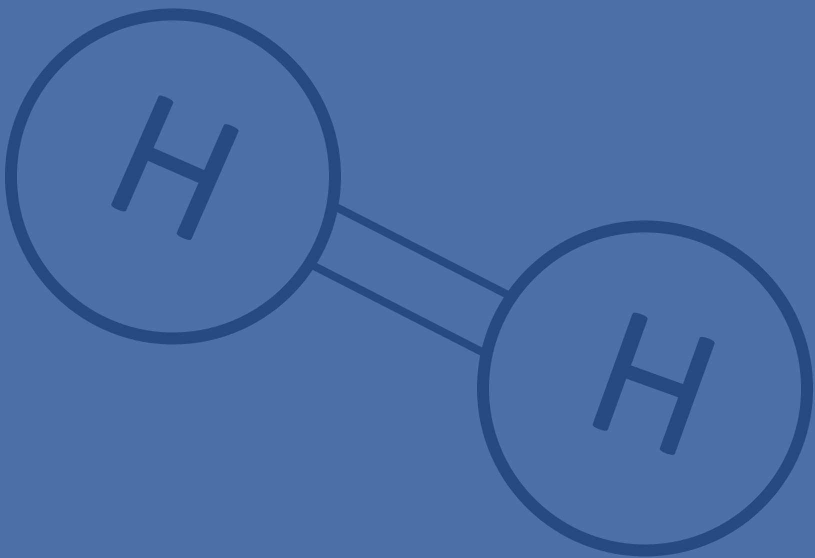
APERC

HYDROGEN REPORT 2023



ASIA PACIFIC ENERGY RESEARCH CENTRE

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Asia Pacific Energy Research Centre (APERC)
Inui Building, Kachidoki 11F, 1-13-1 Kachidoki
Chuo-ku, Tokyo 104-0054 Japan

Tel: (813) 5144-8551
Fax: (813) 5144-8555
E-mail: master@aperc.or.jp (administration_
Website: https://aperc.or.jp/

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FOREWORD

APEC aims to reduce energy intensity by 45 percent by 2035 relative to 2005 levels. Additionally, APEC also seeks to double the share of modern renewables by 2030 relative to 2010 levels. Hydrogen is currently acknowledged as a promising tool that could help APEC member economies achieve these goals, particularly in hard-to-abate sectors such as industry and air transport.

Despite increased attention on low-carbon hydrogen in recent years, its future viability as a low-emissions fuel remains uncertain. Cost competitiveness and the delay in the development of infrastructure are among the key challenges that could slow its widespread adoption. Technological advancements, economies of scale, and cumulative production will reduce costs. Until substantial cost reductions are realized, the commercial development of a low-carbon hydrogen market will heavily rely on supportive government policies, including subsides, which vary widely among APEC economies.

This report provides an update on hydrogen projects and government policies related to hydrogen in the APEC economies. It also describes the current challenges to substantial growth in the industry and the importance of international standards in facilitating that growth.

This report is part of the APERC fossil fuel reports series, published annually. I hope this report will be assist APEC policymakers design and implement hydrogen strategies for each economy. I would like to express my sincere gratitude to the authors and contributors for their time and effort in writing and publishing this report. I am also grateful to APEC member economies for providing updated data through the APEC Expert Group on Energy Data and Analysis (EGEDA).

Kazutomo IRIE

President
Asia Pacific Energy Research Centre

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Author

Manuel Antonio HEREDIA MUNOZ

Editors

Glen E. SWEETNAM

Munehisa YAMASHIRO

Design

Manuel Antonio HEREDIA MUNOZ

Highlights

- Most APEC economies are implementing policies designed to increase the production, transportation, and consumption of zero- and low-carbon hydrogen as a fuel.
- As a result of these new policies and expected future policies designed to encourage zero- and low-carbon hydrogen fuel use, many projects are being proposed in a number of APEC economies.
- Very few of these projects have achieved final investment decision (FID). The primary reasons are the current high costs of producing zero- and low-carbon hydrogen, the lack of infrastructure and high cost of transporting zero- and low-carbon hydrogen, and the uncertainty about future demand for zero- and low-carbon hydrogen.
- Reducing the cost of zero-and low-carbon hydrogen poses challenges due to a significant portion of the production costs are tied to the cost of the energy used.
- Another uncertainty relates to future international standards for zero- and low-carbon hydrogen. The development and widespread adoption of these international standards would remove key uncertainties that may slow the financing of zero- and low-carbon hydrogen projects.

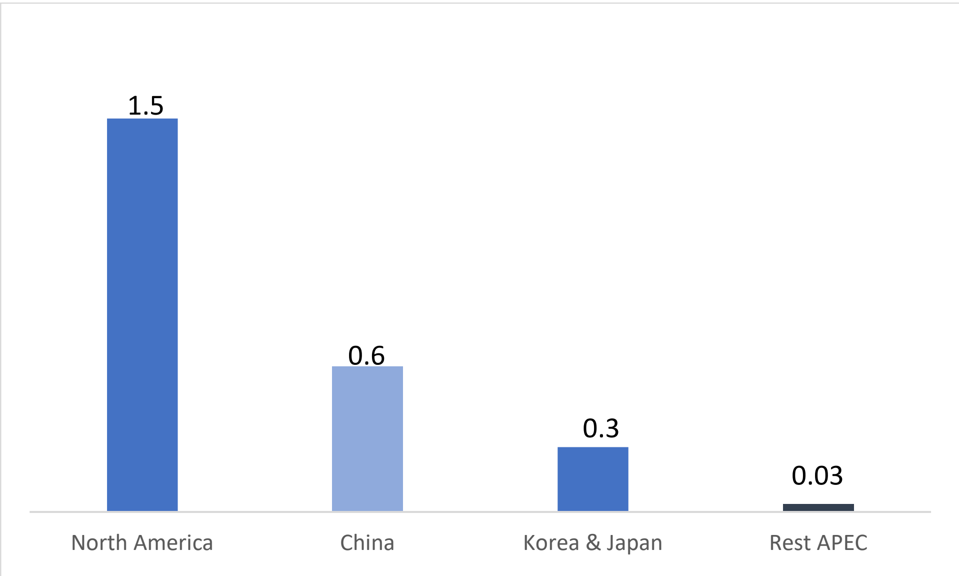
Advances in Hydrogen Projects

According to the Hydrogen Insights 2023 Updates (Hydrogen Council and McKinsey & Company, 2023), more than 1400 large-scale hydrogen projects, representing USD 520 billion of investment that is expected to be commissioned by 2030, were announced by October 2023. However, most of these projects are in the planning phase while globally less than 7% have reached final investment decision. Most of the projects that have committed investment are in China and North America, APEC member economies.

Perhaps the biggest challenges in this nascent industry faces lie on the uncertainty of future demand and the need of adequate distribution infrastructure to transport hydrogen to the end-users. Projects that have reached final investment decision could provide around 2.5 million tonnes of hydrogen by 2030 per year. This capacity can satisfy less than half of the end-use hydrogen demand estimated in the 8th edition of the APEC Energy Supply and Demand Outlook (APERC, 2022) in the carbon neutrality scenario.

The role of APEC in the development of the hydrogen industry cannot be underestimated as this region hosts the biggest consumers and producers of hydrogen. Several announced projects are located withing the APEC region. Canada and USA are currently developing fossil fuel-based low-carbon hydrogen projects meanwhile China has committed several renewable hydrogen projects and is also rapidly expanding its electrolyser manufacturing capacity. On the other hand, Japan is actively working on developing hydrogen supply chains in collaboration with other APEC economies such as Australia.

Figure 1 Estimated committed annual H_2 generation capacity by 2030 (Million tonne of H_2)



Source: Estimation based on the Hydrogen Insights 2023 update report and APERC

Australia

By April 2023, hydrogen projects with total production capacity of 475 tonnes of hydrogen per year are operating in Australia (Commonwealth Scientific and Industrial Research Organisation, 2023). Most of these projects use water electrolysis as the core hydrogen production technology.

The Hazer Commercial Demonstration Plant, with a capacity of 100 tonnes of hydrogen per year, uses a proprietary hydrogen production technology, known as Hazer process. This plant uses renewable methane obtained from biogas produced from biomass and organic waste to obtain low-carbon hydrogen.

Hydrogen Park South Australia and Western Sydney Green Gas projects with a combined capacity of 2,150 tonnes of hydrogen per year are under construction. They will produce hydrogen via electrolysis. Other important projects are Yuri Renewable Hydrogen to Ammonia with a capacity of 640 tonnes per year of hydrogen, Geelong New Service Station with a capacity of 365 tonnes per year and Goondiwindi Hydrogen and Sumitomo Green Hydrogen Production and Rio Tinto Decarbonisation Production Pilot Project with a capacity of 300 tonnes per year.

Another important hydrogen project in Australia is the Hydrogen Energy Supply Chain (HESC). In this project, hydrogen is produced from brown coal and biomass from Latrobe, a Southeastern ciy in Victoria, via gasification and then is liquefied and transported through specially designed hydrogen carriers to Japan. The pilot phase of this project purchased carbon offsets to mitigate emissions and the main objective was to demonstrate the technical viability of the implementation of a hydrogen energy supply chain. The pilot was successfully completed in February 2022 with the arrival of the Suiso Frontier, the World's first liquified hydrogen carrier, in Kobe, Japan with a load of liquefied hydrogen. In March 2023, Japan Suiso Energy (JSE) confirmed it had chosen to allocate the Japanese Government's Green Innovation Fund (GIF) grant of JPY 210 billion to the commercial demonstration phase of Victoria's HESC project. In this new phase, J-Power and Sumitomo Corporation will produce low-carbon hydrogen using coal from Latrobe and carbon capture and storage technologies. In Japan, Kawasaki Heavy Industries and Iwatani Corporation will purchase and use this low-carbon hydrogen. The capacity of HESC in the commercial phase is between 30,000 to 40,000 tonnes per year.

On the other hand, the Western Green Energy Hub project is among the biggest projects that is expecting to reach final investment decision by 2028. This project plans to uses electrolysis and renewable energy to produce 3.5 million tonnes of hydrogen per year or 20 million tonnes of green ammonia for domestic consumption and export and includes the construction of 50 GW of solar and wind power capacity. If the project is built, it will be one of the biggest hydrogen production projects.

Other important project is the Australian Renewable Energy Hub, previously known as the Asian Renewable Energy Hub. With a capacity of 1.6 million tonnes of green hydrogen or 9 million tonnes of green ammonia, this project will develop 26 GW of solar and wind capacity. However, this project had some problems to receive environmental approval by the authorities.

Brunei Darussalam

Brunei Darussalam was host of an important project that was a milestone for long-distance hydrogen transport. The Advanced Hydrogen Energy Association for Technology Development (AHEAD) was a demonstration project completed in 2020 and was Bruneian-Japanese effort that consisted of the development of a hydrogen supply chain using methylcyclohexane (MCH) as the hydrogen carrier. First, hydrogen is produced via steam methane reforming at Brunei LNG. Next, hydrogen was converted into MCH by reacting hydrogen and toluene. Later, MCH was shipped to Tokyo where hydrogen was extracted using a dehydrogenation process. Finally, to close the hydrogen supply chain, toluene is transported back to Brunei Darussalam for reuse. In December 2020, members of the AHEAD project announced successful completion of the project, transporting 100 tonnes of hydrogen over 10 months, demonstrating technical viability of this method of transporting hydrogen that will compete with ammonia and liquid hydrogen. The hydrogen was used in a gas turbine in Keihin refinery in Japan.

Canada

According to Canada’s National Strategy for Hydrogen, annual hydrogen production reaches 3 million metric tonnes, primarily sourced from natural gas. Among the most relevant operating projects are the following: the Quest at the Scotford upgrader, Northwest Sturgeon refinery, and Horizon Oil Sands. The hydrogen produced in these projects is used into the bitumen refining process and totally consumed on site. These projects have a hydrogen production capacity of approximately 700,000 tonnes of hydrogen per year and have incorporated carbon capture and storage (CCS) technologies.

The Hydrogen Insights 2023 identifies North America as the region that leads with committed investment in hydrogen projects, especially low-carbon hydrogen projects. More than 550,000 tonnes of hydrogen production capacity are committed, being the Net-Zero Hydrogen Energy Complex the most important with a capacity of 520,000 tonnes of hydrogen per year. This project consists of an Auto-Thermal Reformer hydrogen production facility, with carbon capture technology with a rate of capture of 95% removal of CO_2. Hydrogen-fuelled gas turbines will provide electricity to the project and the grid. Additionally, 30 tonnes per day hydrogen liquefaction facility will provide hydrogen to the industrial and transport sector in Canada.

A shift from fossil fuel-based hydrogen production, predominant in projects with committed investments, to renewable energy-based hydrogen production, in recently announced projects, is evident. For example, Nujio’qonik, located in St George’s Bay in Newfoundland and Labrador, has an announced hydrogen production capacity of 250,000 tonnes of green hydrogen per year, 1.5GW of electrolyser and 3GW of wind energy power plant.

Additionally, two projects will also use wind energy to produce hydrogen and ammonia in Point Tupper Industrial Park in Nova Scotia: The Bear Head project with 350,000 tonnes of hydrogen and 2 million tonnes of ammonia per year and the EverWind project with 200,000 tonnes of hydrogen and 1 million tonnes of ammonia per year.

In total, announced hydrogen production capacity are estimated at around 2 million tonnes per year by the first half 2023.

Chile

There are over 40 projects of different scales announced in Chile following the introduction of the National Green Hydrogen Strategy and the current phases of development vary depending on the project. Chile has taken actions through the Production Development Corporation (CORFO) by supporting six projects as a crucial step in implementing the National Strategy. The selected projects are the following:

- HyEx: In its pilot phase, this project aims to yield 3,200 tonnes of green hydrogen for ammonia production. A proposed upscale aim to increase capacity to 130 000 tonnes of green hydrogen or 700 000 tonnes of ammonia per year.
- Antofagasta Mining Energy Renewable (AMER): Envisioned to produce an annual output of 60,000 of e-methanol.
- HyPro Aconcagua: Aiming to displace fossil-fuel-derived hydrogen in refineries, this endeavor has a projected capacity of 3,000 tonnes of green hydrogen.
- Hidrógeno Verde Bahía Quintero: Anticipating an annual production of 430 tonnes of green hydrogen. However, the project faced challenges in securing sufficient demand which posed a risk to its developmental progress.
- H2V CAP: Set to establish a green hydrogen facility with a capacity to generate 1550 tonnes of green hydrogen annually.

- Faro del Sur: Envisaged to produce 25,000 tonnes of hydrogen per year, with intentions to manufacture e-methanol and e-gasoline for export purposes. However, this project recently halted its advancement due to regulatory requisites imposed by the authorities.

Additionally, the Haru Oni project, located in Punta Arenas in the South of Chile, exported its first 2,600 liters of synthetic fuel produced with green hydrogen in 2023. The e-fuel was exported to England to be tested by Porsche as the car company plans to use carbon-neutral fuels in the Porsche Mobil 1 Super Cup.

In August 2023, Chile inaugurated the first industrial green hydrogen facility in Latin America to supply hydrogen to two hundred forklifts' fuel cells. There are also pilot projects that blend hydrogen with natural gas 20% (v/v)[1], for heating some households in Coquimbo, located in the Near North region of Chile.

People's Republic of China

China currently stands as the world's largest consumer and producer of hydrogen. According to the International Energy Agency's Global Hydrogen Review 2022, China's hydrogen demand was approximately 28 million tonnes in 2021, constituting nearly 30% of the global demand. Most of this demand is met through unabated coal-based hydrogen production.

China has emerged as a frontrunner in committed investments within the APEC region, with a strong focus on green hydrogen projects. S&P Global Commodity Insights for 2022 indicates that 307MW of electrolysers were installed worldwide, with 224MW installed just in China. Installed capacity of electrolyzers is estimated in 1.2 GW by 2023.

Sinopec, the world's largest refiner by volume, has set an ambitious target to ensure that 60% of its annual hydrogen production will be green hydrogen by 2025. To achieve this goal, Sinopec has undertaken the Kuqa Hydrogen Project in the Xinjian region. This facility commenced operations in June 2023 and is expected to supply 20,000 tonnes of green hydrogen annually to a nearby refinery by 2025. The plant is powered by solar power and consists of 52 electrolysers, each with a capacity of 1,000 Nm3/h, totaling 260MW of electrolyser capacity.

Another notable project by Sinopec is the Ordos Project in Inner Mongolia. This facility is recognized as one of the largest green hydrogen projects, with an annual production capacity of 30,000 tonnes that will replace coal-based hydrogen in nearby chemical plants. The Ordos Project relies on 450MW of wind power and 270MW of solar power.

Furthermore, Sinopec is advancing its green hydrogen initiatives, with plans for a 400-kilometer hydrogen pipeline connecting the Ulanqab Green Hydrogen Plant to Sinopec's Yanshan Petrochemical Plant in Beijing. This pipeline is designed for an annual production capacity of 100,000 tonnes. Notably, this pipeline is a component of the extensive 6,000-kilometer network anticipated by 2050, as outlined by the China Petroleum Pipeline Engineering Corporation.

Inner Mongolia's local government has also given the green light to several other projects, including a significant 1.68GW solar and 370MW wind project. This project is expected to generate a substantial 66 900 tonnes of green hydrogen annually. With these projects gaining approval, the aggregate hydrogen production capacity in Inner Mongolia, if fully realized, could reach approximately 500,000 tonnes of green hydrogen. This surpasses the national target of producing

[1] (v/v) stands for volume over volume and indicates the concentration of the hydrogen relative to total volume of the mixture.

100,000 to 200,000 tonnes of hydrogen per year by 2025, putting substantial pressure on the expansion of the hydrogen distribution system in China.

Preceding these recent developments were noteworthy projects such as the Baofeng Energy Solar PV/Hydrogen Project, featuring a 150MW alkaline electrolyser paired with a 200MW solar array, which came to fruition in 2021.

Regarding fossil fuel-based hydrogen projects, in 2022, Sinopec successfully completed a carbon capture and storage (CCS) project in Jiangsu province, integrated into a synthetic ammonia plant and a coal-to-hydrogen plant. This project captures approximately 200,000 tonnes of CO_2 annually, with the primary objective of sourcing CO_2 for enhanced oil recovery (EOR). A similar approach is being applied in another Sinopec project located in Shangdong, where 700,000 tonnes of CO_2 are captured annually.

In 2022, Sinopec finished a carbon capture and storage project in Jiangsu province that was installed in a synthetic ammonia plant and coal to hydrogen plant, capturing around 200,000 tonnes of CO_2 per year. The objective of this project is obtaining CO_2 for enhanced oil recovery. This concept is also applied in other Sinopec's project in Shangdong with a capture of 700,000 tonnes of CO_2 per year. The Yangchang Integrated Carbon Capture and Storage project is under construction and linked to oil production activities.

Furthermore, 2022 marked a significant milestone with the ignition of China's first biomass gasification-to-hydrogen project.

Indonesia

Pertamina, an Indonesian state-owned oil and natural gas corporation, announced its plan to produce green hydrogen using energy from the Ulubelu Goethermal plant. The primary objective of this project is to supply clean hydrogen to the processes in the Plaju and Dumai refineries. The proposed facility is intended to produce 100 kg of hydrogen per day.

Additionally, Panca Amara Utama, PAU, an Indonesian ammonia production and sales company entered a Memorandum of Understanding (MOU) with Japanese companies. The main objective of this collaboration is to develop clean fuel ammonia production in Central Sulawesi, Indonesia. The project will convert PAU's ammonia plant to produce 700,000 tonnes of clean ammonia for exports and will be supplied by natural gas from local reserves.

In October 2023, Persusahaan Listrick Negara (PLN), the Indonesian state-owned company, inaugurated the first green hydrogen plant located in Jakarta with a yearly production of 51 million tonnes of hydrogen.

Later, in November 2023, Indonesia announced the successful culmination of the feasibility study concerning a 300 MW project in the Aceh province. The estimated investment in this project is approximately USD 500 million, and the plant is expected to produce 98.5 tonnes per day using renewable electricity starting in 2026, taking advantage of Indonesia's geothermal potential.

Japan

Japan has been actively investing in hydrogen projects across various economies, including Australia, Singapore, and more. However, there are also noteworthy local initiatives, primarily in the form of demonstration projects. Among these, the Fukushima Hydrogen Energy Research Field (FH2R) stands out. This project was equipped with a 10MW electrolyser and a 20MW solar generation plant. It held the title of the largest green hydrogen plant from 2020 until bigger projects emerged in other economies in recent months. This plant has the capacity to supply hydrogen to power approximately 150 households or 560 fuel cell vehicles daily.

In May 2023, Hokkaido Electric Power announced the beginning of hydrogen production of its 1MW electrolyser facility. Over the next three years, the plant will be connected to the grid. Subsequently, it will utilize excess renewable electricity to contribute to grid stabilization. Furthermore, ongoing feasibility studies are exploring the potential for a substantial 100MW electrolysis unit, to tap into Hokkaido's ample renewable energy resources.

In the realm of technological advancements, Mitsubishi Power's hydrogen gas turbine technology is aiming to demonstrate its ability to run the 40MW unit on 100% hydrogen by the end of 2023 and targeting its commercialization by 2025. Cofiring 50-50% natural gas–hydrogen in 400MW turbines was already successfully verified.

This innovative technology enables the conversion of existing gas-fired power plants into highly efficient and cost-effective hydrogen-fueled facilities. The goal is to reduce CO_2 emissions from thermal power generation by initially blending hydrogen with natural gas and eventually transitioning to 100% hydrogen utilization.

Republic of Korea

Korea had been actively pursuing various hydrogen projects and initiatives as part of its efforts to transition towards a hydrogen-based economy. In alignment with its hydrogen economy roadmap and the establishment of hydrogen cities, several projects have started construction in recent years, with several more expected in the following years.

In 2020 Korea announced plans to build hydrogen pilot cities. The first selected cities were Ulsan, Ansan, and Jeonju/Wanju. During this pilot phase, more than 20 km of hydrogen pipelines were built, several fuel cells residential systems were installed including 437 units of 1.320 MW fuel cells were installed in Ulsan, over 60 hydrogen buses were operated, and hydrogen operation and safety management centres started construction. It is estimated that this pilot phase may contribute with a annual reduction of emissions of 10,996 tonnes of CO2-eq in the three cities. In 2023, the government declared successful implementation of the aforementioned project and announced a similar project at greater scale in six additional cities: Pyeongtaek, Namyangju, Dangjin, Boryeong, Gwangyang, and Pohang. A hydrogen city must use this gas in major urban functions in buildings, transport, and industry. Some projects consider hydrogen production from fossil fuels with carbon capture and storage, organic waste such as cattle dropping, and other activities such as petrochemical in the form of by-products. Another important characteristic is that there are hydrogen uses not only in transportation or steelmaking, but also in air-conditioning in buildings.

In December 2022, SK E&S, a prominent Korean corporation, received approval for the construction of the world's largest blue hydrogen facility near the Boryeong LNG Terminal. This endeavour utilizes liquefied natural gas (LNG) to produce blue hydrogen and is expected to yield an annual output of 200,000 tonnes of hydrogen for power generation, in addition to 50,000 tonnes intended for hydrogen filling stations in the form of liquefied hydrogen, all to be achieved by 2025.

Ulsan city, a notable player in Korea's hydrogen landscape, revealed intentions to build 6GW of offshore wind power by 2030. Of this capacity, 20% will be dedicated to the production of green hydrogen utilizing sea water with the aim of reaching an annual production of 84,000 tonnes per year. The development of Donghae 1, a 200MW floating offshore wind power plant, is an initial step towards achieving this vision.

Hyundai Group has unveiled a long-term hydrogen strategy. As part of this strategy, Hyundai Oilbank, a refinery oil company within the group, plans to produce 100,000 tonnes of hydrogen per year from natural gas and refinery by-products employing carbon capture technologies. Concurrently, Hyundai Oilbank aims to build 180 hydrogen fuel stations by 2025. Moreover, in 2022, Hyundai Oilbank entered into a business agreement with ARAMCO to explore the feasibility of a long-term supply of ammonia from Saudi Arabia for fuelling liquefied natural gas boilers.

The industrial conglomerate Doosan is committed to develop the Changwon Hydrogen Liquefaction Project in Gyeongnam. Located in Changwon City, this facility represents Korea's first hydrogen liquefaction plant, with a daily capacity of 5 tonnes of liquefied blue hydrogen that will be used for supply to charging stations.

Kogas, a state-owned Korean gas corporation, has initiated the construction of a hydrogen production facility in Gwanju with a capacity of 1,400 tonnes per year, with plans for additional facilities in Changwon and Pyetntaek. Kogas aspires to produce 1.035 million tonnes of hydrogen by 2030, comprising 668,000 tonnes of gray hydrogen, 167,000 tonnes of blue hydrogen (both sourced from natural gas), and 200,000 metric tons of green hydrogen. Additionally, Kogas envisions the importation of 1.21 million tonnes of green hydrogen starting in 2030.

Furthermore, there are plans to construct a nuclear plant employing Small Modular Reactor technology in the Uljin Nuclear Hydrogen National Industrial Complex, intended to supply electricity to hydrogen production companies that will be in that region.

SK Gas has unveiled a business plan that includes the construction of a hydrogen production complex scheduled for completion by 2025. SK's vision also includes the establishment of 100 hydrogen refuelling stations throughout Korea by 2030.

In September 2022, Jeju Island launched what was considered the biggest Korea’s green hydrogen project. The project uses a 12.5 MW electrolyser to produce up to 1 176 tons of green hydrogen per year at 60% of capacity factor and the use of the hydrogen is to power vehicles, drones, and power other uses. This project is expected to run until 2026. Later, Jeju announced plans a 30 MW electrolyser green hydrogen plan after a feasibility study is concluded.

In December 2022, Korea’s SK E&S announced the approval for the construction of the world’s biggest blue hydrogen facility in the vicinity of Boryeong LNG Terminal. This project uses LNG to produce blue hydrogen and has an output of 200,000 tonnes of hydrogen per year for power generation and 50,000 tonnes of hydrogen for hydrogen filling stations in the form of liquified hydrogen by 2025.

Malaysia

PETRONAS, a Malaysian state-owned energy company, signed a MOU with ENEOS, a Japanese oil company, to develop competitive clean energy supply between Malaysia and Japan. This partnership will explore opportunities for hydrogen production in Malaysia and the use of methylcyclohexane (MCH) for the long-distance hydrogen transportation.

Additionally, there are also other partnerships between Korean and Malaysian companies to study the feasibility of a 900MW hydropower-based green hydrogen project called H2biscus. If developed, this project will potentially export hydrogen to Korea.

Mexico

According to the Mexican Hydrogen Association, approximately 10 hydrogen projects are currently in various stages of development. For instance, the state-owned electric utility of Mexico, Comisión Federal de Electricidad unveiled plans for pilot hydrogen projects. Two of those projects center around two solar energy power plants: Cerro Prieto in Baja California and Puerto Peñasco in Sonora. Significantly, Pemex, the state-owned oil company of Mexico, has also announced the use of green hydrogen to decarbonize its operations.

Energía Los Cabos, a 40 MW solar power plant located in Baja California, is under development and will use hydrogen as energy storage of excess electricity that can be converted back into electricity through fuel cells technology.

Similarly, Las Delicias solar plant, located in Guanajato and with a capacity of 31 MW, is poised to yield annual hydrogen output of 3,200 tonnes. Meanwhile, the Neptuno solar plant is projected to achieve higher output with 18,300 tonnes of hydrogen annually.

Adding to these projects is the proposal for a hydrogen-fueled train renowned as the Tren Maya. This pioneering concept seeks to harness the potential of hydrogen as a clean fuel source, exemplifying a forward-looking approach to sustainable transportation.

New Zealand

There are some clean hydrogen projects that are under development or study in New Zealand. Halcyon Power green hydrogen plant, the first green hydrogen plan in New Zealand, started operations in 2021. The project is powered by geothermal energy plant in Taupo. The plant capacity is 1.5 MW.

The Pouakai NZ project, located in Taranaki, is a large-scale initiative focused on the production of hydrogen, power, and ammonia/urea. The project utilizes the Allam Cycle process, which generates power by combusting natural gas in an environment of pure oxygen. This process results in the production of carbon dioxide (CO_2) and steam. The CO_2 is subsequently captured, contributing to the environmental sustainability of the project. The project also involves a series of processes including partial oxidation, gas heated reforming, and autothermal reforming. These processes, powered by the electricity generated, lead to the production of hydrogen with a claimed efficiency of 87%. The project aims to complete construction by 2023 and achieve a production capacity of 600 tonnes of hydrogen per day.

Despite facing some challenges, Kapuni Green Hydrogen Project, located in Kapuni, Taranaki, is projected to start operations in 2023. The project includes the installation of an electrolysis plant and a hydrogen storage facility. Additionally, four wind turbines are expected to supply 75% of the power needed for the operations of the electrolysis plant. The hydrogen produced will be used in the manufacture of urea, potentially replacing 7,000 tonnes of this imported urea.

Hiringa Energy, a company that produces green hydrogen to decarbonise transport and industry, is developing a hydrogen refuelling network in New Zealand, constructing 4 sites (Hamilton, Palmerston North, Auckland, and Tauranga) that are expected to be operational by the end of 2023. The number of hydrogen-refuelling sites is expected to reach 24 by 2028, and 100 by 2030.

In addition to them, there are several demonstration projects spread throughout New Zealand, mainly focused on hydrogen for transports.

Papua New Guinea

While there are currently no projects under development in Papua New Guinea, the nation's significant renewable energy potential, particularly in hydro and geothermal resources, positions Papua New Guinea to explore hydrogen as a promising energy source for both domestic consumption and international trade. Several feasibility studies are underway to assess the viability of such projects.

Peru

Engie Peru signed an agreement to supply renewable energy certificates to Industrias Cachimayo to certify 100% green energy use in its ammonium nitrate plant in Cuzco. The plant, fully privately invested, produces around 33,000 tonnes of ammonium nitrate per year.

In January 2024, Fenix, one of the main electricity producers with a combined-cycle natural gas-fuelled thermal plant, inaugurated its first green hydrogen project. This installation is located inside its power plant and comprises a photovoltaic plant that powers an electrolyser. The project aims to produce 8,000 m3 of green hydrogen annually, meeting 100% of the internal hydrogen demand for the cooling system for generators.

Philippines

Hydrogen de France (HDF) Energy, Zamboanga Sibugay, and the three off-grid towns of Olutanga, Mabuhay, and Talusan on the island signed the memorandum of cooperation for the construction of the first hydrogen power plant project in the Philippines. This pilot project consists of a capacity of 10MW.

Russia

The Russian original Roadmap for Hydrogen Development has a strong vision for export. As a result, some of the announced projects are geared towards establishing hydrogen hubs with the vision of exporting to the Asia Pacific or European market as well as supplying local demand.

The Ministry of Trade and Industry of Russia launched the Russian Atlas of Hydrogen and Ammonia production projects that aim to become a reference point for investors and domestic manufacturers. At its launch the Atlas showed 41 projects in 21 regions. Most of them are green hydrogen projects, mainly fed by tidal and wind power plants, with a total production capacity of 6.9 million tonnes of hydrogen per year, followed by blue hydrogen/ammonia projects with a total capacity of 13.6 million tonnes of ammonia per year and 100,000 tonnes of hydrogen per year. There is also 1 turquoise hydrogen project.

The largest hydrogen production project observed in the Atlas is the hydrogen-power cluster based on Penzhinskaya tidal power plant in Kamchatka. With a total capacity of liquified hydrogen production of 5 million tonnes of hydrogen or 31 million tonnes of ammonia, the facility will be powered by the total capacity of 110GW Penzhinskaya tidal power plant, although this is a long-term plan. The project will be implemented by phases and the first phase, expected to start operations by 2034, will produce 17,500 tonnes of liquid hydrogen or 115,000 tonnes of ammonia per year and will use 100MW of wind and 300MW of tidal power plants, although shipments of products are expected to start in 2026. The second phase will include 1GW of wind and 21.4GW of tidal power plants to produce 1.200 billion of hydrogen or 7.7 million tonnes of ammonia per year.

Another ambitious project is the production of 500,000 tonnes of hydrogen per year via electrolysis fed by Mezensk tidal power plant. This project is expected to operate in 2030 and can expand its capacity to 1 million tonnes per year by 2033.

On side of the blue hydrogen/ ammonia project, the biggest ammonia production project is the North-East Alliance in Yakutia that will be implemented by phases with 3 million tonnes of ammonia per year by 2026 and 6 million tonnes per year by 2030. The project will use steam methane reforming with CO2 capture that will be used in enhanced oil recovery in oil reservoir. The main market for these products would be the domestic market and the Asia Pacific region.

Additionally, Rosatom, the State Atomic Energy Corporation, adopted hydrogen development as a major strategic plank of its business in 2020. It announced plans to launch pilot hydrogen production in Kaliningrad, Murmansk, and Sakhalin. Kaliningrad will produce green hydrogen using wind energy to supply domestic and European demand. In Murmask, the Kola Nuclear Power Plant will include a test hydrogen production facility with the capacity to produce 200 tonnes of hydrogen for exports by 2025.In Sakhalin, two hydrogen production projects are expected to be launched in 2025: one will produce hydrogen by electrolysis using wind power, and the other, in collaboration with Gazprom, will produce blue hydrogen. Both projects are for export to the Asia Pacific Region.

Chinese Taipei

Chinese Taipei has undertaken a series of demonstration and research projects, collectively reaching several hundreds of KW of electrolyser capacity. While local hydrogen consumption has been modest until now; Chinese Taipei’s ambitions are resolute: to install 91MW capacity by 2025, according to its Hydrogen Energy Development Roadmap.

On the other hand, the fuel cell manufacturing sector anticipates a promising surge in the forthcoming years. This surge is largely attributed to burgeoning demand in other economies in the world, positioning Chinese Taipei's industry on a trajectory of growth and expansion.

Singapore

Singapore announced the construction of a 600MW Keppel Sakra Cogen Plant, a combined-cycle gas turbine facility, that can run on natural gas with 30% of hydrogen and it is expected to run 100% on hydrogen in the future. This plant is expected to enter operation during the first quarter of 2026.

Thailand

Lam Takhong Wind Hydrogen Hybrid Project, a project owned by the Electricity Generating Authority of Thailand (EGAT), was one of the first green hydrogen project in Southeast Asia. The project, part of a renewable energy complex, uses excess electricity from a 22MW wind energy power plant and 1MW electrolyser to store energy as green hydrogen that will be converted into electricity through fuel cells.

In April 2023, PTTGroup, Thailand’s state-owned oil and gas conglomerate, announced plans to build a Plant that will produce 225,000 tonnes of green hydrogen equivalent to 1.2 million tonnes of ammonia.

United States

United States is the second largest hydrogen consumer and producer. According to the report, “Pathway to Commercial liftoff: Clean Hydrogen”, the domestic demand of clean hydrogen could rise from 1 million tonnes of hydrogen per year to 10 million tonnes by 2030, and 50 million tonnes by 2050. In the short term, most of the demand will be driven by the transition from the current use of high-carbon-intensity hydrogen to low-emission hydrogen. In recent years US has intensified its efforts to develop the hydrogen value chain.

According to the White House’s blog “The Economics of Demand-Side Support for the Department of Energy’s Clean Hydrogen Hubs”, of all US clean hydrogen projects announced by 2022, which add up to 12 million tonnes of hydrogen per year, only 1.5 million had reached financial investment decision by the end of that year.

According to the report “Pathway to Commercial Liftoff: Clean Hydrogen”, most of the announced clean hydrogen capacity, which is around 10.5 million tonnes, is associated with projects where production is developed in conjunction with midstream processes and/or specific end uses. Projects that are solely dedicated to clean hydrogen production represent 1.4 million tonnes. Meanwhile, projects that only involve midstream processes and end-use account for less than 0.1 million tonnes per year.

Some green hydrogen projects that are expected to enter production:

- St Gabriel Hydrogen Plant in Louisiana with a daily production of 15 tonnes, expected to grow up to 500 tonnes by 2025 and 1000 by 2028.
- Sauj Valley green hydrogen project with a capacity of 52 tonnes per year and will be able to store 400 kg of hydrogen on site.
- Kingsland green hydrogen project will produce 15 tonnes of hydrogen per day in Georgia,
- Casa Grande, producing 10 tonnes per day in Arizona. The hydrogen produced by this project will be used for transportation.
- Donaldsonville Green Hydrogen project will consist of 20MW electrolyser to produce 20,000 tonnes of green ammonia per year.

Among future projects that are still under development, Advanced Clean Energy Storage (ACES) project stands out as important initiative. It will be built in Utah and will use 220MW alkaline electrolysis with two salt caverns to store clean hydrogen with a storage capacity of 5500 tonnes. ACES is expected to start operation in 2025 and will use stored excess renewable energy to stabilize the grid. Later, hydrogen will be used by the Intermountain Power Agency to cofire its gas turbine. The vision is that these turbines will run on 100% of hydrogen by 2045.

Air Products is currently developing one of the biggest blue hydrogen projects in Louisiana with a daily production of 21 million of standard m^3 and it is expected to be finished by 2026. The purpose of this project is to provide low-carbon hydrogen to the refineries along the US Gulf coast. The nominal CO_2 capture rate of this project is 95%.

There are also announced pilot projects that involve blending hydrogen into the natural gas pipeline systems for power generation. Dominion Energy has initiated the first hydrogen blending pilot program in Ohio, introducing a 5% (v/v) blend. However, in this initial phase, the hydrogen blend will be utilized exclusively in a limited scope of 16 households. This project followed a demonstration performed in 2022, where blending of 5% (v/v) hydrogen-natural gas was used in the long ridge terminal power plant in Hannibal, Ohio.

Numerous hydrogen projects have recently been announced and are anticipated to reach a higher level of maturity in the coming years.

Viet Nam

In March 2023, TGS, a leading clean energy company, commenced the construction of a green hydrogen plant located in the province of Tra Vinh. This project aims to deliver an initial annual production of 24,000 tonnes of green hydrogen alongside 195,000 tons of oxygen. Additionally, the establishment of an industrial cluster in Ben Tre province was announced. The initial phase of this plan has a 400MW electrolyser-powered green hydrogen plant, with an annual capacity of 45,000 tonnes – of which 13,500 tonnes are for commercial utilization.

Hydrogen policies and strategies

Most APEC members have expressed interest in the development of a hydrogen market and want to study the potential role that this gas may play in their future potential energy system.

APEC region has been a leader in developing and implementing strategies to promote the nascent hydrogen industry. Each strategy in APEC corresponds to the unique characteristics and priorities of the economy member that developed it. Among the most relevant policies developed in the APEC region we have the followings:

Table 1 H2 Policies in APEC

Economy	Main documents or policy	Key goals
Australia	*National Hydrogen Strategy* *Hydrogen HeadStart Program*	• Establishment of export supply chains and development of shipping and logistics capabilities for hydrogen exports. • Clean hydrogen under AUD2 per kg H2
Brunei Darussalam	No specific policy	• To be defined
Canada	*Hydrogen Strategy for Canada* *The Emission Reduction Plan 2030*	• Expansion of clean hydrogen production. • Creation of different regional hubs. • The strategy envisioned Canada as a consumer and an exporter of hydrogen.
Chile	*National Strategy of Green Hydrogen*	• 5GW of electrolyser installed by 2025. • To produce the lowest-cost green hydrogen by 2030. • Being one of the 3 main green hydrogen exporters by 2040.
People Republic of China	*China's Hydrogen Energy and Fuel Cell Industry Development Plan (2020-2030)* *Hydrogen Industry Development Plan (2021-2035).*	• 50,000 hydrogen fuel-cell vehicles on the road by 2025. • Green hydrogen production using renewable feedstock resources to reach between 100,000 to 200,000 tonnes per year by 2025. • Besides transport, China envisages the use of clean hydrogen in other sectors: energy storage, electricity generation and industry
Hong Kong China	Climate Action Plan	• Hong Kong China mentions hydrogen in its Climate Action Plan, especially for use in transportation.

Indonesia	*National Hydrogen Strategy*	• To be defined
Japan	*Strategic Roadmap for Hydrogen and Fuel cells* *Hydrogen Strategy Roadmap* *Green Growth Strategy* *Basic Policy for the realization of Green Transformation* *Revised Basic Hydrogen Strategy*	• 3 million tonnes of H2 by 2030, 12 million tonnes by 2040 and 20 million tons by 2050. • The threshold for clean hydrogen is 3.4kg of CO2/kg H2 on a Well-to-Gate basis. • The threshold for ammonia is 0.84kg of CO2/kg NH3 on a Gate-to-Gate basis.
Republic of Korea	*Hydrogen Economy Roadmap 2019* *Hydrogen Economy Promotion and Hydrogen Safety Management Act* *1st Basic Plan for the Implementation of the Hydrogen Economy*	• Korea wants to become one of the leading global fuel cell vehicles manufacturers with 6.2 million vehicles and 1200 refilling stations by 2040. • Hydrogen demand supplied by 100% of low-carbon hydrogen by 2050. 82% will come from overseas, while 60% of the domestically produced hydrogen is green and the remainder is blue. The estimated hydrogen demand in 2050 is 27.9 million tonnes. • 10% of green hydrogen from marine sources by 2040. • Blending 20% ammonia in at least half of the coal plants by 2030 and 30% or more hydrogen by 2035 in all the gas-fired power plant.
Malaysia	*Hydrogen Economy & Technology Roadmap*	• Phase out gray hydrogen by 2030. • The cost of green hydrogen by 2050 are the following: • USD 1.45/kg solar • USD 2.11/kg hydro • USD 1.72/kg biomass • USD 1.25 kg biogas
Mexico	Under development	• To be defined
New Zealand	Vision for Hydrogen in New Zealand	• Clean hydrogen plays a key role in the establishment of a low emissions economy.
Papua New Guinea	No specific policy	• To be defined
Peru	*Law that establishes Climate Energy as a National Interest* *Green Hydrogen Promotion Law*	• Promotion of production, R&D, transport, distribution, and end use of green

		hydrogen for domestic and international market.
Republic of Philippines	In process of formulating a Strategic Roadmap	• To be defined
Russia	*Energy Strategy to 2035* *Roadmap for Hydrogen Development until 2024*	• Exports of 0.2 million metric tons by 2024 and 2 million by 2035. • Development of three hydrogen clusters.
Singapore	*Singapore's National Hydrogen Strategy*	• Combined cycle gas turbines will be able to run on 100% hydrogen by 2030. • Hydrogen will satisfy 50% of the projected demand of electricity by 2050. • Low-carbon hydrogen can be used to produce biofuels and synthetic fuels.
Chinese Taipei	*Hydrogen Energy Development Roadmap.*	• Hydrogen is targeted to reach between 9-12% of total power generation mix.
Thailand	*Study on the production and consumption of hydrogen under policies recommendations to promote hydrogen in Thailand*	• This document was released for public consultation
United States	*Hydrogen Shot* *Inflation Reduction Act* *Clean Hydrogen Strategy and Roadmap*	• 10 million tonnes per year of clean hydrogen by 2030, 20 million by 2040 and 50 million by 2050. • Reduction the cost of clean hydrogen to 1 USD per kg H2 in a decade.
Viet Nam	Hydrogen Energy Development Strategy	• 100,000 to 500,000 tonnes per year of renewable and low carbon hydrogen by 2030 with a vision to produce 10 to 20 million tonnes per year by 2050.

Australia

Australia was the second economy in APEC to develop a hydrogen strategy. In contrast to the Japanese vision that was influenced by the scarcity of domestic natural resources, Australia recognized the potential use of its abundant natural resources and existing energy infrastructure for producing and becoming a leading global exporter of clean hydrogen. Australia launched its *National Hydrogen Strategy* in 2019 outlining the economy's vision: large-scale, low-cost hydrogen production hubs across the economy, the promotion of hydrogen adoption in transport, industry, and power generation, among other uses. The strategy also aspires to establish export supply chains and to develop shipping and logistics capabilities for hydrogen exports. This strategy is under review in 2023.

Following the *National Hydrogen Strategy,* Australia launched other complementary documents such as the *First Low Emission Technology Statement* in 2020 that identifies clean hydrogen as a priority technology, and highlights the government's commitment to supporting their development, deployment, and commercialization, highlights the stretch goal of reaching clean hydrogen under AUD 2 per kg H_2 , the *Technology Investment Roadmap* in 2020 that sets out Australia's plan to accelerate the development and deployment of low-emissions technologies, with hydrogen being one of the key focus areas.

In 2023, the Department of Climate Change, Energy, the Environment, and Water unveiled the *National Hydrogen Infrastructure Assessment*. This comprehensive assessment serves as a critical review of the hydrogen infrastructure needs, enabling informed decisions for prioritizing infrastructure investments.

Additionally, Australian states and territories have developed individual strategies or action plans to facilitate the development of hydrogen projects in their territories, aligning these initiatives with the overarching framework of the *National Hydrogen Strategy*.

In 2023, the Australian Government announced up to AUD 2 billion in the H*ydrogen HeadStart Program* to fund, in the form of a production credit, large clean hydrogen projects to accelerate the development of Hydrogen industry in Australia. To be eligible for the program, projects must include electrolysers with capacity of at least 50 MW that are powered by 100% renewable energy. The program will fund a maximum of10 years of eligible clean hydrogen production since the date of commissioning starting 2026. By the end of 2024, selected projects will be known.

Canada

Canada presented the *Hydrogen Strategy for Canada* following the Canadian Net-Zero Emissions Accountability Act in 2020. In this document, Canada wants to maintain its leading role in the global energy market. The strategy focuses on expanding clean hydrogen production, creating different regional hubs that take advantages of different natural resources in each region. The strategy envisioned Canada as a consumer and an exporter of hydrogen.

The strategy states that clean hydrogen has the potential to deliver up to 30% of Canada's end use energy by 2050, abating to 190Mt of CO_2e. Canada also aims to become one of the top three clean hydrogen producers globally.

Canada aims to develop a hydrogen infrastructure network, including hydrogen production facilities, storage, and transportation infrastructure. The strategy focuses on building hydrogen refuelling stations for FCEVs (Fuel cell electric vehicles), establishing hydrogen hubs, and utilizing existing natural gas pipelines for hydrogen transport, storage, and distribution.

The Emission Reduction Plan 2030 has established an ambitious target: By 2030, the aim is to ensure that zero-emission vehicles constitute 35% of the total sales within the medium and heavy-duty vehicle category.

In addition, Canada has implemented some amendments to its legislation to support clean hydrogen development such as the amendments to the *Electricity Act in Nova Scotia* to include green hydrogen projects in the definition of wholesale customers or the expansion of the scope of the Underground Hydrocarbons Storage Act to include hydrogen, ammonia, and carbon sequestration.

Additionally, hydrogen projects are eligibles tax for credits between 15% to 40% for hydrogen production under the proposed *Clean Technology investment Tax Credit*.

Chile

Chile presented the *National Strategy of Green Hydrogen*, a comprehensive strategy to promote the development and export of green hydrogen, known as the Green Hydrogen Strategy in 2020. Among the main goals of this strategy are the following:

- 5GW of electrolyse installed by 2025.
- To produce the lowest-cost green hydrogen by 2030.
- Being one of the 3 main green hydrogen exporters by 2040.

Chile aims to become a leading producer of green hydrogen by leveraging its abundant renewable energy resources, particularly solar and wind power. The strategy focuses on developing large-scale renewable energy projects dedicated to hydrogen production through electrolysis, with an emphasis on cost reduction and scalability. The economy aims to establish long-term partnerships with other countries and leverage its geographic advantages, such as proximity to international markets, to position itself as a reliable supplier of clean hydrogen.

In December 2023, Chile released the draft of the *Green Hydrogen Action Plan* for public consultation. This preliminary document that prioritizes 30 measures required to implement the National Strategy of Green Hydrogen, ranging from the implementation of demonstration pilot projects to regulatory reforms that facilitate the development of hydrogen project, is open for comments and observations until February 2024. The action plan was launched in May 2024.

People's Republic of China

By 2023, China is already the World's largest producer and consumer of hydrogen and launched its national hydrogen strategy in November 2020. The strategy, officially titled *China's Hydrogen Energy and Fuel Cell Industry Development Plan (2020-2030*), was announced by China's Ministry of Science and Technology, Ministry of Industry and Information Technology, and National Development and Reform Commission. This strategy outlines China's vision, goals, and policy directions for the development and utilization of hydrogen energy and fuel cells over the next decade (2020-2030). This document emphasizes the importance of hydrogen in China's energy transition, decarbonization efforts, and technological innovation. The strategy aims to position China as a relevant global player in the hydrogen industry. This approach to hydrogen is rooted in China's dedication to curbing carbon emissions, bolstering energy security, and driving technological innovation.

Some key aspects of China's national hydrogen strategy are the following:

China aims to expand the production and supply of hydrogen, with a focus on green hydrogen (produced from renewable energy sources) and clean hydrogen (produced with carbon capture and storage technologies). The strategy includes plans for building large-scale hydrogen production facilities, developing hydrogen infrastructure, and establishing hydrogen supply chains.

Additionally, China released the *Hydrogen Industry Development Plan (2021-2035).* This document establishes some guidelines regarding the trajectory of the hydrogen industry in the following years and try to help the orderly growth of this new industry. This plan focuses on two areas: hydrogen production and hydrogen fuel cell vehicles. China envisions 50,000 hydrogen fuel-cell vehicles on the road by 2025 and additional hydrogens refuelling stations[2]. The plan targets green hydrogen production using renewable feedstock resources to reach between 100,000 to 200,000 tonnes per year by 2025. Besides transport, the plan envisages the use of clean hydrogen in other sectors: energy

[2] By 2023, the number of fuel cell vehicle charging stations have been estimated in 354, with a combined goal of several provinces of more than 1200 stations by 2025.

storage, electricity generation and industry. In that regard, China will establish five demonstrations clusters (Jing-Jin-Ji, Shanghai, Guangdong, Hebei, and Henan) for the demonstration of fuel cell vehicles.

An important characteristic of Chinese vision of hydrogen is that industrial by-product gas will play a role during the first years of the hydrogen industry development.

In August 2023, the regional government of Inner Mongolia issued a decree aiming to transform the region into a prominent hydrogen hub. This ambitious initiative envisions Inner Mongolia as a central player in the development of a hydrogen industry where green hydrogen will play an important role on reaching 30% of hydrogen production.

Japan

Japan has positioned itself as a global leader in the development of the hydrogen market. Japan became the first APEC member to formulate and release a national hydrogen strategy in 2017 that was known as the *Basic Hydrogen Strategy*. Japan's vision described in this document included the widespread use of hydrogen in several sectors including transport, power generation, and industrial processes and aimed to support research and technological advancement to drive cost reduction throughout the hydrogen value chain. Japan also acknowledged the need of international collaboration and partnerships with other economies to develop a global hydrogen market. Japan aimed to procure 300,000 kg of H_2 at JPY 30/Nm^3 which is equivalent to JPY 334/kg H_2 by 2030 and JPY 20/Nm^3 or JPY 223/kg H_2 by 2050. Following the Basic Hydrogen Strategy, several documents considering hydrogen as an important fuel were released such as the *Strategic Roadmap for Hydrogen and Fuel cells* (2019), *Hydrogen Strategy Roadmap* (2020), and the *Green Growth Strategy* (2020).

In February of 2023, Japan introduced the *Basic Policy for the realization of Green Transformation* (GX). The principal objective of this initiative is to facilitate the transition of Japanese energy sector from a predominantly fossil fuel-based paradigm to one firmly rooted in clean energy sources. This transition should ensure a stable energy supply following the guidelines delineated in the Sixth Strategic Energy Plan. The GX initiative lists a series of actions for execution over the next decade, that includes the acceleration of hydrogen and ammonia as important fuels within Japanese energy matrix. Japan targets establishing its large and resilient supply chain, including production, transportation, and utilization. Japan also aims to develop co-firing and single firing technologies as well as measures to promote the widespread adoption of hydrogen and ammonia in transportation sector.

In June 2023, Japan revised the Basic Hydrogen Strategy updating some goals: increase supply from current 2 million to 3 million tonnes of hydrogen by 2030, to 12 million tonnes by 2040 and 20 million tons by 2050, expand the installed capacity of water electrolysis equipment with Japan-made components to 15GW globally by 2030, and attract more than JPY15 trillion in public and private sector.

This new strategy indicates Japanese government will subsidize clean hydrogen or ammonia projects based on their carbon intensity. The threshold for clean hydrogen is 3.4kg of CO_2/kg H_2 on a Well-to-Gate basis, and the threshold for ammonia is 0.84kg of CO_2/kg NH_3 on a Gate-to-Gate basis.

In December 2023, the Ministry of Economy, Trade and Industry (METI) announced a proposal for a subsidy scheme for big scale hydrogen production projects of at least 10 000 tonnes of H_2/year, with a carbon intensity of 3.4 $kgCO_2/kgH_2$. This subsidy in the form of Contracts for Difference (CfD) will close the gap between hydrogen market price, i.e. hydrogen produced by unbated fossil fuels, and a reference price set by the Japanese government. In case the market price is higher, the producer will pay the difference. The subsidies will last 15 years and projects will be required to run for another decade.

Republic of Korea

Korea announced its vision of expanding hydrogen production capacity and developing a hydrogen supply chain through its *Hydrogen Economy Roadmap 2019*. Although Korea wants to increase hydrogen production from various sources, including renewable energy, this expansion will be insufficient to meet potential future demand requirements and Imports might be required.

Korea seeks to promote the widespread use of hydrogen across various sectors, including transportation, industry, and residential applications. Special emphasis is put on the deployment of hydrogen fuel cell vehicles (FCVs) as Korea wants to become one of the leading global fuel cell vehicles manufacturers with 6.2 million vehicles and 1200 refilling stations by 2040. Additionally, Korea aspires to introduce 40,000 fuel cell buses, 80,000 taxis and 30,000 trucks by 2040. On the other hand, the roadmap indicates that Korea will promote the manufacturing of fuel cells for power generation with a combined capacity of 15GW by 2040.

Also, the *Hydrogen Economy Promotion and Hydrogen Safety Management Act (*Hydrogen Act) was approved in 2020. This legislation provides a legal framework to support the development of the hydrogen industry in Korea in accordance with the vision described in the Hydrogen Economy Roadmap. The act includes provisions related to hydrogen production, utilization, safety standards, research and development, and incentives for investment and adoption.

In 2021, Korea announced *1st Basic Plan for the Implementation of the Hydrogen Economy.* The plan set some goals for 2050: total hydrogen demand will be supplied by 100% of low-carbon hydrogen. 82% will come from overseas, while 60% of the domestically produced hydrogen is green and the remainder is blue. The estimated hydrogen demand in 2050 is 27.9 million tonnes. There is also a goal to produce 10% of green hydrogen from marine sources by 2040. Also, in 2021, the government set the goals of blending 20% ammonia in at least half of the coal plants by 2030 and 30% or more hydrogen by 2035 in all the gas-fired power plant.

In November 2022, the government announced a new hydrogen policy direction emphasizing the role of clean hydrogen. The clean hydrogen standard is currently under discussion. The government seeks to establish a clean hydrogen supply and create a world-leading hydrogen industry. The three strategies to achieve that vision were: “scale-up”, “build-up”, and “level-up”. Some of the plans include the construction of the world’s largest liquid hydrogen plant, an ammonia and hydrogen receiving terminal and the opening of a hydrogen bid market.

The action plan includes the goal of producing 30,000 hydrogen-powered commercial vehicles by 2030, building 70 liquid hydrogen fuelling stations and clean hydrogen being 7.1% of the country's energy mix by 2036.

In 2024, Korea launched the clean hydrogen energy portfolio standards (CHPS). This system aims to facilitate clean hydrogen-fuelled power trade in clear hydrogen power bid market. To implement this initiative, Korea will implement a Clean Hydrogen Certification System that allows to provide incentives according to 4 different tiers depending on the hydrogen carbon intensity measured in well-to-gate basis.

Korea is expected to open the first round for 6.75 TWh of capacity of clean hydrogen energy bidding during the first half of 2024. The delivery of energy is expected for 2027 or 2028.

Indonesia

The Directorate of New, Renewable Energy and Energy Conservation of the Ministry of Energy and Mineral Resources published the National Hydrogen strategy report in December 2023. The report shows scenarios where hydrogen demand increases mainly in transport, starting in 2030, and industry, starting in 2040. Hydrogen is considered as a key element to reach carbon neutrality by 2060.

Malaysia

In 2023, Malaysia released its *Hydrogen Economy & Technology Roadmap*. This roadmap is comprised by 5 strategic thrust -namely strengthening governance system, institutional framework, and regulatory mechanism; facilitating enabling environment and economic instruments, accelerate commercialization of technology to enable export and domestic uptake, Capacity development and capability enhancement; and communication, education, public and awareness-, 9 strategies and 29 Action Plans. Malaysia targets to phase out grey hydrogen by 2030, and increase competitiveness of green hydrogen from solar, hydrogen, biomass, and biogas in the long-term. This document estimates that the adoption of hydrogen in the energy mix can create a demand of 68.2 TWh/year by 2050.

New Zealand

In 2019, New Zealand released its *Vision for Hydrogen in New Zealand*, a green paper where clean hydrogen plays a key role in the establishment of a low emissions economy. New Zealand has abundant renewable energy sources that are a big part of the economy's electricity fuel mix. This electricity system can supply renewable energy to produce clean hydrogen in several parts of the New Zealand.

Vision for Hydrogen in Zealand explores different projects and is the foundation on which the New Zealand's Road Map, scheduled to be finalized by 2024, is being built. The road map will explore the potential of green hydrogen in New Zealand and will set a pathway for the development of the industry that can support transition to net zero 2050. This roadmap will be integrated into the General Energy Strategy.

Peru

Peru approved the Law that establishes Climate Emergency as a National Interest. This law assigns development of a green hydrogen roadmap to the Ministry of Energy and Mines.

Later, in 2024, the Green Hydrogen Promotion Law was issued. This law aims to promote the development of the green hydrogen value chain to supply both domestic and international markets through specific policies, actions, and fundings. This law defines green hydrogen as that produced using technologies with low emission of emission of greenhouse gases. The Ministry of Energy and Mines is also responsible for promoting green hydrogen produced from renewable energy, developing complementary rules that define the requirements for the certification of origin and the condition to access potential tax and financial benefits.

Russia

Hydrogen is a component of Russian strategic vision for its energy sector. Russia, as major hydrocarbon producers, seeks to secure its leading position as an energy producer and exporter given its location that facilitates commercialization with the Asia Pacific region, the existence of a well-developed gas industry including relevant infrastructure that can be adapted for production and transport of hydrogen, scientific and engineering expertise, and vast hydrocarbon resources.

In 2020, Russia released its *Energy Strategy to 2035* that was followed by the *Roadmap for Hydrogen Development until 2024*. Although specific actions are not defined, the documents describe the Russian vision of becoming a world-leading producer and exporter of low-carbon hydrogen energy. Its official goals are to export 0.2 million metric tons by 2024 and 2 million by 2035. In the documents, Russia plans to develop three hydrogen clusters, a Northwest cluster, an Eastern cluster, and an Arctic cluster.

Later in 2023, due to the war in Europe, Russian officers announced that hydrogen production goals could be reduced to 550,000 tonnes per year by 2030, mainly for domestic consumption.

Singapore

In 2022, Singapore launched its *Singapore's National Hydrogen Strategy*. The strategy has been influenced by the goal of decarbonizing the economy to reach net zero by 2050, considering the scarce available land and renewable resources. This document outlines Singapore's vision on the use of hydrogen within the economy:

- Combined cycle gas turbines will be able to run on 100% hydrogen by 2030.
- Hydrogen will satisfy 50% of the projected demand of electricity by 2050.
- Low-carbon hydrogen can be used to produce biofuels and synthetic fuels.

In addition, Singapore, a significant global hub for shipping and air travel, recognizes the potential of hydrogen to drive decarbonization across various sectors, including maritime transport, port operations, aviation, and airport services. This transformation can be achieved through methods such as electrification, ammonia utilization, and the promotion of sustainable aviation practices.

The emphasis on decarbonizing power generation in this strategy is due to the responsibility of this sector of 40% of primary greenhouse gas emissions, despite being fuelled by natural gas.

Singapore is also signing agreements with other APEC economies to cooperate on low-carbon hydrogen.

Thailand

In 2022, the Energy Planning and Policy Office (EPPO) of the Ministry of Energy released preliminary results from a study on the production and consumption of hydrogen under policies recommendations to promote hydrogen in Thailand. This study, conducted by the Energy Research Institute, Erdi-CMU, and H2ydrogen, was presented for public consultation to obtain feedback that are being used for the development of future Thai hydrogen policies.

Chinese Taipei

The Ministry of Economic Affairs and the Industrial Technology Research Institute (ITRI) released the *Hydrogen Energy Development Roadmap* in July 2022. Hydrogen is considered one of the 12 strategies that Chinese Taipei will use to reach net zero by 2050. Hydrogen is targeted to reach between 9-12% of total power generation mix.

Like Singapore, the primary source of emissions in Chinese Taipei is the power sector. As a result, hydrogen has emerged as a priority within this sector. Chinese Taipei has outlined ambitious plans to progressively integrate hydrogen into its energy landscape. Specifically, their goal is to increase hydrogen utilization from 0.57MW in 2022 to 91MW by 2025, and further to 891MW by 2030. Notably, they are set to embark on a trial operation of a hydrogen co-firing power demonstration plant, incorporating a fuel mixture of 5%.

Looking ahead to the span of 2031-2050, their National Determined Contributions (NDC) plan envisions a substantial integration of hydrogen into power generation. This is anticipated to occur through co-firing with LNG (Liquefied Natural Gas) or even its exclusive use, with the aim of elevating its contribution to total power generation to 9%-12% by 2050. Furthermore, beyond power generation, Chinese Taipei envisions an expanded role for hydrogen, encompassing applications in steel production and other vital industrial processes.

United States

Department of Energy of the United States released the *National Hydrogen Strategy and Roadmap* in June 2023. Hydrogen is envisioned to play a key role for the achievement of a 100% clean power grid by 2035. This strategy targets 10 million tonnes per year of clean hydrogen by 2030, 20 million by 2040 and 50 million by 2050.

In December 2020, the United States Congress passed the *Energy Act of 2020*, which included provisions to support research, development, and demonstration of hydrogen technologies. This act authorized funding for various hydrogen-related projects and activities.

In 2021, the bipartisan Infrastructure Law established the Regional Hydrogen Hubs and Electrolysis and Clean Hydrogen Manufacturing and Recycling programs and allocated USD9.5 billion to fund these initiatives. Most of these resources, 8 billion UDS will be used to develop at least 4 regional hydrogen hubs creating a network that will connect hydrogen producers and consumers and expand the necessary hydrogen distribution.

Also, in 2021, U.S. Department of Energy launched the *Hydrogen Shot*, an initiative program that is part of the Energy Earth Shots Initiatives. The objective of the hydrogen shot is to reduce the cost of clean hydrogen to 1 USD per kg H_2 in a decade.

In 2022, *The inflation Reduction Act*, also known as IRA, was approved. This act introduced the 45V Hydrogen Production Tax Credit, which awards up to USD3 per kg H_2 produced with gas emission intensity of less than 0.45 kg CO_2e/kg H_2. Additionally, individual states within the United States were taking their own initiatives to develop hydrogen strategies and support the growth of the hydrogen economy. For example, California have been at the forefront of hydrogen fuel cell vehicle adoption and is actively promoting the use of hydrogen as an alternative energy source.

Viet Nam

In February 2024, Viet Nam announced its *Hydrogen Energy Development Strategy*. This document aims to produce 100 000 to 500 000 tonnes per year from renewable or from fossil fuels with carbon capture and storage by 2030. There is also a vision of producing between 10 to 20 million tonnes per year by 2050.

Other APEC economy members

Other APEC economy members have expressed its interest and vision regarding the future hydrogen industry although they have not specifically adopted or developed formal hydrogen strategies yet. Hydrogen is sometimes mentioned as an emerging decarbonizing technology in more comprehensive action plan or other legal tools. For example, Hong Kong China mentions hydrogen in its *Climate Action Plan*, especially for use in transportation and is developing the Strategy of Hydrogen Development in Hong Kong China that is expected for the second half of 2024.

The Department of Energy of the Philippines is working in the process of providing a national policy and general framework, roadmap, and guidelines for hydrogen in the energy sector. In addition, Viet Nam, and Thailand are currently formulating their hydrogen roadmaps.

Despite the difference between the hydrogen policies established by the economies, there are common principles on the design of these policies that can be appreciated:

- Clearly define the long-term vision for hydrogen utilization and set specific, measurable goals to guide the strategy. These goals could include targets for hydrogen production, infrastructure development, sectoral applications, emissions reduction, and economic growth.
- Evaluate the economy's renewable energy resources and other potential sources for hydrogen production, such as natural gas.
- Establish a comprehensive hydrogen infrastructure network that includes production facilities, storage systems, transportation infrastructure (such as pipelines or shipping), and refuelling/recharging stations.
- Develop a supportive regulatory framework that encourages investment, facilitates market development, and ensures safety and environmental standards for hydrogen production, transportation, storage, and utilization. Address any regulatory barriers or gaps that may hinder the growth of the hydrogen industry.
- Identify key sectors where hydrogen can play a transformative role, such as transportation, industry, power generation, and heating. Develop policies and incentives to support the adoption of hydrogen technologies in these sectors, including the deployment of fuel cell vehicles, integration into industrial process.
- Develop mechanisms to support domestic demand, incentivize hydrogen adoption, and establish partnerships with other countries to facilitate knowledge sharing, standardization, and utilization.
- Foster domestic market growth while exploring opportunities for international collaboration and hydrogen trade.

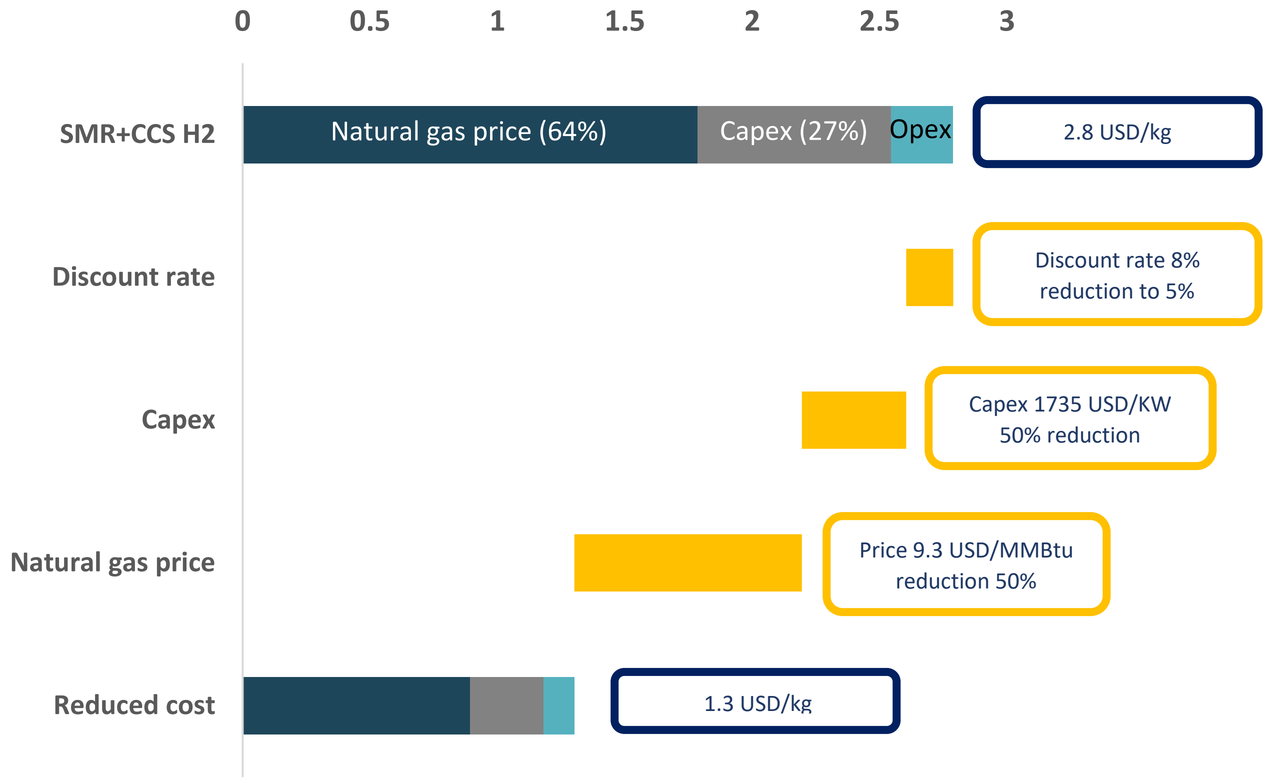
Current Challenges

The APEC region is progressing in the development of low-carbon hydrogen supply and promoting the use of hydrogen in applications such as fuel cell vehicles and the decarbonization of natural gas supply. However, there are challenges that need to be addressed to facilitate the widespread adoption of hydrogen as a clean alternative to fossil fuel energy.

High cost of hydrogen

To enhance competitiveness against inexpensive fossil fuel energy, both low-carbon hydrogen and zero-carbon hydrogen must undergo cost reductions. Currently, energy feedstock—specifically, electricity or natural gas—constitutes over half of the production cost for low-carbon hydrogen. The cost of natural gas can account for approximately 65% of the levelized cost of low-carbon hydrogen produced through the SMR process and CCS. It is noteworthy that a reduction in CAPEX, the second-most influential factor in the cost of hydrogen production, is comparatively less impactful than fluctuations in fuel prices.

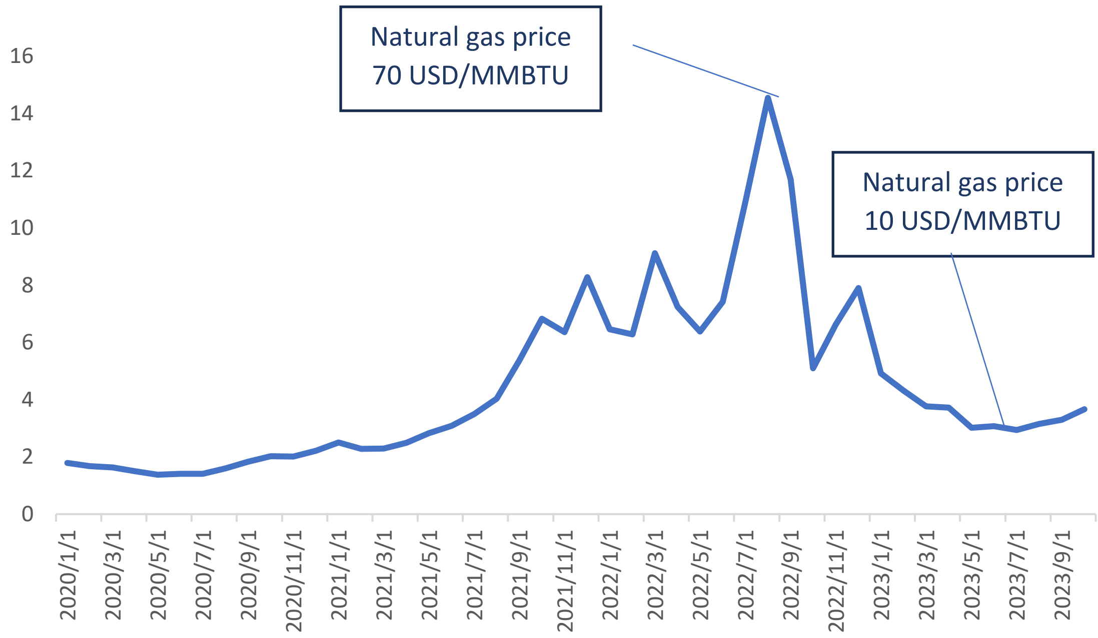
Figure 2 Impact of factor on the cost of hydrogen produced via SMR+CCS (USD/kg)



Note: The cost assumed were estimated for US. The price of natural gas was estimated using Henry Hub prices for August 2022.

The volatility of natural gas prices observed in recent years, particularly in 2022, had the potential to significantly impact the cost of hydrogen production based on natural gas. In Europe, one of the leading future hydrogen markets where natural gas prices are generally higher than in other regions, hydrogen produced from natural gas might have been more expensive than green hydrogen during certain months of 2022. The prices of natural gas not only directly impact hydrogen production costs but also contribute to higher equipment supply costs.

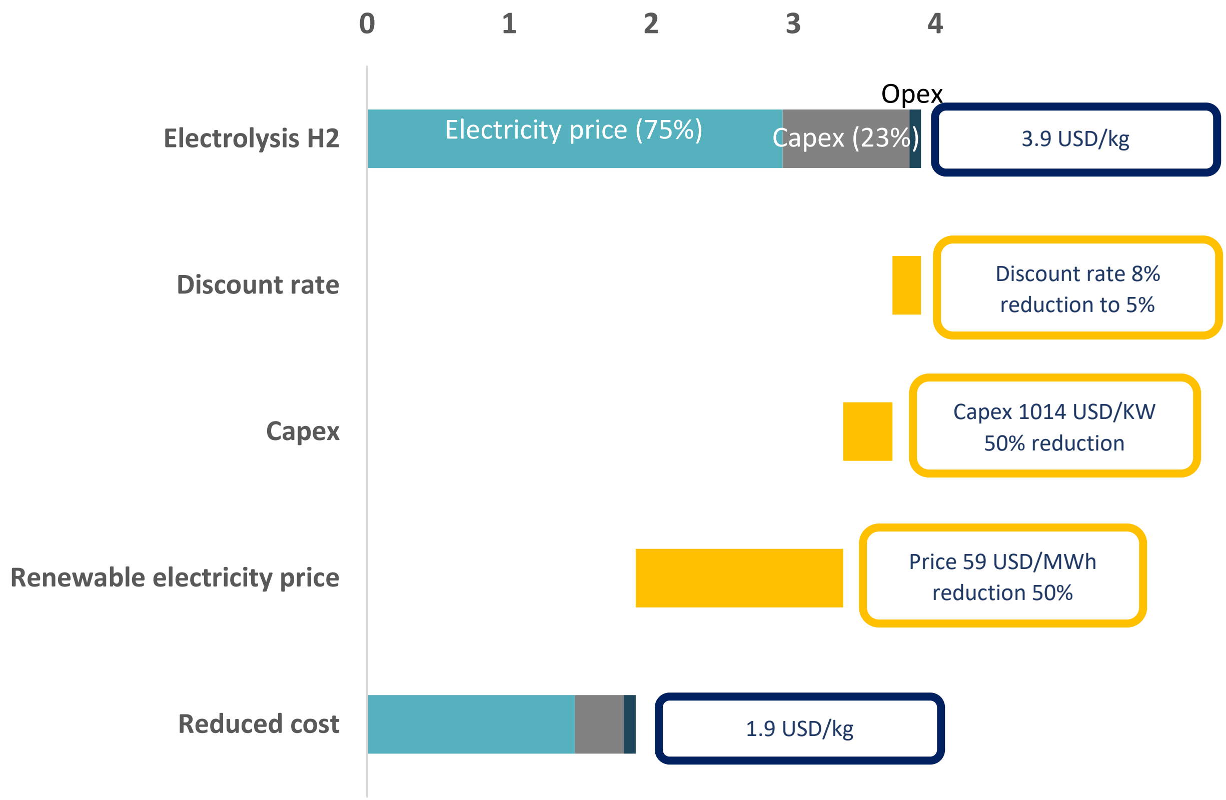
Figure 3 Estimated cost of SMR+CSS based Hydrogen using natural gas prices in EU (USD/kg)



In the case of electrolysis-based hydrogen, electricity prices constitute 75% or more of the total cost of hydrogen production. Since the goal is to integrate hydrogen production with renewable energy power plants, challenges extend beyond the pricing of renewable electricity to include considerations of the electrolyser's capacity factor. Achieving a capacity factor exceeding 70% in the hydrogen plants is crucial for reducing the cost of hydrogen production. This level of capacity factor surpasses the current levels in solar and wind power plants. While connecting the power plant to the grid can enhance capacity factors in the electrolyser, it may introduce challenges related to emission compliance and zero-emission certification.

Scalability will contribute to decreasing the cost of hydrogen production. While bigger and more ambitious projects have been announced, these projects are also more complex than those previously developed, creating other technical challenges. For example, FH2R in Japan still has one of the biggest single-stack electrolysers with a capacity of 10 MW. Projects that require higher capacity will need to connect, operate, and balance several modules to achieve the expected hydrogen production capacity. This can become a driving force to slow down the cost decline of future systems.

Figure 4 Impact of several factors on the cost of electrolysis-based hydrogen (USD/kg)



Note: It was assumed that the cost of electricity to be equal to the levelized cost of energy of wind power in US and the capacity factor of electrolyser 50% to match the capacity factor of the power plant. Capital cost of renewable energy plant is included in electricity price.

Additionally, the increased demand for hydrogen production equipment will drive costs upward by placing stress on the supply chain of raw materials. For instance, the manufacturing of proton exchange membrane (PEM) electrolysers requires a supply of iridium and platinum, which are rather scarce elements.

Hydrogen Transport

The delivery of hydrogen from the production point to end users is one of the areas where more advances are required. Hydrogen has a comparatively low volumetric energy density, meaning that there is low energy per unit of volume under most conventional conditions. When hydrogen is blended with natural gas at a 20% (v/v) rate, the delivered energy per unit of volume is reduced by 14%, and emissions decrease by 7% per unit of delivered energy. For that reason, the use of hydrogen carriers such as ammonia (NH_3), methylcyclohexane (MCH), and methanol (CH_3OH) has been proposed.

Ammonia has gained attention the advantage due to its high hydrogen content. It is liquid at standard conditions which is better for handling and transportation. Infrastructure associated with ammonia already exists, but it will need to be drastically expanded if ammonia becomes an important hydrogen carrier. The direct use of ammonia as a cofiring agent in coal power plant has been proposed as a measure to decarbonize power sector. Ammonia is also mentioned in several hydrogen-related policies and strategies developed in APEC.

Methanol shares some of the same advantages as ammonia as a hydrogen carrier. Methanol can be used as an alternative fuel for internal combustion engine and as anti-freeze agent. The Haru Oni project in Chile uses the produced green hydrogen to manufacture methanol for exports.

On the other hand, ammonia and methanol are harmful for humans and require special handling measures; therefore, updates of safety regulations will be required.

Table 2 Properties of hydrogen carriers

		gas		liquid		
Properties	**unit**	**compressed H_2**	**H_2**	**CH_3OH**	**NH_3**	**MCH**
Temperature	°C	25	-259.9	25	25	25
Storage Pressure	MPa	69	0.1	0.1	0.99	
Density	kg/m3	39	70.8	792	600	770
Volumetric Energy Density (LHV)	MJ/L	4.5	8.49	15.8	12.7	33.5
Gravimetric Hydrogen content	(% weight)	100	100	12.5	17.8	6.16
Volumetric Hydrogen content	kg-H_2/m^3	42.2	70.8	99	121	47.4
Energy to Extract Hydrogen	kJ/mol-H_2	-	0.907	16.3	30.6	68.3

MCH has already been proven as a hydrogen carrier in the AHEAD project conducted between Brunei Darussalam and Japan. Although some research has been conducted to use MCH directly in solid oxide fuel cells, its primary role is as a hydrogen carrier, implying that hydrogen will be extracted at the point of arrival for distribution or use.

he use of energy carriers is currently justified under conditions of high hydrogen demand and long transportation distances. In the near term, as demand is being built and distances between hydrogen production sites and the end-use point increase, the role of trucks transporting compressed hydrogen and pipelines will be relevant.

Direct Combustion of hydrogen and ammonia

The use of hydrogen and ammonia as cofiring agents or as the sole fuel has been proposed as a measure to decarbonize power generation. The main adaptation required for turbine systems to adopt these fuels is in the burners where combustion occurs, and several companies are working on the design of these systems and commercial availability is expected in the coming years. However, both have different combustion characteristics than coal or natural gas.

Table 3 Combustion Characteristics of ammonia, hydrogen, and methane.

Fuel	Unit	NH_3	H_2	CH_4
Boiling temperature at 1 atm	°C	-33.3	-252.9	-161.5
Lower heating Value (LHV)	MJ/kg	18.6	120.0	50.0

Higher heating Value (HHV)	MJ/kg	22.5	141.7	55.5
Flammability limit	%vol	15-28	4-75	5-14.3
Adiabatic flame temperature	°C	1800	2210	1963
Flame speed	m/s	0.07	1.7	0.4

One of the most significant effects of using hydrogen and ammonia for direct combustion is the formation of NOx. This formation is facilitated by the higher temperatures reached during the combustion of hydrogen. Additionally, the higher flame speed, allowing fast flame propagation, and the wide range of flammability limits make hydrogen a fuel that requires special care. These characteristics must be considered when analysing the potential use of hydrogen in residences.

On the other hand, the direct combustion of ammonia is challenging and requires the use of a pilot fire for combustion. To control NOx formation, very careful control of the air/ammonia ratio is necessary.

When used as cofiring agents, one of the most significant effects of using hydrogen and ammonia is the formation of NOx. This formation is facilitated by the higher temperatures reached during the combustion of hydrogen.

International hydrogen standards

Given that the use of colours to identify different pathways for hydrogen production has failed to account for the actual carbon intensity of the produced hydrogen, APEC has also identified the need to establish an international standard for hydrogen as a condition to facilitate international trade. Even though the establishment of the international hydrogen standard will take several years, some APEC economies, namely Japan and the USA, have started defining criteria based on carbon intensity to allocate support for hydrogen production.

Some important issues that require consensus building include the boundaries within the project where emissions are measured, especially for estimating the carbon intensity in fossil fuel-based hydrogen. Other considerations involve the concepts of additionality, temporal correlation, and geographic correlation in the case of renewable energy projects for hydrogen production[3].

The adequate criteria for international hydrogen demand should be designed to avoid the raising of barriers.

There are some criteria that have been established by different economies to access some benefits and support. For example, tax credits for hydrogen production are tiered by well-to-gate emission intensity in US. In contrast, Japan established in its Revised Basic Hydrogen Strategy its threshold for clean hydrogen as 3.4kg of CO_2/kg H_2 on a Well-to-Gate basis. The threshold for ammonia is 0.84kg of CO_2/kg NH_3 on a Gate-to-Gate basis.

[3]Additionality refers to idea that a project has increased renewable energy generation that would not have occurred otherwise. Temporal correlation refers to the degree that renewable energy production matches actual demand. Geographic correlation is the special alignment between the space where demand is located and the space where the energy is produced.

Table 4 45V tax credits for clean hydrogen production according to IRA in US.

Emission Intensity ($KgCO_{2e}/kgH_2$)	**Tax credit (USD/kg H_2)**
0-0.45	3.00
0.45-1.5	1.00
1.5-2.5	0.75
2.5-4	0.60

Table 5 Definition of clean hydrogen and ammonia according to the Revised Basic Hydrogen Standard in Japan

	Emission Intensity ($KgCO_{2e}/kgH_2$)	**System Boundary**
Clean Hydrogen	3.4	Well to gate
Clean Ammonia	0.84	Gate to gate

Table 6 Definition of Tiers in proposed Clean Hydrogen Energy Standard in Korea

Carbon intensity ($kgCO_{2eq}/KgH_2$)	**Tiers**
0-0.1	1
0.1-1	2
1-2	3
2-4	4

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