Chapter 4

East Asia Summit Hydrogen Working Group Meetings

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Most developed countries are committed to achieving carbon neutrality by 2050, but most ASEAN Members have set a target of 2060 or 2070. The first two phases of the hydrogen production potential study helped energy policymakers enhance their understanding of hydrogen technology, while this third phase focussed more on the role of hydrogen to support carbon neutrality in ASEAN+.

Due to the COVID-19 pandemic, ERIA and the Institute of Energy Economics, Japan (IEEJ) hosted two workshops virtually in March and June 2021. The first workshop discussed the role of hydrogen in achieving carbon neutrality towards 2050 within ASEAN, highlighting several best practices from selected EAS members. It published a press release to raise awareness of hydrogen's contribution to decarbonisation and to encourage regional cooperation on hydrogen usage in the region. The second workshop focussed on hydrogen's technology advancement and potential supply chain in the EAS region, followed by a progress report on hydrogen projects. Issues and challenges of hydrogen penetration from supply and demand sides were also discussed during roundtable sessions.

1. First Hydrogen Working Group Meeting, 23 March 2021

1.1. Japan's Hydrogen Policy and Strategy to Achieve Carbon Neutrality by 2050

Representatives from Japan's Ministry of Economy, Trade, and Industry presented Japan's hydrogen policy and strategy to achieve carbon neutrality by 2050. Ari Ugayama of the Hydrogen and Fuel Cell Strategy Office stated that Japan's policy – 'Hydrogen Society' – has embedded hydrogen into the basic economic plan, national strategy, and hydrogen road map. He said that hydrogen is a key contributor to decarbonisation, energy security, and industrial competitiveness. The Hydrogen Strategy is the first comprehensive national strategy to highlight hydrogen as a future energy option towards 2050 with the explicit goal of making hydrogen affordable. To realise this goal, three conditions must be met. On the supply side, low-cost feedstock and large-scale hydrogen supply chains are critical; on the demand side, mass applications, including power generation and industrial processes, are essential. Further, several technologies are being developed for hydrogen production, hydrogen transport, and fuel cell use.

The long-term target is to reduce hydrogen costs from $3 per kilogram in 2030 to $2 per kilogram by 2050. Hydrogen demand targets will be raised from 3 million tons per year by 2030 to around 20 million tons per year by 2050. Positioning hydrogen as a new resource in energy portfolio encourages a wide range players – and not only for mobility applications.

To expand the supply and demand of hydrogen, several actions have been taken in the context of hydrogen mobility applications, local/regional projects, international hydrogen supply chains, and power generation. To develop infrastructure, Japan established a joint venture, Japan H2 Mobility, in 2018 to develop hydrogen station networks. Furthermore, Japan also created hydrogen hubs in collaboration with various companies in different cities, and international collaboration to advance hydrogen technology has occurred through multiple pilot projects conducted with Brunei Darussalam and Australia. Lastly, the establishment of hydrogen power generation in the US, and stationary fuel cells for household and industrial use, show that the potential supply and demand of hydrogen will increase in the future.

1.2. How Will Hydrogen Contribute to Carbon Neutrality in the Future?

Shigeru Kimura, special advisor to the President on Energy Affairs, ERIA, stated that most countries in Europe and North America – and some in Asia – have set carbon-neutral targets by 2050 and have included hydrogen technology in their long-term energy policies. However, no ASEAN Members have any such targets. Under the business-as-usual scenario, share by energy source will be still dominated by fossil fuels (i.e. around 40%) with 20% going to renewable energy.

To set a carbon-neutral scenario for ASEAN, energy efficiency conservation should be promoted, and conventional renewable energy sources should be increased, such as hydro, geothermal, and biomass power generation. The region should also think about shifting from fossil fuels to new renewable energy, such as solar PV, wind, or nuclear power. Moreover, thermal power generation with CCUS should be used, and oil-based transport should be replaced with FCVs. These scenarios will be developed under the carbon neutral road map, with the specific goal of replacing coal and gas power generation with ammonia and hydrogen in 2030–2080 (with an increase in the mixing rate from 5% to 100%). When these carbon-neutral scenarios have been put into place, CO_2 emissions generated by fossil fuels can be reduced up to 90% under an alternative policy scenario by 2080.

1.3. Introduction of a Hydrogen Strategy

This session discussed policies, regulations, targets, technology transfer, value chains, and other related matters of hydrogen application from Australia, China, India, and New Zealand.

Australia's Policy and Hydrogen Status, James Hetherington, Hydrogen Strategy Team, Department of Industry, Science, Energy, and Resources, Government of Australia. Australia has very promising hydrogen production areas. Australia has vast resources to support not only a large-scale hydrogen industry but also large-scale renewable energy. In this case, renewable hydrogen and CCS hydrogen production can be supported.

In phase 1 of its strategy, Australia has set priorities to build foreign partnerships, advance technology demonstration, conduct groundwork, and obtain technology validation for hydrogen production. Phase 1 also covers supply chain testing and development and capacity enhancement to scale up to global markets.

The government is engaged in a variety of actions, including bilateral and multilateral collaborations, to strengthen supply chain linkages, shape markets, and foster investment. Work is currently being undertaken to examine regulatory barriers now in place, as well as the rules that must be changed to expand the hydrogen industry. In phase 2, from 2025, strategies will focus on large-scale market activation, identification of hydrogen market engagement, scaling up projects to support export and domestic needs through building partnerships, construction of Australian hydrogen supply chains, and creation of large-scale export industry infrastructure.

The next steps will focus on reducing the cost of hydrogen. A low-emission technology statement was released on a hydrogen initiative in Australia, emphasising the lower-emission future technology and low-emission trade. With advanced technology that has been identified, the focus now is to lower hydrogen cost to around $2, including in the production chain, making it more competitive. Building international partnerships is also highlighted; cooperation between Australia and Japan on a liquefied hydrogen supply chain would help accelerate uptake. Australia is, therefore, looking forward to advancing partnerships to support global hydrogen industry growth in the future.

Recent Policies and Status of Hydrogen Energy in China, Zheng Lyu, Carbon Data and Carbon Assessment Research Center, Shanghai Advanced Research Institute, Chinese Academy of Sciences. In 2020, the government announced new goals to boost the share of non-fossil fuels in primary energy consumption to 25% by 2030, as part of its intended nationally determined contributions to peak CO_2 emissions before 2030, and to achieve carbon neutrality before 2060. The transport sector will be the main target for fuel cell and hydrogen utilisation, although coal still contributes most of the CO_2 emissions. Recent national policies on hydrogen set demonstration application of FCVs, which will focus on heavy trucks. The demonstration application for city clusters should concentrate on three key areas: construction of a comprehensive industrial chain using FCVs, application of new FCV models and technologies, and establishment of a commercial operation model to strengthen the economy.

In the vehicle industry development plan for 2021–2035, several goals, including a research project on key technologies for new energy vehicles, support the commercial demonstration, industrialisation, and application of by-product hydrogen as well hydrogen production by renewable energy. In addition, the plan includes improving the standard system and management of hydrogen production, storage, transport, and refuelling infrastructure. In recent years, more than 40 provinces have released plans to promote FCVs and the hydrogen energy industry, including conducting research and development of key technologies on hydrogen production, storage, transport, fuel cells, and FCVs; developing an FCV industry chain; demonstrating application of fuel cell buses, trucks, and hydrogen-fuelling stations; and providing subsidies for purchasing FCVs as well constructing hydrogen-fuelling stations.

Currently, the annual hydrogen production in China is around 21 million tons. About 62% of hydrogen comes from coal, and 19% is from natural gas. Water electrolysis only accounts 1%, and rest is by-product hydrogen. By the end of 2020, cumulative sales of FCVs were more than 7,000, most of them buses or trucks, and 124 hydrogen-fuelling stations were built.

India’s Initiative towards Hydrogen Economy, Natarajan Rajalakshmi, Senior Scientist and Former Team Leader, Centre for Fuel Cell Technology, International Advanced Research Centre for Powder Metallurgy and New Materials, Telangana. Hydrogen is considered a potential answer to climate change and air pollution issues due to its storage, energy, and chemical properties. Currently, the cost of green hydrogen is declining, demand is expanding, and regulations to leverage hydrogen's benefits are being strengthened globally. Together with India's cheap and enormous untapped renewable resources potential, the country is an ideal location for green hydrogen generation.

India currently imports 38% of its energy – 30% of its coal, 85% of its oil, and 0% of its natural gas are imported. By utilising the green hydrogen generation capacity of domestic renewables, the country's import expenses can be greatly reduced. By 2050, India estimates that import costs may be cut by about $20 billion per year under an ambitious green hydrogen scenario.

Costs of green hydrogen generated from renewables are beginning to catch up with those of leading fossil fuel technologies, such as steam methane reformation, which utilises natural gas. Due to the high cost of grid electricity in India – particularly for industrial customers – off-grid configurations are more appealing. The high capital expenditures of CCUS, and the limited capacity of carbon storage sites, restrict hydrogen's role in fossil fuels to specific places.

Hydrogen deployment in various industries will take place across time and for a variety of reasons. By 2030, India intends to implement a comprehensive hydrogen system in refineries and steel mills. In terms of power, it is separated into two categories: short-term storage and seasonal storage, the latter of which will likely be dominated by hydrogen from the 2040s. Additionally, steel and ammonia will lead the development of high hydrogen consumption in the industrial sector, followed by refineries and methanol. Hydrogen is already employed in the manufacturing of ammonia, refineries, and methanol. Steel is projected to be the primary new development area within industry, as hydrogen can replace coal in the iron ore processing process.

FCVs’ total conversion efficiency (22%) is lower than that of battery electric vehicles (73%), suggesting that hydrogen will likely be reserved for certain modes of transport where electrification is not feasible. Hydrogen-fuelled vehicles could be used in conjunction with battery electric vehicles. Additionally, hydrogen's future significance in long-distance and heavy-duty applications are considerable.

India has committed to reduce greenhouse gas emissions by 35% below 2005 levels and to generate 40% of electricity from non-fossil fuel sources by 2030. Hydrogen has the potential to be a critical component in low-carbon energy systems. In terms of enhanced air quality and less dependency on imported fossil fuels, hydrogen-fuelled automobiles can complement battery electric vehicles in the transport industry. Hydrogen can assist industry in reducing emissions from operations that require input materials or feedstock produced from fossil fuels, such as the manufacturing of fertilisers, chemicals, petrochemicals, iron, and steel.

New Zealand Hydrogen Policy, Vidushi Challapali on behalf of Mark Pickup, Policy Advisor, Energy Market Policy, Energy and Resource Markets, Ministry of Business, Innovation and Employment, Government of New Zealand. New Zealand committed to 100% renewable electricity by 2030 and net-zero carbon emissions by 2050. New Zealand's hydrogen research and development have been established with the collaboration of several energy research institutes. The government already has legislated a target of decreasing all greenhouse gases, except for biogenic methane, to zero by 2050. New Zealand already had a highly renewable electricity mix in 2019, as 84% of its electricity generation came from its abundant hydro, wind, and geothermal resources. Yet relative reliance on hydropower means that there are challenges in ensuring the needs to manage interseasonal-year risk. In late 2020, an initiation was launched to consider the feasibility of pump hydro and other storage solution potential, including hydrogen-ensuring energy security.

New Zealand's energy sector is the largest contributor to national greenhouse gas emissions, and is therefore a priority. Green hydrogen made from renewable sources has a critical role to play in energy transition. 'A Vision for Hydrogen in New Zealand', published in 2019, is the first step in a hydrogen strategy. It outlined New Zealand's potential for hydrogen in the country, and some of the issues and barriers to its use.

Hydrogen is most likely to be used to decarbonise transport, particularly heavy transport and industrial processes. There is also significant potential for hydrogen export utilising New Zealand's renewable energy capacity. The next stage in the hydrogen strategy is a road map that will explore issues that need to be resolved in hydrogen use in the wider economy and what steps are necessary to resolve this. Work on the road map is expected to start in 1 year. It will consider a business-as-usual scenario to accelerate a deployment scenario, covering hydrogen demand and supply, capability, opportunities, effects on the electricity system and transport network, water requirements, and social licence. It will also consider legislation and regulations needed.

In the meantime, the hydrogen economy continues to grow. The Obayashi Corporation and Tuaropaki Trust have constructed a pilot hydrogen production facility, the first small green hydrogen production and refuelling facility at the port of Auckland. New Zealand has also funded several small and large hydrogen projects, including a study on hydrogen reticulation in the First Gas network, to enhance understanding on how hydrogen can be used and how the gas can be converted.

New Zealand has recently established a new national energy development centre to help lead the country's transition to a low-carbon future. The centre will help create new businesses and jobs, while helping the country move towards clean, affordable renewable energy. Local studies have also highlighted the value of hydrogen in New Zealand, including a First Gas study, post-aluminium smelter hydrogen, and a green freight strategy.

New Zealand has been active in research on hydrogen. The government research institute, Scion, is pursuing options for utilisation of biomass and hydrogen by thermal processing. Another government research institute, GNS Science, has projects on fuel cells, eco-friendly hydrogen production, and electrocatalytic energy production and storage. In addition, a project under the Ministry of Business, Innovation, and Employment and the German Federal Ministry of Education and Research supports green hydrogen research. The New Zealand Hydrogen Council is also collaborating with various German research institutes.

1.4. Hydrogen Strategies of Selected ASEAN Members

Overview of Hydrogen Opportunities for Brunei Darussalam, Shaikh Mohamad Faiz Shaikh Hj Fadilah, Special Duties Officer Grade II, Renewable Energy Unit, Sustainable Energy Division, Ministry of Energy, Government of Brunei Darussalam. Brunei Darussalam is working with Japan on the Advanced Hydrogen Energy Chain Association for Technology Development demonstration project, which will test the international transport of MCH. Under this project, hydrogen is created by steam reforming natural gas, then it is shipped to Japan in ISO containers. NEDO is funding this study.

In the energy value chain flow, since the idea is to replace oil and gas, the value chain of fossil fuels must be considered as well. Regarding oil, which is primarily used for transport, from the point of supply to delivery, 15% can be estimated as lost.

Hydrogen utilisation options in Brunei Darussalam have been discovered, including those related to power generation, FCVs, and renewables. Co-firing with natural gas is used to generate electricity at a pre-existing 30% efficiency. FCVs can be used as an alternative to electric vehicles for low-carbon vehicle deployment. However, charging electric vehicles is less expensive than hydrogen fuel cells. Renewable hydrogen enables the utilisation of excess renewable energy generation and requires a carrier to maintain stability and transport. Because this possibility will require additional investment and infrastructure in comparison to the country's pre-existing energy system, a compelling economic case is required to convince stakeholders.

Brunei Darussalam needs to dig deeper into its resource availability for both blue and green hydrogen. As a way forward, the country can start to formulate a strategy and policy to enable hydrogen industry development. As a historically energy export-oriented country, it is recommended that the main priority be to assess export opportunities. The export industry would facilitate in-country use of hydrogen, as Brunei Darussalam is currently focussing on diversification and growth of its economy. New business opportunities can provide the means to fund in-country hydrogen use.

Current Status and Prospect of Hydrogen Development in Indonesia, Saleh Abdurrahman, Senior Advisor to the Minister for Environment and Spatial Planning, Secretariat General, Public Bureau, Ministry of Energy and Mineral Resources, Government of Indonesia. Indonesia's 2017 national energy general plan established a renewable energy target of 31%

by 2050 and a commitment to reduce greenhouse gas emissions by 29% by 2030. Indonesia is optimistic about developing hydrogen, because the country has significant reserves of blue and green hydrogen as well as untapped gas resources. Furthermore, geothermal resources in Indonesia can be utilised as renewable green hydrogen sources.

The development of hydrogen in Indonesia is being studied by research institutions in partnership with state-owned companies and international institutions. Furthermore, HDF Energy and independent power producers completed a preliminary study on hybrid green hydrogen with solar PV and wind power in East Nusa Tenggara. PT Pertamina Geothermal Energy has also begun a pilot project to produce green hydrogen using geothermal energy.

Papua has untapped potential for hydropower, but the electricity consumption is low there due to its low population. Through the ERIA hydrogen concept plan, this potential can be exploited in the future. The plan is to build a hydroelectric plant in Papua to generate hydrogen and to convey it to more densely populated areas (e.g. Java, Bali, and Sumatra). This could also be a way to enhance development in Papua.

Demand and Supply Potential of Hydrogen Energy in Malaysia, Muhamad Izham Abd Shukor, Principal Assistant Secretary, Electricity Policy and Planning Division, Ministry of Energy and Natural Resources, Government of Malaysia. Since 2006, Malaysia has had solar, hydrogen, and fuel cell road maps. In 2020, it set a target for 31% renewable energy in 2025 and 40% in 2035, as well as 45% emissions reduction by 2030 from the 2005 level. Hydrogen is part of future, as stated in 12th Malaysia Plan 2021, although it is still in a research and development stage.

Regarding Malaysia's electrical profile, gas accounts for around 42% of capacity in 2019, followed by coal (32%), renewables (22%), and other sources (4%). Coal has the biggest share of the generation mix (42%), followed by gas (39%), and large-scale hydro (17%). Malaysia's power planning is guided by the energy trilemma principle (i.e. energy security, affordability, and sustainability). Hydrogen may be considered if it meets specific criteria and produces a balanced output in accordance with this principle.

Malaysia's most recent power development includes Peninsular Malaysia electricity plans, which meet 80% of the country's electricity demand. A battery energy storage system, with a total capacity of 500 MW, will be introduced under this strategy between 2030 and 2034. Additionally, renewable energy and natural gas will gradually phase out coal, and the new power generation development plan anticipates the retirement of approximately 7,000 MW of coal by 2033.

Hydrogen is seen as an opportunity for economic growth in Malaysia. On the business side, Petronas is driving hydrogen projects, and the company is committed to net-zero emissions by 2050. It has signed many memoranda of understanding to realise this commitment. In addition, Petronas established its hydrogen business in October 2020 and is actively seeking customers.

Sarawak will be the first state in Malaysia with an integrated hydrogen production plant. The federal government believes that Malaysia needs to balance planning based on the energy trilemma principle, but Sarawak has a different perspective, given that it has great hydropower capacity. Sarawak will be ready to produce hydrogen fuel for export by 2023 with the completion of a large-scale production facility in Bintulu with the capacity to produce 1,000 tons per year in the first few years, which can be scaled up to 10,000 tons per year in the future.

There is a possibility of hydrogen application in transport due to the country currently working on low-carbon mobility targets. Electric vehicles are the main choice for the government to push forward, and FCVs are seen as the last mile in reducing emissions. Malaysia can also explore its energy storage potential, such as battery storage. By 2030, if hydrogen technology can be competitive enough for other types of storage, Malaysia will choose hydrogen.

Updates on Hydrogen Technology Development in Thailand, Twarath Sutabutr, Chief Inspector General, Ministry of Energy, Government of Thailand. Thailand is a hydrogen-producing country, as hydrogen is produced as a by-product from refineries and gas plants. The country also has a pilot project using hydrogen with hydrolysis technology. Thailand's National Energy Plan is focussed on it becoming a net-zero carbon-neutral country. CCUS is the priority.

Thailand has also formed an alliance of major players in hydrogen technology, the Thailand Hydrogen Alliance. Toyota, PTT, and Bangkok Industrial Gas have carried out collaborative research with the aim of implementing a pilot project to identify the entire supply chain from petrochemical by-products to renewable energy to maximise industry benefits and to boost FCVs in the transport sector. The goal is to provide a technological rationale for putting hydrogen onto the road map, having incentives and policies in place, and verifying the operation of FCVs and hydrogen infrastructure, which is expected to make Thailand a net-zero country in the future.

2. Second Hydrogen Working Group Meeting, 10 June 2021

2.1. Forecast of Hydrogen Production Potential Based on Unused Energy in the East Asia Summit Region

Kutani Ichiro, IEEJ, presented the potential of hydrogen production based on unused energy in the EAS region. He stated that the fundamentals of hydrogen production can be elaborated by two types of feedstock employed: hydrocarbon and water. Three types of unused energies were chosen as feedstock in this study: lignite coal, flared gas, and untapped hydropower potential.

Lignite coal is not being used at the time, despite the fact that there is sufficient lignite reserves. Commercialisation rates were assumed to be 75% of available resources (high) and 25% of available resources (low). The hydrogen output from coal was assumed to be 21 tons of lignite to produce 1 ton of hydrogen. In EAS countries such as Indonesia, it was assumed that two-thirds of lignite was reserved in Kalimantan and one-third in Sumatra. In Japan and

Myanmar, the reserves were shown to be insufficient to sustain hydrogen production for years. In the Lao PDR, no reserves for hydrogen production remains.

To utilise CCS hydrogen, it is necessary to assess the possible capacity of the ground to hold CO_2 emissions. Although no data were available for each country, Table 4.1 contains data for Australia, China, and India.

Table 4.1. Carbon Dioxide Emissions from Lignite and Potential of Carbon Capture and Storage, Selected Countries

		Australia	China	India
Carbon content of lignite	kg/GJ	27.6	27.6	27.6
Lignite consumption for producing hydrogen	million tons	56,299	2,496	2,718
Net caloric value of coal	kJ/kg	9,800	10,000	9,546
CO_2 emissions from lignite	Gton-CO_2	56.0	2.5	2.6
Potential of Carbon Capture and Storage				
Sub-Commercial	Gton-CO_2	43.60	105.00	0.84
Undiscovered	Gton-CO_2	360.30	3,067.00	63.30

CO_2 = carbon dioxide, Gton = gigaton kg = kilogram, kJ = kilojoule.
Source: IEEJ estimation based on IEA (2020) and Pale Blue Dot Energy (2020).

The availability of flared gas validates the reserve–production ratio of oil reserves, which is used to determine whether a country can sustain crude oil output and thus gas flaring in 2040. A country with a reserve–production ratio of less than 5 years will be unable to maintain oil production beyond 2040. For the assumption of hydrogen output from natural gas, the transformation efficiency is 70% (i.e. using GCV/GCV basis). In certain EAS countries, such as New Zealand and Thailand, crude oil production has ceased, resulting in no gas flaring in 2040. In Indonesia, 25% of oil production is estimated to be in Kalimantan, 50% in Sumatra, and 25% on Java.

Final untapped hydroelectric feedstock indicated hydropower capacity expansion up to 2040 under specified policy and sustainable development scenarios, with new development beginning in 2018. Similar to lignite coal, commercialisation rates were assumed to be 75% of available resources (high) and 25% of available resources (low). Hydrogen production from electricity was assumed to be 5 kilowatts per ton of hydrogen, with a conversion efficiency of 70% (i.e. GCV basis).

In conclusion, lignite coal has the greatest potential for use as a hydrogen source. Australia has the greatest potential for production, followed by New Zealand and Indonesia. Hydrogen production potential from conventionally unused energies was negligible in comparison to hydrogen demand potential. Solar PV and wind energy generation have the potential to increase production. Additionally, hydrogen produced from lignite and hydropower has the advantage of having a controllable output.

2.2. Optimisation of the Hydrogen Supply Chain in the East Asia Summit Region

ERIA and the ASIAM Research Institute produced a study on the optimisation of the hydrogen supply chain in the EAS region. Shigeru Kimura, ERIA and Hiruma Takahisa, ASIAM Research Institute explained that hydrogen is an innovative energy technology that will help the EAS region achieve carbon neutrality in the future. Hydrogen will be traded amongst countries in the EAS region, from those that export it to those that import it.

ERIA examined optimal solutions for hydrogen trade in the EAS region in 2040 using the linear programming method. Australia, Brunei Darussalam, Indonesia, Malaysia (Sarawak State), and New Zealand represented the hydrogen-supply countries in the region, while Japan, Korea, Malaysia (Peninsular), Singapore, and Thailand were the hydrogen-demand countries. MCH and liquefied hydrogen represented the two methods of transporting hydrogen.

In terms of hydrogen demand in 2040, hydrogen supply will consist entirely of hydrogen production from unused energy. The forecast placed a premium on the balance of hydrogen supply and demand. Total demand was adjusted for each hydrogen-producing country based on the forecast for hydrogen production. As a result, total hydrogen production was equal to total hydrogen demand. The costs of hydrogen transport were tentatively forecasted for both MCH and liquid hydrogen under a variety of assumptions. They must be refined as hydrogen transport technology advances.

In conclusion, MCH is effective over a short distance, while liquefied hydrogen is extremely competitive over a long distance. For intermediate distances, both modes of transport are nearly identical. An advantage of a liquefied hydrogen ship is that it produces no CO_2. As a result, chemical tankers will be required to switch from conventional fuel oil to zero-emission fuels such as hydrogen or ammonia.

With a cruising range of 5,000–6,000 km, liquefied hydrogen was recommended if hydrogen demand is high; however, if hydrogen demand is moderate and small, MCH was recommended due to tanker operations. Brunei Darussalam, Indonesia, Malaysia, and New Zealand could be critical points for hydrogen supply. The transport costs for MCH and liquefied hydrogen used in this study were provisional, as there is considerable uncertainty in the future; thus, this result is still in the test stage. However, the characteristics of both modes of transport are readily apparent.

2.3 Hydrogen Gas Turbine – Practice from Mitsubishi Heavy Industries

Tanimura Satoshi, a representative of Mitsubishi Heavy Industries, announced that Mitsubishi has set a goal of helping achieve a net-zero carbon society by 2050. Mitsubishi's strategy is to increase efficiency and the use of hydrogen and ammonia as fuels, as well as to increase the capacity of existing facilities and to use battery energy storage systems to support renewable energy systems. Its road map outlines a strategy for reducing CO_2 emissions, which includes efficiency improvements, modernisation of existing facilities, use of energy storage, CO_2 recovery, and fuel conversion, such as the development of hydrogen gas turbines. Additionally, Mitsubishi Power is increasing its portfolio of carbon-free power generation options. Around 30% hydrogen co-firing has already been achieved, and by 2025, it is predicted to reach 100%.

Mitsubishi has advanced technology development by utilising the most advantageous hydrogen combustion technologies available. Hydrogen gas turbines have a number of environmental and economic benefits, including that they require minimal investment, act as a catalyst for infrastructure expansion and cost reduction, are carrier-agnostic, and operate in a flexible manner. Mitsubishi Power offers three types of combustion technology to meet the needs of individual projects and hydrogen density targets: diffusion (Type 1) with a target of 100% hydrogen density, pre-mix (DLN, Type 2) with a target of 30% hydrogen density, and multi-cluster (DLN, Type 3) with a target of 100% hydrogen density.

In 2021, Mitsubishi Power commenced development of the world's first ammonia-fired 40 MW-class gas turbine system with the target to expand the line-up of carbon-free power generation options with commercialisation around 2025. Mitsubishi Power's hydrogen gas turbine projects are located mostly in the US, Europe, South Australia, and Singapore.

Mitsubishi Power's approach to a hydrogen society is to expand the scope of activities, including strategic partnerships; develop a market for green hydrogen and ammonia; participate in front-end engineering design activities; and pursue business feasibility studies in the run-up to commercialisation.

2.4 Progress Reports of Hydrogen Projects

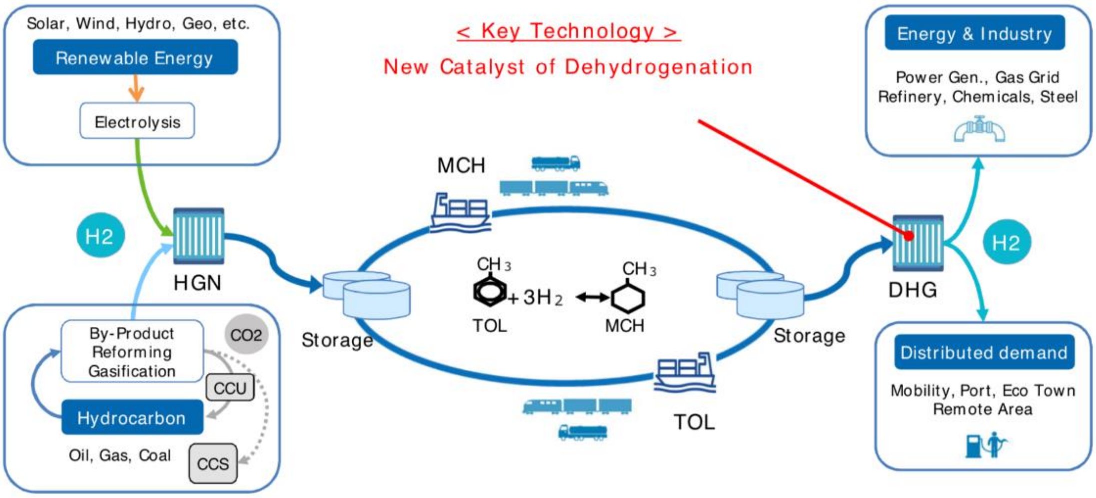
Fukushima Hydrogen Energy Research Field (FH2R) Project in Japan, Hara Daishu, Advanced Battery and Hydrogen, Technology Department, NEDO. NEDO, Toshiba Energy Systems and Solutions Corporation, Tohoku Electric Power, and Iwatani Corporation announced that the FH2R, which had been under construction in Namie, Fukushima Prefecture since 2018, has been built with a renewable energy-powered 10 MW-class hydrogen production unit, the largest class in the world, at the end of February. It began operations in March 2020, after a nearly 2-year development phase.

The FH2R is a 10 MW alkaline electrolysis system capable of producing up to 1,200 Nm^3 of hydrogen per hour (rated power operation) utilising renewable energy. Additionally, the hydrogen produced at the FH2R will be used to power stationary hydrogen fuel cell systems and to fuel mobility devices such as fuel cell automobiles and buses. FH2R serves as a research lab for future hydrogen by examining how green hydrogen can be used to manage and optimise electrical power fluctuation. To that goal, extensive management systems have been developed to control devices such as electrolysers, solar PV-producing facilities, and hydrogen storage units.

SPERA Hydrogen Pilot Project in Brunei Darussalam, Ikeda Osamu, Hydrogen Business Department, Chiyoda Corporation. Chiyoda Corporation is attempting to diversify its business portfolio into greener and new industries such as hydrogen. The hydrogen supply chain is a component of Chiyoda's mid-term growth strategy, which includes expansion into the technology and service sectors.

The company's energy coverage under the energy transformation strategy is divided into three distinct areas: hydrogen, CCSU, and new utility. At the moment, the primary focus of hydrogen research is on MCH, although ammonia and liquefied hydrogen are also included. Chiyoda is also expanding its CCSU business, which includes syngas, para-xylene, ethylene (electrosynthesis), and concrete material. For new utilities, energy management (e.g. balancing and low-carbon) and microgrids (e.g. resilience and low-carbon) are also covered.

Figure 4.1. Methylcyclohexane Hydrogen Supply Chain



Source: Chiyoda Corporation.

Figure 4.1 represents hydrogen production and hydrogen demand using MCH. Energy is in industry, as are distributed demands such as mobility, ports, eco-towns, and remote areas. When hydrogen gas is poured into water electrolysis using renewable energy or fossil fuels, hydrogen gas is converted to liquid using toluene as the hydrogen carrier. For toluene, the hydrogen reacts and converts to MCH and then is transported to the demand side. The hydrogen will extract hydrogen gas and change the toluene back into hydrogen so that the toluene will be recycled. This is a hydrogen transport mechanism using MCH. Almost all technologies are proven, but dehydrogenation is the challenge.

Key features of MCH hydrogen technology are (i) its chemical stability, as it has only minor MCH loss during long-term storage and long-distance transport; (ii) its ease of handling, as the liquid remains liquid under ambient temperatures and pressure (i.e. 1/500 in volume); (iii) liquid that can be utilised by existing infrastructure, standards, and regulations to minimise social investment for hydrogen introduction; (iv) its safe storage and transport, which means liquids can be managed as petroleum products; and (v) almost all technology is a combination of conventional and new technology.

In MCH technology development phase 1, Chiyoda developed a dehydrogenation catalyst in 2008 that achieved optimum performance over 12,000 hours of continuous operation. Meanwhile, under phase 2, Chiyoda confirmed the performance and long life of the catalyst through 10,000 hours of continuous operation of its pilot plant from April 2013 to November 2014. Under phase 3, Chiyoda and partners established the Advanced Hydrogen Energy Chain Association for Technology Development and initiated the world's first global hydrogen supply chain demonstration project. In this phase, Chiyoda transported a vehicle from Brunei Darussalam to Japan – around 5,000 km overseas. A maximum scale of 210 tons per year of hydrogen has since been transported. The project is supported by the Government of Japan, and Chiyoda operates this supply chain.

The SPREA hydrogen network is enlarging the supply chain to deliver hydrogen to Japan, storing hydrogen as a form of MCH for delivery to a decentralised city, and working as a large-scale storage hub.

Hydrogen Energy Supply Chain Pilot Project, Fukuma Yuko, Project Section 2, Project Department, Project Group, Hydrogen Strategy Division, Kawasaki Heavy Industries. Kawasaki Heavy Industries has fertiliser plants, liquefied hydrogen storage tanks, liquefied hydrogen containers, and hydrogen gas turbines. By applying these technologies, it is leading entry into the hydrogen energy supply chain.

Utilisation of large volumes of hydrogen is essential for decarbonisation. Renewable energy-only energy systems and battery storage have limits on energy scale, facility costs, and applications. Liquid hydrogen enables the transport and storage of large, long-lasting energy, and connects various sectors. With a very wide range of industries involved in the hydrogen supply chain and demand field, hydrogen has been highlighted as creating a cycle that is good for the environment and economy. Kawasaki Heavy Industries is contributing to decarbonisation, as it is the only company to own an entire hydrogen supply chain technology from production, transport, and storage, to utilisation.

Hydrogen can be produced from a variety of sources and countries. Hydrogen also allows for large-scale, long-distance, long-term energy delivery and storage, as well as sector integration, which contributes to resilience. Furthermore, future energy is affected by the movement of liquid hydrogen carriers. Kawasaki Heavy Industries can deliver renewable energy throughout the world using liquid hydrogen. It allows hydrogen to be produced not just from fossil fuels combined with CCUS, but also from renewable energy sources. Kawasaki Heavy Industries is also in discussions with many stakeholders to realise the hydrogen supply chain.

The concept of a CO_2-free hydrogen supply chain promoted by Kawasaki Heavy Industries is to provide a stable energy supply while reducing emissions. The supply chain is undertaking a pilot project between Australia and Japan with many partner companies using hydrogen brought to Japan as liquid hydrogen. This supply chain is very similar to the energy supply chain. The difference between natural gas and hydrogen is that hydrogen is a secondary energy and can be produced from many resources, but natural gas is one of the most promising resources for large-volume hydrogen reduction. Kawasaki Heavy Industries believes this large-scale supply chain will accelerate the realisation of decarbonisation and a sustainable future.

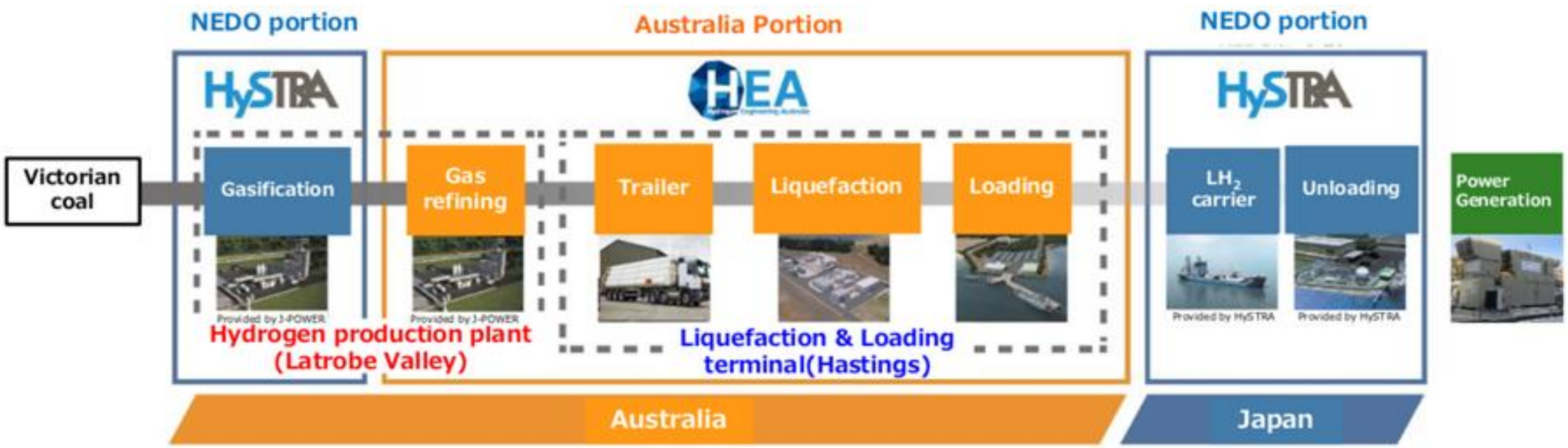
As a mass transport mechanism for hydrogen, Kawasaki Heavy Industries has chosen transport by melting hydrogen. By liquefying hydrogen, the volume of gas in atmospheric form can be lowered to 1/800. As a result, it can be transported in large quantities – efficiently. In terms of characteristics, liquid hydrogen has a high purity, requiring no refinement, and may be delivered to fuel cells via evaporation alone. Hydrogen is also non-toxic, odourless, and has no greenhouse effect. It is harmless if discharged into the atmosphere in an emergency, which is a significant benefit. The mass transport of hydrogen can be realised by integrating this storage technique with energy carrier technology.

Figure 4.2. Well-to-Tank Carbon Dioxide Emissions
(per normal cubic metre liquid hydrogen)

CCS = carbon capture and storage, H2 = hydrogen, PV = photovoltaic.
Source: Kawasaki Heavy Industries.

Some may be concerned about CO_2 emissions if fossil fuels are used. Figure 4.2 shows the well-to-tank CO_2 emissions from each hydrogen production method (i.e. renewables or lignite). In the case of lignite, carbon capture and storage will be required. CO_2 emissions from liquid hydrogen made by lignite carbon capture and storage will be the same as other productions made by renewable energy. This is critical information in terms of lignite usage.

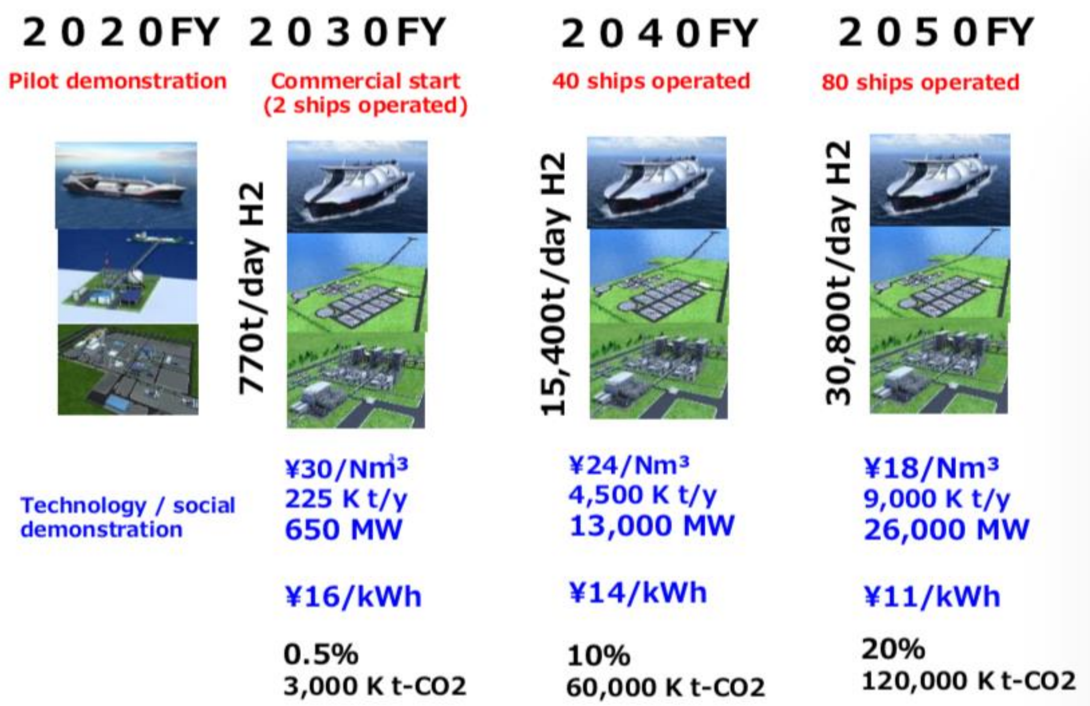
Figure 4.3. Pilot Demonstration Structure between Australia and Japan



Source: Kawasaki Heavy Industries.

Kawasaki Heavy Industries is working with several partners on the pilot project supported by the governments of Japan and Australia. Figure 4.3 shows the two portions of pilot demonstration: NEDO and Australia. The scope of the NEDO portion is liquefied hydrogen carriers and unloading in Japan, and it is supported by the Ministry of Economy, Trade, and Industry and HySTRA. In Australia, the scope is gas refining in the loading terminal, and it is supported by the Government of Australia performed by Hydrogen Engineering Australia.

Figure 4.4. Share of Power Generation Carbon Dioxide Reduction Forecast



CO_2 = carbon dioxide, FY = fiscal year, H2 = hydrogen, Kt = kiloton, kWh = kilowatt-hour, NW = megawatt, Nm^3 = normal cubic metre, y = year

Source: Kawasaki Heavy Industries.

Through the relationship between energy demand and cost reduction, it is possible to further reduce hydrogen costs in the future. Figure 4.4 depicts a commercial hydrogen business starting in 2030 and increasing demand in 2050. Carbon pricing or government assistance is not considered, so it is likely that costs will be reduced further. In the future, when commercialisation is widespread, the cost of hydrogen power generation can be competitive with that of fossil fuel.

Hydrogen from fossil fuels linked to CCUS will realise a broad, affordable energy supply that will contribute to energy security. No CO_2 emissions occur – only water is emitted – which will realise clean energy. In addition, hydrogen will realise an energy supply that will contribute to energy security, and widespread use will lead to industrial growth, including increased infrastructure export deployment as well as future sustainability.

In conclusion, Kawasaki Heavy Industries emphasised the importance of the CO_2 hydrogen supply chain to achieve decarbonisation. Hydrogen from fossil fuel resources such as natural gas and coal with CCUS relies on both energy supplies. This contributes to the proper supply and security of energy. In addition, the use of hydrogen emits less CO_2, so hydrogen is expected to play a low role in decarbonisation. The widespread use of hydrogen will lead to industrial and economic growth. Hydrogen production began with fossil fuels and will eventually convert to renewable energy in the future, which has the potential to create a sustainable energy society.

2.5 Country Updates from ASEAN+ Representatives on Issues and Challenges of Supply and Demand in Hydrogen's Penetration

Roundtable discussions were conducted on issues and challenges in hydrogen penetration, particularly supply and demand. Seven countries took part, including four ASEAN Members (i.e. Brunei Darussalam, Indonesia, Malaysia, and Thailand), China, India, and New Zealand. The discussion is summarised in Table 4.2.

Table 4.2. Country Updates from ASEAN+ Representatives

Country	Updates
Brunei Darussalam	The country supports hydrogen utilisation and is exploring green hydrogen opportunities. Per the Petroleum Authority, it is looking to grey and blue hydrogen using solar PV.
China	Utilisation of hydrogen is expanding, as more local governments have announced plans to develop hydrogen. The government set a target to utilise 10,000 FCVs by 2025. Furthermore, several companies have plans to build around 5,000 hydrogen-fuelling stations by 2025. Around 42%–60% of emissions come from steel productions. Some companies are attempting to use hydrogen for ship fuel and for the steel industry. Hydrogen is also used by automotive manufacturers as well as construction sectors. As power generation is still highly dependent on fossil fuels, hydrogen can substitute for coal power plants in the future.
India	For the past 3–6 months, India has greatly progressed on hydrogen technology. The government is planning to initiate green hydrogen development by generating 30 GW of electrolysis plant capacity. This initiation will be started in the refinery, fertiliser, and steel industries. For electricity generated by both solar PV and wind, the country plans to locate refineries close to solar PV and wind sources to reduce the costs of electricity.
Indonesia	It is setting up hydrogen policy; green hydrogen is part of a long-term strategy for climate resilience to be developed by 2035. Indonesia will concentrate on green hydrogen for the power sector, as well as blue hydrogen from coal (lignite). Indonesia may still use coal by 2050 with down-streaming hydrogen. Pertamina, the state-owned oil and gas company, is continuing its research on hydrogen, and is collaborating with Japan, Australia, and New Zealand on geothermal power plants with electrolysis methods to produce hydrogen. In consideration of carbon

Country	Updates
	pricing, Indonesia has just launched the new cap and trade initiative for power generation. It has begun to examine the carbon market and its price for relevant companies. Stakeholders can only sell the credit domestically.
Malaysia	The science academy in Malaysia presented a hydrogen road map to the Ministry of Economy to promote hydrogen use. Malaysia's economic planning unit is looking into the implementation of hydrogen, and the country is still waiting on a hydrogen policy. Malaysia held a climate action council meeting on carbon pricing, and the Ministry of Environment is exploring carbon pricing. Malaysia has similar issues to Indonesia regarding carbon trading limitations.
New Zealand	Several hydrogen pilot projects are operational. Demand for hydrogen use is evident in the transport sector, port infrastructure, and industry sectors such as urea plants. Several small-scale hydrogen production pilot projects have been launched as well, but the primary one is a joint venture between Japan's Obayashi Corporation and Tuaropaki Trust. Numerous well-funded local and international organisations are currently searching for large-scale green hydrogen development in New Zealand. Several of these projects focus on an area called Taranaki in the middle of the North Island in an offshore gas field. They are either repurposing existing offshore gas platforms for wind turbines or developing new floating wind turbines. In the south, an electricity smelter is scheduled to close in 2024, producing approximately 800 MW of renewable energy. There is emphasis on companies that believe in green hydrogen production as well. In terms of policy and regulation, New Zealand published a hydrogen policy in 2019 that was largely educational in nature. New Zealand intends to develop a road map outlining the optimal pathway and expected volume of hydrogen production in the country. Additionally, the country will determine the optimal level of the government involvement in private sector development, investment in New Zealand's self-sufficient hydrogen nation, or in a hydrogen exporter. Meanwhile, the government has concentrated its efforts on identifying regulatory impediments to hydrogen development. In terms of hydrogen economics, New Zealand can produce hydrogen at a cost-competitive rate using renewable energy. In terms of hydrogen transport technology, New Zealand should be an exporting nation, potentially be small exporter on liquid hydrogen or MCH, it will inevitably need to follow the major market
Thailand	Thailand has a working group composed of public and private sector organisations, including PTT and Toyota, which conducts hydrogen pilot projects and monitors a variety of issues, including regulation and safety. The country's policy framework places a premium on electric vehicles. Hydrogen will play a role in automobile applications as well as in stationary energy storage. Thailand also has a few pilot projects that convert excess electricity from wind farms to hydrogen; another is a household-level pilot project. Additional research is required, and a policy framework should be established in the near future.

FCV = fuel cell vehicle, GW = gigawatt, MCH = methylcyclohexane, MW = megawatt, PV = photovoltaic.