Chapter 5

EAS Hydrogen Working Group

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Chapter 5
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1. First East Asia Summit Hydrogen Working Group Meeting

Hydrogen is highlighted in East Asia Summit (EAS) region as one of the clean energies, which are variable renewable energy (vRE) such as solar and wind. Some EAS countries which consist of ASEAN 10 + 8 countries – Australia, China, India, Japan, the Republic of Korea (henceforth Korea), New Zealand, Russia, and the United States (US) – started to set up their hydrogen strategic plans to utilise hydrogen in 2030–2050. Hydrogen has advantages compared to the existing vRE: (i) it is not intermittent; (ii) it has a large capacity factor; (iii) it has a large supply potential; (iv) it is easy to store and transport; (v) it is not affected by seasonal change, etc. However, its supply costs (production and logistic) are currently expensive due to the need for a huge infrastructure investment to support the hydrogen supply chain.

Based on this background, the Economic Research Institute for ASEAN and East Asia (ERIA) organised the First EAS Hydrogen Working Group (WG) Meeting in ERIA in Jakarta on 16 December 2019 to discuss the prospect of hydrogen use in the EAS region. Representatives from EAS countries and industry stakeholders from Japan attended the 1-day workshop. The workshop was divided into four sessions, namely, the introduction of (i) the terms of reference of the working group, (ii) national hydrogen policies, (iii) ERIA's hydrogen potential study – phase 1, and (iv) the Japan-promoted hydrogen pilot projects.

The following sections summarise the presentations and discussions that took place in each session.

1.1. Introduction of the working group's terms of reference

Shigeru Kimura, Special Adviser to the President on Energy Affairs of ERIA, presented the importance of hydrogen (i) as an alternative renewable energy apart from solar PV and wind; (ii) as a potential energy alternative in many sectors, especially transportation, power generation, and industry; and (iii) because it can be produced from various resources and pathways.

However, Mr Kimura explained several issues and challenges that need to be solved for hydrogen to penetrate the market. On the supply side are the high hydrogen production cost, the difficulty to treat CO_2 emissions when hydrogen is produced from fossil fuels, and the high costs of the supply chain. On the demand side are several bottlenecks, such as the high cost of fuel cell in the transport sector and the expensive cost of burner combustion technology to mix natural gas with hydrogen. Finally, the development of hydrogen technology needs government support on both the supply and demand sides through various incentives and subsidies.

Mr Kimura explained four objectives of the working group: (i) to increase the common understanding on hydrogen in the EAS region, (ii) to project the hydrogen potential on the demand and supply sides by 2040, (iii) to investigate the region-wide hydrogen supply chain, and (iv) to study the appropriate hydrogen policies for the Energy Cooperation Task Force (EAS–ECTF) and the Energy Ministers Meeting (EAS–EMM).

According to Mr Kimura, the WG is expected to (i) share information on hydrogen amongst the members; (ii) submit recommendations to ERIA on the content of hydrogen research studies; (iii) review past and ongoing hydrogen research studies performed by ERIA; (iv) organise discussions, seminars, and workshops on hydrogen supply chain; and finally (v) submit policy recommendations on hydrogen to the EAS–ECTF and EAS–EMM.

As a closing, Mr Kimura stated that ERIA shall organise WG meetings per year until 2025 with the ERIA team composed of members from (i) ERIA, (ii) The Institute of Energy Economics, Japan (IEEJ), (iii) Chiyoda Co., and (iv) Kawasaki Heavy Industries Co. WG members are grouped into two topics, namely, hydrogen production and demand potential. The group on hydrogen production potential comprises Alison Reeve (Director, Department of Energy and Environment, Australia); Adelina Haji Mohammad Jaya (Director, Marketing and Trading Department, Petroleum Authority, Brunei Darussalam); Saleh Abdurrahman (Senior Adviser, Ministry of Energy and Mineral Resources, Indonesia); Iman Bin Yussof (Energy Sector, Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC), Malaysia); and Mark Pickup (Principal Policy Adviser, Ministry of Business, Innovation & Employment, New Zealand). The group of hydrogen demand potential consists of Zheng Lyu (Senior Researcher, Chinese Academy of Sciences, China); Natarjan Rajalakshmi (Senior Scientist, Center for Fuel Cell Technology, International Advanced Research Centre for Power Metallurgy & New Materials, India); Daishu Hara (Director, New Energy and Industrial Technology Development Organization [NEDO], Japan); and Twarath Sutabutr (Inspector General, Ministry of Energy, Thailand).

1.2. Introduction of national hydrogen policies

Hydrogen producers

Three countries' representatives explained their respective hydrogen policies from the point the point of view of hydrogen producers, i.e. Indonesia, Malaysia, and New Zealand.

<u>Indonesia's Hydrogen Policy by Ari Mustaba, Ministry of Energy and Mineral Resources (MEMR), Indonesia</u>

Ari Mustaba explained that Indonesia commits to reduce at least 29% CO_2 emission from BAU (business-as-usual scenario) level by 2030 or by 41% with international support as it has already ratified the Paris Agreement in 2016 by Law 16/2016. Through Government Regulation No. 79 of 2014, the country has set the target of new and renewable energy at 23% shares by 2025. However, it is also aware that the main challenge of applying renewable energy is its intermittency.

One solution to resolve the intermittency issue is by integrating solar power with the energy storage system, which can provide a back-up when solar power is down. A combined solar power and storage system will also give stable power, which is good for the grid.

One example of renewable energy and energy storage system is the application of solar power that is combined with fuel cell and battery. This technology produces stable and reliable power for the whole day. The combined system is also suitable to be implemented in small islands where the grid is very sensitive to intermittency.

Currently, the private sector is the only stakeholder capable of implementing this technology. MEMR Regulation Number 50 of 2017 regulates the mechanism of how the renewable energy business process implemented by Independent Power Producer (IPP) can sell its electricity to the state electricity company (Perusahaan Listrik Negara or PLN). Nevertheless, that regulation has not yet accommodated a system that combines renewable energy with storage from the perspective of both business model and tariff.

For this reason, Indonesia needs to study the implementation of renewable energy and its storage system – especially on small islands, both technically and economically – and the business model that is doable in Indonesia.

Mustaba made three points on Indonesia's situation, as follows:

First, he explained a set of actions that Indonesia is taking to realise the 'Tokyo Statement' since the last hydrogen energy ministerial meeting in 23 September 2018). This statement includes the achievement of the Paris Agreement's objectives, including combating climate change. Hydrogen is expected to have an important role in decarbonising the global energy system. In turn, numerous sectors including transportation, industrial manufacturing, heat, and power generation can use hydrogen. Hydrogen will be an important source of energy, coexisting with current fossil fuels and growing renewable energy, for greater sustainability of our planet. The application of hydrogen technology as energy storage in renewable energy power plants (solar PV and wind power plants) can improve the reliability of the system. Indonesia is planning to pilot a manufacturing hydrogen installation that can be integrated with a renewable energy power plant. PT KAI (Kereta Api Indonesia, the Indonesian Railway Public Corporation) and ALSTOM are collaborating to develop a hydrogen fuel cell train. MEMR, with PT KAI and Alstom, is preparing a memorandum of understanding to develop a hydrogen fuelled train in Indonesia.

Second, on the perspective of hydrogen in Indonesia: hydrogen, as a clean fuel in the energy sector, can be used in transportation, power plant, and energy storage. The deployment of hydrogen fuel cell vehicles is a further step in the electrical vehicle national programme. Hydrogen converted to electric power through fuel cell will be the alternative energy storage technology in addition to using the battery. Hydrogen can be used as storage media. In Eastern Indonesia, hydrogen can be utilised as an energy storage for intermittent generation. Hydrogen source potentials are also available. Indonesia can potentially supply hydrogen from gas and lignite as fossil fuel sources, and solar, hydro, and wind as renewable energy sources. The challenge is how to make hydrogen economically viable, financially attractive, and socially beneficial in the country.

Finally, hydrogen would potentially decrease domestic oil/gas/coal demand for electricity and heat and transport fuel with combination of renewable energy, in addition to the export opportunity.

The Future of Hydrogen in Malaysia by Imran Yussof, Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC), Malaysia

Energy policy in Malaysia was firstly elaborated by the issuance of the Petroleum Development Act in 1976. Renewable energy matters were first mentioned in 2001 in the Fuel Diversification Policy. The first hydrogen and fuel cell road map, together with solar, was established in 2006 in the Ninth Malaysia Plan (RM9). Now, hydrogen and other renewable energy options are regulated under Renewable Energy Act 2011.

In Malaysia, the Energy Commission takes care of energy matters, in coordination with the Ministry of Economic Affairs (MEA) and MESTECC. At the same time MESTECC also coordinates with the Sustainable Energy Development Agency and Malaysia Power. Other ministries than MEA and MESTECC are the Ministry of Rural Development, the Ministry of Primary Industry, the Ministry of Domestic Trade and Consumer Affairs, and Petronas.

Mr Yussof explained that the transport sector accounted for nearly 25% of energy use in 2016, which made it the highest energy-consuming sector in Malaysia. At the same time, the total final energy consumption is still dominated by petroleum products (53%), followed by natural gas (22%) and electric power (22%). Electric power depends primarily on coal (46%) and gas (nearly 40%) whilst hydropower gets around 13%. Coal and gas make around 74% of total installed power capacity whilst renewables contribute around 22%. with a large share coming from large hydropower (16%). From the demand side, the industry and the commercial sectors in Malaysia make around 78% of total electricity demand. Most of the electricity demand is concentrated in Peninsular Malaysia, i.e. 112,572 GWh which is nearly 80% of the total electricity demand. The total installed capacity in Peninsular Malaysia is around 26,603 MW, which is about 80% of the national total installed capacity (33,095 MW).

Malaysia is targeting to reach 20% of renewable energy installed capacity share by 2025 (around 8,400 MW), a fourfold growth from the Eleventh Malaysia Plan in 2019 of 2,068 MW. With a total production capacity of not more than 20,000 kg/day, hydrogen is produced for industrial purposes as a by-product. Some hydrogen projects have taken place, e.g. the commissioning of the first integrated hydrogen production plant and refuelling stations with the rolling out of three hydrogen-powered buses in Sarawak state (2019). At the same time, hydrogen-related policies in Malaysia principally deal with academic institutions, e.g. around RM40 million in grants have been allocated for research and development (R&D) between 1997 and 2013.

The Hydrogen Policy of New Zealand by Mark Pickup, Principal Policy Advisor, Energy Market Policy, Energy & Resource Markets, Ministry of Business, Innovation & Employment, New Zealand

With the current renewable (geothermal) energy share already reaching 85% in power generation, the New Zealand government aims to achieve 100% renewable electricity by

2035 and net zero–carbon emissions by 2050. Green hydrogen strategy is amongst its main renewable energy strategies to help reduce global emission. The government has partnered with Japan to develop hydrogen technology, and its green hydrogen strategy has been set to contribute to reaching the national target of net zero–carbon emissions in 2050, considering the potential demand growth for power, transport, and the industry sectors as well as for export.

There are currently several main activities in hydrogen strategy in New Zealand, such as studies, demonstration, and pilot projects.

The strategy itself has two parts: (i) the development of a hydrogen vision with a final report to be issued in 2020, and (ii) the development of a hydrogen road map that should be completed in 2020. The road map will consider regulatory and standards gaps, business-as-usual versus an accelerated deployment scenario of hydrogen.

Hydrogen consumers

There were three presentations from China, India, and Thailand from the hydrogen consumers point of view.

Policies and Status of Hydrogen Energy in China by Zheng Lyu, Carbon Data and Carbon Assessment Research Center, Shanghai Advanced Research Institute, Chinese Academy of Sciences, China

Since 2006, China has surpassed the US in becoming the world's largest CO_2 emitter. China's energy consumption will continue to increase with coal and other fossil fuels, accounting for a high proportion of the energy mix, whilst crude oil will still be heavily dependent on imports.

China's nationally determined contributions by 2030 per the Paris Agreement are as follows: (i) to achieve CO_2 to reach its peak around 2030 and to make the best efforts to reach this earlier, (ii) to lower CO_2 emission per unit of GDP by 60% to 65% from the current 2005 level, and (iii) to increase the share of non-fossil fuels in primary energy consumption to around 20%.

China's main national policies on hydrogen energy has been elaborated since 2012 in many development, action, and initiative plans. Amongst the main targets are the development of hydrogen energy and fuel cell vehicles (FCVs) to facilitate energy transition (that includes production, distribution, storage, transportation, standardisation, etc.); realisation of several pilot and demonstration projects; and green industry guidance with hydrogen energy application. In the meantime, in recent years, more than 30 provincial or city governments have released plans or instructions to promote FCVs and the hydrogen energy industry.

To develop hydrogen energy use in transportation, the central government maintains a high subsidy for FCVs – from RMB200,000 to RMB500,000 per car – and the local government provides additional subsidies of around 30% to 100% of this amount. More than RMB4 million of subsidies were also applied to the construction of hydrogen fuelling stations.

Currently, China produces around 21 million tonnes of hydrogen annually with 62% coming from coal, 19% from natural gas, 1% from water electrolysis, and the remaining from industrial by-product. In 2019, 1,527 units of FCVs were sold, mostly buses or trucks, and around 23 tanking stations built.

Finally, China targets hydrogen development after the hydrogen industry road map was documented in the Blue Book of China's Hydrogen Industry Infrastructure Development (China National Institute of Standardization, 2016). Amongst its targets are producing 10,000 FCVs by 2020, 2 million by 2030, and 10 million by 2050, and building more than 100 hydrogen fuelling stations by 2020 and 1,000 by 2030.

In 2019, the China Hydrogen Alliance released the White Book of China's Hydrogen Energy and Fuel Cell Industry with more detailed hydrogen targets not only in the transport sector but also in the industry and power generation sectors until 2050.

The Initiative of the Advanced Research Centre International (ARCI) India on Hydrogen Technology by N. Rajalakshmi, Senior Scientist and Team Leader, Center for Fuel Cell Technology, International Advanced Research Centre for Power Metallurgy & New Materials (ARCI), India

ARCI is an autonomous R&D centre of the Government of India's Department of Science and Technology located in three cities: New Delhi, Hyderabad, and Chennai. Amongst its centres are the Centre for Fuel Cell Technology that deals with research on the Polymer Electrolyte Membrane Fuel Cell system and hydrogen generation and the Centre for Automotive Energy Materials that deals with Li ion battery, magnets for motors, and thermoelectric devices.

Hydrogen and fuel cell activities in India started in the '80s. The number of involved research and industry institutions has grown from only around 10 in the '90s to the current around 100. In 2012, the government approved a significant budget to promote and produce 6 million electric vehicles and hybrid electric vehicles by 2030. At the same time, the finance minister announced a concessional excise duty of 10% for fuel cell and/or hydrogen cell technology. In India, several pathways of hydrogen use in transport are being studied with some demonstration or pilot projects. Amongst the scrutinised pathways are the use of hydrogen as internal combustion engine for two, three, or four wheelers; the use of alkaline fuel cells for three wheelers (*bajaj*); and the use of polymer electrode membrane (PEM) and phosphoric acid fuel cells. Apart from these, many pilot and demonstration projects are also conducted, especially on hydrogen production and hydrogen use in other sectors, such as telecommunication.

India is also actively organising workshops, seminars, and conferences on hydrogen technologies and collaborating with international experts.

Hydrogen – The Missing Link in the Energy Transition: Decarbonising the Energy Sector by Twarath Sutabutr, Inspector General, Ministry of Energy, Thailand

Between 2012 and 2021, in its Alternative Energy Development Plan (AEDP), Thailand targets to reach 30% renewable shares in its total energy consumption by 2036. Included in this target is the objective to reach a 10.1% share of renewable sources or around 3,353 ktoe by 2021 to generate electricity, of which 0.86 ktoe is expected from new energy that includes hydrogen. The AEDP sets out that, by 2036, hydrogen would meet 10 ktoe of energy consumption.

Currently hydrogen production in Thailand comes mainly from natural gas steam reforming. It is used mainly in the refinery to produce petroleum and petrochemical products. Several ongoing development projects that use hydrogen as energy storage, to feed FCEVs, especially heavy-duty vehicles, and to be produced on-site as green hydrogen whilst replacing grey hydrogen produced from fossil fuels.

1.3. Introduction of ERIA's hydrogen potential study – part 1

Mr Kimura introduced the study on hydrogen potential conducted by ERIA.

According to the ERIA outlook, the energy supply in the EAS grew at an annual rate of 1.48% in 2000–2015 and will grow 1.46% in 2015 and 2040. Coal has been taking a major share of the supply during the observed period and, geographically, India and China, being the two biggest countries with the biggest supply. The energy intensity of the regions should decrease by 9% in 2000–2015 and by 38% in 2015–2040. At the same time, in 2040, by going through an 'energy potential' scenario, the region can possibly save its total primary energy supply (TPES) by 13% and its total final energy consumption by 10%. Overall, this means a reduction of 24% of CO_2 emissions in the business-as-usual scenario (BAU).

According to Mr Kimura, hydrogen has three potential benefits to be explored: (i) the potential to be a low or zero carbon-emitting energy, (ii) the possibility to be produced from various sources and pathways, and (iii) the ability to be used as a transportable energy storage.

Mr Kimura explained the current trends of hydrogen development in the world that consist of (i) Japan's policy regarding its basic hydrogen strategy that touches every aspect of hydrogen development, i.e. supply, cost, usage (mobility and power generation), and the development of fuel cells; (ii) the hydrogen ministerial meetings; and (iii) the global hydrogen market, which should be formed as a result of the Paris Agreement.

The study consisted of

- reviewing the climate, renewable energy, and hydrogen policies of ASEAN countries (except Cambodia, the Lao PDR, and Myanmar), Australia, China, India, Japan, Korea, and New Zealand (to be done by IEEJ);
- forecasting hydrogen demand potential in road transport (fuel cell bus [FCB], fuel cell trucks, hydrogen stations, etc.), power generation (hydrogen turbine), and industrial heat (IEEJ);
- forecasting hydrogen supply potential from fossil fuels and renewable sources, including the potential ways of transporting and distributing, with cost as the main parameter (Chiyoda Corporation),
- conducting well-to-wheel analysis of energy use, emissions, and costs (ERIA); and
- surveying several sites (ERIA, Chiyoda, and IEEJ supported by the Mitsubishi Co. and Mitsui & Co.)

Hydrogen Demand Potential by Motokura Mitsuru, Senior Coordinator, Global Energy Group 1, Strategy Research Unit, The Institute of Energy Economics, Japan (IEEJ), Japan

Mr Motokura explained the two study phases on hydrogen demand potential.

Phase one of the study is summarised as follows:

The scenario of hydrogen until 2040 includes three sectors (electricity, industry, and transport). Conventional fossil fuel use will be shifted to hydrogen or a mix of hydrogen and fossil fuels with the introduction of various hydrogen-related technologies in the three sectors. For example, in the transport sector, it is the introduction of fuel cell cars, FCBs, and fuel cell trains.

Basic assumptions consist of the categories of hydrogen technologies that would prevail and be commercialised, carbon content, net calorific value, hydrogen specification (density), thermal efficiency for power generation, and the different conversion factors.

In the electricity generation sector, the scenarios are differentiated by the percentages of hydrogen penetration (10%, 20%, and 30%, respectively) as power generation fuels in 2040 in BAU (0%). These assumptions and different scenarios in the power sector are also applied in the industry sector.

In the transport sector, the scenarios are based on the exogenous assumptions of hydrogen use shares that grow in each of the concerned transport mode, i.e. passenger cars, buses, and trains. These different shares are obtained through assumptions on the number of vehicle stocks, considering the different techno-economic characteristics of the different vehicle types (mileage, fuel economy, etc.)

Some results are obtained in terms of hydrogen demand. First, by 2040, Indonesia would potentially have the highest hydrogen demand in ASEAN whilst China followed by India would have the most demand for hydrogen in the EAS region. Second, electricity would be the sector with the most hydrogen demand, followed by transport and then industry.

CO_2 emissions could be reduced up to 2.7% depending on the scenario compared to the ERIA benchmark outlook. The economic impact is calculated by simply multiplying the CO_2 emission reduction amount and CO_2 price, which is assumed to be US$41/t$CO_2$. Net natural gas demand will increase because 20% of coal-fired electricity generation is assumed to be converted to hydrogen and natural gas mixed fuel.

Phase 2 is the revision of assumptions and scenarios of phase 1 based on consultation with the Mitsubishi Hitachi Power Systems and Toyota Motor Corporation that focused on the transport and power generation sectors. For example, in the power sector, the study assumes that, in an intermediate year (2030), a gas mix of hydrogen and natural gas (30:70) would penetrate the alternative policy scenario. The 2040 situation is divided into two distinct scenarios: one that assumes a 50:50 share of pure natural gas and pure hydrogen whilst the other assumes a 50:50 share of pure natural gas and mix (30:70) of hydrogen and natural gas.

In the transport sector, the study assumes certain shares in the zero-emission vehicle (ZEV) amongst the registered passenger cars in 2040, i.e. 30% in scenario 1 and 50% in scenario 2, with both FCV shares of 20%.

Other improvements to the scenario building is the clustering of countries (regions) into four groups, i.e. combinations resulting from low or high income and low or high hydrogen supply cost. The study also assumes the different hydrogen technologies or facility development rates based on those clusters.

The results of the phase 2 hydrogen demand are then more detailed than those of phase 1 as the hydrogen demand of different countries are analysed based on their cluster characteristics.

Hydrogen Production Potential by Ikeda Osamu, Group Leader, Hydrogen Chain Demo Project Section, Chiyoda Corporation, Japan

Mr Ikeda presented the results of the phase 1 study concentrating on the hydrogen production potential and supply cost forecast.

The study categorised the 16 EAS countries into three groups to identify the positioning for hydrogen trading in 2040 by utilising forecasted data of energy balance between production and demand, including hydrogen. The three groups are exporting (Indonesia, Australia, Brunei Darussalam, New Zealand, Lao PDR); importing (Japan, Korea, Singapore, Cambodia), and trading intra-regionally (China, Thailand, India, the Philippines, Viet Nam, Myanmar, Malaysia, and some parts of Indonesia).

The study estimates hydrogen production cost from various sources, i.e. fossil fuel and renewable resources. In 2040, the production cost would be in the order of gas reforming, water electrolysis (stable power), biomass gasification, lignite gasification, and water electrolysis (fluctuating power).

Hydrogen production cost grows linearly with feedstock price. Hydrogen production from the steam reforming of gas is the most economical, and water electrolysis with a high capacity factor (70%) plus low electricity cost will enhance its cost competitiveness.

Amongst the group of exporting countries, Australia and Indonesia would have the largest potential to produce hydrogen; major sources are solar, wind, and lignite. Amongst the intra-regional trading group, China and India would have the largest potential to produce hydrogen with the largest demand, with solar and biomass as the main sources.

The study suggests that hydrogen can be transported in four modes (rail, ship, truck, and pipeline) through at least four types of carrier (liquid hydrogen [LH2], ammonia [NH3], chemical hybrid [methylcyclohexane, MCH], and compressed hydrogen [CH2-700 Mpa]. Ships transporting liquid and chemical hydrogen are ideal for extremely long distance (global) hydrogen logistics. For small volume compressed gas, the transport by trucks of liquid/chemical hydrogen is suitable for local and short distance whilst high volume compressed gas, liquid/chemical hydrogen via train is ideal for medium and long distance. Pipeline is suitable for transporting compressed gas hydrogen domestically with flexible delivery volume.

To understand the magnitude of local hydrogen supply chain cost and characteristics of each technology, we applied three scenarios utilising three different hydrogen carriers (LH2, NH3, and MCH). We assumed the same centralised hydrogen production with a capacity of 2.5 bio Nm^3-H2/year followed by a centralised carrier synthesis for the three scenarios. The scenarios differ after the carrier synthesis. In the first scenario, we assumed the following sequence: a long-distance ship transportation (600 km), followed by 100 km of truck transportation to deliver to hydrogen pumping stations for hydrogen FCVs. In the second scenario, we assumed a 300-km train delivery followed by 100-km truck delivery to the pumping stations. For the third scenario, hydrogen is transported only by truck for 100 km from the carrier synthesising to the pumping stations.

As a result, the study found that supply chain costs are in the order of MCH, NH3, and LH2 from the lowest in 2020–3030, and NH3 will be the lowest cost carrier in 2040–2050.

The study results are summarised as follows:

- Hydrogen demand and supply in the region is assumed to be well-balanced between the exporting, importing, and intra-regional trading countries in 2040 with enough additional potential.
- In the early stage, the major hydrogen source will come from fossil fuels. In the future, the sources will largely shift to abundant renewable energy as a result of technology development and will expand its network globally and regionally.
- In the early stage (2020–2030), local supply chain and global trading with Japan will start. It is expected to grow into a global hydrogen energy supply chain network in this region in 2040–2050.
- In case of the liquefied natural gas (LNG) business, it has taken 15 years to start the first LNG shipment since the adequate transportation technology was established in 1954 and over 30 years for the LNG business to mature. In the early stage, the LNG price was quite high compared to the oil price. LNG was introduced with government support including tax incentives, subsidy, lending support until crude oil price rose with the oil crisis. LNG production and transportation costs have been reduced by technology development and scaling up of its projects.
- The study proposed two policy approaches – national and regional – towards establishing the global hydrogen market and supply chain in the EAS region: (i) the **national approach** that is based on the national hydrogen strategy and road map, government support and awareness programme; and (ii) the **regional approach** that is based on standardisation, i.e. evaluation or labelling standard development of carbon reduction value of hydrogen, the definition of hydrogen price per volume unit for global trading and statistics and technology or safety standard development in the region.

1.4. Introduction of hydrogen pilot projects promoted by Japan

KHI Hydrogen Road, an Australia Case, by Hasegawa Taku, Hydrogen Energy Use Promotion Section, Project Promotion Department, Hydrogen Project Development Center, Corporate Technology Division, Kawasaki Heavy Industries (KHI), Ltd, Japan

The KHI hydrogen road is a concept being implemented in Australia, which is based on carbon capture and sequestration–equipped hydrogen production from Australian brown coal transported as a liquid carrier. According to a life-cycle analysis (LCA) performed by Mizuho Information & Research Institute, in terms of well-to-tank CO_2 emission, this pathway of production and supply chain emits 0.2 kg CO_2e/Nm^3-H2, which is better than producing hydrogen from Japan's wind farm or solar PV combined with compressed hydrogen gas carrier supply chain which has an emission factor of 0.34 kg CO_2e/Nm^3-H2.

The total hydrogen cost of this pathway is around ¥29.7/Nm^3; around two-thirds of the cost components are contributions from production and liquefaction. This pathway should produce hydrogen at 225,400 tonnes per year, equal to the energy demanded by 3 million fuel cell cars or 1 GW power generator.

The Australian brown coal project is located in Latrobe Valley, Victoria. Brown coal is cheap since it has high moisture content and can potentially feed 240 years of power generation in Japan. The carbon capture and storage (CCS) offshore facility located 80 km from the Latrobe Valley brown coal mine is developed under the CarbonNet Project promoted by the Australia federal and Victoria state governments.

The KHI uses its cryogenic technology to liquify hydrogen, a carrier form to transport a high volume of hydrogen over long distance. The liquid carrier volume is 1/800 of its gas volume, needs no further refinement process, non-toxic, odourless, and free of greenhouse gas (GHG). The KHI is also developing a large-scale liquid hydrogen carrier of 40,000 m x 4 cargo size that is fuelled by evaporated hydrogen gas and has its own tank/storage as well as container to store and transport hydrogen by truck. The KHI is also developing its own hydrogen refuelling stations (HRSs) and gas turbine technologies.

The KHI started its hydrogen project in 2014 that included the development of production, liquefaction, and supply-chain technology and components as well as its Strategy Energy Plan and Strategy Road Map for Fuel Cell and Hydrogen. The KHI aims to do a technology demonstration during the summer Olympics in Tokyo (2020) and targets to start its commercial operation by 2025.

The demonstration project is a cooperation between Japan (NEDO) and Australia. NEDO through HySTRA (CO_2-free Hydrogen Energy Supply-Chain Technology Research Association) is dealing with gasification, carrier and end transportation/storage chains whilst the Australian federal and Victoria state governments through Hydrogen Engineering Australia is dealing with gas refining, transporting to the liquefaction site, the liquefaction process, and the loading of liquefied hydrogen into ships.

Brunei Darussalam Case by keda Osamu, Group Leader, Hydrogen Chain Demo Project Section, Chiyoda Corporation, Japan

Mr Ikeda gave an update of the world's first global hydrogen supply chain demonstration project. He explained that Chiyoda and its partners established the new entity called AHEAD and started the world's first global hydrogen supply chain demonstration project towards 2020. In brief, the project is a creation and operation of hydrogen supply chain produced in Brunei Darussalam, transported in ISO tank container in ships and trucks, and finally used in Kawasaki city as fuel for gas turbine power plants. The total annual maximal volume is 2010 tonnes whilst the demonstration period is between January 2020 and December 2020. The demonstration project is funded by NEDO.

In brief, LNG is produced in the Lumut LNG plant di Brunei Darussalam. The processed gas is transported to Spark hydrogenation plant and liquid hydrogen in the form of MCH is produced. MCH is transported in ISO container in trucks to the container port in Muara and then shipped in container vessels to Kawasaki city. In Kawasaki port, the ISO containers are uploaded in the container yard and transported in trucks to the de-hydrogenation plant in Keihin Industrial Zone. In the plant, MCH is dehydrogenated to become hydrogen gas. The hydrogen gas is then fed to power generation in Kawasaki. In the dehydrogenation plant, the MCH's hydrogen is separated; what is left is toluene that is brought in ISO containers by the trucks back to the container yard. This is then shipped back to Brunei to be used again to bring hydrogen in MCH form back to Japan.

2. Conclusion and Way Forward

Mr Kimura (ERIA) summarised all presentations made during the 1-day meeting. He also presented the plan to organise the second WG meeting to be held in ERIA in March 2020. In said meeting, participants would discuss at least five topics: (i) the hydrogen policies and activities in Australia, Brunei, Indonesia, and Japan; (ii) the standardisation of hydrogen in the EAS region; (iii) the progress of the ERIA phase 2 study; (iv) the proposed content of the phase 3 study; and (v) the policy recommendations to the EAS Energy Ministers Meeting. Unfortunately, due to the COVID-19 pandemic, the second WG meeting has been cancelled and the topics to be discussed during this meeting are transferred to the hydrogen phase 3 study to be implemented in 2020–2021.