# Chapter 6

# Hydrogen Workshops

December 2020

**This chapter should be cited as**

ERIA (2020), 'Hydrogen Workshops', in Kimura, S., I. Kutani, O. Ikeda, and R. Chihiro (eds.), *Demand and Supply Potential of Hydrogen Energy in East Asia – Phase 2.* ERIA Research Project Report FY2020 no. 16, Jakarta: ERIA, pp.102-28.

# Chapter 6
# Hydrogen Workshops

The results of the hydrogen potential study phase 1 are relevant, meaningful, and indicate future energy trend. To enable energy policymakers to gain a deeper understanding of hydrogen and confirm the prevailing common understanding on hydrogen, four workshops were planned in Bangkok, Thailand; Brunei Darussalam; New Delhi, India; and Kuching, Malaysia.

However, due to the COVID-19 pandemic, workshops in India and Malaysia were cancelled, so that this chapter introduces the results of only two workshops held in Thailand and Brunei Darussalam.

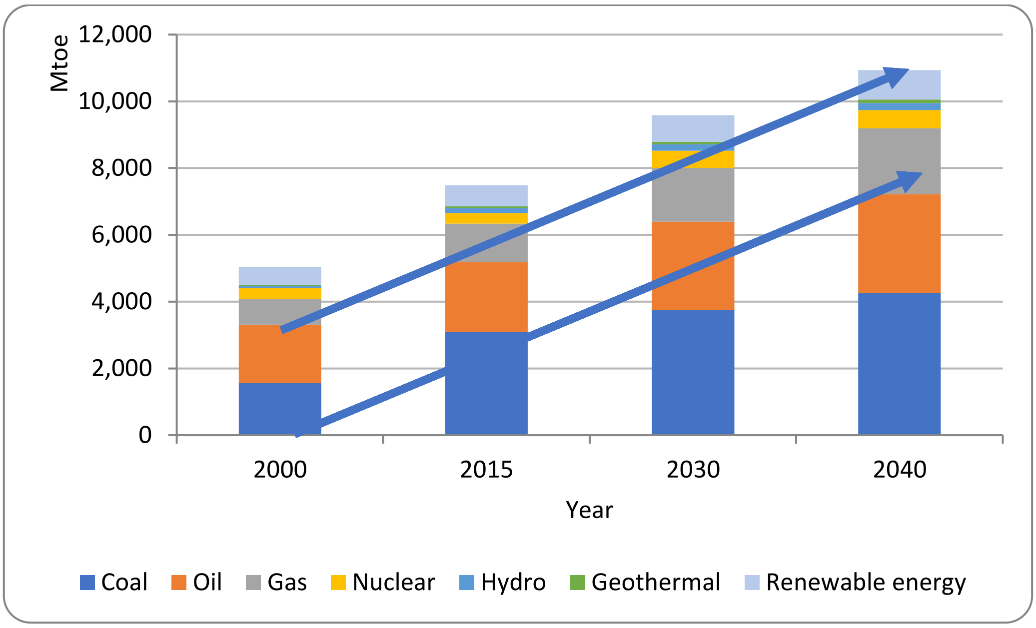
## 1. Hydrogen: A Potential Energy Source – Supply and Demand Outlook to 2040

ERIA was invited to a public seminar of the Petroleum Institute of Thailand (PTIT), which is organised regularly in Bangkok, to present the major outcomes of its study on the demand and supply sides of hydrogen potential, specifically on phase 1 conducted in 2018–2019. The seminar was held at the PTT Auditorium, PTT Building on 30 May 2019 (13:30–16:00). Kurujit Nakornthap, PTIT Executive Director, delivered the opening remarks, followed by presentations of speakers from ERIA. Around 180 participants from Thailand attended the seminar. After ERIA's presentations, several meaningful questions on electric vehicles vs FCVs, amongst others, were raised. This section summarises ERIA's presentations at the PTIT public seminar.

### 1.1. Introduction

According to the EAS energy outlook produced by ERIA, the total primary energy supply (TPES) will increase from 7,487 Mtoe in 2015 to 10,931 Mtoe in 2040. The annual growth rate will be 1.5% (1.46 times) and it will be lower than 3.5% of GDP growth rate in the same period. The share of fossil fuels consisting of coal, oil, and gas will be more than 80% in 2040, and it was the same as 2015 (Figure 6.1). In this regard, $CO_2$ emissions will also increase 1.5% yearly, the same as the TPES.

**Figure 6.1: Future Projection of TPES, Mtoe**




RE = renewable energy, TPES = total primary energy supply.
Source: ERIA (2019).

Consequently, the most important energy policies in the EAS region are the promotion of energy efficiency and conservation (reducing fossil fuel consumption) and the shift to low carbon energy (reducing $CO_2$ emissions) such as nuclear power generation and renewable energies. Hydrogen is one of the renewable energies. Currently, it is being highlighted to contribute to the reduction of $CO_2$ emissions due to the following reasons:

1) Zero $CO_2$ emissions
Hydrogen bonds with oxygen to generate electricity/heat, with water being the only by-product.
2) Unlimited supply
Hydrogen can be extracted from a wide range of substances such as oil, natural gas, biofuels, sewage sludge, and can produce unlimited natural energy through water electrolysis.
3) Storage and transportation
Hydrogen can be stored for a long period (from summer to winter) because is not depleted and can be transported long distance (from south to north).

In this regard, ERIA conducted a study on hydrogen potential with the following research contents:

1) Introduction of representative hydrogen projects in Japan
2) Forecasting future hydrogen demand potential
3) Forecasting future hydrogen supply potential, including its supply costs
4) Well-to-wheel analysis on the economics and emissions of fuel cell vehicles (FCVs).

## 1.2. Introduction of representative projects in Japan

Japan depends on overseas fossil fuels for about 94% of its primary energy supply. Therefore, electricity sourced from renewable energy has been gradually increasing and accounted for 15% of Japan's total power generation in FY2016 in consideration of the need to reduce greenhouse gas (GHG) emissions. As a result, Japan's Fifth Basic Energy Plan emphasised the importance of renewable energy to account for 22%–24% of total power generation. The plan also includes a goal to raise Japan's energy self-sufficiency rate to about 24% by 2030.

Hydrogen can potentially diversify Japan's primary energy supply structure and substantially reduce its use of carbon. To promote the widespread use of hydrogen and enable Japan to become a world-leading hydrogen-based society, the government formulated the Basic Hydrogen Strategy in December 2017. The strategy outlines the vision for the year 2050 and serves as an action plan through the year 2030. On 23 October 2018, the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO) jointly held the Hydrogen Energy Ministerial Meeting in Tokyo. It was the first ministerial meeting to discuss the realisation of a hydrogen-powered society as its main subject. As the latest activity of government policy, on 12 March 2019, the Council for a Strategy for Hydrogen and Fuel Cells renewed the existing Strategic Road Map for Hydrogen and Fuel Cell to achieve the goal set forth in the Basic Hydrogen Strategy and the Fifth Strategic Energy Plan: the realisation of a hydrogen-based society.

Under these circumstances, NEDO, as one of largest public agencies promoting national research and development (R&D) projects, conducts the following projects to realise the shift to a hydrogen society:

**Polymer electrolyte fuel cell (PEFC)**: The main objective of the project is to reduce usage costs for transportation means such as FCVs, since the PEFCs for such use need the highest level of reliability for use in commercial vehicles.

**Solid oxide fuel cell (SOFC)**: The project is being undertaken to reduce cost and improve the durability of SOFCs as well as develop the technology of larger-scale SOFC systems.

**Hydrogen refuelling station (HRS)**: The actual operation of HRS in Japan has provided various hints to resolving issues related to cost reduction of capital expenditure (CAPEX) and/or operating expense (OPEX). A regulatory reform of FCV/HRS is one such approach. Unstaffed operation with remote monitoring is one solution. However, a risk assessment on HRS needs to be considered deeply. Developing low-cost equipment such as polymer materials for dispensers and electrochemical compressors is an important target as well.

**Large-scale supply chain**: NEDO is focusing on hydrogen power generation that can generate power from hydrogen combustion in a gas turbine to provide electricity and thermal energy in residential areas in Kobe city. To develop a large-scale supply chain, NEDO has embarked on technological development to convert unused energy from overseas into hydrogen and transport this hydrogen long distance to Japan. Therefore, NEDO selected two types of hydrogen carriers: one is liquid hydrogen from Australia, and the other is organic chemical hydrides from Brunei in a large-scale demonstration project.

**Power-to-gas (P2G)**: NEDO conducts several P2G projects. One example is the world's largest-scale P2G demonstration with 10-MW electrolysis in Fukushima Prefecture. Hydrogen generated from renewable energy will be stocked and delivered to other areas for utilisation, such as in the Tokyo Olympic/Paralympic Games in 2020.

### 1.3. Hydrogen demand potential

The hydrogen supply chain has many uncertainties due to varying promotion policies, utilisation technologies, transportation and distribution logistics, and costs. This study refers to various available resources, the latest hydrogen use and technology trends, and other demand estimation documents. ERIA's energy outlook estimated the hydrogen demand potential in 2040 according to following assumptions and scenarios.

**1) Assumptions and Scenarios**

**a) Basic assumptions**

- The national hydrogen pipeline, as well as refuelling stations, will only be partially established in 2040.
- Ammonia is excluded.
- Commercialised $H_2$ utilisation technologies in 2040:
  - ✔ $H_2$ and natural gas mixed fuel gas turbine
  - ✔ $H_2$ and natural gas mixed fuel large-scale boiler
  - ✔ Passenger fuel cell vehicle (PFCV)
  - ✔ Fuel cell bus (FCB)
  - ✔ Fuel cell train (FCT)

**b) Assumptions of the electricity generation sector**

Twenty percent of new coal-fired and natural gas–fired electricity generation will be converted to natural gas and hydrogen mixed fuel-fired generation. Three scenarios are developed, which consist of hydrogen concentration of mixed fuel, 10%, 20%, and 30%.

**c) Assumptions of the industry sector**

Twenty percent of natural gas consumption for industrial purposes will be replaced by natural gas and hydrogen mixed fuel. Scenarios are the same as those of electricity generation.

**d) Assumptions of the transport sector**

Transport fuel demand will be converted to hydrogen. Scenarios consist of the share of hydrogen.

**e) Scenarios of PFCV**

Gasoline demand will be converted to hydrogen.

| Scenario | 1 | 2 | 3 |
|---|---|---|---|
| OECD | 2.0% | 10% | 20% |
| Non-OECD | 1.0% | 5% | 10% |

OECD = Organisation for Economic Co-operation and Development.
Source: Author.

**f) Scenarios of FCB**

Diesel demand will be converted to hydrogen.

| Scenario | 1 | 2 | 3 |
|---|---|---|---|
| Japan | 0.05% | 0.1% | 0.2% |
| Others | 0.025% | 0.05% | 0.1% |

Source: Author.

**g) Scenarios of FCT**

Diesel consumption for rail transport will be converted to hydrogen.

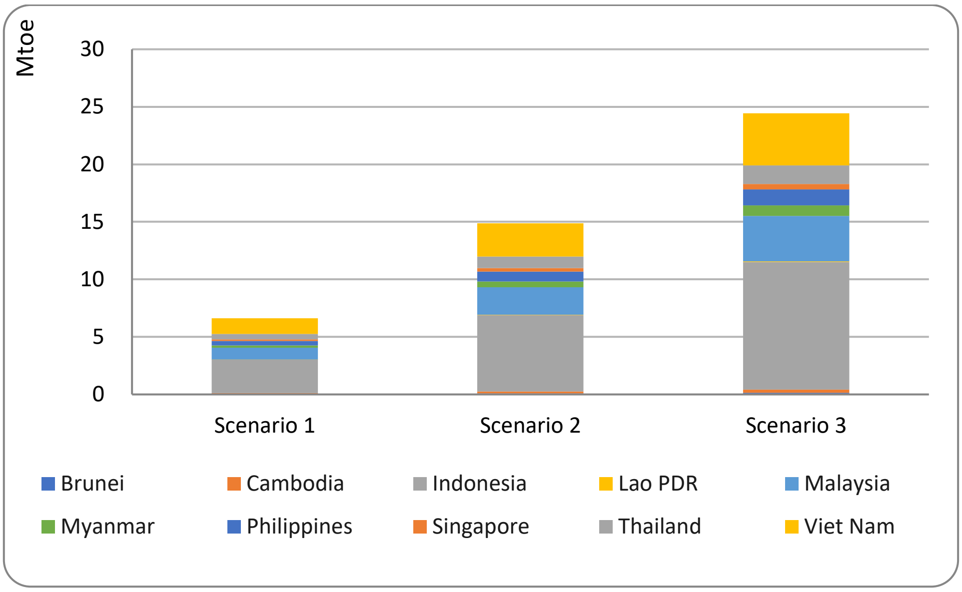
| Scenario | 1 | 2 | 3 |
|---|---|---|---|
| ASEAN | 5% | 10% | 20% |

Source: Author.

### 2) Hydrogen Demand Potential in ASEAN

Indonesia has the largest hydrogen demand potential amongst ASEAN member countries, followed by Malaysia and Viet Nam. Thailand has the fourth-largest hydrogen demand potential in ASEAN (Figure 6.2).

**Figure 6.2: Forecasted Hydrogen Demand (2040)**

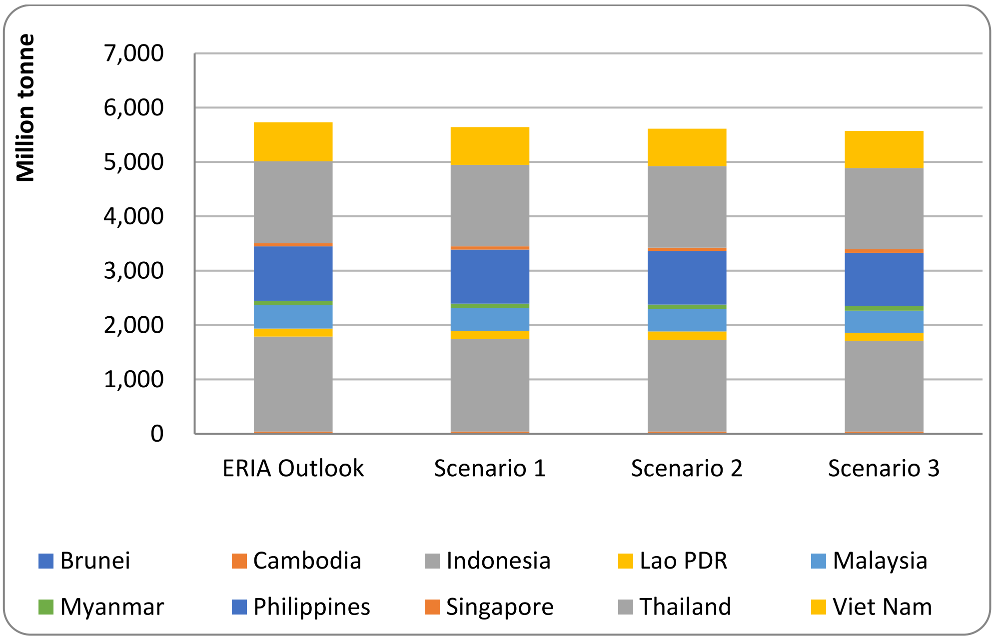



Source: Author.

### 3) $CO_2$ Emission Reduction in ASEAN

$CO_2$ emission can be reduced by up to 2.7% depending on the scenario, compared to the ERIA benchmark outlook. The $CO_2$ emission reduction rate of Thailand is smaller than the ASEAN average, –0.2%, –0.4%, –0.5% in respective scenarios (Figure 6.3).

**Figure 6.3: Forecasted $CO_2$ Reduction, by Scenario**




Source: Author.

### 1.4. Potential and Costs of Hydrogen Supply

There is enough potential to supply hydrogen to satisfy demand in the EAS region, including trading within the region.

In the early stages, the major hydrogen source will be fossil fuels and stable hydro and geothermal power generation. This will largely shift to abundant renewable energy as a result of technological and market development.

Hydrogen supply chains are assumed to start from supply-intensive countries to Japan, Korea, with some local supply chains in China and India. These will expand their network globally and locally in the EAS region in 2040–2050.

#### 1) Hydrogen Production Method

Hydrogen can be produced from any kind of primary energy, from fossil fuels to renewables.

Three major fossil fuel production methods are by-product hydrogen from petrochemical industry, reformed hydrogen from gas, and gasified hydrogen from coal and petroleum liquid or solid products.

It is important to effectively manage the $CO_2$ resulting from hydrogen production from fossil fuels. $CO_2$ can be used for carbon capture utilisation and storage (CCUS) or carbon capture and storage (CCS).

Renewable electricity can be converted to hydrogen through water electrolysis; biomass can also produce hydrogen via gasification.

In the future, new technology, such as biotechnology and photocatalysts, will be expected to diversify and increase the options to produce hydrogen from renewables.

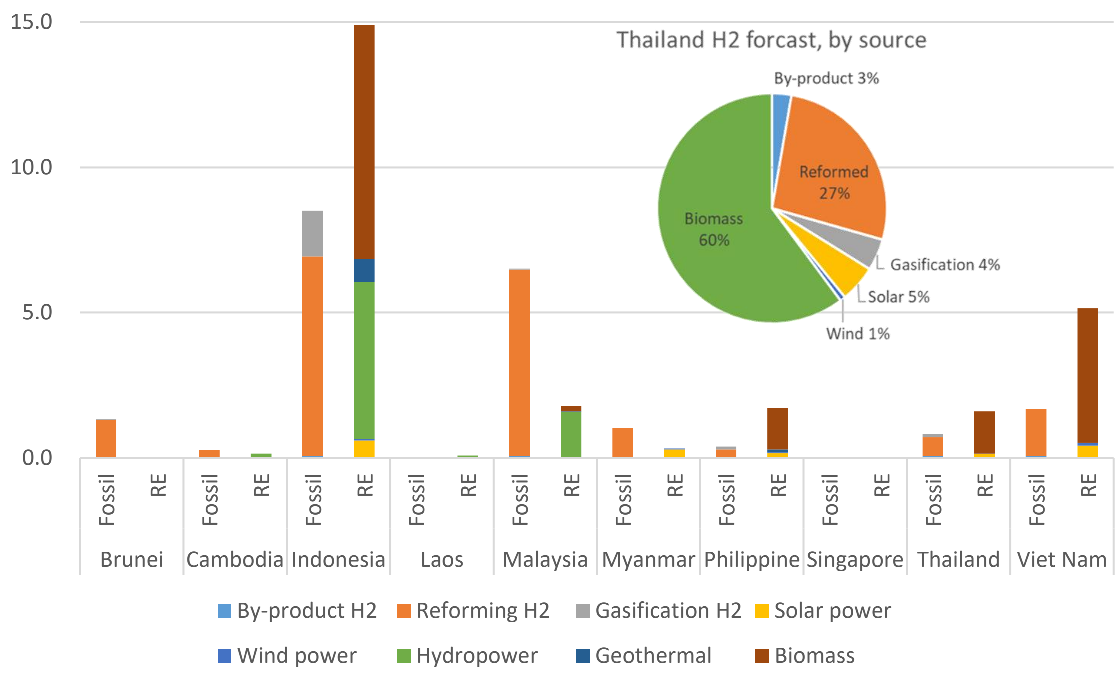
#### 2) Hydrogen Production Forecast in 2040 (ASEAN)

In 2040, the ASEAN region is forecasted to produce 50 Mtoe of hydrogen, with Thailand accounting for 4.8% of the share, the fourth-largest producer in this region.

As a source of hydrogen in Thailand, renewable energy accounts for 66%; biomass gasification takes the largest share at 91%, followed by photovoltaics (PVs) at 8%.

Amongst fossil fuel–derived hydrogen (remaining 34%), reformed hydrogen takes the largest share at 78%, followed by vacuum residue or coke gasification hydrogen at 13%.

**Figure 6.4: Hydrogen Production Potential (2040)**



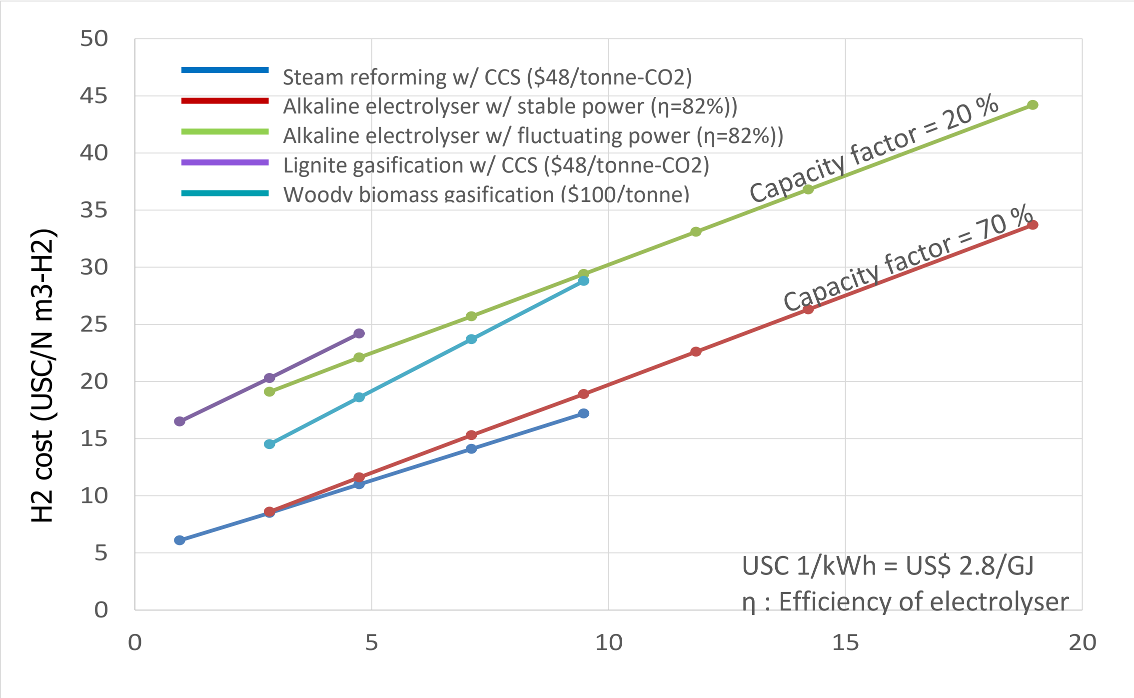

H2 = hydrogen, Lao PDR = Lao People's Democratic Republic, PV = photovoltaics, RE = renewable energy.
Source: Author.

### 3) Hydrogen Production Cost

Figure 6.5 illustrates the hydrogen production costs by production method. Hydrogen production cost by gas reforming is the most economical method, depending on CCUS availability. Water electrolysis with a high capacity factor plus a low feedstock price will enhance its cost competitiveness.

Lignite gasification with CCS and woody biomass gasification shows the same level of hydrogen production cost; water electrolysis with a low capacity factor shows the highest range.

**Figure 6.5: Hydrogen Production Cost (2040), by Feedstock Price**



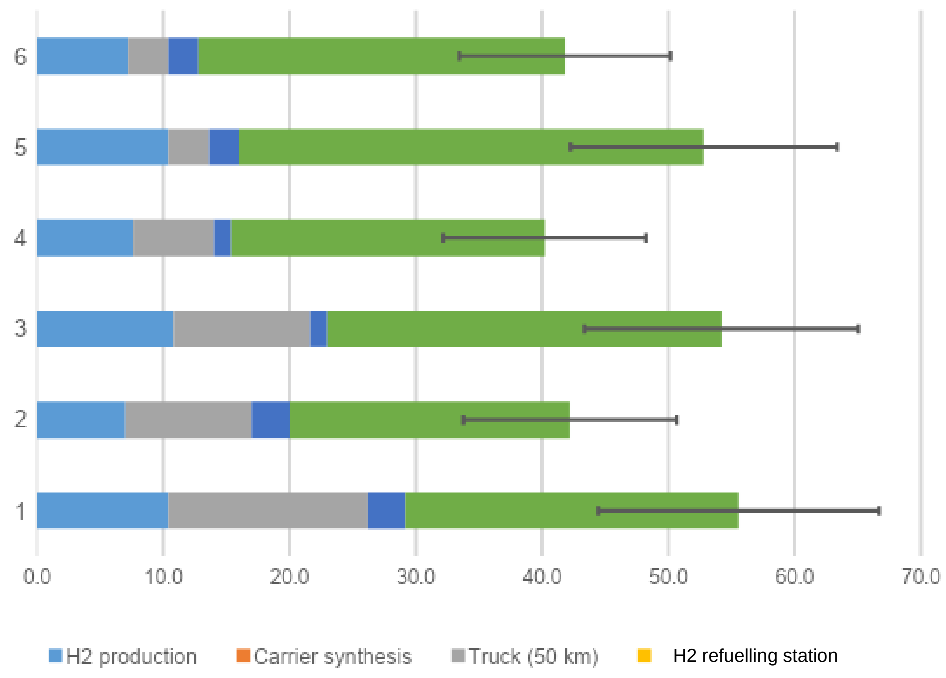

CCS = carbon capture and storage.
Source: Author.

### 4) Local Hydrogen Supply Chain Cost

Figure 6.6 shows an example of the costs of a local hydrogen supply chain using the selected carriers. The costs include the use of large-scale hydrogen production with carrier synthesis, and smaller scale distribution with truck transport of 50 km to hydrogen refuelling stations (HRSs).

The costs from the lowest in 2020–2030 will be in the order of methylcyclohexane (MCH), ammonia (NH3), and liquified hydrogen (LH2). NH3 will have the lowest cost in 2040–2050.

**Figure 6.6: An Example of Local Hydrogen Supply Chain Cost**

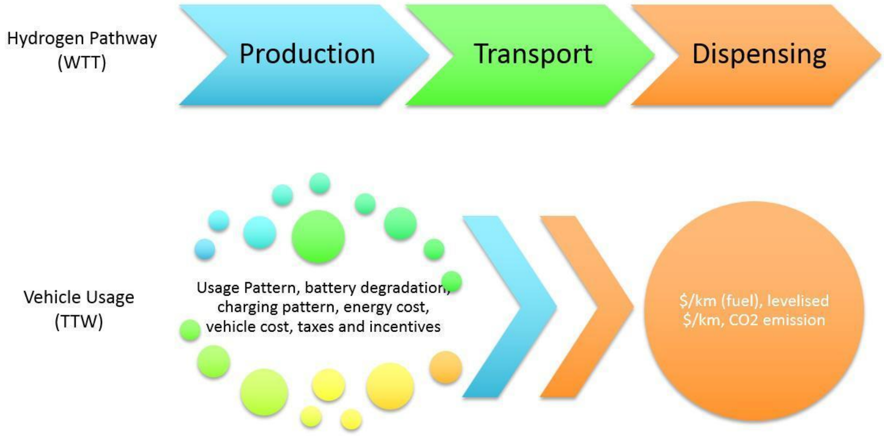



H2 = hydrogen.
Note: The data were customised based on the Institute of Applied Energy (2016).
Source: Author.

### 1.5. Well-to-wheel (WTW) analysis on the economics and emissions of FCVs

This study builds a WTW model to capture the energy production and consumption process, as well as the costs and emissions involved. Based on the WTW concept, a total cost of ownership (TCO) is further developed to access the cost of owning, as well as driving, a vehicle through its lifetime. The studied vehicle fleets include midsized passenger cars, buses, and heavy-duty trucks.

**Figure 6.7: Well-to-Tank, Tank-to-Wheel, and Total Cost of Ownership**




TTW = tank-to-wheel, WTT = well-to-tank.
Source: Authors.

Figure 6.7 shows the relationship between the WTW model and the TCO model. Basically, TCO is integrated into the tank-to-wheel part of the WTW.

Table 6.1 presents the primary energy consumption per km, carbon emissions per km, TCO per km, as well as fuel cost per km of fuel cell electric vehicles (FCEVs) consuming hydrogen produced from several ways mentioned in section 6.1.4 , compared with those of the vehicles with alternative power trains under the current circumstances. The numbers presented are the outcome of an unweighted average of all ASEAN countries. Detailed results for each country are available upon request.

**Table 6.1: Current Energy Consumption, $CO_2$ Emissions, TCO, and Fuel Cost, by Vehicle Type**

| | | WTW Primary Energy (kWh/km) | WTW $CO_2$ Emissions (kg/km) | TCO ($/km) | Fuel Cost ($/km) |
|---|---|---|---|---|---|
| Passenger Cars | FCEV | 0.528 | 0.109 | 0.684 | 0.083 |
| | BEV | 0.223 | 0.093 | 0.529 | 0.024 |
| | PHEV | 0.415 | 0.146 | 0.454 | 0.050 |
| | ICEV | 0.392 | 0.132 | 0.326 | 0.048 |
| Buses | FCEV | 1.401 | 0.290 | 2.658 | 0.220 |
| | BEV | 1.587 | 0.662 | 1.110 | 0.170 |
| | PHEV | 2.537 | 0.886 | 1.515 | 0.305 |
| | ICEV | 4.700 | 1.586 | 1.289 | 0.576 |
| Trucks | FCEV | 7.076 | 1.463 | 2.037 | 1.109 |
| | BEV | 1.521 | 0.635 | 0.648 | 0.163 |
| | PHEV | 2.777 | 0.937 | 0.688 | 0.340 |
| | ICEV | 3.610 | 1.219 | 0.728 | 0.442 |

BEV = battery electric vehicle, FCEV = fuel cell electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle, TCO = total cost of ownership, WTW = well-to-wheel.
Source: Authors.

Table 6.2 presents the results of the future scenario (by 2030) from our model.

**Table 6.2: Future Energy Consumption, $CO_2$ Emissions, TCO, and Fuel Cost in 2030, by Vehicle Type**

| | | WTW Primary Energy (kWh/km) | WTW $CO_2$ Emissions (kg/km) | TCO ($/km)) | Fuel Cost ($/km) |
|---|---|---|---|---|---|
| Passenger Cars | FCEV | 0.528 | 0.109 | 0.376 | 0.046 |
| | BEV | 0.223 | 0.093 | 0.531 | 0.040 |
| | PHEV | 0.415 | 0.146 | 0.484 | 0.090 |
| | ICEV | 0.392 | 0.132 | 0.294 | 0.090 |
| Buses | FCEV | 1.401 | 0.290 | 1.426 | 0.123 |
| | BEV | 1.587 | 0.662 | 1.184 | 0.283 |
| | PHEV | 2.537 | 0.886 | 1.755 | 0.550 |
| | ICEV | 4.700 | 1.586 | 1.912 | 1.208 |
| Trucks | FCEV | 7.076 | 1.463 | 1.167 | 0.622 |
| | BEV | 1.521 | 0.635 | 0.691 | 0.271 |
| | PHEV | 2.777 | 0.937 | 0.969 | 0.621 |
| | ICEV | 3.610 | 1.219 | 1.114 | 0.831 |

BEV = battery electric vehicle, FCEV = fuel cell electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle, TCO = total cost of ownership, WTW = well-to-wheel.
Source: Authors.

In conclusion, the higher TCO of FCEVs is driven by the very high CAPEX of the vehicles. The adoption of FCEVs must also bear higher costs for the services of fuel transportation and dispensing.

Hydrogen production pathways are not competitive yet, except for those based on natural gas, coal, and biomass, with current level of technologies.

But all these disadvantages are highly likely to be overturned as continuous R&D brings about technological breakthrough, combined with the effects of learning curve and economy of scale, when the hydrogen supply chain, hydrogen transmission and distribution infrastructure, and manufacturing of FCEVs enter commercial operation.

If the GHG emissions benefit of renewable energy–based hydrogen supply chains is considered, the advantages of hydrogen will further boost its competitiveness against other alternative power trains.

### 1.6. Policy recommendations and way forward

Based on the study results, the following policy recommendations and way forward are extracted:

1) Many EAS countries, especially developing ones, do not have a clear hydrogen policy. Because these countries have many energy choices which are fossil fuel, biomass, renewable energy such as hydropower and new energy, such as solar PV. In this regard, hydrogen is one of their choices and ERIA should pay attention to this. A comparison study on cost and $CO_2$ emissions between hydrogen and other energy will be implemented for these countries.
2) Hydrogen demand fully depends on its supply costs and prices of FCV and hydrogen power generation system. In this study, ERIA applied the scenario approach for penetration of hydrogen demand. However, it is recommended that, after deeper research on FCV and hydrogen power system, with collaboration of their experts, the scenario will be revised.
3) Hydrogen supply costs at the station are forecasted at US\$0.40–0.50/$Nm^3$ but it is still higher than US\$0.30/$Nm^3$ which is the target of Japan's Basic Hydrogen Strategy. The higher price comes from higher transport cost. Consequently, an in-depth study on hydrogen transportation including technology research will be necessary. Technology to separate hydrogen and chemical products at low cost might be crucial.
4) Places of hydrogen demand are usually different from hydrogen production sites. The study extracted Australia, Brunei, Indonesia, Sarawak of Malaysia, and New Zealand as hydrogen production sites. On the other hand, Japan and Korea have large hydrogen demand. Consequently, to establish overseas hydrogen supply chains, the following studies are needed: (i) standardisation of transport method, (ii) investment to shipping and receiving terminals, and (iii) seeking for large-scale hydrogen production and transportation amounts.
5) In this regard, a working group (WG) to discuss about a common understanding on hydrogen and standardisation of the supply chain will be set up and the WG meeting will be held regularly. WG members comprise EAS countries that have hydrogen production and demand potential.

## 2. The Role of Hydrogen in ASEAN's Energy Transition

Brunei Darussalam has the potential to develop hydrogen fuel as it is a renewable, secure, and reliable energy source, as mentioned by Minister of Energy Dato Seri Setia Dr Awang Haji Mat Suny bi Haji Mohd Hussein at the opening of a seminar titled 'The Role of Hydrogen in ASEAN's Energy Transition' at Empire Brunei, 20 February 2020.

The first global hydrogen supply chain funded by Japan's New Energy and Industrial Technology Development Organization (NEDO), and operated by Japan's Advance Hydrogen Energy Chain Association for Technology Development's (AHEAD), was started between Brunei Darussalam and Japan. Located in Sungai Liang Industrial Park, the plant was officially launched in November 2019; it aimed to supply 210,000 tonnes of hydrogen to a gas power plant in Kawasaki, Japan. Using Chiyoda Corporation's SPERA hydrogen technology, this hydrogenation (HGN) plant produces hydrogen from by-product gas produced during a liquefaction process from natural gas to liquefied natural gas (LNG), then transported in a conventional commercial shipping in the form of a stable compound, called methylcyclohexane (MCH).

Supporting the ASEAN Plan of Action for Energy Cooperation 2016–2025, the minister also reaffirmed Brunei's support to achieve its goal of 'enhancing energy connectivity and market integration in ASEAN' to establish energy security, accessibility, affordability, and sustainability for all. Also, Brunei will chairthe EAS Energy Ministers Meeting 2021 and will explore further hydrogen energy opportunities.

Utilising hydrogen in the transport sector is one of the main reasons for unlocking the potential of hydrogen demand. Jainatul Halida Jaidin, Acting Director of the Institute of Policy Studies, Universiti Brunei Darussalam, explained that hydrogen will be a power alternative for vehicles and bolster Brunei's effort of decarbonisation. The Ministry of Energy, working closely with the Ministry of Transport and Infocommunications, is conducting intense research on hydrogen fuel cells to fulfil the growing demand for hydrogen vehicles.

This 1-day seminar was hosted by the Brunei National Energy Research Institute , the Institute of Policy Studies and the Centre for Advanced Material and Energy Sciences under Universiti Brunei Darussalam, in collaboration with the Economic Research Institute for ASEAN and East Asia (ERIA). The seminar focused on reviewing the potential of hydrogen as a future energy in the ASEAN region, technology use provided by the Chiyoda Cooperation and Kawasaki Heavy Industries, hydrogen realisation from automotive companies, Japan's hydrogen strategies, and country updates from the ASEAN Committee on Science, Technology and Innovation.

### 2.1. Hydrogen as Future Energy by Shigeru Kimura, Special Adviser to the President on Energy Affairs, ERIA

Mr Kimura presented the results of the previous ERIA research project on the EAS Energy Outlook Framework 2017. Utilising the energy outlook model and the econometrics analysis of The Institute of Energy Economics, Japan (IEEJ), the study produced an energy outlook in the business-as-usual scenario (BAU) and the alternative policy scenario. It also includes the energy efficiency targets and the energy saving potential report.

Macro assumptions of ASEAN as basis of the study from 2015 to 2040 encompassed (i) economic growth (4.8% per year); (ii) population growth (0.9% per year, or 634 million people in 2015 to increase to 786 million in 2040); (iii) GDP per capita (from US$4.4 thousand per person in 2015 to US$11.6 thousand per person in 2040 (constant 2010 price and US$); and (iv) crude oil price – nominal price (to increase to around US$125 per barrel (2016 constant price) in 2040 due to a tight balance between demand and supply in the future).

Key findings based on the energy modelling analysis are as follows: under BAU, the total final energy consumption will rise around 3.7% per year by 2040, with the oil and electricity sectors as the primary energy source; coal power generation will be utilised around 53% by 2040; and renewable energy will also remarkably increase. For the TPES under BAU, the share of fossil fuels (including coal, oil, and gas) will be around 84% in 2040. Based on the model, renewable energy will significantly increase yet its share will be around 14%, including biomass (about 8%) in 2040. Meanwhile, under the alternative policy scenario, the renewable energy target is 23% in 2040. In addition, ASEAN states are preparing energy saving goals and renewables to contribute to reducing fossil fuel consumption and carbon emissions under BAU. However, the emissions will still increase by 2040.

In response to that, hydrogen is proposed to be an alternative energy source to accelerate the reduction of carbon emissions. Hydrogen supply is unlimited because it can be extracted from a wide range of substances, including coal, oil, natural gas, biofuels, and sewage sludge, and can be generated from water electrolysis.

Additionally, in producing hydrogen, we need to focus on different unused energy sources, which have potential but lack capacity to utilise them. These unused sources are from flared gas, low-ranked coal (such as lignite), renewable energy electricity (i.e. hydropower stations, solar PV), and electricity from nuclear power plants.

Hydrogen in the future is expected to fulfil demand in the following sectors:

1) Road transport: FCVs (hydrogen vehicles)
2) Rail transport: FCTs
3) Power generation: natural gas and hydrogen mixed or 100% hydrogen fuel
4) Industrial heat demand: as substitute for natural gas, diesel oil, and LPG (liquefied petroleum gas)
5) Household or commercial: fixed-type fuel cell facility (cogeneration of electricity and heat)

If hydrogen can replace the oil source in the transport sector as well as coal and gas in the power generation sector, the amount of $CO_2$ emission will reduce significantly, particularly in the ASEAN region. Hydrogen is predicted to reduce the emission up to 370 Mtoe, which emission is generated by oil consumption in the transport sector in 2040. In the electricity sector, the emission will be reduced up to 360 Mtoe and 180 Mtoe from coal and gas generation, respectively, in 2040.

One advantage of hydrogen is that it can be stored throughout the year regardless of the seasons and can be transported long distance for distribution purposes. The main challenges of hydrogen production are to make hydrogen production and consumption economically viable, financially attractive, and socially beneficial. The main obstacles of expanding hydrogen production lie on the technology costs to utilise, such as liquid hydrogen (LH2), NH3, and chemical hydride (MCH) from fossil fuel and renewable energy as well as the transport costs for distribution.

Two factors should be considered in deciding the transportation options for distributing hydrogen: delivery volume (MJ/year) and distance (km). For domestic use, pipelines, trucks, and trains can be potential modes to distribute compressed gas, liquid or chemical carrier mode. Ships can also be an option for domestic distribution, especially for the archipelagic country. Moreover, for global distribution, a designated ship is suggested to be used to deliver hydrogen in liquid or chemical form.

We can learn from the hydrogen strategy of METI because, since 2017, Japan has been scaling up hydrogen use and allocating it to generate power and for transport. In 2020, Japan is targeting to develop an international hydrogen supply chain, establish hydrogen-derived domestic renewable energy, and fossil fuel–derived hydrogen production technology. Above all, the main goals of Japan's hydrogen production are to generate $CO_2$-free hydrogen using advanced technology and renewable energy.

### 2.2. Hydrogen demand and supply potential

This session was divided into two presentations: hydrogen demand potential, presented by the IEEJ representative, and hydrogen supply potential and production infrastructure by Chiyoda Corporation.

*Hydrogen Demand Potential, by Mitsuru Motokura, The Institute of Energy Economics, Japan (IEEJ)*

IEEJ analysed the hydrogen demand potential of EAS countries under the following basic assumptions:

1) A nationwide hydrogen pipeline will be partially established in 2020 as well as HRSs.
2) Ammonia, as the hydrogen carrier for combustion purposes, is excluded in the analysis as well as hydrogen for generating ammonia and/or methanol.
3) The scheme of commercialised and prevailing hydrogen technologies in 2040 will be:
    - Hydrogen and natural gas mixed fuel gas turbine
    - Hydrogen and natural gas mixed fuel large-scale boiler
    - PFCV

- FCB
- Fuel cell train (FCT)

This study identified the potential demand of hydrogen from major sectors: electricity generation, industry, and transport.

In the electricity generation sector are three scenarios, each of which is differentiated by different percentages of hydrogen concentration (10% under scenario 1, and 20% and 30% under scenarios 2 and 3, respectively). Hydrogen demand will increase by around 20% in 2040 utilising the mixed fuel natural gas and hydrogen methods. These scenarios are also applied to the industry sector.

For the transport sector, three different scenarios are based on assumptions of hydrogen use shares on conventional transport fuels, which are PFCV, FCB, and FCT. In Japan, in 2040, around 2% of gasoline-powered passenger vehicles will be converted to hydrogen-based vehicles. Meanwhile, 0.1% of diesel consumption for the transport sector and 10% for rail transport will be utilised by hydrogen.

Summarising the results of the study, Indonesia has the largest demand potential in the ASEAN region, followed by Malaysia and Viet Nam. Meanwhile, China has the largest demand potential in the EAS region. In Brunei Darussalam, the electricity sector will generate the highest demand for hydrogen, which is estimated at 0.04 Mtoe, 0.09 Mtoe, and 0.14 Mtoe under scenarios 1, 2, and 3, respectively. The next potential demand comes from the transport and the industry sectors.

The study also analysed the competitive price of hydrogen from the demand side perspective by comparing differences in CAPEX and OPEX (except fuel) with conventional energy. For the electricity generation sector, the calculation entails comparing it with fossil fuel import prices. In the industry sector, it is compared only with current natural gas sales price for industry in Japan. Lastly, only a comparison with current gasoline retail rice in Indonesia and Japan is applied to the transport sector. It is important to reduce the hydrogen cost to make it economically feasible and, hence, able to penetrate market.

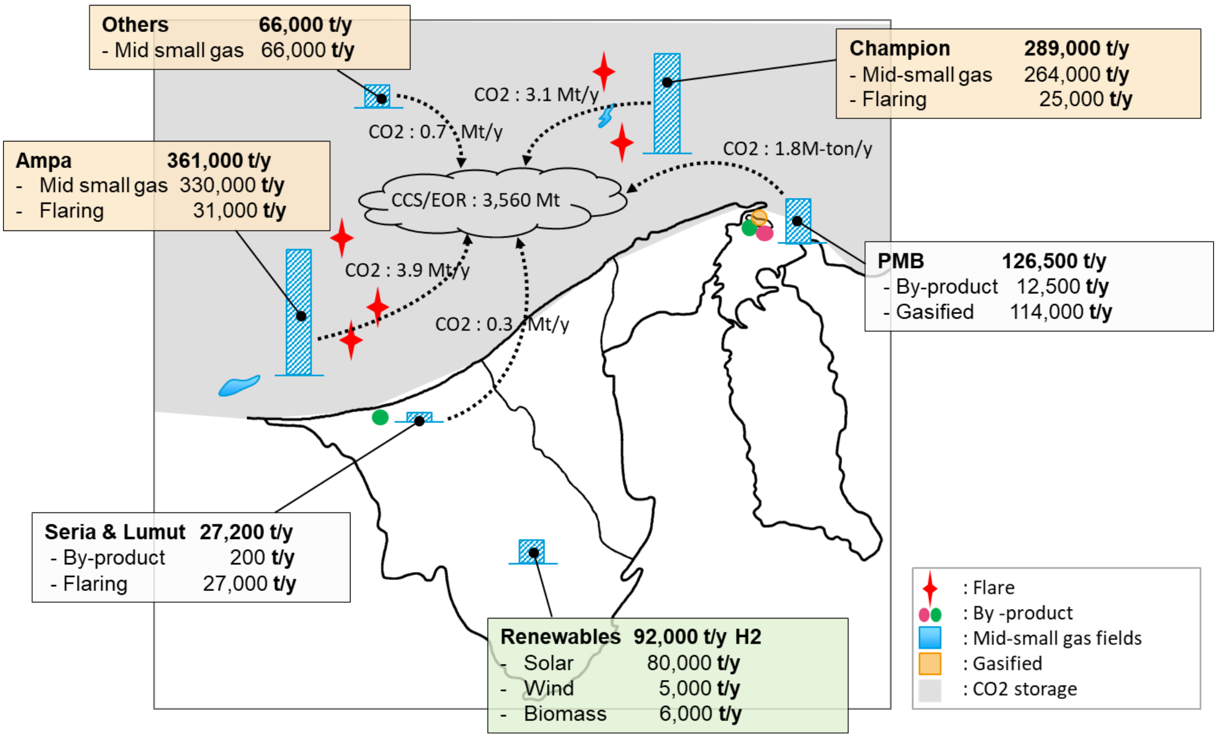
As the impact of hydrogen penetration will reduce $CO_2$ emission, in Brunei Darussalam, the reduction is estimated to reach 0.3 million tonnes-$CO_2$ under scenario 1, 1.05 million tonnes-$CO_2$ in scenario 2, and 0.7 million tonnes-$CO_2$ in scenario 3. By sector, electricity generation will contribute the most, followed by the transport and the industry sectors. The economic impact of $CO_2$ emission reduction will reach around US$20 million in 2040 on average.

*Hydrogen Supply Potential and Production Infrastructures in ASEAN and Brunei Darussalam, by Osamu Ikeda, Chiyoda Corporation*

In the EAS region, there is enough potential to supply hydrogen to meet the demand. Positioning the 16 EAS countries for hydrogen trading in 2040, five + one countries/region will potentially be in hydrogen 'exporting', including Australia, Indonesia (Eastern Region), Malaysia (Borneo), Brunei, New Zealand, and Lao PDR (export by electricity); four countries will be in hydrogen 'importing', including Japan, Korea, Malaysia (Peninsula), and Singapore and the rest of the countries will be as 'intra-regional' group, which are China, India, Indonesia (Java, Sumatera Island), Thailand, Philippines, Viet Nam, Myanmar, and Cambodia. The potential of hydrogen production is enough to fulfil the 2040 demand forecast, and exporting countries are expected to be able to cover the demand from importing countries. Meanwhile, the intra-regional trading countries could satisfy their domestic demand.

Brunei can potentially generate hydrogen mainly from natural gas, residues, and coke for large-scale production. Furthermore, hydrogen production from by-product, solar, and biomass are expected to fulfil the domestic supply. The engineering company, Chiyoda Corporation, had mapped the hydrogen potential resource in Brunei (Figure 6.8).

**Figure 6.8: Brunei Hydrogen Resource Map**




Source: Chiyoda Corporation presentation (2020).

In the early stage of the development, hydrogen will be generated mainly from fossil fuels or from stable hydro or geothermal and partially from renewable energy, such as solar or wind power, to supply local needs. However, in the future, a shift to abundant renewable energy is expected because of technology advancement and market development.

In 2020–2030, local supply chain and global trading to Japan will start. The global hydrogen energy supply chain network is expected to expand to the EAS region by 2040–2050. Moreover, to establish the global hydrogen market and supply chain in the EAS region, Chiyoda proposed a national and regional policy approach, as follows:

**1) National Policy**

a) Establish a national hydrogen strategy and road map, aimed at introducing hydrogen into the national energy market from the technical to the market and business perspectives.

b) Enhancing government support, including the introduction of financial support (tax incentives, lending support, etc.) and market mechanisms (carbon trading), especially in the early stages of development.

c) Establishing an awareness programme to enlighten key organisations and the public so that all stakeholders have a common understanding to be part of the hydrogen market.

**2) Regional Policy**

***Standardisation****:* Labelling the carbon reduction value of hydrogen, price determination, volume unit for global trading and statistic, and technology development as well as its safety standards.

### 2.3. Hydrogen Utilisation: Perspectives from the Transport and Power Generation Sectors

The following section elaborates the utilisation of hydrogen in the transport sector, as presented by the Toyota Motor Corporation as Japan's representative, and the Kawasaki Heavy Industries as the representative of the power generation sector.

*Toyota's Initiatives for the Realisation of a Hydrogen-based Society, by Akihito Hayasaka, Toyota Motor Corporation, Japan*

Toyota sets zero $CO_2$ emissions challenges by 2050 to support the Sustainable Development Goals. The emission challenges urge to target producing zero-$CO_2$ emission new vehicles to be applied at all Toyota plants worldwide by 2050. Since 2010 when the fuel economy (km/litre) standards have been tightened, Toyota has started increasing the production of electric vehicles to achieve the targets. Besides, it has also improved the operations at its plants by applying the low-$CO_2$ production technologies and daily kaizen (continuous improvement), as well as utilising renewable energy and hydrogen source.

In 1997, Toyota became the world's first mass producer of hybrid electric vehicles. This did not stop Toyota from innovating to produce more low-carbon emission vehicles. Using the hybrid technology as basis, Toyota started producing plug-in electric vehicles, battery electric vehicles, and FCEVs Toyota targets to make available the electrified version of all vehicle models at around 2025.

Mr Hayasaka elaborated the advantages of FCEVs apart from its zero emissions. FCEVs have solid performance in cold conditions, which means hydrogen storage will not be an issue during winter. The refuelling time is fast, only around 3–5 minutes. Their cruising distance is long range, around 312 miles. Also, FCEVs can be a power supply of electricity.

Toyota Mirai, established at the end of 2014, was the first FCEV. In its first 5 years, about 10,000 units were sold in Japan, the US, and Europe. Later, the sales volume will increase to more than 30,000 per year by 2020 onwards. To achieve this target, Toyota is currently expanding the fuel cell production facilities to further produce more FCEVs, FCBs, and fuel cell forklifts. Additionally, FCEV diversification will trigger more demand on hydrogen production.

Toyota also dedicated to establishing a low-carbon hydrogen plant, starting from the Toyota's Motomachi plant that produces fuel cell forklifts. The Motomachi plant has a newly established on-site hydrogen station to produce low-carbon hydrogen. This station receives gas and electricity supply from Chita city that generates city gas from biogas and Toyota city that produces electricity from biomass combustion. Throughout these low-carbon processes, the Motomachi plant has iproduced 72 units of fuel cell forklifts.

To enable the hydrogen environment and society, it is crucial to engage all stakeholders from the automotive industry, customers, governments, and academia, such as universities and research institutes, to create hydrogen demand. On the supply side, the reduction of operational costs, as well as the improvement of operation rates and optimisation of transport methods, is needed to make hydrogen supply affordable. Besides, hydrogen demand can be expanded by reducing the fuel cell system costs and expanding fuel cell mobility and hydrogen use at plants. Governments, therefore, must accommodate both sides by accelerating the revisions of regulations that support hydrogen utilisation, enacting related regulations regarding $CO_2$ reduction in other sectors, and providing incentives and tax benefits. If a society of diverse energy sources has been established, slowly fossil fuel consumption will be reduced, and hydrogen and other renewable energy sources can be maximised.

*Development of Hydrogen Supply Chain and Gas Turbine Project, by Ryo Chishiro, Kawasaki Heavy Industry, Ltd., Japan*

Based on the Paris Agreement, the power generation sector is required to shift from low carbon to de-carbonisation to address global warming. Japan targets to reduce $CO_2$ up to 26% by 2030 and 80% by 2050. To achieve the 2030 target, the proportion of zero-$CO_2$ emission power, such as nuclear and renewable energy, should be 44% or more in the total power generation. As such, power retailers must achieve that composition ratio based on the agreement. In 2018, the low-carbon power (non-fossil fuel) market was created. To increase low-carbon power, gas turbine power generation will play an important role to enhance the stability of the electricity grid by compensating intermittent power from renewable energies.

Fuel change from natural gas to hydrogen can also regulate the fluctuation of renewable energies without $CO_2$ emissions.

Hydrogen infrastructure technology is divided into three groups: production, transport and storage, and usage. At the production stage are two technologies: brown coal hydrogen production (through drying, pulverising, and other lignite processing technology processes), and hydrogen liquefier (using plant or urbine technology). Moreover, for the transport and storage system, ihydrogen can be employed through ultra-low temperature sealing system technology for loading system, then stored as liquefied hydrogen in the designated tanks. Liquefied hydrogen can later be transported using liquefied hydrogen cargo ships, containers, and trailers. Lastly, the hydrogen is used by gas turbines, which generate stable energy and clean combustion technology. Additionally, the liquified hydrogen has beneficial characteristics to be on large-scale transport because it has an extremely low temperature ($-253^0$ Celsius), 1/800th the volume of hydrogen gas, highly pure which means there is no need for refinement, and is a sustainable energy carrier because it is non-toxic and has no emissions.

$CO_2$-free hydrogen chains offer a stable energy supply whilst suppressing $CO_2$ emissions. The chains ensure low carbon emission from production to utilisation of hydrogen. For example, in Australia, hydrogen is produced at low costs from unused resources (brown coal) and/or abundant recyclable energy. Then the hydrogen is transported or stored in the form of liquefied hydrogen via cargo ships, containers, and storage tanks, and exported to Japan as the utilising country. In Japan, the liquified hydrogen is processed using semiconductors and solar batteries, oil refinement, and desulphurisation. It is also used in the transport sector and in power plants.

The Kawasaki Heavy Industries (KHI) have had hydrogen demonstration projects since 2014. In 2014, the 'Strategic Energy Plan' was published and in 2018 the hydrogen gas turbine cogeneration project was launched in Kobe. The pilot project demonstration is expected to be launched in 2020 and the commercial supply chain of hydrogen can be achieved in 2030. This pilot project is a bilateral cooperation between Japan (HySTRA/Technology Research Association Hydrogen Supply Chain Propulsion Mechanism) and Australia (HEA/ Hydrogen Engineering Australia).

## 2.4. Country Perspectives on Future Hydrogen: Brunei Darussalam and Japan

***Brunei Darussalam***

*Perspectives on Future Hydrogen Energy in Brunei, by a representative from the Petroleum Authority of Brunei Darussalam.*

Hydrogen is generated by different energy sources such as gas, coal, renewables, and nuclear, and has multiple applications, including in the transport, industry, and power generation sectors. However, the technical, cost of production, and operational aspects are the main challenges in commercialising its bulk production. Brunei has developed hydrogen and is currently producing about 125,000 Mt per year. The AHEAD Hydrogen Plant can produce 210,000 tonnes per year for export purposes, whilst the Hengyi Refinery and Petrochemical Plant is allocated for domestic use.

Looking at BAU, hydrogen produced in Brunei heavily relies on fossil fuels which generate GHG emissions. The power generation and the transport sectors are also the main contributors to the increase of GHG emissions. Such emissions are expected to further increase in the coming years when the demand for power generation increases due to industrial growth. Therefore, Brunei established the Brunei energy mix to speed up renewable energy to reduce its carbon footprints. Solar power is currently the primary focus of renewable energy. Meanwhile, hydrogen also provides opportunities to further achieve Brunei's commitments to tackle the impacts of climate change. An example of such combination is when hydrogen production is powered by renewable energy.

In promoting the hydrogen society in Brunei, the government developed short- and medium-term plans. In the short term, the plan focuses on making Brunei an initiator of hydrogen application, such as FCEVs in the transport sector. Research and development (R&D) is intensively conducted, for example, by studying the small-scale application of hydrogen produced by AHEAD for 2021/2022. This study will be applied in the small and mid-term plan. Also, the government conducts a comparative study on expansion or commercial scale of AHEAD plant and renewable hydrogen. For the long term, Brunei plans to combine renewable energy and hydrogen production. By then, there will hopefully be cost-competitive technology options for commercial deployment.

There are several challenges in creating hydrogen as an affordable technology. During the production process, limited resources for technology development is one challenge, specifically, in producing CCU-derived fuels for the transport sector as well as combining renewable energy and hydrogen technology for the future. This limitation encompasses funding, availability of raw materials, and proven competitive technologies. In terms of technology application, the challenges lie on creating a competitive life cycle cost, affordable infrastructure, and regulation for safer operation. Brunei aims to incorporate these challenges in its 'National Climate Change' policy.

***Japan***

*Japan's Hydrogen Strategy by Daishu Hara, representative of the New Energy and Industrial Technology Development Organization (NEDO).*

Mr Hara elaborated on NEDO's role in Japan's hydrogen development and application.

NEDO was established in 1980 under the Ministry of Economy, Trade and Industry (METI), Japan. This organisation supports the government to enhance technology and innovation development and policy formation. The development of hydrogen is necessary due to the contribution to the 3Es (environment/decarbonisation, energy security/energy independency, and economic/low-cost feedstock), and safety. Also, the government has allocated hydrogen energy as one of Japan's primary energy since 2015. Japan's 2050 vision is to make hydrogen a new energy option following renewable energies, and make it affordable, at US$2 per kg.

To achieve these goals, in 2018 during Hydrogen Energy Ministerial Meeting in Tokyo, the chair highlighted, in his Tokyo statement, four main keys: (i) collaborating on technologies and coordinating on harmonisation of regulation, codes, and standards of hydrogen development; (ii) promoting information sharing and international joint R&D; (iii) evaluating and studying hydrogen's potential across sectors; and (iv) improving communication, education, and outreach.

NEDO also established a strategic road map for hydrogen use in mobility, especially for fuel cells. Approaches to implementing the action plans mainly lie on technical improvement to expand the application of hydrogen, collaboration amongst stakeholders, and regulation of reforms to realise a global hydrogen society.

The current status of fuel cell application in Japan covers many sectors, including residential, commercial/industrial, and automotive. For residential use, 'Ene-Farm', the world's first fuel cell unit for practical home use, usually for water heaters, has set a lower selling price to boost its installation units. Then the SOFC units have been sold for commercial and industrial use since March 2019. This technology aims to increase power and heat generation efficiency. Lastly, until 2019, 3,500 FCVs were sold on-road, including around 100 units of HRSs, throughout Japan following its application on 22 FCBs, several delivery trucks, and forklift vehicles.

Moreover, strong support from the government on hydrogen development for fuel cell expansion resulted in the establishment of the Japan Hydrogen Station Network Joint Company, or Japan H2 Mobility in February 2018. This network was intended to encourage collaboration amongst various stakeholders, including automakers, infrastructure developers, and investors to develop strategic deployment of hydrogen stations, lower the cost of the stations, and improve FCV customers' convenience whilst using the HRS.

NEDO's programmes on R&D are divided into two main steps covering (i) a promotion fuel cell application, and (ii) the development of hydrogen demand and integration with the energy system. In the first step, NEDO's direction is to improve the application of fuel cells for mobility by improving its productivity and focusing on basic research to accelerate material development. The SOFCs were targeted to improve efficiency for stationary use. Meanwhile, NEDO is trying to reduce the CAPEX and/or OPEX, as well as develop low-cost equipment of the HRSs, to address regulatory reform on FCVs and HRSs in Japan. For the second step, to increase hydrogen demand, NEDO has taken several steps, including incorporating hydrogen with gas turbine (H2 gas turbine/H2GT) and improving electrolysis technology to boost power-to-gas systems.

### 2.5. Country updates from ASEAN's Committee on Science, Technology, and Innovation

A roundtable discussion in the last session was delivered by the ASEAN countries' representatives that are from the Committee on Science, Technology, and Innovation (COSTI), and is led by Romeo Pacudan from the Brunei National Energy Research Institute as moderator. The country updates of the energy policies and strategies related to hydrogen development are summarised in Table 6.3.

**Table 6.3: Country Energy Updates by COSTI's Representatives**

| Country | Policy and Strategy Updates |
|---|---|
| **Malaysia** | ● The Government of Malaysia has set hydrogen fuel cell production as a priority research since 1997.<br>● Some universities are also actively contributing to hydrogen research, indicated by the establishment of the Institute of Fuel Cell at the Universiti Kebangsaan Malaysia (UKM), and a Center of Hydrogen Energy at the Universiti of Technology Malaysia (UTM).<br>● Malaysia also established a showcase of hydrogen economy, called the Malaysian Eco-house, at the UKM. It exhibits the use of renewable energy (solar) to generate electricity and power electronic devices, fuel cells, cooking stoves, etc.<br>● In 2008, the UTM successfully developed a fuel cell motorcycle run by a 7-kilowatt fuel cell system as the motor to drive the back wheel.<br>● In 2014, the UKM first launched a body named Malaysian fuel cell indigenous motorcycle vehicle.<br>● For the policy perspectives, Malaysia has a Hydrogen Road Map 2015–2030 aiming to develop hydrogen as a source of energy and economic competitiveness. According to the road map, Malaysia planned:<br>➢ To establish the first hydrogen refuelling system (HRS) in 2009; yet, it had no station until 2015.<br>➢ In 2018, Malaysia set up the Fuel Cell Hydrogen Blueprint; yet, there are no actions, only policy related to hydrogen was established.<br>➢ To include hydrogen in the 12$^{th}$ Malaysian Plan, which will be announced in 2020.<br>● The first hydrogen production was launched in 2019 by a private company under the state government of Serawak. It is expected to produce 130 kg of hydrogen and hydrogen buses. Also, Serawak will add six more HRSs. |

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| | ● Challenges the governments face, mostly on the technical approaches:<br>➢ Hydrogen production is still at the pilot skill stage; difficult to scale up for production and efficiency, storage, and transportation<br>➢ Fuel cell quality and priorities<br>➢ Proposing more fund from the government to support the research & development (R&D)<br>➢ Intellectual exchanges with other countries<br>➢ Difficulties in commercialising hydrogen energy due to its higher cost of production and operation compared to fossil fuel, as well its public acceptance. |
| **Lao PDR** | ● The main energy sources in the Lao PDR are hydro, solar, and bioenergy.<br>● The Lao Ministry of Science and Technology has conducted several pilot projects for new energy technology, but hydrogen has not yet been included in the energy projects. The country is focusing more on maximising the current energy sources. Therefore, there are no hydrogen production and stations up to now. |
| **Singapore** | ● The national energy policy of Singapore focuses on the development of natural gas, solar power, regional power grid, and low-carbon energy, including hydrogen.<br>● The Office of the Prime Minister is conducting a feasibility study on hydrogen potential. It is looking into the operational, R&D, and hydrogen policy recommendations. The report on this study is planned to be released in July 2020.<br>● Singapore plans to import hydrogen from other countries. |
| **Thailand** | ● Thailand has been developing fuel cell technology since 1992, generating hydrogen from the Bangkok Coal Power Plant. However, it is not yet for commercial purposes.<br>● Thailand has many refinery plants, and each refinery runs a hydrogen production unit.<br>● For hydrogen from renewable energy source, Thailand is considering using biogas and ethanol.<br>● Currently, Thailand is looking at hydrogen as a chemical storage to produce fuel cell for electricity and transport mobility.<br>● In terms of R&D, the Thailand government has many international collaborations with several universities, such as in the United Kingdom and France, as well as with Thai universities. |

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| **Myanmar** | ● Myanmar's main energy sources are hydropower, coal, natural gas, and solar.<br>● Myanmar has utilised only around 40% of energy development, thus, more collaboration with many stakeholders is needed to maximise its energy sources. |
| **Indonesia** | ● Indonesia is developing hydrogen energy from fossil fuels and focuses more on hydrogen production than fuel cell.<br>● The National Research Priority Plan 2020–2040 clearly states that biohydrogen is one of the top priorities. Biohydrogen is produced through biological fermentation and anaerobic process – the so-called biomass source, which is made of fatty acid methyl ester or FAME from crude palm oil, palm oil crown (palm oil industries), cassava (agricultural industries), and molasses from sugar cane industries.<br>● Indonesia is developing a prototype of biohydrogen reactor. As it is still at the early stage, its capacity is still low. So far, it has been able to produce 720 litres of hydrogen gas per hour with 99% purity, which is expected to reduce the hydrogen price. This reactor is also possible to be installed close to the biomass source that is located on the agricultural industries.<br>● The researchers are trying to connect the reactor to the existing electricity grids to stabilise electricity generation.<br>● In 2018, the government collaborated with the National Electricity Agency and Toshiba Japan to develop green hydrogen production, combined with renewable energy sources, mainly solar PV and wind turbine.<br>● The Science and Technology Research Centre implemented a project called Autonomous Hydrogen System (H2-1), targeted for commercialisation by 2023.<br>● To develop clean hydrogen energy, the government needs to focus on the infrastructure development of renewable energy. One of the priorities is to increase the capacity of solar PV up to the megawatt scale. The target is for the electricity generated from solar energy to be stored in batteries and be able to produce hydrogen.<br>● The key challenges in producing hydrogen are as follows:<br>➢ Technical challenges<br>➢ Ensuring constant delivery and stable power from hydrogen<br>➢ Improving the current power system<br>➢ Implementing the smart battery system<br>➢ Storing hydrogen effectively when it is combined with the electrolysis system<br>➢ How to decrease hydrogen operational costs |

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| **Viet Nam** | ● Up to now, Viet Nam has no hydrogen production units at the industry scale, even though many refineries exist in the country.<br>● In the Viet Nam energy road map, Viet Nam targets 30% of its energy production to be generated from renewable energy, including solar power, hydropower, wind power, and hydrogen by 2040.<br>● Increasing interests in hydrogen technology research are from the Ministry of Science and Technology and several universities |