery, owned by Repsol, commenced the operation of a hydrogen plant in 2016.

Potential to green the mining industry

Peru is one of the world's leading mineral producers, and the mining industry accounted for nearly 10 percent of Peru's GDP in 2021. Since the mining industry categorically needs the energy to extract, process, melt, and refine metals, a rich renewable energy supply can support decarbonizing the sector. Furthermore, hydrogen from renewable sources can support greening the mining industry through fuel for mining trucks, as well as heat and electricity for the production process.

The future of hydrogen in Peru

Peru is expected to generate 0.173Mt green hydrogen per year by 2030. Thanks to abundant renewable energy resources and hydrogen technology, Peru can potentially become an export hydrogen hub. However, legislation and government funding are needed to further support the development of hydrogen.

The Philippines: Potential self-sufficient hydrogen producer

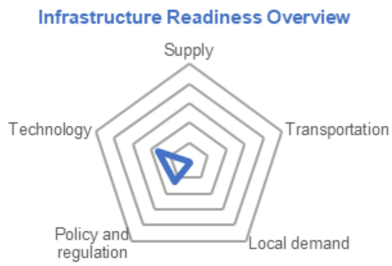
Current capacity
0*Mt/yr*

Current demand
0*Mt/yr*

Future (2030) capacity
0*Mt/yr*

Future (2030) demand
N/A

Domestic Hydrogen Policy In Place? x



Supply

- Produces large amounts of gray hydrogen

Transportation

- 504km length of gas/hydrogen pipeline infrastructure
- 3 regasification terminals are under construction

Local demand

- Local demand is driven by the industrial and transport sectors

Policy and regulation

- No net zero targets, but has a GHG reduction emission mandate
- No domestic hydrogen strategy
- Incentives offered to renewable energy developers

Technology

- Electrolyzer is available
- Few hydrogen start-ups
- DoE signed MoU with Japanese and Australian firms for hydrogen research

Hydrogen production from renewables with a focus on offshore wind farms

The Philippines has relatively high renewable resource potential, which helps reduce its dependence on imported fossil fuels and carbon dioxide emissions. Currently, renewables account for 21 percent of the economy's total energy mix, which includes geothermal, hydropower, wind, solar, and biomass. According to Philippine Energy Plan, renewables are expected to reach 35 percent of the energy mix by 2030 and 50 percent by 2040. Given the plentiful renewables supply, green hydrogen from renewables is a promising fuel for the decarbonization strategy. For offshore wind resources, there are currently 42 approved contracts with an indicated capacity of 31GW. Thanks to its high growth of approximately 30 percent by 2050, the Department of Energy (DoE) shows interest in creating an Offshore Wind Development and Investment Council to develop offshore wind and electricity for green hydrogen production. More importantly, the DoE has signed an MoU with Japanese and Australian firms to boost hydrogen research.

Hydrogen for industrial use and road transport

Hydrogen demand is mostly from the industrial and mobility sectors. For the industrial sector, refining and chemical account for the major use of hydrogen. Hydrogen is used in the conversion of crude oil for hydrocracking, hydrotreating, and hydrogeneration in the refining industry, whereas it is used as feedstock to produce ammonia in fertilizer. For road transport, hydrogen is used as a fuel to produce electricity in hydrogen vehicles. The Philippines is decarbonizing the transport sector by introducing more sustainable modes of public transport and considers hydrogen vehicles and hydrogen EVs in line with the government's plan to push green hydrogen production.

Progress leveraging partnerships

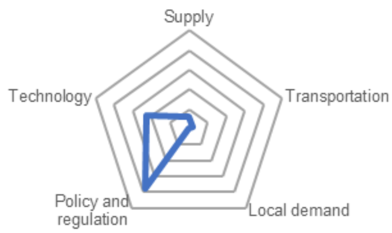
For the public sector, the Philippines' DoE signed an MoU with Australia's Star Scientific Limited for to use offshore wind to produce green hydrogen with proprietary HERO technology. It also signed an MoU with Japan's HTI and Toshiba to support R&D and production of hydrogen. For the private sector, Pilipinas Shell partnered with Air Liquide Philippines to operate a hydrogen production facility. Bangtangas Clean Energy operates a power plant project using natural gas and green hydrogen. Moreover, AC Energy and MetroPacific Investment Group have assessed green hydrogen.

The future of hydrogen in the Philippines

The Philippines will be hydrogen self-sufficient, as the DoE's main goal is to ensure the economy's energy security. However, the government needs to issue a policy and roadmap toward green hydrogen to guarantee that the economy can produce enough green hydrogen to serve its economy.

The Russian Federation: Energy export giant moving to hydrogen

Current capacity 0*Mt/yr*	Future (2030) capacity 0.39*Mt/yr*
Current demand N/A	Future (2030) demand N/A
Domestic hydrogen policy in place?	x



Supply

- Currently all gray hydrogen production
- ~5 projects in the pipeline, all blue
- Expected capacity at 0.39Mt by 2030

Transportation

- One of the largest gas supply systems
- 2 liquefaction plants and 1 regasification plant
- No ammonia-cracking facilities

Local demand

- Unclear policy in intended domestic hydrogen application
- Demand is driven by the industrial and transport sectors

Policy and regulation

- Published decarbonization and hydrogen strategy
- Hydrogen-targeted funding initiative
- Carbon tax in discussion

Technology

- Feasibility study on hydrogen production
- ~13 start-ups involved in hydrogen
- Working group engaging ministries and industry players

Natural gas reserve indicates potential for blue hydrogen

The Russian Federation is endowed with a vast reserve of natural gas and has been one of the world's largest natural gas producers. State-owned gas company Gazprom produced 18 Tn cubic feet of gas in 2021. Coupled with CCUS technology, the Russian Federation is well-positioned to produce blue hydrogen. While it is nascent in CCUS technology, according to IEA, the Russian Federation accounts for 20 percent of global underground carbon storage. As hydrogen is recognized as an increasing priority in the Russian Federation, it is also investing in decarbonizing blue hydrogen, including carbon capture technology. Although it is also rich in wind energy, considering the fossil fuel-dominant grid electricity mix and lack of large-scale development in renewables, the Russian Federation is expected to spearhead its clean hydrogen production with blue hydrogen.

Aiming to be a prominent hydrogen exporter

The Russian Federation has established an export-oriented production strategy and identified four production clusters, targeting four international markets in Europe, southern Europe, Asia, and other potential exports. RUB8 Bn (USD108.8 Mn) is announced to be used in developing technology in hydrogen production, transport, and storage in the next three years. The target export volume of 50Mt in 2050 would essentially replace all natural gas export to Europe today. Although Gazprom has indicated concerns about transporting hydrogen with its export natural gas pipelines, Novatek has been exploring the production of clean ammonia at its Yamal LNG port. The export would be dependent on the evolution of EU climate legislation, due to the clear preference for green over blue hydrogen in EU policies. The drafted Additionality Delegated Act could prohibit blue hydrogen by 2035. There is also R&D support on transport and storage.

International collaborations drive hydrogen development

The Russian Federation is active in engaging in international collaboration in developing its hydrogen economy, mostly driven by the private sector. Many international companies, including Air Liquide and TotalEnergies, have formed a partnership with companies from the Russian Federation, such as Notatek, to either produce or offtake hydrogen. A bilateral collaboration agreement on hydrogen production has also been signed with the UAE and Japan. Collaboration with Germany has also been sustained with the recent confirmation of setting up a German hydrogen diplomacy office in Moscow.

The future of hydrogen in the Russian Federation

The Russian Federation is expected to embark on its hydrogen transition through blue hydrogen, and eventually move toward green hydrogen, considering the trend for cleaner hydrogen demand.

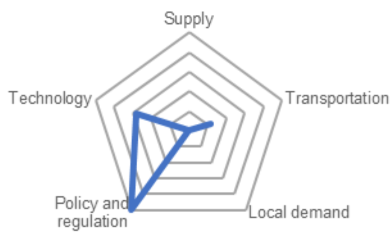
Singapore: Establishing green maritime hub with hydrogen

Current capacity	Future (2030) capacity
0*Mt/yr*	N/A

Current demand	Future (2030) demand
0*Mt/yr*	0*Mt/yr*

Domestic hydrogen policy in place? ✓

Infrastructure Readiness Overview



Supply

- Currently all gray hydrogen capacity
- 4 production projects in the pipeline
- Unclear future production capacity

Transportation

- Established natural gas infrastructure
- 1 regasification plant
- RD&D ammonia-cracking technology

Local demand

- Gas turbines in the power sector
- Maritime and aviation fuel
- CCUS with hydrogen

Policy and regulation

- Published decarbonization plan and hydrogen strategy, carbon tax
- A*STAR, MAS, and ESG set aside funding for the hydrogen project

Technology

- Operational hydrogen technology
- 12 start-ups in hydrogen
- Multiple consortia engaging universities and research institutes

Green maritime and ammonia bunkering

As part of the importing infrastructure, Singapore is active in researching ammonia-cracking technology, considering its existing positioning as a transport hub globally. Significant RD&D effort has been made in catalyst development, and a research partnership with Australia's CSIRO has been established. Decomposing ammonia back to hydrogen would not only enable hydrogen offtake use, but also facilitate meeting marine ammonia bunkering needs, which is also a strategic development area in Singapore's aim to be a first mover. The Maritime and Port Authority of Singapore is active in driving maritime decarbonization, and recognizes ammonia as an alternative fuel potentially to be applied widely in international maritime. Feasibility studies and regulatory discussions are being made to advance the transition toward ammonia bunkering.

Early advocate for hydrogen development

Although Singapore had just released its national hydrogen strategy in late 2022, it has devoted a lot of support and resources to hydrogen infrastructure and development. Dedicated funding is set aside for hydrogen project development, with examples including SGD129 Mn (USD96 Mn) in funding under Low Carbon Energy Research (LCER) phase II, which is likely to set hydrogen as a focal point. An academic institution is also funded to pioneer research in hydrogen technology breakthrough. The Center of Hydrogen Innovations (CHI) has been established with SGD25 Mn (USD19 Mn) in support from Temasek and NUS, being the first of its kind in South East Asia.

Leveraging international partnerships

Given the nascent stage of hydrogen, Singapore has collaborated with foreign companies for domestic hydrogen transition. In 2020, five Singaporean firms (PSA Corporation, Jurong Port, City Gas, Sembcorp Industries, and Singapore LNG Corporation) signed an MoU with two Japanese companies (Chiyoda Corporation and Mitsubishi Corporation) to explore the use of hydrogen in the economy. In 2021, Singaporean engineering company Sembcorp partnered with major Japanese hydrogen transport and storage player Chiyoda for decarbonized hydrogen import to Singapore in five years. Besides that, Singapore forms international partnerships as the basis for future positioning as a facilitator in global hydrogen transport flow. It has signed a cooperation agreement with New Zealand and a separate agreement with Chile to promote the development of hydrogen.

The future of hydrogen in Singapore

Singapore will become a trendsetter in maritime decarbonization, especially in South East Asia, leveraging its existing position as the transport hub in the region. Singapore will be an importer and one of the sandboxes for maritime fleet and aviation with hydrogen power technology.

Chinese Taipei: Supply chain provider in the making

Current capacity
0.002*Mt/yr*

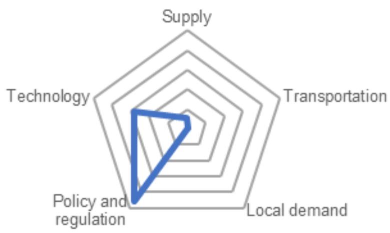
Current demand
0*Mt/yr*

Future (2030) capacity
0.004*Mt/yr*

Future (2030) demand
0.15*Mt/yr*

Domestic hydrogen policy in place?	✓

Infrastructure Readiness Overview



Supply

- One plant producing at a small scale
- ~1 production project in the pipeline
- Estimated 4Kt production capacity in 2030

Transportation

- Adequate gas pipeline area coverage
- No liquefication or ammonia-cracking facilities
- 2 regasification plants

Local demand

- A focus on hydrogen power generation before 2030, with a demand of ~900MW

Policy and regulation

- National decarbonization and hydrogen roadmap
- Targeted funding for hydrogen
- Carbon tax release in 2023 (passed assessment period)

Technology

- Long-standing R&D in fuel cell technology since 1993
- Operational application and supply chain in fuel cell back-up power
- 8 start-ups in hydrogen

Crucial role of hydrogen in power generation

Hydrogen has a crucial role in the energy transition not only due to its target to reduce coal and phase out nuclear as an energy source, but also because of Chinese Taipei's energy security need from its isolated grid. Hydrogen used in power generation is one of the first-wave technologies on the hydrogen roadmap, aiming for cofiring demonstration before 2040 and pure hydrogen application by 2050. Hydrogen will provide 9–12 percent of the energy demand at that time. To support this, hydrogen production and import infrastructure development are emphasized on the hydrogen roadmap. With abundant offshore wind resources and well-established clean hydrogen giant Air Liquide, Chinese Taipei has the potential for producing a reasonable amount of hydrogen for domestic use.

Integral key player in the global fuel cell supply chain

As another part of hydrogen development, Chinese Taipei could also leverage its strong established fuel cell supply chain. Hydrogen R&D subsidy was provided in Chinese Taipei as early as 1993 under the "National Green Energy Development Program." A mature fuel cell supply chain has been established, with producers in raw material, fuel cell stack, and system application to peripheral products, including storage tank and testing equipment. Chinese Taipei has become an integral part of the fuel cell supply chain, supplying key components to some of the largest global fuel cell manufacturers, including Bloom Energy, Siemens, and Ballard Power Systems. Based on some key producers in 2021, the total output of the fuel cell industry in Chinese Taipei amounted to around TWD4 Bn (USD140 Mn).

National lab driving hydrogen application development

Industrial Technology Research Institute (ITRI) in Chinese Taipei, apart from being a key drafter of the hydrogen roadmap, has been behind much progress in Chinese Taipei hydrogen application development. ITRI is active in forming an industry-academia consortium to develop hydrogen applications. ITRI is behind China Steel Corporation's demonstration line in hydrogen-powered steelmaking of 50kg/hr in 2024. Another example is an AVIX demonstration flight of a hydrogen-powered drone developed by ITRI.

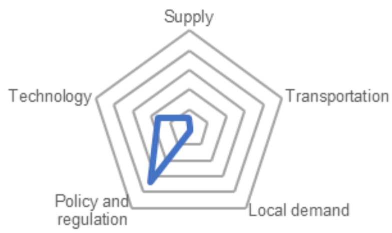
The future of hydrogen in Chinese Taipei

Chinese Taipei is expected to focus on power generation and industrial decarbonization with hydrogen in the midterm, using hydrogen for 9–12 percent of its power generation in 2050, powering the steelmaking and petrochemical industry. To supply these hydrogen applications, global hydrogen supply needs to be secured and hydrogen-receiving facilities established, as local renewable resources may be insufficient to power large demand for power generation and industrial use

Thailand: Green fuel leading the way in the development

Current capacity **0.0001***Mt/yr*	**Future (2030) capacity** **0.03***Mt/yr*
Current demand **0.0001***Mt/yr*	**Future (2030) demand** **0.5***Mt/yr*
Domestic hydrogen policy in place?	x

Infrastructure Readiness Overview



Supply

- Currently, 1 operating green hydrogen asset producing 0.08Kt hydrogen per annum
- <10 projects in the pipeline
- Estimated 0.03Mt production in 2030.

Transportation

- Adequate gas pipeline area coverage
- No liquefication or ammonia-cracking facilities
- 2 regasification plants

Local demand

- Increasing development in hydrogen fuel cell mobility

Policy and regulation

- Decarbonization strategy, ETS and carbon market
- No domestic hydrogen policy
- Published incentives for hydrogen production and related activities

Technology

- Small-scale and experimental projects only
- Few start-ups in hydrogen
- Thailand Hydrogen Group

An economy set for decarbonization transition

Thailand has pledged to achieve carbon neutrality by 2050 and net zero by 2065, while the largest energy player in Thailand, PTT, has announced a target to reach net zero by 2050, pioneering the economy's energy transition. In pursuit of these targets, Thailand has laid out a roadmap to decarbonize its economy across the manufacturing, power generation, agriculture, and transport sectors. The energy sector takes up 69 percent of Thailand's carbon emissions, detailing fuel combustion, transport, and manufacturing. According to the decarbonization roadmap, hydrogen has a key role to play in the manufacturing and transport sectors. Green hydrogen is planned to be adopted by hard-to-abate sectors, including iron and steel, by 2045, and fuel cell vehicles, especially long-haul trucks, will be widely adopted, as the cost will lower soon.

Hydrogen as the transition frontier fueling transport

As hydrogen is recognized as a key source for decarbonization in Thailand, hydrogen used for transport fueling has taken the first step in development. In late 2022, Toyota announced a partnership with Thai conglomerate CP Group to power fuel cell trucks with hydrogen from waste. The project is expected to open Thailand up to a new market of hydrogen fuel cell vehicles. As for the supporting infrastructure, a consortium led by PTT, Thailand's largest Oil and Gas SOE, has unveiled the first hydrogen refueling station (HRS) in Thailand. On an industrial level, the Industrial Estate Authority of Thailand (IEAT) recently announced plans to invest in hydrogen, including pioneering initiatives for hydrogen-powered vehicle use in one of its industrial estates, Smart Park, serving S-curve industries in the Eastern Economic Corridor.

Cross-sector collaboration driving changes

The hydrogen initiatives in Thailand have been driven by cross-sector consortia and international collaborations. One example is the establishment of Thailand Hydrogen Group, initiated by SOE PTT, engaging public and private-sector players to promote the development and adoption of hydrogen in Thailand. Internationally, a partnership with Germany has also been established. As part of the H2Upp program aiming to promote green hydrogen projects in emerging economies, market expertise and hydrogen know-how are being transferred to support hydrogen economy growth in Thailand.

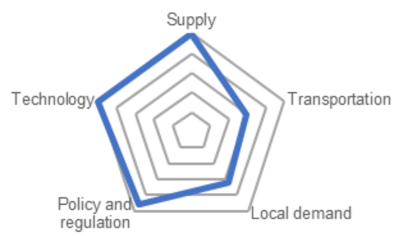
The future of hydrogen in Thailand

Thailand, although a novice in hydrogen development, is estimated to be a fast-growing hydrogen economy, with push from the national decarbonization strategy, industry consortium, and international support.

The United States: Advancing Hydrogen development at domestic and global scale

Current capacity 1.78*Mt/yr*	Future (2030) Capacity 10*Mt/yr*
Current demand N/A	Future (2030) Demand 10*Mt/yr*
Domestic hydrogen policy in place?	x

Infrastructure Readiness Overview



Supply

- <5% clean hydrogen production
- ~68 projects in the pipeline
- Aim for 10Mt production in 2036

Transportation

- 1,600 miles of hydrogen pipeline
- 18 liquefication and 10 regasification plants
- Patented ammonia-cracking technology

Local demand

- Local hydrogen demand is estimated to be 10Mt in 2036
- Huge potential in long-haul trucking and chemicals

Policy and regulation

- Hydrogen shot initiative
- Strong policy support in decarbonization and hydrogen
- Regional ETS in place

Technology

- Operational fuel cell vehicles, forklifts, refueling stations, stationary power, generation, and storage
- 646 start-ups involved in hydrogen
- Triple-helix collaboration, including H2@Scale and MachH2

Low-cost strategy as a backbone for the hydrogen economy

The United States Department of Energy (DoE) has laid out extensive plans and initiatives to facilitate hydrogen development. One example is the Inflation Reduction Act (IRA), which provides USD369 Bn in funding for new renewable and green energy projects in the form of a tax credit. The expected impact is that clean the hydrogen price (USD0.4/kg) will be 30 percent cheaper than the grey hydrogen price (USD 1–1.5/kg) by 2030. Moreover, the government has pushed collaborations in R&D and scale-up to further reduce hydrogen prices from production to delivery. Specifically, the DoE has launched a new consortium of national labs, industry, and academia, H2NEW, to target electrolyzer technology and process scale-up.

Connecting supply and demand to quickly scale up

As a continuous strategy from the low-cost initiative and connection between supply and demand, the United States focuses on building regional hydrogen hubs by co-locating large-scale hydrogen production centers with multiple end users. This allows for a jumpstart in the hydrogen economy, as the market is well-matched and infrastructure is easier to build. USD7 Bn in funding has been announced to establish six to 10 regional hubs. As for the supporting function of the hubs – transportation and storage– the United States has developed infrastructure buildout to strengthen its well-established energy infrastructure, with 1,600 miles dedicated to hydrogen pipeline, more than 3 Mn km in NG pipeline, the world's largest liquid hydrogen storage vessel in Florida, and the largest geological carven in Texas.

Global advocate for hydrogen transition

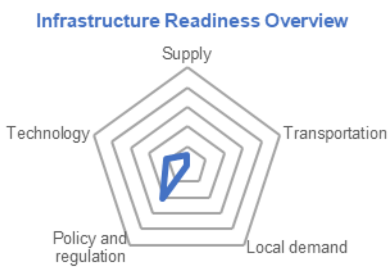
Internationally, the United States plays an active role in boosting the green energy transition. It is one of the founding members of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) to foster international collaborations in terms of policy, production, and trading with other 21 economies. It joined the Just Energy Transition Partnership to finance energy transition in developing economies such as South Africa, Indonesia, and Viet Nam.

The future of hydrogen in the United States

The United States is envisioned to be one of the key players in the global hydrogen ecosystem, with a strong domestic economy, as well as technology export and international partnerships. After 2030, the United States should be able to scale up green hydrogen production and retrofit gray hydrogen production. It will be producing and consuming ~49.2Mt of clean hydrogen in 2050, with application in trucks, storage, fuels, ammonia, etc., generating USD750 Bn in revenue and 3.4 Mn jobs.

Viet Nam: Vast natural resources indicate potential

Current capacity	Future (2030) capacity
0*Mt/yr*	**0.02***Mt/yr*
Current demand	**Future (2030) demand**
0*Mt/yr*	**N/A**
Domestic hydrogen policy in place?	x



Supply

- Currently no green hydrogen production
- <10 production projects in the pipeline

Transportation

- Adequate gas pipeline area coverage
- No liquefication or ammonia-cracking facilities
- Regasification terminals in development (LNG to power projects)

Local demand

- Unclear policy on promoting hydrogen as an energy source
- Potential replacement of natural gas with hydrogen by 2050

Policy and regulation

- No domestic hydrogen policy
- Inclusion of hydrogen in PDP VIII in discussion
- ETS in discussion

Technology

- Limited hydrogen development, largely relies on foreign investment and partnership for technology
- No start-up in hydrogen

Underdeveloped hydrogen landscape despite resources

Viet Nam is rich in resources for solar and wind power, both onshore and offshore, with more than 20GW of solar and wind energy produced at the end of 2021. Abundant renewable energy positions Viet Nam well for green hydrogen production, for both domestic consumption and exporting. Thang Long Wind 2, a project in the pipeline, has a capacity of 2000MW to produce green hydrogen with offshore wind energy for export to Japan; Korea; and Singapore. Hydrogen could also potentially be one of the solutions to excessive renewable energy. Despite the opportunity, Viet Nam is yet to be clear on its hydrogen development strategy, currently with only a general focus on diversifying energy sources with other renewable energy.

International partnership driving hydrogen development

The current development of hydrogen is driven by international initiatives and partnerships. Hydrogen training and seminars engaging stakeholders from public and private sectors are hosted by GIZ (German Ministry of Economic Affairs and Energy) and the United States consulate (as part of the V-LEEP program). G2G collaboration with the United States, Korea, and Singapore in clean energy has also addressed the role of hydrogen. For the private sector, the majority of hydrogen production development involves cross-border partnerships. TGS, which invested USD840 Mn in the first green hydrogen plant in Viet Nam, is partnering with German company Thyssenkrupp for hydrogen production. Recently, Viet Nam SOE Petro Vietnam signed an MoU with HDF France for green hydrogen manufacturing.

On the global map for the transition to green energy

As an economy at a premature stage in hydrogen technology, Viet Nam is leveraging international collaboration, although mainly under the umbrella of clean energy collaboration for the time being. Viet Nam has just signed up to JETP (Just Energy Transition Partnership), a consortium of developed and developing economies to accelerate the transition to green energy. The agreement will provide Viet Nam with USD15.5 Bn in funding to reduce emissions from the energy sector and strengthen renewable energy production and infrastructure.

The future of hydrogen in Viet Nam

Following the path of solar and wind energy, Viet Nam can be a significant hydrogen power producer, with capacity for domestic consumption and potential exports, driven by abundant clean energy resources, support from international partnerships, and local and international private investments. However, this is dependent on the development of supporting policies, funding, infrastructure, and technology.

8.2 Webinar conducted on 30 March 2023

As a means of socializing the knowledge from this report, a webinar was conducted on 30 March 2023 with three main objectives:

- Increase focus on energy access and achieving an affordable, reliable, resilient and sustainable energy supply, responding to APEC EWG's Strategic Plan for 2019-2023
- Increase understanding of the status of hydrogen infrastructure in the region; enhance the knowledge of stakeholders in the region to support hydrogen policy and investment decisions
- Solicit direction and guidance on integrating provided feedback and commentary into the final report

Five main topics were discussed at the webinar:

- Global state of hydrogen
- State of hydrogen infrastructure in APEC
- Selected case studies from APEC economies (Australia; Canada; Chile; China; Japan; Korea, Singapore; The United States.)
- Guest presentations by Dr. Sunita Satyapal of the U.S. Department of Energy and Barnik Maitra from Arthur D. Little
- Strategy and policy recommendations

The webinar had a fantastic turnout, with +55 participants across 14 APEC economies in attendance. Diversity was also shown with a female representation of 42 percent.

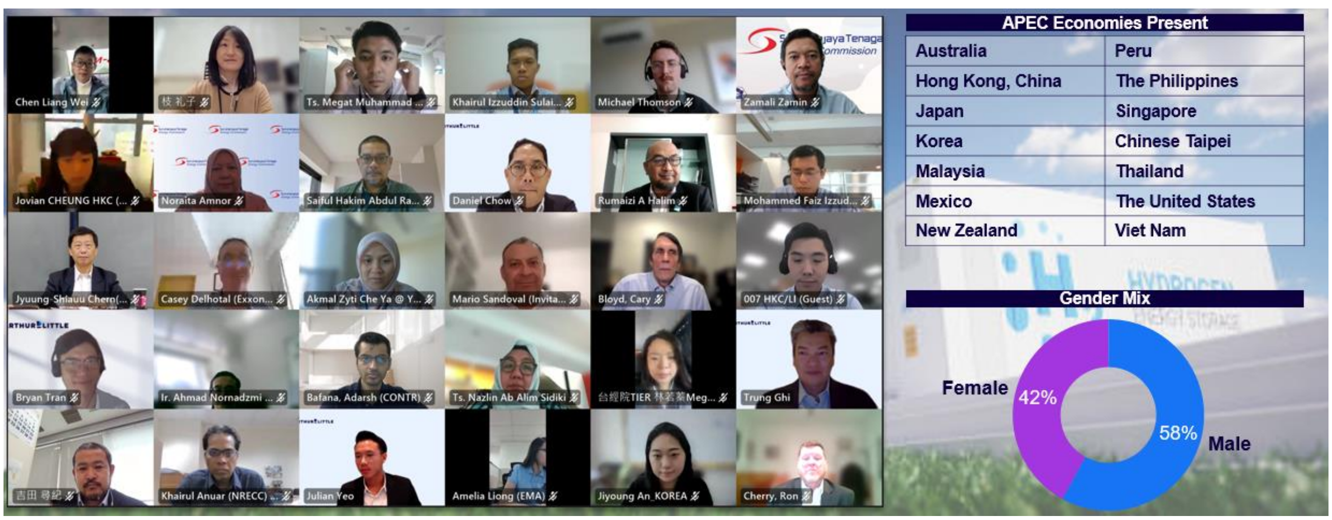


Figure 22: Webinar turnout and statistics

Additionally, as shown in ***Figure 23,*** feedback from the webinar was positive across the board.

Figure 23: Webinar outcomes and feedback from participants

Participants noted that they gained new knowledge from the webinar, including:

- Different aspects of the hydrogen economy
- Adapting processes and policies to their own economy
- Importance of hydrogen for zero-carbon
- Vast information on policies, projects and activities undertaken by each economy towards establishing a hydrogen economy

Webinar Feedback and Discussion Points

There were three discussion points raised both during the webinar and in the post-webinar feedback that has been incorporated in more detail as part of individual sections within this post-webinar final report. A summary of discussion points and remarks are summarized in ***Table 11***.

Table 11: Webinar feedback and discussion points

	Discussion Point	Remarks
1	Definition of hydrogen colours and the differences between them	This discussion comes at an interesting time given that the IEA had just published a new report just before the G7 Climate, Energy and Environmental Ministerial meeting in April 2023 on defining hydrogen based on their emissions intensity, thereby moving away from the use of terminologies based on colours or other terms that have created issues with contracts during investments. While the implementation of such a structure has the potential to enhance transparency significant and serve as a valuable catalyst for investment, there could be some uncertainty in the short-term given the nascency of this regulation. Developments in this new regulations will need to be closely monitored.

2	Ammonia and specifically ammonia cracking	The topic of ammonia is important for hydrogen discussion given that the midstream (i.e., transportation) element of the hydrogen value chain is often overlooked. Ammonia is hence often talked about as an energy carrier and means of transporting hydrogen. It is more energy-efficient to transport than hydrogen, while the globally established infrastructure for transportation of ammonia is relatively safe. Green ammonia is typically transported to its destination by ship, and undergoes the ammonia cracking process to separate it into hydrogen and nitrogen. In order to separate the hydrogen and nitrogen, an ammonia cracker is employed. The initial step involves heating the ammonia until it transitions into a gaseous form. Subsequently, it is introduced into a reactor where catalytic ammonia splitting occurs. The resulting product is then cooled, allowing for the separation of residual by-products and the acquisition of a pure hydrogen stream, which can be utilized directly or directed into a pipeline. More details on this can be found in **Section 4.3 and Section 4.4.**
3	Economies need to understand their required level of development and the means to achieve that level	This is no doubt an important consideration, which is why Section 7 features heavy elaboration on the role of economies within the hydrogen value chain depending on their state of development. For instance, some regions and economies will remain highly industrialized and create demand for hydrogen that cannot be met with domestic production – economies such as Japan, Korea and parts of Europe, while other economies like Australia are blessed with natural resources and could serve as exporters of hydrogen. This once again highlights the importance of infrastructure. As we transition towards low-emission hydrogen, it is likely that output and demand will no longer be co-located, and we are seeing that the best places to produce cheap, low-emission hydrogen may be far away from demand centres, which would require infrastructure as a link. Furthermore, new sources of demand such as transport, aviation and shipping are more distributed than existing industrial demand centres, making infrastructure all the more important.

References and sources

About the Hydrogen Materials Advanced Research Consortium. (n.d.). https://www.hymarc.org/about.html

ANALYSIS | US unveils draft national clean hydrogen strategy and roadmap — with three key priorities. (2022, September 23). Recharge | Latest Renewable Energy News. https://www.rechargenews.com/energy-transition/analysis-us-unveils-draft-national-clean-hydrogen-strategy-and-roadmap-with-three-key-priorities/2-1-1308355

Advanced Power and Energy Program (APEP), UC Irvine. (n.d.). https://www.apep.uci.edu/

Austrade. Korean Hydrogen Market Update. (2022, June). https://www.intralinkgroup.com/getmedia/8ba563f7-08f6-43de-ab4a-4467c7e8b3bd/Austrade-Korean-Hydrogen-Market_Report

Australia - HyResource. (2023, February 6). HyResource. https://research.csiro.au/hyresource/policy/australia/

Australia's international clean energy partnerships - DCCEEW. (n.d.). https://www.dcceew.gov.au/climate-change/international-commitments/international-partnerships

Australian Government. A decade leading Australia's energy transition. (2022, September 27). https://www.cefc.com.au/media/fq2prayo/cefc-annual-report-2021-22.pdf

Canada, F. C. a. R. I. I. (2020, September 10). Hydrogen: An emerging innovation in Canada's renewable energy industry. Invest in Canada. https://www.investcanada.ca/blog/hydrogen-emerging-innovation-canadas-renewable-energy-industry

Canada, N. R. (2022, November 14). Minister Wilkinson Announces up to $800 Million in Project Funding to Advance Canada's Clean Fuels Sector. Canada.ca. https://www.canada.ca/en/natural-resources-canada/news/2022/11/minister-wilkinson-announces-up-to-800-million-in-project-funding-to-advance-canadas-clean-fuels-sector.html

Canada, N. R. (2022a, August 23). The Hydrogen Strategy. https://natural-resources.canada.ca/climate-change-adapting-impacts-and-reducing-emissions/canadas-green-future/the-hydrogen-strategy/23080

China's Solar Giants Make a Bid to Dominate Hydrogen Power. (2021, December 13). Bloomberg.com. https://www.bloomberg.com/news/articles/2021-12-12/china-s-solar-giants-make-a-bid-to-dominate-hydrogen-power#xj4y7vzkg

China's nascent green hydrogen sector: How policy, research and business are forging a new industry. (2022, June 28). Merics. https://merics.org/en/report/chinas-nascent-green-hydrogen-sector-how-policy-research-and-business-are-forging-new

CSIRO. Hydrogen RD&D Collaboration Opportunities: Global Report. (2022, August 18). http://mission-innovation.net/wp-content/uploads/2022/09/H2RDD-Global-FINAL.pdf

Chandak, P. (2023, February 21). PBBM Supports AboitizPower And JERA Push For Greener Fuels In The Philippines. SolarQuarter. https://solarquarter.com/2023/02/21/pbbm-supports-aboitizpower-and-jera-push-for-greener-fuels-in-the-philippines/

Demaco. Hydrogen Transportation: Three well-known energy carriers compared. (n.d.) https://demaco-cryogenics.com/blog/hydrogen-transportation-three-energy-carriers/

DOE Fact Sheet: The Bipartisan Infrastructure Deal Will Deliver For American Workers, Families and Usher in the Clean Energy Future. (n.d.). Energy.gov. https://www.energy.gov/articles/doe-fact-sheet-bipartisan-infrastructure-deal-will-deliver-american-workers-families-and-0

Department of the Premier and Cabinet. (n.d.). Media Statements - World-leading Pilbara renewable hydrogen project attracts major international investment. https://www.mediastatements.wa.gov.au/Pages/McGowan/2022/06/World-leading-Pilbara-renewable-hydrogen-project-attracts-major-international-investment.aspx

Energy Market Authority, MPA Singapore. Call for Expression of Interest to Develop Low or Zero-Carbon Power Generation and Bunkering Solutions. (2022, December). https://www.mpa.gov.sg/docs/mpalibraries/mediareleases/older/joint-media-release_call-for-expression-of-interest-to-develop-low-or-zero-carbon-power-generation-and-bunkering-solutions

European Commission - Have your say. (n.d.). European Commission - Have Your Say. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12407-Clean-energy-an-EU-hydrogen-strategy_en

European Clean Hydrogen Alliance. (n.d.). Internal Market, Industry, Entrepreneurship and SMEs. https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/european-clean-hydrogen-alliance_en

Grubnic, P. (2022, November 13). Port Bonython Hydrogen Hub - HyResource. HyResource. https://research.csiro.au/hyresource/port-bonython-hydrogen-hub/

Home - CERTIFHY. (2023, January 16). CERTIFHY. https://www.certifhy.eu/

H2@Scale. (n.d.). Energy.gov. https://www.energy.gov/eere/fuelcells/h2scale

Hydrogen Shot. (n.d.). Energy.gov. https://www.energy.gov/eere/fuelcells/hydrogen-shot

Hydrogen Technology Cluster Australia (H2TCA) : NERA National Energy Resources Australia. (n.d.). https://www.nera.org.au/Regional-Hydrogen-Technology-Clusters

Hydrogen Council. Hydrogen Insights 2022 - An updated perspective on hydrogen market development and actions required to unlock hydrogen at scale. (2022, September). https://hydrogencouncil.com/wp-content/uploads/2022/09/Hydrogen-Insights-2022-2.pdf

Hydrogen from Next-generation Electrolyzers of Water (H2NEW) | H2NEW. (n.d.). https://h2new.energy.gov/

HyBlend: Opportunities for Hydrogen Blending in Natural Gas Pipelines. (n.d.). Energy.gov. https://www.energy.gov/eere/fuelcells/hyblend-opportunities-hydrogen-blending-natural-gas-pipelines

Huber, I. (2022, July 15). Unlocking Private Investment in Low-Carbon Hydrogen. https://www.csis.org/analysis/unlocking-private-investment-low-carbon-hydrogen

HIF Global. (2023, March 7). Haru Oni - HIF Global. https://www.hifglobal.com/haru-oni

IEA. The Future of Hydrogen. (2019, June). https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf

Initiation of basic design in the first half of 2020, completion of hydrogen city construction by 2022 (n.d.). http://www.molit.go.kr/USR/NEWS/m_71/dtl.jsp?id=95083342

IRENA. Green Hydrogen Cost Reduction. (2020). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

IRENA. Green Hydrogen – A guide to policy making. (2020). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_hydrogen_policy_2020.pdf?rev=c0cf115d8c724e4381343cc93e03e9e0

Infrastructure Investment and Jobs Act (IIJA) Implementation Resources. (n.d.) https://www.gfoa.org/the-infrastructure-investment-and-jobs-act-iija-was

J. (2022, April 28). $140m announced for Pilbara and Kwinana hydrogen hubs. Australian Manufacturing. https://www.australianmanufacturing.com.au/140m-announced-for-pilbara-and-kwinana-hydrogen-hubs/

Jones, J. S. (2022, January 12). Chile – $50 million for green hydrogen development. Enlit World. https://www.enlit.world/hydrogen/chile-50-million-for-green-hydrogen-development/

Kumagai, T. (2020, June 25). S&P Global Commodity Insights. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/natural-gas/062520-ahead-launches-brunei-japan-hydrogen-supply-chain-for-power-generation-in-tokyo-bay

Korean Culture and Information Service (KOCIS). (n.d.). 15 corporations join "hydrogen alliance," to invest KRW 43T by 2030 : Korea.net : The official website of the Republic of Korea. Copyright(C) 1999-2016 KOCIS. All Rights Reserved. https://www.korea.net/NewsFocus/Business/view?articleId=203617

Ministry of Energy (2020, November). Chile. https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf

Nam, J. M. (2022, July 7). Korea hydrogen council launches $382 Mn fund. KED Global. https://www.kedglobal.com/hydrogen-economy/newsView/ked202207070007

Nakano, J. (2022, September 21). Japan's Hydrogen Industrial Strategy. https://www.csis.org/analysis/japans-hydrogen-industrial-strategy

Netherland Enterprise Agency. Hydrogen development in Taiwan. (2022, February). https://www.rvo.nl/sites/default/files/2022-08/20220201%20Hydrogen%20Developments%20in%20Taiwan.pdf

New Zealand Hydrogen Scenarios, Report to MBIE, (2022, June). New Zealand Hydrogen Scenarios Report June 2022 (mbie.govt.nz)

Oates, T. (2023, January 30). Funding for projects under HyGATE initiative. Energy Magazine. https://www.energymagazine.com.au/funding-for-projects-under-hygate-initiative/

Overview of the Green Innovation Fund Projects | NEDO Green Innovation Fund Projects. (n.d.). NEDO Green Innovation Fund Projects. https://green-innovation.nedo.go.jp/en/about/

Pang, I. (2021, November 9). China offers cheaper green loans. ING Think. https://think.ing.com/articles/china-offers-cheaper-green-loans

Promoting development of hydrogen transport. (n.d.). https://www.info.gov.hk/gia/general/202305/24/P2023052400318.htm?fontSize=1

Promoting the development of carbon markets. (n.d.). https://www.info.gov.hk/gia/general/202303/22/P2023032200196.htm

Renews Ltd & reNEWS Ltd. (2022b, June 16). EU electrolyser production initiative launches. reNEWS - Renewable Energy News. https://renews.biz/78519/eu-electrolyser-production-initiative-launches/

Reuters. (2021, May 18). Japan allocates up to $3.4 bln from green fund to accelerate R&D in hydrogen. https://www.reuters.com/business/sustainable-business/japan-allocates-up-34-bln-green-fund-accelerate-rd-hydrogen-2021-05-18/

Reuters. (2022, November 11). Indonesia's Pertamina to explore green hydrogen projects with Keppel, Chevron. https://www.reuters.com/business/sustainable-business/indonesias-pertamina-explore-green-hydrogen-projects-with-keppel-chevron-2022-11-11/

Reuters. (2022, June 3). South Korean companies to build $1 billion green hydrogen plant in UAE. https://www.reuters.com/business/energy/south-korean-companies-build-1-bln-green-hydrogen-plant-uae-2022-06-03/

Roundtables of the European Clean Hydrogen Alliance. (n.d.). Internal Market, Industry, Entrepreneurship and SMEs. https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/european-clean-hydrogen-alliance/roundtables-european-clean-hydrogen-alliance_en

Rystad Energy. Can Southeast Asia blue ammonia exports compete in 2030 (2023, May 22). https://www.rystadenergy.com

Six Canadian companies chasing the carbon capture market. (2019, April 10). JWN Energy. https://www.jwnenergy.com/article/2019/4/10/six-canadian-companies-chasing-carbon-capture-mark/

Taiwan Gives Subsidy to Micro Fuel Cell Company - News. (2020, July 20). https://eepower.com/news/taiwan-gives-subsidy-to-micro-fuel-cell-company/#

Tasmania's Green Hydrogen Hub Vision | Renewables, Climate and Future Industries Tasmania. (n.d.). https://www.stategrowth.tas.gov.au/recfit/future_industries/green_hydrogen/tasmanias_green_hydrogen_hub_vision

Three trial projects on hydrogen fuel technology given agreement-in-principle by the Inter-departmental Working Group on using hydrogen as Fuel. (n.d.). https://www.info.gov.hk/gia/general/202303/28/P2023032800732.htm?fontSize=1

United States, Ministry of Industry and Trade Launch $36 Million Clean Energy Project | Vietnam | Press Release | U.S. Agency for International Development. (2022, June 3). U.S. Agency For International Development. https://www.usaid.gov/vietnam/press-releases/jun-3-2022-united-states-ministry-industry-and-trade-launch-36-million

Wood Mackenzie. What Role Will Ammonia Play in Global Hydrogen Trade (2022, January 10). https://www.woodmac.com/news/opinion/what-role-will-ammonia-play-in-global-hydrogen-trade/

World Bank Group. Green Hydrogen in Developing Countries – Renewable hydrogen and Green Powerfuel opportunities for South Africa. (2021, April 13). https://www.ee.co.za/wp-content/uploads/2021/04/Fernando-de-Sisternes-presentation.pdf

World's Longest Green Corridor Planned Between Singapore and Rotterdam. (2022, August 2). The Maritime Executive. https://maritime-executive.com/article/world-s-longest-green-corridor-planned-between-singapore-and-Rotterdam