Exchange of Best Practices for the Development of Green Hydrogen Roadmaps in the Asia-Pacific Region

APEC Energy Working Group

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Produced by
Dr. Antonios Antoniou
Contractor contact:
Email: ant.antoniou@external.euc.ac.cy

Reviewed by
Ministry of Energy and Mining of Peru (MINEM)
Project Overseer contact:
José Meza
Email: jmeza@minem.gob.pe

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

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Contents

1.0 Executive summary

The primary objective of this report is to provide information for the development of hydrogen economy, in the APEC region. The importance of this report lies in the fact that is the first of its kind to analyze in detail the existing information on hydrogen development, roadmaps, and strategies in the Asia-Pacific Economic Cooperation (APEC) and that it collects data from the economies through a questionnaire, analyze the data and derive best practice recommendations for the economies. Conclusions are drawn and presented at the very end of this report, hoping that they will be helpful for the APEC economies in order to accelerate the hydrogen economy and mitigate environmental pollution.

2.0 Introduction

As the world population increases, energy demand also rises; this global energy demand will grow faster than the population growth rate through 2050 [1]. In this regard, many economies are committed to achieving net zero by 2050 at the United Nations Climate Change Conference in Glasgow (COP26) held in 2021 [2].

Given its potential to help address the climate crisis, enhance energy security and resilience, and create economic value, there is an interest in producing and using clean hydrogen is intensifying worldwide. Zero- and low-carbon hydrogen is a key part of a comprehensive portfolio of solutions to achieve a sustainable and equitable clean energy future. The United States is stepping up to accelerate progress through historic investments in clean hydrogen production, midstream infrastructure, and strategically targeted research, development, demonstration, and deployment (also known as RDD&D activities) in this critical technology. Indeed, current hydrogen production is largely grey. Of the 34 million tons of hydrogen that China produced in 2021, 80.3% was produced from fossil fuels, 18.5% from industrial byproduction and 1.2% from electrolysis (less than 0.1% from electrolysis powered by renewable energy sources). Demand for green hydrogen is greatly constrained by cost and availability, as its applications are currently limited to a few small pilot projects in the transport sector that account for less than 0.1% of total hydrogen consumption.

Storing energy as a renewable gas can be used for energy distribution across sectors and regions and as a buffer for renewables. It also provides a way to decarbonize segments in power, transport, buildings, and industry, which would otherwise be challenging.

2.1 Climate change reality

Many pieces of evidence confirm that the planet is warming at an unprecedented rate that has not been seen in the last 10,000 years, and human activity is the principal cause. The contemporary warming trajectory is distinct due to its attribution to human activities since the mid-1800s, along with its unprecedented pace not observed over recent millennia. It is indisputable that human activities have generated atmospheric gases, leading to the increased retention of the Sun's energy within the Earth's system. This surplus energy has engendered the warming of the atmosphere, ocean, and land, consequently precipitating comprehensive and rapid alterations within the atmosphere, ocean, cryosphere, and biosphere [3].

Earth-orbiting satellites and advanced technologies have facilitated the comprehensive collection of diverse data concerning our planet's climate on a global scale. These extensive datasets, accumulated over an extended period, provide compelling evidence of the evolving climate patterns.

In the mid-19th century, scientists elucidated the heat-trapping properties of carbon dioxide and other gases. Numerous scientific instruments utilized by NASA for climate study are designed to analyze the impact of these gases on the transmission of infrared radiation within the atmosphere. The observed effects of heightened levels of these gases leave no doubt that the increasing concentrations of greenhouse gases induce warming of the Earth's surface [3]. Ice cores extracted from regions such as Greenland, Antarctica, and tropical mountain glaciers have furnished compelling evidence regarding Earth’s climate responsiveness to shifts in greenhouse gas concentrations. Furthermore, ancillary insights gleaned from sources including but not limited to tree rings, ocean sediments, coral reefs, and sedimentary rock strata collectively serve as indicators of paleoclimate dynamics. These indications demonstrate that the current pace of warming surpasses the post-ice age average warming rate by approximately tenfold. Moreover, the escalation of carbon dioxide from human activities outpaces natural emissions after the last Ice Age by roughly 250. [3]

2.2 The importance of hydrogen in mitigating climate change

Mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases. Mitigation, together with adaptation to climate change, contributes to the objective expressed in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) [4]. Mitigating climate change entails the reduction of heat-trapping greenhouse gases released into the atmosphere. This can be accomplished by minimizing the sources of these gases, such as the combustion of fossil fuels for electricity, heat, or transportation, and by bolstering the “sinks” that amass and store these gases, such as the oceans, forests, and soil. The objective of mitigation is to prevent substantial human intervention in Earth's climate, stabilize greenhouse gas levels within a timeframe conducive to natural ecosystem adaptation to climate change, ensure the preservation of food production, and facilitate sustainable economic development. [4,5]

Hydrogen is widely recognized as a crucial future energy source for various applications. It acts as an indirect climate influencer, impacting methane, ozone, and stratospheric water vapor, all potent greenhouse gases. The findings suggest that transitioning to a green hydrogen economy would reduce carbon dioxide emissions across different timeframes and leakage rates. In contrast, traditional hydrogen production could increase carbon dioxide and methane emissions, resulting in a potential climate penalty, particularly at higher leakage rates or with a significant share of blue hydrogen. Therefore, managing the leakage rate and selecting appropriate hydrogen production pathways are vital factors in realizing the climate benefits of a large-scale shift to a hydrogen-based economy [6].

2.3 Hydrogen Production Methods

Hydrogen may be generated through diverse processes and energy inputs. A standardized color-coded nomenclature is very often employed to streamline discourse (Fig.1 and Fig. 2). Nonetheless, policymakers should develop policies informed by an objective assessment of the impact rooted in life-cycle greenhouse gas (GHG) emissions, particularly in instances where the delineation between color categories is ambiguous, such as with mixed hydrogen sources or electrolysis utilizing grid electricity [7].

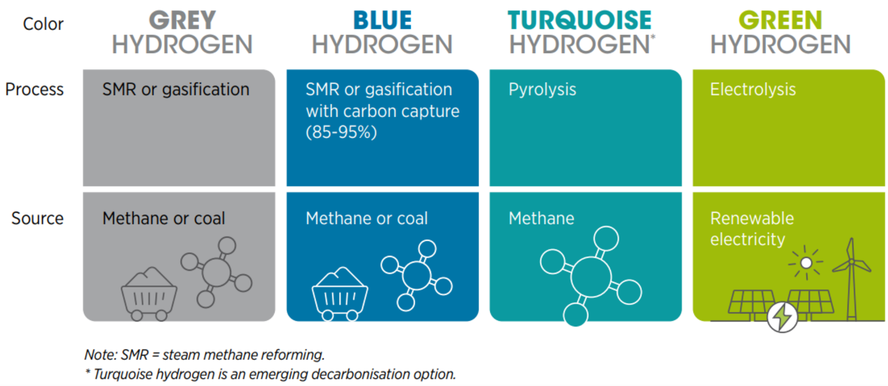

Fig. 1. Different colors of hydrogen [7]

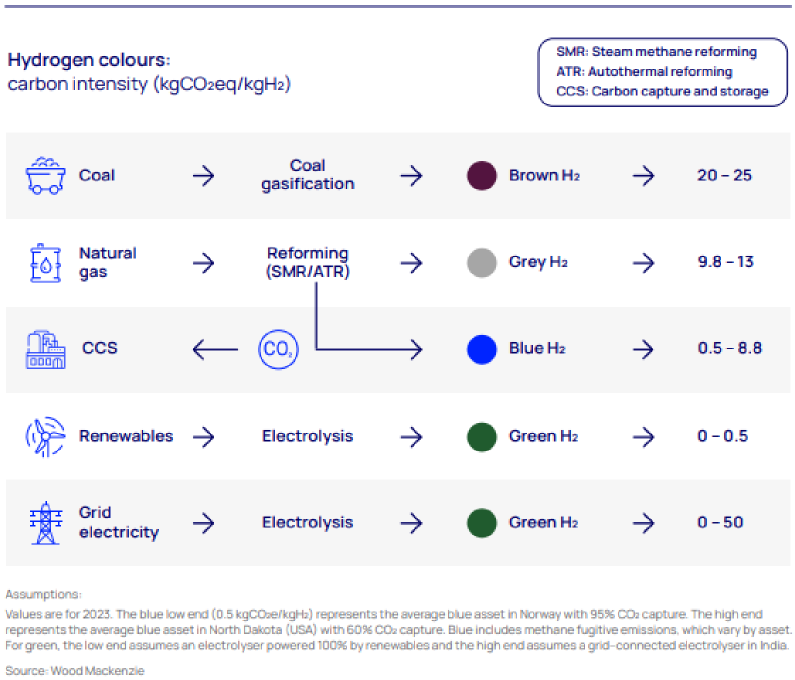

Fig. 2. Different colors of hydrogen-related to CO_2 emission intensity [8]

Grey hydrogen is derived from fossil fuels, namely methane, through steam methane reforming (SMR) or coal gasification, resulting in substantial CO2 emissions. Consequently, these hydrogen technologies are deemed unsuitable for achieving net-zero emissions [7].

In the initial phases of the energy transition, the adoption of blue hydrogen, which involves the utilization of grey hydrogen with carbon capture and storage (CCS), may serve to foster the expansion of the hydrogen market. Presently, approximately three-quarters of hydrogen is sourced from natural gas. The implementation of CCS in existing assets enables the continued utilization with reduced greenhouse gas emissions. This approach presents an opportunity to produce hydrogen with diminished emissions, thereby alleviating the burden on the installation rate of renewable energy capacity needed for green hydrogen production [7].

Industries reliant on a continuous supply of hydrogen, such as steel production, may find blue hydrogen to be an interim solution while green hydrogen's production and storage capacities are being scaled to meet the continuous flow requirement. Nonetheless, certain constraints impede the widespread deployment of blue hydrogen. These include the reliance on finite resources, susceptibility to fluctuations in fossil fuel prices, and limited support for energy security objectives. Furthermore, social acceptance issues persist due to the additional costs associated with CO2 transport and storage, as well as the necessity for monitoring stored CO2. Additionally, CCS capture efficiencies are projected to reach a maximum of 85-95%, leaving 5-15% of CO2 to be emitted, and achieving these high capture rates remains a challenge. The carbon emissions associated with hydrogen generation could potentially be diminished through Carbon Capture and Storage (CCS) technologies, but complete elimination may not be achievable. Furthermore, these processes rely on methane, which introduces the risk of upstream leakages. Methane possesses a significantly higher potency as a greenhouse gas (GHG) per molecule in comparison to CO_2. Consequently, while the adoption of blue hydrogen has the potential to mitigate CO_2 emissions, it does not align with the imperatives of a net-zero future. Therefore, blue hydrogen should be regarded solely as a transient measure to facilitate the transition to green hydrogen, in support of the trajectory toward net-zero emissions [7].

In contrast, turquoise hydrogen leverages natural gas as a feedstock without CO_2 production. By means of pyrolysis, methane's carbon content is transformed into solid carbon black. Notably, there exists an established market for carbon black, which offers an additional revenue stream. Furthermore, the storage of carbon black is more manageable than that of gaseous CO_2. However, it is noteworthy that turquoise hydrogen remains in the pilot phase. [7]

Green hydrogen, derived from renewable energy sources, stands out as the most viable option for enabling a fully sustainable energy transition. The predominant technology for green hydrogen production is water electrolysis powered by renewable electricity. While this report concentrates on this technology, it is noteworthy that other renewable-based methods for hydrogen production exist, although aside from steam methane reforming (SMR) with biogases, these have yet to attain commercial maturity [7].

The utilization of electrolysis for green hydrogen production aligns with the pursuit of net-zero emissions, enabling synergistic benefits through sector coupling, thereby reducing technology costs and enhancing power system flexibility. The declining costs of variable renewable energy (VRE) and technological advancements contribute to driving down the production expenses of green hydrogen, hence generating a surge in interest towards this sustainable option. Furthermore, alternative technologies such as autothermal reforming offer the potential for capturing up to 94.5% of emitted CO_2. Other methods encompass biomass gasification, thermochemical water splitting, photocatalysis, supercritical water gasification of biomass, and combined dark fermentation and anaerobic digestion [7].

However, the industry necessitates increasingly precise project-level certification of carbon intensity as the market for low-carbon hydrogen evolves. Given the sector's substantial requirement for capital investment and subsidies to bolster supply and demand growth, it is imperative to transcend superficial assessments and ascertain the genuine environmental impact of hydrogen [8].

2.4 Hydrogen Storage

Currently, the mainstream methods for hydrogen storage include high-pressure gaseous storage, cryogenic liquid storage, organic liquid storage, and solid-state storage [9]. The characteristics of the four main hydrogen storage methods are shown in Table 1. Fig. 3 also demonstrates similar methods of hydrogen storage [10].

Storage methods	High-pressure gaseous hydrogen storage	Cryogenic liquid hydrogen storage	Solid hydrogen storage	Organic liquid hydrogen storage
Hydrogen storage principle	At a certain temperature and volume, increasing pressure will increase the gas content of the system, and compress hydrogen gas into high-pressure hydrogen storage tanks.	At normal pressure, hydrogen changes from gas to liquid state when the temperature drops to 20K, and then it is stored in an insulated container.	The hydrogen storage materials such as metal hydrides are used to store hydrogen by utilizing their reversible ability to absorb and release hydrogen.	The process of absorbing hydrogen is achieved by hydrogenation and dehydrogenation reactions of carbon atoms in organic compounds.
Hydrogen storage density	1.0–5.7(wt%)	5.7–10(wt%)	1.0–4.5(wt%)	5.0–7.2(wt%)
Advantages	The technology is mature, the operation is easy, the hydrogen filling speed is fast, and the cost is relatively low.	High volumetric hydrogen storage density and high purity of liquid hydrogen.	The hydrogen storage density is high in volume, no high-pressure container is required, high-purity hydrogen can be obtained, it is safe, and flexible.	The hydrogen storage density is high, and it is convenient for storage, transportation, and maintenance with high safety, and can be used repeatedly.
Disadvantages	The hydrogen storage density is low, and compressing it requires a lot of energy, which poses a high safety risk due to high pressure.	The process of liquefaction requires a lot of energy, and the liquefied hydrogen is prone to vaporization, which leads to high costs, and has strict requirements for insulation equipment.	The mass storage density is low, the cost is high, there are temperature requirements for hydrogen adsorption and release, and the cyclic stability of some materials is poor.	High cost, strict operating conditions, and possibility of side reactions, low purity.
Technology Readiness Level (TRL)	Developing rapidly	Mature technology	Early stage of industrialization	Industry Demonstration
Notes	The current methods for hydrogen storage in vehicles	It is mainly used in the aerospace industry and has limited civilian applications.	Widely used in various fields, main development direction in the future.	It can make use of traditional petroleum infrastructure and has a good prospect.

Table 1. Technical characteristics of four hydrogen storage methods [9]

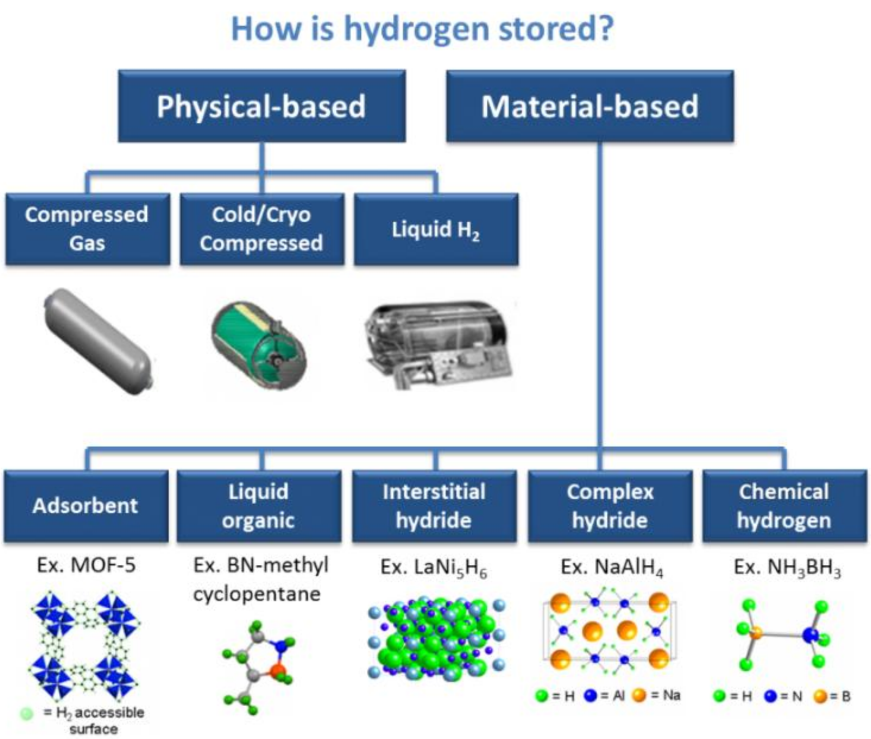

Fig. 3 Various methods of hydrogen storage [10].

High-pressure gaseous hydrogen storage involves using high-pressure gas cylinders as containers for storing gaseous hydrogen through compression. This method offers the advantage of quick hydrogen refueling, well-established technology, operation at room temperature, and low cost. However, it has drawbacks such as low energy density, energy consumption during high-pressure hydrogen compression, larger storage volume compared to other fuels like gasoline, and increased safety requirements for storage containers [9].

Cryogenic liquid hydrogen storage uses low-temperature storage tanks as hydrogen containers, by cooling hydrogen gas to 20K to transform it from a gas to a liquid, which can be stored in liquid hydrogen tanks, liquid hydrogen tanker trucks, liquid hydrogen railway tanker cars, etc. Cryogenic liquid hydrogen storage has advantages such as high hydrogen storage density, small storage containers, and high purity. However, liquefying hydrogen gas requires a large amount of energy, requires high insulation performance of the storage container, and is relatively expensive [9].

Solid-state hydrogen storage technology entails the utilization of hydrogen to achieve reversible adsorption and desorption properties in high surface area materials under specific temperature and pressure conditions. Implementation of this technology encompasses physical hydrogen storage via adsorption employing activated carbon, carbon nanotubes, carbon nanofibers, and other carbon-based materials. Furthermore, chemical hydrogen storage involves reversible adsorption and release of metal hydrides, including magnesium-based, iron-based, lanthanum-nickel-rare earth-based, titanium-based, and zirconium-based alloys. Notably, solid-state hydrogen storage offers advantages such as high-volume hydrogen storage density, obviates the need for high-pressure containers, ensures high purity hydrogen, and entails low energy consumption. However, it is important to note that this technology is still in its nascent stages and exhibits low hydrogen charging and discharging efficiencies [9].

Organic liquid hydrogen storage technology entails the use of specific organic liquid substances to serve as carriers for hydrogen under relatively low pressure and high-temperature conditions. This approach offers the advantages of high hydrogen storage density and enhanced safety. Furthermore, the liquid can be transported at room temperature and atmospheric pressure, leveraging the existing refueling infrastructure. With properties akin to gasoline, it can be seamlessly integrated with current petroleum tankers, tank cars, and gas stations. However, notable limitations include high cost, stringent operating conditions, potential for side reactions, and lower purities. The implementation of organic liquid hydrogen storage technology is presently progressing from its developmental stage in research laboratories to large-scale industrial production [9].

2.5 Hydrogen Transportation

Hydrogen is conveyed from its production site to its destination via a network of pipelines, cryogenic liquid tanker trucks, or gaseous tube trailers and by sea using ships. Pipelines are established in areas with substantial and enduring demand while liquefaction facilities, liquid tankers, and tube trailers are positioned in regions with moderate or emerging demand. The use of chemical carriers, notably in barges, for large-scale applications such as export markets is also currently being tested. At the point of use, standard infrastructure elements include compression, storage, dispensers, meters, as well as technologies for detecting and purifying contaminants. Notably, stations developed to dispense hydrogen into medium- and heavy-duty fuel cell vehicles are projected to compress hydrogen to 350–700 bar pressure and discharge at rates of up to 10 kg/min. State-of-the-art high-throughput technologies are currently in progress to meet these performance criteria [11].

The delivery technology for hydrogen infrastructure is currently available on the commercial market, and multiple companies are engaged in bulk hydrogen delivery. While some existing infrastructure supports hydrogen usage in industrial applications, the broader expansion of hydrogen demand will necessitate extensive research and development (R&D), supply chain expansion, and the implementation of new deployment strategies. Notably, due to its relatively low volumetric energy density, the transportation, storage, and final delivery of hydrogen to end-users result in considerable costs and contribute to the energy inefficiencies associated with its role as an energy carrier [11].

The challenges associated with hydrogen delivery encompass the reduction of costs, enhancement of energy efficiency, preservation of hydrogen purity, and minimization of hydrogen leakage. Further research is imperative to comprehensively assess the trade-offs between various hydrogen production and delivery options when viewed holistically as a system. Establishing a big-scale hydrogen delivery infrastructure presents a formidable obstacle. Its development will necessitate an extended timeframe and is anticipated to entail a combination of diverse technologies. The specific infrastructure requirements and available resources will vary according to region and market type, including urban, interstate, and rural settings. Moreover, the spectrum of infrastructure options will undergo evolution alongside the growth in hydrogen demand and advancements in delivery technologies [11].

Fig. 4 demonstrates various methods of transporting hydrogen from the production point to the end user, depending on the distance between them [12&13]

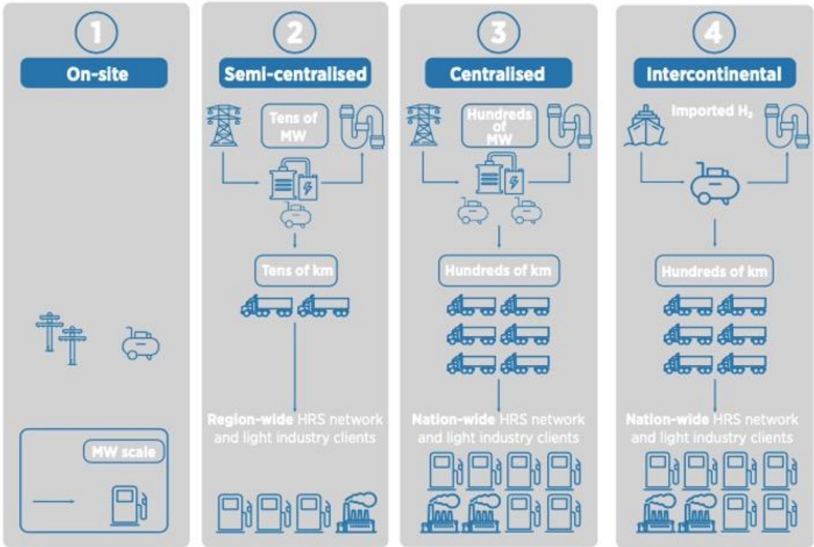

Fig. 4. Transportation of hydrogen [12]

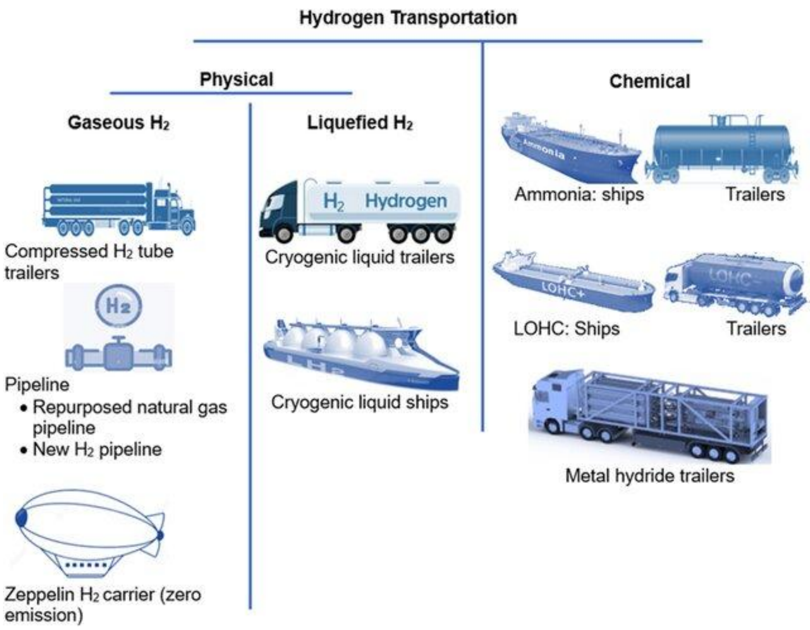

Fig. 5. Transportation of hydrogen [13]

2.6 Hydrogen Utilization

The spectrum of hydrogen applications is as diverse as the element itself. Historically, hydrogen has been extensively used in industrial processes such as fertilizer production and mineral oil refining. However, there is a growing emphasis on exploring additional avenues for hydrogen utilization, particularly in transportation, heating, and electricity, as part of endeavors toward climate neutrality. For comprehensive insights into the multifaceted applications of hydrogen, its pivotal role in climate preservation and the energy revolution, as well as the attendant challenges [14].

The primary objective of hydrogen applications is to attain climate neutrality within all energy supply systems. Clean (renewable or green) hydrogen, being devoid of emissions [15], serves as a viable alternative to natural gas, contributing to environmental preservation while offering a substitute to the costly and contentious extraction practices associated with natural gas. Additionally, hydrogen utilization enhances prospects within the mobility sector, facilitating zero-emission driving for heavy goods vehicles. Furthermore, a key aspiration of hydrogen applications is sector coupling, which effectively integrates the three sectors of the energy industry (electricity, mobility, and heat supply), providing holistic solutions across all domains [14].

Hydrogen serves as a highly efficient energy carrier and enables the indirect storage of electricity through electrolysis. This method proves particularly invaluable for the management of electricity generated from renewable sources, which often experiences seasonal fluctuations. Excess electrical power can be converted into hydrogen via electrolysis and subsequently stored. When demand for electricity rises, the stored hydrogen can be employed in conjunction with oxygen within a fuel cell, thus initiating a reverse electrolysis process that yields a substantial amount of energy. This energy can then be reintroduced into the electrical grid. Therefore, hydrogen presents a viable solution for the long-term storage of electricity derived from renewable energies [14].

In transport, hydrogen is the most promising decarbonization option for trucks, buses, ships, trains, large cars, and commercial vehicles, where the lower energy density (hence lower range), high initial costs, and slow recharging performance of batteries are major disadvantages. Fuel cells also require significantly less raw materials than batteries and combustion engines. Because the transport segment makes up of a big portion of CO2 emissions, its decarbonization represents a critical element of achieving the energy transition [16]. In the field of civil aviation, hydrogen-powered fuel cells are seen as potential energy sources for aircraft, drawing from their established use in space travel. These fuel cell modules can supply electricity to the aircraft's electrical system as emergency generator sets or as an auxiliary power unit. More advanced concepts include utilizing fuel cells to initiate the main engine and propel the nose wheel for ground movements by commercial aircraft [17]. In aviation, fuel cells are currently undergoing testing as potential energy sources for on-board power supply. In contrast, the use of hydrogen-powered fuel cells for ship propulsion is still in the early stages of design or trial phase, mainly in smaller passenger ships, ferries, and recreational craft. The low- and high-temperature fuel cell (PEMFC) and the solid oxide fuel cell (SOFC) are considered the most promising for nautical applications. Notably, as of now, no fuel cells have been scaled for and used on large merchant vessels [17].

Numerous sectors of industry persist in their utilization of fossil fuels, culminating in substantial CO_2 emissions. Notably, facilities dedicated to the production of steel, glass, and ammonia rely heavily on coal or natural gas for their operations, thereby rendering the transition to electric-powered processes unfeasible in certain cases. Conversely, clean hydrogen presents as a viable substitute for natural gas and offers the potential for substantial emissions reduction. Furthermore, owing to its elevated heat capacity, hydrogen can be effectively employed as a cooling agent within power plant settings [14].

The storage of hydrogen and its subsequent reversion through reverse electrolysis presents potential applications within the heat and heating sector. The process of converting hydrogen into energy not only produces water but also generates a substantial amount of heat, which could serve as a viable option for future building heating solutions [16]. Utilizing existing gas pipelines, older buildings that have not yet been outfitted for electric heating present an ideal scenario for implementing hydrogen-based heating. Moreover, district and local heating networks could achieve climate-neutral operation through the use of green hydrogen for heat generation, albeit requiring retrofitting for such purposes [14].

The potential of hydrogen for climate protection is significant, but it comes with its own set of challenges. Firstly, it is crucial that the hydrogen used in various applications is guaranteed to be clean. Additionally, many of the applications of hydrogen in different sectors are still in the early stages of development. To make the use of hydrogen-powered vehicles feasible, a network of hydrogen refueling stations would need to be established. In many areas, the necessary technical infrastructure for heat and heating still needs to be developed or existing systems need to be converted. Large-scale storage caverns for reconversion will also need to be constructed. Furthermore, transporting hydrogen presents a challenge due to its numerous applications in different locations [14].

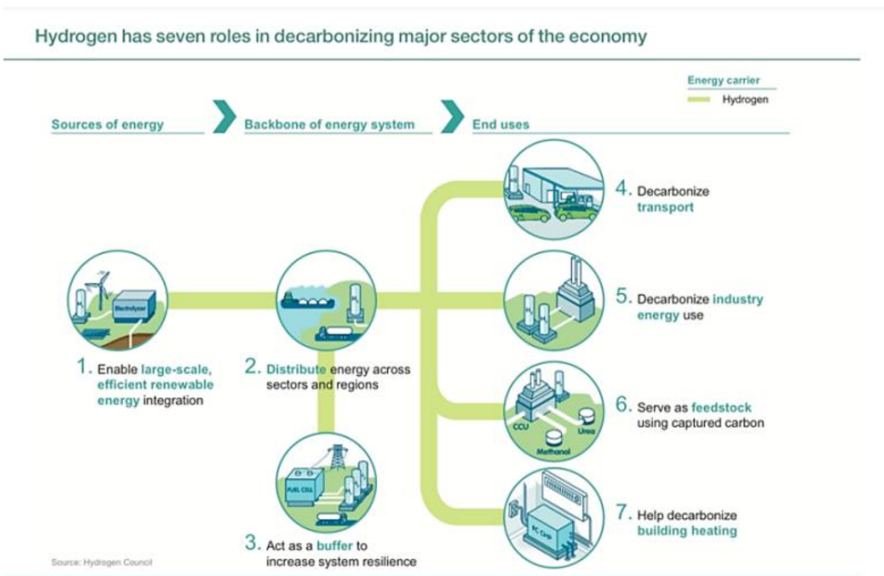

Fig. 6. Hydrogen's role in decarbonizing various sectors of the economy [17]

3.0 Methodology

This study will first briefly explain climate change due to CO2 emissions. Then, it addresses the importance of hydrogen in achieving decarbonization along with other technologies and creating hydrogen roadmaps and strategies. The existing roadmaps in the APEC region will be analyzed, and the critical points will be identified and reported. Afterwards, a questionnaire data collected from the economies is presented and commented on accordingly. The recommendations for best practices will include essential plans and goals not mentioned at the general level. The idea is to help economies that don't have a roadmap to develop one and those with one to enhance it.

4.0 Information on Existing Roadmaps and Strategies of the 21 APEC Economies and Replies to Questionnaire

Some APEC economies have already developed roadmaps for low carbon and clean hydrogen. During a meeting of the APEC Energy Working Group in Lima, Peru, in March 2024, Senior Vice president of APERC, Glen Sweetnam, presented case studies of low-carbon hydrogen policies implemented across 21 member economies of the Asia-Pacific Economic Cooperation (APEC). He emphasized the variation among economies in their approach to low-carbon hydrogen, with some highlighting production capabilities while others focusing on different aspects such as utilization and distribution, and hydrogen's role in decarbonizing energy end-use and power sector [18]. This chapter reviews and analyzes the existing roadmaps and strategies, in conjunction with the information gathered from the economies through a questionnaire.

4.1 Revision of APEC Economies Hydrogen Development, Roadmaps and Strategies

Online search indicated that most many economies developed or will developed roadmaps and strategies for low-carbon and clean hydrogen. Some economies are still at the initial point and they will need some more time to develop such roadmaps and strategies. Below is information found for all 21 economies:

The United States

The U.S. National Clean Hydrogen Strategy and the strategic roadmap examine the potential for clean hydrogen to contribute to the decarbonization objectives of this APEC member across multiple facets of the economy. It offers an analysis of current hydrogen production, transportation, storage, and utilization in the United States. Additionally, it presents a strategic framework aimed at accomplishing large-scale production and use of clean hydrogen, considering various scenarios for 2030, 2040, and 2050. Furthermore, the strategy and roadmap underscore the importance of collaboration among federal government agencies, industry, academia, laboratories, state, local, and tribal communities, environmental and justice communities, labor unions, and diverse stakeholder groups to expedite progress and market deployment. Concrete targets, market-driven metrics, and tangible actions have been established to gauge success across sectors [19].

To aid in the realization of the US hydrogen strategy, the Biden-Harris Administration has initiated the Hydrogen Interagency Task Force to further promote a comprehensive government approach to clean hydrogen. The Strategy and Roadmap adhere to the legislative requirements outlined in section 40314 of the Infrastructure Investment and Jobs Act (Public Law 117-58), commonly known as the Bipartisan Infrastructure Law (BIL). The document was initially released in draft form for public comment in September 2022, and the ultimate version has been shaped by stakeholder feedback, in-depth market deployment analysis, and engagement across various federal agencies and the White House Climate Policy Office. Subsequent opportunities for stakeholder feedback are anticipated, as the report necessitates updating at least once every three years [19].

The U.S. National Clean Hydrogen Strategy and Roadmap is in accordance with the Administration's objectives, comprising [19]:

1) Achieving a 50% to 52% reduction in U.S. greenhouse gas (GHG) emissions from 2005 levels by 2030
2) Attaining 100% carbon pollution-free electricity by 2035
3) Establishing net zero GHG emissions by no later than 2050
4) Ensuring that 40% of the advantages derived from Federal climate investments are directed towards underprivileged communities.

The cornerstone of the US roadmap resides in the prioritization of three fundamental strategies to ensure the development and adoption of clean hydrogen as an efficacious tool for decarbonization, ultimately maximizing the benefits for the United States [19].

- Strategy 1: Targeting Strategic, High-Impact Uses of Clean Hydrogen [19].

  The focus is on employing clean hydrogen to address the challenging decarbonization of key sectors within the economy [19]:

  a) Industrial Applications: Including but not limited to chemicals, steelmaking, and industrial heat.

b) Transportation: Encompassing medium- and heavy-duty vehicles, maritime, aviation, and rail.

c) Power Sector Applications: Enabling grid services, backup power, and long-duration energy storage.

- Strategy 2: Reduce the Cost of Clean Hydrogen Prioritize cost reductions across the value chain [19].

  a) Hydrogen Production Cost
  By 2026 - USD2 per kg
  By 2031 - USD1 per kg

  b) Onboard Storage Cost
  By 2030 - USD9 per kWh (700-bar)

  c) Delivery and Dispensing Cost
  By 2030 - USD2 per kg

- Strategy 3: Focus on Regional Networks [19]

  a) Regional networks will enable large-scale, clean hydrogen production close to hydrogen users, enabling the development and sharing of a critical mass of infrastructure.

  b) Regional Clean Hydrogen Hubs: Locate large-scale clean hydrogen production near end users to jump-start infrastructure development.

  c) Economic Benefits: This initiative will create well-paid jobs and tax revenue for regional economies, establishing a network of hydrogen producers and consumers.

In addition, U.S. federal government agencies in collaboration with state, local, and Tribal governments, as well as stakeholders, will follow eight Guiding Principles to develop and implement technologies that will promote a sustainable, resilient, and equitable clean hydrogen economy. These principles are [19]:

1) Enable deep decarbonization through strategic, high-impact uses.
2) Catalyze innovation and investment.
3) Promote domestic manufacturing and strong supply chains.
4) Take a holistic approach.
5) Ensure affordability and versatility.
6) Advance energy and environmental justice.
7) Foster diversity, equity, inclusion, and accessibility.
8) Create high-quality jobs.

The United States endorses producing clean hydrogen from designated low-carbon energy sources. These sources include but are not limited to, fossil fuels using carbon capture and storage (CCS), hydrogen-carrier fuels such as ethanol and methanol, renewable energy resources, biomass, and nuclear energy. The United States delineates clean hydrogen as hydrogen generated with a carbon intensity that is equivalent to or less than 2 kilograms of carbon dioxide produced at the production site per kilogram of hydrogen manufactured. Originally, the standard was established at 4 kilograms of carbon dioxide-equivalent per kilogram of hydrogen (kg CO_2e/kg H_2) based on a well-to-gate life cycle, aligning with the predominant viewpoint of stakeholders who provided feedback on the preliminary Clean Hydrogen Production Standard. Furthermore, the entity accountable for this standard is mandated to revise it within five years of establishing the initial standard [19].

China

On 23 March 2022, China's National Development and Reform Commission (NDRC) and National Energy Administration jointly unveiled the "Medium and Long-term Plan for the Development of Hydrogen Energy Industry Development (2021-2035)." This marks the first instance of China's central government issuing a comprehensive strategy for hydrogen development. The plan delineates targets until 2035, underscoring the pivotal role of hydrogen in China's energy sector and its endeavor to achieve carbon peaking and carbon neutrality by 2030 and 2060, respectively. By 2035, China aims to establish an integrated hydrogen supply chain, encompassing applications in transportation, energy storage, and industry. China is currently the largest producer of hydrogen globally, with an annual production of 34 million tons. Most of this hydrogen is derived from fossil fuels (80.3%), followed by industrial by-products (18.5%), and electrolysis (1.2%). This economy aims to increase its renewable hydrogen production to 100,000 to 200,000 tons per year (equivalent to 3.3-6.7 TWh or 1.3 GW of electrolysis capacity) by 2025. Furthermore, China plans to further boost the use of renewable sources for hydrogen production by 2035.[20].

China aims to expand its hydrogen economy by building more hydrogen refueling stations and expects hydrogen to reduce around 1-2 million tons of carbon dioxide emissions per year by 2025. To achieve this, the central government will establish an inter-ministerial group to coordinate industry development and create supporting policies. Lawmakers will introduce a comprehensive policy for the hydrogen industry, provide financial support, and promote hydrogen applications through pilot projects. The plan outlines four key tasks for developing the hydrogen economy, emphasizing the use of renewable hydrogen as well as hydrogen from industrial by-products and nuclear power. Notably, the government's focus is on clean hydrogen, with no mention of promoting grey or blue hydrogen derived from fossil fuels [20 & 21].

The key elements of China's hydrogen roadmap and strategies are:

a. In order to support the high-quality development of the hydrogen industry, it is important to establish an innovation system that continuously enhances core technological capabilities. This involves improving key technologies for hydrogen production, storage, transportation, and application, with a specific focus on PEM fuel cells. Additionally, creating an industrial innovation support platform and developing a skilled hydrogen workforce are crucial. It is also essential to actively participate in international cooperation and standardization activities [20 & 21].
b. Coordinate and promote the development of hydrogen energy infrastructure, including the arrangement of hydrogen production facilities and the encouragement of hydrogen utilization from industrial by-products, hydropower, and renewable sources. Explore the use of hydrogen for seasonal energy storage and peak load period support, and support research and development in solid oxide electrolyzers and hydrogen production from PV, seawater, and nuclear power. Additionally, consider the establishment of hydrogen production bases near large-scale demand centers.
c. Create a storage and transportation system by enhancing high-pressure gaseous storage and transportation, reducing costs, and expediting commercialization. Also, promote the industrial application of low-temperature liquid hydrogen storage and transportation, and explore solid-state, deep-cooled high-pressure, and organic liquid transportation and storage. Demonstrate hydrogen pipelines and the blending of hydrogen into conventional natural gas pipelines.
d. Plan a hydrogen refueling network by promoting the construction of hydrogen stations that integrate hydrogen production, storage, and refueling [20 & 21].
e. Promote demonstration projects and diverse applications. Promote demonstration projects in both transportation and energy storage. This includes implementing pilot projects for hydrogen energy storage to increase renewable energy consumption and support peak grid loads. In addition, we aim to establish distributed cogeneration facilities based on hydrogen fuel cells for power generation and to promote the use of hydrogen in urban districts, industrial parks, mining districts, and ports. Furthermore, we will explore additional industrial applications for hydrogen [20 & 21].
f. Improve policies and standards by Enhancing the establishment and refinement of hydrogen energy policies. Develop and implement a standard system for hydrogen energy. Additionally, safety supervision measures should be fortified [20 & 21].

Chinese Taipei

Chinese Taipei imports 98% of its energy and generates around 80% of its electricity from fossil fuels. This economy will face the challenge of establishing carbon reductions, especially considering the power-intensive manufacturing industry, which makes up a large part of Chinese Taipei's economy and accounts for roughly 31% of the total energy consumption [22]. The Chinese Taipei Innovative Green Economy Roadmap (TIGER) consortium comprises ten Chinese Taipei corporations exploring cutting-edge developments in advanced energy technologies, including hydrogen, energy storage, advanced nuclear, and carbon capture. These industrial leaders from Chinese Taipei are evaluating various alternative pathways for the future development of its industrial sector [23]. These Pathways to Net-Zero Emissions in 2050 plan, outlines four major transformations in energy, industry, lifestyle, and society. It also includes two essential governance foundations in technology research and development (R&D) and climate legislation, supported by 12 key strategies [23]. In line with its renewable energy targets, the government of Chinese Taipei aims to have 20% of its electricity supplied by renewable sources by 2025. The main focus is on increasing the production of solar and wind energy, with specific targets for offshore wind power and solar energy (photovoltaics) by 2025. Additionally, the government has set a target for a total fuel cell capacity of 60MW by 2025. However, due to growing energy demand and delays in installing renewable energy capacity, it is projected that renewable power capacity will only reach 15.2% of the total electricity supply in 2025, falling short of the 20% target [24].

In 2021, the government of Chinese Taipei established a high-level "net zero taskforce," consisting of four working groups and an inter-ministerial coordination group. The topic of hydrogen is addressed by the "Decarbonized Energy Working Group," which has formulated a preliminary strategy for hydrogen development. The government's short to mid-term focus will be on importing blue and green hydrogen, with a long-term plan to gradually increase the local production of green hydrogen from surplus renewable energy sources. Additionally, the government will assess the feasibility of developing hydrogen facilities and demonstration sites in the short term, followed by constructing hydrogen infrastructure based on its application and supply in the mid to long term [24].

Chinese Taipei's hydrogen strategy focuses on two primary areas in the near term: power generation and industrial applications. The stable power supply that Chinese Taipei's high-tech industry requires can be supplemented with hydrogen energy as a reliable backup. Initially, power generation will involve co-firing hydrogen in gas turbines. The integration of hydrogen into heavy industry will commence with blast furnace ironmaking and the co-production of steel and chemicals. There are plans to introduce hydrogen into other sectors in the medium to long term [24].

The semiconductor manufacturing industry is already using ultra-high purity hydrogen, specifically in Extreme Ultraviolet Lithography (EUV), rather than for power generation. A joint venture between Air Liquide Far Eastern, a French-Chinese Taipei's company, has announced a EUR200 million investment in facilities in the Science Parks of Hsinchu and Tainan. These facilities will produce industrial gases for the semiconductor industry, with ultra-high purity hydrogen being partially sourced from renewable sources. The combined facilities in Hsinchu and Tainan will have a capacity of 25MW of electrolysis and will generate a total of 5,000 Nm3 of hydrogen per hour [23].

The hydrogen strategy includes the import of blue and green hydrogen in the short and mid-term. However, there are challenges to overcome, such as the unsuitability of Chinese Taipei's current LNG infrastructure for transporting hydrogen or hydrogen carriers. Additionally, the international market for hydrogen is still underdeveloped, and it is not yet traded as a commodity in significant quantities due to its unfavorable cost-effectiveness. The long-term end-users of imported hydrogen in Chinese Taipei, apart from industrial applications, are largely uncertain due to the minimal demand for hydrogen-based solutions. Furthermore, given Chinese Taipei's subtropical climate, there is currently no demand for hydrogen for urban heating, but there are no indications of hydrogen use in the mobility sector [23 &24].

After years of government support, Chinese Taipei has successfully developed a comprehensive and mature fuel cell supply chain. The total output of the Chinese Taipei fuel cell industry amounted to approximately NTD4 billion (≈ USD140 million) in 2021. Despite the advancements in the fuel cell industry in Chinese Taipei, the domestic market for fuel cells is quite limited, with most of the market situated outside this economy. Chinese Taipei fuel cell technology is widely exported, with a rapidly expanding export market in China. Notably, China has included hydrogen in its latest Five-Year Plan and is actively incentivizing hydrogen fuel cells, particularly for the heavy transportation market [23 & 24].

Their supply chain encompasses a wide range of components, including fuel supply systems, backup power generators, charging stations, and scooters. Additionally, it provides international manufacturers with high-quality, cost-effective fuel cell products and related key components, such as raw materials (bipolar plates), battery components (battery packs), stationary and transportation systems, and peripheral products like hydrogen storage tanks and system components. Chinese Taipei companies are key suppliers to some of the world's largest fuel cell manufacturers. For instance, Bloom Energy, a leading American fuel cell manufacturer, sources solid-oxide fuel cell components from Kaori Heat Treatment Co. Another example is CHEM Energy Technology, which exports fuel cell products around the world, has a subsidiary in South Africa and holds partnership agreements with renowned fuel cell manufacturers Siemens and Ballard Power Systems [23 & 24]

Chile

Although small, Chile plays a significant role in addressing rising emissions and transitioning to a low-carbon growth path despite contributing just 0.3% to global greenhouse gas emissions. With high potential in renewable energy, particularly in the northern desert and southern Patagonia, Chile can install 70 times its current electricity generation using renewable energy sources. This abundant green energy will position Chile as one of the leading producers of green hydrogen globally. The National Green Hydrogen Strategy aims to realize this potential [25].

The strategy culminates in collaborative efforts involving industry, academia, civil society, and the public sector. It is vital to this economy's plan to achieve carbon neutrality and uphold its commitment to sustainable development. This strategic initiative will facilitate the production and export of products developed using zero-carbon fuels, positioning exports as environmentally friendly products for consumers. Moreover, it will pave the way for the export of renewable energy globally in the form of green liquid hydrogen, green ammonia, and clean synthetic fuels [25].

Traditionally, Chile had to import the energy it needed due to a lack of fossil fuels. However, with technological advancements, Chile can now lead the way in deep decarbonization efforts both domestically and internationally. This strategy represents Chile's inaugural step in realizing this potential and fulfilling its new promise [25].

The development of green hydrogen in Chile hinges on six pivotal pillars that provide a comprehensive framework for both private and public stakeholders to undertake decisive actions. These pillars are [25]:

1. The state will actively support the mission to establish a new industry through coordinated efforts across multiple sectors. The public sector is poised to assume a pivotal role in the identification and reduction of barriers, while also addressing regulatory, financial, and technical uncertainties to achieve long-term objectives. Private initiatives and capabilities, stemming from companies, academia, and associations, will leverage these foundational efforts to emerge as key drivers in the development of technologies, businesses, investments, and projects necessary for the expansion of efficient and competitive domestic and export markets. This orchestrated public-private collaboration is anticipated to foster clean, intelligent, and inclusive growth within Chile [25].
2. The development of green hydrogen industries should be harmonized with the socio-environmental context, incorporating best practices and encouraging dialogue. Chilean institutions will prioritize the safety of the public and the protection of the environment, along with engaging in meaningful dialogue with local communities. They will uphold respect for and alignment with territorial planning instruments to facilitate a just energy and economic

transition. These institutions are committed to fostering industrial growth that enhances the standard of living for citizens, while overseeing the responsible utilization of water resources and advancing the principles of a circular economy [25].

3. The following text outlines a strategic vision for Chile's emerging export economy, underpinned by green hydrogen. This innovative approach is set to foster a new era of sustainable energy carriers and low-carbon products. As the global economy endeavors to decarbonize, there is an increasing demand for environmentally friendly minerals, food, raw materials, and manufactured goods. Chile is poised to meet these evolving requirements through a robust export sector centered on green hydrogen and its derivatives, along with the production of low-carbon commodities. Reminiscent of Chile's historical significance in the global food supply with saltpeter, the contemporary export of green ammonia is positioned to support the production of low-carbon fertilizers for modern agriculture. Moreover, Chile is on the cusp of a groundbreaking milestone as it prepares to transition into a net exporter of energy to the global market openness to the world, only through international collaboration, will the global green hydrogen economy be developed at the speed that climate action requires. Our transparency, solid institutional framework, non-discriminatory investment rules, and transparent openness to trade have allowed for internationally competitive and dynamic economic sectors to develop in Chile. These same characteristics make it an attractive destination for investing in clean technologies and will be required to enable a rapid scale-up of the green hydrogen industry. Its first stages shall be accelerated by a new paradigm of cooperation and competition, vision denominated as “coopetition”, in which by exporting and importing around the world, Chile will share experiences and technologies [25].
4. Chile remains dedicated to achieving a net-zero economy, with green hydrogen playing a crucial role in this endeavor. Effectively phasing out fossil fuels in favor of clean energy systems necessitates the utilization of green hydrogen and its derivatives, including methanol, ammonia, and synthetic fuels, across various sectors such as maritime, air, and land transportation, mining, industry, and power generation. In Chile, endeavors will be centered on the seamless integration of green hydrogen and its derivatives into applications where they afford efficient emissions reduction. Furthermore, Chile will endeavor to identify alternative solutions for sectors and applications where the economical or practical use of hydrogen is unfeasible [25].
5. Green hydrogen as a catalyst for local growth. The industry and projects developed around this clean fuel will create local hubs for investment, innovation, and economic activity. Public and private stakeholders are in close collaboration to develop green hydrogen in Chile. The government will continue to promote investment and innovation that effectively generate local value in the communities and regions where hydrogen is developed. Initiatives fostering employment and capability development across this economy will be encouraged while considering the unique needs, desires, and strengths of

each territory. Furthermore, the government will explore and promote applications for green hydrogen that yield pertinent local co-benefits [25].

6. Openness to the world. The timely development of the global green hydrogen economy necessitates a collaborative international effort. Chile's robust institutional framework, transparent policies, non-discriminatory investment regulations, and commitment to open trade have fostered the emergence of globally competitive economic sectors. These characteristics render Chile an enticing destination for investment in clean technologies, a prerequisite for the rapid advancement of the green hydrogen industry. An innovative approach termed "coopetition" is poised to expedite the initial phases of this industry, wherein exporting and importing economies will engage in mutual knowledge and technology exchange [25].

Chile action plan is based on:

1. Promotion of domestic and export markets. Launching a funding round of up to USD50 million to support green hydrogen projects. The aim is to assist early and efficient green hydrogen projects focused across the entire value chain, to help bridge economic gaps. Selected projects will contribute to achieving the target cost of USD1.5 per kilogram of hydrogen by 2030. This support is essential for establishing a functioning market and fostering local industry growth. The funding round will be open to companies and consortiums looking to invest in scalable and replicable green hydrogen projects in Chile [25].

2. Establish a public-private roundtable to discuss the path towards a carbon price and taxes that better reflect the externalities of fossil fuels used in Chile. A roadmap aimed at internalizing the social costs associated with the utilization of fossil fuels will be delineated through inclusive deliberations involving pertinent and diverse stakeholders. This framework will encompass the establishment of equitable pricing mechanisms, suitable temporal considerations, and incremental implementation strategies. The rationalization of emission pricing pertinent to hydrocarbon utilization will effectively level the competitive landscape between conventional energy sources and emerging alternatives. In pursuing these objectives, due regard will be accorded to contemporary global research findings and policy recommendations, including those advocated by the International Monetary Fund and the Organization for Economic Co-operation and Development, to underpin the attainment of the objectives outlined in the Paris Agreement [25].

3. Chile intends to employ a strategy of green hydrogen diplomacy to establish its international standing as a supplier of clean fuels and energy carriers. This economy will utilize its extensive network of commercial and technical agreements to mobilize human and material resources, expediting the development of green hydrogen domestically. Crucial for unleashing the

potential of green hydrogen on local and global scales are international platforms and diplomatic relations with 171 states [25].

4. Standards, safety, and piloting. Bridging of regulatory and standards gaps throughout the hydrogen value chain to ensure safety and give certainty to investors. A regulatory development plan, coordinated throughout all public services that hold regulatory authority over the hydrogen value chain, will be executed to establish the standards required by the industry. The result of this action will be more agile and safer development of domestic applications and export industry. Regulation will be developed in coordination with the private sector, promoting international standardization and harmonization [25].

5. The establishment of a task force to provide support for developers during the permitting and piloting processes for green hydrogen projects and derivatives is paramount. Coordinating public services through an agile framework will facilitate the seamless piloting and development of hydrogen projects and new applications, particularly in the mining, transportation, and energy sectors. These measures aim to decrease uncertainty for private initiatives, foster knowledge acquisition, address market coordination failures, and ensure the secure introduction of new fuels and processes [25].

6. A comprehensive evaluation of natural gas regulation and infrastructure will be undertaken to facilitate the implementation of green hydrogen quotas. The assessment will specifically focus on the capacity of existing natural gas infrastructure to safely accommodate hydrogen blending. Furthermore, international best practices will be taken into account to devise a gradual mechanism for the incorporation of green hydrogen quotas within gas grids. This regulatory framework aims to establish a consistent and substantial demand for the domestic production of this environmentally friendly fuel, leveraging the pre-existing infrastructure and complementing natural gas as part of the energy transition towards a sustainable system [25].

7. Social and Local Development: The establishment of early and transparent participatory mechanisms between communities and projects is crucial. The state will play a facilitative role in ensuring effective communication and capacity building to enable constructive dialogue between hydrogen project developers and neighboring communities. It is essential to establish agreements and mechanisms among stakeholders to foster the development of local supply chains, capabilities, and best practices in alignment with territorial and communal interests [25].

8. Exploration of green hydrogen used to replace or complement fossil fuel-based generation in isolated electric systems. Green hydrogen may be a key mechanism to facilitate higher integration of renewable energy into power grids that are isolated from the National Electricity System. An evaluation of

this potential will be carried out, as well as the identification of specific barriers to green hydrogen deployment in these systems, including potential regulatory and market barriers to their integration into the planning and expansion processes of medium-sized systems [25].

9. The appraisal of opportunities and challenges presented by green hydrogen for territorial plans, policies, and distribution is crucial. Historically, policies and plans dictating potential land uses in various regions have neglected to consider the prospect of green hydrogen deployment. Consequently, these regulations will be subject to reassessment in light of the newfound opportunities unlocked by green hydrogen. This reevaluation aims to facilitate a cohesive and reasoned integration of these activities in various regions and their utilization of land and natural resources. Furthermore, specific consideration will be given to potential synergies and challenges with other human activities and requirements, such as the utilization of water resources in San Pedro de Atacama, Antofagasta Region [25].

10. Capacity building and innovation. The collaboration of industry, academia, and technical centers will be pivotal in identifying deficiencies within Chile's capabilities and preparing to meet the demands of the rapidly expanding green hydrogen sector. Through a combined effort, public and private stakeholders will ascertain the essential competencies and technical skills required across the green hydrogen value chain. Subsequently, state educational institutions will work in tandem to equip individuals with these critical capabilities. This proactive approach is anticipated to significantly enhance the prospects for the creation of sophisticated and high-quality employment opportunities [25].

11. The public and private sectors will collaborate to construct an R&D roadmap aimed at overcoming local implementation challenges. This comprehensive plan will include milestones, pilot projects, and necessary activities to advance the knowledge required for the accelerated deployment of green hydrogen. Collaboration with the recipient of the Clean Technologies Institute's innovation platform, which has received up to USD193 million in public funding, will be an integral part of this planning effort. This initiative will address the demands stemming from the growth of this dynamic, challenging, and technologically advanced sector [25].

12. A work consortium will be established in collaboration with publicly traded companies to expedite the integration of green hydrogen within their operations and supply chains. This initiative seeks to delineate the essential prerequisites and strategic measures required to seamlessly incorporate green hydrogen into the processes and undertakings of these entities. The overall objective is to foster a cost-efficient reduction in emissions. Furthermore, this endeavor will serve to fortify the competitive edge and

capabilities of state-owned enterprises, such as ENAP and Codelco in response to the escalating global demand for sustainable goods and energy carriers [25].

Canada

The Hydrogen Strategy for Canada presents a comprehensive framework aimed at establishing hydrogen as a pivotal instrument in attaining the objective of achieving net-zero emissions by 2050 and positioning Canada as a preeminent global purveyor of clean, renewable fuels. This strategic blueprint affirms that by 2050, clean hydrogen can facilitate the realization of net-zero objectives while concurrently engendering employment opportunities, fostering economic expansion, and safeguarding environmental integrity. This endeavor necessitates transitioning from conventional gasoline, diesel, and natural gas to zero-emission fuel sources, harnessing emerging regulatory paradigms and embracing innovative technologies to offer Canadians a broader array of zero-emission alternatives. Canada's trajectory toward 2050 is delineated into three distinct intervals [26]:

1. Near-Term: Laying the Foundation 2020-2025
2. Mid-Term: Growth and diversification 2025-2030
3. Long-Term: Establishment 2030-2050

Recommendations were formulated in consultation with various stakeholders and embody essential actions required to establish a basis for maximizing the advantages of hydrogen within Canada's future energy system mix. The recommendations were delineated across eight key areas [26]:

1. Strategic Partnerships - Strategically leverage both existing and new partnerships to collaborate and delineate the future of hydrogen in Canada.

2. De-Risking of Investments - Establish funding programs, long-term policies, and business models to stimulate industry and government investment in advancing the hydrogen economy.

3. Innovation - Foster further research and development (R&D), determine research priorities, and promote collaboration among stakeholders to ensure Canada maintains its competitive edge and global leadership in hydrogen and fuel cell technologies.

4. Codes and Standards - Update existing codes and develop new ones to keep pace with the rapidly evolving industry, thereby eliminating deployment barriers both domestically and internationally.

5. Enabling Policies and Regulation - Integrate hydrogen into clean energy roadmaps and strategies across all levels of government and provide incentives for its application.

6. Awareness - Take the lead to ensure that individuals, communities, and the private sector are well-informed about the safety, uses, and benefits of hydrogen during a time of rapid technological development.

7. Regional Blueprints - Implement a collaborative, multi-level government effort to facilitate the development of regional hydrogen blueprints to identify specific opportunities and plans for hydrogen production and end use.

8. International Markets - Collaborate with international partners to ensure that the global drive for clean fuels encompasses hydrogen, enabling Canadian industries to thrive at home and abroad.

Canada published its first Progress Report on the Hydrogen Strategy in May 2024, showing how the government is investing in hydrogen infrastructure, including production plants and fueling stations, to support the growing demand for hydrogen in Canada's transportation and industrial sectors, as well as progressing on international agreements to position Canada as a first mover in hydrogen trade and market development.

The Government of Canada has brought forward a number of measures since 2020 to promote the production and use of low-carbon hydrogen. In June 2024, the Clean Economy Investment Tax Credits (ITCs), which include the Clean Technology ITC, the Carbon Capture, Utilization and Storage ITC, the Clean Technology Manufacturing ITC, and the Clean Hydrogen ITC were enacted into law. The Clean Economy ITCs, which represent CAD93 billion in federal incentives by 2034–35, will play an essential role in attracting investment, supporting Canadian innovation, creating jobs and driving Canada's economy toward net zero by 2050. The Clean Hydrogen ITC will provide a 15 to 40 percent refundable tax credit for investments in projects that produce hydrogen, with the projects that produce the cleanest hydrogen receiving the highest levels of support. The Clean Hydrogen ITC will support Canada's hydrogen value chain and position Canada as a competitive producer and supplier of hydrogen and its derivatives.

The Progress Report identified four strategic priorities for the next reporting period on the Hydrogen Strategy, to focus resources in areas to be most effective during this time (2024-2026). These priorities included:

1. De-risk high-impact production projects of low-carbon hydrogen
2. Achieve scalable hubs and strategic corridors, targeting end-uses with greatest potential
3. Advance codes and standards development
4. Grow awareness and enhance market data

Canada's Progress Report confirmed that hydrogen continues to have a role to play in meeting global energy needs in the context of energy security, energy transition and the broader climate imperative. Canada's low-carbon hydrogen produced for export will contribute to sustainable green job creation, international energy security, and global emissions reductions. In Canada's net-zero climate objectives, low-carbon hydrogen will supplement electrification and other carbon mitigation approaches by helping to decarbonize hard-to-abate sectors where electrification alone would be less economical or technically unfeasible.

Japan

In 2017, Japan established the world's inaugural hydrogen strategy, termed the Basic Hydrogen Strategy. This initiative catalyzed the development of hydrogen strategies by the year 2022. Subsequently, Japan hosted the Hydrogen Energy Ministerial Meeting (HEM) the following year with the objective of fostering top-down hydrogen policies and has since assumed a leading role in the global transition towards a hydrogen-centric community. Within the framework of this strategy, Japan has attained numerous achievements. Notably, Japan has commercialized the world's pioneering fuel cell vehicles (FCVs), augmented the integration of fuel cells within households, and procured a substantial number of related patents. Japan has sustained its technological superiority on a worldwide scale and presently commands a prominent position. Capitalizing on the research and development milestones within hydrogen-related sectors, encompassing hydrogen transportation, power generation, and the utilization of hydrogen as a heat source in industrial facilities, Japan has effectively exhibited a diverse array of hydrogen-related technologies in succession [27].

The Japanese strategic initiative encompasses the utilization of hydrogen as both a fuel and a raw material, with a specific focus on recycled carbon products such as ammonia, e-methane, and synthetic fuel (e-fuel). A thorough analysis of the advantages, challenges, and development timelines associated with these products is integral to the plan. The overarching goal is to strategically develop, demonstrate, and industrialize technologies for both manufacturing and utilizing these products, with the primary objective of achieving carbon neutrality [27].

The 2023 hydrogen strategy comprises five distinct chapters, each serving a specific purpose. The introductory chapter elucidates the Basic Hydrogen Strategy, emphasizing Japan's steadfast commitment to achieving carbon-neutral objectives and fostering a hydrogen-based society. Notably, the strategy extends beyond hydrogen to encompass ammonia and other hydrogen-related energy sources, with provisions for periodic review approximately every five years [27&28].

The second chapter delineates Japan's fundamental hydrogen policy, grounded in the pivotal principles of safety, energy security, economic efficiency, and environmental considerations (S+3Es). Moreover, it offers a comparative analysis of Japan's hydrogen policies vis-à-vis those of China; the United States; Europe, other Asian economies, as well as Australia. [27&28].

Chapter three outlines Japan's essential strategy concerning hydrogen and ammonia, elucidating definitive objectives such as supply expansion, demand stimulation, transition to low-carbon hydrogen, renewable energy-based hydrogen production, establishment of domestic and international supply chains, integration of hydrogen and ammonia in power generation, incentivizing hydrogen energy mobility, and application of hydrogen in eco-friendly industrial processes, with considerations for e-methane as a pragmatic initiative. Notably, the government plans to bridge the cost disparity between hydrogen-ammonia and fossil fuels by means of subsidies, with "first movers" eligible for a 15-year subsidy and support for infrastructure development. [27&28].

The subsequent chapter presents a comprehensive framework aimed at enhancing the competitiveness of hydrogen in industries, with a specific focus on five priority areas where Japanese companies hold competitive advantages over their international counterparts. Additionally, the strategy outlines nine strategic investment targets, encompassing areas such as electrolysis development, fuel storage batteries, and large-scale hydrogen transportation vessels. [27&28].

The fifth and final chapter sets forth the Hydrogen Safety Strategy, designed to fortify the safety standards of hydrogen energy. This entails leveraging scientific data, implementing new regulatory protocols for a hydrogen-fueled society, and fostering an environment conducive to hydrogen technology. [27&28].

The 2023 Hydrogen Strategy in Japan outlines four primary objectives. Firstly, it aims to raise the supply of hydrogen and ammonia from 2 million tons to 3 million tons by 2030, followed by an increase to 12 million tons by 2040, and ultimately reaching 20 million tons by 2050. Secondly, the strategy seeks to decrease hydrogen supply costs in Japan from JPY100 per normal cubic meter (Nm3) to 30 yen per Nm3 by 2030, and to JPY20 per Nm3 by 2050. Thirdly, the strategy intends to expand the production capacity of water electrolysis equipment by Japanese companies to approximately 15 GW by 2030 globally. Lastly, the strategy aims to attract investments, both public and private, exceeding 15 trillion yen (USD107.5 billion) over the next 15 years into the hydrogen and ammonia supply chain sector [27&28].

The strategy also stipulates that the Japanese government will provide subsidies for the development of the hydrogen supply chain and related infrastructure based on carbon intensity emissions rather than hydrogen color. The threshold for clean hydrogen is defined as 3.4 kg of CO_2 emissions per kg of hydrogen on a Well-to-Gate basis, and for ammonia, it is 0.84 kg of CO_2 emissions per kg of ammonia on a Gate-to-Gate basis [27&28].

Japan's new hydrogen strategy is aligned with its vision for a hydrogen-based society and decarbonization by 2050. It also reflects the government's commitment to promoting the establishment of international hydrogen supply chains amidst the global energy crisis [27&28].

Australia

Australia possesses the resources and expertise necessary to establish a robust domestic and international hydrogen industry that can contribute to achieving agreed-upon emissions reductions and addressing concerns related to energy security. In 2022, Australia's NDC was updated, and committed this economy to reducing its emissions by 43% on 2005 levels by 2030. The integration of hydrogen across the energy and industrial sectors is one of several available technological options that can aid Australia in meeting its prescribed decarbonization objectives. Furthermore, numerous domestic trends and characteristics favor the widespread adoption of hydrogen [29 & 30].

Australia's strategic approach entails an adaptive framework to eliminate market obstacles, efficiently establish supply and demand, and enhance global cost-competitiveness.

In addition to fortifying clean hydrogen capabilities, Australia will institute definitive regulatory frameworks to ensure a positive influence on energy prices and security. Collaborating with other economies, Australia will establish a mechanism to trace and authenticate the provenance of globally transacted clean hydrogen, thereby influencing international markets and trade [29 & 30].

The pursuit of creating new employment and clean hydrogen-based growth underscores the importance of maintaining safety, cost of living, water accessibility, land preservation, and environmental sustainability. Maintenance of community safety, confidence, and trust, alongside benefits for all Australians, is a shared responsibility of the government and the industry [29 & 30].

To assess progress and achievements, the strategy identifies key indicators reflecting the rapid evolution of technology and markets over the upcoming decade. Transparent benchmarks for success, such as becoming a premier supplier to the Asian market and upholding an impeccable safety track record, will ensure accountability to the lofty expectations of the Australian public. This strategy results from extensive analysis and consultation with experts, industry stakeholders, and the public. It is designed as a dynamic document, subject to updates and revisions aligned with industry evolution [29 & 30].

On the other hand, the Australian Government passed the Future Made in Australia (Guarantee of Origin) Act 2024 and its two supporting Acts in November 2024, establishing the Guarantee of Origin scheme. The GO scheme is a voluntary emissions accounting and verification framework for low emission products such as hydrogen, liquid fuels and metals, as well as renewable electricity. It supports the Australian Government's Future Made in Australia plan to attract investment in low carbon products and renewable electricity. Finally, the GO Scheme has been developed to be an internationally recognised certification scheme and facilitate competitive trade of low emission commodities

Republic of Korea

Korea is working to lead in advancing hydrogen as an alternative energy source, focusing on increasing hydrogen vehicle production, building a comprehensive ecosystem for hydrogen production and distribution, and boosting fuel cell production. This effort is spearheaded by key industrial entities, notably the Hyundai Motors Group. They have committed to a major investment of KRW7.6 trillion (USD6.7 billion) under its "FCEV Vision 2030" and are actively involved in the HyNet consortium to construct 100 new hydrogen refueling stations in Korea by 2022. The successful realization of this vision is expected to result in hydrogen representing 5% of the projected power consumption by 2040, leading to a 43 trillion won economic boost, the creation of 420,000 new jobs, and significant reductions in both fine dust and greenhouse gas emissions [31].

The strategic plan prioritizes reducing greenhouse gas emissions in the transportation sector. Despite efforts, combustion engine vehicles still dominate the global market. In 2018, electric vehicle sales only accounted for 2.2% of total vehicle sales, while hydrogen vehicle sales were minimal at about 7,500 units in 2019. The Korean government predicts that if 10% of the global automobile market transitions to hydrogen vehicles, the market will be valued at approximately USD125 billion [31].

Similar to the uptake of electric vehicles, the dearth of fueling infrastructure poses a significant hurdle to the widespread adoption of hydrogen-powered vehicles. Korea has outlined a strategic plan to augment the current count of 34 refueling stations to 310 by 2022 and 1,200 by 2040. To facilitate this expansion, Korea intends to offer subsidies and streamline regulations to incentivize the construction of new refueling stations [31].

Korea currently generates 307.6 MW of power from fuel cells and aims to increase production to 15 GW by 2040. Out of this target, 8 GW is allocated for domestic use and 7 GW for export. The government plans to introduce a special LNG price for fuel cells and maintain renewable energy certificates (RECs) to create a secure investment environment. Additionally, the government intends to provide extra value to RECs for green hydrogen projects. The plan also includes supplying 2.1 GW of power from fuel cells to households and buildings by 2040, involving incentives such as a special electricity tariff and mandatory measures, including the replacement of cooling systems at public institutions with fuel cell systems [31].

In early 2020, Korea's National Assembly passed the Hydrogen Economy Promotion and Hydrogen Safety Management Law, the first of its kind globally. It provides a legal framework for government efforts, including industry subsidies, and establishes the "Hydrogen Economy Committee" chaired by the Prime Minister to oversee industry promotion, distribution, and safety [31].

The Korean New Deal includes the Digital New Deal and the Green New Deal. Korea aims to transition to a low-carbon economy by 2025 and has committed to spending KRW42.7 trillion on green projects. As part of this deal, the economy targets having 200,000 hydrogen vehicles on the road by 2025 and expanding subsidies for hydrogen vehicles. Additionally, Korea's renewable portfolio standards require increasing power generation from renewable sources, reaching 10% in 2022 [31].

In a vital step toward powering 10 percent of the economy’s cities, counties, and towns with hydrogen by 2030, the Korean government identified three cities as “hydrogen pilot cities” (Ulsan, Ansan, and Wanju) in 2019. These pilot cities will begin testing the application of hydrogen in transportation, industry, and space heating in 2022. To look at one example, the pilot city of Ulsan seeks to produce hydrogen from local petrochemical complexes to power buildings and to refuel FCEVs and ships [32].

Mexico

Mexico's Hydrogen Association, founded in 2021, aims to promote the production and consumption of hydrogen and advocate for the industry in Mexico. Unlike other APEC members, Mexico has no hydrogen regulation or roadmap, so the industry is taking the lead. The association is working to build alliances with states like Oaxaca, Guanajuato, Puebla, and Nuevo León to support local and state initiatives where hydrogen projects can flourish [33].

Mexico is currently supporting four projects, including a solar power plant in Guanajuato, blue ammonia and urea production, zero-carbon green hydrogen, and hydrogen storage for electricity generation. The projects involve internationally backed and local companies with a focus on hydrogen [33].

Mexico has significant potential in renewable energy and is well-positioned geographically, supported by the Free Trade Agreement. This economy offers attractive opportunities for investing in green hydrogen production, with potentially lower taxes compared to other economies. It's crucial for various stakeholders, including academics, scientists, researchers, and the government, to collaborate in this effort [33].

Peru

The Peruvian government is dedicated to reducing carbon emissions and advancing decarbonization efforts. The new legal structure created to promote renewable energy reflects this commitment. Law No. 31992, which promoted green hydrogen and designated it as a subject of domestic interest, was passed in March 2024. This law, which we go over in more depth below, establishes a legal framework especially for low-carbon hydrogen.

The enactment of Law No. 31992, also referred to as the Green Hydrogen Promotion Law, was a significant step forward toward a more sustainable energy transition. In order to reduce carbon emissions and achieve energy decarbonization, this law was a significant step in advancing the development of green hydrogen.

The definition of "green" hydrogen in Article 2 of the law did not explicitly indicate a commitment to decarbonization when it was first published because it did not stipulate that "green" hydrogen had to be produced solely from renewable energy sources, which is an essential component for bringing the law into line with its sustainability objectives.

Legislative Decree No. 1629, which amended Law No. 31992, was released on 22 August 2024, in recognition of this gap. In line with the energy decarbonization objectives outlined in the Paris Agreement, which Peru embraced in its Nationally Determined Contribution, the change offers a more accurate description. In particular, the law's Article 2 has been updated to define green hydrogen as follows:

"*Article 2. Definition of Green Hydrogen*
For the purposes of this law, green hydrogen is that which is obtained from water through processes that use renewable energy resources."

This amended definition ensures that green hydrogen will be generated only utilizing renewable energy sources, ensuring its creation is completely clean and does not emit CO_2. This change enhances Peru's commitment to the energy transition to a low-carbon economy by guaranteeing that green hydrogen projects fully comply with the law's environmental objectives.

With these modifications, Peru's green hydrogen legislation is now more in line with its sustainability objectives, fostering cleaner and more efficient energy development.

On the other hand, based on the transfer of knowledge, complementary technical information has been prepared for the development of the proposal for the National Green Hydrogen Roadmap of Peru, which is under the responsibility of the Ministry of Energy and Mining, and seeks to promote the development of the potential Green Hydrogen and its derived products such as synthetic fuels. This document is under review for its subsequent publication with the corresponding regulations in a Supreme Decree, which implies an official commitment.

The Roadmap for the Production and Use of Green Hydrogen in Peru aims to support the improvement of energy security in the long term, in order to take full advantage of the potential of renewable energies in Peru through regulation of roles in the markets and appropriate standards that make them a sustainable source of energy for the well-being of the population and its economic activities.

Likewise, it is proposed that in 2030 four pilot projects of 255.68 MW be launched on the coast of Peru, as well as pilots for the application of Green Hydrogen in public transportation. Furthermore, by 2040, Peru will be able to export 1210 kilotons of Green Hydrogen.

On the other hand, H2 Peru, also known as the Peruvian Hydrogen Association and established in 2021 with the primary objective of advocating for the advancement of green hydrogen within Peru has presented a comprehensive proposal for a roadmap of green hydrogen in Peru to the Congress Authorities and the Executive Power. This proposal was accompanied by a meticulously prepared document titled "Bases and Recommendations for the Elaboration of the Green Hydrogen Strategy in Peru," wherein diverse aspects of the prospective strategy were thoroughly examined. These included opportunities for Peru, potential application sectors within this economy, export prospects, as well as the proposed implementation of a green hydrogen policy and promotional measures [34].

Peru's initial proposal for a Green Hydrogen Roadmap aims to establish a comprehensive long-term vision to enhance energy security by leveraging Peru's renewable energy potential. The Green Hydrogen Roadmap delineates the development of a regulatory instrument to promote Green Hydrogen by 2024, incorporating this element into Peru's Energy Policy in 2025, and establishing standards and technical regulations for its provision. By 2028, the plan entails the development of pilot projects for green hydrogen refueling stations for electric vehicles. Furthermore, the proposal outlines the launch of four pilot projects totaling 255.68 MW in Callao, Piura, Matarani, and Ica by 2030, in addition to implementing pilot programs for integrating Green Hydrogen in public transportation. The ultimate objective is for Peru to become an exporter of this sustainable energy source by 2040 [35].

Regarding clean hydrogen production in Peru, currently there are two big factories producing green hydrogen in Peru [53]:

1. Engie Peru has entered into an agreement to provide Industrias Cachimayo with renewable energy certificates. This arrangement serves to validate the exclusive use of 100% green energy at its ammonium nitrate facility located in Cuzco. The said facility, which is entirely privately funded, yields an annual production output of approximately 33,000 tones of ammonium nitrate.
2. Fenix, a prominent electricity producer, has commenced its inaugural green hydrogen initiative. This initiative encompasses the installation of a photovoltaic plant to power an electrolyzer within its combined-cycle natural gas-fueled thermal plant. The primary objective of this project is to annually

produce 8,000 m3 of green hydrogen, thereby fulfilling 100% of the internal hydrogen requirements for the generators' cooling system.

Singapore

Singapore strategically addresses three key sectors in its quest to achieve net zero emissions: power, transportation, and industry. Power generation accounts for 39.8% of the economy's primary emissions. Notably, Singapore has transitioned from fuel oil to predominantly relying on natural gas, recognized as the cleanest burning fossil fuel. Moreover, Singapore is actively maximizing solar deployment on available spaces, amplifying energy efficiency solutions, and capitalizing on regional power grids to access cleaner electricity. Transportation contributes 13.7% of Singapore's primary emissions. The envisioned future entails promoting walking, cycling, and public transportation as the preferred modes of land transport. Additionally, Singapore aims for all vehicles to operate on cleaner energy sources by 2040. Industry, which currently contributes 44.4% of the economy's primary emissions, has implemented energy efficiency and resource optimization measures to diminish its carbon footprint. Furthermore, Singapore is continuously exploring low-carbon technologies such as carbon capture, utilization and storage, and low-carbon hydrogen further to mitigate emissions from this sector [36].

Singapore is in the process of transitioning its aviation sector to be more environmentally friendly. In July 2022, the Civil Aviation Authority of Singapore (CAAS), Singapore Airlines (SIA), and Temasek launched a pilot program where blended SAF (Sustainable Aviation Fuel) was used on SIA and Scoot departing flights at Changi Airport for the first time. By 2023, Singapore will also house the world's largest production plant for SAF, a Neste facility with an annual production capacity of 1 million tonnes. Low-carbon hydrogen will play a crucial role in this transition. In the short term, low-carbon hydrogen is expected to support the production of SAFs and other sustainable fuels and chemicals. In the medium term, hydrogen fuel cells could be utilized for airside ground vehicles and aircraft propulsion. In contrast, liquefied hydrogen could potentially become a fuel source for hydrogen-powered aircraft in the long term. However, this will address various challenges, including onboard storage, safety, fuel production costs, and airport infrastructure [36].

In light of the recommendations outlined in the September 2022 publication of the International Advisory Panel (IAP) on Sustainable Air Hub, stakeholders within Singapore's airport community are progressively pursuing initiatives to optimize energy efficiency, curb energy consumption, and transition towards renewable energy sources. These efforts encompass infrastructural enhancements, equipment upgrades, and the electrification of airside vehicles. Moreover, the concerted focus involves a commitment to transitioning all airside vehicles to cleaner energy alternatives, evaluating the potential deployment of solar panels across airfields, alongside conventional rooftop installations, and investigating the feasibility of waste-to-energy initiatives [36].

Singapore organizes its efforts around five key thrusts [36]:

1. Experiment with the use of advanced hydrogen technologies at the cusp of commercial readiness through the Pathfinder project. In our pathfinder projects, we will collaborate with the industry to experiment with advanced hydrogen technologies, address technical, safety, and regulatory issues, and consider technology maturity and end-use applications. Each project will start with a solicitation of proposals and ideas from industry players.
2. Invest in R&D to unlock key technological bottlenecks. Singapore has developed strong research and development capabilities and an active innovation ecosystem with strong links between academia and industry. This has been achieved through consistent investment in research and innovation over the years. In addition to providing general research grants to support low-carbon technology-related research and innovation, Singapore introduced the Low-Carbon Energy Research (LCER) Funding Initiative in 2020, allocating USD55 million to projects focused on enhancing the feasibility of low-carbon technologies such as carbon capture, utilization, and storage (CCUS) and hydrogen.
3. Pursue international collaborations to enable supply chains for low-carbon hydrogen. As a small city-state with no physical resources, Singapore seeks international partnerships to work collectively towards mutually beneficial outcomes. Our focus areas include building a trading and financing ecosystem for low-carbon hydrogen, advancing Guarantee of Origin certification methodologies for cross-border trade, and supporting research collaborations to solve technological challenges.
4. Undertake long-term land and infrastructure planning. In order to deploy low-carbon hydrogen at a large scale, new infrastructure like import and storage facilities, distribution networks, and end-use applications are needed. Although significant infrastructure development is not expected in the near future due to the early stage of the hydrogen supply chain, careful land planning is necessary, including offshore solutions. Leveraging experience from pathfinder projects will help study safety and land use requirements for hydrogen and form plans for gradually building the necessary infrastructure for long-term deployment.
5. Support workforce training and development of a broader hydrogen economy. The government will collaborate with industry, labor unions, and the education sector to support workforce development and provide Singaporeans with the skills and knowledge necessary to prosper in a hydrogen economy, should they desire to do so. We anticipate the emergence of pathfinder project(s) which will identify the new capabilities required in local end-use sectors. Through timely intervention and systematic training, these workers can effectively acquire the new skills necessary.

Singapore is committed to combating climate change by reducing domestic emissions and catalyzing international decarbonization efforts in the maritime and aviation sectors. We see low-carbon hydrogen as a scalable pathway for decarburization and will take a gradual approach to infrastructure development. We will focus on pilot projects, research, and building international partnerships to facilitate global trade of low-carbon hydrogen. We welcome ideas and suggestions from industry and international partners to achieve a sustainable, low-carbon hydrogen future [36].

The Russian Federation

In June 2020, the Russian Federation released its Energy Strategy to 2035, outlining its plans for the energy sector. This includes a focus on hydrogen, with the aims to export 0.2 million metric tons by 2024 and 2 million by 2035. With global hydrogen production at approximately 70 million metric tons in 2019, Russia's strategy includes a broad action plan for developing the hydrogen energy sector. The approach aligns with the goals of increasing socioeconomic development and maintaining a global energy presence. Critical questions about the strategy's implementation remain unanswered. Still, Russia believes it has a competitive advantage in hydrogen production due to its vast fossil fuel resources and expertise in the oil and gas industry. Acknowledging the changing global demand and risks in a decarbonizing economy, Russia's strategy emphasizes defensive aspects in response to climate change and the rising demand for low-carbon products. The plan outlines the creation of low-carbon, export-oriented hydrogen production facilities, with a potential emphasis on green hydrogen [37].

The strategy outlines three development stages: reaching 0.2 million metric tons of exports by 2024, aiming for 2 million metric tons by 2035, and aspiring to export 15–50 million metric tons globally by 2050. The focus is on developing hydrogen clusters, but it lacks clear definition and priority. The roadmap provides timelines until 2024 and emphasizes the need to involve the private sector. Russia aims to be a global leader in hydrogen energy and has signed cooperation agreements with the UAE and Japan [37].

Russia plans to establish three hydrogen clusters: a Northwest cluster for exporting to European markets, an Eastern cluster for Asian markets, and an Arctic cluster for gas resource development. The location of the clusters is yet to be determined but may mirror Russia’s natural gas sector. Potential sites include the Leningrad Oblast, Primorsky Krai, and Yamalo-Nenets Autonomous Okrug [37].

New Zealand

New Zealand's Energy Strategy is to support the transition to a low emissions economy, address strategic challenges in the energy sector, and signal pathways away from fossil fuels. The first Emissions Reduction Plan in 2022 included the development of a Hydrogen Roadmap. This roadmap will outline the New Zealand Government's position on the future role of hydrogen and establish a pathway for creating a hydrogen industry in Aotearoa New Zealand to support the transition to net zero by 2050.The Hydrogen Roadmap builds on the 2019 green paper 'A Vision for Hydrogen' and is part of the upcoming New Zealand Energy Strategy alongside other initiatives. In late 2023, the Ministry of Business, Innovation and Employment (MBIE) sought feedback on the Interim Hydrogen Roadmap, which outlines the government's initial position on the potential of hydrogen in New Zealand's energy transition and the actions being taken to establish a sustainable and safe hydrogen industry in Aotearoa New Zealand [38 & 39].

The potential for hydrogen infrastructure deployment in New Zealand, particularly at freight hubs and ports, is being actively explored through demonstration projects. While the current cost of hydrogen production is high, there is potential for scaling up production to power port vehicles, maritime vessels, and trains. Fuel-cell powered ferries and small ships are also being developed in various parts of the world to kickstart international hydrogen trade [39].

New Zealand's rail services primarily focus on transporting bulk freight, such as logs or coal, as well as handling the import and export of goods. The Ministry of Transport projects that rail freight volumes will increase to 23 million tonnes per year by 2031. One proposed solution to reduce emissions in the rail sector involves converting or replacing existing rolling stock with hydrogen-powered trains and using ancillary hydrogen-fuelled equipment like container handlers. This approach would offer significant environmental benefits and eliminate the need for future costly electrification of the network. Additionally, transitioning to hydrogen trains in the South Island, where the track is not electrified, would yield further advantages [39].

At airports, the air-side and land-side areas present an opportunity to integrate fuel cell electric vehicles (FCEVs) alongside electrified operational vehicles, particularly for essential 24/7 operations. Although liquid hydrogen fuel holds potential for aviation, it comes with the trade-off of higher energy consumption and potentially elevated costs. While hydrogen-powered aircraft are still in the developmental phase, hydrogen has long-term potential to substantially mitigate international transport emissions as a decarbonized fuel source [39].

Hydrogen has long-term potential in transportation if production and utilization costs become competitive. Carefully crafted policy support and lifecycle analysis are crucial for effective deployment. Initially, converting daily 'return-to-base' fleets and public transport fleets will be economically favorable. Fuel Cell Electric Vehicles (FCEVs) are predicted to break even with Battery Electric

Vehicles (BEVs) in the longer term. Public policy can support by easing regulatory burdens, undertaking business case and implementation plans, and engaging with industry stakeholders. Developing a roadmap and implementation plan for hydrogen and wider renewable energy is important, aligning with New Zealand's net-zero carbon emission 2050 target [39].

Hong Kong, China

In November 2020, Hong Kong, China has announced the goal of carbon neutrality before 2050. This commitment was exemplified through the subsequent release of two government publications: the "The Hong Kong’s Climate Action Plan 2050" in 2021 and the “Strategy of Hydrogen Development in Hong Kong" in 2024. These publications outlined strategies towards the goal of carbon neutrality and to create an environment conducive to the development of hydrogen energy [41&42].

The development of hydrogen faces numerous challenges, including the high cost of hydrogen fuel and its applications, and inadequate existing infrastructure.

It is imperative for the government to formulate a comprehensive hydrogen policy framework that reflects pioneering approaches to tackle climate change, lower emissions, and encourage widespread participation. Hong Kong, China announced the "Strategy of Hydrogen Development in Hong Kong" in June 2024 with four core strategies for hydrogen development [42]: a. Improving legislations, b. Establishing standards, c. Aligning with the market, d. Advancing with prudence. The Strategy addresses technical challenges in six key areas: safety, suitable technologies, infrastructure, cost-effectiveness, capacity building, and public acceptance. The aim is to enable Hong Kong, China to leverage the environmental and economic opportunities arising from global developments in hydrogen energy, while also fostering cooperation with the APEC region and beyond, integrating into this economy's overall development, and cultivating a new, high-quality productive force [42].

The government will introduce legislative amendments in the first half of 2025 to provide a legal basis for regulating the manufacture, storage, transport, supply, and use of hydrogen as fuel. By 2027, the government will formulate the approach for certifying hydrogen standard that aligns with international practices. Additionally, they will promote regional cooperation, investment outside Hong Kong, China and joint ventures for hydrogen development or importation. The government aims to showcase Hong Kong, China as a demonstration base for development of hydrogen energy and facilitate the development of the hydrogen industry in the APEC region. Furthermore, they will collaborate with relevant organizations to promote business opportunities arising from hydrogen energy development. The government has set up an Inter-departmental Working Group on Using Hydrogen as Fuel in 2022. The roles and functions of the Working Group will be expanded to include coordination of technical standards, advice on wider application and commercialization, support for infrastructure development, and promotion of hydrogen applications. The Working Group will also review the implementation progress and update the Hydrogen Strategy regularly [41&42].

Viet Nam

On 22 February 2024, the Ministry of Industry and Trade (MOIT) organized a conference in Ha Noi to launch Viet Nam's hydrogen energy development strategy until 2030, with a vision for 2050. This strategy was approved by the Prime Minister in Decision No. 165/QD-TTg dated 7 February 2024 [43].

The development of hydrogen energy in Viet Nam is guided by Resolution No. 55-NQ/TW, focusing on technology research, pilot projects, and aligning with global trends. The strategy aims to establish a hydrogen energy ecosystem based on renewable energy and proposes mechanisms to diversify capital sources, increase investment in science and technology, and promote international cooperation. Ministries, agencies, and localities are urged to implement the strategy's goals, update planning, and promote policies to encourage the use of hydrogen fuel. Corporations and enterprises in the energy industry are tasked with implementing the strategy's objectives and mobilizing capital for hydrogen energy projects.[43].

Production capacity will be raised to 10 million to 20 million mt/year by 2050, and the targets are part of Viet Nam's efforts to realize its net-zero commitment by 2050, according to the strategy document [44]. The strategy envisions a dual market for blue hydrogen, obtained from natural gas with carbon capture, and green hydrogen, produced through water electrolysis and renewable energy sources. Both varieties are expected to find utility in domestic and export arenas. Within the domestic market, the H2 strategy sets its sights on fulfilling 10% of Viet Nam's final energy demand with hydrogen utilization. Given the Vietnamese landscape, hydrogen deployment is feasible in the transport sector and offers the potential to decarbonize industries that pose significant challenges to decarbonization [44].

Viet Nam's strategy entails a concerted focus on advancing green hydrogen and carbon capture technologies by 2050, while concurrently establishing hydrogen markets within the domains of electricity production, transportation (including roads, railways, waterways, and airways), industrial manufacturing (covering steel, cement, chemicals, and oil refining), and both commercial and residential sectors. In the realm of electricity generation, Viet Nam anticipates piloting the co-firing of natural gas with hydrogen and coal with ammonia to meet fuel transition objectives outlined in the National Power Development Plan for 2021-2030, with a forward-looking framework extending to 2050. Likewise, Viet

Nam's transformative agenda for the transportation industry encompasses the deployment of hydrogen technologies to drive the decarbonization of public transportation and long-haul trucking. The industrial sector will explore the substitution of grey hydrogen with green hydrogen in fertilizer production and petrochemical refining, and will investigate the integration of hydrogen in the production of green steel and cement. Additionally, there are plans in place to incentivize investments in the export of green hydrogen [44].

In order to facilitate project development, it is imperative to establish a well-defined domestic market for H2, as it plays a pivotal role in the expansion of H2 production capacity. Presently, there is an absence of infrastructure for transporting liquefied BH2 and GH2, and the projected capacity by 2030 is deemed insufficient. Consequently, the H2 market will primarily be domestic, with potential for additional markets in blue ammonia (BNH3) or green ammonia (GNH3) subject to policy frameworks in other APEC members, particularly those mandating decarbonization. Vietnamese investors anticipate that hydrogen funding will receive support through initiatives such as the Asian Development Bank's commitment, announced on 13 March, to mobilize USD2.1 billion as part of the Vietnamese government's Resource Mobilization Plan. This plan aims to implement the Just Energy Transition Partnership, attracting USD15.8 billion in financing from developed economies [44].

Thailand

Thailand is considering using hydrogen to reduce greenhouse gas emissions, but it is in the early stages of developing hydrogen policies and initiatives. Support for capacity building and enhancing the understanding of policies and initiatives among Thai stakeholders is crucial for long-term planning [45].

Thailand hydrogen strategy draft delineates three strategies and a set of enablers. The first strategy, "Acquire Key Technologies for Clean Hydrogen Production," underscores the paramount importance of securing blue and green hydrogen technologies through collaboration with leading technology. Thailand aspires to bolster its technological capabilities through internalization processes and may contemplate importing hydrogen developed abroad based on this economy's hydrogen production technology. The second strategy, "Expand Demand by Laying a Foundation for Hydrogen Utilization," and the third strategy, "Establish Infrastructure to Broaden the Hydrogen Network," is centered on enabling hydrogen utilization across various sectors such as power and transportation. Measures encompass expanding fuel cell power generation and transitioning public buses to hydrogen buses. To ensure a stable hydrogen supply, the strategy advocates for the implementation of hydrogen liquefaction plants, the deployment of hydrogen pipelines, and the establishment of refueling stations [45].

Thailand is actively pursuing initiatives to counteract climate change and transition towards a sustainable energy landscape. The integration of hydrogen technology is being contemplated as pivotal for Thailand's energy sector to curtail carbon emissions and fortify energy resilience. Moreover, the introduction of hydrogen technology holds promise for enhancing Thailand's adherence to environmental regulations such as Europe’s Carbon Border Adjustment Mechanism (CBAM), cultivating high value across diverse levels of the value chain, and delivering substantial advantages to Thai society through the extensive utilization of hydrogen-based gas turbines. Nevertheless, there exist challenges in embracing hydrogen technology in Thailand. The existing high costs associated with hydrogen production render it financially impractical. Hence, it is imperative to strive for economies of scale through technological progress and large-scale production demonstrations. Furthermore, while green hydrogen is presently generated in the central and northeastern regions of Thailand, demand is concentrated in the eastern region, emphasizing the necessity for cost-effective transportation methods from production facilities to consumption points. Private enterprises must devise technology and infrastructure for harnessing hydrogen as an energy source. Accordingly, the government must address legal and regulatory hurdles and encourage pilot programs through assistance and collaboration. Notably, there is an emphasized need for financial backing to procure the essential funds for commercializing hydrogen technology [45].

Indonesia

During the 2024 International Hydrogen Summit, Indonesia's Director of New and Renewable Energy highlighted the ministry's plans to establish regulations offering incentives and tax concessions for green hydrogen developers. These measures are anticipated to be incorporated into the forthcoming EBET Bill, currently under evaluation. The policy is intended to cover a broad range of incentives, including tax holidays, tax allowances, and fundamental carbon trading regulations. These incentives are essential in alleviating the initial capital burden on developers, thereby fostering a competitive market for green hydrogen [46].

The Indonesian government is actively devising a hydrogen strategy with the primary objective of curtailing the use of fossil fuels. As per the strategy, there is a production target of 9.9 million tons per year by 2060, distributed across various sectors: industrial (3.9 Mtpa), transportation (1.1 Mtpa), electricity (4.6 Mtpa), and household gas networks (0.28 Mtpa). Prominent industry leaders, such as Julfi Hadi, CEO of Pertamina Geothermal Energy (PGE), have underscored the necessity of comprehensive guidelines encompassing hydrogen exports, production, transportation standards, and Indonesia’s electricity distribution scheme. Eka Satria, CEO of Medco Power Indonesia, has echoed similar sentiments, emphasizing the need for regulations that underpin a sustainable and low-carbon hydrogen ecosystem to attract foreign investments. [46].

Investment in hydrogen development is regarded as a pathway to a more environmentally sustainable future. Seno Adhi Damono from the Hydrogen Energy Center Indonesia has highlighted that the advancement of hydrogen technology can notably diminish fossil fuel dependency. However, realizing this vision requires substantial investment in infrastructure and technology, alongside supportive government policies. Indonesia's strategic geographical proximity to major hydrogen markets such as Japan; Korea; and Singapore, representing a combined market size of approximately 4 Mtpa, positions it advantageously. Indonesia's substantial gas reserves and CO2 storage capacity make it well-suited for blue hydrogen production. Furthermore, Indonesia's extensive geothermal and solar power potential provides a strong foundation for the development of green hydrogen [46].

Malaysia

Hydrogen technology is evolving to meet market demands, with two primary types currently dominating the market: small-scale production systems and large-scale industrial technologies. Each type is tailored to specific resource availabilities and market needs. Small-scale production systems are designed for quick deployment, relatively simple installation, and cost-effective solutions. Conversely, large-scale industrial technologies emphasize system optimization, reliability, and cost efficiency, particularly for larger production volumes. The diversity of renewable feedstock announced for green hydrogen production suggests a need for various electrolyzer technologies. These technologies must be compatible with the capacity factor and efficiency of each type of renewable energy source [47].

The State of Sarawak is at the forefront of hydrogen development in Malaysia, overseeing the progress of two significant hydrogen manufacturing projects expected to commence operations in 2027. Additionally, the state has initiated testing for an urban transportation system utilizing hydrogen-powered smart trams in Kuching. Several forthcoming projects are also in the pipeline, emphasizing the utilization of hydrogen in telecommunications, mobility, and production sectors [47].

However, despite these initiatives, using hydrogen as a fuel in Malaysia is still in its preliminary stages. The high production cost currently hinders its economic feasibility, while hydrogen transportation and storage challenges cannot be overlooked. Moreover, the absence of a clear legal and regulatory framework acts as a deterrent for potential investors [48]

To realize Malaysia's vision of becoming a leading economy in the Hydrogen Economy by 2050, the Hydrogen Economy and Technology Roadmap (HETR) delineates three primary objectives [49]:

a. Establish hydrogen as the cornerstone of Malaysia's new energy economy, positioning Malaysia as a leader among ASEAN members and asserting a robust global presence within the hydrogen supply chain. This entails a strategic shift from modest to substantial trade, focusing on hydrogen exports to the Asia Pacific region over the short-, medium-, and long-term, yielding an anticipated cumulative revenue of MYR648 billion.

b. Attain a sustainable energy mix by diversifying energy sources and elevating the proportion of clean energy within Malaysia's energy composition. This can be accomplished by fostering the utilization of hydrogen in energy storage and as a fuel in combined cycle gas turbines (CCGT), thereby generating a long-term hydrogen demand of 68.2 TWh/year.

c. Invest in hydrogen technologies to address domestic energy consumption, bolster energy stability, fortify energy security, sustain international energy trade, and curb carbon emissions. This encompasses cultivating a comprehensive ecosystem, particularly within the mobility sector, fostering a long-term hydrogen demand of 30.5 TWh/year.

As outlined in the HETR, attaining these objectives necessitates a comprehensive approach comprising five strategic thrusts, nine strategies, and twenty-nine action plans involving diverse ministries, agencies, research institutions, and stakeholders. This concerted effort aims to establish a resilient and competitive hydrogen ecosystem capable of realizing a projected revenue of MYR89 billion by 2050. The realization of the targets specified in the HETR addresses the energy trilemma presented in the National Energy Policy 2022-2040, offering a secure, cost-effective, and sustainable alternative fuel source. [49] The realization of the objectives articulated in the Hydrogen Roadmap will unfold gradually, with the timeline for executing the various action plans from 2024 to 2050. This strategic roadmap signifies initiating the hydrogen economy development in Malaysia, envisioning a potential revenue of MYR89 billion by 2050. Furthermore, it mirrors the concerted endeavors to tackle and manage Malaysia's energy trilemma [48].

The Republic of the Philippines

The Philippines pursuit of a more sustainable and low-carbon future within the energy sector and the reduction of greenhouse gas (GHG) emissions, the role of hydrogen in the energy transition has been acknowledged by the Department of Energy (DOE) as an innovative solution with the ability to meet future energy demands and offer diverse applications in the power, transportation, commercial, and industrial sectors. The Philippines policy framework comprises four core pillars [50]:

1. Energy Security: Diversifying energy sources and increasing the utilization of indigenous resources in the production of hydrogen and its derivatives are aimed at reducing dependence on imported oil, thus mitigating the Philippines' vulnerability to energy supply disruptions and fluctuations in the global energy market.
2. Environmental Sustainability: The promotion of renewable energy (RE), alternative fuels, and emerging technologies, coupled with intensified energy efficiency and conservation (EEC) measures, is intended to support initiatives aimed at mitigating GHG emissions and aligns with the Nationally Determined Contribution for the Paris Agreement.
3. Research and Technological Development: Innovation within the industry will be fostered through collaboration with science and technology institutions, the undertaking of research and studies, the implementation of technology demonstration and pilot projects, the encouragement of technology transfer and adoption, as well as the strengthening of capacity-building programs.
4. Access to Financing and Investments: The acceleration of industry development will be facilitated through the formulation of sustainable financing programs and investment roadmaps, encompassing the establishment of fiscal and non-fiscal incentives and the institution of government financial support mechanisms.

The utilization of hydrogen energy stands as a pivotal measure for the Philippine government in its pursuit of long-term decarbonization. The Department of Energy (DOE) hereby embraces the advancement of hydrogen and its derivatives as an alternative fuel, with a primary focus on establishing a policy framework for this economy, institutionalizing development partnerships, and developing supportive infrastructure. Moreover, the DOE, through the Hydrogen Energy Industry Committee (HEIC), will undertake the creation of a comprehensive roadmap to delineate the overarching vision, strategy, milestone targets, and requisite support systems and resources for the industry [50].

Hydrogen energy projects, depending on their technological specifications and overall scope, may qualify for a range of fiscal and non-fiscal incentives under several key Philippine legislative frameworks. These include the Renewable Energy Act of 2008 (Republic Act No. 9513), the Energy Efficiency and Conservation (EEC) Act (R.A. No. 11285), the Electric Vehicle Industry Development Act (EVIDA) (R.A. No. 11697), and the Corporate Recovery and Tax Incentives for Enterprises (CREATE) Act (R.A. No. 11534), amended as CREATE Maximize Opportunities for Reinvigorating the Economy (CREATE MORE) Act (R.A. No. 12066).

Specifically, hydrogen energy projects that focus on the production, import, or export of green hydrogen or its derivatives for power generation or other applications are entitled to various incentives in accordance with the provisions of the Renewable Energy Act of 2008 (RA 9513). These incentives encompass an income tax holiday, exemption from duties on renewable energy machinery, equipment, and materials, preferential real property tax rates on equipment and machinery, net operating loss carry-over, corporate tax rate privileges, accelerated depreciation, a zero percent value-added tax (VAT) rate, tax exemption for carbon credits, and tax credits for domestic capital equipment and services associated with the installation of equipment and machinery. Moreover, the stipulations extend to offer incentivization for the application of hydrogen energy within the transportation sector, the production of hydrogen from nuclear power, and research and development endeavors linked to hydrogen energy [51].

Brunei Darussalam

Brunei Darussalam has initiated the production of hydrogen, referred to as SPERA Hydrogen, from processed gas derived during liquefied natural gas (LNG) production. The hydrogen is intended for export to Japan, commencing in late 2019, with comprehensive backing from Japan. Hydrogen is classified as a clean energy source due to its emission-free combustion of carbon dioxide (CO_2), signifying its potential for global utilization in the future [52].

In 2015, the road transport sector in Brunei Darussalam was accountable for the highest share of final energy consumption, mainly reliant on gasoline and diesel oil, making up 38% of the total. Concurrently, natural gas represented 99% of the power generation source in the same year. Transitioning from oil and gas to hydrogen for transport and electricity generation purposes could substantially curtail oil and gas consumption, in addition to CO_2 emissions, rendering hydrogen a sustainable energy alternative for Brunei Darussalam. Nevertheless, a significant impediment pertains to the high supply cost of hydrogen. This study seeks to delineate the forecasted hydrogen demand in Brunei Darussalam up to the year 2040, with a focus on the energy-intensive road transport and power generation sectors, presently devoid of hydrogen utilization [52].

The adoption of hydrogen may result in a reduction of oil consumption in the road sector by 12% to 58% by 2040, contingent on the scenario. Similarly, gas usage in the power generation sector under different scenarios could decrease by 1% to 32%, leading to a parallel decline in CO_2 emissions. Moreover, the integration of hydrogen could yield economic advantages by diminishing domestic oil and gas consumption, enabling surplus exportation to other Asian economies. Under the specified scenarios, the anticipated economic benefits range between USD70 million and USD391 million, equivalent to 0.5% and 3.0% of the gross domestic product in 2018 [52].

A prediction of hydrogen demand ranges from 126 ktoe to 714 ktoe under the outlined scenarios. The process of hydrogen production from natural gas through the reforming process warrants carbon capture and storage (CCS) to transition from grey to blue hydrogen. Brunei Darussalam holds substantial potential for hydrogen production, exceeding 2,500 to by 2040, achieved through gas reforming, gasification, and solar/photovoltaic processes [52].

While the current supply cost of hydrogen remains notably higher than prevailing oil and gas prices, it is predicted to decline as the production and transportation scales amplify. With an augmented production scale, production costs are projected to diminish. A lowered supply cost of around USD0.80/m3 at a refueling station of 1,000 Nm3/h is predicted when hydrogen demand exceeds 70,000 m3 per hour. While this cost is substantially higher than existing gasoline and gas prices, the Brunei Darussalam government currently fully subsidizes these prices [52].

In light of the benefits of reduced CO2 emissions and savings in oil and gas consumption, a projected cost of USD0.80/m3 may conceivably gain acceptance among the populace of Brunei in the future. In conclusion, the Ministry of Energy of Brunei Darussalam needs to formulate suitable hydrogen utilization policies, action plans, and a comprehensive roadmap, alongside seeking international assistance as necessary, particularly from economies in the East Asia Summit, such as Japan [52].

Papua New Guinea

Papua New Guinea has a significant renewable energy potential, particularly in hydro and geothermal resources. This can help Papua New Guinea explore hydrogen as a promising energy source for domestic consumption and international trade. Several feasibility studies are underway to assess the viability of such projects, but the economy has not yet developed a strategy or roadmap [53].

4.2 Information gathered from the survey

A questionnaire was given to the economies to answer ten questions addressing some essential topics related to the roadmaps and strategies of the economies. The questionnaire is given in Appendix A. The information gathered from the survey is presented below:

Hong Kong, China

Hong Kong, China aims to diminish impediments and facilitate hydrogen projects by adhering to international regulations and standards, engaging with professional institutions, trade partners, and relevant stakeholders, and taking into account the local environment. In pursuit of this goal, the following codes and guidelines have been devised and are being implemented in ongoing trial projects related to hydrogen fuel technology:

1. *Code of practice for hydrogen fuelled vehicles and maintenance workshops.*
2. *Code of practice for hydrogen filling stations*
3. *Guidance note on quantitative risk assessment study for hydrogen installations in Hong Kong.*

Furthermore, the Government of Hong Kong, China will formulate the approach of hydrogen standard certification suitable to the conditions of Hong Kong, China by 2027. The primary objective of this initiative is to promote the sustained development of environmentally friendly, low-carbon hydrogen endeavors within the region. The Government of Hong Kong, China is presently amending the existing Gas Safety Ordinance to regulate the safe usage of hydrogen as fuel. The objective is to establish a comprehensive legislative framework governing the importation, manufacture, storage, transport, supply, and use of hydrogen intended for use as fuel. Having completed trade consultations in March 2024, and having garnered widespread industry support, the government gazetted the amendment bill in April 2025 for the consideration by the Legislative Council.

Land resources in Hong Kong, China are scarce and access to renewable energy sources may be limited, which curtails its capacity for autonomous production of substantial quantities of hydrogen. This predicament necessitates interregional cooperation to facilitate hydrogen importation. Furthermore, the Government of Hong Kong, China is actively assessing the feasibility of various trial projects using hydrogen as fuel, which include the harnessing of landfill gas to produce hydrogen.

Presently, Hong Kong, China has established an extensive town gas pipeline network spanning 3,600 km, serving over 85% of households and businesses, encompassing all areas of the city. Notably, this pipeline infrastructure is equipped to distribute town gas with a hydrogen composition of approximately 49%, offering a strategic advantage for potential exploration of future hydrogen pipeline transmission.

Ongoing trial projects are presently underway, focusing specifically on hydrogen extraction from the existing network. Successful extraction would facilitate convenient access to hydrogen directly from the town gas network, presenting notable time and resource savings that would otherwise be requisite for constructing a dedicated hydrogen supply network. Moreover, tube trailers, utilized in other hydrogen projects, serve to expedite hydrogen delivery.

The Government established the Inter-departmental Working Group on Using Hydrogen as Fuel (Working Group) in 2022, comprising 14 bureaus and departments. The Working Group's mandate is to eliminate hindrances and facilitate the implementation of local hydrogen applications prior to legislative amendments. The Working Group has been instrumental in devising interim standards for hydrogen applications in Hong Kong, China and has granted agreement-in-principle to 26 projects as of April 2025, encompassing cross-boundary hydrogen transportation, supply facilities, green hydrogen production installations and applications pertaining to transport, construction sites, and remote areas, which are progressively commencing.

The Government of Hong Kong, China has been collaborating with franchised bus companies and other stakeholders to trial hydrogen fuel cell buses and heavy-duty vehicles. Since November 2023, the maiden tri-axle hydrogen-powered double-decker bus, alongside the inaugural hydrogen filling station, has been engaged in trial operations. Furthermore, the Government is using three hydrogen fuel cell street-washing vehicles in the first half of 2025.

Beyond these applications, the Government of Hong Kong, China has initiated exploration into the feasibility of decentralized electricity supply using hydrogen to supplant traditional diesel generators for powering offices and machinery at remote construction sites lacking adequate electricity supply, including large-scale construction sites in burgeoning development areas.

The Government of Hong Kong, China is also providing financial support through a range of funding schemes, including the Environment and Conservation Fund, Green Tech Fund, and the New Energy Transport Fund, to promote the broader application of hydrogen energy. This initiative aligns with the objective of achieving carbon neutrality.

Comprehensive publicity and educational campaigns are underway to heighten public and youth awareness of hydrogen energy. Collaboration with the Vocational Training Council (VTC) is being pursued to craft a comprehensive curriculum and deliver practical training to enhance the expertise of hydrogen fuel industry practitioners.

Furthermore, a Memorandum of Cooperation was signed with the State Administration for Market Regulation of the People's Republic of China for establishing a platform to accelerate the hydrogen development through collaborative alignment with domestic and international hydrogen standards, and formulation of a green hydrogen certification framework. Efforts are also made to collaborate with General Administration of Customs of the People's Republic of China in establishing a Green Corridor for the efficient conveyance of hydrogen and hydrogen samples across the border.

New Zealand

The government is committed to publishing an updated Hydrogen Roadmap by the conclusion of 2024. This updated roadmap will delineate the government's planned initiatives aimed at facilitating hydrogen investment in New Zealand and may address specific areas highlighted in the APEC Survey presented in this report.

The government aims to incentivize private investment in the hydrogen sector and is actively engaged in identifying and understanding the regulatory barriers to its adoption in New Zealand. Additionally, efforts are being made to establish a more efficient consenting process for hydrogen products. To address regulatory hurdles, safety regulations for electricity and gas are undergoing review to ensure their applicability for new hydrogen uses. There is also a focus on harmonizing New Zealand's standards with international best practices.

Furthermore, the government of New Zealand is diligently working towards fortifying energy security by diversifying fuels and enabling the utilization of hydrogen as a replacement for natural gas. Hydrogen is presently undergoing testing and demonstration as a low-emissions substitute in heavy industry, heavy and specialty transport, green fuel production, and power generation.

With regard to the potential export of hydrogen from New Zealand, several private sector initiatives are underway to explore large-scale hydrogen export opportunities. The government welcomes foreign investment and expertise in new renewable energy generation, particularly in projects that will significantly augment electricity demand in the New Zealand system, including hydrogen export projects.

The government is also contemplating the establishment of an industry-led leadership group to collaborate with the private sector, support the development of the hydrogen sector, and leverage international relationships to signal New Zealand's openness to hydrogen investment and export.

With regards to cooperation and knowledge-sharing on hydrogen-related issues, New Zealand has entered into various agreements with partners in the Asia-Pacific and other regions. These agreements encompass a Memorandum of Cooperation on Hydrogen with Japan, a partnership on hydrogen cooperation with Singapore, and a research collaboration on green hydrogen with Germany.

Chinese Taipei

The primary objective of hydrogen development in Chinese Taipei is the reduction of carbon emissions. This initiative focuses on three key aspects: hydrogen application (power generation, industry, and transportation), hydrogen supply, and infrastructure. Both public and private sectors will conduct demonstration and verification projects to ensure the direction of hydrogen application and options for related facilities. Chinese Taipei will focus on creating and revising domestic standards for hydrogen energy, developing low-carbon hydrogen tracking systems and technology, and establishing a hydrogen industry chain to accelerate the development of hydrogen energy.

Hydrogen energy development in Chinese Taipei is currently in its initial stages. Investments have been made in key technologies for domestic low-carbon hydrogen production, including water electrolysis through renewable energy and Steam Methane Reforming (SMR) with CCS (blue hydrogen) to establish domestic production capacity. In the presence of excess renewable energy, Chinese Taipei will expand domestic production capacity and reduce production costs to expedite market application.

Addressing fire protection and installation safety is crucial for hydrogen application, transportation, and storage facilities. Future planning should encompass considerations of land use and environmental protection regulations to safeguard the environment and ecology, ensuring appropriate land use and compliance with safety and fire protection measures.

The hydrogen application in Chinese Taipei will be tailored to local conditions, encompassing both the electricity sector and non-electricity sector, including industry and transportation. Given that greenhouse gas emissions are notably higher in power generation and industry sectors, these areas will assume priority in efforts to deploy carbon reduction initiatives. Furthermore, emphasis will be placed on developing long-distance or heavy-duty hydrogen vehicles, considering their specific attributes.

Within the context of Chinese Taipei's industrial landscape, carbon reduction emerges as a primary objective in advancing hydrogen technologies. In the short term, the focus will primarily involve hydrogen/ammonia co-firing for power generation and hydrogen blending for industrial applications, with the goal of advancing advanced combustion control technology and introducing innovative decarbonization processes utilizing hydrogen. Over the medium to long term, the intention is to employ pure hydrogen and ammonia in power and industrial applications.

Given the constraints of natural and land resources in Chinese Taipei, collaborative efforts with experienced entities are underway to conduct a feasibility study assessing the potential import of hydrogen or hydrogen carriers (liquefied ammonia or MCH). The evaluation process and subsequent construction schedule will be adjusted to align with international technology developments and the progress of land reclamation at the designated site.

To foster the advancement of hydrogen technology, the Ministry of Economic Affairs (MOEA) has established various initiatives and subsidies. These include the "Industrial Energy Technology Program" and "Subsidies for Installation of Stationary Fuel Cell Power Generation System," designed to incentivize companies in the development of high-efficiency hydrogen production systems, low-carbon manufacturing processes, hydrogen co-firing for power generation, and fuel cells for distributed generation. These endeavors are also conducive to the development of industrial clusters.

Additionally, MOEA provides subsidies and incentives such as the Chinese Taipei Industry Innovation Platform Program (TIIP), Conventional Industry Technology Development (CITD) from the Industrial Development Administration, and the A+ Industrial Innovative R&D Program from the Department of Industrial Technology. These programs are tailored to spur hydrogen development in Chinese Taipei.

In the drive to promote clean energy usage, public sector resources are leveraged to facilitate hydrogen supply and application. SOE are also actively augmenting hydrogen application through their technological expertise and experiences. To accommodate the evolving work model of hydrogen application, integrated measures, including policies, social dialogue, education, and training, are being implemented to facilitate employment transformation and facilitate companies' entry into the new energy industry.

Concerted efforts are also being made to disseminate comprehensive information to the public and expand avenues for acquiring knowledge concerning hydrogen technology and safety issues. The objective is to deepen public understanding and foster a consensus on the promotion of hydrogen energy.

With regards to international collaboration and technology transfer, Chinese Taipei has inked memorandums of understanding (MoUs) on H2/NH3 co-firing technologies with Germany and Japan. Furthermore, ongoing discussions and evaluations with major hydrogen-exporting economies such as Australia and Canada aim to integrate Chinese Taipei into the international hydrogen supply chain. Meanwhile, Chinese Taipei, in partnership with a major company, is conducting an evaluation on the construction of a domestic liquefied hydrogen receiving terminal as part of the "Hydrogen Energy Supply Chain (HESC) Project.

Japan

In the "Basic Hydrogen Strategy," Japan intends to explore the standardization of regulations to establish a hydrogen supply chain. Notably, there is an emphasis on the importance of instituting international standards and certification schemes for transactions based on carbon intensity within the framework of the G7 and other pertinent organizations.

Additionally, the plan involves creating an environment conducive to the development of a large-scale hydrogen supply chain, including the streamlining and optimization of necessary safety regulations for the extensive use of hydrogen and other resources. Special provisions are envisioned for regulations within the Law for the Promotion of a Hydrogen Society, scheduled for enactment in March 2024.

The strategic plan outlines specific targets and costs for hydrogen supply:
Hydrogen targets:

- 2030: 300 Mt/year (maximum)
- 2040: approximately 1,200 Mt/year
- 2050: roughly 2,000 Mt/year

Hydrogen supply cost (CIF* cost) *Cost, insurance and freight

- 2030: JPY30/Nm3 (approximately JPY334/kg)
- 2050: JPY20/Nm3 (about JPY222/kg)

Furthermore, the Basic Strategy for Hydrogen underscores transportation and storage technologies, including efficient hydrogen liquefiers, hydrogen storage alloys, hydrogen carrier cost reduction, and ammonia cracking technologies, as pivotal innovative technologies needed in the sphere of transportation and storage.

Moreover, the strategic plan details the utilization of hydrogen in the chemical industry to produce ammonia and other chemicals, with the aim of cultivating a foremost market for plastics and other products derived from CO_2. The plan also prioritizes the reduction of emissions from existing naphtha-cracking furnaces, substantial emitters of CO_2, through support for the establishment of combustion technology to convert fuel from off-gas to ammonia.

Industries requiring heat, such as mining, cement, steel, and glass production, are integral in this context. Addressing this, the plan entails the development of hydrogen and ammonia burners and boilers to meet the heat demand based on varying operating temperatures and processes within each industry. Concurrently, technology development and demonstration of boilers will be undertaken. Additionally, in regions where a certain volume of hydrogen supply is anticipated, the introduction and proliferation of hydrogen gas turbines will be encouraged. In areas where access to a large-scale hydrogen supply chain is challenging, the promotion of water electrolysis in factories is advocated. The induction and utilization of water electrolysis and demand equipment like boilers in inland areas are also encouraged in this regard.

Notably, the plan includes a demonstration of hydrogen-reduced ironmaking (COURSE50) using a significant blast furnace within the iron and steel industry, with the objective of commercializing the technology by 2030.

The Green Innovation Fund is currently providing support for the technological advancement of ships propelled by hydrogen and ammonia. In the case of hydrogen-fueled ships, the Fund is actively engaged in the development of hydrogen-fueled engines, fuel tanks, and fuel supply systems, with the objective of initiating demonstration operations by 2027 and commercial operations by 2030 or beyond.

The fund is also fostering the development of demonstration aircraft by the 2030s, along with the advancement and demonstration of Sustainable Aviation Fuel (SAF) production technology. The aim is to substitute 10% of Japan's aviation fuel with SAF by 2030. The government is poised to establish legal targets for the use and distribution of SAF to facilitate the realization of this objective.

Regarding hydrogen power generation, the Green Innovation Fund initiative involves the development of a combustor for hydrogen co-firing and the implementation of a specifically designed hydrogen combustor in a thermal power plant to verify combustion stability. Additionally, the fund is supporting the technological development of hydrogen supply for the load-following operation of power plants.

Japan has established a JPY2 trillion Green Innovation Fund aimed at supporting technology development in both universities and the industry over a 10-year period. This initiative encompasses:

a) Supporting universities and industries in the development of new technological concepts.
b) Providing assurance to investors regarding the safety of their investments.
c) Allocating grants for the development of new projects.
d) Supporting the industry by sponsoring the procurement of new equipment.

In sectors such as iron, chemicals, and power generation, where alternative technologies are limited and conversion is challenging, assistance will be focused on the price differential between existing raw fuels and low-carbon hydrogen. Pilot projects will be initiated in this regard.

To facilitate the stable and cost-effective supply of substantial quantities of low-carbon hydrogen, Japan is committed to establishing an environment conducive to uncovering and accumulating latent demand in the surrounding regions.

Japan has been hosting the Hydrogen Ministerial Conference since 2018 as a platform to advocate for the global use of hydrogen and to foster collaboration among participating economies. Workshops are conducted to cultivate talent by presenting Japan's energy policies and systems and engaging in discussions with companies possessing energy-related technologies.

Japan has entered into Memorandums of Cooperation (MOC) or partnerships concerning energy transition, including hydrogen, with 11 APEC economies: Australia (partnership); Brunei Darussalam; Canada; Chile; Malaysia (Perotonus); New Zealand; Thailand; Thailand-Singapore; Thailand-Singapore-Indonesia; and the US.

Finally, it is important to note that Japan has refrained from setting specific quantitative targets for hydrogen exports and imports.

Chile

In June of this year, the hydrogen facility safety regulation was implemented, drawing primarily from the NFPA 2 standard. This regulation oversees the production, storage, conditioning, packaging, and consumption of gaseous hydrogen, but does not cover aspects such as hydrogen refueling stations and transportation and distribution networks for hydrogen. The regulation also excludes vehicles (land, air, and sea) that operate or transport hydrogen, with these matters falling under the jurisdiction of other regulatory bodies. There are plans to update the regulation in the future to include liquid hydrogen. Chile is expected to implement a certification strategy for hydrogen, ammonia, and e-fuels next year.

In February 2021, the Energy Efficiency Law 21.305 made amendments to Decree Law 2.224 of 1978 and DFL 1 of 1979, both falling under the Ministry of Mining, in order to include hydrogen as an energy source within the Ministry of Energy's competencies and thus regulate it as a fuel. To develop the regulation of the entire hydrogen value chain, a diagnostic study is being conducted to form the basis for an interministerial regulatory work plan. This plan, currently undergoing public consultation, involves commitments between 2024 and 2030 by the ministries of mining, transport, energy, and health. It focuses on constructing sectoral regulations for the hydrogen value chain and ensuring regulatory coherence among the involved services. It also incorporates mechanisms for continuous monitoring and evaluation to support adjustments if necessary.

As for the authorization of hydrogen projects, those designed and constructed under Decree No. 13, the installation safety regulation, fall within scope. However, if a project is based on technology not covered by the current standard or an international standard, it may be submitted to the Superintendence of Electricity and Fuels under a special hydrogen project request for review and authorization. The Special Projects Guide was developed jointly with the Ministry of Energy to provide guidance for individuals and companies interested in implementing hydrogen projects, particularly with regard to production, conditioning, transportation, distribution, storage, or consumption of hydrogen as fuel. It aims to facilitate the processing of authorization requests by assisting in the preparation of the necessary documentation.

In accordance with the Chile's Hydrogen Strategy, the goals by 2025 include the development of 5 GW of electrolysis capacity and a production target of 200 kton/year, with an aim to achieve 25 GW of electrolysis capacity by 2030.

The "Explorador de Hidrógeno Verde" initiative, led by the Chilean Ministry of Energy, has projected a levelized cost of hydrogen ranging from USD5 to USD2.3/kg-H2 by 2030 and USD4.2 to USD1.9/kg-H2 by 2040.

Long-Term Energy Planning forecasts a total demand of 72.8 million Tcal of hydrogen for the medium scenario by 2050, with the levelized cost of hydrogen projected to be approximately USD3.3 to USD1.5/kg-H2 by 2050.

Information regarding the storage methods for hydrogen, such as compressed gas or cryogenic storage, is stipulated in the hydrogen facility safety standard, DS 13/2022. Furthermore, details regarding the transport of hydrogen by trucks are delineated in Decree 298 issued by the Ministry of Transport.

A recently funded chemical industry project is set to produce green hydrogen for the use of ammonia as a feedstock for green fertilizer, scheduled to commence production by 2027. Feasibility studies for projects related to ammonia production for the explosives industry are also underway.

A private copper company has established a roadmap for the development of a green hydrogen valley in the central region of Chile, considering various applications for green hydrogen, including its use in mining trucks.

Chile has announced plans to introduce the first hydrogen-powered bus for public transport in Santiago by the first semester of 2025. Additionally, there are proposals for deploying heavy trucks and passenger cars for cargo transportation. Furthermore, a private, hybrid hydrogen-electric bus and three hydrogen cars are operational in the metropolitan area. Anticipated for the second semester of 2024 in Antofagasta city, a Chilean company has spearheaded the deployment of the first hydrogen train.

Regarding maritime transportation, feasibility studies for green corridors have been initiated for the exportation of green copper and the importation of sulfuric acid. Pre-feasibility studies for domestic routes related to the salmon industry are also being conducted. Furthermore, the Chilean Navy, in collaboration with the Ministry of Energy, will develop a Continuous Shipbuilding Plan addressing various topics, including the development of a ship equipped with a sustainable fuel engine.

In April, the official launch of the Sustainable Aviation Fuels Roadmap (SAF) 2050 took place. This initiative is the culmination of collaborative efforts between public and private entities, with a primary objective of enhancing sustainability in the aviation industry. The roadmap, formulated based on the experiences and challenges articulated by stakeholders in the aviation, transport, and energy sectors during the SAF Roundtable, outlines the steps towards the deployment of clean fuels in Chile, with an overarching ambition to achieve 50% usage by 2050.

A Chilean company, Gasvalpo, operating under the brand Energas, has embarked on a pioneering endeavor to produce and introduce Green Hydrogen into its Natural Gas distribution networks in Coquimbo and La Serena. This initiative aims to substantially lower CO2 emissions, thus contributing to the global effort to combat climate change, benefitting more than 2,000 residences and commercial establishments. The oversight of the entire project is entrusted to the Superintendency of Electricity and Fuels and the esteemed Universidad de La Serena.

The Green Hydrogen Strategy of Chile does not encompass hydrogen importation and envisions the export of green ammonia from the hubs in Magallanes and Antofagasta by 2030. Chile has entered into various agreements with ports in Europe and Asia to facilitate the development of requisite infrastructure. Moreover, the Green Hydrogen Strategy forecasts the potential market value for Chilean green hydrogen and ammonia exports to reach BUSD 11 by 2040 and BUSD 19 by 2050.

Chile is diligently pursuing numerous programs to foster technological development and innovation within the local ecosystem. These initiatives involve formulating roadmaps and guidelines for research and development activities associated with the green hydrogen value chain, establishing specialized Green Hydrogen Technological Development Centers like the Magallanes Technological Development Centre and the Technological Development Centre for the Maritime Industry, and providing financial support for scientific and technological applied research projects with significant economic and/or social ramifications, with particular emphasis on green hydrogen.

Chile has announced the impending launch of a financial facility by the conclusion of 2024, allocating over USD1 billion to support projects that have reached the final investment decision stage. The implementation of projects within the local industry through co-financing of pilot initiatives related to green hydrogen and its derivatives, as well as public transportation endeavors, is underway. Moreover, Chile is committed to promoting domestic consumption of green hydrogen by fostering H2V self-production or consumption projects and potentially aggregate demand projects, thereby stimulating local production.

Chile is set to launch Technological Programs aimed at reinforcing projects that support local demand and manufacturing capabilities. A total of CLP17,500 million will be allocated, allowing up to CLP3,500 million per project through two rounds of proposals.

The Green Hydrogen Action Plan encompasses several measures to encourage investment in Green Hydrogen in Chile:

- Allocation of state lands for the development of the green hydrogen and its derivatives industry
- Enhancement of CORFO's (Chilean Production Development Corporation) promotion instruments with a focus on green hydrogen
- Stimulation of the domestic demand for hydrogen through an Emissions Trading System (ETS)
- Establishment of a fund for tax credits related to the first category tax with a "green" dimension
- Implementation of a development rate for investment that facilitates a reduction in first category taxes for investments boosting business productivity
- Tax incentive for Research and Development, strengthening Law 20.241
- Update CORFO's "Green Credit" instrument for banking and non-banking financial intermediaries
- Establishment of a financing facility for green hydrogen projects and its value chain
- Provision of financial support and advisory services for projects related to the production and/or consumption of green hydrogen and derivatives
- Acceleration of the implementation of the initial industrial projects of green hydrogen and derivatives through financing rounds.

Furthermore, Chile is taking proactive steps to advance the use of Green Hydrogen as a substitute for fossil fuel consumption. The initiatives include various strategic measures:

1. Facilitating technological advancements in the industry through the "Impulsa Technological Transition" (CORFO) program.
2. Supporting the green hydrogen industry by launching Technology Programs to stimulate demand and promote manufacturing development. It is projected that the projects initiated under these programs could potentially escalate the demand for hydrogen in Chile by up to 1,000 tons per year, with the potential to reach 45,000 tons per year through the replication of developed technologies.
3. Identifying companies offering services related to the value chain of green hydrogen and its derivatives and ensuring accessibility to this information.
4. Encouraging the establishment of electrolyzer factories within Chile.

In addition, the successful deployment and operation of the green hydrogen industry and its value chain necessitate competent individuals capable of applying the required knowledge across various facets of the production process. To address this, the primary Green Action plan encompasses the following key areas of focus:

1. Sector-specific development of the Technical Professional Qualifications Framework (TPQF) and curriculum proposal, offering three distinct profiles: Hydrogen plant maintainer, Hydrogen plant operator, and Hydrogen plant supervisor.
2. Cultivating operational skills for technicians in green hydrogen energy through the execution of training programs aimed at enhancing competitiveness in green hydrogen and its derivatives.
3. Providing opportunities for industrial workers to participate in international internships to foster competitiveness.
4. Implementation of the "Train the Trainers" program aimed at enhancing the instructional capabilities of green hydrogen industry trainers.
5. Introduction of a practical teaching module into technical professional high schools in various regions of Chile.

Chile has actively fostered cooperation and knowledge exchange through the establishment of agreements, memorandums of understanding (MOUs), and project contracts with various international economies. The following is a comprehensive list of these collaborative initiatives:

1. On 15 February 2021, Chile signed a Memorandum of Understanding with the Ministry of Commerce and Industry of Singapore to promote bilateral and multilateral collaboration in the development of low-carbon hydrogen.
2. Chile and the Port of Rotterdam in the Netherlands entered into a Memorandum of Understanding on 23 March 2021, to facilitate the establishment of an international hydrogen supply chain from Chile to Rotterdam.
3. A Joint Declaration was formalized with the Department for Business, Energy, and Industrial Strategy (BEIS) on 24 June 2021.
4. On 9 November 2021, an MOU was signed between the Ministry of Energy of Chile and the Ministry of Trade, Industry and Energy of Korea, focusing on Low Carbon Hydrogen Collaboration.
5. Chile and Germany collaborated on a Joint Declaration, signed on 29 June 2002, to establish a ministerial task force on Green H2 within the Energy Partnership.
6. On 30 June 2021, a Joint Declaration with the Ministry of Ecological Transition of France emphasized the significance of low-carbon hydrogen as an essential energy vector for climate neutrality.
7. A Joint Declaration with the Ministry of Economics and Climate Policy of the Netherlands was signed on 1 July 2021.
8. An MOU was established on 4 November 2021, between the Ministry of Energy of Chile and the Ports of Antwerp and Zeebrugge in Belgium

to progress in establishing an international hydrogen supply chain from Chile to Antwerp and Zeebrugge.

9. An MOU was signed on 24 August 2022, between the Ministry of Energy of Chile and the Ministry of Economy and Innovation of the City of Hamburg and the Port of Hamburg to explore the creation of corridors for the transportation of green hydrogen or its derivatives.
10. Chile and Japan formalized a Memorandum of Cooperation on Energy Transition on 28 April 2022, between the Ministry of Energy of the Republic of Chile and the Ministry of Economy, Trade and Industry (METI) of Japan.
11. On 1 August 2022, the Ministry of Economy, Finance and Recovery of France and the Ministry of Energy of Chile signed a Letter of Cooperation for the engagement of an International Technical Expert (ETI) in the field of Transport based on New Fuels.
12. An extension agreement of the Memorandum of Understanding between the Ministry of Energy of Chile and the Port of Rotterdam was signed on 23 March 2023.
13. The Ministry of Energy of Chile and the Ministry of Climate and Energy Policy of the Netherlands formalized a Joint Declaration on 27 March 2023.
14. Chile and the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping signed a Memorandum of Understanding on 23 May 2023.
15. France and Chile signed a Joint Declaration on 9 June 2023, for the establishment of a working group on green and/or low-carbon hydrogen.
16. A Joint Declaration of Intent for collaboration and formal initiation of the Team Europe project for the Development of Renewable Hydrogen in Chile was signed on 14 June 2023.
17. On 17 July 2023, a Joint Declaration of Intent was established between the Ministry of Energy of the Republic of Chile and the European Investment Bank, focusing on a just energy transition in Chile with a special emphasis on hydrogen and other green technologies.
18. Chile and the Japan Bank for International Cooperation formalized a Memorandum of Understanding of Strategic Cooperation on 4 August 2023.
19. The Ministry of Energy of the Republic of Chile and the Department of Energy of the United States signed a Memorandum of Cooperation on 16 August 2023, for collaboration in the energy transition and the development of the energy sector.
20. An extension of the Memorandum of Understanding between the Ministry of Energy of the Republic of Chile and the Port of Antwerp - Bruges was signed on 4 November 2023.

Australia

Australia responded to the ten questions with a brief paragraph, stating that they have developed the National Hydrogen Roadmap (2017) and the Hydrogen Strategy (2019), which is currently under review. The review paper for that strategy, as well as the hydrogen information resource linking to hydrogen policy around Australia and related policies around the world, are available online:

https://consult.dcceew.gov.au/review-of-the-national-hydrogen-strategy
https://research.csiro.au/hyresource/

5.0 Survey data analysis and discussion

Upon careful examination of the data that was collected, it is evident that certain economies have established comprehensive roadmaps and strategies while others are planning to do so in the near future. This indicates a widespread realization of the significance of hydrogen and its pivotal role in decarbonizing economies. The urgency of addressing the issue of global warming is clear, although it is acknowledged that implementing drastic changes overnight is not feasible. Hence, it is imperative to establish targets within a specific timeframe. This will pave the way for a successful transition to zero emissions, a goal that is anticipated to be achieved by 2050, provided that consistent and precise targets are set and regularly revised to ensure their attainability.

Furthermore, based on the analysis of the gathered information, it is crucial for economies to conduct a thorough examination of the complete hydrogen value chain. This examination should aim to identify the most suitable production methods that align with regulatory standards, enabling economies to attain their goals. Additionally, fostering collaboration with other economies is a pivotal factor to consider. Such collaboration facilitates mutual learning and the swift implementation of hydrogen across various industrial sectors. Notably, the design and manufacturing of hydrogen-related equipment, such as electrolyzers and fuel cells, will play a critical role, given the anticipated surge in demand since hydrogen projects will dramatically in the next five years due to the various projects the economies are planning to implement.

It is evident that low-carbon hydrogen derived from natural gas reforming with carbon capture, usage, and storage plays a crucial role in the development of hydrogen economies. Discrepancies in production methods, technology selections, gas supply, energy requirements, and carbon capture rates result in varying emission estimates, necessitating the exploration of new research avenues. Companies should seek advanced technologies, such as autothermal reforming, that enable the capture of exceptionally high carbon emissions.

Furthermore, the emissions associated with the production and transportation of the fossil fuel source must be factored into the emissions profile of low carbon hydrogen derived from fossil fuels. It is noteworthy that improved technologies have the potential to reduce the estimated lower CO2 emissions limit of hydrogen produced from methane to the upper limit of renewable hydrogen. Meeting the technological demand will require substantial research and development efforts. As delineated in the roadmaps and strategies of numerous economies, the embrace of new technological advancements will entail close collaboration among academia, industry, and both private and governmental institutions.

6.0 Workshop 'Exchange of best practices for the development of green and low-carbon hydrogen roadmaps in the Asia-Pacific region'

This workshop was held in Lima on 11 August 2024. Below you can find a summary of the most important points of each session. Please also find the presentations during the workshop in **Appendix B**.

6.1 APSEC remarks during the opening session

Mr. Steivan Defilla, President Assistant of APEC Sustainable Energy Center (APSEC) briefly presented itself and provided the following recommendations to be regarded at APEC level:

- 19 APEC economies practice some form of trade with "Energy Attribute Certificates" for electricity ("green electricity certificates")
- APEC-wide experience exists with this type of certificate and its trade; APEC "DNA" has a strong focus on the economy and trade.
- Objective: generate finance for the development of clean hydrogen, discharging government budgets of APEC economies
- Prerequisite for trade with clean hydrogen certificates:
- Certification of clean hydrogen in each participating APEC economy
- Harmonization of mechanism for the creation and redemption of certificates
- Certificate trade is independent of physical trade
- Integration with compliance markets: Glasgow COP 26 agreed on global rules facilitating cooperative approaches on compliance markets to achieve climate targets
- Project should be driven by an interested APEC economy

- Measures in individual APEC economies
- “No-regret” measures to be taken anyway in the next 2 years
- “Forward guidance” measures to be taken sometime before 2030
- “Value to wait” measures to be taken after 2030– if at all
- Clean, low-carbon hydrogen currently accounts for only a minor portion of international and APEC hydrogen use.
- As part of the energy transition towards decarbonization, we must promote clean hydrogen, such as the so-called “blue” hydrogen from fossil fuels with CCS and the so-called “green” hydrogen from renewable power generation.
- There are many methods to produce hydrogen with zero- or low-carbon emissions, including the so-called “pink” hydrogen from nuclear power generation and the so-called “turquoise” hydrogen from pyrolysis of natural gas (i.e., methane).
- Now, it may be better to focus on “clean and low-carbon hydrogen.” based on carbon intensity of hydrogen, forgetting their “colors”

6.2 APERC remarks during the opening session

Dr. Irie Kazutomo, President of Asia Pacific Energy Research Centre (APERC) presented the Future of Hydrogen in the APEC Region, and the targets of APEC related to hydrogen.

The following points were highlighted:

- APEC aims to reduce energy intensity by 45 percent by 2035 relative to 2005 levels. APEC also seeks to double the share of modern renewable energy 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 transportation.
- However, most of the hydrogen produced and traded within the APEC region as well as in the world is responsible for high level of CO2 emissions during its life cycle.
- Today, hydrogen is mainly produced from fossil fuels without applying carbon capture and storage (CCS) technology.
- Despite increased attention on clean and low-carbon hydrogen in recent years, its future viability as a clean, low-emissions energy source 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 clean and low-carbon hydrogen market will heavily rely on supportive government policies, including subsidies, which vary widely among APEC economies.

APERC also pointed out the following regarding its efforts on hydrogen:

- Considering great opportunities and serious challenges for hydrogen energy in the APEC region, APERC has been working hard for research and knowledge sharing about hydrogen energy for APEC member economies.
- APEC Symposium on Pursuing Decarbonization of Fossil Fuels (Kobe, Japan: 11-12 October 2023)
- APEC Workshop on Stocktaking Challenges and Opportunities for Energy Transition towards Decarbonization both in Energy Demand and Supply Sides (APEC Energy Transition Workshop)
(Nanjing, China: 20 May 2024)
- APERC Hydrogen Workshop (Kaohsiung, Chinese Taipei: 23 April 2024)
- APERC Hydrogen Report 2023 (May 2024)

The following remarks were mentioned related to APEC Symposium on Pursuing Decarbonization of Fossil Fuels:

- APERC organized APEC Symposium on Pursuing Decarbonization of Fossil Fuels on 11-12 October 2023 in Kobe, Japan.
- One of major topics of the symposium was hydrogen and its deliverable, ammonia, from fossil fuels.
- As for hydrogen, production, transportation, and utilization issues were discussed by experts. Production, generation, and shipping of fuel ammonia were also discussed.
- Kobe was chosen as the venue of the symposium as there are many companies in Kobe City and nearby Takasago City which expand their business into hydrogen markets.
- Participants visited hydrogen-related facilities of Kawasaki Heavy Industries, Kobe Steel, and Mitsubishi Heavy Industries as site visits.

Finally, some key points from the APERC Hydrogen 2023 report were presented:

- APERC started to publish the APERC Hydrogen Report to support as well as EGCFE. The first edition of report series was published online in May 2024.
- 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 new report was referenced in drafts of the "APEC Policy Guidance to Develop and Implement Clean and Low-Carbon Hydrogen Policy Frameworks in the Asia-Pacific."

6.3. Session 1 'Scenarios for Decarbonization projects: Experiences and good practices'

This session was held as a panel discussion and explored the challenges and opportunities presented to developing economies by renewables and clean hydrogen projects as well as its derivatives, emphasizing the need for harmonized regulatory frameworks to stimulate technology development, enhance transparency, and fuel market growth.

The moderator, Mr. Deger Saygin, who is Industry Programme Lead, Clean Energy Finance and Investment Mobilisation at OECD Environment Directorate, invited speakers to respond to the following guiding questions:

• How can projects aiming to shift from fossil fuels to clean energy sources be effectively implemented? (financing, capacity building, policies)

• What are some of the risks that do not allow renewable-energy-based hydrogen projects to reach the finish line? How can these risks be addressed to unleash the power of clean hydrogen for the clean energy transition?

6.3.1 Session 1: Realizing Decarbonization in Yokohama.

Takaaki ITO, Executive Director of the Zero Carbon Society Promotion department of Yokohama City in Japan, presented the following):

- Yokohama city has a population of 3.8 million, 1.8 million of households, an Area of 438km2 and 118 thousand number of offices.
- Total GHG emissions in Yokohama in 2022 was 16.41 million tons, 4.3% decrease compared to the previous year and 24% decrease from the base year (2013).
- Yokohama City signed a collaboration agreement with ENEOS, an energy company (including electricity and hydrogen), to build a hydrogen supply chain (November 2021）
- Both parties are working together to study the development of a hydrogen supply infrastructure, including pipelines, and are challenging the realization of a hydrogen society.
- Yokohama City has signed a collaboration agreement with Tokyo Gas Co., Ltd. to supply biomass resources from its neighboring sewage treatment

centers and waste incineration plants to support the development of decarbonization technologies.

- Decarbonization of the port area (accounting for 40% of Yokohama's CO2 emissions) are critical challenges in the city's decarbonization policy.
- Decarbonizing the port area through public-private partnering. 100% decarbonization of Central Yokohama by 2030 is expected. The Yokohama project can create a model for decarbonizing other big cities.

6.3.2 Session 1: Korea's Hydrogen policy.

Mrs. Sangme Hang secretary general of H2Korea presented the association and its dedication to promoting the hydrogen industry in Korea. The Korean government designated the organization on July 1st, 2020.

H2Korea has 154 Member organizations, including public/private enterprises, research institutes, finance, etc. Some special members include local government, trade representatives, etc.

H2KOREA Launched a Global Hydrogen Industrial Association Alliance. Expanded global partnerships, strengthened private-sector cooperation activities, promoted joint R&D and international standards cooperation, etc.

Korea's Hydrogen Economy development includes the following:

- Lean Hydrogen Certification System Operations Plan: Production Hub Projects, Clean Hydrogen Demand will increase to 800,000 tons by 2030, and the hydrogen utilization rate will increase to 7.1% by 2035.
- Fostering Strategy for MPE (Materials, Parts, and Equipment) in the Hydrogen Industry. The goals are to achieve an 80% localization rate of MPE in 10 strategic fields by 2030 (40% in 2022) and foster 20 global hydrogen MCE companies by 2030 (2 in 2022).
- Measures to Increase the Supply Rate of Hydrogen Electric Vehicles to 300,000 units by 2030.Installation of 660 dispensers in Refueling Stations by 2030.
- Operation Plan for Korea is to increase the Alkaline Water Electrolysis includes Alkaline and PEM water electrolysis. Development of a 10MW-class pressurized water electrolysis system by 2030 and Commercialization of multi-MW-class high durability, low-cost water electrolysis system by 2030.
- Opening a Clean Hydrogen Power Generation Bidding Market. The annual hydrogen power generation targets established in consideration of the 10th Basic Plan for Power Supply and Demand, domestic greenhouse gas reduction targets, and other factors.

- Certification Scheme. Classification into four grades based on emissions up to hydrogen production and fixed support by grade.
- Private Investment Plans in Hydrogen Industry, government policies serve as a priming water source to activate private investment. In response to government hydrogen economy policies, private companies invest a total of USD3.1 billion. Refinery· gas companies announced hydrogen economy visions as part of future new industries. Small and medium-sized companies in the hydrogen sector plan to invest USD880 million by 2030.
- Securing Oversea Clean Hydrogen Supply Chain. Focus on economies in Southeast Asia, the Middle East, and Australia with favorable hydrogen production environments.
- Construction of Ammonia Receiving Terminals. Establish large-scale receiving terminals in three regions: the West Sea, the East Sea, and the South Sea, with a capacity of 1.1 Mt/y by 2027 and 4 Mt/y by 2030.
- Trends of Korea's Hydrogen Economy.
  SK E&S, Construction of a liquefied hydrogen plant (Incheon).
  Hyundai has expanded its production capacity of hydrogen buses to 3,000.
  HD Korea Shipbuilding & Offshore Engineering Order of ammonia-powered ship.
  Hanwha, Success in using Hydrogen in gas turbines.
  Doosan Enerbility,
  Development of hydrogen combustion turbine.

Achievements of Korea's Hydrogen Economy include the increase of hydrogen vehicle use to 34,872 by April 2024. Passenger cars: 34,383 vehicles, Buses: 757 vehicles, Trucks: 20 vehicles. Construct 218 Hydrogen Refueling Stations and about 1063 MW of Fuel Cell Power Generation.

The final statement of the presentation indicated that there is a need for Close Collaboration to Implement a Global Hydrogen economy among APEC economies.

6.3.3 Session 1: Scenarios for Decarbonization projects: Experiences and Good Practices Moderator's presentation.

Mr. Deger Saygin an Industry Programme Lead of OECD (Organization for Economic Co-operation and Development) presented the following:

- The Current use in ammonia fertilizer production and refineries and the Future use in steel, shipping, aviation, trucks, storage.
- The Current Industry produces and consumes 100Mt of hydrogen per year, which is used in ammonia production and refineries. 2% of hydrogen is clean and used currently, 1% green, and 1% blue. The rest, 98%, is grey

hydrogen. 900 Mt of CO_2 emissions per year and upstream methane. They will be 4x-6X increase in hydrogen demand by 2050.

- The conclusion is that green hydrogen is a key factor in decarbonizing the hard-to-abate industry.
- In expected end-use applications, ammonia dominates.
- 46% of all electrolyzer capacity is expected to produce hydrogen for ammonia production in 314 projects worldwide.
- Significant iron & steel activity (7%) and 31 projects worldwide.
- Methanol production, with biogenic methanol as a competing option for shipping supply, 73 projects worldwide.
- E-Sustainable Aviation Fuel (SAF), 52 projects worldwide.
- The remaining output is largely used as hydrogen directly, with various applications including Mobility (10%) and Refining (4%).
- There is limited use for hydrogen in power production (5%) and for grid injection (3%), reflecting that these usually are not considered very competitive uses of hydrogen.
- Final investment decision on projects in emerging markets and developing economies (EMDEs) are in Asia and Middle East.
- Why are still there few projects with final investment decision?
  - Renewable hydrogen is currently more expensive than conventional and low-carbon hydrogen, making it economically unfeasible. For project financing, a predictable cash flow is essential to recover expenses, underscoring the need for reliable off-takers.
  - Despite ambitious high-level policies, the bankability of renewable hydrogen projects remains low due to uncertain demand and a limited number of potential off-takers. Additionally, generous subsidies in various economies distort the market, making projects in emerging markets and developing economies (EMDEs) less attractive.
  - The high cost of financing in EMDEs further complicates the situation. These projects require substantial investment, often amounting to several billion dollars each, and due to the complex nature of hydrogen projects, there is currently no established track record of bankable transactions. This includes challenges related to electrolyzers and systems integration, as there is no standardized plug-and-play solution available.
  - Furthermore, an Engineering, Procurement, and Construction (EPC) wrap is not yet feasible due to technical and risk complexities and a lack of credible technology suppliers. Many projects are contingent upon the completion of feasibility studies, and the expectation of rapid cost reductions makes investors hesitant,

contributing to the first-mover dilemma. Lastly, the lack of enabling infrastructure poses an additional challenge for the successful implementation of these projects.

- Identified key risks are linked with the availability of risk mitigation mechanisms or tools.
- Asset risk profile comparison of hydrogen with other sectors.
- Examples of key measures to improve the enabling conditions for clean hydrogen projects include standards and certification, access to infrastructure, green mandates, partnerships, contractual strategy in the construction phase, and technical assistance.
- Selection of de-risking instruments for clean hydrogen.
- Forthcoming report (ended in 2024): Leveraging de-risking instruments & enhanced international coordination to catalyze investments.
  The report builds on OECD publications in 2022-2024 to:
  - Provide a better understanding on the financial risk mitigation instruments to crowd in private capital for clean hydrogen projects in EMDEs.
  - Emphasize the importance of enhancing international coordination to accelerate investment for clean hydrogen development.
  - Provide learnings from case studies of clean hydrogen projects and instruments from OECD members & non-OECD members, such as:
    - De-risking instruments can have a better leverage than direct financing instruments to mobilize private capital.
    - Strategic use of de-risking instruments can reduce the total project cost, therefore limiting the public finance support to make projects bankable. This effect is particularly important in EMDEs.
    - Offtake guarantees, political risk and foreign investment insurance, technology guarantees, and partial credit guarantees are particularly promising for clean hydrogen projects in EMDEs.
    - Instruments should not be deployed in silos but should be integrated in risk mitigation packages.
- Map of Clean Hydrogen Case Studies OECD (2022-2024)
  21 case studies on clean hydrogen projects, covering >35 GW electrolyzer capacity in 20 economies as well as 11 case studies on economic, derisking and financing instruments.
- OECD - Clean Hydrogen Project Case Studies (2022-2024).
- OECD - Clean Hydrogen Financing Instruments Case Studies (2024)

6.4 Session 2: Best practices for the development of hydrogen roadmaps

During the session, Mr. Manuel Heredia, Senior Researcher, Asia Pacific Energy Research Centre (APERC), commented about the progress made by APEC economies regarding their status of their own Hydrogen Strategies and Roadmaps. Afterwards, he gave the floor to each representative from the participant economies.

6.4.1 **Australia's statement**.

An official statement from Australia, regarding their Hydrogen Strategy was presented:

"I am pleased to submit the following statement on the development of Australia's Hydrogen Strategy, composed by our colleagues who are responsible for the strategy in the Department of Climate Change, Energy, the Environment and Water (DCCEEW):

Australia was among the first economies in the world to publish a Hydrogen Strategy in 2019. Consistent with an adaptive approach to hydrogen industry development, in early 2023 Australia committed to undertake a review of its Strategy to ensure it positions Australia on a path to be a global hydrogen leader by 2030 on both an export basis and for the decarbonization of Australian industries.

The updated Strategy will take account of developments in technologies, markets and the global policy landscape since Australia's inaugural strategy was published. Over the past 5 years, Australia's governments have focused efforts on the early foundations for industry growth. The updated Strategy will move beyond early industry activation measures, including through the significant new production incentives announced by the Australian Government in May 2024 that will drive economies of scale and build experience.

Australia's current Hydrogen Strategy and information about our Strategy review is available on the DCCEEW website."

It is particularly interesting to note that being Australia one of the first APEC economies with a Hydrogen Strategy, they continue to advance their efforts to focus on their hydrogen industry development by incentivizing the adoption of clean energy sources.

6.4.2 Session 2: Research Report containing Best Practice Data Repository and Survey Results.

Dr. Antonios Antoniou, a researcher for APEC and the MINEM (Ministry of Energy and Mining of Peru) presented the following summary of the research work named ‘Exchange of best practices for the development of green and low carbon hydrogen roadmaps in the Asia-Pacific region’.

- Summary

He mentioned the scope of the workshop, which is to serve as a platform for collaboration and exchange of experiences among APEC economies by discussing the best practices for developing Hydrogen Roadmaps and other related guidelines and regulations. He noted that the conclusions and the outcome of this workshop will become valuable input for the final report of the research project. Also mentioned that the objective of this report is to provide information for the development of the hydrogen economy in the APEC region. He specified that the importance of this report lies in the fact that is the first of its kind to analyze in detail the existing information on hydrogen development, roadmaps, and strategies in the Asia-Pacific Economic Cooperation (APEC) collect data from the economies through a questionnaire, analyze the data, and derive best practice recommendations for the economies. Conclusions are drawn and presented at the very end of this report, hoping that will be helpful for the APEC economies in order to accelerate the hydrogen economy and mitigate environmental pollution.

- Climate change reality

He indicated that many pieces of evidence confirm that the planet is warming at an unprecedented rate that has not been seen in the last 10,000 years, and human activity is the principal cause. The contemporary warming trajectory is distinct due to its attribution to human activities since the mid-1800s and its unprecedented pace not observed over recent millennia. It is indisputable that human activities have generated atmospheric gases, increasing the Sun's energy retention within the Earth's system. This surplus energy has engendered the warming of the atmosphere, ocean, and land, consequently precipitating comprehensive and rapid alterations within the atmosphere, ocean, cryosphere, and biosphere. Earth-orbiting satellites and advanced technologies have facilitated the comprehensive collection of diverse data concerning our planet's climate on a global scale. These extensive datasets, accumulated over an extended period, provide compelling evidence of the evolving climate patterns.

In the mid-19th century, scientists elucidated the heat-trapping properties of carbon dioxide and other gases. Numerous scientific instruments utilized by NASA for climate study are designed to analyze the impact of these gases on the transmission of infrared radiation within the atmosphere. The observed effects of heightened levels of these gases leave no doubt that the increasing concentrations of greenhouse gases induce warming of the Earth’s surface.

- The importance of hydrogen in mitigating climate change

Mitigation is defined as a human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Mitigation, together with adaptation to climate change, contributes to the objective expressed in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) [4]. Mitigating climate change entails the reduction of heat-trapping greenhouse gases released into the atmosphere. This can be accomplished by minimizing the sources of these gases, such as the combustion of fossil fuels for electricity, heat, or transportation, and by bolstering the “sinks” that amass and store these gases, such as the oceans, forests, and soil. The objective of mitigation is to prevent substantial human intervention in Earth's climate, stabilize greenhouse gas levels within a timeframe conducive to natural ecosystem adaptation to climate change, ensure the preservation of food production, and facilitate sustainable economic development.

- Existing Roadmaps and Strategies of the 21 APEC Economies.

Upon careful examination of the data that was collected, it is evident that certain economies have established comprehensive roadmaps and strategies while others are planning to do so shortly. This indicates a widespread realization of the significance of hydrogen and its pivotal role in decarbonizing economies. The urgency of addressing the issue of global warming is apparent, although it is acknowledged that implementing drastic changes overnight is not feasible. Hence, it is imperative to establish targets within a specific timeframe. This will pave the way for a successful transition to zero emissions, a goal anticipated by 2050, provided that consistent and precise targets are set and regularly revised to ensure their attainability. Furthermore, based on the analysis of the gathered information, economies must conduct a thorough examination of the complete hydrogen value chain. This examination should identify the most suitable production methods that align with regulatory standards, enabling economies to attain their goals. Additionally, fostering collaboration with other economies is a pivotal factor to consider. Such collaboration facilitates mutual learning and the swift implementation of hydrogen across various industrial sectors. Notably, the design and manufacturing of hydrogen-related equipment, such as electrolyzers and fuel cells, will play a critical role, given the anticipated surge in demand since hydrogen projects will increase dramatically in the next five years due to the various projects the economies are planning to implement.

- Recommendations based on best practices to develop roadmaps and strategies.

Implementing the clean and low-carbon hydrogen policy framework is crucial for developing hydrogen project and broad use. The following are some guiding principles that can help the economies to develop and implement strategies and roadmaps: 1. Utilize local resources and foster cross-border collaboration. Utilizing local strengths is a crucial initial step in policy design, which should be complemented by cross-border cooperation and trade to unlock efficiency gains. 2. Establishing certainty is crucial for driving down costs and attracting investment. Economies must set clear targets and make firm commitments to minimize policy risks and market uncertainty. 3. Offer explicit support for hydrogen across the entire value chain. Specific support for hydrogen is needed in production, midstream infrastructure, and end-use sectors such as industry and transport to catalyze and expand new markets. 4. Take both societal value into account. Societal value should be considered in policy decisions. Well-designed hydrogen policies can positively contribute to several sustainable Development Goals. 5. Implementing standardized certification programs and comprehensive certification systems is crucial for advancing the hydrogen economy and facilitating transnational hydrogen trade. Support the implementation of effective carbon pricing. It is important to establish strong regional carbon pricing mechanisms by integrating existing schemes and collaborating with specific support for hydrogen to drive efficient and effective adoption in the long term while also addressing carbon leakage.

6.4.3 Session 2: Thailand Hydrogen Roadmap.

Dr. Wongkot Wongsapai of Chiang Mai University presented the following factors driving the use of hydrogen:

- Thailand needs to find an energy source reliable clean to reduce GHG emission (emit around 372 MtCO2-e in 2019) while maintaining ability to response to energy demand.
- Hydrogen as a clean energy source is highlighted both on the global stage and within the Framework of National Energy Plan.
- Promoting the use of Hydrogen in Energy sector aligns with the Global trends, helping to achieve climate goals while ensuring energy stability.
- The Development of Commercial Hydrogen.
- Strategic plan: Hydrogen utilization in the Energy sector 2023 – 2050.
- Short-term strategic plan: Hydrogen utilization in the Energy sector 2023 –2030.
- Hydrogen Market in Energy Sector.
- Thailand Hydrogen roadmap.
- Driving Factor for Power Generation.

- Driving Factor for Industrial Sector.
- Driving Factor for Transport Sector.

6.5 Session 3: The Renewables and the potential for clean hydrogen in the hard-to-abate industries, transportation and power generation. Hydrogen certification and the importance of moving toward mutual recognition.

This session discussed the rise of clean hydrogen as a feasible substitute for traditional hydrogen production methods, which has opened up fresh possibilities for incorporating renewable energy sources into the energy mix. Session 3 also emphasized the potential of a hydrogen pathway to reduce greenhouse gas emissions and combat climate change by decarbonizing transportation, industry, and power generation sectors.

The moderator, Mr. Steivan Defilla, President Assistant of APEC Sustainable Energy Center (APSEC), invited speakers to respond to the following guiding questions:

• What is the pivotal role for the APEC Region to boost renewable electricity market growth?

• How can hydrogen broaden the reach of renewable solutions?

• How can hydrogen's potential revolutionize various sectors, from transportation to industrial processes? Cannot be overstated.

Mr. Laurent ANTONI Executive Director of IPHE (International Partnership for Hydrogen and Fuel Cells in the Economy) presented the following:

- Hydrogen is a critical enabler of the energy transition.
  International Hydrogen Trade Forum Ministerial Meeting 13 May 2024 in Rotterdam presentation indicates that there is a need of >180 Mtpa of hydrogen is required by 2035 for the energy transition to stay on course to decarbonize the planet. 70% of H_2. Demand required by industries which have no or limited alternative decarbonization options.
- Need to Get to a Global Scale – International Trade.
  Linking demand centers to regions with advantageous access to renewable and low-carbon energy resources can save 3.7 trillion US dollars globally by 2050. Through 2050, USD25 can be saved for every dollar investment in H2 trade infrastructure.
  Questions rising are: How can uncertainties be reduced? How do we create trust? Is the "clean" hydrogen I am producing / buying/financing / using"?
- Certification is a crucial instrument for the H2 economy. It builds consumer trust, facilitates demand creation, and enables trade.
  Evidence of the sustainability attributes of hydrogen (carbon footprint in particular) credibly and consistently internationally and support project

bankability by enabling access to compliance markets. Create transparency for consumers and enable consumer choice. Allow consumers to signal the demand for hydrogen based on its sustainability credentials. Create trust between prospective importers and exporters, fostering global, cross-border trade in hydrogen based on its sustainability credentials.

- Risk of Market fragmentation Jurisdictions currently developing their domestic / regional certification schemes. Incompatibility of certification design/ requirements will lead to a lack of fungibility of certificates and then barriers to cross border trade.
  There is an urgent need for Mutual Recognition of Certification Schemes for Renewable and Low-Carbon Hydrogen and its Derivatives.
  IPHE Certification Task Force Hydrogen Certification Inventory involves Information on 20+ certification schemes across 11 IPHE members. Detailed information for six key elements: 1. GHG emissions accounting 2. Criteria for electricity 3. Other environmental and social criteria 4. Chain of custody 5. Governance and delivery 6. IT technology used.
  It is indicated that harmonization is needed even for “common” criteria on terminology, system boundaries, and quantification.
- Unlocking a global hydrogen trade: Establish a common understanding between governments on certification.
  The overarching approach involves using a common language, developing technical recommendations, agreeing on harmonized underlying methodologies, and establishing a common understanding between governments on certification mechanisms.
  The ongoing technical actions and main implementing bodies involve the Development of paper Hydrogen Certification 101, the production of technical recommendations including environmental and social criteria, the methodology for GHG emissions assessment of hydrogen (ISO Technical Specification followed by International Standards), the coordination of actions, and the annual stocktake and monitoring of progress.

6.5.1 Session 3: The Renewables and the potential for clean hydrogen in the hard-to-abate industries, transportation and power generation. Hydrogen certification and the importance of moving toward mutual recognition.

Mr. Steivan DEFILLA, President Assistant, APEC Sustainable Energy Center presented the following:

- Conditions for APEC region to boost renewables

Essential frameworks: Carbon pricing and Taxonomy of green economy: Carbon pricing, being either: Carbon tax or ETS or carbon credit system. Taxonomy of green economy: Describes sectors (or projects) eligible for green finance (preferential conditions)

In addition, some questions arising during his presentation were:

- Do APEC economies apply carbon pricing? Is low-carbon hydrogen subject to carbon pricing? Do taxonomies of APEC economies include hydrogen? If so, is it only clean hydrogen or all hydrogen? E.g., China: “shall we meet China’s standards?”
- In which niche markets is hydrogen cheaper than other decarbonization solutions (“pilot activities”)?
  Essential frameworks: Energy Attribute (or Green Certificates).
  Different names for RECs: US and Canada: Renewable Energy Certificates RECs • EU and Russia: Guarantees of Origin.
  Latin America and East Asia: International I-RECS or Tradable Instruments for Global Renewables TIGR.
  Australia; Japan; Korea: Domestic systems; Japan and Australia now cooperate with I-RECS
  Question arising: Does any APEC economy apply hydrogen certification and certificate trading, following the example of electricity?
  Should EWG discuss an APEC-wide trading scheme for clean hydrogen certificates?
- Which “no regret” measures to be taken immediately?
  Should EWG discuss an APEC-wide trading scheme for clean hydrogen certificates?
  19 APEC economies practice some form of trade with “Energy Attribute Certificates” for electricity (“green electricity certificates”)
  APEC-wide experience exists with this type of certificate and its trade; APEC “DNA” focuses on economy and trade.
  Objective: generate finance for the development of clean hydrogen • Prerequisite for clean hydrogen certificate: Certification of clean hydrogen in each participating APEC economy. Harmonization of mechanism for the creation and redemption of certificates. Certificate trade is independent of physical trade.
  Integration with compliance markets: Glasgow COP 26 agreed on global rules facilitating cooperative approaches on compliance markets to achieve climate targets.
  Project to be driven by an interested APEC economy.
- Which “forward guidance” measures to be taken in future?
  Essential frameworks: Public procurement better than subsidies / tax reductions. Public procurement increases GDP.
  Subsidies/tax reductions do not increase GDP.

This also applies to the generalized GDP (Gross Holistic Product GHP), the GDP of the circular economy. For more details see APEC Urban Energy Report 2023 Driving Cities Through the Low Carbon Transition https://www.apec.org/publications/2024/06/apec-urban-energy-report-2023-- driving-cities-through-the-low-carbon-transition
To diminish production prices of clean hydrogen, strive for internationally competitive tendering for clean hydrogen • To make public procurement budget-neutral, use proceeds from carbon pricing (carbon tax, ETS, carbon credit) as financing source.
For production and marketing of clean hydrogen, set up a specialized agency in a public private partnership (PPP) framework, ensure technology transfer. See APEC Green Finance Report: https://www.apec.org/publications/2023/03/apec-green-finance-report-unlocking-the urban-energy-transition
Question: Is any APEC economy using a public procurement approach in its hydrogen strategy? If so: is it based on internationally competitive tendering?

- Which "value to wait" measures are premature also in future?
  Local measures to be taken after 2030: If a marginal cost market develops, promotion by internationally competitive tendering covering the capital cost of electrolyzers is advisable. If a full cost market with long term contracts (equivalent to PPAs) develops: No promotion is needed. Investment promotion by internationally competitive tendering for specific cases. Quotas for clean synfuels in road transport. Promotion of FCEVs. Observation of upcoming technologies. Promotion of specific cases (avoid energy poverty). Internationally competitive tendering for clean syn-methane supply. Technology-neutral promotion of clean hydrogen cogeneration is recommended.

6.6 Session 4: Igniting the Role of Women in the Hydrogen & Renewable Sector

During this session the speakers delved into the experiences that amplify the role of women in propelling the clean energy sector to new horizons. It also remarked women's perspectives, insights, and contributions that shape a more inclusive and innovative energy landscape.

The moderator, Ms. Vanessa Mohme, Head of Institutional Relations at Luz del Sur, asked the panelists to share their experiences regarding how women professionals are breaking down barriers and reshaping the traditional narrative in the clean energy domain. Ms. Daniela Schweiger, Commercial Manager at

Andes Solar, said that the energy sector is recognized for its combination of technical innovation and sophisticated business practices. As we transition to the new energies required for achieving Net Zero goals, there are exceptional chances for a variety of emerging leaders, who must demonstrate resilience, flexibility, and creativity to tackle the numerous obstacles that lie ahead. On the other hand, Ms. Christine Angelo highlighted the importance of her efforts to take part and initiatives to gain a place for her professional development in the energy sector.

Furthermore, the moderator asked the speakers to exploring the pivotal role women play in championing sustainable practices to ensure a more resilient and eco-conscious energy future.

Ms. Daniela Schweiger mentioned that the current changing energy landscape is creating a need for new leaders who can assimilate the momentum and transform it into effective proposals; thus, women are globally seizing the opportunity to take on these roles. In this regard, Ms. Amanda Wormald, Counsellor on Climate and Energy from Australia, noted that the present Australian Government is committed to achieving gender equality in the energy sector, through committing to equal pay, equal leadership and equal opportunities for women in the clean energy sector by 2030, which would lead to a different but crucial point of view on sustainable practices"

Finally, Ms. Vanessa Mohme encouraged the panelists to discuss the importance of considering women in shaping policies that drive the adoption and growth of clean technologies. Ms. Schweiger said the renewable energy industry is leading in innovation and advancement, providing encouraging prospects for a cleaner and more sustainable tomorrow. Nevertheless, despite its possibilities, the sector faces a striking gender imbalance that hinders its progress, which is also preventing the crucial role of women in contributing to develop energy policies that promote female participation in the value chain of clean energy.

6.7 Session 5: Clean & Low-Carbon Hydrogen Horizon: Challenges and Opportunities.

Mr. Glen Sweetnam, Senior Vice President, APERC presented the following:

- Clean & low-carbon hydrogen: opportunities & challenges.
  OPPORTUNITIES involves: Power Generation, Electricity storage, Blending with gas and coal Industry, Green steel Transport, Sustainable aviation fuels, E-fuels, Fuel cells.

CHALLENGES involves: Energy Losses, Electrolysis, Combustion Costs, Production, Shipping, Consumption Definition of green and low-carbon hydrogen, Identifying situations where surplus electricity overlaps with difficult-to-abate fuel use.

- Green" hydrogen as seasonal storage.
  Overall efficiency of using hydrogen as seasonal storage is very low – 25% is an optimistic estimate.
  An electrolyzer needs to run at a capacity factor of at least 60% to be commercial.
  Electrolyzers that are co-located with renewables would benefit from additional power supply from the electric grid.
  However, power supply from the grid may introduce challenges related to emission compliance and zero-emission certification.
- Hydrogen blending for CO2 emissions reduction
  The energy density of hydrogen is lower than methane. Therefore, the energy contents of the blend are lower than pure methane.
  A 25% hydrogen blend (by volume) reduces CO2 emissions by 9% for the same electricity output.
- Innovation can create opportunities for new hydrogen uses in the industry
  Hydrogen is crucial in various industrial processes, but as a feedstock rather than as an energy source. The use of hydrogen as a fuel remains challenging. Electrification is viable for low heat requirements. The use of green and low-carbon hydrogen in high-temperature applications is feasible but costly with current technology.
- E-fuels could be cost effective in reducing emissions.
  In some markets, electric vehicles face mineral resource constraints, charging, and range challenges. E-fuels could play a role in the transition from ICE vehicles to EVs. E-fuels can use existing petroleum product infrastructure, provide an additional decarbonisation pathway for passenger transport, and can use green or blue hydrogen.
- Reducing the cost of green and low-carbon hydrogen will create opportunities.
  Renewable hydrogen costs are determined mainly by the cost of electricity. Decreasing renewable electricity costs would improve the economics of electrolyzers. High-capacity electrolyzers need continuous electricity supply. Electricity storage helps but increases electricity cost. Grid electricity introduces emission compliance challenges.
- High shipping costs is a key challenge
  Low energy density makes hydrogen transport challenging. Transporting hydrogen affects efficiency and environmental benefits. Safety protocols must adapt to toxic hydrogen carriers. Transportation costs vary by method and demand. Compressed hydrogen is cheaper for short distances. Lack of investment in hydrogen transport infrastructure will slow hydrogen adoption.

- Summary: Opportunities for green and low-carbon hydrogen will be found in the power generation, industry, and transport sectors. Challenges include energy losses, the high cost of production, shipping, and consumption with current technologies, and the definitions of green and low-carbon hydrogen. Technological innovations are required. Pilot projects and research centers in APEC are working to discover those technologies. At present zero- and low-carbon hydrogen innovation and pilot projects are not advancing quickly enough for hydrogen to play a substantial role in decarbonization before 2040. Early-stage opportunities will likely occur where surplus electricity overlaps with difficult-to-abate fossil fuel use.

7.0 Recommendations based on best practices to develop roadmaps and strategies

Implementing the clean and low-carbon hydrogen policy framework is crucial in achieving hydrogen project development and broad use. The following are some guiding principles that can help the economies to develop and implement strategies and roadmaps:

1. Utilization of local resources and foster cross-border collaboration. Utilizing local strengths is a crucial initial step in policy design, which should be complemented by cross-border cooperation and trade to unlock efficiency gains.
2. Establishing certainty is crucial for driving down costs and attracting investment. Economies must set clear targets and make strong commitments to minimize policy risks and market uncertainty.
3. Offering explicit support for hydrogen across the entire value chain. Specific support for hydrogen is needed in production, midstream infrastructure, and end-use sectors such as industry and transport to catalyze and expand new markets.
4. Taking societal value into account is crucial. Societal value should be considered in policy decisions. Well-designed hydrogen policies can positively contribute to several Sustainable Development Goals.
5. Implementing standardized certification programs and comprehensive certification systems is crucial for advancing the hydrogen economy and facilitating transnational hydrogen trade. In this regard, it is advisable to design these certification schemes in line with the relevant international standards to enhance regional interoperability and facilitate trade. Likewise, economies, such as Singapore and Japan are welcome to focus on advancing certification methodologies for cross-border trade as an opportunity for other economies to develop a regional framework for harmonising APEC certifications schemes.

6. Supporting the implementation of effective carbon pricing. It is important to establish strong regional carbon pricing mechanisms by integrating existing schemes and collaborating with specific support for hydrogen, to drive efficient and effective adoption in the long term, while also addressing carbon leakage.

Other further important points to consider when developing a strategy and roadmap are the following recommendations

1. Encourage collaboration between universities, private companies, and government organizations (using the triple helix concept) to identify and prioritize hydrogen projects that can be promptly implemented in the industry. It is also crucial to promote and fund clean hydrogen derivatives in order to boost the demand for hydrogen.
2. APEC economies should collaborate with universities and training institutes to support and sponsor courses related to the production, storage, and use of hydrogen for the general public and technicians. With the increasing number of hydrogen projects, the demand for knowledge will also increase. Education plays a significant role, and economies should implement policies to support it.
3. The text below outlines how economies should invest in initiatives that will yield returns and benefit the environment. It suggests supporting funding mechanisms from banks and other institutions to speed up practical projects. While trading can assist economies with limited renewable resources and water in obtaining green hydrogen, the focus should be on local production to reduce costs and emissions. The efficient and smart production of hydrogen will play a vital role in making off-grid systems connected to renewable energies, like photovoltaics, commercially viable.
4. Electrolyzers play a critical role in the hydrogen production process. Supporting new, innovative, and efficient technologies, such as uncoupled electrolyzers, will significantly reduce hydrogen prices. Discovering new, Earth-abundant electrolyzer materials for electrodes and catalysts will decrease electrolyzer (EL) production costs and reduce CO2 emissions resulting from intensive mining processes.
5. Encourage member economies to share knowledge and collaborate by communicating their technical expertise. This will help less developed economies catch up. Improving transportation and storage will be beneficial; however, reducing the costs of hydrogen production and storage should be a priority. This can be achieved by supporting research and development.
6. Economies should encourage the involvement of professionals in governmental and other organizations to help with technical matters and avoid unnecessary bureaucracy due to the lack of knowledge.

7. An important concept for the economies to understand is that technology exists to make the hydrogen economy a reality soon, but policy development hinders this from happening.
8. There is a need to hire more professionals with experience in hydrogen, especially in high level positions.
9. Hydrogen production and projects must be set as a high priority goal across APEC region by means of the development of instruments that promote engagement among all economies while considering their domestic concerns.
10. The role of both the private and public sector is critical and becomes a necessity to have them work in a close partnership when it comes to developing APEC economies' hydrogen strategies and road maps.

8.0 Conclusion

Numerous economies and have implemented hydrogen strategies and plans that outline how hydrogen and its derivatives will contribute to shifting their energy demands towards a low-emission future. In this research, we have gathered essential international hydrogen strategies and roadmaps, meant to serve as a valuable resource for APEC economies to keep developing or updating theirs, bearing in mind that these recommendations are constantly evolving in response to the fast-changing global hydrogen sector.

APEC economies are strongly advised to adhere to the subsequent guiding principles as they pursue the objectives outlined in their domestic roadmaps. Below are the eight fundamental principles:

- Cultivate high-quality employment
- Promote diversity, equity, inclusion, and accessibility.
- Promote energy and environmental equity.
- Facilitate cost-effectiveness and adaptability.
- Adopt a comprehensive perspective.
- Boost local production and strong supply networks
- Spark innovation and funding
- Facilitate profound decarbonization via targeted, high-effect applications.

It is also crucial to take into consideration that hydrogen competes with various other decarbonization options. However, the justification for adopting green and low-carbon hydrogen in business depends on government policies to promote decarbonization. Understanding the emissions linked to potential hydrogen investments is crucial. Investments in hydrogen must consider the entire value chain and its geopolitical aspects. The transportation of hydrogen is costly and should therefore be reduced. The storage of hydrogen is a critical component of the value chain and demands increased attention.

Peru has managed to get the adoption of an instrument named APEC Policy Guidance on Clean and Low-Carbon Hydrogen Policy Frameworks in the Asia-Pacific, which intends to be a living document that will advise APEC working groups on potential areas of cooperation to further promote the coherent development of a clean and low-carbon hydrogen ecosystem in the region:

https://www.apec.org/docs/default-source/groups/ewg/apec-policy-guidance-to-develop-and-implement-clean-and-low-carbon-hydrogen-policy-frameworks-in-the-asia-pacific.pdf?sfvrsn=45fb78ac_1

This initiative adopted by APEC economies acknowledges the variety of economic and social circumstances across APEC economies while recognizing the cross-cutting nature of clean and low-carbon hydrogen in supporting energy transition. Thus, APEC economies can concentrate, but not limit, their work on the following key areas, in line with different domestic circumstances: Standards and certification, Value Chain, Research and innovation, Finance and investment, and Public and social awareness. The implementation of this Policy Guidance will build on previous and ongoing work and progress achieved so far in different regions and organizations. It will add to the implementation of international and cross-regional commitments that are consistent to the objectives of this instrument. Due to the living nature of this instrument, it contains three annexes:

- ANNEX A: Mapping of APEC local hydrogen roadmaps, strategies, market instruments and financing tools.
- ANNEX B: Table of current APEC projects related to clean and low-carbon hydrogen
- ANNEX C: List of current APEC collaboration with regional and global organizations.

Specifically, Annex A intends to be updated by the economies regarding the status of the local hydrogen roadmaps. It is evident that this Annex provides the groundwork for further development of green hydrogen roadmaps in the Asia-Pacific region.

In this regard, the “Implementation Plan of the APEC Policy Guidance to Develop and Implement Clean and Low-Carbon Hydrogen Policy Frameworks in the Asia-Pacific” has been circulated by June 2025. As indicated in the Policy Guidance, the Expert Group on Clean Fossil Energy (EGCFE) and the Expert Group on New and Renewable Energy Technologies (EGNRET) are responsible for its technical implementation. This Implementation Plan was discussed extensively during the Joint Meeting of both Expert Groups, held in Hong Kong, China, in April 2025. Likewise, further comments and suggestions from members have been received intersessionally, all of which have been pondered properly and incorporated accordingly. Eventually, the Implementation Plan has been considered endorsed by both the EGCFE and the EGNRET.

In the end, the central idea is that APEC economies need to accelerate the adoption and expansion of the hydrogen economy through the prompt formulation of comprehensive roadmaps and strategies or by enhancing the existing ones. It is crucial to acknowledge that hydrogen holds considerable significance not only for the future but also for the current state of affairs. Given the existing availability of hydrogen technologies in the market, member economies should take proactive steps to capitalize on these solutions. Concurrently, efforts and resources need to be directed toward the development of new technologies to support the expansion of hydrogen-powered projects into new areas and applications. It is also essential to consider that renewable energy and storage in general, along with other technologies, can help us pass from the zero level of civilization to the first level, which will bring amazing results to humanity. This civilization-level concept has been circulating in the fields of astrophysics for many years, but now is time to make it happen.

Appendices

Appendix A

Questionnaire about plans and strategies to develop green hydrogen in the Asia-Pacific region.

This questionnaire aims to gather data that can be used to establish best practices for developing a roadmap for green or clean and low-carbon hydrogen in APEC. These recommended best practices will assist economies without roadmaps in creating one and help those with existing roadmaps to enhance them.

Directions: Feel free to contribute as many lines of content as you desire for every question part a), b), c), d), e)

What are your economy's plans for green or clean and low-hydrogen related to?

1. Facilitate hydrogen projects and reduce barriers to the emerging industry.
a) Standards & Certification
b) Adjusting existing legislation, regulations, permissions
c) Licensing requirements.

2. Expected production and cost

a) Period 2024 to 2030
b) Period 2030 to 2040
c) Period 2040 to 2050

3. Storage, transport, and safety
a) Type of storage such as compressed gas, cryogenic, etc.
b) Transport through pipes, trucks, etc.
c) Safety measures, proper storage and transportation

4. Use and applications in industry, mobility, etc.
a) Chemical Industry for the production of ammonia and other chemicals
b) Industries such as mining, cement, steelmaking, glass manufacturing, and other processes need heat.

c) Medium and heavy-duty trucks and buses
d) Boats and ships
e) Aviation

5. Blending hydrogen with natural gas
a) Percentage of blend using existing non-modified infrastructure and equipment.
b) Percentage of blend using existing minor modified infrastructure and equipment.
c) Percentage of blend using existing major modified infrastructure and equipment

6. Exporting or importing Hydrogen
a) Period 2024 to 2030
b) Period 2030 to 2040
c) Period 2040 to 2050

7. Promoting technology innovation, investment, project funding, and support to Industry
a) Supporting Universities and industries to develop new technological ideas
b) Assure investors about the safety of their investment
c) Make available grants for developing new projects
d) Support the Industry by sponsoring the purchase of new equipment, etc.

8. Build new market demand, grow quality jobs, and foster diversity, equity, and inclusion.
a) Promote and sponsor hydrogen use in various applications that are now using fossil fuels
b) Assure that the new jobs will offer a pleasant and fair environment for all employees

9. Promote education of the public and professionals on hydrogen and its applications
a) Seminars
b) Workshops
c) Professional courses

10. Cooperation and knowledge sharing with other economies
a) Agreements, MOUs, contracts for projects, etc.

Appendix B

1. **Opening Session**

   https://drive.google.com/drive/folders/1U4tvGaTR1pSMq4qBhUpJhliqFsxYnbZZ?usp=sharing

2. **Session 1: Scenarios for Decarbonization projects: Experiences and good practices**

   https://drive.google.com/drive/folders/1MhCdwqqSDWkY4tpyyDLL5DvmTr7KPMFo?usp=sharing

3. **Session 2: Best practices for the development of hydrogen roadmaps**

   https://drive.google.com/drive/folders/1eVQIkhMjYJvAKty0Xod40CdRESKkjT4R?usp=sharing

4. **Session 3: The Renewables and the potential for clean hydrogen in the hard-to-abate industries, transportation and power generation**

   https://drive.google.com/drive/folders/1cLpUbPKfsmtMuiGyeO07ofZvFyO7clNb?usp=sharing

5. **Session 5: Clean & Low-Carbon Hydrogen Horizon: challenges & opportunities**

   https://docs.google.com/presentation/d/1q1vl4W6wqgI-YtFQvq-IEW8Jowr2EIro/edit?usp=drive_link&ouid=101442642056991860380&rtpof=true&sd=true

References

1. Spencer Kimball, “Global energy demand will outpace population growth through 2050, Kuwait oil CEO says”, CBC article, published Tuesday, March 19, 2024
2. COP26: Together for our planet, https://www.un.org/en/climatechange/cop26
3. NASA, “Evidence”, https://science.nasa.gov/climate-change/evidence/
4. A PCC, 2014: Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
5. NASA, “Responding to Climate Change”, https://science.nasa.gov/climate-change/adaptation-mitigation/
6. A Didier Hauglustaine, Fabien Paulot, William Collins, Richard Derwent, Maria Sand and Olivier Boucher, “Climate benefit of a future hydrogen economy”, COMMUNICATIONS EARTH & ENVIRONMENT | (2022) 3:295 | https://doi.org/10.1038/s43247-022-00626-z | www.nature.com/commsenv
7. IRENA, Green Hydrogen: A guide to policy making, International Renewable Energy Agency, Abu Dhabi, 2020.
8. Flor Lucia De la Cruz, “A Over the rainbow: Why understanding full value–chain carbon intensity is trumping the colour of hydrogen”, Wood Mackenzie, February 2024.
9. Gemeng Zhang , Zhenqiang Jiang, “Overview of hydrogen storage and transportation technology in China”, Unconventional Resources, Volume 3, 2023, Pages 291-296,
10. https://www.energy.gov/eere/fuelcells/hydrogen-storage
11. https://www.energy.gov/eere/fuelcells/hydrogen-delivery
12. IRENA report, “Hydrogen: a renewable energy perspective”, Report prepared for the 2nd Hydrogen Energy Ministerial Meeting in Tokyo, Japan, September 2019
13. Mohammad Anwar Omid, Mustafa Ergin Şahin, Ömer Necati Cora, “Challenges and Future Perspectives on Production, Storage Technologies,

and Transportation of Hydrogen: A Review", 09 January 2024, https://doi.org/10.1002/ente.202300997Ci
14. EWE, "Hydrogen – a versatile energy carrier", https://www.ewe.com/en/shaping-the-future/hydrogen/hydrogen-applications
15. Renewable hydrogen: what are the benefits for the EU? https://www.europarl.europa.eu/topics/en/article/20210512STO04004/renewable-hydrogen-what-are-the-benefits-for-the-eu, Published: 17-05-2021, Last updated: 12-07-2023.
16. Fuel Cells and Hydrogen 2 Joint Undertaking, *Hydrogen roadmap Europe – A sustainable pathway for the European energy transition*, Publications Office, 2016, https://data.europa.eu/doi/10.2843/341510"
17. HYDROGEN EUROPE – TECH, https://hydrogeneurope.eu/wp-content/uploads/2021/11/Tech-Overview_Hydrogen-Applications.pdf
18. APEC Advances Green and Low-Carbon Hydrogen Transition, https://www.apec.org/press/news-releases/2024/apec-advances-green-and-low-carbon-hydrogen-transition.
19. U.S. National Clean Hydrogen Strategy and Roadmap, June 2023. https://www.hydrogen.energy.gov/library/roadmaps-vision/clean-hydrogen-strategy-roadmap
20. China released the first medium- and long-term hydrogen roadmap, March 25, 2022, https://climatecooperation.cn/climate/china-released-the-first-medium-and-long-term-hydrogen-roadmap/
21. World Economic Forum, "Green Hydrogen in China: A Roadmap for Progress", white paper, June 2023.
22. Chinese Taipei innovative green economy roadmap (tiger), MIT publication.
https://energy.mit.edu/research/
23. Chinese Taipei pioneering pathway to net-zero carbon emissions, East Asia Forum, 12 August 2023, https://eastasiaforum.org/2023/08/12/
24. Hydrogen developments in Chinese Taipei, By the Netherlands Innovation Network at the Netherlands Office Taipei Wouter Janssen - February 2022.
25. National green hydrogen strategy, Chile, a clean energy provider for a carbon neutral plane, published by the Ministry of Energy, Government of Chile Alameda 1449, Santiago Downtown Tower II, 13th Floor Santiago, Chile November 2020.
26. Hydrogen strategy for Canada, Seizing the Opportunities for Hydrogen A Call-to-Action December, 2020, Cat. No. M134-65/2020E-PDF (Online) ISBN 978-0-660-36760-6.
27. https://thediplomat.com/2023/07/a-look-at-japans-latest-hydrogen-strategy/
28. Basic Hydrogen Strategy, June 6, 2023, Japans Ministerial Council on Renewable Energy, Hydrogen and Related Issues.
29. Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D, Hartley P (2018) National Hydrogen Roadmap. CSIRO, Australia.

30. COAG Energy Council Hydrogen Working Group, Commonwealth of Australia, “Australia's National Hydrogen Strategy”, 2019. ISBN: 978-1-922125-62-0.
31. Troy Stangarone, “Korea’s efforts to transition to a hydrogen economy”, Clean Technologies and Environmental Policy https://doi.Org/10.1007/s10098-020-01936-6.
32. https://www.csis.org/analysis/south-koreas-hydrogen-industrial-strategy
33. Mexico’s hydrogen roadmap, 2022. https://theenergyyear.com/articles/mexicos-hydrogen-roadmap/
34. Roadmap of green hydrogen in Peru https://www.edp.com/en/innovation/new/roadmap-of-green-h2-peru
35. MINEM prepares a Roadmap project for the promotion of Green Hydrogen in Peru, March 04, 2024, Bnamericas, https://www.bnamericas.com/en/news/minem-prepares-a-roadmap-project-for-the-promotion-of-green-hydrogen-in-peru
36. Singapore's National Hydrogen Strategy, October 2022, https://www.mti.gov.sg/Industries/Hydrogen
37. https://www.csis.org/analysis/russias-hydrogen-energy-strategy
38. https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-strategies-for-new-zealand/hydrogen-in-new-zealand/roadmap-for-hydrogen-in-new-zealand.
39. New Zeeland Government, “A vision for hydrogen in New Zeeland”, September 2019.
40. Civic Exchange, “A White Paper Outlining the Hydrogen Strategy of Hong Kong”, May 16, 2024, https://civic-exchange.org/report/a-white-paper-outlining-the-hydrogen-strategy-of-hong-kong.
41. The government of the Hong Kong Special Administrative Region of the People's Republic of China announces “Hong Kong's Climate Action Plan 2050”, October 8, 2021. https://www.info.gov.hk/gia/general/202110/08/P2021100800588.htm
42. The government of the Hong Kong Special Administrative Region of the People's Republic of China announces “Strategy of Hydrogen Development in Hong Kong”, June 17, 2024 https://www.info.gov.hk/gia/general/202406/17/P2024061700427.htm
43. Announcing the Hydrogen Energy Development Strategy of Vietnam, February 27 2024, https://vietnamenergy.vn/announcing-the-hydrogen-energy-development-strategy-of-vietnam-32233.html
44. S&P Global, Vietnam's hydrogen economy takes shape with national strategy, projects, March 15, 2024, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/031524-vietnams-hydrogen-economy-takes-shape-with-national-strategy-projects

45. Development of a National Hydrogen Strategy and Action Plan for Accelerating Thailand's Net-zero Target, June 2024,
46. Regulatory Roadmap for Green Hydrogen in Indonesia Established, June 21, 2024. https://energynews.biz/regulatory-roadmap-for-green-hydrogen-in-indonesia-established/#google_vignette
47. Indonesian Hydrogen Outlook 2024, December 28, 2023. https://www.petromindo.com/news/article/indonesian-hydrogen-outlook-2024
48. Hakcipta Terpelihara Kementerian Sains, Teknologi dan Inovasi (MOSTI), "Hydrogen Economy and Technology Roadmap", 2023, ISBN 978-967-2741-11-4
49. https://www.skrine.com/insights/alerts/october-2023/malaysia-launches-hydrogen-economy-technology-road
50. The Republic of the US, Department of Energy, "providing a policy and general framework, roadmap, and guidelines for hydrogen in the energy sector", https://doe.gov.ph/announcements/invitation-public-consultation-draft-department-circular-providing-national-policy-and
51. HIROSE Nao (EnviX, Ltd.)**, "**Philippine to Promote Hydrogen Energy under New Guideline", 26 of February 2024.
52. ERIA Research Project Report 2020, No.04, Economic Research Institute for ASEAN and East Asia, "Brunei Darussalam: Shifting to a Hydrogen Society", 2020.