Hydrogen Demand and Supply in ASEAN's Industry Sector: Current Situation and the Potential of a Greener Future

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Foreword

Climate change and the energy transition have made research and development in clean energy a priority as countries aim to reach net zero in the next decades. Hydrogen, singled out as a possible source of energy in the not-too-distant future, has emerged as a primary focus of discussion on the transition to sustainable energy. It is widely used for many applications including refining ammonia and petroleum, and the production of methanol and synthetic fuels. These applications accounted for more than 93% of global hydrogen consumption in 2020.

In the Association of Southeast Asian Nations (ASEAN) countries, currently, hydrogen is used mostly as feedstock for fertiliser in agriculture, and in methanol production, the steel industry, and oil refining. However, most hydrogen in use in the world today is not 'green' or 'low carbon' hydrogen, which is produced from renewable resources.

Most ASEAN Member States have realised the importance and potential of hydrogen as an alternative to fossil fuels and that can be employed across industries, power generation, and transport. Therefore, these countries have begun implementing their own hydrogen strategies to initiate the development of the hydrogen economy that will become an essential and crucial aspect of their energy transition process in the future.

With this research, the Economic Research Institute for ASEAN and East Asia (ERIA) tries to show the potential role of hydrogen in the industry sectors in ASEAN in the context of decarbonisation, an area that has hitherto received limited analysis and remains largely unexplored. ASEAN Member States should have an in-depth look at the findings of this research that can be considered as important elements to complete and to improve their current hydrogen strategies.

Tetsuya Watanabe

President, Economic Research Institute
for ASEAN and East Asia

Preface

Recognising that the current utilisation of hydrogen in the Association of Southeast Asian Nations (ASEAN) countries is predominantly confined to the industrial sector, primarily through conventional steam methane reforming with high carbon intensity, this study seeks to provide insights for an optimal hydrogen market development strategy in the region. The significance of this strategy is paramount, given the pivotal role hydrogen is poised to play in ASEAN's energy transition towards achieving carbon neutrality by the middle of the century.

The specific goal of this study is to provide a set of policy recommendations for policymakers in the ASEAN Member States to accelerate the process of obtaining lower carbon intensity of hydrogen supply in the industry sector, as part of an optimal hydrogen market development strategy for the ASEAN region.

This goal is attained via two pathways. First, by understanding hydrogen use in the ASEAN countries for the last 5 to 10 years and its current and future demand and supply to the industry sector, and second by analysing how the supply of hydrogen in the ASEAN countries can become greener or less carbon intensive. This includes an analysis of future production, storage, transport costs, and capacity development along the different low-carbon hydrogen production routes.

To accelerate the process of obtaining low-carbon hydrogen supply in the industry sector, this study recommends the governments of ASEAN Member States to proceed with the following:

- Continue to increase renewable electricity generation's share and reduce transmission costs.
- From the perspective of sectoral, regional, and international political economy, formulate strategies and manage the horizontal and vertical institutional interactions to gain maximum support for the greening of hydrogen production for key industrial applications in the ASEAN region.
- Elaborate policies on how to combine public sector co-financing, subsidies, and/or tax breaks with optimal carbon pricing to incentivise the production of low-carbon (green) hydrogen in the near term.
- Launch low-carbon hydrogen pilot projects, such as producing it from the surplus electricity generated by variable renewable energy resources including solar photovoltaic and geothermal or producing it from electricity generated by variable renewable energy in remote areas where electricity demand is negligible. Along these production pathways, hydrogen plays the role of batteries and/or transportable batteries, thus facilitating penetration of variable renewable electricity.

The authors hope that this study will provide new insights on an optimal hydrogen market development strategy for the ASEAN region.

Alloysius Joko Purwanto

Project Leader

Acknowledgements

This study was undertaken in close collaboration with the working group members that come from different institutions representing expertise in five industry subsectors in ASEAN, i.e. oil refining, ammonia, methanol, iron and steel, and chemical industries.

In-person and virtual discussions with industrial players and policymakers were organised during the study period. The authors thank the participants of the online workshops on 3 November 2021 and on 2 August 2023.

The presentations at the workshops – from the region's industry players, government authorities, and stakeholders – and ensuing discussions were useful and inspiring to develop future strategies and policy measures to support development activities.

The authors also express sincere appreciation to Aris Mulya Azof (PT Pertamina Persero), Hari Y. W. Sasongko (Air Products Indonesia), Somrudee Predapitakkun (Petroleum Authority of Thailand [PTT] PLC), Thana Sornchamni (PTT PLC), Satthawut Suwanthitirata (Bangkok Industrial Gas Co. Ltd.), and their teams for the extensive discussions and support for this study.

As a disclaimer, all errors and mistakes are the authors' responsibility.

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Table of Contents

List of Figures

List of Tables

List of Appendices

List of Abbreviations and Acronyms

ACE	ASEAN Centre for Energy
AEO	ASEAN Energy Outlook
AHEAD	Advanced Hydrogen Energy Chain Association for Technology Development
AMS	ASEAN Member States
APAEC	ASEAN Plan of Action for Energy Cooperation
APS	Announced Pledges Scenario
ASEAN	Association of Southeast Asian Nations
ATR	Autothermal Reforming
ATS	AMS Targets Scenario
BAU	Business-As-Usual
BECCS	Bioenergy with Carbon Capture and Storage
BEV	Battery Electric Vehicle
BF-BOF	Blast Furnace–Basic Oxygen Furnace
CAGR	Cumulative Annual Growth Rate
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage
CN	Carbon Neutral
CO2	Carbon Dioxide
COP	Conference of the Parties
COVID	Novel Coronavirus Disease
DAC	Direct Air Capture
DACCS	Direct Air Capture with Carbon Capture and Storage
DNV	Det Norske Veritas

DRI	Direct Reduced Iron
DRI-EAF	Direct Reduced Iron-Electric Arc Furnace
EE	Energy Efficiency
EJ	Exajoule
ERIA	Economic Research Institute for ASEAN and East Asia
EUR	Euro
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt
HBI	Hot Briquetted Iron
HDF	Hydrogene De France
IEA	International Energy Agency
IEEJ	Institute of Energy Economics Japan
IESR	Institute for Essential Services Reform
IISIA	Indonesian Iron and Steel Industry Association
INDC	Intended Nationally Determined Contribution
IRENA	International Renewable Energy Agency
ISOM	Isomerisation
JETP	Just Energy Transition Partnership
KBPD	Thousand Barrels per Day
KTPA	Kilo Tons per Annum

Lao PDR	Lao People's Democratic Republic
LCOE	Levelized Cost of Electricity
LED	Light Emitting Diode
LNG	Liquefied Natural Gas
LS	Likely Scenario
MEA	Mono-ethanolamine
MEMR	Ministry of Energy and Mineral Resources
METI	Ministry of Economy, Trade and Industry
MOU	Memorandum of Understanding
MT	Million Tons
MTBE	Methyl Tertiary Butyl Ether
MTPA	Million Tons per Annum
MW	Megawatt
NDC	Nationally Determined Contribution
NZE	Net-Zero Emissions
OGJ	Oil and Gas Journal
PEM	Proton Exchange Membrane
PLN	PT Perusahaan Listrik Negara
PNOC	Philippine National Oil Company
PT	Perseroan Terbatas
PTT	Petroleum Authority of Thailand
PV	Photovoltaic
RE	Renewable Energy

SDG	Sustainable Development Goals
SDS	Sustainable Development Scenario
SEA	Southeast Asia
SEAISI	Southeast Asia Iron & Steel Institute
SMR	Steam Methane Reforming
STEPS	Stated Policies Scenario
TPA	Tons per Annum
TWh	Terawatt Hour
US	United States
US$	United States Dollar
USGS	United States Geological Survey
VRE	Variable Renewable Energy
WEO	World Energy Outlook


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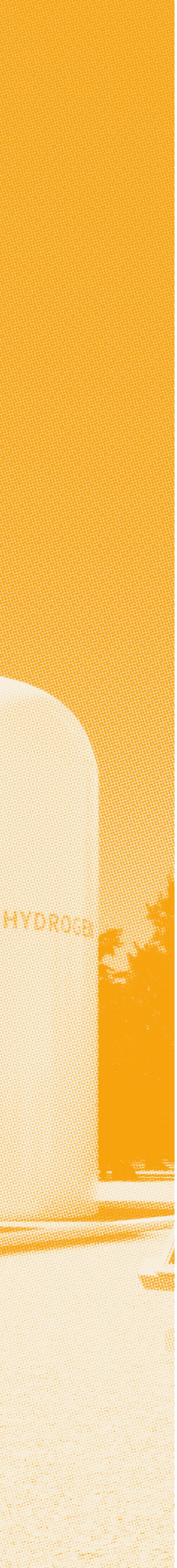

Chapter 1

Introduction

Alloysius Joko Purwanto
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Hydrogen gas continues to be extensively used in industrial processes like oil refining, chemicals, fertilisers, and steel production (IEA, 2019). Whilst in the future it is expected to power fuel-cell electric vehicles (FCEV) in some countries, economic considerations and infrastructure limitations have constrained its use in transportation to date. This is expected to change.

On the supply side, competitively priced hydrogen continues to be sourced primarily from steam reforming of natural gas ('grey hydrogen') or coal gasification. Whilst hydrogen from water electrolysis ('green hydrogen') has the potential to compete with transport fuels, especially when petroleum prices are high, it is much more expensive than grey hydrogen used for industry (Ball and Weeda, 2015). However, recent research and pilot projects lead to the expectations that technologies like natural gas reforming combined with carbon capture ('blue hydrogen') and electrolysis of water using renewable-based electricity are gaining prominence and could dominate hydrogen production in the future (APERC, 2018; IEA, 2021a).

On the demand side, industry will continue to be the largest user of hydrogen, far exceeding use in transport. Whilst demand for battery electric vehicles (BEV) including plug-in hybrid vehicles has been rising in recent years due to increased subsidies and expanding charging station networks, the transport and logistics sectors are yet to settle to any dominant technology. Indeed, recent findings indicate a future market split between BEVs dominating the light passenger vehicle markets travelling shorter distances and FCEVs used in heavier, long distance utility vehicles such as trucks and rail (Milton, 2020). Furthermore, the potential of hydrogen gas as a future energy carrier is still being developed.

Given the complex set of factors affecting demand, supply, storage, and transport of hydrogen, the search for an optimal hydrogen development strategy requires an analysis of not only technological and economic variables but also a country's geography, energy demand, and supply situation and, equally importantly, their institutional setup.[1] Only by understanding a country's geography, demographic, and institutional history and the technological and economic determinants of hydrogen demand, supply, storage, and transport can an optimal hydrogen development strategy be formulated.

Industries and countries, just like companies, can become victims of their own success. The literature on innovation incentives is abound with reports on industrial and institutional inertia (Belleflamme and Peitz, 2010). In the automobile sector, for example, the German automobile multinationals have been slower than their Chinese competitors and Tesla in shifting their business models towards electric vehicles. The reason lies in their efficient infrastructure and operations being geared towards internal combustion engine technologies and supply chains and their historically strong political lobbying power (Schüsseler, 2018). The latter leads them to rely on the German government to continue helping them maintain their lead in their existing markets and technologies. As a result, the technologies and market infrastructure including charging networks were not built as rapidly as in China or Tesla's target markets.

[1] Rusli (2013) considers geographic, demographic, economic, and socio-political determinants in developing an optimal energy policy for the oil, gas, and coal industries in Southeast Asia.

1. Background

The grand objective of this study is to contribute to the optimal hydrogen market development strategy for the Association of Southeast Asian Nations (ASEAN) region.

First, the ASEAN region had a population of 660 million and a combined gross domestic product (GDP) of more than US$3.0 trillion in 2020 (ASEAN, 2021). Second, the region's refinery, chemical, and steel sector output and demand for passenger and logistics transportation are concentrated in Singapore, Thailand, Indonesia, Malaysia, and Viet Nam, five countries that makeup the region's largest industrial output and consumption market. Third, ASEAN harbours some of the world's largest natural gas reserves and resources (IEA, 2021a). Fourth, the existing natural gas pipeline networks in Malaysia, Indonesia, Thailand–Myanmar, and Viet Nam offer the potential for a future regional network of gas transport pipelines, the trans-ASEAN natural gas pipeline network, which can be crucial for the region's hydrogen market development (ACE, 2022). Fifth, whilst the hydrogen-consuming industries and the automobile production and supply chains in Thailand and Indonesia dominate the region, they are not over-developed yet and have the potential for significant and rapid growth into the future. The proportion of renewable energy-based electricity generation is small, and ASEAN aims to grow its renewable energy capacity to 23% of primary energy consumption by 2025 (Hamdi, 2020). Thus, the region still holds potential for future adaptation and transformation, to be guided by the right future development strategy and policies for its energy sector including hydrogen.

In line with the Seventh Sustainable Development Goal of the United Nations, ASEAN and East Asian Summit countries need to seriously promote the use of renewable sources, energy efficiency, and energy transition measures to cleaner fuels. The use of new energy technologies such as carbon capture usage and storage (CCUS) or carbon recycling and hydrogen should also be incorporated along with the adoption of clean technologies. Hydrogen technology should play a key role as an alternative to fossil fuels and can be applied across sectors, i.e. the industry sector in the short and medium term and the future power generation and transportation sectors in the long term.

The International Energy Agency (IEA) (2019) pointed out that the top four single uses of hydrogen today are found in the industry sector as feedstock such as in oil refining (33%), i.e. for hydrocracking and hydrotreating as well as for processes in biorefinery, in ammonia production (27%), i.e. for urea and other fertilisers, in methanol and its derivates production (11%), and in steel production via the direct reduction of iron ore (3%). Det Norske Veritas (DNV, 2022) estimates that a total of 90 million tons (MT) of hydrogen was produced in 2020, i.e. 48 MT was used as feedstock to produce ammonia and other chemicals, including methanol, 37 MT was used as feedstock in oil refining, and only around 5 MT was used in the production of direct reduced iron.

The specific goal of this study is to provide a set of policy recommendations for policymakers in the ASEAN Member States to accelerate the process of greening the hydrogen supply in the industry sector as part of an optimal hydrogen market development strategy for the ASEAN region. Hydrogen will play an important role in the energy transition in ASEAN that aims to reach carbon neutrality by the middle of the century.

This specific goal can be broken down into two objectives. The first objective is to understand hydrogen use in the ASEAN countries for the last 5 to 10 years and its current and future supply to the industry sector. In more detail, this objective includes:

- Stocktaking and understanding the current use of hydrogen in the industry sector in the ASEAN countries.
- Reviewing and analysing the current hydrogen sources, production processes, supply mechanisms, and infrastructure in the ASEAN countries.
- Estimating regional hydrogen demand and supply through the different possible scenarios to the horizon 2050.

The second objective is to analyse how the supply of hydrogen in the ASEAN countries can become greener and the associated carbon intensity can be reduced through various production routes, such as methane steam reforming using CCUS, electrolysis with electricity coming from renewable sources in the ASEAN countries, etc. The second objective includes analyses of future production, storage, and transport costs and capacity development along the different production routes.

2. Net-Zero Emissions Targets

The idea of having hydrogen as a future energy source and carrier to mitigate climate change is not new. For example, in 2007, based on a scenario that explores the consequences of more ambitious carbon policies that aim at a long-term stabilisation of the concentration of carbon dioxide (CO_2) in the atmosphere close to 500 parts per million volume by emerging and developing countries and assuming a series of technology breakthroughs that significantly increases the cost effectiveness of hydrogen technologies, in end-use in particular, the European Commission (2007) projected a global move to a hydrogen economy starting on 2030.

That study, which can be considered one of the first comprehensive global energy outlook analyses that emphasise the use of hydrogen for industry, estimates that by 2050 two-thirds of electricity generation from fossil fuels would be in plants equipped with carbon capture and sequestration (CCS). The use of hydrogen would take-off after 2030, driven by substantial reductions in the cost of the technologies for producing hydrogen and the demand-pull in the transport sector. By 2050, hydrogen could provide 13% of final energy consumption, compared to 2% in the reference case. The share of renewable energy in hydrogen production will be 50% and that of nuclear 40%, with around 90% of hydrogen used for transport. Under this scenario, global emissions of CO_2 would be stable between 2015 and 2030 and decrease thereafter. However, by 2050, CO_2 emissions would still be 25% higher than in 1990.

Nowadays, the objective of reaching net-zero emissions targets clearly puts hydrogen together with ammonia as one of the future energy sources and carriers. IEA (2021) for instance considers hydrogen electrolysers, together with advanced batteries and direct air capture and storage (DACCS) as the three biggest innovation opportunities that would make vital contributions to the reductions in CO_2 emissions between 2030 and 2050. The study also considers hydrogen and hydrogen-based fuels, together with energy efficiency, behavioural changes, and electrification, renewables, bioenergy, and CCUS as key pillars of the decarbonisation of the global energy system.

On the supply side, the production of electrolyser-based hydrogen would increase. IEA (2021a) points out how the use of electricity by hydrogen merchants would increase strongly from only 4,000 terawatt hours (TWh) in 2020 to more than 9,000 TWh in 2030 and around 10,000 TWh in 2050, by then equalling around two-thirds of the total energy consumed by hydrogen merchants.

Global hydrogen use is anticipated to expand from less than 90 MT in 2020 to more than 200 MT in 2030 to around 530 MT in 2050. In 2050, around 25% of hydrogen would be produced within industrial facilities (including refineries), and the remainder as merchant hydrogen (hydrogen produced by companies, e.g. industrial gas producers, to sell to others).

The share of low-carbon hydrogen would grow from around 10% in 2020 to almost 100% by 2050; around half of the low-carbon hydrogen produced globally in 2030 will come from electrolysis and the remainder from coal and natural gas with CCUS. By 2030, around 150 MT of low-carbon hydrogen will be produced and consumed and about 850 gigawatts (GW) of electrolysers would be installed around the world. By 2050 these figures should reach 520 MT of produced and consumed low carbon hydrogen with more than 3,000 GW of installed electrolysers capacity.

From the consumption perspective, IEA (2021a) emphasises that low-carbon hydrogen use would expand rapidly after 2030. In the electricity sector, hydrogen and hydrogen-based fuels would be used in co-firing with natural gas and should make around 2% of overall electricity generation in 2050.

In the transport sector, hydrogen and hydrogen-based fuels would mainly fuel long-haul heavy-duty trucks. In shipping, together with advanced biofuels, hydrogen-based fuels such as ammonia would increasingly displace oil. Hydrogen is expected to provide around one-third of fuel use in trucks in 2050 in the net-zero emissions (NZE) target. By the same year, hydrogen-based fuels should also provide more than 60% of total fuel consumption in shipping.

A study by ERIA (Li, Han, and Kimura, 2021) based on a collaboration between ERIA and the Institute for Energy Economics, Japan (IEEJ) did, therefore, seek carbon-neutral pathways for ASEAN countries towards the horizon years 2050 and/or 2060 by applying optimisation approaches to choose low- or zero-emissions technologies under a CO2 emissions constraint and cost minimum objective function.

In the study, hydrogen is represented as amongst the innovative energy technologies, together with ammonia, CCUS direct air capture (DACCS), and biomass energy with CO2 capture and storage (BECCS). These innovative energy technologies are added to conventional low-emissions energy technologies and measures, including energy efficiency and conservation, hydropower, geothermal, nuclear power, and biomass, in the transition period.

In the power generation sector, ammonia and hydrogen together would account for around 26% of the total power to be generated in ASEAN by 2060, which shows the importance of co-firing in future power plants. During the period 2040–2050, co-firing at existing coal- and gas-fired power stations, gas-fired power generation with CCUS, and 100% ammonia-fired power generation are expected to be expanded, and a major share of thermal power generation shifts to 100% ammonia-fired power generation by 2060.

In the scenario where ASEAN countries will reach carbon neutrality by 2050 and 2060 considering the use of a carbon sink, the total power generated from hydrogen-fired power plants would reach nearly 500 TWh by 2060. Electricity generation from 100% hydrogen at gas-fired plants would reach around 200 TWh, whilst power generated by gas-hydrogen co-firing with CCUS would reach around 150 TWh.

When carbon neutrality is reached by 2050 and 2060 but a carbon sink use is not considered, the total power generated from hydrogen fired power plants would reach around 1,000 TWh by 2060, double of the situation when a carbon sink is considered. Without considering a carbon sink use, electricity generation from 100% hydrogen at gas-fired plants would reach around 400 TWh, also double the scenario where a carbon sink use is considered. The part of gas-hydrogen co-firing with CCUS would remain around 150 TWh, like the scenario with a carbon sink. It can be concluded that when carbon neutrality targets become more stringent, i.e. when a carbon sink use is not considered, the role of low-carbon hydrogen across decarbonisation pathways will become critical.

Hence, achieving carbon neutrality cannot rely solely on variable renewable energy (VRE) but necessitates integrating combinations of CO_2 reduction technologies. In addition to switching to VRE, energy efficiency measures, implementation of negative-emissions technologies, and switching towards lower carbon fossil fuels, the ASEAN region's use of hydrogen and ammonia can play important decarbonisation roles in the region.

Finally, apart from perceived significant use of hydrogen in the power sector, namely hydrogen turbine and natural gas-hydrogen co-firing, the ERIA study (Li, Han, and Kimura, 2021) also sees some penetration of the use of hydrogen in various end-use applications, including fuel cell electric vehicles (FCEV), hydrogen-based direct reduced iron–electric arc furnaces, fuel cell ships, hydrogen fuelled aircraft, hydrogen heat for industries, and fuel synthesis (methane, liquid fuel, ammonia).

3. Scope and Structure of the Study Report

Studies offering future energy outlooks, several of which have been described briefly in the previous section, hardly touch the use of hydrogen as feedstock in the industry sector, i.e. oil refining, ammonia and fertiliser industry, methanol production, iron and steel industry. Amongst the reasons is the fact that the primary focus of those studies is to provide an energy analysis, whereby the use of hydrogen as feedstock might not have been analysed in detail.

This study aims to address this uncovered area for two reasons. First, nearly 100% of the current hydrogen use, especially in ASEAN and other emerging economies, is as feedstock in the industry sector, and second, the current hydrogen production routes are important sources of greenhouse gas emissions. By understanding the demand and supply of hydrogen as the industry sector's feedstock in ASEAN countries and being able to make recommendations on how to reduce the current hydrogen carbon intensity, the study is in a position to provide several important elements to increase the economy of scale of hydrogen production starting from its current use in the industry sector and to decrease its carbon intensity under more feasible economic conditions.

The study starts by analysing the historical and current hydrogen demand and supply for the industry sector in the ASEAN countries in Chapter 2. Depending on the available data and information, analysis is conducted on the four sectors: oil refining and chemicals, ammonia and fertiliser industry, methanol industry, and iron and steel industry. The periods of 2015–2020 and 2015–2021 in eight ASEAN Member States (AMS), i.e. Brunei Darussalam (Brunei), Indonesia, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam are studied.

In Chapter 3, several future scenarios are elaborated. The chapter starts with a review of scenarios taken from several most important energy outlook studies that include hydrogen as one amongst the low-carbon technologies, energy sources, and carriers. Four scenarios are elaborated with trends and economic, socio-economic, and technological assumptions and policy measures taken from the reviewed studies. The bottom-up methodology to implement the scenarios is explained where socio-demographic trends and external policy measures are two key factors that determine the demand and supply of hydrogen as feedstock in the four industrial sectors mostly by the intermediary of the effects on technology costs.

Results of the analysis of these scenarios are reported in Chapter 4 starting with country-sectoral level analyses. Scenario assumptions and considered policy measures are explained more in the detail in this chapter than in the previous chapter. At the end of the chapter, an aggregated view of the region's future hydrogen demand and supply is analysed at the ASEAN level.

Chapter 5 presents an overview of the economics of hydrogen by analysing the different studies that cover not only Southeast Asia but also other parts of the world, which estimate the current and future costs of hydrogen that are determined by various factors. Amongst the most important factors are the price of renewable electricity across industries and the price of the different types and capacities of electrolysers which can be distinguished into capital expenditure and operational expenditure. Beyond those two key factors, the necessity to transport, and the different final use of hydrogen such as in industry, i.e. ammonia, refineries, methanol, steel and in the transportation sector, are discussed. Using the most relevant data, estimates, and assumptions, this study calculates a set of future hydrogen prices produced from renewable electricity onsite at the industrial locations.

Chapter 6 presents a discussion on the political economy of hydrogen in the ASEAN region. A transition towards low carbon hydrogen will be expensive for Southeast Asia's emerging and transition economies. Therefore, one would expect the need for strong pressure and support from international and domestic, public and private, and political and economic institutions for ASEAN governments to stand a chance of realising their ambitious decarbonisation objectives. In this chapter the relationships and dynamics of the different players are discussed in term of horizontal and vertical interactions between the region and international policy institutions, governments, and firms. Several determinants of success based on those analysed interactions will be presented at the end of the chapter.

Finally, Chapter 7 provides elements of conclusions of the study and detailed policy recommendations for the ASEAN Member States to increase the economy of scale of the current use of hydrogen as the industry sector's feedstock, to decrease the cost of hydrogen production and procurement, and to allow expansion of its use to help lower the carbon intensity of the region's industry and energy sectors, and thus economies.


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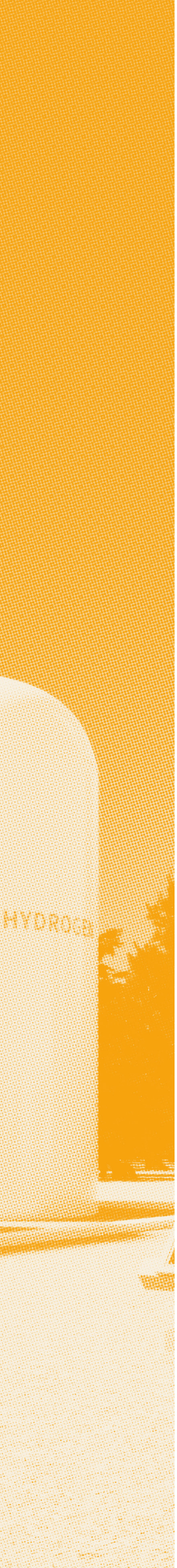

Chapter 2

Current Hydrogen Demand and Supply

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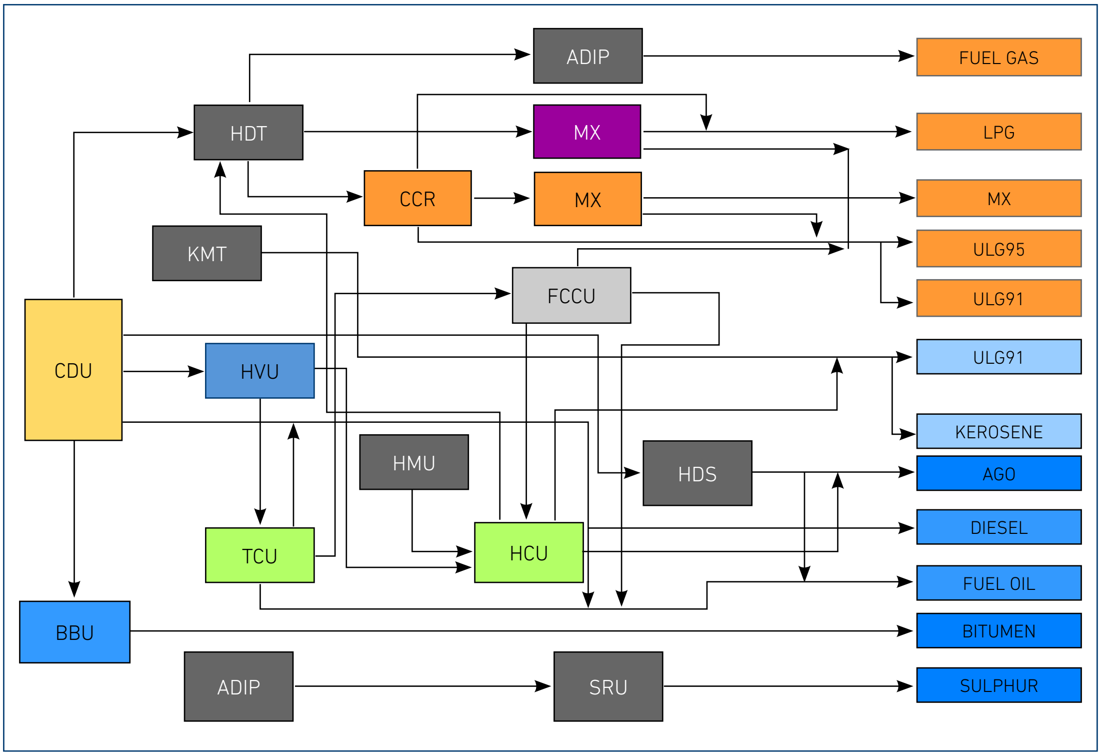
Veradika Elsye
Ryan Wiratama Bhaskara
Nadiya Pranindita

1. Hydrogen in the Oil Refining, Chemical, and Other Industries

Oil refineries consist of a number of processing units designed to produce marketable petroleum products including fuels and chemical intermediates out of crude oil. Figure 2.1 gives an example of the involved processing units. Key refining processes range from front-end atmospheric and vacuum distillation and multiple separation processes, catalytic cracking and catalytic reforming to produce mainly gasoline and reformed naphtha, hydrocracking for middle distillates including diesel and kerosene, hydrotreating including hydrodesulphurisation, alkylation, isomerisation, and many other processing units (Meyers, 1997).

Figure 2.1. Schematic Diagramme of Oil Refinery Process



TCU = AGO = KMT = BBU = LPG = liquid petroleum gas.

Key processing units include crude distillation (CDU) and high vacuum distillation (HVU) units, hydrocracking (HCU), hydrotreating (HDT), hydrodesulphurisation (HDS), isomerisation (ISOM), fluid catalytic cracking (FCCU) and catalytic reforming (CCR), hydrogen production unit (HMU), mixed xylenes (MX), amine process (ADIP), and sulphur recovery (SRU), etc.

Source: Adapted from Thai Oil's September 2022 investor presentation.

Hydrogen is a crucial molecule involved in many refining processes. Besides as a by-product in dehydrogenation and aromatisation processes, in refineries hydrogen is mainly produced through steam methane reforming of natural gas and the catalytic reforming process. The latter produces reformates, i.e. premium ingredients of gasoline. When captive hydrogen thus produced is insufficient to satisfy internal requirements, refiners may purchase hydrogen from merchant producers, many of which also use steam methane reforming. On the other hand, its main consumption stems from the critical importance of hydrogen in hydrocracking to produce diesel and kerosene and jet fuel in hydrotreating to desulphurise and denitrify multiple refined products and chemical intermediates (Castaneda, Munoz, and Ancheyta, 2010). Additionally, lesser volumes of hydrogen are consumed in isomerisation and de-aromatisation. The more complex a refinery configuration and the heavier and sourer the crude oil feedstock, the higher the consumption and captive production, and thus the more significant a role hydrogen will play (Kaiser, 2017).

As the oil refining process is the second largest industrial consumer of hydrogen – after ammonia – both in the industrialised West and in Southeast Asia, the gradual transition to a decarbonised future requires that oil refiners significantly increase the share of green hydrogen, or at least in the near future, blue hydrogen production via renewable energy-powered electrolysis of water (IHS, 2021). Additionally, the chemical and processing industries need to shift their purchases to green or blue hydrogen. Besides ammonia and methanol, the largest and third largest industrial consumers of hydrogen in Southeast Asia, other chemical and industrial processes consume hydrogen for the production of fatty alcohols for cleaning and personal care products, oxo chemicals for plasticisers and other additives, hydrogen peroxide, hydrochloric acid, electronics, and float glass manufacturing as well as other chemical processes (IHS, 2021).[1]

In subsections 1.1 until 1.5 we describe, in turn, the key supply and demand drivers of hydrogen in the oil refining and chemical and processing industries. Section 2.1.6 elaborates on ERIA's hydrogen historical supply and demand estimates from oil refining and chemical processing for eight ASEAN countries: Indonesia, Thailand, Singapore, Malaysia, Philippines, Viet Nam, Brunei, and Myanmar ('ASEAN-8').

1.1. Data Sources for Oil Refineries and Chemicals

Most international studies by, for example, IHS Markit (HIS, 2021), the International Energy Agency (IEA, 2022a; 2022b), the International Renewable Energy Agency (IRENA, 2022) and Det Norske Veritas (DNV, 2022) forecast their Southeast Asian hydrogen estimates for the combined region (IEA, 2022a; IRENA, 2022; DNV, 2022; IEA, 2019). By contrast, BP's (2022) historical data do not only document the Asia-Pacific region in aggregate, but also provide country break down for selected data (BP, 2022). For example, BP (2022) reports historical refinery throughput, oil and products consumption volumes for

[1] ERIA and the authors thank Pertamina, PTT, Air Products, and Bangkok Industrial Gases for valuable inputs and discussions before and during our first public workshop in September 2022.

the Asia-Pacific region and key countries China, India, Japan, Indonesia, Thailand, Singapore, Malaysia, Viet Nam, and the Philippines. To enable an estimate of the current and future demand for and supply of hydrogen in each of the ASEAN-8 key refining centres, publicly available information on the refinery and chemical sectors, the pledged, announced, and documented decarbonisation policies for the eight countries, company websites, as well as selected state-owned oil firms and gas merchant's data, market research reports, and the Oil and Gas Journal's (OGJ) (2020) survey are studied.

For Indonesia's refineries we studied the national oil and gas firm Pertamina's 2021 annual report, 2020–2021 company data for hydrocracking, hydrotreating, isomerisation, steam methane reforming, and platforming. We compare the country's refinery data with OGJ (2020) and BP (2022) refinery capacities, throughput volumes and oil demand. We also studied Pertamina's 2025 Refinery Development Master Plan for the company's announced and in-progress expansion plans. For Thailand, Malaysia, Singapore, Viet Nam, and the Philippines we make use of OGJ (2020) capacities and throughputs and other public information. For Thailand we compared these with data from parent Petroleum Authority of Thailand's (PTT) and Thai Oil's investor presentations and annual report data, as well as Thai Oil's 2024–2025 clean fuel project and capacity expansion presentation (Thai Oil, 2020). In the case of Malaysia, we reviewed Petronas' investor presentations and annual reports. Estimates for Singapore's refineries include the 2021 capacity and throughput reduction at Shell's Bukom refinery. Last but not least, for Brunei and Myanmar we studied OGJ (2020) capacities and throughputs as well as public information and news articles.

1.2. Hydrogen Demand and Supply Estimation Approaches

Whilst Pertamina made its recent hydrogen demand and supply data available, hydrogen demand and supply are estimated using approximated hydrogen demand and supply ratios, i.e. multiples for crude throughput and hydrocracking and hydrotreating volumes. For the estimates we lean on the study by Castaneda, Munoz, and Ancheyta (2010) and assume average multiples of 3.0 weight % of hydrogen consumption for hydrocracking and 0.5 weight % for hydrotreating. Whilst these multiples are at the higher end of their ranges, we reckon that Southeast Asia's refineries' increasing imports of sour and heavy Middle Eastern crude justify such assumptions. On the supply side, an average multiple of 2.0 weight % of hydrogen production from catalytic reforming and platforming is used. These multiples are calibrated against Pertamina's actual hydrogen demand and supply statistics and unit-by-unit refinery capacity and runs, i.e. throughputs. We also cross-check our multiples using multiple references such as Amadei (2013) on hydrogen yields in catalytic reforming, Srinivas et al. (2014) on hydrogen in refineries, and Elgowainy et al. (2019) on hydrogen demand in refineries. Furthermore, in the case of countries and refineries for which only processing unit capacities but not refinery throughput data are available, we adjust the hydrogen demand and supply estimates based on the estimated refinery capacity utilisation using BP (2022) historical throughput and oil consumption data where available.

Combining all the above sources and approaches we estimate the historical 2015–2021 hydrogen demand and supply for the eight main Southeast Asian countries. In particular, using more accurately calibrated 2020 estimates historical hydrogen demand supply for 2015–2019 and 2021 based on each country's refinery throughput volumes is calculated. It is also assumed that independent gas and hydrogen merchants supply any shortfall of hydrogen to the refinery sector or purchase, i.e. offtake any excess hydrogen produced in the refineries.

The above estimation approach may be subject to several shortcomings. First, refinery capacity volumes differ across the different surveys and reports for each country and refinery. Second, reported data may differ in terms of accuracy, whilst others may be inconsistent with regard to the distinction between capacity versus throughput volumes. Third, using similar hydrogen consumption and captive production multiples across all refineries in the eight countries based on an Indonesian calibration coupled with ranged estimates across several estimation sources and algorithms may result in inaccuracies given differences in refinery configuration and operating conditions. Fourth, estimating hydrogen demand and supply volumes based on refinery throughputs and oil consumption volumes implicitly assumes comparable operating conditions and similar fuel export–import proportions over the years, which introduce inaccuracies. Fifth, only announced capacity expansion projects are considered, resulting in merchant supply and offtake volumes being used as stop-gap to make-up for the differences.

For the refinery sector, historical 2015–2021 hydrogen demand estimates and forecasts until 2025 are compared with figures reported by IHS (2021). IHS calculates historical and forecast hydrogen demand net of captive production. Since the IHS only reports captive production for 2020, these figures are used to estimate captive production to arrive at gross hydrogen demand for the same years. Lastly, whilst selected fatty alcohol and oxo chemical production and growth data exists in the public domain, the IHS (2021) historical sectoral break down data for 2015–2020 and forecasts until 2025 is assumed. Subsections 2.1.4 and 2.1.6 show historical demand and supply for hydrogen in the ASEAN-8 countries' oil refining and chemical and processing industries.

For future refining throughput and hydrogen production capacity estimates region-wide and country-specific growth estimates for refined petroleum products production are considered, whilst making adjustments for capacity utilisation and refinery throughput volumes based on the historical BP (2022) statistics. Refined products growth rates 2020–2050 follow ERIA-chosen scenarios, which are elaborated in Section 3. These are adjusted for announced capacity expansion plans and configuration changes, including Indonesia's Refinery Development Master Plan, Thai Oil's clean fuels project, and capacity expansions in Viet Nam and Brunei. The forecasts for the oil refining and chemical sectors are presented and discussed in Sections 4.1 and 4.2. Note that actual hydrogen production forecasts shall also be affected by refinery capacity utilisation and throughput volumes. As a result, the reforming throughput and thus part of captive hydrogen production changes with the hydrocracking and hydrotreating volumes and thus hydrogen demand.

1.3. Southeast Asia's Refinery Sector

A summary of the ASEAN-8 refinery sector is depicted in Figure 2.2

Figure 2.2. Summary of ASEAN-8 Refinery Sector

CDU = crude distillation, VDU = vacuum distillation unit, CC = catalytic cracking, CR = catalytic reforming, HC = hydrocracking, HT = hydrotreating, ISOM = isomerisation, MNPBD = million barrels per day, KPBD = thousand barrels per day.

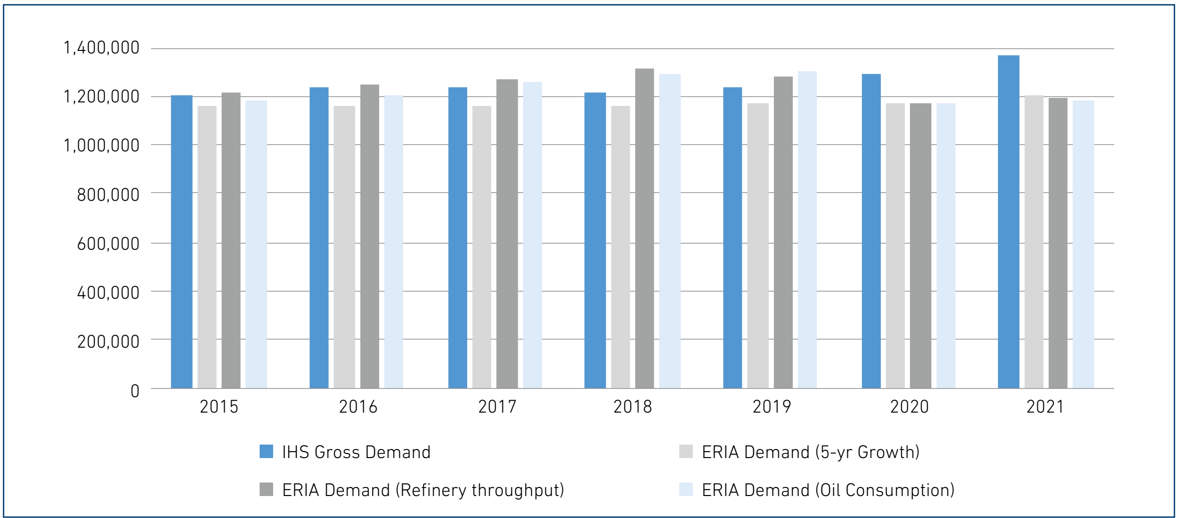
Sources: Author's estimates based on BP (2022), OGJ (2020), company websites, public information.

Southeast Asia's largest refineries and aggregate refining capacity are located in Thailand, Indonesia, Singapore, and Malaysia. The region's single largest, single-site refinery is Exxon in Singapore with almost 600 thousand barrels per day (KPBD) crude distillation capacity, followed by Thai Oil's approximate 400 KBPD after completion of its clean fuel project. By contrast, Indonesia's national oil company Pertamina owns and operates the largest single-company refining capacity with 1.14 million barrels per day of aggregate crude capacity. The region's most complex refineries include Thai Oil (9.8 Nelson complexity index, to increase to 12.8 post-completion of its clean fuel project in 2014), Pertamina's Balongan refinery (11.8 Nelson index), Singapore's refineries of Exxon and Shell, and Petronas Malaysia's integrated refinery and chemical Pengerang refinery.

1.4. Historical Hydrogen Demand and Supply in Oil Refining

Figure 2.3 depicts a comparison of historical Southeast Asian hydrogen demand as reported by IHS (2021) and ERIA.

Figure 2.3. Southeast Asia's Hydrogen Demand from Oil Refining (TPA)

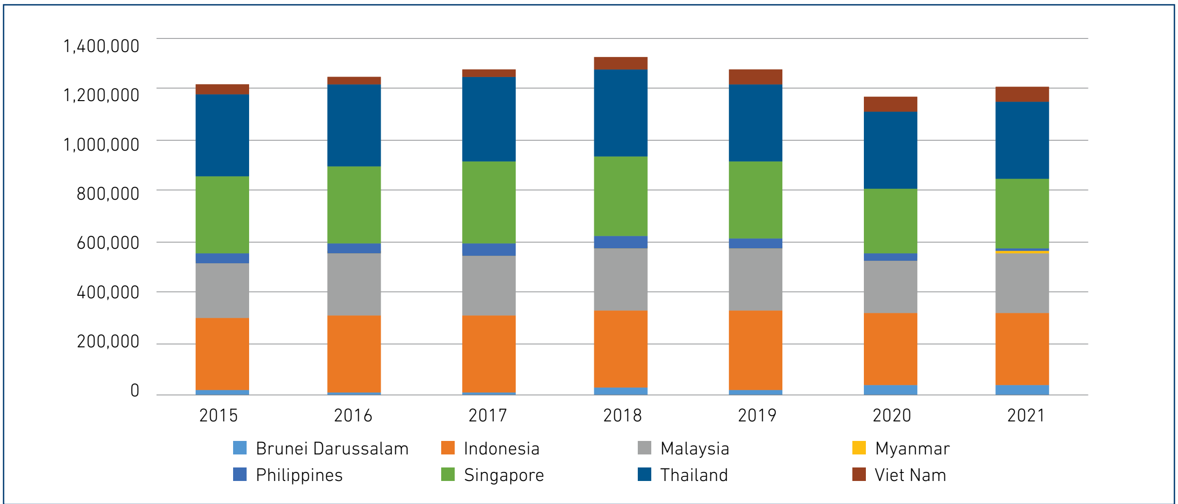


TPA = tons per annum.

Sources: Public information sources, IHS (2021), company data, authors.

IHS figures are grossed up from net demand by estimating and adding-back estimated captive hydrogen supply volumes (IHS, 2021). For our historical estimates we use our cross-checked 2020 regional and country-by-country hydrogen demand as a basis and extrapolate 2015–2019 (backward) respectively 2021 (forward) figures using three methods: steady growth following a 1.4% historical 5-year cumulative annual growth rate (CAGR), year-on-year changes in line with fluctuations in refinery throughput, versus oil consumption volumes. For all three approaches adjustment is made for the closure of part of Shell's refinery in Bukom island, Singapore. For the historical country break down of hydrogen demand, historical refinery throughput volumes are used, resulting in the following hydrogen country-level demand break down for the same time period (Figure 2.4).

Figure 2.4 . Hydrogen Demand from Oil Refining (TPA)



TPA = tons per annum.

Sources: Public information sources, BP (2022), authors.

Figure 2.4 demonstrates that hydrogen demand from oil refining mirrors the relative sizes of the refinery sector capacity and, in particular, throughput volumes across Southeast Asian countries. Indonesia, the region's most populous and geographically dispersed country surpassed Thailand in 2019 but was affected more during the subsequent pandemic years. Both countries, like Malaysia, are Southeast Asia's largest consumers of hydrogen, even more than the regional refining hub Singapore. The 2015–2020 hydrogen demand growth estimates range from a strong negative in the case of Philippines to more than –0.2% per annum CAGR for Indonesia, to more than 10% per annum for Viet Nam, Brunei, and Myanmar (Table 2.1). The drop in pandemic year 2020 was succeeded by at least partial recovery and resumption of growth in 2021.

Table 2.1. Cumulative Annual Growth Rate (CAGR) for Hydrogen Demand in Southeast Asia

Country	CAGR 2015–2020	CAGR 2015–2021
Indonesia	-0.2% pa	-0.2% pa
Thailand	-1.6% pa	-0.6% pa
Singapore	-0.9% pa	2.3% pa
Malaysia	-2.4% pa	16.3% pa
Viet Nam	12.2% pa	8.0% pa
Philippines	-12.9% pa	-25.5% pa
Brunei	22.0% pa	NA
Myanmar	22.0% pa	NA
Southeast Asia	**-0.7% pa**	**3.1% pa**

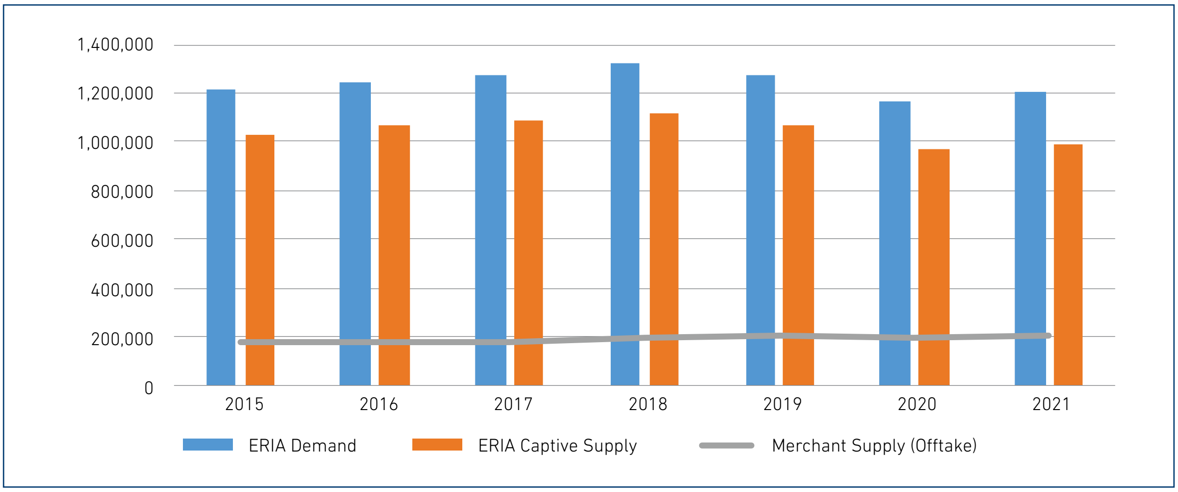
NA = not available, pa = per annum.

Sources: Public information, BP (2022), authors (esp. Brunei, Myanmar).

It is noteworthy that Indonesia's, Thailand's, Singapore's, and Malaysia's refinery throughput volumes, reflecting market demand for fuels and other refined products in these countries, exhibit flat or slightly negative CAGRs between 2015 and 2020, partially affected by the pandemic. The Philippines was affected by the shutdown of the Shell refinery in 2020, following Chevron's refinery closure in 2003. Growth resumed in 2021 across the region. By contrast, demand for fuels and refined products in Viet Nam, Brunei, and Myanmar grew strongly in the same period. This trend is expected to continue with Exxon's expansion of its hydrotreating and hydrodesulphurisation capacity in 2023 and Thai Oil's anticipated clean fuel project start-up in 2024–2025.

Figure 2.5 depicts historical demand and supply estimates for hydrogen in the Southeast Asian refinery sector. The net consumption, i.e. balance between hydrogen-consuming hydrocracking and hydrotreating and captive supply and hydrogen by products is supplied by independent gas merchants. The 2020 and 2021 volumes clearly demonstrate the effects of the recent COVID-19 pandemic.

Figure 2.5. ERIA Southeast Asian Hydrogen Supply and Demand from Oil Refining (TPA)



TPA = tons per annum.
Sources: Public information sources, company data, authors.

A detailed analysis of the longer term 2025 to 2030 and 2050 forecast of hydrogen demand and supply will be presented and discussed in Section 4. In particular, four scenarios ranging from the Frozen case to IEA's Stated Policies (STEPS), Announced Pledges (APS), and Likely scenarios will be described and analysed for each sector studied in this report – ammonia, oil refining, methanol, steel and/or direct reduced iron (DRI) – as well as the chemical and processing industries.

1.5. Hydrogen-consuming Chemical and Processing Sectors in Southeast Asia

Besides oxo alcohols and fatty alcohols, important hydrogen consumers in the chemical and processing industries are found in the production of hydrogen peroxide, cyclohexane, hydrochloric acid, caprolactam, 1-4 butanediol, and in the electronic and float gas manufacturing. According to IHS (2021) hydrogen consumption in the chemical and processing industries is split across oxo chemicals including oxo alcohols (roughly 27%), fatty alcohols (25%), hydrogen peroxide (14%), hydrochloric acid (11%), cyclohexane (10%), caprolactam and 1-4 butanediol (9%), and electronics and float glass (4%).

Fatty alcohols are produced via hydrogenation of fatty acids and esters. Historically petroleum-based with ethylene as key feedstock, a majority of today's fatty alcohol capacity is located in Southeast Asia and China and primarily uses palm kernel oil as main feedstock (Shah et al., 2016). Total nameplate production capacity of fatty alcohols surpassed 5 million tons per annum (MTPA) since 2015, of which about 77% is palm oil-based and almost half is located in Southeast Asia, spread between Indonesia, Malaysia, Thailand, and the Philippines (Rossall, 2015). Today, Southeast Asia hosts some of the world's largest palm oil producers, processors, and exporters. Amongst the region's palm oil producers, Indonesia and Malaysia make up more than half of global exports in fatty alcohols. Indonesia alone controls more than 30% of global fatty alcohol exports.

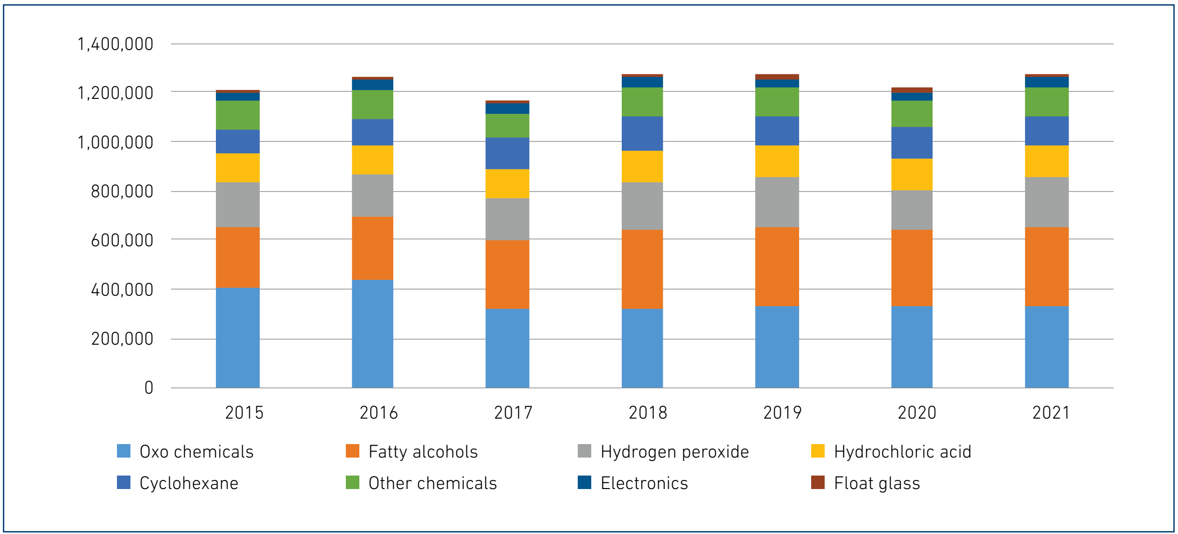
By comparison, oxo alcohols such as 2-ethylhexanol and butanol are important ingredients for plasticisers, which are additives used in the automotive industry, construction, consumer products applications, acrylates for the production of polymers for paints, adhesives, and for lube oil additives (GMI, 2021). They are produced out of olefins and require hydrogen in the hydrogenation steps.

Hydrogen is also used in the production of several important chemical products and intermediates and in electronics and float glass manufacturing. Hydrochloric acid is one of the most versatile chemical molecules. Whilst cyclohexane is an important intermediate and solvent, hydrogen peroxide is used for bleaching, personal hygiene, and household products. Caprolactam is the key intermediate for nylon 6 filament, fibre, and plastics. 1-4 butanediol is an industrial solvent used in the production of various plastics and polymers. Last but not least, hydrogen's excellent heat transfer property and efficient reducing and etching properties drive hydrogen's importance in semiconductor, display, light emitting diode (LED), and photovoltaic manufacturing. Furthermore, its reducing function renders it a useful oxidation prevention agent in the float glass manufacturing process.

1.6. Historical Hydrogen Demand and Supply in Chemicals

Figure 2.6 indicates that oxo chemicals and fatty alcohols are the largest consumers of hydrogen, followed by hydrogen peroxide, cyclohexane, and hydrochloric acid. Unlike large multinationals in Europe and North America and several large fatty alcohol producers, who maintain their inhouse steam methane reforming and other hydrogen production facilities, the relatively smaller scale of chemical, electronics, and glass manufacturing facilities in Southeast Asia source their hydrogen from independent merchants and gas companies.

Figure 2.6. Southeast Asia's Hydrogen Demand in Chemicals and Processing by Subsector (TPA)

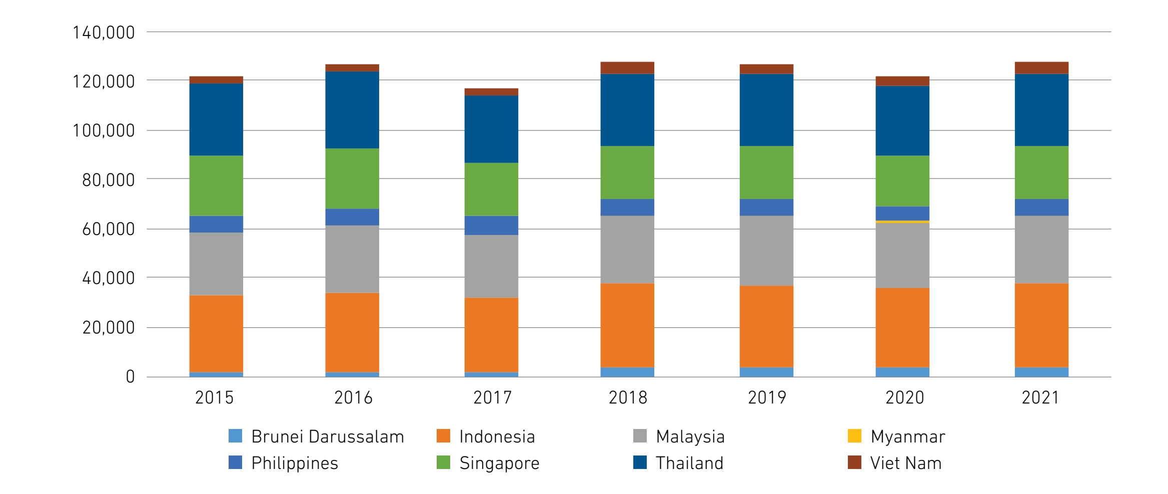


TPA = tons per annum.

Sources: IHS (2021), public information sources, authors.

Figure 2.7 depicts the historical estimates of hydrogen demand for the chemical and processing industries, broken down by country. The region's chemical and manufacturing sector demand for hydrogen is again concentrated in Indonesia, Thailand, Singapore, and Malaysia, with the remaining four countries sharing the rest. The Philippines' contribution mainly comes from its palm oil and fatty alcohol industry. Whilst the regional aggregate estimates follow IHS (2021), we assume that the chemical and processing sectors' hydrogen demand from fatty alcohols production is split roughly 35% each between Indonesia and Malaysia, and 15% each between Thailand and the Philippines. For the remaining chemical segments and product groups we break down hydrogen demand following the estimated hydrogen demand from each country's refinery sector. Apart from majority palm oil-based fatty alcohols and notwithstanding the importance of inorganic hydrogen peroxide and hydrochloric acid, a simple positive correlation between the scope and depth of a country's chemicals and its oil refining industries is assumed.

Figure 2.7. **Hydrogen Demand of Chemicals by Country (TPA)**



TPA = tons per annum.

Sources: IHS (2021), public information sources, authors.

2. Ammonia Production

Demand

Ammonia is a colourless gas with a pungent, suffocating odour, composed of nitrogen and hydrogen with the chemical formula NH_3. The properties of ammonia are shown in Table 2.2.

Table 2.2. **Properties of Ammonia**

Property	Ammonia (NH_3)
Physical description	Colourless gas with a pungent, suffocating odour. Often used in aqueous solution
Physical state	Gas (at room temperature)
Boiling point (°C)	-33.35
Freezing point/melting point (°C)	-77.7
Molecular weight (g/mol)	17.03

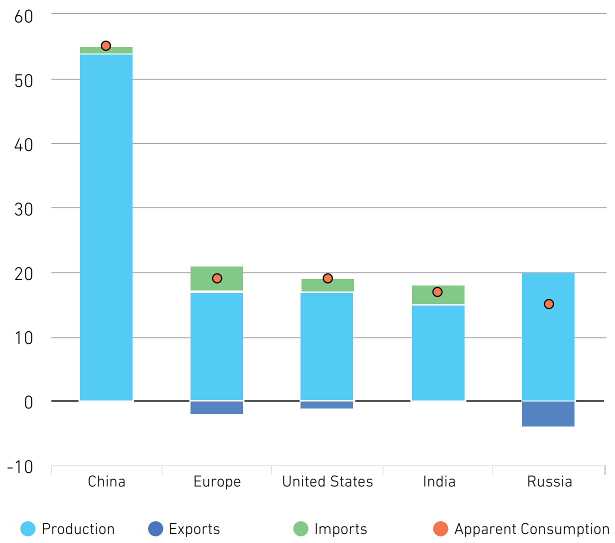
Property	Ammonia (NH_3)
Decomposition point (°C)	500
Flash point (°C)	11
Density, gas (g/L)	0.7710
Density, liquid (g/L)	0.6818
Vapor pressure (atm)	8.5
Vapour density	0.5697
Critical temperature (°C)	132.4
Critical pressure (atm)	111.3
Heat of fusion (kJ/mol)	58.1
Heat of Vapourisation (kJ/mol)	23.3
Heat of Combustion (kJ/mol)	-316
Ionisation potential (eV)	10.18
Specific gravity at –33,35°C	0.6818
Lower explosive limit (LEL)	15%

atm = atmosphere, g/L = gram per litre, kJ = kilojoule eV = electronvolt.

Source: Authors.

Ammonia is primarily used in agriculture, with approximately 85% of ammonia production used directly or indirectly in chemical fertilisers (American Chemical Society, 2021). The remaining 15% is used in various industrial applications such as plastics, explosives, synthetic fibres, refrigeration systems, and water treatment. Ammonia is also used in wastewater treatment, leather, rubber, and paper industries. It is a naturally occurring gas that serves as a chemical building block for a range of commercial and household products, including cleaning supplies (American Chemistry Council, 2022). Between 1990 and 2020 global ammonia demand increased broadly in line with the rise in population. Ammonia production and consumption volumes are shown in Figure 2.8. Globally, in 2020, 235 million tons (MT) of ammonia was produced, with China being the largest producer of ammonia (30% of total production) (IEA, 2021a). All the ammonia produced is traded around the world, with global exports equating to about 10% of total production.

Figure 2.8. Production, Consumption, and Trade of Ammonia in Selected Countries and Regions, 2020



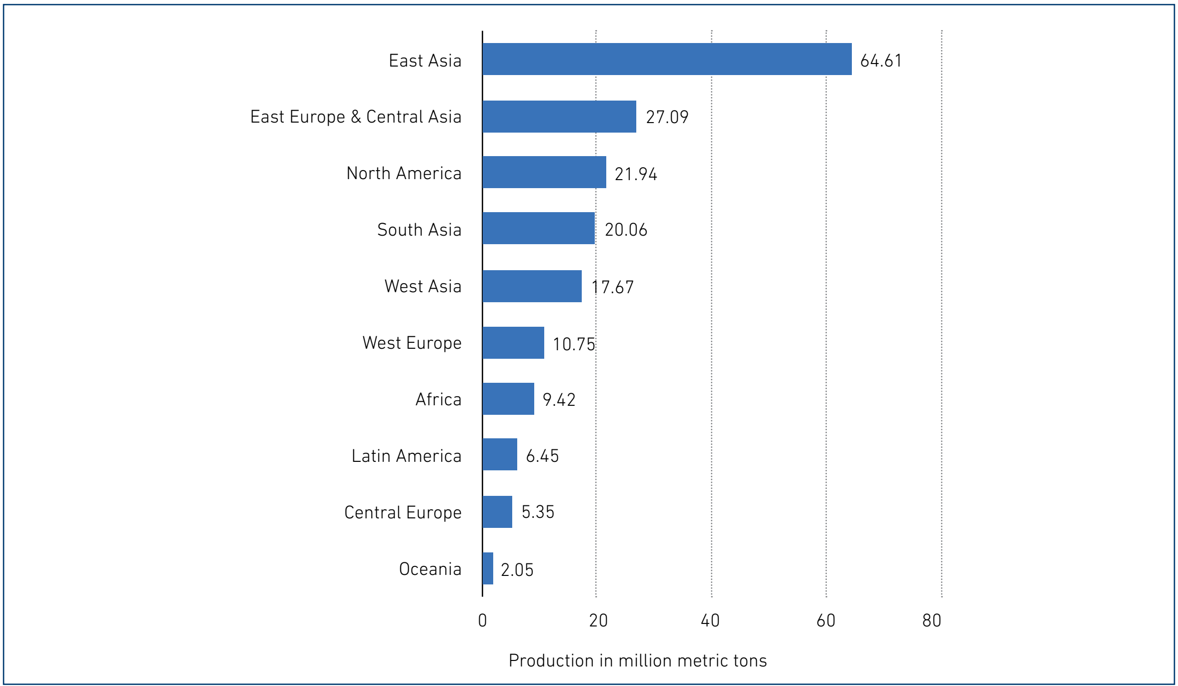
MT = million tons.
Source: IEA (2020).

Global ammonia demand is expected to grow at a CAGR of 3%–4% between 2016 and 2022 and to increase to around 8% from 2022 to 2031, the primary driver of this growth being increased demand from the agricultural segment in Asia (Kenneth Research, 2022). The ammonia market for Southeast Asia reached US$27.4 billion and is expected to increase in demand in the coming years.

Supply

The Asian continent plays a critical role in the global ammonia production landscape, as it is currently the foremost ammonia producing region worldwide. In 2020, the production of ammonia was markedly higher in East Asia than in any other region globally as shown in Figure 2.9. China is currently the world's leading ammonia producer, with production figures estimated at roughly 42 million tons of contained nitrogen as of 2022 (Statistika, 2023). India also holds considerable significance as an ammonia producer, although it still relies on imports of ammonia and fertilisers to support its agricultural sector. Additionally, several Asian countries have ammonia plants, including Japan, Indonesia, Myanmar, Viet Nam, Brunei, and Singapore. Japan, for instance, has set a goal to develop ammonia-exclusive firing technology by 2030, which could have the potential to aid coal-fired power.

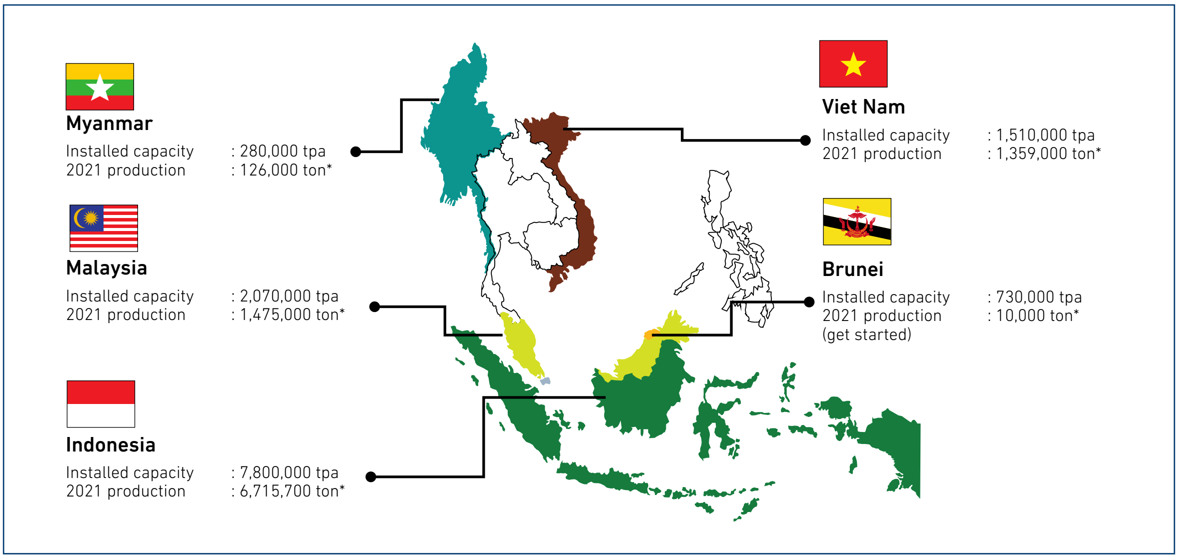
Figure 2.9. Production of Ammonia Worldwide in 2020 by Region



Source: Statistika (2023).

There are currently five countries within the ASEAN region that house ammonia plants with a combined capacity of 11,670,000 tons per annum (TPA) as shown in Figure 2.10. The major players in the Southeast Asian ammonia market include Yara International ASA, PT Pupuk Indonesia, Petronas Chemicals Group Berhad, and others. Amongst these countries, Indonesia boasts the largest ammonia installed capacity (7,800,000 TPA) with production in 2021 at 6,715,700 tons. This is in part due to Indonesia's status as an agricultural nation, where the demand for fertilisers, including those containing ammonia, steadily increases each year. Furthermore, Indonesia's ample reserves of natural gas serve as a plentiful and valuable resource for ammonia production. Indonesia's chemical industry, inclusive of the ammonia sector, has undergone significant expansion in recent years, culminating in Indonesia's emergence as the second largest ammonia producer in Asia, trailing only China.

Figure 2.10. Ammonia Production Plants in ASEAN



ASEAN = Association of Southeast Asian Nations, TPA = ton per annum.

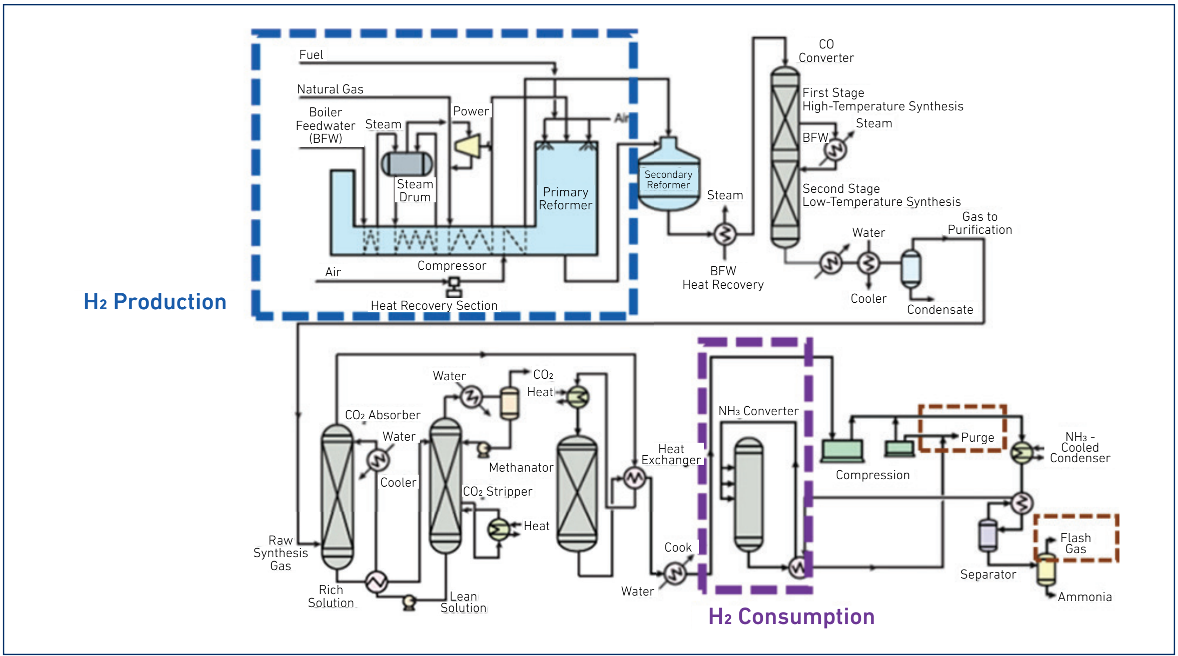
Source: Authors.

In the near future, the demand for ammonia is predicted to extend beyond its conventional use as a fertiliser, given its potential to penetrate the energy sector. Plans to construct ammonia plants in Southeast Asia to facilitate coal-fired power have already been put forth. Japan, for example, has set its sights on developing technology for ammonia-exclusive firing by 2030, and has recently augmented its collaborative efforts with Indonesia, Thailand, and Singapore concerning ammonia and hydrogen fuel via new agreements. Malaysia and Indonesia are presently conducting feasibility studies to assess the potential for co-firing ammonia in coal power plants, with similar intentions in Singapore, Thailand, and Viet Nam.

2.1. Ammonia Production Process

Major steps involved in the manufacture of synthetic ammonia are gas preparation, carbon monoxide conversion, gas purification, and ammonia synthesis. Figure 2.11 shows a simplified flow diagramme for a modern ammonia plant.

Figure 2.11. **Flow Diagramme for Ammonia Synthesis Plant**



Source: Pattabathula and Richardson (2016).

Gas Preparation – Desulphurisation

In preparation for the reforming process, it is necessary to purify the hydrocarbon feed by eliminating any sulphur-containing compounds that could prove deleterious to the reforming catalyst and downstream catalysts. This desulphurisation step may be achieved through the adsorption of sulphur-containing compounds onto either active carbon or molecular sieves, or by means of catalytic hydrogenation of organic sulphur compounds followed by the adsorption of hydrogen sulphide on zinc oxide.

Gas Preparation – Primary Reformer

In the process of steam methane reforming, the feedstock – which may encompass a variety of materials such as natural gas or heavy naphtha – is blended with steam at a steam-to-carbon ratio that is typically determined by both the specific properties of the feedstock and the operating conditions under which the process occurs. This ratio typically ranges between 2.5–4 moles of steam per mole of carbon present in the feed. The mixture of steam and hydrocarbon is then directed through the primary (tubular) reformer, which is heated via the combustion of fuel. Within the reformer, the feed undergoes conversion into a composite mixture of carbon oxides, hydrogen, and methane that has not been fully converted. Along the course of this process, reactions occur between the natural gas and the steam.

$$CH_4 + H_2O \Leftrightarrow CO + 3H_2$$
$$CH_4 + 2H_2O \Leftrightarrow CO_2 + 4H_2$$

The reactions taking place during the process are endothermic, meaning they require a substantial amount of heat to occur. As a result, the typical outlet temperatures from the primary reformer range from 750°C –820°C. Additionally, a secondary exothermic reaction also takes place.

$$CO + H_2O \Leftrightarrow CO_2 + H_2$$

Gas Preparation – Secondary Reformer

After leaving the primary reformer, the gas stream comprises hydrogen, carbon monoxide, carbon dioxide, excess steam, and unreacted methane. This effluent gas is directed to an adiabatic reactor, known as a secondary reformer, which contains the same type of catalyst as the primary reformer. In this reactor, the unreacted methane is further reduced to a level of approximately 0.2%. To promote the reaction, a controlled amount of air is introduced into the reactor to supply sufficient oxygen for residual methane reforming and to provide the necessary nitrogen to maintain a 3:1 hydrogen-to-nitrogen ratio in the synthesis gas makeup. The desired reaction in the secondary reformer is:

$$CH_4 + O_2 \Leftrightarrow CO_2 + H_2$$

The gas that exits the secondary reformer typically CO_2, CO, H_2, N_2, and CH_4, with more than 50% H_2 produced. To generate high-pressure steam required for the reforming process, hot flue gas from the furnace of the primary reformer is utilised to preheat the feed gases. The outlet temperature from the secondary reformer usually ranges between 950-1,025ºC. The gas from the reformer is then directed to a waste-heat boiler, where additional high-pressure steam is generated. To regulate the temperature and provide extra steam for the shift reaction that follows, condensate is added to the gas as required.

Carbon Monoxide to Hydrogen Conversion – Shift Conversion

The conversion of carbon monoxide, which is produced in both the primary and secondary reformers, into hydrogen takes place through a reaction with steam in the presence of a catalyst in the shift converter. This process is referred to as the shift reaction and can be represented as follows:

$$CO + H_2O \Leftrightarrow CO_2 + H_2$$

The conversion of carbon monoxide to hydrogen takes place in the shift converter through reaction with steam and a catalyst. The conversion achieved depends on several factors such as the steam-gas ratio, catalyst temperature, catalyst activity, and gas space velocity. Numerous catalysts and processes are available for this reaction, with magnetite being the classical catalyst promoted with chromia and sometimes with potassium or other promoters. The reaction is carried out in a single converter unit packed with multiple beds of catalyst. The steam-gas mixture first passes through a high-temperature catalyst operated at 700 °F–900°F, where carbon monoxide is reduced to 2% or less. Then, the gas is cooled by heat exchange or quenched with steam condensate and passed through a low-temperature catalyst operated at 375 °F–500°F. Here, carbon monoxide is reduced to 0.2%–0.3%, whilst the hydrogen composition increases to more than 60%. To remove all traces of sulphur and chloride compounds that act as poisons to the catalyst, a bed of zinc oxide is located above the bed of the low-temperature catalyst. The shift reaction is exothermic and does not require additional heat.

Purification – Acid Gas Removal

In facilities that employ steam reforming of light hydrocarbons, the shift-converted product gas typically contains around 18% carbon dioxide on a dry basis. Conversely, gas produced by the partial oxidation of heavy hydrocarbons or gasification of solid feedstocks has even higher concentrations of carbon dioxide, along with potentially significant amounts of hydrogen sulphide due to the feed's sulphur content and shift conversion technology. The carbon dioxide removal solvents used in ammonia synthesis gas are characterised by the type of absorption process employed. Chemical absorption involves the reaction of carbon dioxide with the solvent, which is then reversed during solvent regeneration, and typically employs alkanolamines such as mono-ethanolamine (MEA) or hot solutions of potassium carbonate.

Generally, the shift-converted gas flows from the shift converter to the purification stage, where carbon dioxide is scrubbed out using a counter current MEA solution. The MEA solution, now rich in carbon dioxide, is regenerated in a separate tower using steam stripping and recirculated. During the absorption and regeneration steps, the following reaction occurs:

$$2HOCH_2CH_2NH_2 + CO_2 + H_2O \Leftrightarrow (HOCH_2CH_2NH_2)_2H_2CO_3$$

Purification – Methanation

After the removal of carbon monoxide and carbon dioxide in the shift conversion and carbon dioxide removal sections, the synthesis gas still contains residual amounts of these compounds, along with water. These impurities must be removed to low parts per million (ppm) levels before the gas can enter the synthesis converter, as oxygen-containing compounds can be detrimental to the ammonia synthesis catalysts.

The most effective method for removing the remaining traces of carbon monoxide and carbon dioxide from ammonia synthesis gas is methanation. This process involves the use of a nickel-containing catalyst at temperatures between 250°C–350°C, which results in the complete conversion of carbon oxides to levels below 10 ppm. The reaction is exothermic and can be represented as follows:

$$CO + 3H_2 \Leftrightarrow CH_4 + H_2$$
$$CO_2 + 4H_2 \Leftrightarrow CH_4 + 2H_20$$

Methanation is the final step in purifying the ammonia synthesis make-up gas by reducing the concentrations of carbon oxides. It is essential to keep these impurities as low as possible to prevent carbon monoxide from poisoning the ammonia synthesis catalyst and carbon dioxide from reacting with ammonia to form ammonium carbamate deposits in pipelines and plant equipment. After purification, the make-up gas, consisting of the proper ratio of hydrogen and nitrogen, small amounts of methane and argon, is compressed for ammonia synthesis. However, water may also be present in the gas from the methanation unit, which can be removed by either adsorption on molecular sieves or by co-condensation and washing with ammonia before adding to the synthesis loop. In many ammonia plants, the latter method is used, where the synthesis gas is added to the synthesis loop upstream of the product ammonia separation.

Ammonia Synthesis

The process of ammonia synthesis is initiated by combining the compressed make-up gas with the synthesis recycle gas and then filtering the mixture to remove oil. The gas is then directed to an ammonia-cooled condenser, where the concentration of ammonia is lowered to 4% or less. After this, the gas flows through a separator and a heat exchanger before entering the synthesis converter, where the reaction between hydrogen and nitrogen takes place:

$$3H_2 + N_2 \Leftrightarrow 2NH_3$$

The exothermic nature of the ammonia synthesis reaction imposes an equilibrium limitation on the process, which means that only a partial conversion can occur during the gas's passage through the synthesis reactor, given practical conditions. Moreover, in most practical cases, the product ammonia is separated from the unreacted gas by cooling the gas to a temperature low enough to condense and separate the liquid ammonia from the gas. To achieve a reasonable efficiency for product recovery, relatively low temperatures are required at realistic pressures.

2.2. Data Sources

Historical data on ammonia demand for each Asian country between 2010 and 2021 were collected from various sources. However, this information is limited and only available for some countries. For instance, records of ammonia demand in Indonesia were retrieved from annual reports by Pupuk Indonesia and Panca Amara Utama. The data for Malaysia from 2003 to 2009 were obtained from the United States Geological Survey (USGS) Minerals Resources Program report published by IndexMundi (indexmundi.com). In the case of Myanmar, ammonia production data covering the period between 2003 and 2012 were obtained from a USGS Minerals Resources Program report published by IndexMundi. Finally, production data for Brunei were obtained from the Brunei Fertilizer Industries reports as the engineering, procurement, and construction consultant for the installation of the Brunei ammonia plant.

2.3. Estimation Method and Models

The volumes of hydrogen supply and demand from ASEAN's ammonia Industry were estimated based on ammonia production data. In this report, a conversion factor of 0.19 ton hydrogen per ton ammonia (obtained from typical ammonia production in Indonesia) was used. The hydrogen demand is defined by the required amount of hydrogen to produce industrial ammonia. Therefore, countries with no ammonia production facility will have zero hydrogen demand from ammonia industry.

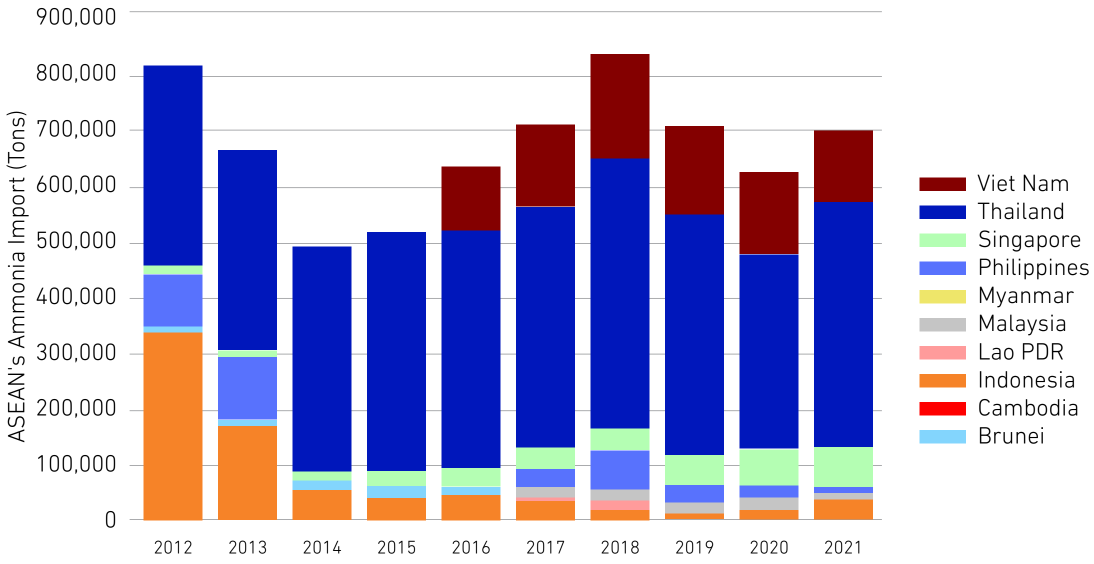
All ammonia production data were estimated using past plant utilisation data except for Indonesia. Data for Indonesia were based on real production data reported by companies.

Forecasts of supply and demand of ammonia using CAGR from Southeast Asian ammonia historical demand from 2012 to 2021 (2.7%) and ammonia production volumes in 2025 onwards are calculated based on current capacity and announced capacity with 90% plant utilisation. The demand for ammonia is calculated by using the export, import, and production data of each country.

$$\textit{Demand} = \textit{production} + \textit{import-export}$$

2.4. Historical Ammonia and Hydrogen Demand and Supply in Ammonia Production for Southeast Asian Countries

Figure 2.12. Southeast Asia's Ammonia Historical Import Volume



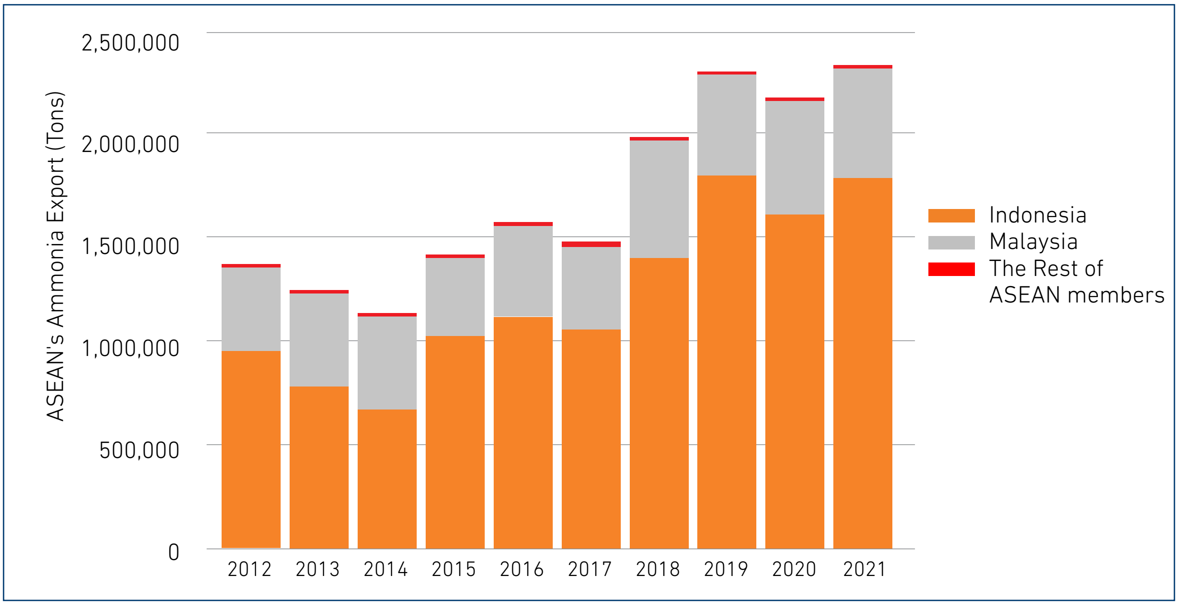
ASEAN = Association of Southeast Asian Nations.

Source: Authors.

Thailand has emerged as the largest importer of ammonia amongst Southeast Asian countries. As Thailand has no ammonia plant of its own, it imports ammonia to serve diverse purposes such as fertiliser, monosodium glutamate, rubber and latex, metal heat treatment, lower NOx emissions (DeNOx), and as an environmentally friendly refrigerant (R 717) for industrial refrigeration systems. Ammonia has become a crucial component of the country's agricultural and industrial sectors, particularly in the context of rice cultivation, which accounts for a significant portion of the country's agricultural production. Whilst agriculture accounts for a relatively modest 6% of Thailand's gross domestic product (GDP), it is the livelihood for approximately one-third of the country's labour force. Consequently, the demand for ammonia in Thailand continues to increase every year, with approximately 70% of the imported ammonia being used for fertilisers. The vast tracts of arable land in Thailand, covering roughly 52% of the country, and the primacy of rice cultivation in the agricultural landscape, contribute to the country's growing dependence on ammonia imports.

Singapore, the Philippines, Lao People's Democratic Republic (Lao PDR), and Myanmar exhibit lower levels of demand for imported ammonia than Thailand, as their primary sectors for ammonia use are not agricultural in nature and thus do not require as high a volume of ammonia imports. Rather, ammonia serves as a raw material for the chemical industry, albeit not the primary one. Notably, Viet Nam, the third-largest producer of ammonia in Southeast Asia after Indonesia, has experienced a significant surge in ammonia imports since 2016. This is attributed to the fact that Viet Nam's ammonia plant has reached 90% of production capacity, whilst the country's agricultural sector is growing.

Figure 2.13. Southeast Asia's Ammonia Historical Export Volume

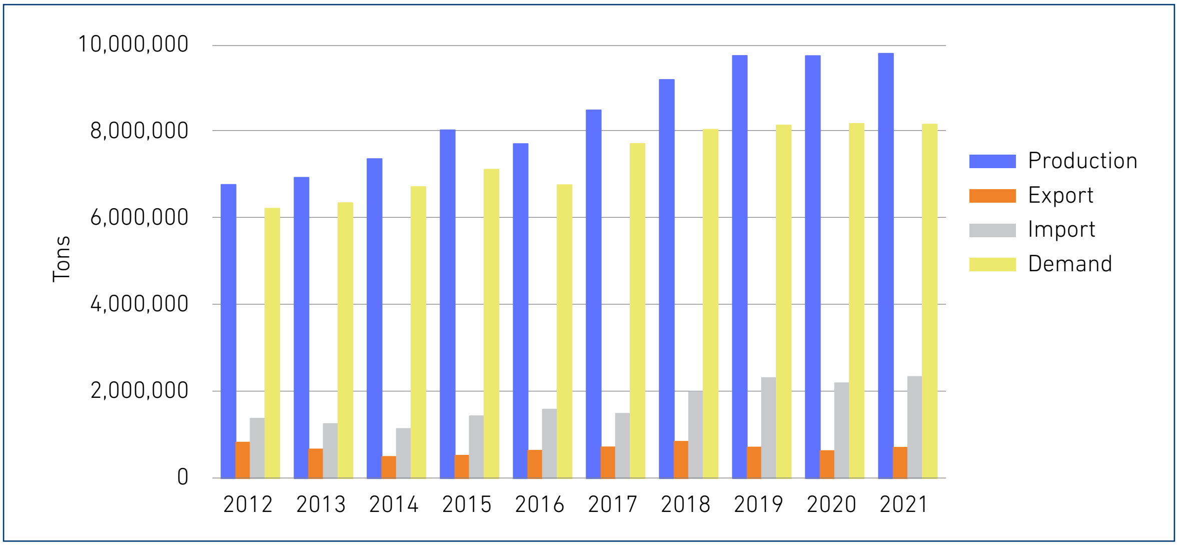


ASEAN = Association of Southeast Asian Nations.

Source: Authors.

Indonesia and Malaysia are the primary ammonia exporters in Southeast Asia, with both countries having the highest production of ammonia and possessing plants with significant installation capacities. Indonesia, in particular, dominates the ammonia export market, indicating that the country's current installed industry is capable of fulfilling domestic demand for ammonia.

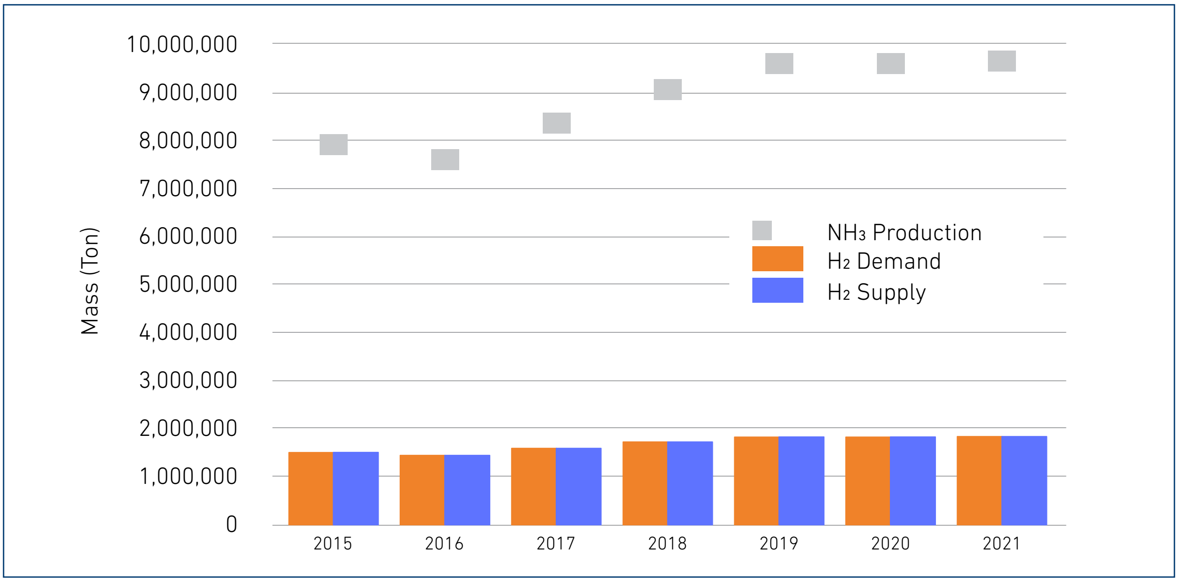
Figure 2.14. **Southeast Asia's Ammonia Historical Supply and Demand**



Source: Authors.

On a global scale, and within the context of Southeast Asia, the volume of ammonia production from each plant in every country appears to adequately satisfy the total demand for ammonia across Southeast Asian nations as shown in Figure 2.14 and Figure 2.15. This conclusion is supported by the higher export value of ammonia in comparison to the total annual imports.

Figure 2.15. **Southeast Asia's Hydrogen Supply and Demand from Ammonia Industry**

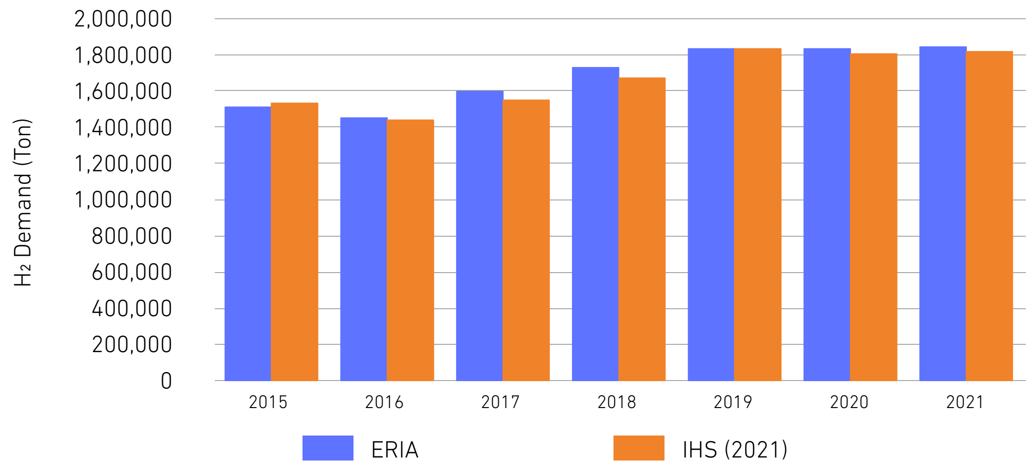


Source: Authors.

Up to this point, it can be observed that the supply and demand for hydrogen in Southeast Asia are aligned, with production levels closely related to ammonia production requirements on a yearly basis. This indicates that hydrogen production from reforming processes is being fully utilised for ammonia production, and there has been no further exploration into potential applications of the produced hydrogen gas.

This trend highlights a lack of diversity in the utilisation of hydrogen gas beyond its role in ammonia production. In order to further expand the use of hydrogen and its potential benefits by exploring these alternative uses, the full potential of hydrogen as a versatile and sustainable energy carrier can be better realised in the Southeast Asian region.

Figure 2.16. Southeast Asia's Hydrogen Demand from Ammonia Industry, 2015–2021



Source: Authors.

ERIA's analysis on hydrogen demand in the ammonia industry has been found to be accurate and aligned with available data from IHS, specifically the 'Hydrogen' chapter in the Chemical Economics Handbook published in 2021 (IHS, 2021). Although there may be slight differences in the results of these studies, these variations are considered insignificant. As a result, the ERIA data can be considered relevant and useful for further research in this area.

3. Methanol Production

Demand

Methanol is a hydrocarbon compound consisting of carbon, hydrogen, and oxygen. It is a type of alcohol with its molecular formula of CH_3OH, which is liquid at room temperature. Methanol can be called methyl alcohol, hydroxymethane, or methyl hydrate. Methanol can be combusted completely without any soot or particulates left, giving a bright blue flame. Methanol is similar to ethanol as it is colourless, volatile, flammable, and has a distinctive alcoholic odour. The properties of methanol, ethanol, and gasoline are compared in Table 2.3.

Table 2.3. Comparison of the Properties of Methanol, Ethanol, and Gasoline

Property	Methanol (CH_3OH)	Ethanol (C_2H_5OH)	Gasoline (C_4-C_{12})
Molecular weight (kg.mol-1)	0.032	0.046	~0.114
Specific gravity at 25°C	0.789	0.788	0.739
Vapor density rel. to air	1.10	1.59	3.0 to 4.0
Liquid density (kg/m3 at 25°C)	790	790	400
Boiling point (°C)	65	78	27 to 245
Melting point (°C)	-98	-144	-
Vapor pressure @ 38°C (kPa)	31.72	17.24	~50 - 69
Heat of evaporation (kJ/kg-1)	1097.8	963.6	314.1
Heating value (MJ/kg-1) Lower	20.1	26.9	43.4
Heating value (MJ/kg-1) Upper	22.8	29.8	46.5
Tank design pressure (kPa)	103.4	103.4	103.4
Viscosity (Pa-s)	0.00054	0.0012	0.00056
Flash point (°C)	11	14	-45
Auto-ignition temperature (°C)	460	363	250 – 460
Solubility in H_2O (%)	Miscible (100%)	Miscible (100%)	Negl. (~0.01)
Azeotrope with H_2O	None	95% EtOH Hygroscopic	Immiscible
Peak flame temperature (oC)	1870	1920	2030
Minimum ignition energy in air (MJ)	0.14		0.23

kg = kilogramme, kgm_3 = kJ = kPa = kilopascal, MJ = megajoule, Pa-s = pascal second.

Source: Sikarwar et al. (2017).

The produced methanol can be utilised in many industrial sectors, both directly and indirectly, for example as a raw material for fuel production in the energy sector. It is a precursor in the production of plastics in various forms. The form of utilisation of methanol produced are summarised in Table 2.4.

Table 2.4. Applications of Methanol in Various Industries

Product type	Industry type	Methanol Utilisation
1. Olefin	Chemicals	Methanol is used in the production of olefins that are classified as upstream petrochemical products consisting of ethylene and propylene. Olefins are the precursors for the production of polyolefins and other related products such as polyvinyl chloride, plastic granules, styrene monomer, etc.
2. Dimethyl Ether (DME)	Energy	Methanol is used in the production of DME fuel by either an indirect production through methanol dehydration process or direct DME production. DME can be utilised in two main ways: 1) Mixed with liquefied petroleum gas (LPG) to provide heating in households 2) Used as fuel for vehicles. DME is often mixed with diesel or benzene to produce a mixed fuel. It can also be used by vehicle engines directly.
3. Biodiesel	Energy	Methanol is used in the production of biodiesel that is obtained from spent vegetable oil or animal fat or oil by a process called transesterification. The vegetable oil or animal oil is mixed with methanol over a catalyst.
4. Gasoline Blending	Energy	Methanol is mixed with benzene to be used as fuel in the transportation sector.
5. Methyl chloride (chloromethane)	Chemicals	Methanol is used in the production of methyl chloride, which can be used as a refrigerant in air conditioners, as known as R-40.
6. Methylamine	Chemicals	Methanol is used in the production of methylamine that is used as a solvent in various dye-related industries such as the tanning industry, catalyst, film development, and organic chemical synthesis. It is also used as an inhibitor in polymerisation process, rocket propellant, and ingredients in household cleaning agents, dishwashing detergents, etc.
7. Methanethiol (Methylmercaptan)	Chemicals	Methanol is used in the production of methylmercaptan that is an additive in liquefied petroleum gas to give a warning odour for safety purpose.
8. Dimethyl terephthalate (DMT)	Energy	Methanol is used in the production of DMT that is the raw material for many polyester products such as polyethylene terephthalate (PET), polytrimethylene terephthalate, and polybutylene terephthalate (PBT).

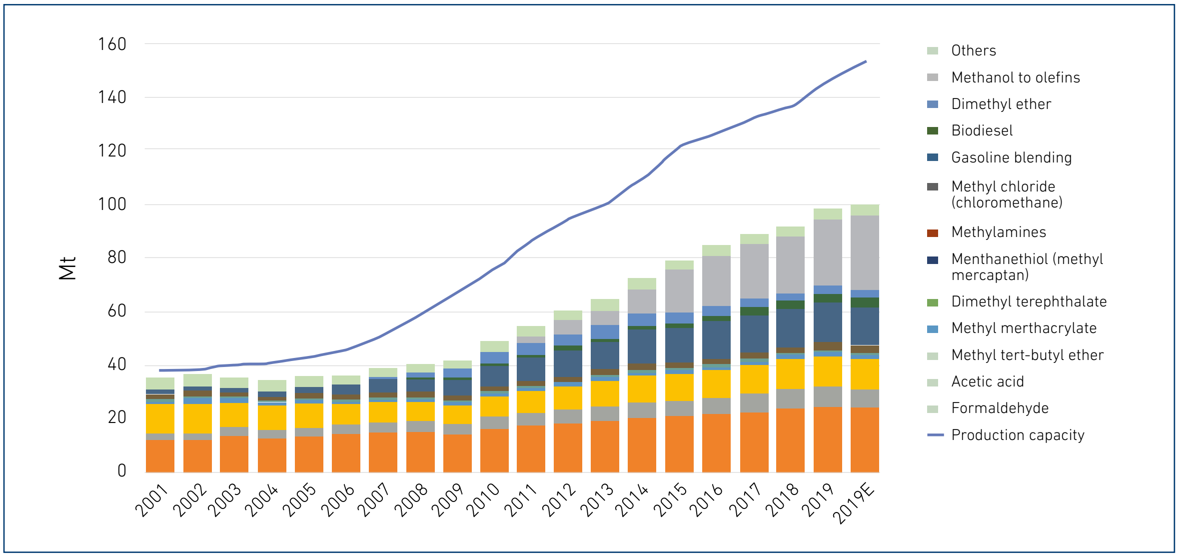
Product type	Industry type	Methanol Utilisation
9. Methyl methacrylate	Chemicals	Methanol is used as a raw material for the production of methyl methacrylate that has many applications: 1) Used for the production of polymethyl methacrylate (PMMA) as known as an acrylic. It is highly durable and transparent; therefore it is used to produce unbreakable transparent sheets. 2) Used for the production of hard contact lenses 3) Used for the production of resins such as methyl-methacrylate butadiene-styrene (MBS), which is an impact resistant resin . 4) Used for surface coating to give hardness and durability.
10. Methyl tertiary butyl ether	Chemicals	Methanol is used in the production of methyl tertiary butyl ether (MTBE) that is an oxygen-containing chemical. It is produced by a chemical reaction between methanol and isobutane. In the past, the substance was widely used in the oil refinery industry by adding it to gasoline to help reduce the amount of carbon monoxide in the exhaust of vehicles and increase the octane of the oil instead of lead.
11. Acetic acid	Food Chemicals Agriculture Medicine	Methanol is used as raw material in the production of acetic acid that has many applications such as: 1) Used as a raw material for vinegar production 2) Used for the production of acetic acid derivatives such as terephthalic acid, acetic anhydride, etc. 3) Used as an ingredient in food to prevent the growth of microorganisms that cause spoilage. Used to adjust the acidity and alkalinity of food, and help extend the shelf life of food. It is also used for adding sour taste in food is important. 4) Used as an active ingredient of fungicides, bio-fermented liquid 5) Used as an ingredient in pharmaceutical products for inhibiting the growth of fungi or microorganisms that cause ear infections.
12. Formaldehyde	Food Chemicals Agriculture Medicine	Methanol is used as raw material for production of formaldehyde and has the following uses: 1) Used as raw material in the production of urea formaldehyde, melamine formaldehyde, etc. 2) Used as a disinfectant 3) Used as a pesticide 4) Used as a preservative

Mt =million ton.

Source: Various sources compiled by authors.

Methanol is an important basic chemical, along with ethylene, propylene, and ammonia, which are used as precursors and intermediates to produce other chemical products. Approximately one-third of methanol produced are consumed as raw materials for the production of chemicals, e.g. formaldehyde, acetic acid, and plastics. The use of methanol for the production of polyethylene and propylene has grown significantly from nearly zero in 2009 to 25 million tons (MT) in 2019. The remaining methanol is used as fuel for automobiles, ships, boilers in industry, and food production. Another important application is the blending of methanol with other commercial fuels to produce biodiesel, methyl tertiary butyl ether, and dimethyl ether. During 2001-2020, the methanol production rate increased every year. In 2020, the world production of methanol was more than 140 MT and the consumption of methanol was almost 100 MT. Most methanol is produced from natural gas or coal. The details of methanol production and consumption are shown in Figure 2.17.

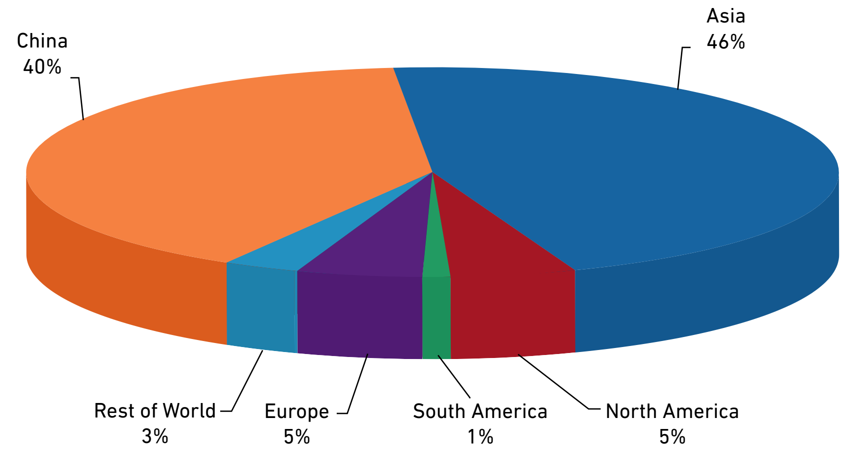
Figure 2.17. World Production and Consumption of Methanol, 2001–2020



Source: IRENA and Methanol Institute (2021).

As shown in Figure 2.18, the Asia-Pacific region is the largest consumer of methanol, accounting for over half of the world's demand. China is the largest market for methanol (40%), driven by its rapid economic growth and large manufacturing industry. Other countries such as India, the Republic of Korea, and Southeast Asian nations, are also expected to see increasing demand for methanol in the coming years. In Europe and North America, demand for methanol is growing but at a slower pace compared to Asia. The growth in these regions is driven by the increasing use of methanol in the production of biofuels, as well as its use as a fuel for shipping and other transportation applications. Overall, the demand for methanol is expected to continue growing in the coming years, driven by the need for clean and renewable energy sources, and the increasing demand for chemicals and plastics in developing countries.

Figure 2.18. Methanol Demand by Major Regions in 2020



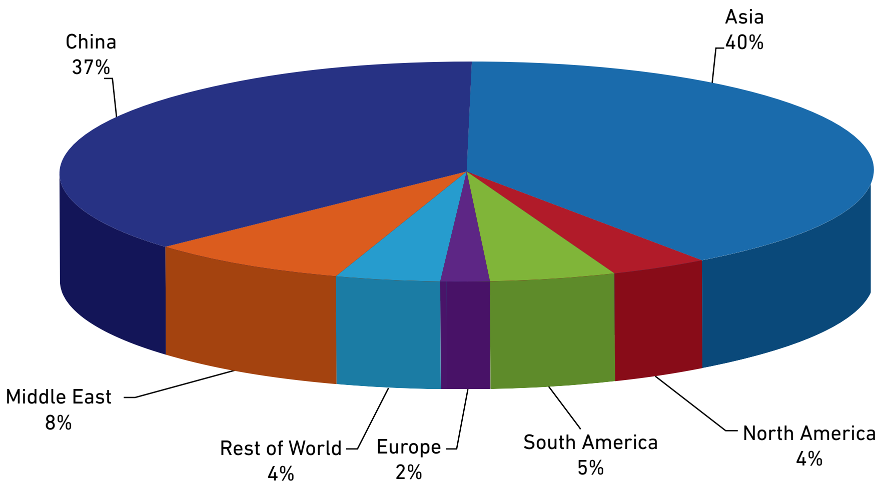
Source: Methanol Market Services Asia (2021).

Southeast Asia has seen a growing demand for methanol in recent years, driven by the region's economic growth and the increasing use of methanol in various industries. The chemical industry is a major consumer of methanol, using it as a feedstock for the production of formaldehyde, acetic acid, and other chemicals. The region is also home to a growing number of plastics manufacturers, which use methanol as a key ingredient in the production of resins, fibres, and films. The demand for methanol as a fuel is also increasing in Southeast Asia, particularly in the transport sector where it is used as a clean-burning alternative to gasoline. This is driven by the growing concern for the environment and the need for clean and renewable energy sources. In addition, the region has a large shipping industry, and methanol is being used as a fuel for shipping due to its lower emissions and cost-effectiveness compared to traditional fuels. Countries such as Thailand, Indonesia, and Viet Nam are leading the growth in methanol demand in Southeast Asia, due to their large manufacturing industries and expanding economies. Other countries in the region, such as the Philippines, Malaysia, and Myanmar, are also expected to see increasing demand for methanol in the coming years.

Supply

Figure 2.19 illustrates the methanol supply by regions in 2020. China is the largest producer of methanol in the world, accounting for 37% of the global methanol supply. This is due to several factors, including the availability of abundant natural gas reserves, which are used as feedstock for methanol production, and the favourable economic and policy environment for methanol production in China. Asia as a whole accounts for 40% of the world's methanol supply, with China and India being major methanol producers in the region. The growth of the methanol industry in Asia is driven by the region's economic growth and the increasing demand for methanol in various industries such as the chemical and plastics industries. In addition, the abundance of natural gas in the region makes it a favourable location for methanol production.

Figure 2.19. Methanol Supply by Major Regions in 2020



Source: Methanol Market Services Asia (2021).

The Middle East is another important region for methanol production, accounting for 8% of the world's methanol supply. The growth of the methanol industry in the Middle East is driven by the region's abundant natural gas reserves and the favourable economic environment for methanol production. Countries like Iran, Saudi Arabia, and Qatar are major methanol producers in the region. North America and Europe are also significant producers of methanol, but their combined share of the world's methanol supply is only 4%. This is due to several factors, including the higher cost of natural gas in these regions and the limited availability of natural gas reserves. However, advancements in methanol production technology and the development of alternative feedstock are expected to increase methanol production in these regions in the future.

Table 2.5. Applications of Methanol in Various Industries

Methanol Plants in Southeast Asia	Capacity (million tons per annum)
Petronas Methanol Sdn Bhd	2.4
Petronas Chemicals Fertiliser (Kedah) Sdn Bhd	0.07
PT Kaltim Methanol Industry (KMI)	0.66
Brunei Methanol Company Sdn Bhd	0.85

Source: Authors.

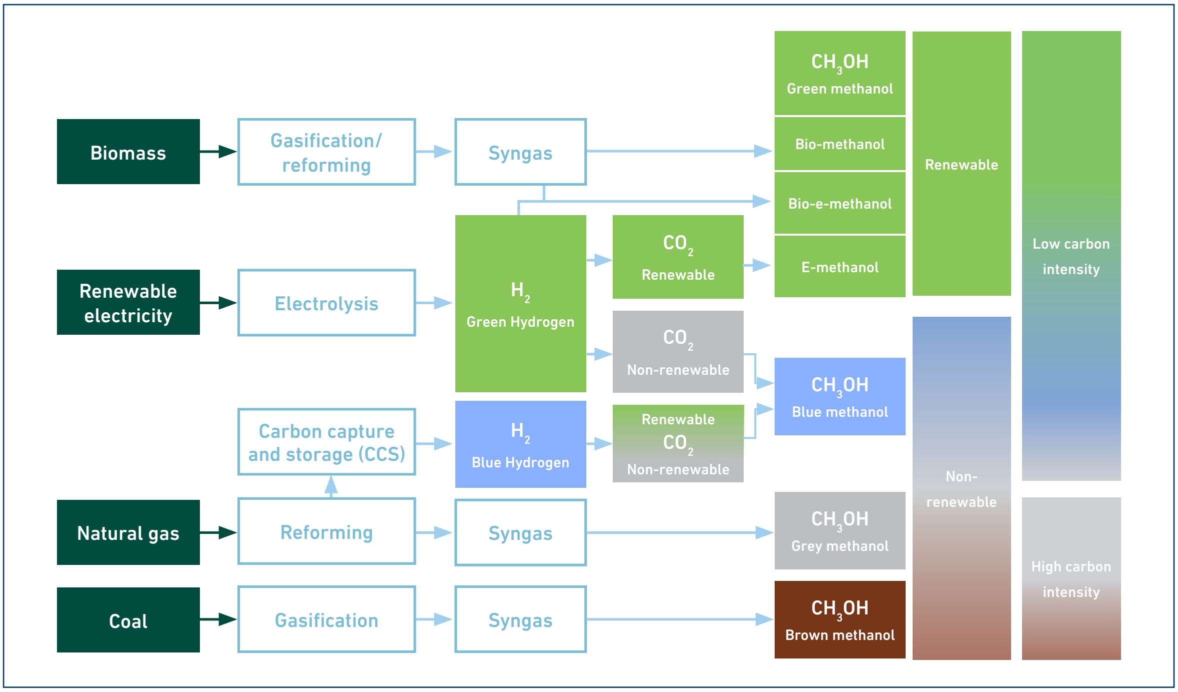
It can be stated that Southeast Asia, specifically Malaysia, Indonesia, and Brunei, have seen significant growth in their methanol industry, with several new methanol production plants being built or planned in these countries (Table 2.5). These plants are being constructed to meet the growing demand for methanol in the region and to take advantage of the region's abundant natural gas reserves, which are used as a feedstock for methanol production. The construction of new methanol plants in Malaysia, Indonesia, and Brunei is driven by the region's economic growth, which is increasing demand for methanol in various industries such as the chemical and plastics industries, as well as its growing use as a fuel. In addition, the abundance of natural gas in these countries makes it a favourable location for methanol production, as natural gas is the primary feedstock for methanol production.

There is a new player in the market as well, as Singapore is working towards building global infrastructure for the production and supply of methanol as a marine fuel. A partnership between the shipping and fuel industries plans to establish the first green e-methanol plant in Southeast Asia in Singapore, which is already known as the world's largest bunkering hub for the shipping industry. The initiative is led by A.P. Moller–Maersk and involves partners such as PTT Exploration and Production, Air Liquide, YTL Power Seraya, Oiltanking Asia Pacific, and Kenoil Marine Services. They plan to launch a Green Methanol Value Chain Collaboration to explore the feasibility of a green e-methanol pilot plant with a minimum production capacity of 50,000 tons per annum. This marks a significant step towards transforming captured biogenic CO_2 and green hydrogen into green e-methanol, making it a commercially accessible low carbon fuel for the maritime industry (Maritime Executive, 2022).

3.1. Processes in Methanol Production

Methanol can be produced from coal, natural gas, biomass, and biogas by a variety of processes such as methane reforming, gasification and electrolysis (Figure 2.20).

Figure 2.20. Methanol Synthesis Process



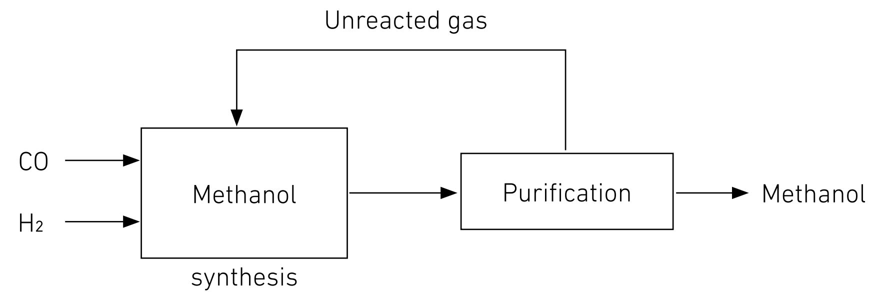
Source: IRENA and Methanol Institute (2021).

The synthesis of methanol is basically the reaction between carbon monoxide and hydrogen over a catalyst such as zinc oxides and copper. The temperature is approximately 250°C and the pressure is between 50–100 bar. The chemical reactions are shown in Equations 1 and 2.

$CO+2H_2$	CH_3OH	Equation 1
$CO_2+ 3H_2$	$CH_3OH + H_2O$	Equation 2

Synthetic gas is a mixture of hydrogen and carbon monoxide produced by the reaction between methane and water. But sometimes, in addition to CO and H_2, CO_2 gas is also produced during the production process. For the production of methanol from synthetic gas, CO, H_2, and CO_2 are reacted as in equations 1 and 2 to produce methanol. The product is then subjected to a purification process to obtain pure methanol fuel as shown in Figure 2.21.

Figure 2.21. The Process of Synthesising Methanol from CO_2



Source: Cifre and Badr (2007).

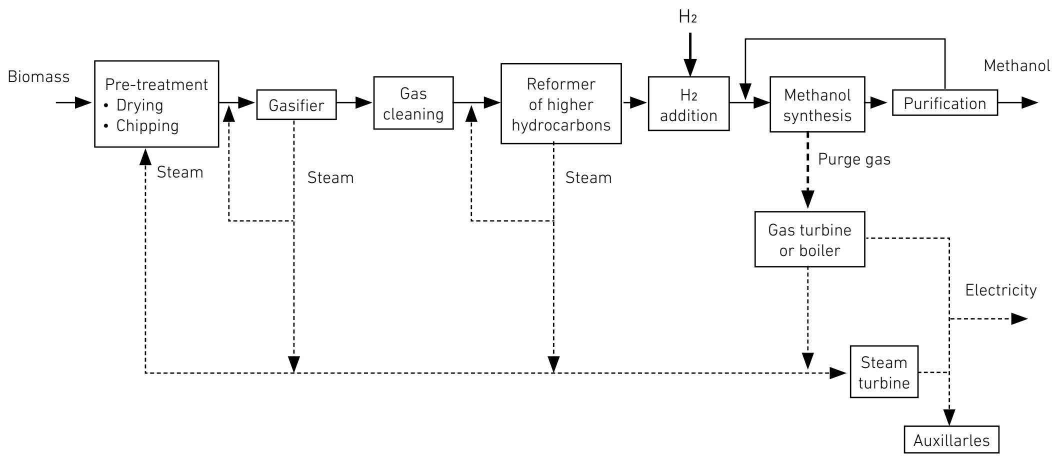
Synthetic gas (syngas) can be obtained via a number of routes. If the raw material is natural gas or biogas, methane reforming processes, such as steam methane reforming (SMR) and autothermal reforming (ATR), are the most common routes. The processes are conducted over a nickel-based catalyst at high temperature and pressure. The SMR heats methane and steam in a reactor to give a syngas which is mainly CO and H_2. However, there is also some excess carbon dioxide that needs to be removed from the product. The ATR uses oxygen or oxygen with steam to react with methane directly to form syngas. The reaction takes place in the same reactor where methane is partially oxidised. The chemical reactions are given below:

$CH_4 + H_2O\ (steam) \rightarrow CO + 3\ H_2$	SMR-1
$CO + H_2O\ (steam) \rightarrow CO_2 + H_2$	SMR-2
$2CH_4 + O_2 + CO_2 \rightarrow 3H_2 + 3CO + H_20$	ATR-1
$4CH_4 + O_2 + H_2O \rightarrow 10\ H_2 + 4CO$	ATR-2

Syngas can also be synthesised from solid fuels, e.g. biomass, coal, or solid waste, through gasification. With limited oxygen, the hydrocarbons are partially oxidised to form carbon monoxide and hydrogen. Due to the nature of solid raw materials, particulates and other impurities are often found in the produced syngas which needs further cleaning. To produce methanol, additional hydrogen is fed into the methanol reactor.

Figure 2.22 shows the whole process.

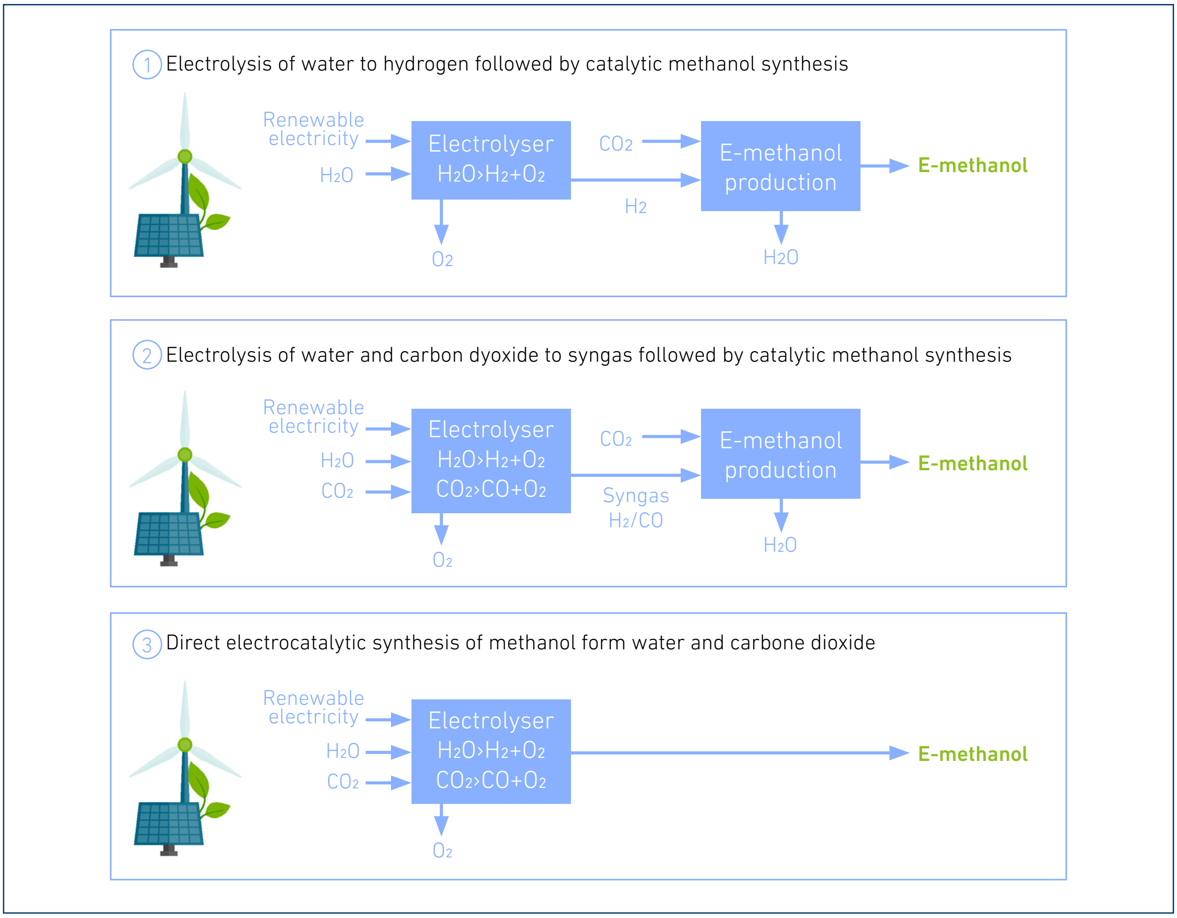
Figure 2.22. Biomass Methanol Synthesis Process



Source: Cifre and Badr (2007).

Methanol can be produced via electrolysis process coupled with a reaction with carbon dioxide. As the hydrogen is produced from renewable energy, it is always green. However, CO_2 can originate from either renewable or non-renewable sources. If the CO_2 is captured from the atmosphere or from combustion of renewable biomass, the product is considered to be e-methanol with very low carbon intensity. On the other hand, if the CO_2 is from fossil-based combustion, the product is classified as blue methanol which has a higher carbon intensity. The production process is shown in Figure 2.23.

Figure 2.23. E-methanol from Electrolysis Process



Source: Ellis et al. (2019).

There are other processes under development for methanol production. Methanol can also be made biologically. The process takes place by using special types of microorganisms that release enzymes as catalysts from the methanol forming reaction. Methanotrophic bacteria are often used to convert methane to methanol. It is also found that pyrolysis of biomass can be used to produce methanol. This process can be used to produce methanol from biomass such as hazelnut shell, hardwood, and softwood. At a temperature of 295K–850K, a heating rate of 2K–4K per second for 300–500 seconds, it was found that methanol can be produced from the shell of hazelnuts as high as 7.8%±0.5% and from hardwood at 1.7%±0.2 % by weight.

Hydrogen is a key ingredient in the production of methanol and is typically supplied in one of two ways: as a by-product of the steam reforming process or as a separate commodity obtained from external sources. In the steam reforming process, hydrogen is produced as a by-product of the reaction between natural gas and steam. This hydrogen can then be used directly in the synthesis reaction to produce methanol. In this case, the hydrogen is said to be 'captive' or 'onsite' as it is produced at the same location as the methanol production plant. Alternatively, hydrogen can be obtained from external sources as a separate commodity. This hydrogen is typically produced using steam reforming, partial oxidation, or electrolysis and is supplied to methanol production plants by merchant hydrogen suppliers. The use of merchant hydrogen allows methanol producers to access hydrogen from locations where it is produced more efficiently or at a lower cost. In both cases, the hydrogen used in methanol production must meet strict quality and purity standards to ensure that it can be used effectively in the synthesis reaction. The source and method of hydrogen supply can have a significant impact on the cost, efficiency, and sustainability of methanol production, and it is an important consideration for methanol producers.

3.2. Data Sources

The 2010–2021 historical data of methanol demand in each Asian country were retrieved from various sources. Nevertheless, such data are scarce and only available in some countries. The records of methanol in Thailand were from the Department of Industrial Works, Ministry of Industry and the Department of Pollution Control, Ministry of Natural Resources and Environment. For Indonesia, the data were retrieved from an academic work of Suseno and Umar (2021), which provided mathematic models for import, export, and consumption. For Malaysia, the methanol production data were obtained from a report of the Labuan Methanol Plant by Maybank (2018). For other countries, the methanol trade balance from an online database (indexmundi.com) was used for the consumption estimation.

3.3. Estimation Methods and Models

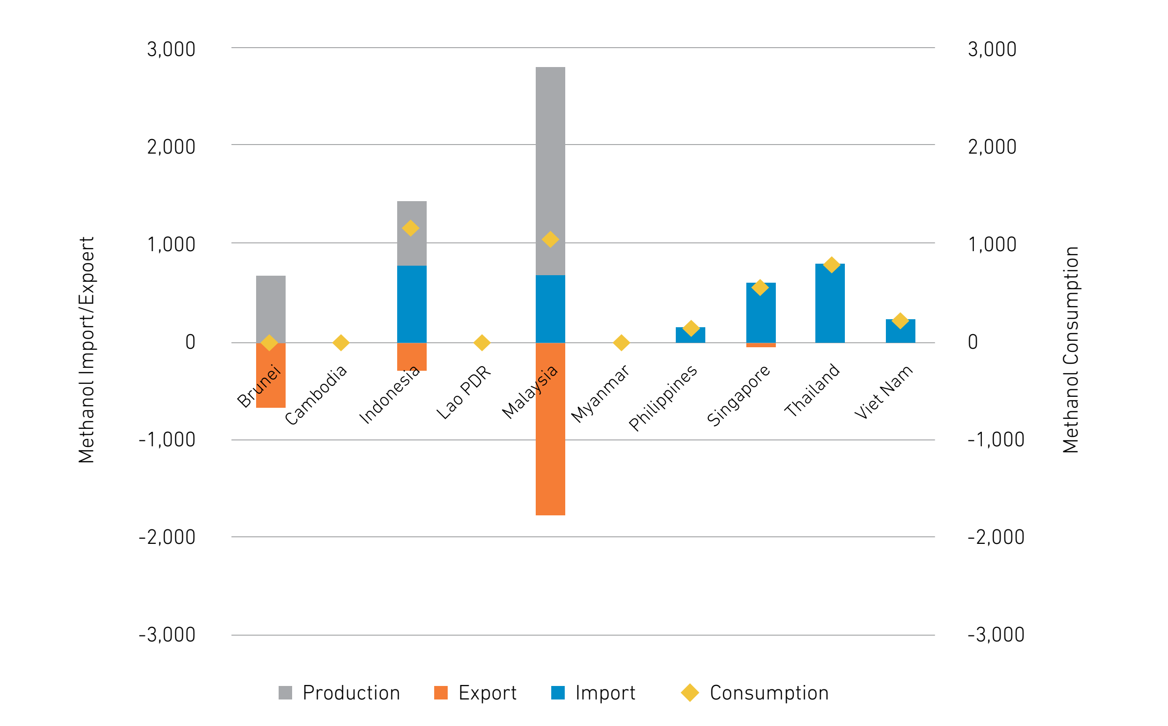
The yearly methanol consumption is calculated from the following equation:

$$\textit{Domestic Consumption} = \textit{Production} + \textit{Import} - \textit{Export}$$

Then the hydrogen demand is calculated by stoichiometry. Thus, the production of 1 ton of methanol (CH_3OH) requires 1/8 tons of hydrogen.

3.4. Demand and Supply in Different Processes

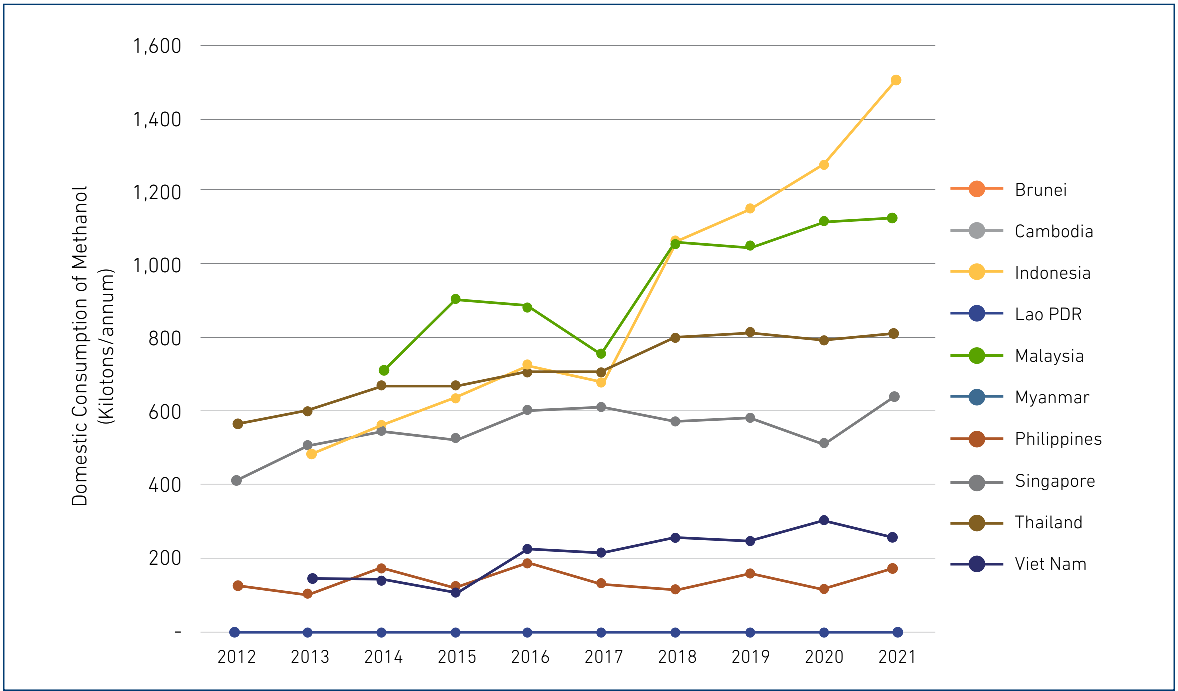
Figure 2.24. Methanol Trade Balance in Southeast Asia in 2019



Source: Authors.

The methanol trade balance for Southeast Asia in 2019 (Figure 2.24) showed that the region imported a total of 4,225.3 thousand tons of methanol and exported 2,074.6 thousand tons of methanol. The largest importer was Singapore with 607.9 thousand tons and the largest exporter was Malaysia with 1,763.1 thousand tons. The other countries in the region, including Brunei, Cambodia, Indonesia, Lao PDR, Myanmar, the Philippines, Thailand, and Viet Nam had a mix of imports and exports, with imports ranging from 0.1 thousand tons to 773.7 thousand tons and exports ranging from 0 tons to 668.4 thousand tons. Overall, the region had a net import of 2,150.7 thousand tons of methanol in 2019, with production in the region totalling 3,450.0 thousand tons and consumption reaching 5,600.7 thousand tons.

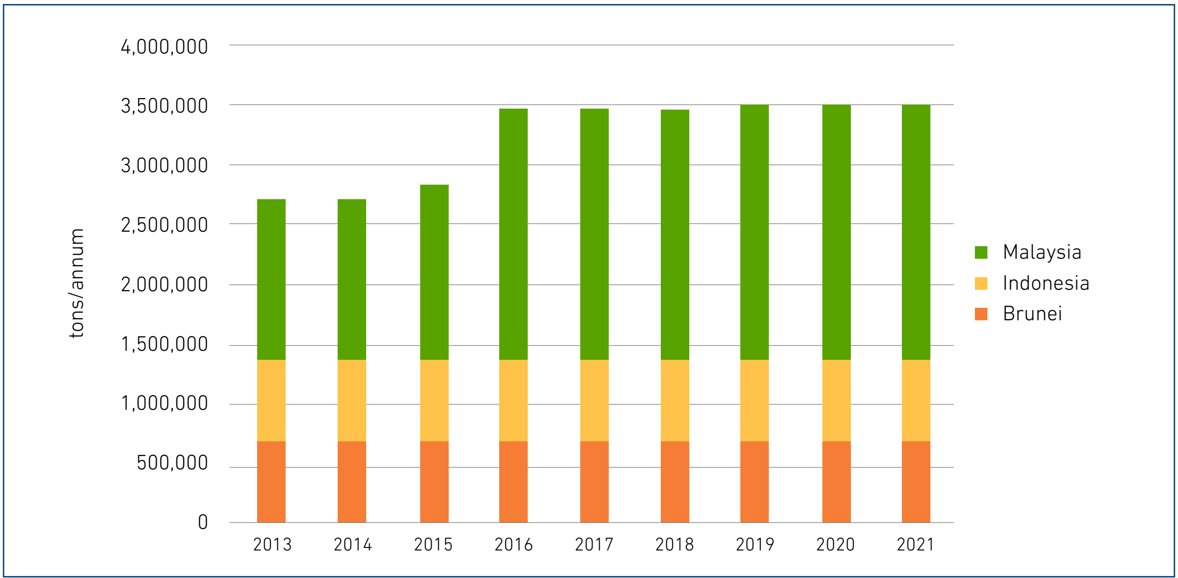
Figure 2.25. Domestic Consumption of Methanol between 2012 and 2021



Source: Authors.

Figure 2.25 shows the growth of methanol consumption in major countries in Southeast Asia. Indonesia, Malaysia, Thailand, and Viet Nam experienced a steady increase in methanol consumption from 2012 to 2021, with some fluctuations during certain years. The Philippines also saw a growth in methanol consumption, although it remained relatively low compared to the other countries. Singapore, on the other hand, showed a decline in methanol consumption from 2012 to 2015, but experienced a steady increase from 2016 to 2021. The average annual growth rate of methanol consumption in Indonesia was 8.1%, in Malaysia was 3.8%, in the Philippines was 2.5%, in Singapore was 4.6%, in Thailand was 1.5%, and in Viet Nam was 6.1% from 2012 to 2021. The compound annual growth rate (CAGR) for methanol consumption in Indonesia was 7.7%, in Malaysia was 2.6%, in the Philippines was 2.2%, in Singapore was 3.7%, in Thailand was 1.3% and in Viet Nam was 5.4% over the same period. In conclusion, methanol consumption in Southeast Asia has been growing in most of the major countries, with Indonesia experiencing the highest average annual growth rate and CAGR, followed by Viet Nam. The growth in methanol consumption reflects the economic development and increasing industrialisation in these countries.

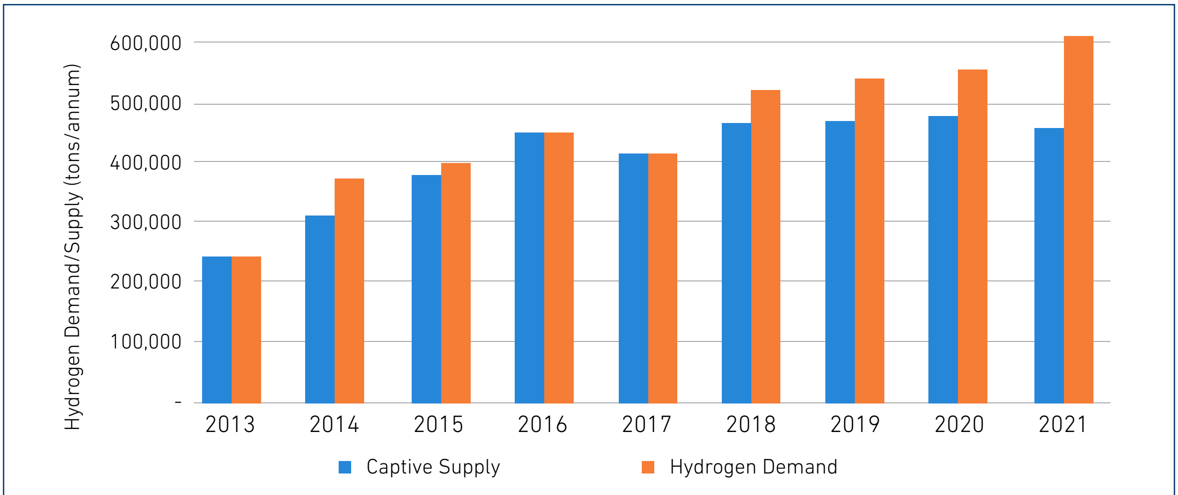
Figure 2.26. **Production of Methanol in Brunei, Indonesia, and Malaysia**



Source: Authors.

From Figure 2.26, the three major producers of methanol in Southeast Asia were Brunei, Indonesia, and Malaysia. These three countries produced a total of 0.72, 0.66, and 1.33 MTPA per annum, respectively in 2013. The total production of methanol in Southeast Asia increased over the years and reached 3.5o MTPA in 2021.

Figure 2.27. **Hydrogen Demand and Supply for Methanol Production (TPA)**



TPA = tons per annum.

Source: Authors.

In Figure 2.27, the hydrogen demand for methanol production was calculated stoichiometrically using a 1:8 ratio and was estimated to increase from 225,694 tons per annum in 2013 to 418,236 tons per annum in 2021. All hydrogen supplies were provided by the captive internal units of each producer. The hydrogen demand in Figure 2.27 was computed based on the methanol demand within the region. The discrepancy between hydrogen supply and demand can be attributed to the fact that the growth in methanol demand exceeded that of hydrogen. Imports of methanol from external sources, such as China and other countries, were utilised to bridge this gap.

4. Hydrogen in Raw Steel Production

In the production of iron and steel, several processes are carried out to process iron ore into products. Iron and steel can be produced by two main methods – direct reduction and indirect reduction. The indirect reduction process involves using a blast furnace to produce iron. In the process, iron ore, coke, and limestone are fed into the furnace, where the coke used as a reducing agent indirectly reduces iron oxide to ferrous metal. Whereas the direct reduction process involves the direct use of a reducing agent, usually natural gas or hydrogen, to remove oxygen from the iron oxide without liquefaction of the iron ore resulting in the production of direct reduced iron (DRI). This process can take place in a shaft furnace, rotary kiln, or fluidised bed reactor. Direct reduction is gaining popularity because of its potential to reduce carbon emissions and more flexible operation than indirect reduction, despite the fact that indirect reduction still dominates.

The iron and steel industry plays an important role in global economic development because it includes various subordinate sectors. However, the iron and steel industry face challenges aimed at sustainable and responsible growth. One thing of major concern to the iron and steel industry is related to environmental issues. The conventional technology that still dominates the production of iron and steel using blast furnace technology is highly dependent on coal and coke, resulting in greenhouse gas emissions, depletion of natural resources, and air pollution. On the other hand, the iron and steel industry is one of the industries with very high energy consumption for its processes, such as smelting and refining.

Demand for iron and steel is influenced by several factors, including the availability and quality of raw materials, technological advances, and government policies. The largest iron and steel-producing countries such as China, India, Japan, the Russian Federation, and the United States have significant iron ore reserves and advanced manufacturing capabilities, making these countries key players in the world iron and steel industry (World Steel Association, 2022a). Iron and steel production is highly closed with several major producers accounting for a significant share of global production. The availability of raw materials such as iron ore and coal are an important factor in determining the supply of iron and steel. The demand for iron and steel is strongly influenced by the growth and development of a country's economy. One of them is the rapid industrialisation and urbanisation in developing countries causing high demand for iron and steel. The supply and demand for this iron can be affected by a variety of factors, including economic growth, changes in trade policies, and geopolitical events. For example, limiting economic growth can lead to a decrease in demand for steel, whilst trade policies that limit the import or export of steel can impact both supply and demand.

Talking about the high demand and suppliers in the world, iron and steel industry cannot be separated from the significant flow of international trade. Exports and imports of iron and steel are very important for the growth of a national economy, especially those with limited natural resources or production capacity. Some countries have a comparative advantage in iron and steel production, whilst others may have a competitive advantage in the downstream manufacturing sector that relies on steel inputs. The top iron and steel exporting countries include China, Japan, and the Republic of Korea, accounting for more than half of the world's iron and steel exports. On the other hand, the largest iron and steel importing countries include the United States, Germany, and Italy (World Steel Association, 2022b).

The COVID-19 pandemic has had an impact on the iron and steel industry, including in the ASEAN region. ASEAN countries are major producers and exporters of steel and iron, and the pandemic affected the production, demand, and trade of these commodities in the region. Although, several ASEAN countries have continued to invest in their steel and iron industries and implement measures to enhance their competitiveness and sustainability. For example, countries such as Viet Nam and Indonesia have implemented policies to increase domestic steel production and reduce reliance on imports, whilst others such as Singapore and Malaysia have focused on developing high-value steel products for export (Mysteel, 2020).

During the transitional period from the COVID-19 pandemic, one of the main challenges facing the industry was the need to adapt to new market conditions and changing demand patterns. During the pandemic, many industries that are the main consumers of steel and iron products, such as construction and the automotive industry, experienced a significant slowdown. As the world recovers from the pandemic, the industry may not return to pre-pandemic activity levels, which could impact demand for steel and iron products. At the same time, new industries and technologies such as renewable energy and electric vehicles, can create new opportunities for the steel and iron industry. Another challenge facing the industry is the need to address environmental concerns and reduce its carbon footprint. The steel and iron industry is a major contributor to global carbon emissions, and there is growing pressure from governments, investors, and consumers to reduce these emissions and shift to more sustainable production methods. In a post-pandemic world, the industry needs to invest in new technologies and processes to reduce its environmental impact and meet these growing expectations. At the same time, the post-pandemic world presents opportunities for the steel and iron industry. The global economic recovery is expected to boost demand for steel and iron products, especially in emerging markets. In addition, the transition to a more sustainable economy could create new markets for industry, such as in the production of low-carbon steel and iron products.

Currently, the iron and steel industry cannot be separated from coal as a reducing agent. In 2019 coal consumption in this sector reached around 900 million tons, equivalent to 26.2 exajoule (EJ) or around 15% of global coal demand. On the other hand, high energy consumption requires electricity supply of around 1,230 terawatt hours (TWh) equivalent to 4.4 EJ in 2019. The high supply of coal and fossil fuels in this sector generates around 2.6 gigawatts (GW) of direct CO_2 emissions per year, about 30% of total direct emissions to current industrial emissions, whilst the total direct and indirect CO_2 emissions were around 3.7 Gt in 2019. It is estimated that by 2050, gas and electricity consumption will increase by up to 155 billion cubic metres and around 1,740 TWh. This is influenced by the increasing availability of scrap from 32% to 45% and the production of iron and steel using DRI-EAF technology will dominate in the future. Facing this situation with the demand for iron and steel which will continue to increase every year, will be a challenge for this industry sector.

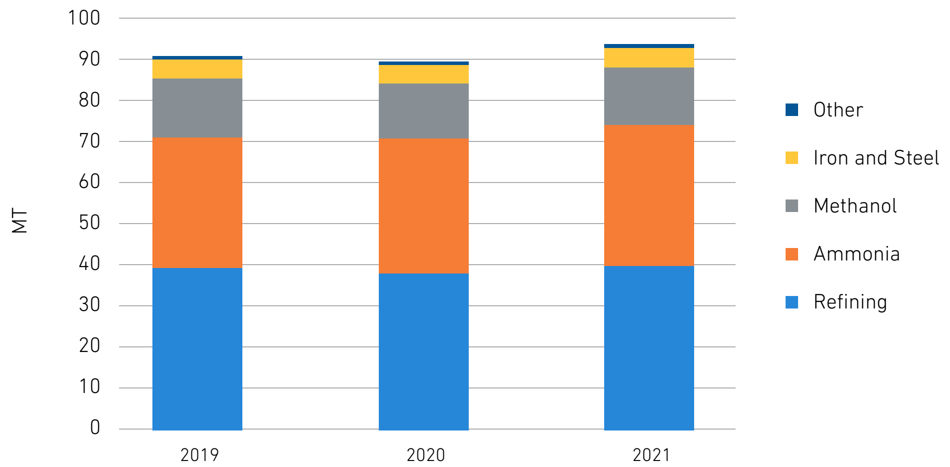
The steel industry requires sustainable technology by transitioning to low-carbon energy sources such as renewable energy and hydrogen, which can reduce the resulting gas emissions. Then, the implementation of carbon capture, utilisation, and storage (CCUS) technology can capture and store CO_2 emissions. To increase energy efficiency through technological advances and process optimisation is important. Switching to electric arc furnaces (EAF) powered by renewable energy sources can also lower carbon emissions. In 2050, the energy demand for this sector is approximately 121 million tons of oil equivalent (Mtoe) (14%) less than in 2019. The use of coal is reduced by 40% due to increased use of low-emissions route technologies with which CO_2 emissions are expected to be less than half of their original value in 2019, which is equal to 1.2 Gt CO_2. However, this transition to decarbonisation technology will require twice the electricity consumption, amounting to 2,470 TWh including the electricity consumption required for the production of electrolytic hydrogen. Pursuing the target of net-zero emissions by 2030, material efficiency and technological performance are the right steps before the adoption of innovative technologies such as CCUS and hydrogen-based production for further emission reductions.

There are specific examples of technological modifications in the iron and steel industry, such as waste heat recovery systems that can reduce the net energy consumption of certain units such as EAF and BOF, and the quality of raw materials such as coke used will reduce energy consumption, the high levels of iron contained in ore can also reduce the energy required. Then, replace fuel using natural gas or bioenergy and use electrolytic hydrogen as a primary reducing agent in the DRI furnace. The use of natural gas instead of coal can reduce emissions by about 20%. If the DRI unit is equipped with CCUS technology and or electrolytic hydrogen for the fuel unit, this unit will be much better, which can reduce 5% of relative cumulative emissions.

Increasing technological performance, material efficiency, and fuel substitution can contribute 75% of cumulative emissions reduction from 2020 to 2050. However, the development of near-zero emissions production pathways innovations will expand quickly later, such as the use of CCUS and hydrogen. At this time, the technology is still not commercially available and takes time to apply. Hydrogen is the main key for offering a pathway towards decarbonisation and sustainability. Hydrogen produced from fossil fuels without the application of CCUS technology is expected to continue to increase until 2030, from 5 MT to 7 MT. Later it will decrease to 6 MT in 2050. Meanwhile, the use of hydrogen via DRI with CCUS will increase by around 1 MT in 2050. Then, electrolytic hydrogen will account for around 70% of the total hydrogen use in this sector. The required electricity capacity is estimated at 720 TWh in 2050.

The global use of hydrogen in the iron and steel industry is currently the fourth largest source of hydrogen demand, amounting to 5.2 MT hydrogen per year, or about 5.5% of the total hydrogen used in 2021, after oil refining, ammonia, and methanol (Figure 2.28) (IEA, 2022). Just as in the oil and chemical refinery sector, the iron and steel sector also produce large quantities of hydrogen, which are mixed with other gases as by-products, for example, coke oven gas. Of course, all of this hydrogen is produced from coal and other fossil fuels. Some of it is consumed again within the sector, and some of it is redistributed for use elsewhere. Based on current trends, the use of hydrogen to achieve the Net-Zero scenario, hydrogen achieves 6% of the total accumulated emissions reduction (World Steel Association, 2022b). With the high demand for iron and steel in the future and efforts to reduce emissions, it is hoped that the production of iron and steel using hydrogen as the main reducing agent on a commercial scale can be carried out in the near future. Meanwhile, low-carbon hydrogen can now be mixed into existing processes to reduce gas emissions.

Figure 2.28. Global Hydrogen Demand by Sector in the Net-Zero Scenario, 2019–2021



Source: IEA (2022).

Demand for hydrogen production, especially ironmaking, is expected to increase in line with the gas-based DRI-EAF route (World Steel Association, 2022c). The hydrogen is produced in dedicated facilities, not as-a by-product, by using natural gas (reforming) and the rest using coal (gasification). Nonetheless, natural gas will still play an important role in supplying the remaining hydrogen in 2030, resulting in a natural gas demand of 31 billion cubic metres per year (World Steel Association, 2022c). Using 100% hydrogen on the DRI-EAF route for all primary steel production will substantially eliminate CO_2 emissions, using renewable sources of electricity.

4.1. Data Sources for Raw Steel Production

There are many sources that are used, such as World Steel, the International Energy Agency, MIDREX Statistics, Southeast Asia Iron & Steel Institute (SEAISI), and the Indonesian Iron and Steel Industry Association (IISIA), to predict the forecast of demand for Southeast Asian hydrogen in the iron and steel industry. The data in Word Steel are used for historical data on iron and steel production in the world or the ASEAN region. The IEA reports the current historical demand for hydrogen and the hydrogen needed to achieve net-zero emissions by 2030 and 2050. MIDREX Statistics provides DRI production data globally or by region from year to year. Due to the limited data used to predict the demand and supply of hydrogen in DRI production, refer to the MIDREX Statistics report for estimates of hydrogen use in the Southeast Asian region (MIDREX Technologies, 2021).

From the data provided by the SEAISI, information such as the situation of the ASEAN steel industry and key developments can be obtained. ASEAN steel production increased by 3.7% to support reduced imports from supply chain disruptions in 2020. Several countries such as Malaysia, the Philippines, and Singapore, were impacted by severe lockdowns in the first quarter of 2021. Meanwhile, in several other countries, including Thailand and Viet Nam, construction activities expanded. On the one hand, the use of steel in the automotive sector decreased by 32% compared to 2019. On the other hand, the manufacturing sector had an impact due to lockdowns carried out in several ASEAN countries, except for Viet Nam, which continued to experience growth. In Viet Nam, several developments are on-going (at the time this report is written), such as the addition of crude steel capacity with a forecast capacity of 162.6 MT. At present, the development of steelmaking still dominates using BOF technology rather than EAF, which will continue for the next few years, so in the future ASEAN countries will tend to implement CCUS technology to reduce greenhouse gas emissions. Of course, steel produced using low-carbon technology will compete with conventionally produced steel on the market (World Steel Association, 2022d; JM Baxi, 2020).

The iron and steel prices in Indonesia are obtained from a report published by the IISIA in 2021. This includes matters relating to global steel demand projections, steel demand projections in 2021–2050, as well as challenges and strategies for the development of the steel industry in Indonesia. Global steel demand increased rapidly by 5.8% due to the impact of the COVID-19 recovery. In the ASEAN region, it was excepted that the growth in global steel demand would increase to a maximum of 6.5% in 2022 (no updated at the time this report was written). Then, Indonesia will be one of the affected countries with the largest GDP level in 2050. This is in line with the growth in steel needs in the future. Indonesia is expected to require a very large additional capacity, more than 100 MT, to meet domestic demand in 2050 (Mysteel, 2020; ACE, 2022).

4.2. Hydrogen Demand and Supply Estimation Approaches

A study by Hall et al.(2021) reported that producing metallic hot briquetted iron (HBI)/DRI resources from ore or pellets is needed in the amount of 650 normal cubic metre (Nm^3) of hydrogen (about 58 kg) per ton DRI, and the purity of this hydrogen must be 99.8% to facilitate the reduction process. The requirement of hydrogen for direct reduction purposes is shown Table 2.6.

Table 2.6. Specific Hydrogen Required for Direct Reduction Purpose

Parameter	Unit	Value
H_2 amount:	Nm^3/t DRI	650
	kg/t DRI	58
H_2 purity:	Volume %	99.8
H_2 pressure (at TOP):	Bar_g	min. 4.5

DRI = direct reduced iron, H_2 = hydrogen, kg/t = kilogramme per ton, Nm^3/t = normal cubic metre per ton.
Source: Hall et al. (2021).

The International Energy Agency (IEA, 2020a reported that the major raw materials for iron and steel making today are iron ore, energy (dominantly coal, electricity and gases, natural gas), limestone, and steel scrap. In iron and steel making, coal and natural gas, whilst limestone will help to remove impurities such as sulphur, phosphorus, and silica.

The production of crude steel has three important steps: the preparation of raw material, iron making, and steel making. In the iron making step, the process known as DRI or DRI/EAF is the iron making process, which has a relation with hydrogen supply and demand.

The process of reducing iron ore for the manufacture of iron and steel includes three stages: reduction of iron ore, refining steel into semi-finished steel, and finally, the forming process to convert steel into finished materials. In the process of making iron, the process of reducing iron ore can be done by two processes – indirect reduction and direct reduction. The indirect reduction process is carried out in the blast furnace, where around 94% of the world's raw steel production is currently using this technology. In the process, the feed materials used are iron ore, coal, and limestone. Based on the mass balance, to produce 1 ton of pig iron, 1.6 tons of iron ore and 90 kg–120 kg of coal are required to be put into the blast furnace in layers. In this reduction process, pressurised hot air is exhaled with a temperature range of 1150°C –1250°C, so that there is a reaction in the blast furnace with the following equations.

$$2C + O_2 \rightarrow 2CO$$
$$3Fe_2O_3 + CO \rightarrow 2Fe_3O4 + CO_2$$
$$Fe_3O_4 + CO \rightarrow 3FeO + CO_2$$
$$FeO + CO \rightarrow Fe + CO_2$$
$$CO_2 + C \rightarrow 2CO$$

From this scale, it can be seen that CO-reducing gas is produced from the reaction between coal and hot air. The reducing gas is not put directly into the blast furnace but is produced from the process in the blast furnace. This process is known as an indirect reduction process. This CO-reducing gas will reduce the iron ore gradually. Then, since this process is exothermic, the iron will be in a liquid state. On the other hand, the coal that is fed will clash with the impurities present in the iron ore to form slag, which will float on top of the molten iron because it has a lower specific gravity. Liquid iron resulting from the process in the blast furnace is called pig iron, with a temperature of around 1,530°C. Based on the mass balance, for every ton of pig iron, 400 kg of slag is produced. Pig iron containing around 3%–4% carbon will be further processed to reduce levels of impurities such as dephosphorisation and sent to the steel-making process to reduce its carbon content using basic oxygen furnace (BOF) technology.

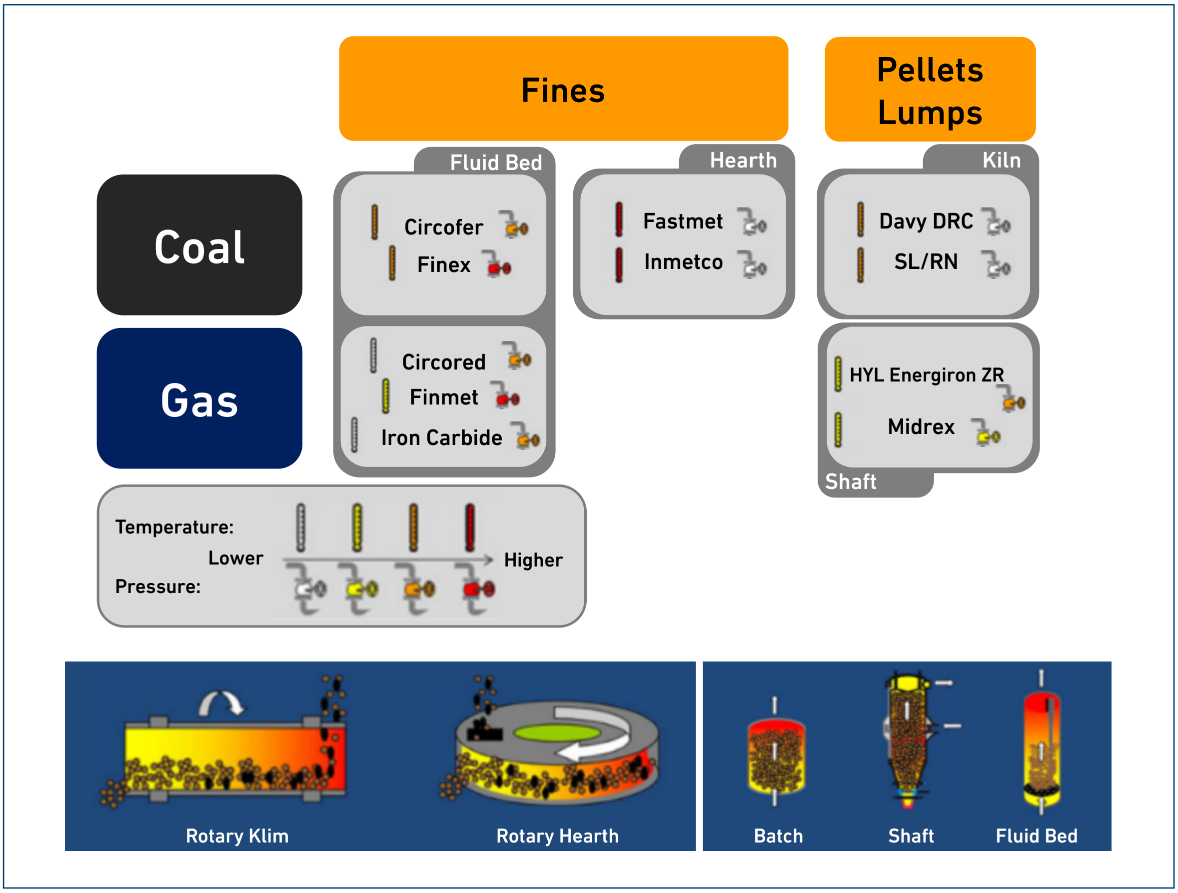
In the direct reduction process, there are several technologies that can be used such as MIDREX, HYL-I, HYL-II, HYL-III, Fion, Finmet, Circored, and others. This direct reduction process produces a product in the form of sponge iron in a solid state. Of the various technologies that can be used, the principle of the direct reduction process is to introduce a gas-reducing agent into the furnace so that the iron ore reduction reaction occurs. The reduction gas used in the DRI production process can be divided into two – coal-based processes and natural gas-based processes. In MIDREX technology, the reducing agent gas that is fed is not pure hydrogen but a mixture of hydrogen and carbon monoxide gas with a ratio of H_2/CO = 1.6 at a temperature of 900 ^{0}C. Conversely, in HYL-III, the ratio H_2/CO = 3 at 930°C. The total reaction that occurs in the direct reduction process is as follows.

$$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$$

The reducing gas that is fed will reduce the iron ore directly, and the reaction is endothermic so that the reduced iron ore does not melt. The raw steel from this process is called sponge iron. In sponge iron, the carbon content contained is 2.5% which will be sent to the next stage to be refined at the steel-making stage with EAF technology.

Direct reduced iron (DRI) is produced from the reduction of iron ore with a reducing synthesis gas (made from natural gas or coal) at 800°C to 1,050°C. DRI oxidises easily and must be quickly processed into steel on an integrated site. DRI is generally mixed with scrap steel before treatment with oxygen in an electric arc furnace (EAF) at 1,800°C to produce crude steel, often suitable for speciality The schematic and the classification of DRI can be seen in Figure 2.29.

Figure 2.29. Classification of Direct Reduced Iron



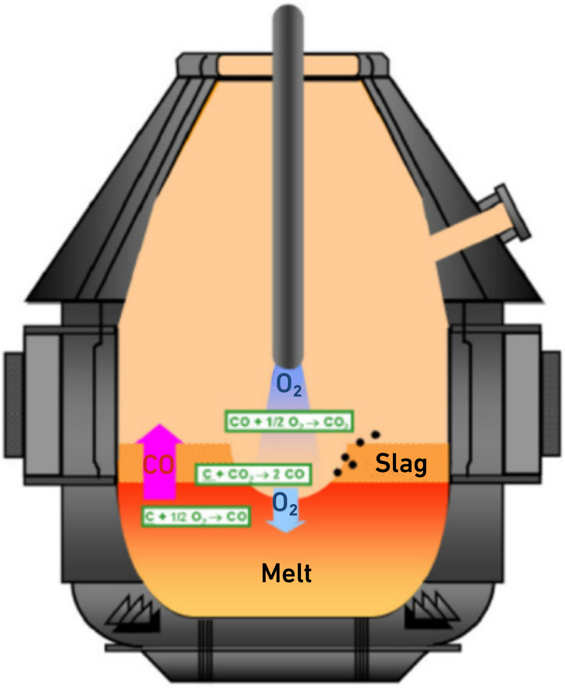
Source: International Iron Metallics Association. (n.d.)

The direct and indirect raw steel reduction results from the iron-making process are continued into steelmaking, which can be processed with two technologies: BOF and electric arc furnace (EAF). Pig iron is processed using BOF technology, whilst sponge iron and scrap are processed using EAF. The principle of the BOF process is to blow gaseous oxygen into molten iron so that a reaction occurs according to the following agreement.

$$2C + O_2 \rightarrow 2CO$$

In addition to oxygen, limestone is also included, which is sensitive to impurities, such as silicon, iron oxide, and other impurities, to form $CaO\text{-}SiO_2\text{-}FeO$ slag so that the steel becomes purer with a carbon content of around 0.04%. In the world, steel production with BOF technology reaches around 51%. The schematic BOF process can be seen in Figure 2.30.

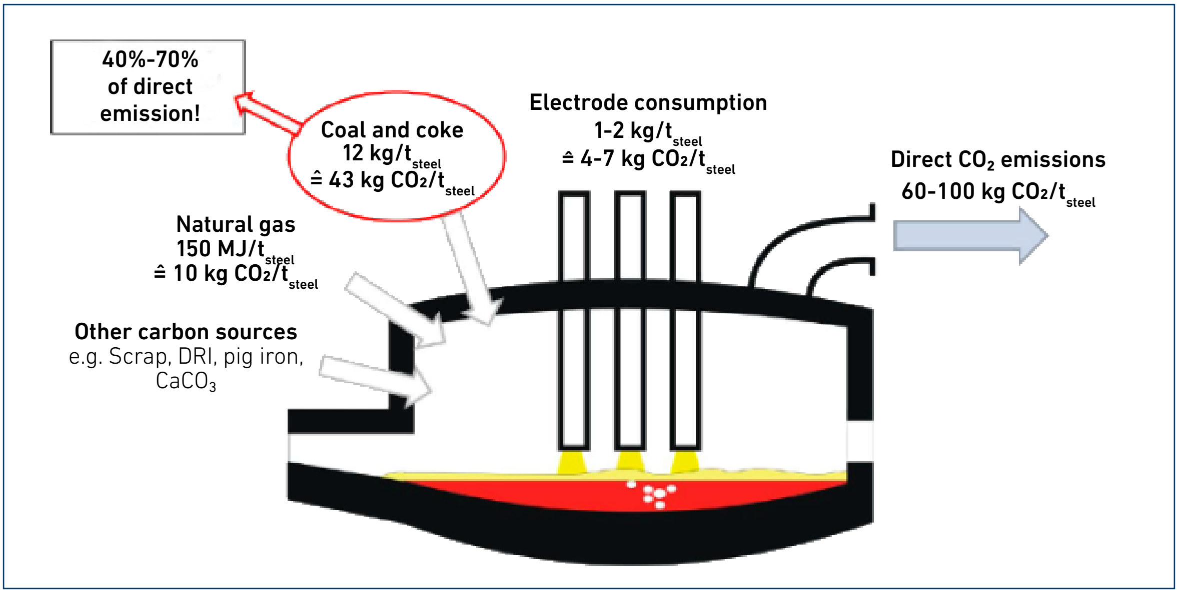
Figure 2.30. Schematic Process of Basic Oxygen Furnace



Source: Pericleous et al. (2011).

On the other hand, EAF technology uses an anode and cathode made of electrified graphite to melt sponge iron and scrap. When electrified, sparks arise with high temperatures. During the process, oxygen is also supplied to the molten iron to reduce the carbon content with the same chemical reaction as in the BOF process. On the other hand, flux is also added to molten iron to attract existing impurities such as silicon, sulphur, phosphorus, aluminium, and calcium. After the molten iron has obtained the desired composition, the molten steel is poured into the mould to form a slab or directly into the tundish in the continuous casting process. As for other additional processes, producing high-quality steel such as tool steel, stainless steel, and others, a special process is needed, the secondary metallurgy process. These processes will go through stages with various technologies, such as ladle furnace, argon-oxygen decarburisation furnace, vacuum-oxygen decarburisation, and Ruhrstahl-Heraeus(RH)-type degassing unit. A schematic EAF process can be seen in Figure 2.31.

Figure 2.31. Schematic Process of Electric Arc Furnace

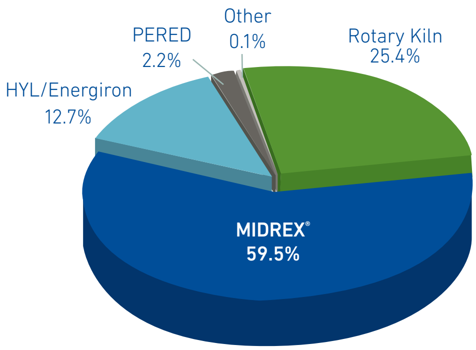


$CaCO_3$ = calcium carbonate, CO_2 = carbon dioxide, DRI = direct reduced iron, kg/t – kilogramme per ton, MJ = megajoule.
Source: Demus et al. (2012).

Since 2016, worldwide DRI output has grown by almost 46.4 MT, or nearly 64%, primarily driven by the increase in coal-based DRI in India, new gas-based plants in Iran, and ramp-up of new gas-based capacity in Algeria, Egypt, the United States, and the Russian Federation. The reduced effects of the global COVID-19 pandemic, an 18.8% jump in coal-based production in India, as well as the completion and start-up of new natural gas-based facilities in Algeria and the United States had a large effect on the DRI production increase in 2021 compared to 2020. The production of hot DRI, which is fed directly to a nearby melt shop for energy savings and to improve productivity, was 13.8 MT, a 21.2% increase compared to 2020, and made up 11.6% of the total in 2021. The production of hot briquetted iron (HBI) – a compacted form of DRI ideally suited for shipping and for use in the blast furnace – is estimated to have been 10.4 MT, a 9.3% increase over 2020 and a 7.4% increase over 2019 (MIDREX Technologies, 2021). Total DRI production on 2021 has achieved 119.2 MT worldwide and consist of MIDREX (59.5%), HYL/Energion (12.7%), PERED (2.2%), rotary kiln (25.4%), and other technology (0.1%) as shown in Figure 2.32.

Figure 2.32. DRI Production Worldwide by Process, 2019–2021

2021 World DRI Production by Process



Total World Prosuction: 119.2 Mt

	2019	2020	2021
MIDREX®	60.5%	60.2%(r)	59.5%
HYL/Energiron	13.2%	12.4%	12.7%
PERED	2.1%	2.9%(e)	2.2%(e)
Other	0.2%	0.2%	0.1%
Rotary Kiln	24.0%	24.3%(r)	25.4%

(e) estimated (r) revised

DRI = direct reduced iron, Mt = million tons.

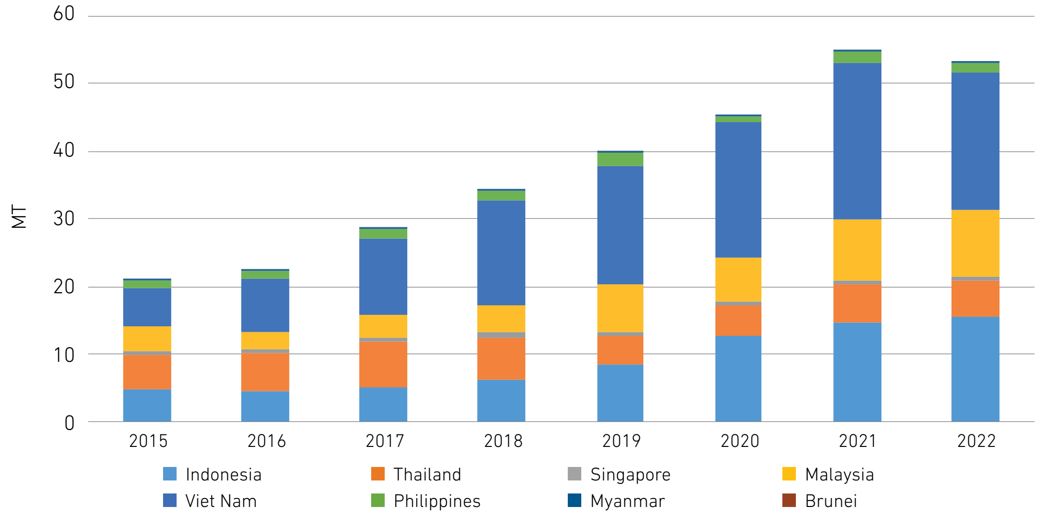
Source: MIDREX Technologies (2021).

To get further information about hydrogen supply and demand in the steel sector, investigating the MIDREX process is the right choice. Markotic, Dolić, and Trujić (2002) reported that the MIDREX process is based upon low pressure, moving bed-shaft furnace where the reducing gas moves counter current to the lump iron oxide ore. The reducing gas is produced from reforming process. Dutta and Sah (2016), for instance, provides a detailed explanation of a MIDREX process including its relationship with hydrogen supply and demand in the steel sector.

4.3. Southeast Asia's Raw Steel Production

Total world crude steel production will reach around 1,885 MT in 2022, which has decreased compared to the previous year's level of 1,962 MT (Figure 2.33). In Southeast Asia, Viet Nam's crude steel production dominated with 23.0 MT in 2022 (ACE, 2021). This steel production figure experienced a very large decline of -7.3% during the first half of 2022, year-on-year (MEMR, 2021b). According to most researchers, the decline in recent world crude steel production, which has occurred in almost all producing countries, is related to high coking coal prices, declining construction levels, as well as lower demand and prices for steel production.

Figure 2.33. **Total Production of Raw Steel in the ASEAN Region, 2015–2022**



Source: Worldsteel (2022a).

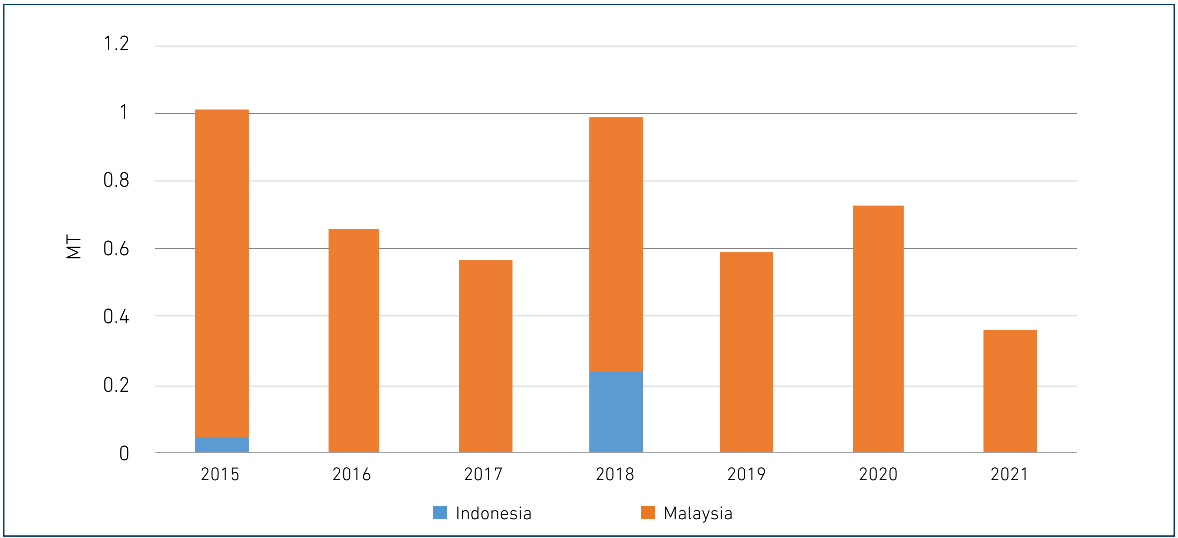
The ASEAN countries before the COVID-19 pandemic consumed more than 80 MTPA of raw steel, in 2021 the amount of consumption decreased to 72 MT. During 2023 it is expected to return to pre-pandemic levels, around 81 MT. This is based on the ASEAN countries such as Viet Nam, Indonesia, Singapore, Malaysia, Thailand, and the Philippines. The recovery of the construction and automotive industries will lead to significant growth in steel consumption in these countries. On the other hand, ASEAN is not only a strong player in world steel consumption, but also a steel producer with a total production capacity of more than 50 MT per year. The amount of steel production in ASEAN countries has increased from year to year even though in 2022 it experienced a slight decline.

Iron and steel are produced not only through an indirect reduction process. World DRI production reached 119.2 MT in 2021, an increase of 13.7% from 104.8 MT in 2020. DRI-producing countries are dominated by India and Iran which use MIDREX, Rotary Kiln, HYL technology/Energy, Pered, and others (Asia Pacific Energy, 2015).

In the ASEAN region, there are several countries that produce iron and steel with a direct reduction process using a mixture of hydrogen and carbon monoxide gases.

The largest DRI-producing countries in ASEAN are Malaysia and Indonesia (Figure 2.34). There are several factories in Malaysia, such as Antara Steel Mills, Lion DRI, and Perwaja Steel, using MIDREX and HYL/Energy technology. However, only Antara Steel Mills, which is still operating today uses MIDREX technology, with a capacity of 0.65 MTPA, and a product in the form of hot briquetted iron (HBI). Meanwhile, several plants in Indonesia including PT Krakatau Steel and PT Meratus Jaya use HYL/Energiron technology and rotary kiln. Only PT Meratus Jaya is still operating with a capacity of around 0.32 MTPA with a product in the form of cold direct reduced iron (Asia Pacific Energy, 2015).

Figure 2.34. DRI Production in ASEAN Region, 2015–2021



DRI = direct reduced iron, MT = million ton.

Source: MIDREX Technologies (2021).

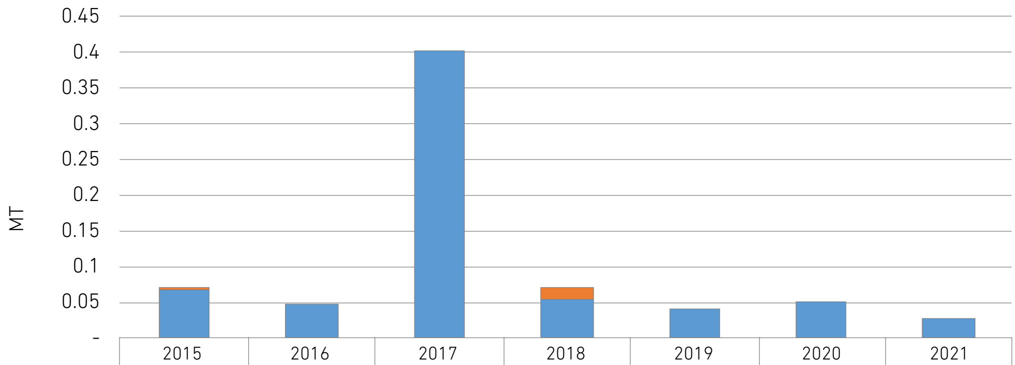
These DRI-based companies use hydrogen as the main raw material to reduce iron ore, except for PT Meratus Jaya because it uses rotary kiln technology. Companies such as PT Krakatau Steel, Antara Steel Mills, Lion DRI, and Perwaja Steel use hydrogen reducers supplied by other companies. PT Krakatau Steel uses natural gas from PT Pertamina (Pertagas) or other companies depending on availability and price. Likewise, Antara Steel Mills, Lion DRI, and Perwaja Steel use natural gas from PT Petronas or other companies. Thus, DRI-producing companies in ASEAN still do not have their own hydrogen-producing facilities.

4.4. Historical Hydrogen Demand and Supply in Raw Steel Production

The use of hydrogen obtained from the use of natural gas or coal is the current solution for reducing greenhouse gas emissions. The reducing agent used at this time is hydrogen mixed with carbon monoxide in a certain ratio depending on the technology used. The current use of hydrogen in the iron and steel industry reached 5.2 MT in 2021. Efforts are being made to achieve net-zero emissions by 2030; hydrogen supply of around 9–11 MTPA is needed and in 2050 hydrogen supply needed will be around 47–67 MTPA with the use of 100% pure hydrogen (World Steel Association, 2022c). Thus, the DRI-EAF route will be the best choice for iron and steel manufacturing processes in the future.

So far, the production of iron and steel using the DRI process is still minimal. There are only two countries that produce iron and steel with this process. Total DRI production reached 0.73 MT in 2020 and 0.36 MT in 2021. In the past 5 years DRI production in the ASEAN region has fluctuated with peak production reaching 1.01 MT in 2015 (Asia Pacific Energy, 2015). The use of hydrogen as a reducing agent is still mixed with carbon monoxide in a certain ratio. Hydrogen as a reducing agent is produced by two processes, natural gas (steam methane reforming) and coal (gasification). The use of hydrogen in the H-DRI process is estimated at 50–70 kg of hydrogen for every ton of steel (Asia Pacific Energy, 2015). Figure 2.35 shows the demand for hydrogen needed in the iron and steel industry in Indonesia and Malaysia.

Figure 2.35. Hydrogen Demand from Raw Steel Production in Indonesia and Malaysia



	2015	2016	2017	2018	2019	2020	2021
Indonesia	0.0035	0	0	0.0168	0	0	0
Malaysia	0.0672	0.0462	0.399	0.0525	0.0413	0.0511	0.0252

MT = million ton.

Note: There are limited data available on the specific demand for hydrogen in the iron and steel sector in Southeast Asia. This hydrogen demand is estimated by assuming that every 1 ton of steel produced requires 50-70 kg of H_2.

Source: MIDREX Technologies (2021).

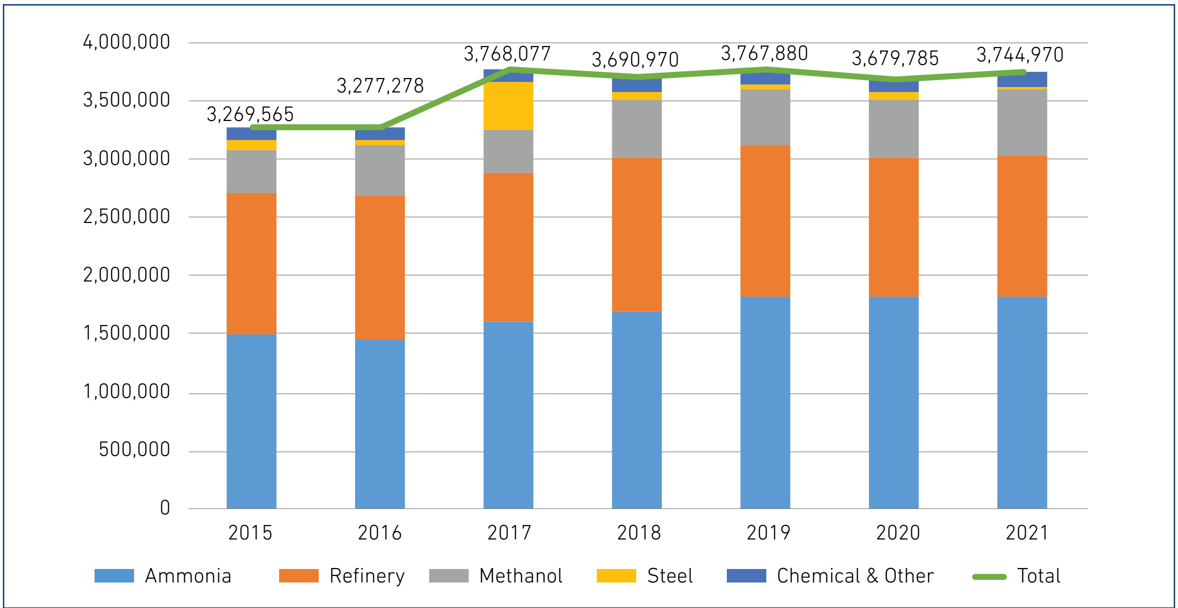
5. Total Hydrogen Demand and Supply in Industry Sectors

Hydrogen demand in industry sectors in ASEAN grew from around 3.270 million MTPA in 2015 to around 3.745 million MTPA in 2021, i.e. a compound annual growth rate (CAGR) of 2.3% during the period as shown in Figure 2.36. The COVID-19 pandemic influenced the growth of hydrogen demand as the 2019–2020 period saw a drop of -2.3%. During the next period (2020–2021) the growth rate turned back to 1.8%.

With CAGR of around 7.3%, the methanol industry grew the fastest during the observed period, followed by the ammonia industry with its CAGR of around 3.4%. The oil refining industry hydrogen demand remained stable as its CAGR approached 0%, whilst iron and steel industry saw a strong drop in their hydrogen demand, i.e. from 70,700 MTPA in 2015 to 25,200 MTPA in 2021 or CAGR of -15.8% during 2015–2021 period.

The share of hydrogen demand from the ammonia industry increased steadily from around 46% in 2015 to 49% in 2021, whilst that of oil refining dropped from around 37% in 2015 to around 32% in 2015. The methanol industry's hydrogen demand share increased from around 11.2% in 2015 to almost 15% in 2021. The iron and steel industry on the other hand saw its hydrogen demand share drop from 2.2% in 2015 to 0.7% in 2021. The chemical industry's hydrogen demand share remained relatively stable during the observed period as it fluctuated slightly from around 3.7% in 2015 to around 3.4% in 2021.

Figure 2.36. Total 2015–2021 Hydrogen Demand in Industry Sector in ASEAN (TPA)

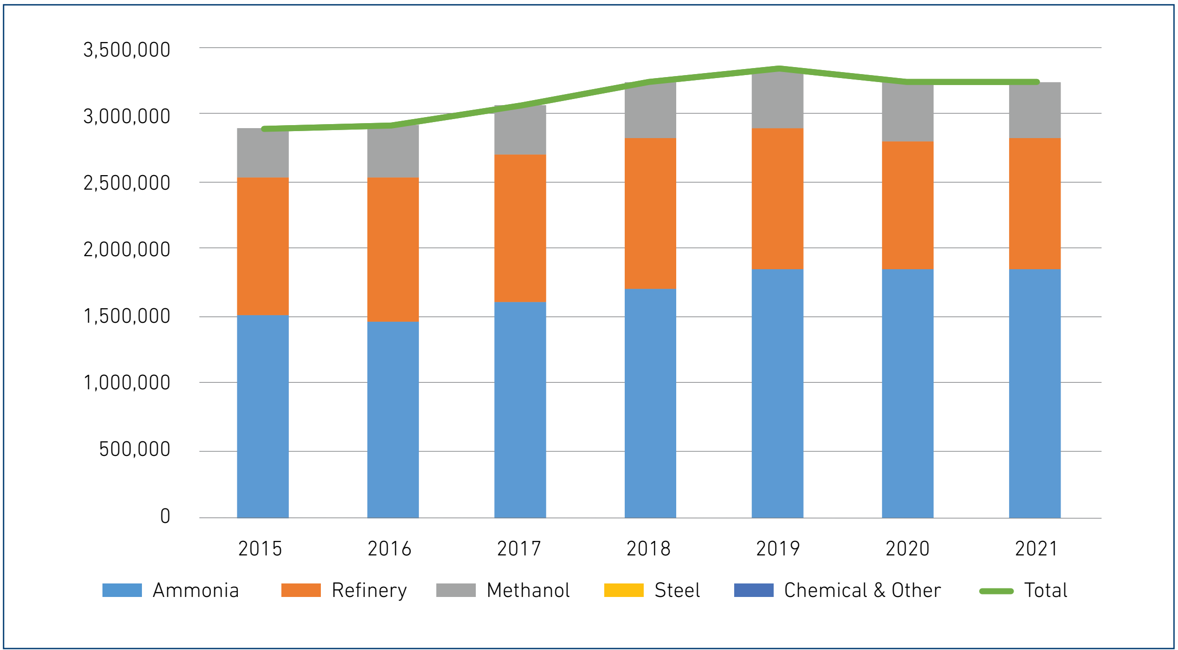


TPA = tons per annum.

Source: Authors.

Most of the hydrogen demand in the industry sector in ASEAN was supplied by captive on-site production. In total, around 88% of the demand was met by captive hydrogen supply in 2015. By 2021 this percentage dropped slightly to 86.5%. Figure 2.37 shows that captive supply increased from around 2.878 million tons in 2015 to around 3.330 million tons in 2019 before decreasing to reach 3.240 million tons in 2021.

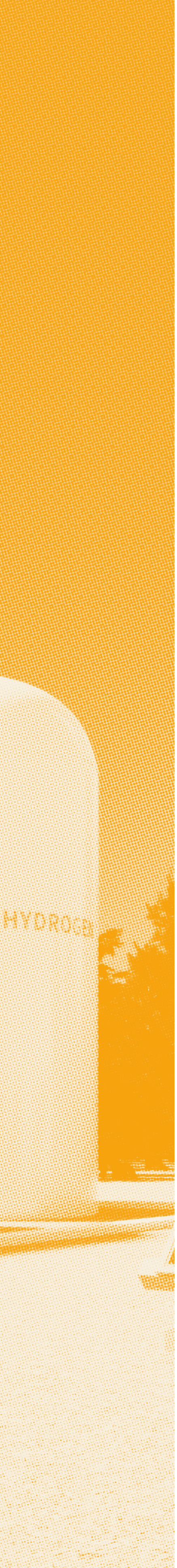
Figure 2.37. Total 2015–2021 Hydrogen Captive Supply in Industry Sector in ASEAN (TPA)



ASEAN = Association of Southeast Asian Nations, TPA = tons per annum.
Source: Authors.

As its captive hydrogen production met the demand entirely, the ammonia industry is the hydrogen self-sufficient sector. On the other hand, iron and steel and chemical industries did not produce hydrogen onsite, i.e. supply from hydrogen merchants met 100% of those industry demand for hydrogen. The oil refining sector met around 80–90% of its hydrogen demand by its own onsite production and by-product, whilst methanol industry capacity to meet its hydrogen demand declined in recent years to about 75% in 2021.


H2
HYDROGEN
H2



Chapter 3

Elaboration of Future Scenarios

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Following the analysis of the historical and current situation of hydrogen supply and demand in the previous chapter, this study aims to project the possible situations that might happen in the future. This chapter provides an overview of how future scenarios are selected, elaborated, and implemented.

In the first part, a review is performed on future scenarios of the world or Southeast Asia's energy systems as elaborated in several existing studies and their reports.

In the second part, based on the results of the first part review, several scenarios are selected and further elaborated. The scenarios are selected based on their identified policy measures that allow to make future projection of hydrogen supply and demand in the Southeast Asian region and/or countries in the four industry sectors: oil refining and chemicals, ammonia and fertiliser production, iron and steel production, and methanol production. In the final part, the methodology of each scenario's quantitative projection is given.

1. Scenarios in Different Energy Transition Outlooks and Studies

The following studies and reports provide analysis of future situations of the world and/or Southeast Asia's energy system represented in scenarios. In the subsections that follow, an overview of those scenarios in each of the studies are given:

- International Energy Agency's (IEA) 'Southeast Asia Energy Outlook 2022' Report
- IEA's 'World Energy Outlook 2022' Report
- ASEAN Centre for Energy's (ACE) '7th ASEAN Energy Outlook' Report
- Det Norske Veritas' 'Hydrogen Forecast to 2050' Report
- ERIA/IEEJ's 'Decarbonisation of ASEAN Energy Systems: Optimum Technology Selection Model Analysis up to 2060' Report

1.1. IEA's 'Southeast Asia Energy Outlook 2022' Report

The *Southeast Asia Energy Outlook 2022* (IEA, 2022a) is the fifth edition of this World Energy Outlook Special Report of the International Energy Agency (IEA) published in May 2022. The first edition was published in 2013 and the reports provide insightful prospects for the 10 ASEAN member countries. This edition includes three scenarios:

- The Stated Policies Scenario (STEPS) that reflects the countries' current policy settings based on a sector-by-sector assessment of the specific policies that are in place or have been announced.
- The Sustainable Development Scenario (SDS), which delivers on the Paris Agreement goal to limit the temperature to 'well below 2°C', alongside the goals of energy access and air pollution. This scenario is consistent with Southeast Asia's current announced climate aspirations.

- The Net-Zero Emissions (NZE) by 2050 scenario, which sets out a pathway for the energy sector to achieve net-zero CO_2 emissions in 2050 and limits the rise in global average temperatures to 1.5°C. The NZE scenario provides a global benchmark against which changes at the regional level can be assessed.

The STEPS would bring Southeast Asia's total energy supply from nearly 30 exajoules (EJ) in 2020 to more than 50 EJ by 2050, whilst CO_2 emissions would reach around 2.75 Gt of CO_2 by 2050.

In the SDS, total energy supply in Southeast Asia will reach its peak by 2045 at a bit more than 40 EJ, before decreasing to a bit below 40 EJ by 2050. The SDS is marked by the modern energy that will be available more readily and quickly than in the STEPS. Lower energy demand in the SDS reflects much greater efficiency than in STEPS, which includes the inherent efficiency gains associated with energy transitions. CO_2 emissions in the SDS would reach its peak in 2025, i.e. nearly 1.9 Gt CO_2 before decreasing significantly to a level of below 0.75 Gt CO_2 by 2050. Therefore, in the SDS, 2025 CO_2 emissions are decoupled from the growth of energy supply.

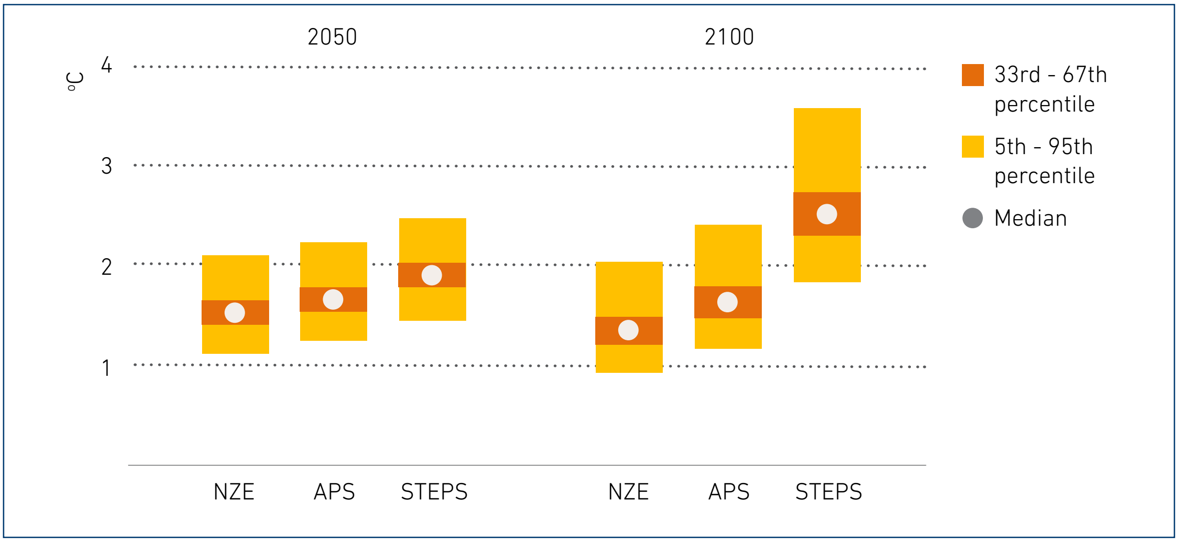
1.2. IEA's 'World Energy Outlook 2022' Report

The 2022 IEA's *World Energy Outlook* (WEO) 2022 Report (IEA, 2022b) is IEA's analysis and projections, a part of the publication series that has appeared every year since 1998. It provides insights into global energy supply and demand in different scenarios and the implications for energy security, climate targets and economic development.

The *World Energy Outlook 2022* includes three scenarios:
- The STEPS shows the trajectory implied by today's policy settings. Instead of focusing on what the governments would achieve, it analyses what the governments are actually doing to achieve the targets and objectives they have set out and assesses where this leads the energy sector.
- The Announced Pledges Scenario (APS) assumes that all aspirational targets announced by governments are met on time and in full, including their long-term net-zero and energy access goals. In other words, this scenario examines where all current announced energy and climate commitments – including net-zero emissions pledges as well as commitments in areas such as energy access – would lead the energy sector to if implemented in full and on time.
- The NZE by 2050 scenario maps out a way to achieve a 1.5°C stabilisation in the rise in global average temperatures, alongside universal access to modern energy by 2030.

Figure 3.1 shows that NZE is the scenario that would most successfully curb the world's temperature rise. By 2050 temperature rise peaks at less than 1.6 °C and falls to around 1.4 °C by around 2100. In the STEPS, the world temperature rise would exceed 2 °C by 2060 and should continue to increase. The APS would keep the world temperature increase below 2 °C.

Figure 3.1. Temperature Rise in 2050 and 2100 in the World Energy Outlook 2022 Scenarios



NZE = Net-Zero Emissions by 2050 Scenario, APS = Announced Pledges Scenario, STEPS = Stated Policies Scenario.

Notes: Temperature rise estimates in this section are relative to 1850–1900 and match the IPCC Sixth Assessment report definition of warming of 0.85˚ C between 1995–2014.

Source: IEA (2022b).

1.3. ACE's '7th ASEAN Energy Outlook' Report

This 7th edition of *ASEAN Energy Outlook* (ACE, 2022) known as AEO7 reports the latest status of ASEAN's energy landscape. Using historical data from 2005 to 2020, the report forecasts the ASEAN energy system until 2050.

AEO7 complements the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025 Phase II: 2021–2025 (ACE, 2020b), creating pathways towards achieving regional energy targets and provides analysis of four central scenarios are continued:

- The Baseline Scenario, that follows the historical trend of ASEAN Member States (AMS) energy systems. It assumes a business-as-usual level of effort put forth by each AMS, without any modelling interventions to meet existing national renewable energy or energy efficiency (RE/EE) targets.
- ASEAN Member States (AMS) Targets Scenario abbreviated as ATS, that ensures attainment of official national policies, especially for EE and RE targets. Includes power distribution panel installation targets are firmed capacity additions and provides modelling interventions to meet energy related targets under countries' Nationally Determined Contributions (NDC).

- APAEC (Regional) Targets Scenario (APS), that seeks to bridge the gap between national and regional targets outlined in APAEC 2016–2025 by escalating national energy intensity reduction and RE targets, and/or setting new targets for ASEAN Member States that could potentially adopt specific policies.
- The Least-Cost Optimisation Scenario, which is a technology-neutral optimisation applies to the power sector. It reflects all potentially viable technologies in emerging economies, such as ASEAN. This scenario considers the cost-effectiveness, affordability, and technology maturity to fulfil the growing electricity demand. It also includes the deployment of energy storage and interconnection.

Four groups of modelling parameters or assumptions have been used in ACE (2022) to obtain results of the above scenarios, i.e. energy efficiency, renewable energy, power generation capacity, and energy targets and measures in the NDC. Its results focus on identifying the gap between the AMS' targets and the regional APS targets and on the recommendations on what the ASEAN countries and regions should do to the fill the gap, therefore achieving regional targets.

1.4. DNV's 'Hydrogen Forecast to 2050' Report

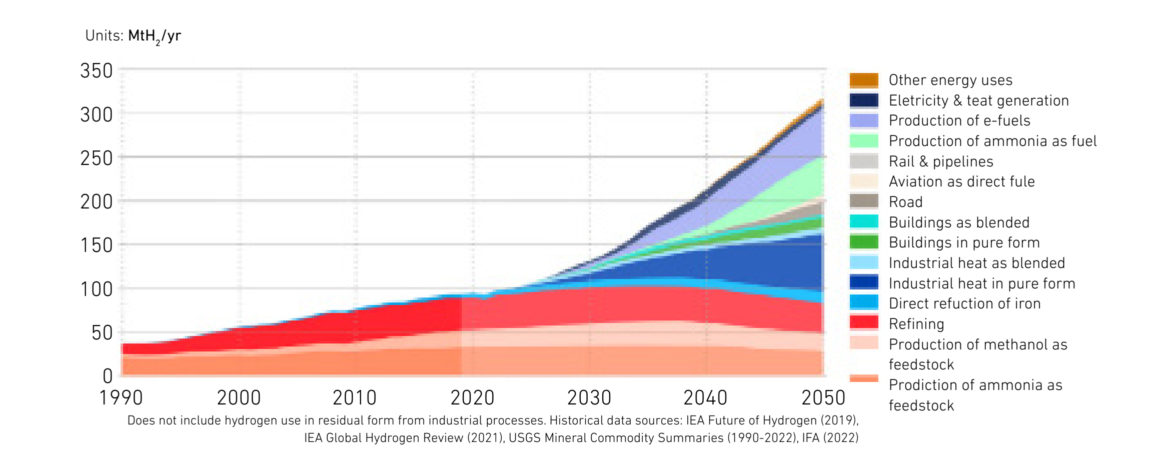
DNV, through the report *'Hydrogen Forecast to 2050'* (DNV, 2022) lays the projection of the hydrogen market in the world. The report focuses more on what is the most likely share of hydrogen uptake in the forecast, rather than what amount of share should be up taken in 2050. It clearly lays the ground on how hydrogen will be used not only as energy carrier but also as feedstock in industrial use, and this trend is projected to continue up to 2050.

The study forecasts that non-energy uses of hydrogen would grow slowly until the mid-2030s, and then would decline. Substantial growth would come from hydrogen use for energy, directly, or indirectly, i.e. hydrogen-based ammonia and e-fuels.

In 2030, 22 MT out of the 131 MT hydrogen produced globally will be used for energy purposes. That means that only around 17% of hydrogen produced in 2030 will be used for energy purpose. Production of ammonia as fuel should see it begins in the 2030–2040 decade. By 2040, hydrogen demand for energy will catch up with non-energy use of hydrogen whilst the total hydrogen produced globally would reach around 210 MT (Figure 3.2).

By 2050, only 30% of global hydrogen supply will be used for non-energy purposes. 39% will be direct use of hydrogen as energy, whilst 31% will be converted to ammonia or e-fuel for energy end users.

Figure 3.2 Global Hydrogen Demand by Sector



Source: DNV (2022).

The study predicts that by 2050, Southeast Asia's hydrogen and its derivatives demand would reach 3.6% of the total global hydrogen. This means a slight increase in the region's share from around 3.4% in 2020 (IHS, 2022).

Furthermore, it is expected that hydrogen consumption for industrial use will remain as a main offtake in the future, and oil refineries will still be seen as a big demand for hydrogen. Detailed projections at global level for each of the three subsectors (oil refineries, ammonia and methanol, and iron and steel) are as follows:

Oil Refineries

The global hydrogen demand used in oil refinery processing will still see a slight increase up to 2030. The demand is projected to reach 41 MT in 2030 from the current amount of 37 MT. However, this trend will turn around and start to decline following the fall in demand for oil. The projected demand is expected to reach 34 MT in 2050.

Currently, the demand is satisfied by captive production (hydrogen captured within the refining process), and the report projected the trend is continuing, with 47% of supply is fulfilled through this process, and 8% out of this proportion is combined from CCS. Another 39% is supplied from methane reforming (both conventional and coupled with CCS). No more than 15% is supplied through electrolysis.

Ammonia and Methanol
Hydrogen demand for ammonia production will be diversified, not only as a feedstock for conventional production for industrial use (e.g. fertiliser), but also as energy carrier (ammonia as green fuel). Hence, the production for ammonia as a feedstock will run into a slight decline. 147 Mt is the projected amount of supply of hydrogen derivatives in 2050, where two-thirds are for energy carriers, and the rest, which amount to around 49 MT, will be for ammonia and methanol. Out of this, approximately 28 MT is for ammonia and 22 MT is for methanol.
The production for these derivatives will mostly from methane reforming which amounts to around 39%, whilst blue hydrogen is projected to supply 24% of the required demand.

Iron and Steel Industry
The projection sees this industry as the first uptake for hydrogen in the late 2020s. However, historically speaking, hydrogen demand for the iron and steel industry has been relatively small compared to the others. In 2020 the global demand was 5 MT, mostly used as a reducing agent in the electric arc furnace (EAF), which is not widely used compared to the conventional process. However, the trend to decarbonise the industry is already arising, and it is projected the direct reduction of iron (DRI) + EAF process will be much more favoured, hence increasing the hydrogen demand. In 2050 it is projected that 13.5 MT of hydrogen will be used for the steelmaking process. In addition to this, hydrogen in the form of direct energy use will reach 2.8 EJ/year. Hydrogen produced for the iron and steel industry will be mostly produced from methane reforming, amounting to 72% of the total supply in 2050. Hydrogen from electrolysis is not projected to grow significantly in this matter.

In brief, DNV (2022) projects that at the world level total produced hydrogen will increase from 90 MT in 2020 to reach 320 MT by 2050. The summary of the type and purpose of the hydrogen use is given in Table 3.1.

Until 2040, as feedstock hydrogen would be mainly used in non-energy purposes, i.e. in oil refining, in DRI in the steel and iron industry, and to produce methanol and ammonia in the fertiliser industry. It will only be in the 2040–2050 decade where hydrogen will be used as feedstock to produce ammonia and e-fuels such as e-methanol and e-kerosene which can be categorised as the indirect energy use of hydrogen. By 2020, the proportion of hydrogen use as feedstock in the conventional non-energy use and in indirect energy use will reach 50:50 ratio.

The direct use of hydrogen as energy will be starting from late in the 2020–2030 decade in the transport sector as well as in power generation.

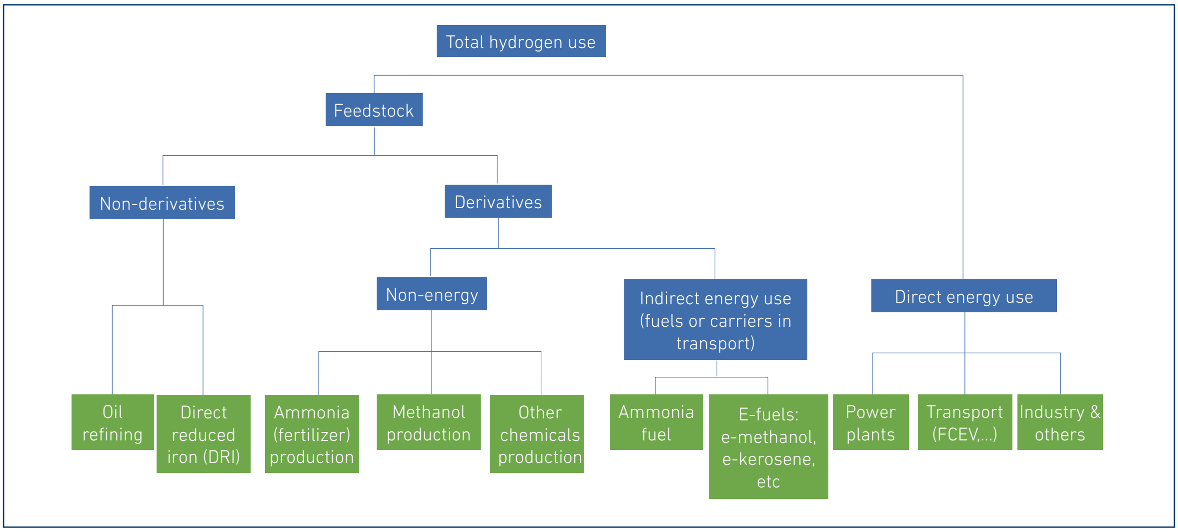
Table 3.1. Global Hydrogen Use by Types and Purpose (million tons)

Type	Purpose	2020	2030	2040	2050
Total	Total globally produced hydrogen	90	131	216	320
Feedstock	Non-energy use	90	109	108	96
	Indirect energy use (ammonia, e-fuel)	0	0	0	99
Energy	Direct energy use of hydrogen	0	22	108	125

Source: Summarised from DNV (2022).

Hydrogen produced globally to be used as feedstock would grow from around 90 MT in 2020 to reach 195 MT in 2050 as seen in Table 3.2. As given in Table 3.1, this 195 MT of hydrogen used as feedstock in 2050 can be distinguished into feedstock for non-energy use of 96 MT and indirect energy use of 99 MT.

Figure 3.3 Breakdown of Hydrogen Use



Source: Summarised from DNV (2022).

Apart from distinguishing the use of hydrogen as feedstock in non-energy use and indirect energy use, the use of hydrogen as feedstock can also be broken down into derivatives and non-derivatives. DNV (2022) estimates that by 2050, out of the 195 MT of hydrogen used as feedstock, 147 MT would be used as derivatives and the remaining 48 MT for non-derivative use (oil refining, DRI, etc.). The derivatives use (147 MT) can be split into indirect energy use (99 MT) for ammonia fuel and e-fuels (e-methanol, e-kerosene, etc) and non-energy use (48 MT), i.e. to produce ammonia (fertiliser industry), methanol, and other chemicals. By 2050, the total direct energy use of hydrogen (for power generation, transport, and industry) would reach a global total of 125 MT. Together with the 195 MT of hydrogen to be used as feedstocks, the total hydrogen produced by 2050 would thus reach 320 MT.

Figure 3.3 and Table 3.2 provide the structural and quantitative breakdown of the hydrogen use based on DNV (2022).

Table 3.2. Global Hydrogen use Break Down (million tons)*

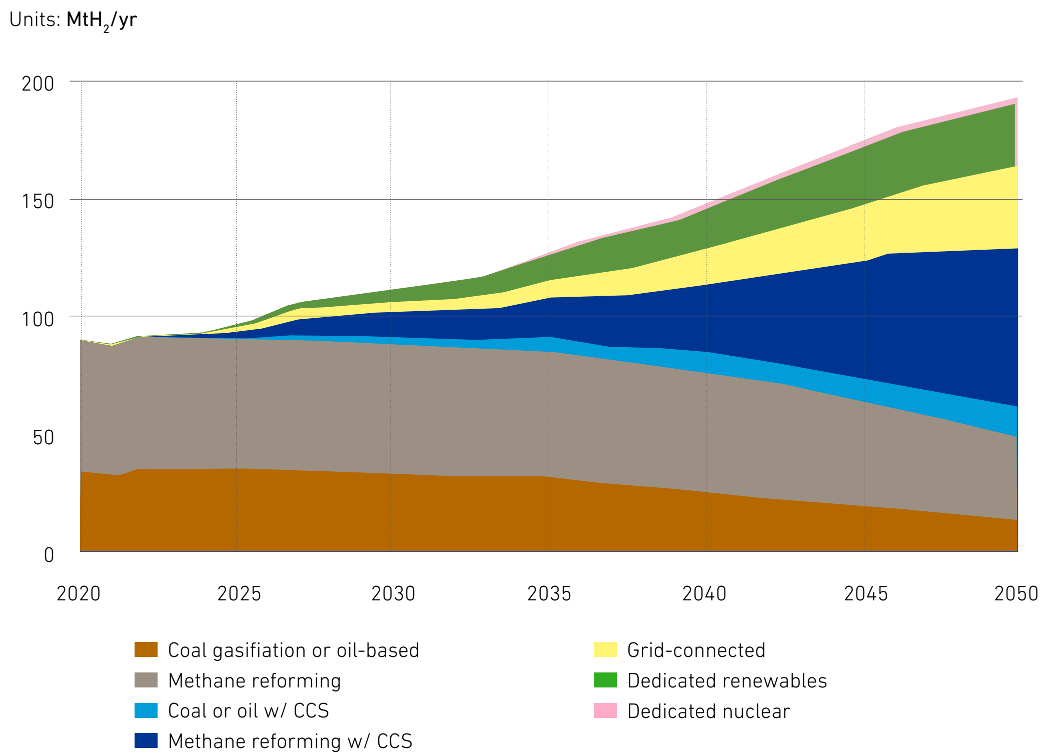
Equation	Hydrogen use	2020	2030	2040	2050
i	Feedstock – derivatives: for indirect energy carriers in transport sector (ammonia, e-fuels)	0	0	0	99
ii	Feedstock – derivatives: production of ammonia and other chemicals, such as methanol.	48			48
iii	Feedstock – non-derivatives: oil refining	37			34
iv	Feedstock – non-derivatives: direct reduced iron (DRI)	5			14
v = i	Total feedstock – derivatives as indirect energy use	0	0	0	99
vi = ii+iii+iv	Total feedstock as non-energy use	90			96
vii = i+ii	Total feedstock – derivatives	48			147
viii = iii+iv	Total feedstock non-derivatives	42			48
ix = vi+vii	Total feedstock	90			195
x	Direct energy use of hydrogen	0			125
xi = ix+x	Total produced hydrogen	90	131	216	320

*Blank cells mean that no information is given explicitly in the DNV (2022).

Source: Summarised from DNV (2022).

On the supply side, Figure 3.4 shows that as of 2020, hydrogen as feedstock is produced by only two production routes: coal gasification or oil-based and methane reforming. Other production routes would enter the market before 2025, but it is only during the 2040-2045 period that other production routes will catch up with that of coal gasification or oil-based and methane reforming. By 2050, methane reforming combined with carbon capture and sequestration (CCS) would make a bit more than one-third of the production of hydrogen as feedstock. Another one-third will be produced by dedicated renewables and grid connected whilst the rest would still be produced by coal gasification or oil-based and methane reforming.

Figure 3.4 Global Production of Hydrogen as Feedstock by Production Route



CCS = carbon capture and sequestration, MtH2/yr = million tons of hydrogen per year.
Source: DNV (2022).

1.5. ERIA's 'Decarbonisation of ASEAN Energy Systems: Optimum Technology Selection Model Analysis up to 2060' Report

ERIA's *'Decarbonisation of ASEAN Energy Systems: Optimum Technology Selection Model Analysis up to 2060'* Report (ERIA, 2022) was written in collaboration with the Institute for Energy Economics, Japan (IEEJ). The study identifies carbon-neutral pathways for ASEAN countries towards the mid 21st century by applying an optimisation approach, i.e. a linear programming model, to choose low- or zero-emissions technologies under a carbon dioxide (CO_2) emissions constraint and cost minimisation objective function.

The study includes five scenarios:

- Baseline scenario where no CO_2 emissions target is set.
- Carbon neutral (CN)2050/2060 scenario that reflects nationally declared carbon-neutral target years and considers carbon sinks in Indonesia, Malaysia, Myanmar, Thailand, and Viet Nam based on discussions with each country. This scenario has two cases as part of sensitivity analysis:
  - CN2050/2060 innovation cases scenario, where five cases describe the impacts of technological innovation.
  - CN2050/2060 stringent 2030 scenario that tightens emissions constraints in 2030 of CN2050/2060 to the same level as the IEA sustainable development scenario.
- CN2050/2060 without carbon sink assumes that energy-related CO_2 emissions become net zero by 2060 and does not consider carbon sinks.

The case assumes that the yearly net-zero emissions are achieved in ASEAN varies by country, based on the World Bank's classification by income level. Brunei and Singapore are assumed to achieve net-zero emissions by 2050 and other countries by 2060.

In the study, the use of zero-emissions energy technologies, i.e. hydrogen/ammonia, carbon capture utilisation and storage (CCUS), direct air capture (DAC), and biomass energy with CO_2 capture and storage (CCS) – will help ASEAN countries' pathways to achieving carbon neutrality by mid of the century. However, they will incur high marginal abatement costs. Hence, innovation in energy technologies will be essential to lower marginal abatement cost levels. An estimation of the amount of carbon offset by forests will be another important element in trying to achieve net-zero emissions in the ASEAN region.

The model used in the study assumes that hydrogen can be used for power generation, fuel synthesis, industry, and transport, whilst ammonia is used only for power generation. In more detail, hydrogen is assumed to be consumed in gas-hydrogen co-firing, hydrogen-firing, methane synthesis, Fischer-Tropsch synthesis, ammonia synthesis, hydrogen-based direct reduced iron-electric arc furnace, hydrogen heat (industry), fuel cell electric vehicles (FCEV) (light-duty vehicles), FCEVs (buses and trucks), hydrogen fuelled ships and aircraft. Hydrogen is assumed to be supplied through the following pathways: coal gasification, methane reforming, water electrolysis, hydrogen trade amongst ASEAN countries, hydrogen imports from outside ASEAN, and hydrogen separation from ammonia. Finally, ammonia is consumed only in coal-ammonia co-firing, and ammonia-fired power plants.

2. Scenarios in this Study

To varying degrees the five study reports, provide the necessary elements to develop future scenarios of hydrogen use in industrial sectors in the ASEAN Member States up to the horizon 2050. Four scenarios are defined to describe future scenarios, i.e. ERIA-Frozen, ERIA-STEPS, ERIA-Likely, and ERIA-APS. The following sub-sections describe these scenarios in detail.

2.1. ERIA-Frozen Scenario

The ERIA-Frozen scenario relates to a future situation where the trend is shown in the demand and supply of hydrogen by the historical trend of the 2015–2020 period as discussed in this section continue as it is. It assumes that ASEAN countries only put a business-as-usual level of effort without any national CO_2 or renewable energy or energy efficiency (RE/EE) targets to meet.

In the ERIA-Frozen scenario, it is assumed that:

- all policies implemented during the 2015–2020 period remain the same,
- hydrogen demand and supply in the future would grow at the average rate of the 2015–2020 period, and
- and that supply will always be able to meet demand using the same supply structure as it is during the 2015–2020 period.

The Frozen scenario is used as a baseline when discussing other future scenarios as it is a hypothetical situation where the only policies implemented are those in place during the 2015–2020 period. This scenario assumes that these past policies are maintained until 2050.

2.2. ERIA-STEPS

The ERIA-STEPS tries to reflect the STEPS given in the IEA (2022a) and IEA (2022b) to the Southeast Asian region.

Mainly based on the IEA's STEPS as described in IEA (2022a) and IEA (2022b), the principal characteristics of the ERIA-STEPS can be given as follows:

- ERIA-STEPS retains current and the latest ASEAN Member States' policies. The most important energy policies considered in this scenario are those related to the Intended Nationally Determined Contribution (INDC) as given in
- Table 3.3.
- For the scenario, it does not matter if governments' goals are achieved or not.
- The scenario has no particular outcome to achieve.
- The scenario explores where the energy system might go without additional policy implementation.
- At maximum, the scenario takes a granular, sector-by-sector look at existing policies and measures and those under development.

Table 3.3. **ASEAN Member States' Individual Intended Nationally Determined Contributions**

Country	Reduction Target
Brunei	Brunei has committed to reduce its total energy consumption by 63% by 2035.
Cambodia	Cambodia has conditionally committed to reduce its GHG emissions by 27% through aggregate reductions from the energy, transport, and manufacturing sectors, as well as others, and an additional contribution from the land use, land use change, and forestry sector.
Indonesia	Indonesia has unconditionally committed to reduce its GHG emissions by 26% by 2020 and 29% by 2030 compared to BAU. The target for 2030 would be increased to 41% if support is provided through international cooperation.
Lao PDR	The Lao PDR has set policies and measures to reduce GHG emissions in multiple sectors, to be implemented by 2030.
Malaysia	Malaysia intends to reduce its GHG emissions intensity of GDP by 45% by 2030, relative to the emissions intensity of GDP in 2005. This reduction consists of 35% on an unconditional basis and a further 10% upon receipt of climate finance, technology transfer, and capacity building from developed countries.
Myanmar	Myanmar has introduced policies and measures to reduce GHG emissions in multiple sectors, to be implemented by 2030.
Philippines	The Philippines has committed to reduce its GHG emissions by 70% by 2030 relative to BAU.
Singapore	Singapore intends to reduce its GHG emissions intensity by 36% from 2005 to 2030 and stabilise its emissions with the aim of peaking around 2030.
Thailand	Thailand has committed to reduce its GHG emissions by 20% by 2030 relative to BAU. This target could increase to 25%, subject to adequate and enhanced access to technology development and transfer, financial resources, and capacity building support through a balanced and ambitious global agreement under the United Nation Framework Convention on Climate Change.
Viet Nam	Viet Nam intends to reduce its GHG emissions by 8% unconditionally by 2030. This target could be increased to 25% if international support is received through bilateral and multilateral cooperation, as well as through the implementation of new mechanisms under the Global Climate Agreement, in which emission intensity per unit of GDP will be reduced by 30% from 2010 levels.

BAU = business-as-usual, GDP = gross domestic product, GHG = greenhouse gas, Lao PDR = Lao People's Democratic Republic.

Source: Summarised AMS information in the Intended Nationally Determined Contributions Portal. https://www4.unfccc.int/sites/submissions/INDC/Submission%20Pages/submissions.aspx (accessed 29 October 2020).

Nevertheless, the two IEA reports, i.e. IEA (2022a and 2022b) do not provide detailed assumed policy measures that are implemented in the industry sector, i.e. oil refining, ammonia/fertiliser, methanol, and the iron and steel industry. Several key parameters assumed are given in Table 3.4 and are taken as assumed parameters in the ERIA-STEPS. IEA (2022b) also mentioned that iron and steel industry, together with the power sector are the two driving sectors that would trigger 60% coal demand increase in Southeast Asia between 2021 and 2050, which is also assumed in the ERIA-STEPS scenario.

Table 3.4. Key Assumed Parameters Used in ERIA-STEPS for Southeast Asia taken from IEA's STEPS

Key Assumed Parameters	2021	2030	2050
Refinery capacity (Mb/d)	5.3	6.3	6.8
Refinery runs (Mb/d)	3.7	5.5	6.4
Oil production (Mb/d)	1.9	1.5	0.9
Oil demand (Mb/d)	4.9	6.7	7.4
Gas demand (bcme)	162	203	272
Natural gas production (bcm)	195	183	129
Natural gas demand (bcm)	162	203	272
Coal production (Mtce)	499	460	474
Coal demand (Mtce)	269	337	422
RE supply (EJ)	5.4	8.7	16.2
Total final consumption (EJ)	19.8	26.5	34.7
Industry consumption (EJ)	8.8	11.4	15.2
Hydrogen demand (PJ)	468	602	848
Hydrogen demand (MT)	3.3	4.24	5.98

bcm = billion cubic metres, bcme = billion cubic metres of natural gas equivalent, EJ = exajoule, Mb/d = million barrels per day, MT = million tons, Mtce = million tons of coal equivalent, PJ = petajoule, RE = renewable energy.

Source: IEA (2022b).

2.3. ERIA-APS

The ERIA-APS is based on the Announced Pledges Scenario (APS) of IEA (2022b) that assumes that all aspirational targets announced by governments are met on time and in full, including their long-term net-zero and energy access goals.

The principal characteristics of the ERIA-APS are as follows:

- Government targets in the scenario are assumed to be achieved on time and in full
- Trends reveal the extent of the world's collective ambition to tackle climate change and meet other Sustainable Development Goals (SDGs)
- The scenario includes all the climate commitments made by governments around the world including NDC as well as longer term NDC targets and assumes that they will be met in full and on time.
- The scenario fills the 'implementation gap' that needs to be closed for countries from STEPS to achieve their announced decarbonisation targets.
- The scenario includes net-zero pledges as announced by countries. In ASEAN countries:

- Malaysia and Viet Nam: carbon neutral target by 2050
- Indonesia: net-zero emissions by 2060 or before
- Thailand: net-zero greenhouse gas emissions target by 2065
- The rest of ASEAN countries: carbon neutral by 2060
- Indonesia, Malaysia, Philippines, and Viet Nam: commitment to the global methane pledge

Some principal characteristics as explained are based on the IEA's APS in IEA (2022b). Some related key assumed parameters for the Southeast Asian region of the IEA's APS Scenario are given in IEA (2022b) as summarised in Table 3.5 and are taken as assumptions in the ERIA-APS.

Table 3.5. Key Assumed Parameters Used in the ERIA-APS for Southeast Asia Taken from IEA's APS

Parameters	2021	2030	2050
Refinery capacity - SEA (Mb/d)	5.3	6.3	6.3
Refinery runs - SEA (Mb/d)	3.7	5.1	4.7
Oil production - SEA (Mb/d)	1.9	1.3	0.5
Oil demand - SEA (Mb/d)	4.9	6	3.9
Gas demand - SEA (bcme)	162	194	177
Natural gas production - SEA (bcm)	195	162	109
Natural gas demand - SEA (bcm)	162	194	177
Coal production - SEA (Mtce)	499	423	262
Coal demand - SEA (Mtce)	269	295	151
RE supply - SEA (EJ)	5.4	10.3	25.1
Total final consumption - SEA (EJ)	19.8	24.5	27.1
Industry consumption - SEA (EJ)	8.8	10.7	12.6
Hydrogen demand - SEA (PJ)	468	593	1566
Hydrogen demand - SEA (MT)	3.3	4.18	11.04

bcm = billion cubic metres, bcme = billion cubic metres of natural gas equivalent, EJ = exajoule, Mb/d = million barrels per day, MT = million tons, Mtce = million tons of coal equivalent, PJ = petajoule, RE = renewable energy, SEA = Southeast Asia.

Source: IEA (2022b).

IEA (2022b) provides detailed assumptions and policy measures at the global level in the three different industrial sectors of ammonia, methanol, iron and steel, of the NZE scenario but not of the APS.

The NZE scenario differs from APS in term of stronger and more effective intergovernmental cooperation in a mutually beneficial manner in emission mitigation that results in more reduced greenhouse gas emissions and therefore more curbed global average temperature rise in the NZE scenario.

The APS, on the other hand, is marked by the different paces of emissions decline in function of the economic levels, i.e. developed economies versus emerging market and developing economies. In the APS, the achievement of national net-zero pledges in some countries is coupled with limited efforts to prioritise emissions reductions in others, and little attention is given to technological spill overs or to the scope for working in partnership.

The ERIA-APS includes some assumed policy measures implemented in three industrial sectors of ammonia production, methanol, and iron and steel industry of the IEA's NZE scenario due to their detailed description as given in Table 3.6. Most of the policy measures and trends given in the table are given at the global level, therefore interpretation of those assumptions will be done at AMS level in chapter 4.

Table 3.6. Assumed Policy Measures and Trends in the Ammonia, Methanol, and Iron and Steel Industries of ERIA-APS Inspired by IEA's NZE Scenario

Industry Sector	Assumed Policy Measures and Trends
Ammonia	• Direct use of hydrogen, and of low-emissions synthetic fuels such as synthetic kerosene and ammonia, increases rapidly to meet demand in long-distance modes of transport, mainly aviation and shipping. • Low-emissions sources of electricity – renewables, nuclear power, fossil fuel power plants with CCUS, hydrogen, and ammonia – expand rapidly. • The use of hydrogen and ammonia blended with natural gas and coal scales up in the late 2020s. Ammonia and hydrogen co-firing, respectively in coal-fired and natural gas-fired power plants, providing 2%–3% of global electricity generation from 2030 to 2050. • By 2050, ammonia meets around 45% of demand for shipping fuel. • Hydrogen and ammonia are emerging as solutions for the seasonal storage of renewable electricity. • Global demand for low-emissions hydrogen – both produced onsite and offsite – rises to 11 million tons (MT) in 2030 for use in the production of ammonia, steel, and methanol.
Ammonia and Methanol	• Over 25% of the hydrogen produced in 2050 is converted to hydrogen-based fuels such as ammonia, methanol, and synthetic hydrocarbons. The remainder is used directly in industry, transport, and buildings.
Iron and Steel	• Global unabated coal use drops by 99% over this period; around half of the remaining 60 Mtce of unabated coal consumption in 2050 is used in the iron and steel industry. • No need for any new coal mines or mine lifetime extensions. Steam coal production falls by 50% to 2030 as coal is rapidly eliminated from the power sector in all countries. Coking coal production falls by about 30% to 2030, a smaller decline than for steam coal since the steel industry has fewer readily available alternatives.

CCUS = carbon capture utilisation and storage, Mtce = million tons of coal equivalent, NZE = Net-Zero Emissions.

Source: IEA (2022b).

The IEA report published in May 2021 (IEA, 2021d) titled *'Net Zero by 2050: A Roadmap for the Global Energy Sector'* also provides detailed information on the expected or assumed policy measures and trends in the industrial sectors in the NZE scenario. For the iron and steel industry sector especially, the report gives several key parameters of the NZE scenario. Those parameters are adopted in the ERIA-APS as presented in Table 3.7.

Table 3.7. Key Assumed Parameters in Iron and Steel Industry in the ERIA-APS based on the NZE Scenario of IEA (2021)

Parameters	2021	2030	2050
Percentage of the use of the different tech types			
Blast furnace - basic oxygen furnace (BF-BOF)			
Direct reduced iron-electric arc furnace (DRI-EAF)	24%	37%	53%
Recycling, re-use: scrap as share of input	32%	38%	46%
World H_2 demand in steel industry (MT H_2)	5	19	54
World on-site electrolyser capacity (GW)	0	36	295
Share of primary steel production:			
Hydrogen based DRI-EAF	0%	2%	29%
Iron ore electrolysis-EAF	0%	0%	13%
CCUS equipped processes	0%	6%	53%
Total final consumption - SEA (EJ)	19.8	24.5	27.1
Industry consumption - SEA (EJ)	8.8	10.7	12.6
Hydrogen demand - SEA (PJ)	468	593	1566
Hydrogen demand - SEA (MT)	3.3	4.18	11.04

BF-BOF =blast furnace-blast oxygen furnace, DRI-EAF = Direct Reduced Iron-Electric Arc Furnace, CCUS = carbon capture utilisation and storage, GW = gigawatt, MT = million tons, NZE = Net-Zero Emissions.

Source: IEA (2022b).

2.4. ERIA-Likely Scenario

The ERIA-Likely scenario represents the most likely to happen situation in the supply and demand of hydrogen in the four industry subsectors in ASEAN from the present time to the horizon 2050. In this sense, DNV (2022) study as described in Section 3.1.4 is a useful study based on which the ERIA-Likely scenario is built.

Several principal characteristics of the scenario are:

- Hydrogen produced globally to be used as feedstock would grow from around 90 MT in 2020 to reach 195 MT in 2050.
- Southeast Asian region's hydrogen and its derivatives demand would reach 3.6% of the total global hydrogen and its derivatives demand by 2050 (DNV, 2022). This means a slight increase in the region's share from around 3.4% in 2020 (IHS, 2022).
- DNV 's hydrogen forecasting: only 0.5% of global final energy mix in 2030 and 5% in 2050.
- Grid-based electrolysis costs will decrease significantly towards 2050 averaging around US$1.5/kg. Globally, green hydrogen will reach cost parity with blue within the next decade.
- Green hydrogen will increasingly be the cheapest form of production in most regions. By 2050, 72% of hydrogen and derivatives used as energy carriers will be electricity based, and 28% blue hydrogen from fossil fuels with CCS, down from 34% in 2030.
- The global hydrogen demand used in oil refinery processing will still see a slight increase up to 2030. The demand is projected to reach 41 MT in 2030 from the 2020 amount of 37 MT but shall decrease to 34 MT in 2050 due mostly to electrification in road transport.
- Hydrogen demand for ammonia production will be diversified, not only as a feedstock for conventional production for industrial use (e.g., fertiliser), but also as energy carrier (ammonia as green fuel) that will show its penetration in the late 2030 or during the 2040-2050 decade.
- No hydrogen uptake in passenger vehicles is foreseen, and only limited uptake in power generation.
- Hydrogen demand for iron/steel industries is currently relatively small compared to the others. Nevertheless, the trend to decarbonise the industry is already arising, and it is projected the direct reduction of iron (DRI) + EAF process will be much more favoured, hence increasing the hydrogen demand toward 2050.

3. Scenario Implementation

As in our analysis of the historical and current situation as in Section 3.2, in each scenario, modelling is done in a bottom-up manner. This implies that scenarios, including assumptions, data, and calculations are implemented at country and commodity level. Quantitative results obtained at the more aggregate level are merely a sum up of the results obtained at country-commodity level.

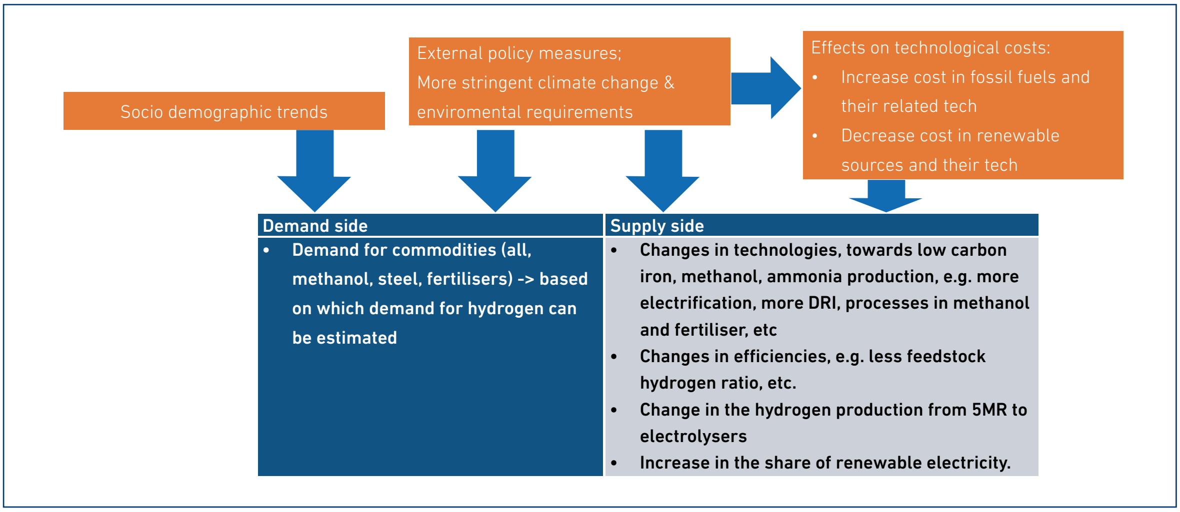
Figure 3.5 shows the principal methodology used for the scenario implementation.

The main inputs to obtain future estimates of hydrogen demand and supply in each country and industry sectors are sociodemographic trends, external policy measures that might include more stringent climate change and environmental requirements, and the effects of those policy measures on the technological costs, i.e. increasing fossil fuels and their technology related costs and decreasing renewable energy sources and their related technology costs.

Based on those inputs spread along the modelled period to the horizon 2050, the development of demand and supply for hydrogen as feedstock would be estimated. For the demand side, the need for hydrogen is to be calculated in function of the final products or commodities, i.e. refined petroleum products in the oil refining sector, fertiliser (and later ammonia fuel) in the ammonia production sector, methanol (and e-methanol) in the methanol industry, and iron and steel.

On the supply side, the inputs should affect at least four aspects the development of technologies, such as the increasing use of low-carbon iron and steel, methanol, and ammonia, low-sulphur petroleum products, the increasing use of direct reduced iron (DRI), etc. The other aspects are the change in efficiencies, such as less needed hydrogen as feedstock, the change of hydrogen production routes, and the change of renewable electricity share.

Figure 3.5 Scenario Implementation Method



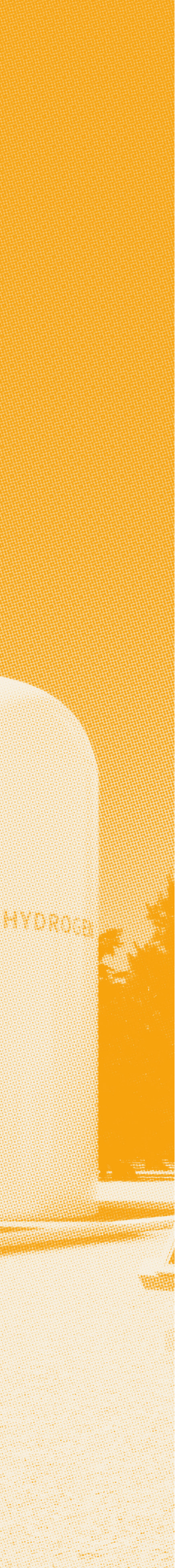
DRI = direct reduced iron, SMR = steam methane reforming.

Source: Authors.

Based on those inputs spread along the modelled period to the horizon 2050, the development of demand and supply for hydrogen as feedstock would be estimated. For the demand side, the need for hydrogen is to be calculated in function of the final products or commodities, i.e. refined petroleum products in oil refining sector, fertiliser (and later ammonia fuel) in ammonia production sector, methanol (and e-methanol) in methanol industry, and iron and steel.

Using a bottom-up approach where the estimates start at the sectoral and country level, the description of the detailed assumptions such as trend, policy measures, infrastructure development, will be given in detail in the following chapter. Chapter 4 will also define the more detail calculation methods implemented in each of the industry sectors.


H2
HYDROGEN
H2



Chapter 4

Future Hydrogen Demand and Supply Forecast

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This chapter provides estimates of hydrogen demand and supply from the ASEAN industry sectors to the horizon 2050. Detailed calculation method, and the estimates in each industry, consecutively oil refining, chemical & other industries ammonia, methanol, and steel are presented in four scenarios, i.e., ERIA-frozen, ERIA-STEPS, ERIA-Likely, and ERIA-APS.

Detailed estimates are given in the four appendices, i.e., Appendix 1: ERIA-Frozen Scenario, Appendix 2: ERIA-STEPS, Appendix 3: ERIA-Likely Scenario and Appendix 4: ERIA-APS. In each of the appendices, the estimates on hydrogen demand/consumption, production, and merchant supply are presented by industry sector broken down into countries.

1. Oil Refining

ERIA's estimation basis for long-term 2020–2050E hydrogen demand in ASEAN for the four scenarios is defined in sections 3.2.1 to 3.2.4 and summarised in Table 4.1.

Table 4.1. ERIA's Projection on Hydrogen Demand in Southeast Asia

Scenarios	2020 – 2030E (CAGR % pa)	2030E – 2050E (CAGR % pa)	2020 KTPA H_2	2030E KTPA H_2	2050E KTPA H_2	Remarks
Frozen (business as usual)						
IHS Markit	4.3%	2.1%	1,168	1,778	2,694	IHS 2020–2025E CAGR, ERIA's estimates for 2025E–2050E
BP Refinery throughput	0.7%	2.1%	1,168	1,256	1,903	Extrapolate 2011–2019 CAGR to 2020–030E
Average gasoline-diesel	4.1%	2.1%	1,168	1,739	2,635	
IEA Future H_2	0.2%		1,168	1,197		IEA's 3.5% SEA share of world H_2.
ERIA–Frozen	**5.2%**	**2.1%**	**1,168**	**1,931**	**2,926**	Eff. CAGR incl. 3.0% products growth plus capacity/ configuration changes. 2.1% CAGR 2030E–2050E for all
IEA STEPS						
IEA Refinery throughput	3.8%	0.8%	1,168	1,690	1,967	
IEA Oil demand	3.6%	0.5%	1,168	1,665	1,839	
ERIA–STEPS	**5.2%**	**0.6%**	**1,168**	**1,931**	**2,177**	Eff. CAGR incl. 3.0% products growth plus capacity/ configuration changes 0.6% CAGR 2030E–2050E.

Scenarios	2020 – 2030E (CAGR % pa)	2030E – 2050E (CAGR % pa)	2020 KTPA H_2	2030E KTPA H_2	2050E KTPA H_2	Remarks
IEA APS and DNV						
IEA Refinery throughput	3.0%	-0.4%	1,168	1,567	1,444	
IEA Oil demand	2.5%	-2.1%	1,168	1,491	0,969	
IEA Future Hv	-1.1%					IEA's 3.5% SEA share of world H_2
DNV	1.0%	-0.9%	1,168	1,294	1,073	DNV's 3.5% SEA share of world H_2
ERIA–APS	**3.5%**	**–2.1%**	**1,168**	**1,649**	**1,078**	Eff. CAGR incl. 1.2% products growth plus capacity/ configuration changes -2.1% CAGR 2030E–2050E
ERIA–Likely (LS)	**3.3%**	**–0.9%**	**1,168**	**1,620**	**1,352**	Eff. CAGR incl. 1.2% products growth plus capacity/ configuration changes -2.1% CAGR 2030E–2050E

APS = Announced Pledges Scenario, CAGR = compound annual growth rate, DNV = Det Norske Veritas, E = estimate, ERIA = Economic Research Institute for ASEAN and East Asia, H2 = hydrogen, IEA = International Energy Agency, KTPA = kilotons per annum, pa = per annum, SEA = Southeast Asia, STEPS = Stated Policies Scenario.

Sources: IHS (2021), IEA (2022a; 2002b), DNV (2022), authors.

We discuss the hydrogen demand-supply balances and country-by-country demand forecasts for each scenario.

ERIA–Frozen Scenario

In the frozen, i.e. business-as-usual scenario, ASEAN governments introduce and implement minimal or no changes to the hydrogen consumption, production, and supply chain in the refinery sector. Table 4.1 compares assumptions and growth projections from several published reports. First, the IHS (2021) estimates for 2020–2025E CAGR are adjusted with lower 2025E–2030E growth rates to estimate an 'IHS-like' case for 2020–2030E CAGR. IHS (2021) projects about 8% per annum growth in hydrogen demand – net of captive supply – in Southeast Asia's oil refining sector between 2022 and 2025. This is higher than IEA's 2020–2030E CAGR estimates for the STEPS and APS.

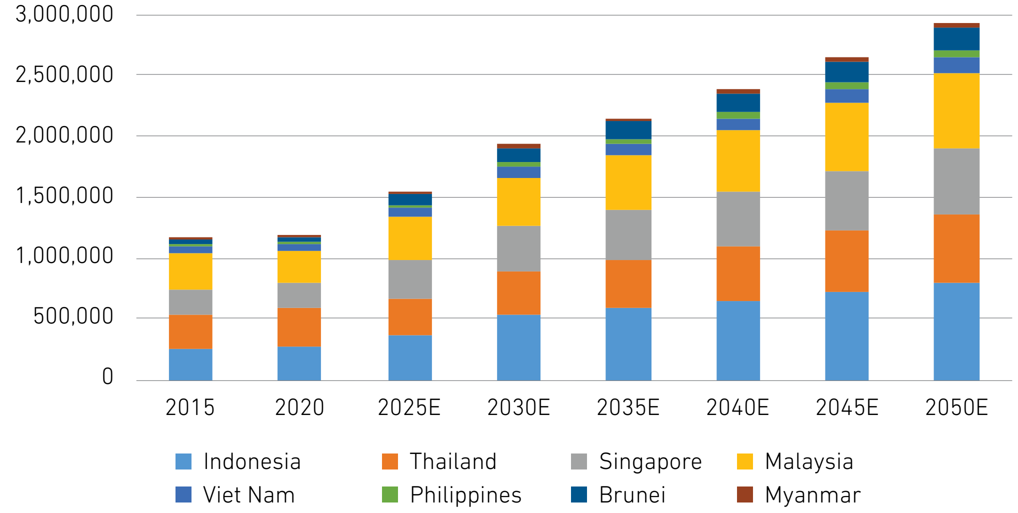
Second, historical refinery throughput volumes for the six countries reported in BP's (2022) statistical yearbook, Indonesia, Thailand, Singapore, Malaysia, Viet Nam, and the Philippines are examined. Adjustments are made for Brunei and Myanmar, whose volumes are much smaller, using public information. Third, average country-level diesel and gasoline consumption figures are analysed using selected data from not only BP (2022) but also Statista, Global Economics, and official government announcements. The 2011–2019 CAGR of refinery throughput volumes and diesel and gasoline consumption data are extrapolated to estimate the regional and country-level hydrogen demand 2020–2030E CAGR. Fourth, for comparison the IEA *Future of Hydrogen report* (IEA, 2019), estimates a similar regional share of 3.5% of world hydrogen demand. The latter was estimated by IEA to grow only by 0.2% CAGR over the same 2020–2030E period, from 40 to 41 million tons per annum (MTPA). This is considered too low for the majority of still industrialising Southeast Asian economies, whose consumers may also not be in a position to shift to electrification and renewable energy solutions as fast as the more developed economies in the West.

Considering the different estimates, demand growth rates of 5.2% per annum (pa) for 2020–2030E and 2.1% pa for 2030E–2050E are projected. The effective 5.2% pa for 2020–2030E is a result of 3% pa refined products demand growth plus the effect of in-progress or announced refinery capacity increases and configuration changes in Indonesia, Thailand, Singapore, Malaysia, Viet Nam, and Brunei. Note that the 3% pa 2020–2030E CAGR compares well with another study's 2018–2025E growth estimates of 3.9% pa, 3.0% pa, and 3.8% pa for gasoline, kerosene respectively diesel consumption in Indonesia, the region's largest market for refined products (Akhmad and Amir, 2018). Furthermore, the estimated 3.0% pa versus 5.2% pa effective CAGR including refinery capacity expansions and configuration changes are consistent with IEA's (2022a) 2020–2030E refined products demand growth forecasts of 3.5%–3.8% in the STEPS (see below). Indeed, in the near and medium term towards 2030E, the BAU/Frozen and STEPS scenarios can be expected to be rather similar, given the complexity and length of the anticipated policy implementation and transformation processes. We discuss the political economy challenges of shifting the region's industries to green hydrogen in Chapter 6.

The long-term region-wide growth rate of 2.1% pa is estimated assuming that demand for refined products in Viet Nam, Brunei, Myanmar, and the rest of the region including Cambodia will continue their more rapid growth, whilst the larger economies Indonesia and Thailand mature and gradually shift away from especially diesel and fuel oil for power and Malaysia and Singapore demand gradually shrink.

Figure 4.1 shows that under the Frozen scenario regional demand for hydrogen from refineries continues growing from 1,167 KTPA in 2020 to 2,926 KTPA in 2050E. Indonesia, Thailand, Singapore, and Malaysia make up approximately 79% of projected regional hydrogen demand from the refinery sector in 2050E, down from 90% in 2020. The difference is the higher demand growth rates in Viet Nam, Brunei and Myanmar (4.5% CAGR 2030E–2050E), at the expense of stagnating demand in Singapore (0% CAGR), and lower growth in Indonesia, Thailand, and Malaysia (2.1% CAGR). This is due to the fact that the latter four governments electrify their transport sectors faster, Indonesia moves away from diesel- and fuel oil-based power, whilst the former economies are growing from a lower demand base.

Figure 4.1. ASEAN-8 Refineries Hydrogen Demand – BAU/Frozen (TPA)

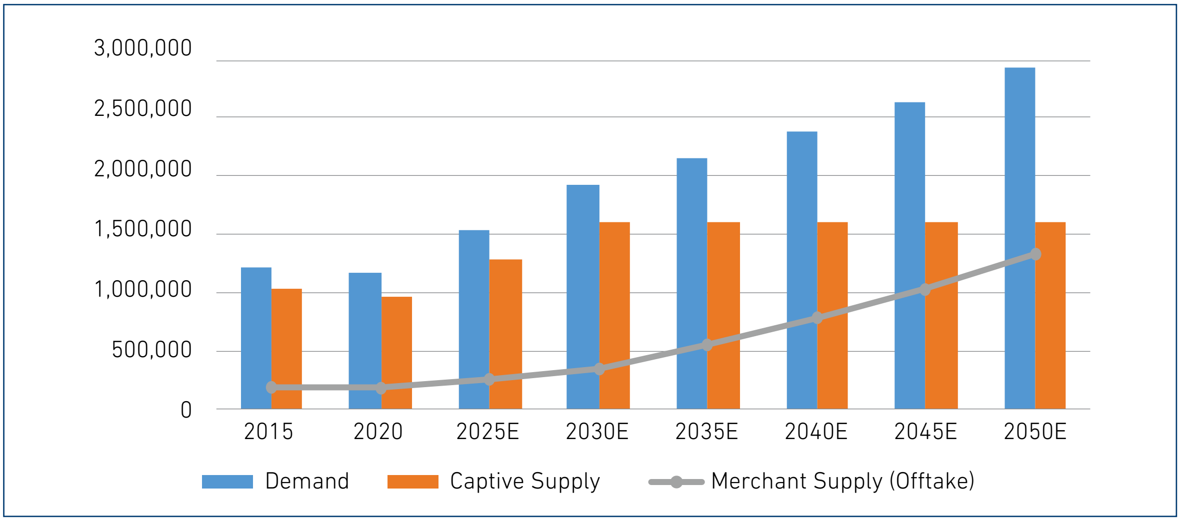


BAU = business-as-usual, E = estimate.

Source: Authors.

Moreover, as regional hydrogen demand continues increasing, the captive supply capacity of Southeast Asian refineries, driven primarily by their steam methane reforming and catalytic reforming capacities, will not be sufficient (Figure 4.2). Indeed, taking all announced and ongoing capacity expansions and configuration changes in the next few years into account, in the Frozen scenario the regional refineries are expected to continue producing hydrogen at their captive capacity limits. Thus, by 2050E, the region's refineries are estimated to require more than 1.3 MTPA of merchant hydrogen supplies, whether imported or independently produced within the region. Therefore, a more important role of independent merchant suppliers in the future is expected, many of which are affiliates of the multinational gas processing companies.

Figure 4.2. ASEAN-8 Refineries Hydrogen Demand-Supply – BAU/Frozen (TPA)



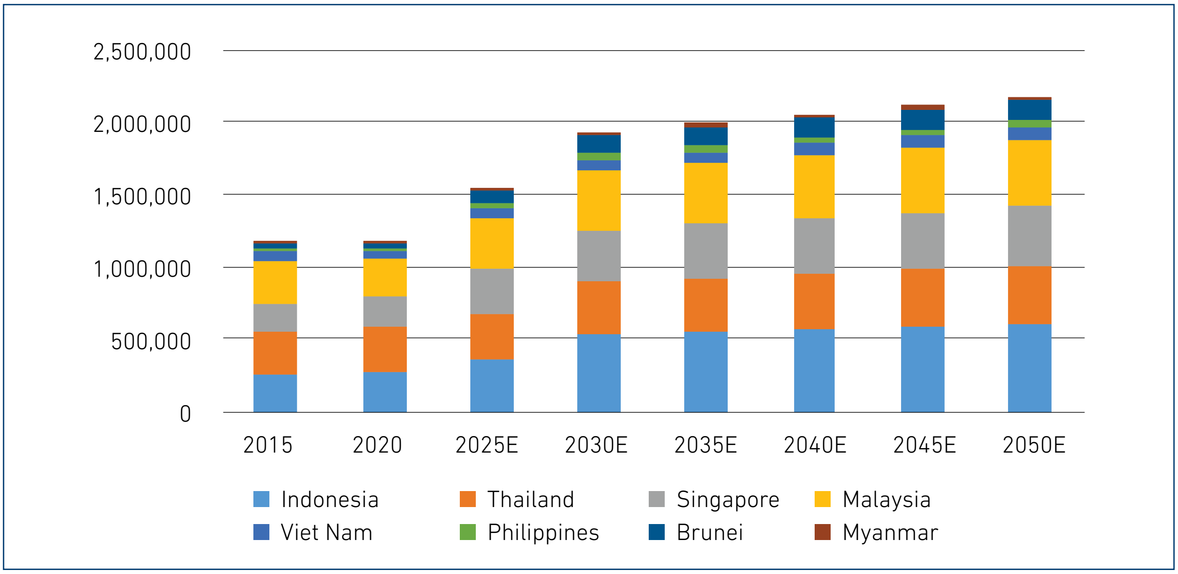
BAU = business-as-usual, E = estimate.

Source: Authors.

ERIA–STEPS

In this scenario, ASEAN governments are assumed to successfully implement their stated policy. As depicted in Table 4.1, for the STEPS, IEA's refinery throughput and oil demand forecasts assumptions are compared and the resulting CAGRs for the periods 2020–2030E and 2030E–2050E estimated. The 2020–2030E CAGR is assumed to parallel the BAU/Frozen scenario, as described above. However, for the long-term 2030E–2050E projection of 0.6% pa IEA's refinery throughput and oil demand CAGRs for the same time period are used as basis. The results can be seen in Figure 4.4.

Figure 4.3. **ASEAN-8 Refineries Hydrogen Demand – STEPS (TPA)**



STEPS = Stated Policies Scenario.

Source: Authors.

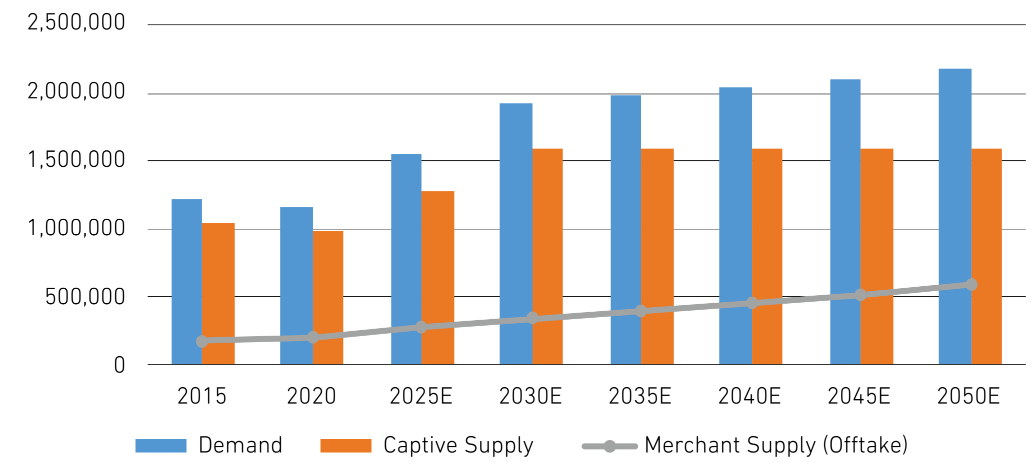
Under the STEPS, Indonesia, Thailand, Singapore, and Malaysia make up approximately 81% of projected regional hydrogen demand from the refinery sector in 2050E, down from 90% in 2020. The difference is the higher demand growth rates in Viet Nam, Brunei, and Myanmar (2.2% CAGR 2030E–2050E), at the expense of declining demand in Singapore (–0.6% CAGR), Indonesia, Thailand and Malaysia (0.6% CAGR). Singapore declines faster as its government electrifies its transport sector faster and exports lower volumes to its increasingly self-reliant neighbours, Indonesia moves away from diesel- and fuel oil-based power. Again, Viet Nam, Brunei, and Myanmar are anticipated to grow faster from a lower demand base.

In this STEPS, hydrogen demand plateaus at about 2.177 KTPA in 2050E. Indonesia, Thailand, Singapore, and Malaysia continue to make up more than four-fifths projected regional hydrogen demand from the refinery sector. Whilst the projected growth rates and hydrogen demand for the 2020–2030E period remains similar to the Frozen scenario above, growth in hydrogen demand slows down in the subsequent 2030E–2050E period. Indeed, under STEPS we maintain the same 2020–2030E CAGR as in the BAU/Frozen scenario, reducing the 2030E–2050E CAGR to 0.6% pa, within the range of IEA's refinery throughput and oil demand projections of 0.5%–0.8% pa.

The demand for refined products in Viet Nam, Brunei, Myanmar, and the rest of the region including Cambodia will continue more rapid growth, whilst the larger economies Indonesia and Thailand mature and gradually shift away from particularly harmful uses of diesel and fuel oil for power and Malaysia and Singapore demand gradually shrink. This results in plateauing demand for hydrogen beyond the 2030s.

Comparing the hydrogen demand supply under STEPS in Figure 4.4we observe similar production forecasts as in the Frozen scenario. This is due to the fact that, in our estimation, under STEPS, captive hydrogen production capacity is fully utilised just like in Frozen, which in return necessitates growing demand for merchant hydrogen supply. Nevertheless, merchant including import requirements under STEPS decrease to about 580 KTPA of hydrogen by 2050E, less than half of the volume projected in the Frozen scenario.

Figure 4.4. ASEAN-8 Refineries Hydrogen Demand-Supply – STEPS (TPA)



STEPS = Stated Policies Scenario, TPA = tons per annum.

Source: Authors.

ERIA–APS

In IEA's strict Conference of the Parties (COP)26 net-zero announced pledges scenario, ASEAN governments accelerate the transition and transform their economies much more quickly than STEPS. Nevertheless, the APS, whilst allowing for only slightly lower growth rates than STEPS towards 2030, is less likely to succeed in the longer 2030E–2050E period due to the extreme decline in oil products demand required to achieve net zero by 20050E.

Table 4.2 summarises ASEAN governments' COP26 pledges.

Table 4.2. ASEAN Member States Governments' COP26 Pledges

Scenarios	Indonesia	Thailand	Singapore	Malaysia	Viet Nam
Electrification	• 2 million four wheelers and 13 million two wheelers 2030E • 20% produced cars 2025E (IESR, 2022a) • Blue/green H_2 (MEMR, 2021a)	• 225,000 cars, 360,000 2-wheelers, 18,000 buses 2025E • 30% of production 2030E (Lim, (2021)	• 60,000 stations 2030E incl. 2,000 carparks (LTA, n.d.) • Diversified imports	• 4,000 EV 2023E • 10,000 charging stations 2025E (Southeast Asia Infrastructure, 2023) • Serawak US$11 trillion by 2050E (Energy Watch, 2021)	• EV production, assembly 2030E • Stop ICE cars 2040E • 100% green EV • 2050E (GRI, 2022)
Blue/green H_2	• Green/blue H_2 incl. for power 2030E	• 10 ktoe Hy 2036E (Ministry of Energy Thailand, 2015)	• Low-carbon H_2 to decarbonise power sector by 2050E • H_2-tech, R&D and infrastructure (MTI, n.d.)	• Targeting global H_2 market worth US$11 trillion (Energy Watch, 2021)	• 216,000 green ammonia and 30,000 green H_2 2024E

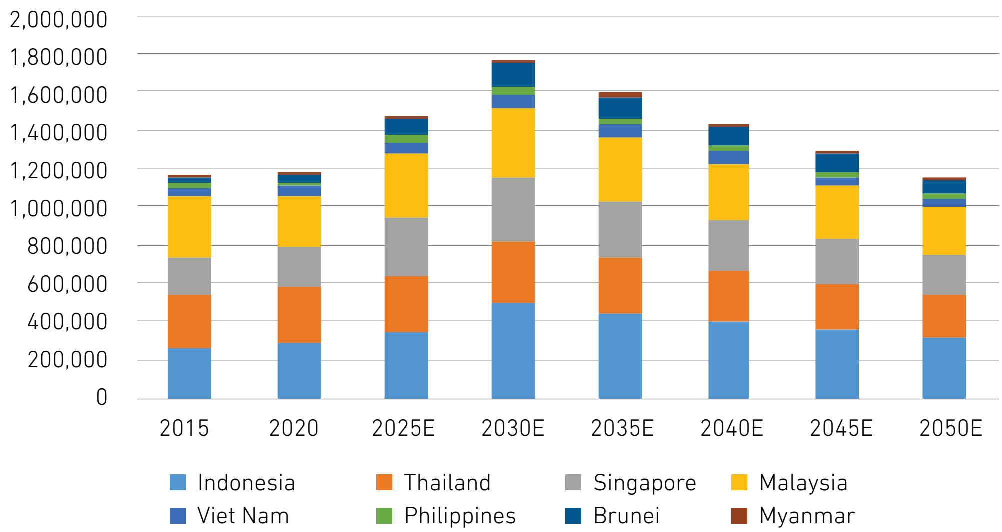
COP = Conference of the Parties, EV = electric vehicle, H_2 = hydrogen, ICE = internal combustion engine, R&D = research and development.

Source: Authors' compilation.

As benchmarks IEA's (2022a and 2022b) refinery throughput and oil demand projections of 2.5%–3.0% pa CAGR for the 2020–2030E period and -2.1% to -0.4% CAGR for 2030E–2050E are examined. By contrast, IEA's (2019) future of hydrogen and DNV's (2022) reports project –1.1%–1.0% of hydrogen demand growth for 2020–2030E.

Thus, 2020–2030E CAGR for regional hydrogen demand from the refinery sector is projected to amount to an effective 3.5% including capacity expansion and configuration changes, which corresponds to 1.2% CAGR pure oil products demand. By contrast, post-2030E the announced pledges necessitate strongly negative demand growth rates of about -2.1%, within the range of IEA estimates and much more negative than DNV's 2030E–2050E CAGR estimates. Figure 4.54.5 depicts the estimation results and country-by-country demand break down.

Figure 4.5. ASEAN-8 Refineries Hydrogen Demand – APS (TPA)



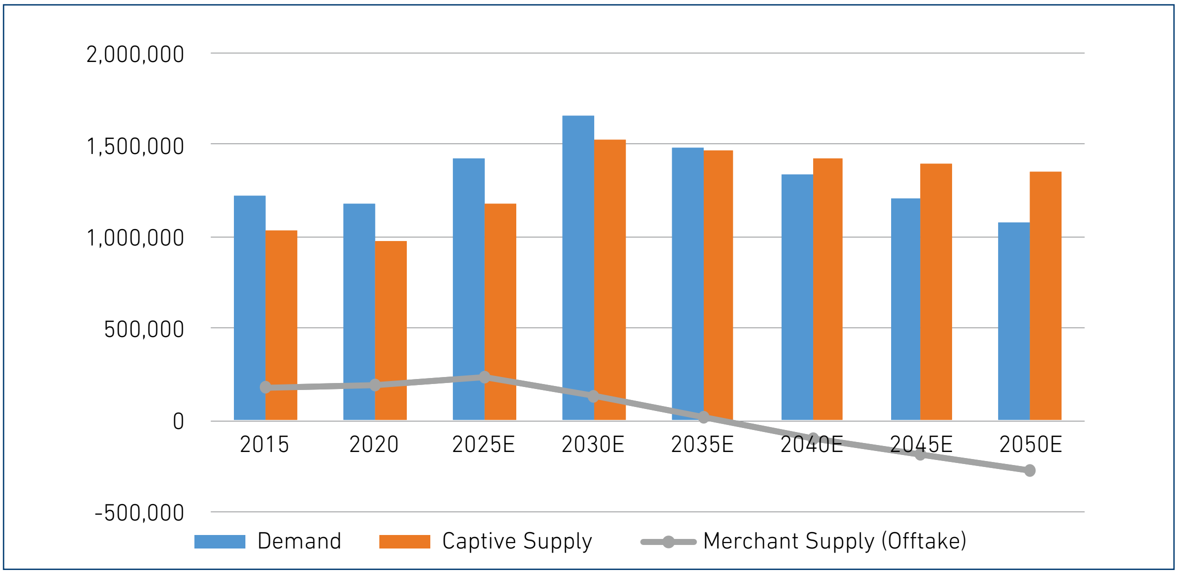
APS = Announced Pledges Scenario, E = estimate, TPA = tons per annum.

Source: Authors.

Under the APS, Indonesia, Thailand, Singapore, and Malaysia make up approximately 81% of projected regional hydrogen demand from the refinery sector in 2050E, down from 90% in 2020. Gradually declining demand for oil products and thus demand from refineries in Viet Nam, Brunei, and Myanmar (–0.7% CAGR 2030E–2050E) contrast Singapore's significant drop (–3.2% CAGR) and Indonesia's, Thailand's, and Malaysia's stronger declines (-2.1% CAGR) over the same period.

Under the APS, regional hydrogen demand increases, albeit more slowly than under BAU/Frozen and STEPS, to peak at 1,650 KTPA in 2030E, before decreasing again to reach 1,078 KTPA by 2050E. Again Indonesia, Thailand, Singapore, and Malaysia dominate the regional demand for hydrogen. Interesting to observe is the fact that captive hydrogen production continues decreasing in the coming years, all the way to 2050E, as shown in Figure 4.6.

Figure 4.6. **ASEAN-8 Refineries Hydrogen Demand and Supply – APS (TPA)**



APS = Announced Pledges Scenario, TPA = tons per annum.

Source: Authors.

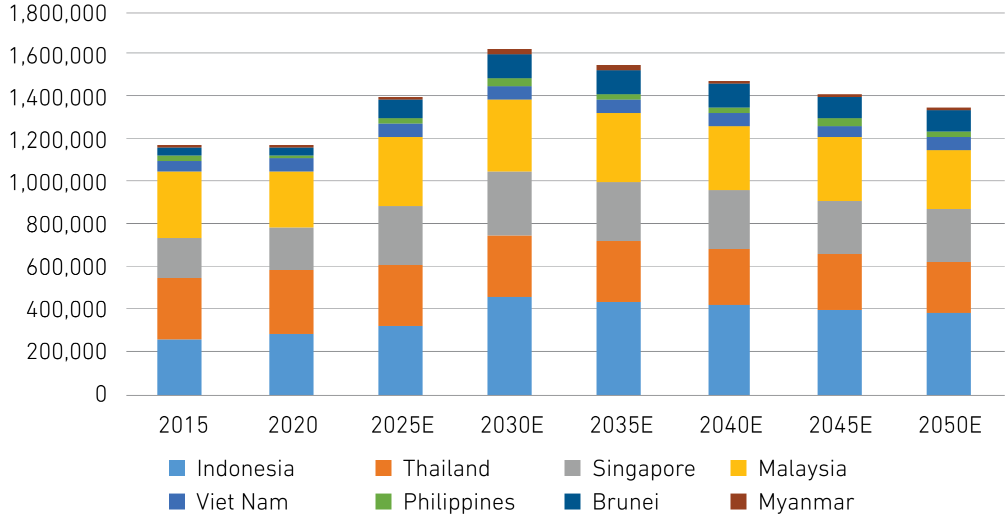
Interesting is the fact that merchant and import shares decrease and actually turn negative beyond 2035E. The latter thus implies that captive hydrogen production capacity would be sufficient to cover the demand through the late 2030s and 2040s. In fact, the regional refineries could supply or export some of their excess hydrogen to the chemical and processing sectors by then, approximately up to 270 KTPA by 2050E.

ERIA-Likely Scenario (LS)

It is estimated that the long-term APS above is less realistic given the anticipated implementation and political economy hurdles. DNV's projected 2020–2030E CAGR growth rates of about 1.0% is more realistic, although we do anticipate that the future Southeast Asian share of global hydrogen demand must increase from DNV's estimated 3.5%, since Western industrialised countries are expected to transition to greener economies faster than Southeast Asian ones.

Thus projected 2020–2030E CAGR for regional hydrogen demand from the refinery sector could amount to an effective 3.3% including capacity expansion and configuration changes, which corresponds to 1.0% CAGR pure oil products demand. By contrast, post-2030E a flatter decline with CAGR of about -0.9% seems appropriate, comparable to DNV's 2030E–2050E CAGR estimates. This may be a more accurate estimation for future hydrogen demand in the region and thus consider this a Likely Scenario (LS). Figure 4.7 depicts the estimation results and country-by-country demand breakdown:

Figure 4.7. ASEAN-8 Refineries Hydrogen Demand – Likely Scenario (TPA)



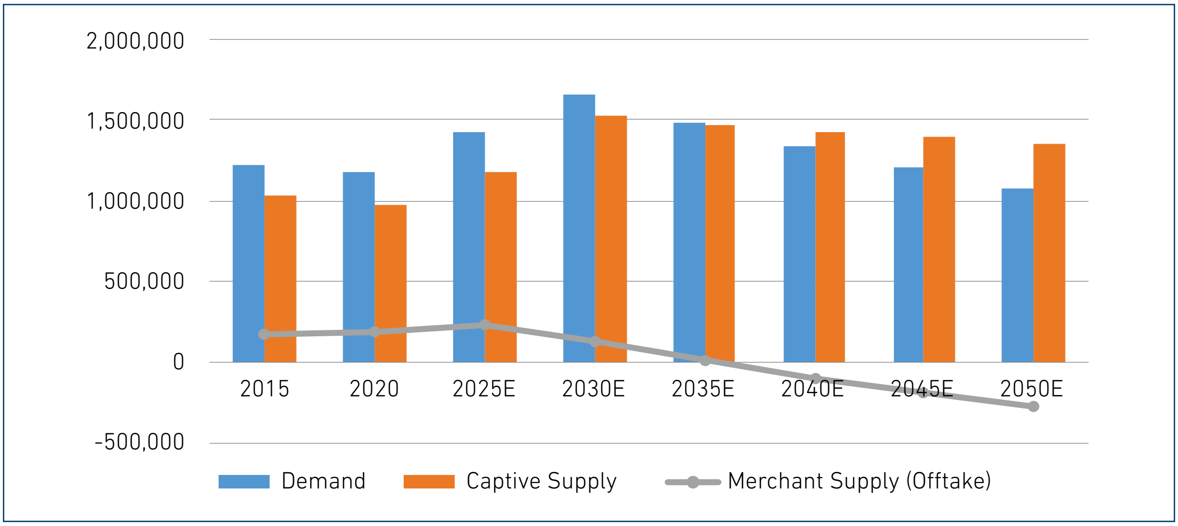
TPA = tons per annum.

Source: Authors.

Again, Indonesia, Thailand, Singapore, and Malaysia make up approximately 81% of projected regional hydrogen demand from the refinery sector in 2050E, down from 90% in 2020. Higher demand growth rates in Viet Nam, Brunei, and Myanmar (0.6% CAGR 2030E–2050E) contrast Singapore's faster (–2.1% CAGR) and Indonesia's, Thailand's, and Malaysia's declines (–0.9% CAGR).

In this Likely Scenario hydrogen demand first increases more slowly than under the BAU/Frozen scenario and the STEPS and comparable to APS, to peak at 1,620 KTPA in 2030E, before decreasing again to reach 1,352 KTPA by 2050E. Again Indonesia, Thailand, Singapore, and Malaysia dominate the regional demand for hydrogen. Interesting to observe is the fact that captive hydrogen production continues decreasing in the coming years, all the way to 2050E, as shown in Figure 4.8.

Figure 4.8. ASEAN-8 Refineries Hydrogen Demand and Supply – Likely Scenario (TPA)



TPA = tons per annum.

Source: Authors.

Thus, merchant and import shares decrease and turn negative beyond 2040E. Thus, captive hydrogen production capacity would be sufficient to cover the demand through the 2040s and regional refineries could supply or export some of their excess hydrogen to the chemical and processing sectors to volumes of at least 80 KTPA by 2050E.

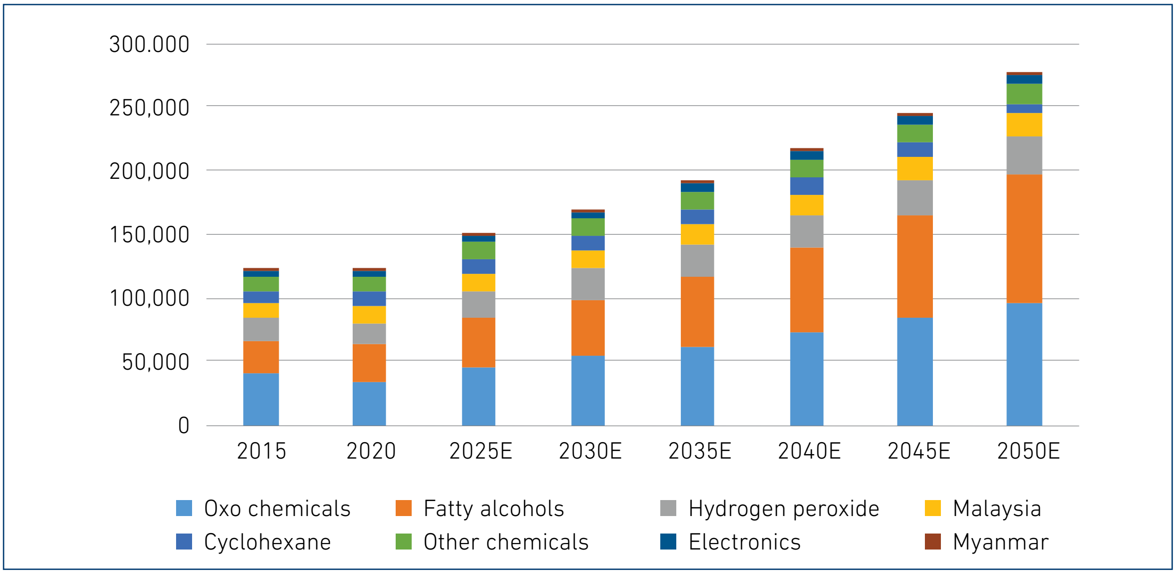
2. Chemical and Other Industries

Future projections for the chemical and processing industries follow a similar set of country break down assumptions like in the historical analysis in Section 2.1.6. Whilst the region-wide estimates for the period 2015–2025E follow IHS (2021), we again single out the largest two segments: Fatty alcohols are split amongst the four countries Indonesia, Malaysia, Thailand, and the Philippines, whilst oxo chemicals and plasticisers are split across these countries and Singapore. For the remaining chemical segments and product groups hydrogen demand is split following the estimated hydrogen demand from each country's refinery sector. Given the fragmented nature and comparatively smaller hydrogen demand for this diversified sector, no distinction is made between the four scenarios discussed for the ammonia, refinery, and methanol sectors.

Forward 2025E–2050E CAGR of 2.5% across the region and all segments is assumed. First, the Southeast Asian fatty alcohols market is projected to grow by about 4%–6% per annum in the medium term (Rossall, 2015; IHS, 2021). Second, economic growth in the Asia-Pacific region is expected to boost growth in oxo alcohols to approximately 3%–5% per annum in the medium term (GMI, 2021). For comparison, Global Market Insight's (2021) medium-term growth forecast for oxo alcohols contrasts with IHS' 1.1% per annum growth for 2022–2025. Third, excluding the higher growth oxo chemicals and fatty alcohols segments above, medium-term growth forecasts for the various chemicals and manufacturing sectors in Southeast Asia range from about 1.2%–2% per annum for hydrogen peroxide, 1%–4% butanediol and float glass, about 1.5% for hydrochloric acid and caprolactam, to stagnating growth for cyclohexane and others (IHS 2021).

The resulting projections for Southeast Asian demand for hydrogen from the chemical and processing industries, broken down by subsector and by country, are depicted in Figure 4.9 and Figure 4.10.

Figure 4.9. Hydrogen Demand in Chemicals by Subsector (TPA)

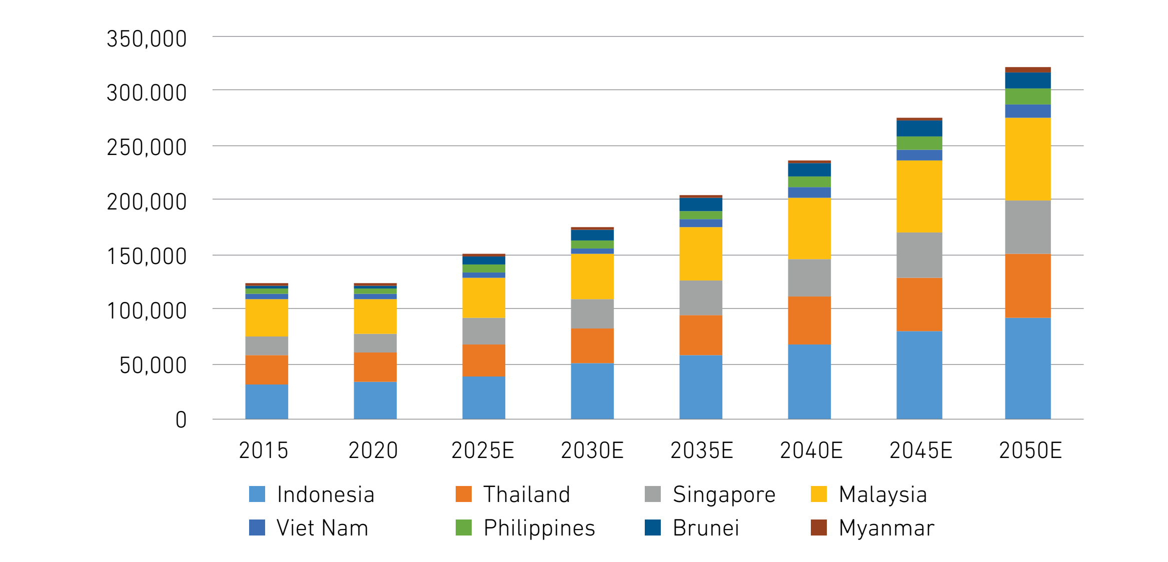


TPA = tons per annum.

Source: Authors.

As observed in Figure 4.94.9, demand for hydrogen from the chemical and processing industries will continue to be dominated by the plasticiser and oxo chemical as well as palm oil-based fatty alcohol segments. Thus, in Figure 4.10 we again see Indonesia, Malaysia, Thailand, Singapore, and the Philippines making up the bulk of hydrogen demand in the region's chemical and processing sectors.

Figure 4.10. Hydrogen Demand in Chemicals by Country (TPA)



Source: Authors.

Lastly, given the more fragmented nature of the chemical and processing subsectors, most of the hydrogen supply may be non-captive and comprise imported and merchant-produced hydrogen. Notable exceptions are the fatty alcohol production facilities in the region, many of which integrate their own captive hydrogen production units.

3. Ammonia Production

There are multiple scenarios that can be utilised to analyse the future demand for ammonia in the ASEAN region from 2020 to 2050. These scenarios consider a range of growth rates and potential novel applications:

1) **Frozen Scenario (Business-as-Usual)**: This scenario is based on historical data on hydrogen demand from Southeast Asia's ammonia industry. Hydrogen demand from the ammonia industry until 2050 is predicted based on a CAGR of real ammonia demand for 2012-2021 of 2.7%. The growth is assumed to be the same for all Southeast Asian members.

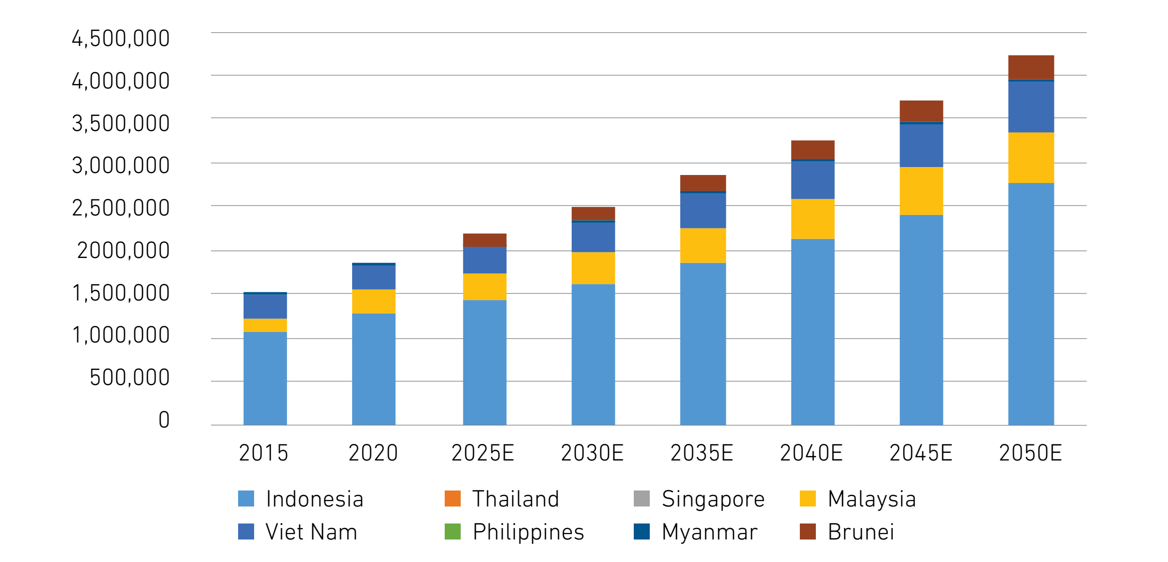
2) **Stated Policies Scenario (STEPS):** This scenario involves employing historical data and applying parameters from IEA's World Energy Outlook, STEPS to forecast the future demand for ammonia. This approach is grounded in the concept that the demand for commodities tends to exhibit consistent periodic growth until the year 2050, primarily driven by the market's increasing interest in green hydrogen energy sourced from ammonia. Consequently, we estimate that the demand for the specified product will experience a compound annual growth rate (CAGR) of 1.4% per annum for the period of 2020–2030 (Southeast Asia average), and a higher CAGR of 3.1% per annum for the following period of 2030–2050 (Southeast Asia average). Hydrogen demand growth rate for each country was estimated from Southeast Asia average growth rate adjusted with population growth projection from the World Bank.

3) **Likely Scenario:** The Likely Scenario is a modest scenario given the numerous political and economic obstacles that currently exist or are anticipated. The prediction is built on parameters from DNV report. We anticipate CAGR of 4.5% from 2030 to 2050 in the share of global ammonia demand in Southeast Asia, considering the prospect of increased adoption of green hydrogen energy in industrialised countries across the West and Southeast Asia. However, it is still higher than the growth rate predicted by the STEPS scenario, which assumes a levelling off of demand in the long run. Furthermore, we estimate that the short-term CAGR for the period of 2020–2030 in regional ammonia demand will be 1.2%, inclusive of capacity expansion and configuration changes. This estimate is supported by Japan's plan to establish an ammonia-based green energy industry in the near future. Hydrogen demand growth rate for each country was estimated from Southeast Asia's average growth rate adjusted with population growth projection from the World Bank.

4) **Announced Pledges Scenario (APS):** The APS is the most optimistic scenario, resulting from the heightened demand from novel energy applications like employing ammonia as a fuel or transforming it into hydrogen for fuel cells. This scenario involves employing historical data and applying parameter from IEA's World Energy Outlook APS to forecast the future demand for ammonia. Under the scenario, the ammonia demand in 2050 will be increased roughly fourfold. Thus, we anticipate that the specified product will encounter a CAGR of 1.2% per annum during the interval between 2020 and 2030, followed by a large rapid CAGR increase of 6.4% per annum from 2030 to 2050. Hydrogen demand growth rate for each country was estimated from Southeast Asia's average growth rate adjusted with population growth projection from World Bank.

ERIA–Frozen Scenario

Figure 4.11. Frozen Scenario for Hydrogen Demand from Ammonia Industry in the Region (TPA)

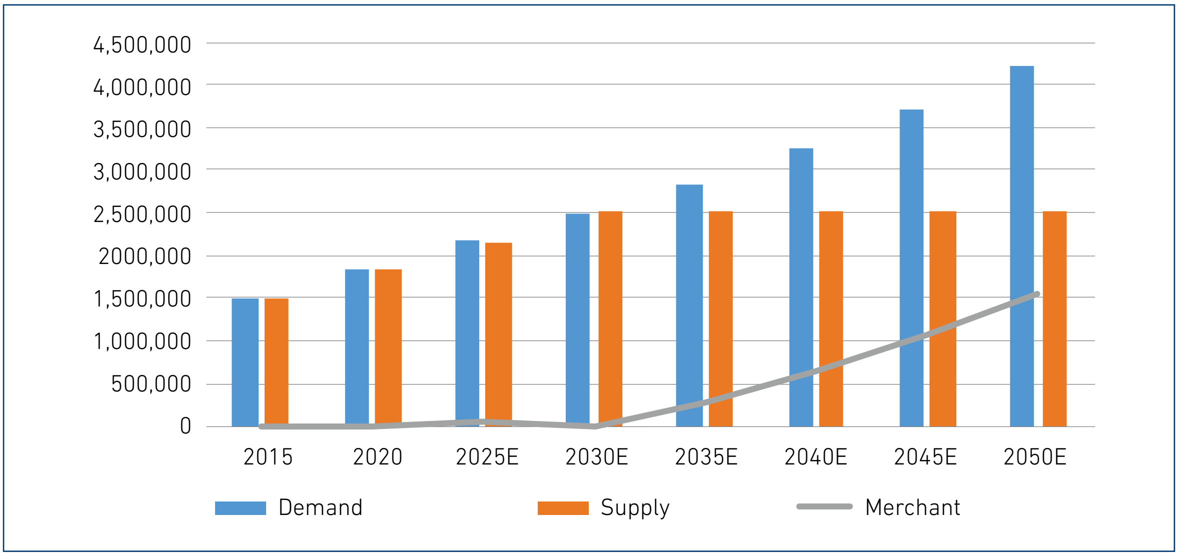


TPA = tons per annum.

Source: Authors.

This scenario relies on historical data related to the demand for hydrogen in Southeast Asia's ammonia industry. As seen in Figure 4.11 and Figure 4.12, the projected CAGR for hydrogen demand for ammonia production up to 2050 is estimated to be 2.7%, with moderate growth in demand for each country, and Indonesia remaining the dominant producer of ammonia in the region.

Figure 4.12. Hydrogen Supply and Demand from Ammonia Production in Frozen Scenario (TPA)

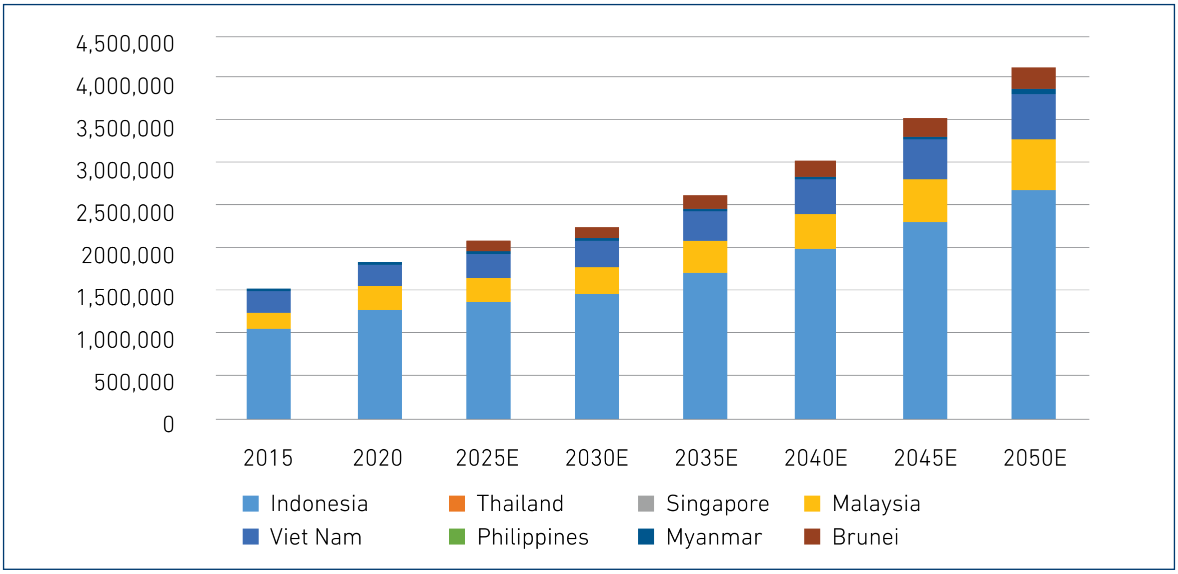


TPA = tons per annum.

Source: Authors.

ERIA–STEPS

Figure 4.13. STEPS for Hydrogen Demand from Ammonia Industry in the Region (TPA)



TPA = tons per annum.

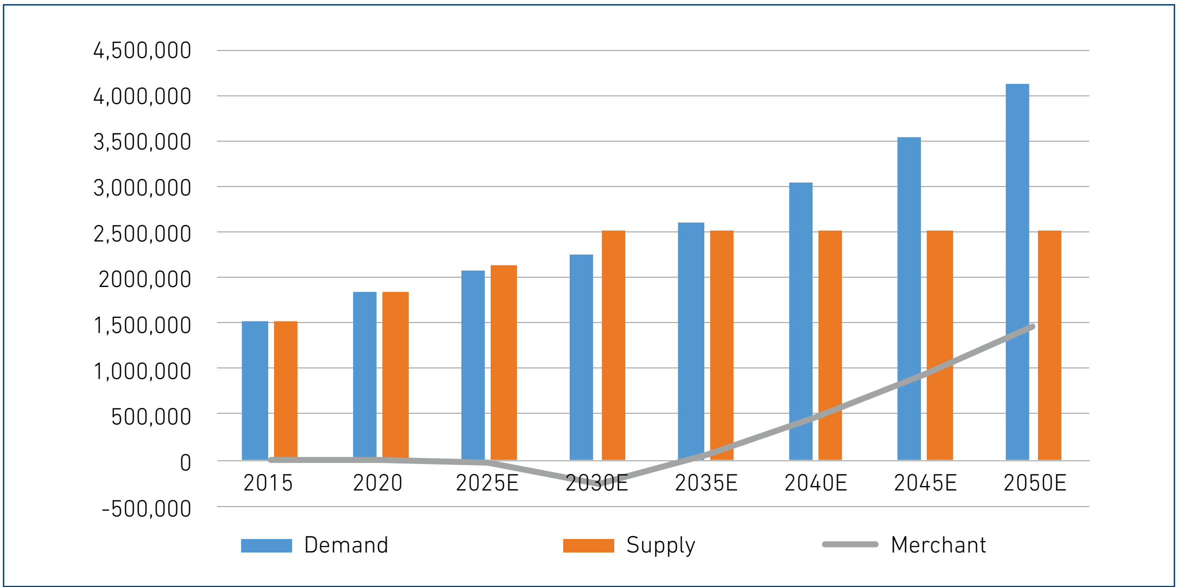
Source: Authors.

As shown in Figure 4.13, in this scenario, it is expected that the demand growth rate for hydrogen in the ammonia industry in the ASEAN region will be largely driven by major economies such as Indonesia, Malaysia, and Viet Nam. Based on the projection, Indonesia's demand for hydrogen is expected to increase from 1,270 KTPA in 2020 to about 2,682 KTPA by 2050, whilst Malaysia's demand is estimated to rise from 281 KTPA in 2020 to approximately 593 KTPA by 2050. Similarly, Viet Nam's demand for hydrogen is predicted to increase from 258 KTPA in 2020 to around 544 KTPA by 2050.

When depicted on a vertical bar chart, the market growth trends for this scenario can be visualised. The chart indicates that in the first few years of the projection (2020–2050), a compound annual growth rate (CAGR) of 1.4% is forecast, and it is anticipated that the demand for hydrogen will rise in many Southeast Asian countries as new applications and technologies emerge. Nonetheless, the bar height for this period is projected to show limited growth due to the ongoing construction phase of policy adjustments and the development of green energy technology.

During the period of 2030–2050, the demand growth rate for hydrogen in the ammonia industry is expected to rise significantly as the market prepares for the transition from conventional energy to green hydrogen energy. This trend is predicted to result in a CAGR of 3.1%, indicating that the bar chart will continue to rise until 2050 as the market has not yet reached its saturation point. However, once the market does reach saturation and countries find new technologies to replace green hydrogen energy from ammonia, a new stationary phase will begin.

Figure 4.14. Hydrogen Supply and Demand from Ammonia Production in STEPS (TPA)



STEPS = Stated Policies Scenario, TPA = tons per annum.

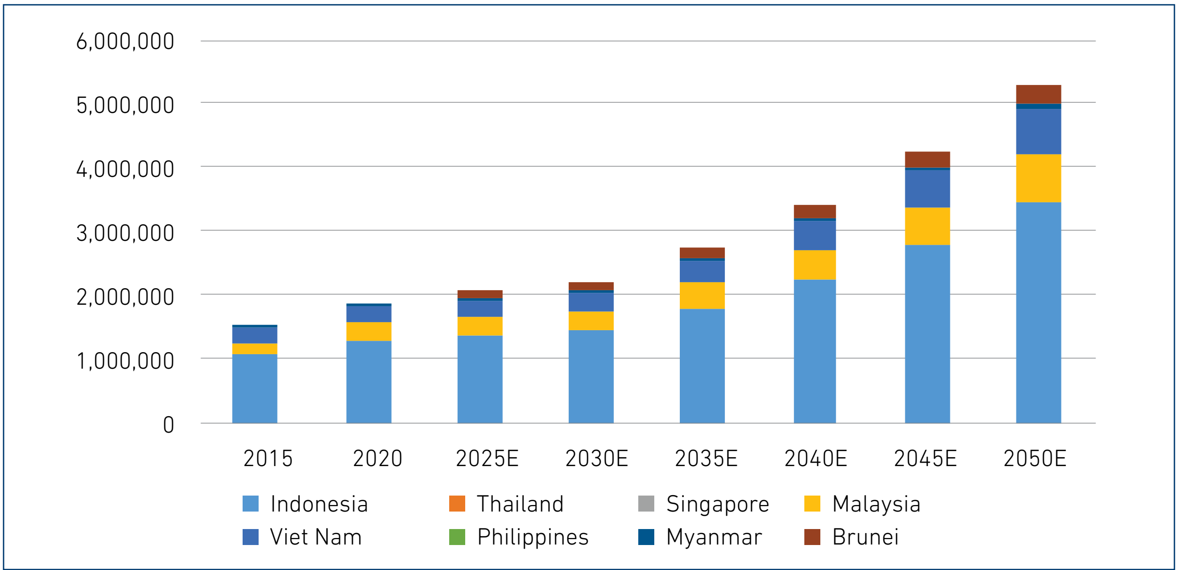
Source: Authors.

In this scenario, an increase in ammonia demand necessitates a corresponding increase in hydrogen supply (Figure 4.14). The CAGR for hydrogen demand is expected to remain in balance with the current industry supply from 2020 to 2030. However, a significant shift is projected to occur from 2030 to 2050, where assuming the hydrogen supply from existing installation capacity remains stagnant, there will be a significant imbalance between hydrogen supply and demand in the ammonia industry. As a result, third-party merchants will need to provide a significant amount of hydrogen to fulfil the demand. This imbalance highlights the necessity of importing hydrogen from external sources to meet ammonia industry demands.

ERIA–Likely Scenario

The growth rate of hydrogen demand for the ammonia industry in this scenario is moderate and more conservative than the APS scenario. It is projected to have a CAGR of 1.2% per year between 2020 and 2030. The demand for ammonia in ASEAN countries is expected to be consistent with the STEPS as developing countries tend to adopt new technologies at a slower pace compared to developed countries. After 2030, the CAGR is anticipated to increase significantly to 4.5% per year until 2050.

Figure 4.15. Likely Scenario for Hydrogen Demand from Ammonia Industry in the Region (TPA)

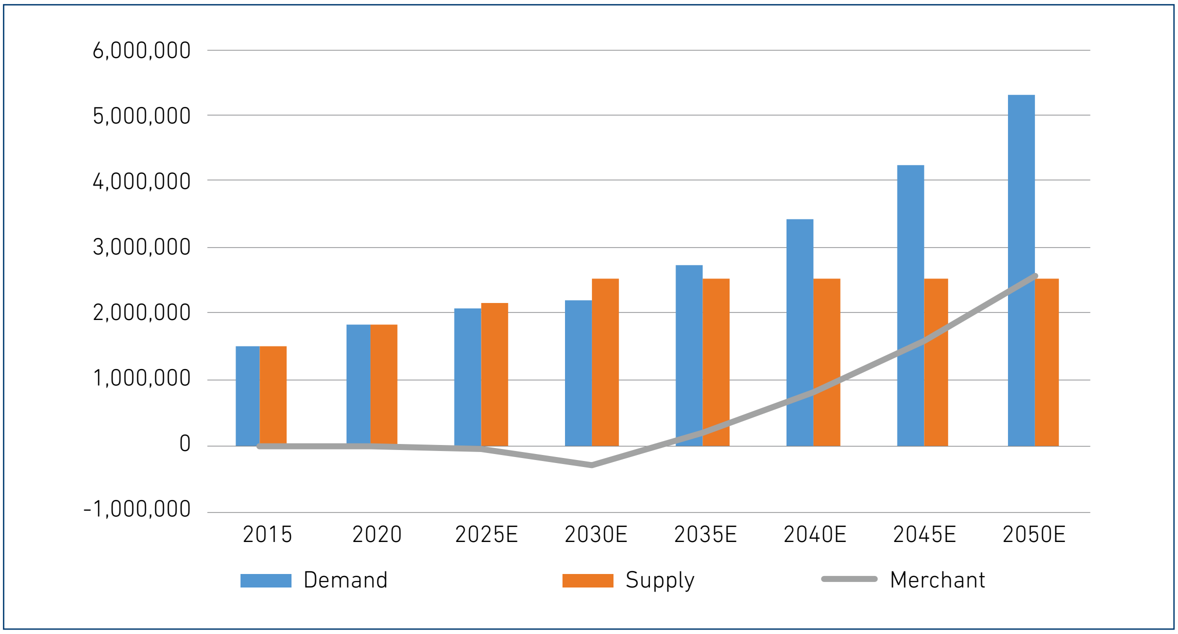


TPA = tons per annum.

Source: Authors.

According to the data presented in Figure 4.15, Indonesia is identified as the top ammonia producer in the region, followed by Malaysia, Viet Nam, and Brunei. This trend indicates an upwards trend in hydrogen demand for ammonia production in the specified countries. Conversely, Singapore, Thailand, and the Philippines, which do not have ammonia production capabilities, did not demonstrate a rise in ammonia demand. It is worth noting that Brunei is projected to commence ammonia production by the end of 2021, and Myanmar is expected to exhibit a low consumption rate of ammonia. The Likely Scenario postulates a gradual expansion in hydrogen demand for ammonia production, matching the earlier mentioned ammonia demand. Indonesia, Malaysia, and Viet Nam display a persistent uptick in hydrogen demand, indicating their growing ammonia consumption.

Figure 4.16. Hydrogen Supply and Demand from Ammonia Production in ERIA-Likely Scenario (TPA)



TPA = tons per annum.

Source: Authors.

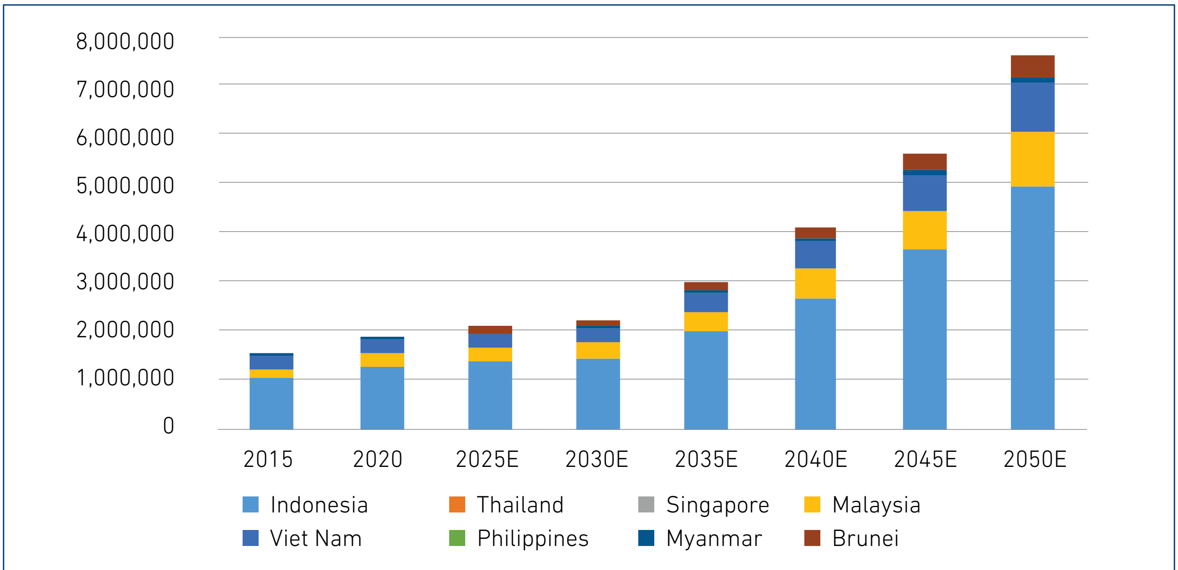
The increasing demand for hydrogen in this scenario necessitates a commensurate rise in the supply of hydrogen (Figure 4.16). Between 2020 and 2030, the hydrogen demand is projected to grow at a CAGR of 1.2%, and the current supply is deemed sufficient to meet demand with minimal reliance on third-party suppliers by early 2025. However, as the share of global ammonia demand in Southeast Asia is expected to grow at a CAGR of 4.5% from 2030 to 2050 and given the potential for an increase in the adoption of green hydrogen energy in developed nations across the West and Southeast Asian regions, the projected scenario indicates that a stagnant hydrogen supply will no longer maintain equilibrium with the increasing demand. Consequently, the hydrogen supply from third-party merchants is likely to increase significantly, and according to the projected scenario, the supply of hydrogen from external sources is expected to be equivalent to domestically-produced hydrogen by 2045–2050. Such a development could lead to stability in ammonia industry production in the region, particularly in the event of supply chain disruptions from foreign suppliers.

The total demand for hydrogen for ammonia production in Southeast Asia rises from 1,834 kilotons per year in 2020 to 5,295 kilotons per year in 2050. Although the growth rate is more conservative than the APS, it is still greater than the growth rate predicted by the STEPS. The moderate increase in demand is affected by the possibility of market saturation and technological advancements that may influence ammonia consumption from time to time.

ERIA–APS

The current projection with APS reveals a substantial rise in the demand for hydrogen in the production of ammonia in the Southeast Asian region, as demonstrated in Figure 4.17. The projected surge from 1,834 kiloton/year in 2020 to 7,609 kiloton/year in 2050 reflects the growing trend of countries adopting ammonia for new energy applications such as fuel usage and conversion into hydrogen for fuel cells. Indonesia leads amongst the ASEAN countries as the primary driver of ammonia demand, followed by Malaysia and Viet Nam, with expected demand increases of 1,271 to 4,956 kiloton per annum, 281 to 1,097 kiloton per annum, and 258 to 1,005 kiloton per annum, respectively, from 2020 to 2050. According to the APS, the research anticipates that these nations will exhibit a compound annual growth rate of 1.23% from 2020 to 2030, which is predicted to escalate significantly from 2030 to 2050, reaching a CAGR of 6.4%. This growth can be attributed to the flourishing economy, burgeoning industrial operations, and the implementation of sustainable energy sources in these regions.

Figure 4.17. APS for Hydrogen Demand from Ammonia Industry in the Region (TPA)

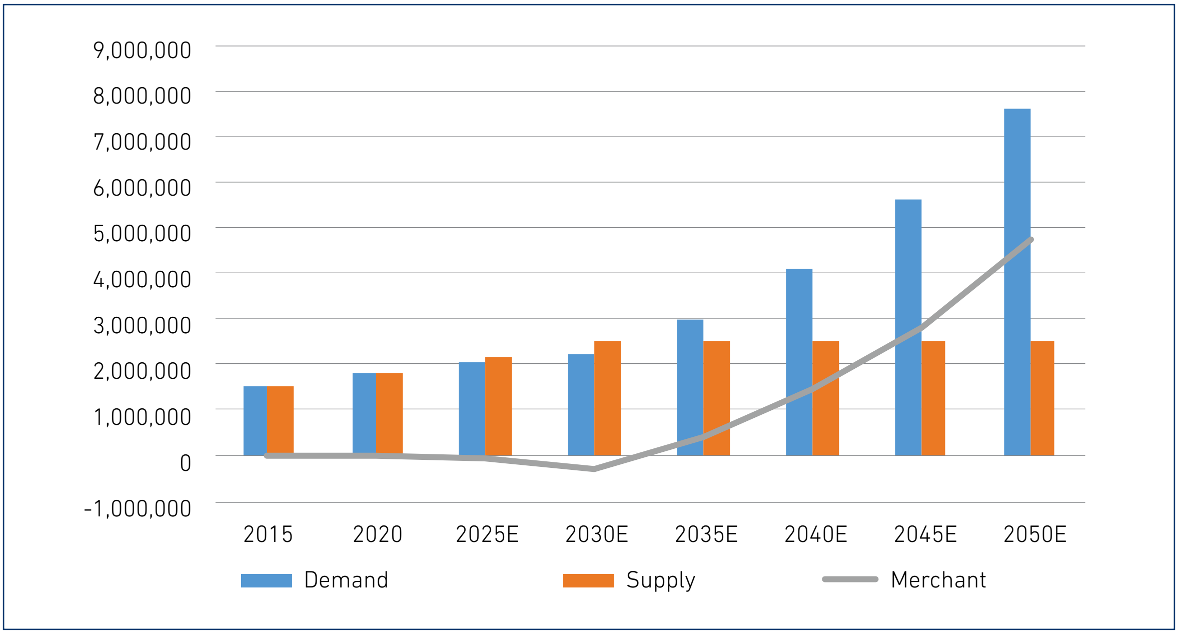


APS = Announced Pledges Scenario.

Source: Authors.

According to the APS, the demand for hydrogen in the Southeast Asian region for ammonia production shows a significant increasing trend from 2020 to 2050. The exponential rise in hydrogen demand can be attributed to the growing interest in ammonia as a sustainable energy source. Figure 4.18 indicates that whilst hydrogen consumption is projected to increase between 2030 and 2050, there will not be a concurrent increase in hydrogen-producing countries in the region, due to limitations in their reserves of natural gas resources.

Figure 4.18. Hydrogen Supply and Demand from Ammonia Production in APS (TPA)



APS = Announced Pledges Scenario, TPA = tons per annum.

Source: Authors.

The APS analysis reveals that the increasing demand for ammonia in the Southeast Asia region will require a corresponding increase in the supply of hydrogen. The projected CAGR of 1.2% for hydrogen demand from 2020 to 2030 is expected to be met by current supply levels with little dependence on third-party suppliers. However, an optimistic CAGR of 6.4% from 2030 to 2050 implies that the current stagnant supply of hydrogen will be grossly insufficient to meet the increasing demand for ammonia production. As a result, the reliance on third-party suppliers is projected to increase significantly, with the supply from these traders almost doubling the region's available supply. Ammonia-producing countries may need to consider alternative strategies to meet their hydrogen requirements, such as exploring more environmentally friendly energy sources or seeking supplies from abroad. Nonetheless, too much reliance on third-party suppliers can pose significant risks, including price fluctuations and unreliable supply availability. Therefore, it is essential for ammonia producers to prioritise the sustainability and reliability of hydrogen supply by developing domestic production capabilities and energy resources in a more sustainable manner.

The total hydrogen demand for ammonia production in the ASEAN region is expected to increase rapidly from 1834 kilotons per annum in 2020 to 7609 kilotons per annum in 2050. It is important to note that this scenario represents an extreme case in which all ASEAN countries aggressively pursue net-zero emissions, make significant investments, and incur all the necessary costs to achieve their ambitious climate targets.

4. Methanol Production

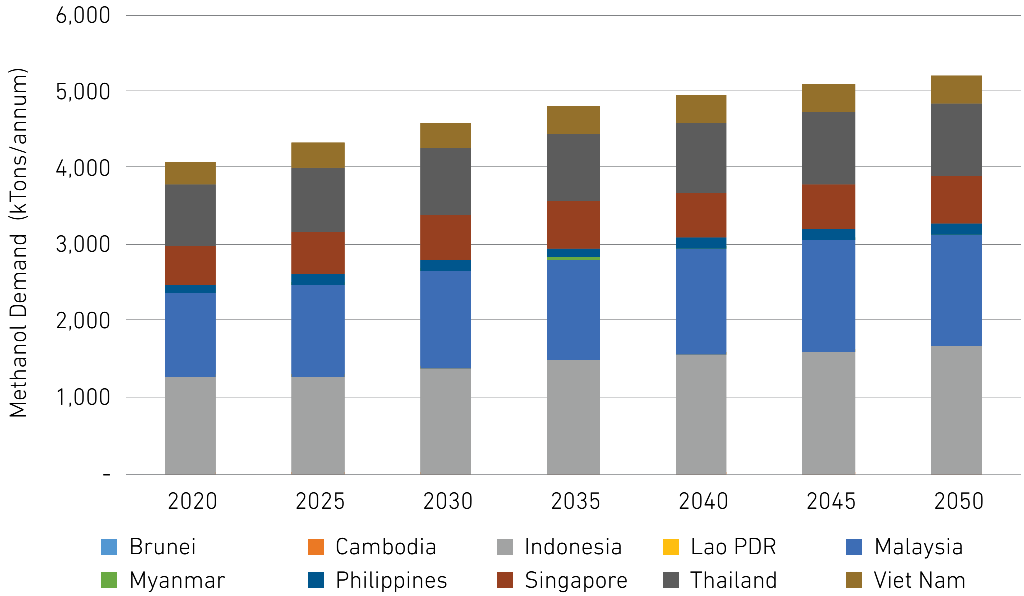
The future demand for methanol in the ASEAN region from 2020 to 2050 can be analysed using three different scenarios, which consider various growth rates and potential new applications:

1) STEPS: This scenario uses historical data and fits it with a logarithmic model to predict future demand. This is based on the assumption that commodity demand usually levels off in the long run, as economies mature, and markets become more saturated. Under this scenario, the growth rate of methanol demand might slow down over time, with the demand curve eventually reaching a plateau.
2) APS: This scenario assumes a progressive linear growth rate due to increased demand from new applications in the energy sector, such as using methanol as a fuel or converting it into hydrogen for fuel cells. Under this scenario, the demand for methanol in 2050 is estimated to be approximately three times the demand in 2020. This corresponds to a CAGR of 5.5%, which would lead to a substantial increase in methanol demand in the region.
3) Likely Scenario: This scenario predicts a more moderate increase in methanol demand, with the growth period split into two main phases. In the first phase, lasting until 2030, methanol consumption in ASEAN nations is projected to mirror that in STEPS, as developing countries are expected to adapt at a slower pace than their developed counterparts. Post 2030, the CAGR is estimated to be 4% per annum until 2050.
   This growth rate is more conservative than the APS, as it takes into account potential market saturation and technological advancements that may impact methanol demand. However, it is still higher than the growth rate predicted by the STEPS, which assumes a levelling off of demand in the long run.

It is important to note that these scenarios are based on different assumptions and projections, and the actual future demand for methanol in the ASEAN region will depend on a variety of factors, such as economic growth, technological advancements, government policies, and market dynamics. As new information and data become available, these scenarios may need to be updated or revised to better reflect the evolving context.

ERIA–STEPS

Figure 4.19. STEPS for Methanol Demand in the Region



STEPS= Stated Policies Scenario.

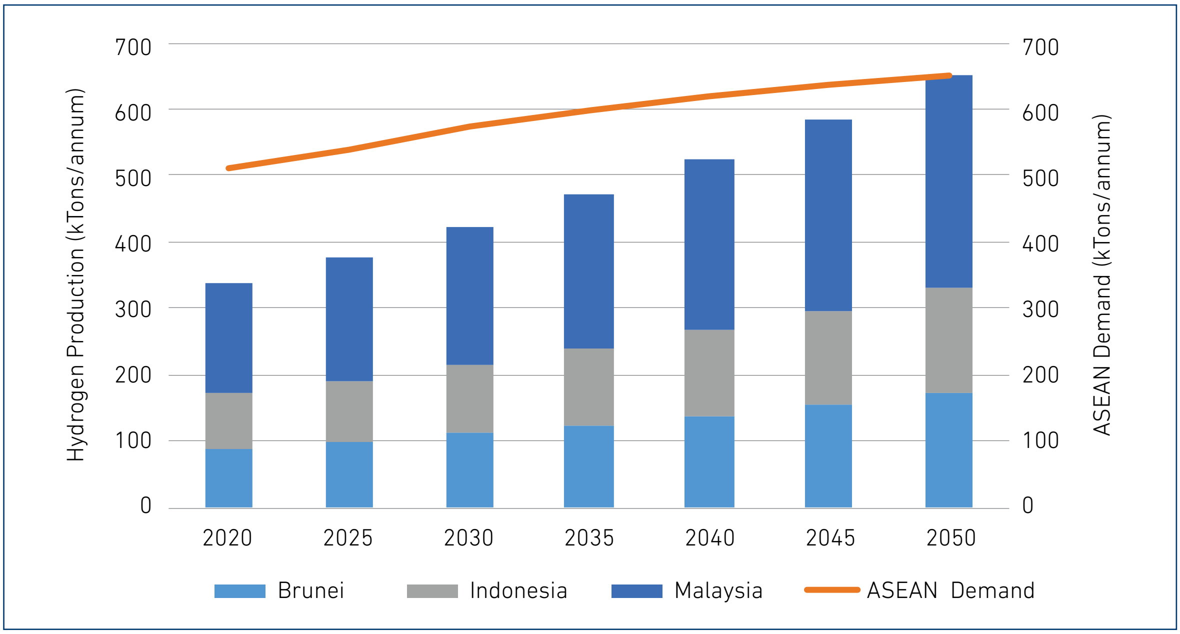
Source: Authors.

In the STEPS, the methanol demand in the ASEAN region is projected based on historical data and trends, following a logarithmic growth pattern. This assumes that the demand will level off in the long run as markets mature and become more saturated. When visualising this scenario on a vertical bar chart, you can expect to observe the following trends:

- Initial growth: In the early years (2020–2030), you would likely see a period of growth in methanol demand across most ASEAN countries, as new applications and technologies emerge, and the regional economies continue to expand. The height of the bars would increase during this period.
- Slowing growth: Moving towards the middle years (2030–2040), the growth rate of methanol demand would begin to slow down, as the market approaches saturation and the low-hanging fruit in terms of applications have been captured. In this phase, the height of the bars on the chart would continue to increase, but at a slower rate.
- Plateau: As we approach the later years (2040–2050), the methanol demand would start to level off, reaching a plateau. This would be due to market saturation, advances in alternative technologies, or shifts in government policies that might limit the growth of methanol demand. During this phase, the height of the bars on the chart would remain relatively constant, showing little to no increase.

The major economies in the ASEAN region such as Indonesia, Malaysia, and Thailand, would contribute significantly to the methanol demand in this scenario. For example, Indonesia's demand might grow from 1,256 KTPA in 2020 to around 1,653 KTPA by 2050. Similarly, Malaysia's demand could increase from 1,110 KTPA in 2020 to approximately 1,473 KTPA by 2050. Thailand might see its demand grow from 793 KTPA in 2020 to around 943 KTPA by 2050.

Figure 4.20. Hydrogen Demand from Methanol Production in STEPS



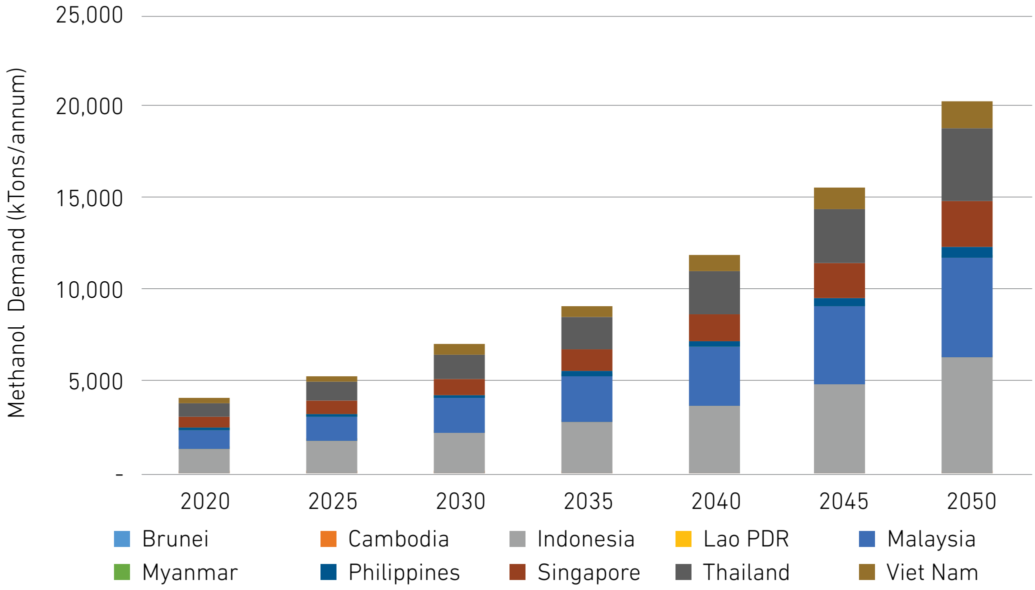
STEPS = Stated Policies Scenario.

Source: Authors.

In response to the growing methanol demand, more hydrogen is needed for its production. Figure 4.20 shows both evolutions of hydrogen demand and supply from methanol production in ASEAN in STEPS. Based on the assumption, the hydrogen demand is projected to grow at a relatively modest CAGR of 2.2% between 2020 and 2050. This limited growth is likely due to the assumption that the STEPS scenario will not attract new producers, which will restrain the growth potential of hydrogen production. Amongst the existing methanol producers, Malaysia has the highest hydrogen demand, increasing from 166.5 kilotons per annum in 2020 to an estimated 319.8 kilotons/annum in 2050 and will play a significant role in the regional hydrogen production landscape. Both Indonesia and Brunei are projected to experience steady growth in hydrogen demand during the period. Indonesia's hydrogen production is expected to rise from 82.5 kilotons/annum in 2020 to 158.5 kilotons per annum in 2050, whilst Brunei's production is predicted to increase from 90.3 kilotons per annum in 2020 to 173.5 kilotons per annum in 2050. The total hydrogen demand for the ASEAN region is projected to grow from 339.3 kilotons/annum in 2020 to 651.8 kilotons per annum in 2050. This growth, albeit modest, highlights the region's efforts to meet the demand for methanol production within the constraints of the STEPS.

ERIA–APS

Figure 4.21. APS for Methanol Demand in the Region



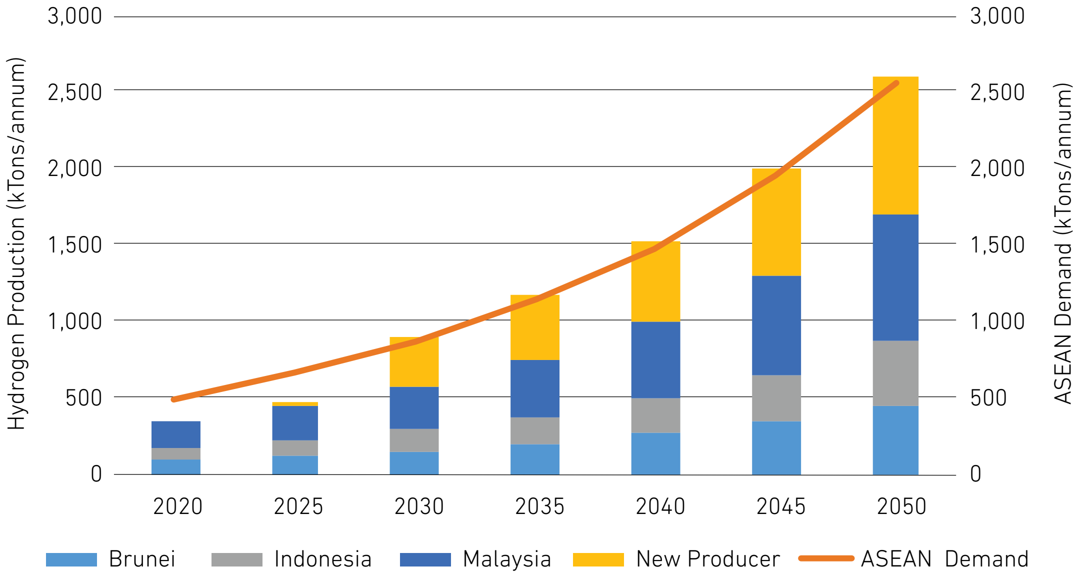
APS = Announced Pledges Scenario.

Source: Authors.

Figure 4.21 shows the significant demand growth of methanol in the ASEAN region. It is projected to rise from 4,074 kilotons per annum in 2020 to 20,303 kilotons per annum in 2050. This substantial increase suggests that these countries are adopting methanol for new applications in the energy sector, such as using it as a fuel or converting it into hydrogen for fuel cells. Indonesia and Malaysia are the major drivers of methanol demand in the region. Indonesia's demand is expected to increase from 1,256 kilotons per annum in 2020 to 6,262 kilotons per annum in 2050, whilst Malaysia's demand is projected to rise from 1,110 kilotons per annum in 2020 to 5,530 kilotons per annum in 2050. The growth in these countries can be attributed to their expanding economies, increased industrial activities, and adoption of cleaner energy sources.

Thailand's methanol demand is forecasted to grow from 793 kilotons per annum in 2020 to 3,951 kilotons per annum in 2050. Singapore, being a significant regional hub for trade and refining, is also expected to see a substantial increase in methanol demand from 505 kilotons per annum in 2020 to 2,517 kilotons per annum in 2050. Countries such as the Philippines, Viet Nam, and Myanmar will experience moderate growth in methanol demand. The demand in these countries is projected to increase due to factors like economic development, urbanisation, and growing energy needs. The significant methanol demand growth in the APS for ASEAN countries can be attributed to increased demand from new applications in the energy sector, economic expansion, industrial growth, and the pursuit of cleaner energy sources. The growth is particularly notable in Indonesia, Malaysia, Thailand, and Singapore, as these countries lead the region in economic and industrial development.

Figure 4.22. Hydrogen Demand from Methanol Production in the APS



APS = Announced Pledges Scenario.

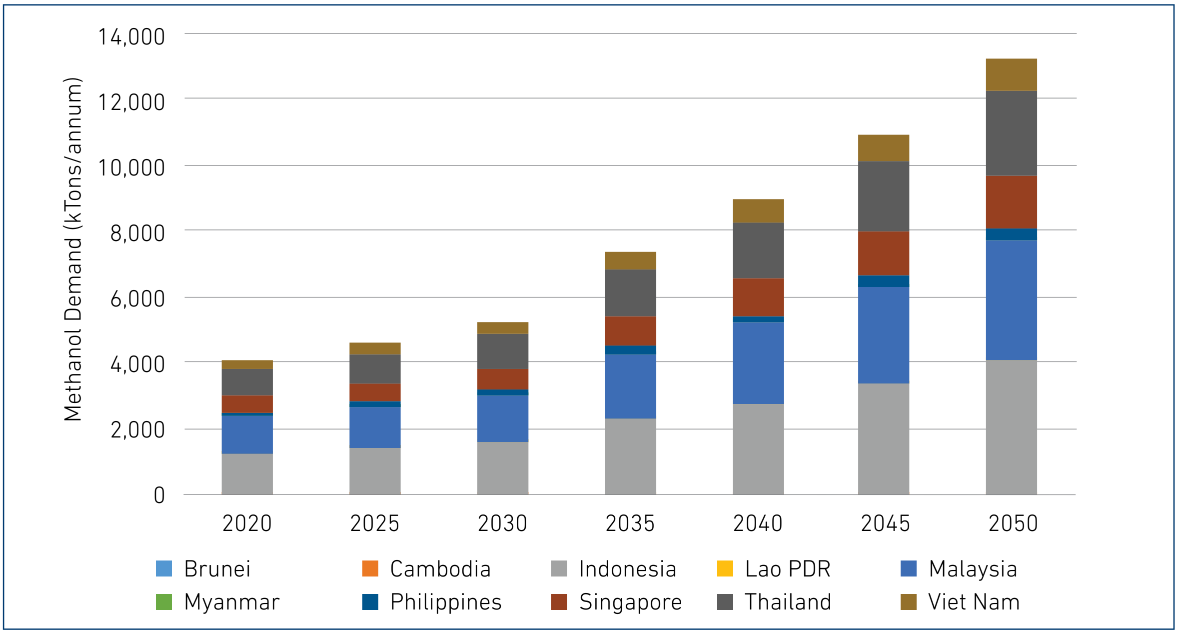
Source: Authors.

In the APS, hydrogen demand for methanol production (kilotons per annum) in the ASEAN region demonstrates a significant upwards trend between 2020 and 2050. Hydrogen demand experiences a rapid increase, which can be attributed to the growing interest in methanol as an alternative energy source. Figure 4.22 shows the appearance of new producers, starting from 2025, to cater to the burgeoning demand for green methanol. These new producers play a crucial role in serving the emerging market of green methanol as a marine transport fuel, which is gaining traction as a cleaner and more sustainable alternative to conventional fossil fuels. This development is driven by stringent environmental regulations and the shipping industry's commitment to reducing its carbon footprint.

Brunei, Indonesia, and Malaysia as regional leaders show substantial growth in hydrogen demand for methanol production throughout the forecast period. The continued growth in these countries indicates their central role in the regional hydrogen production landscape, as well as their potential to capitalise on new market opportunities. The total ASEAN hydrogen demand for methanol production increases considerably, from 339.3 kilotons per annum in 2020 to 2,602.9 kilotons per annum in 2050. It is worth noting that this represents an extreme case where growth in hydrogen demand for methanol production is exceptionally high. In this scenario, all countries in the ASEAN region are rushing towards net-zero emissions, making significant investments and bearing any costs necessary to achieve their ambitious climate goals.

ERIA–Likely Scenario

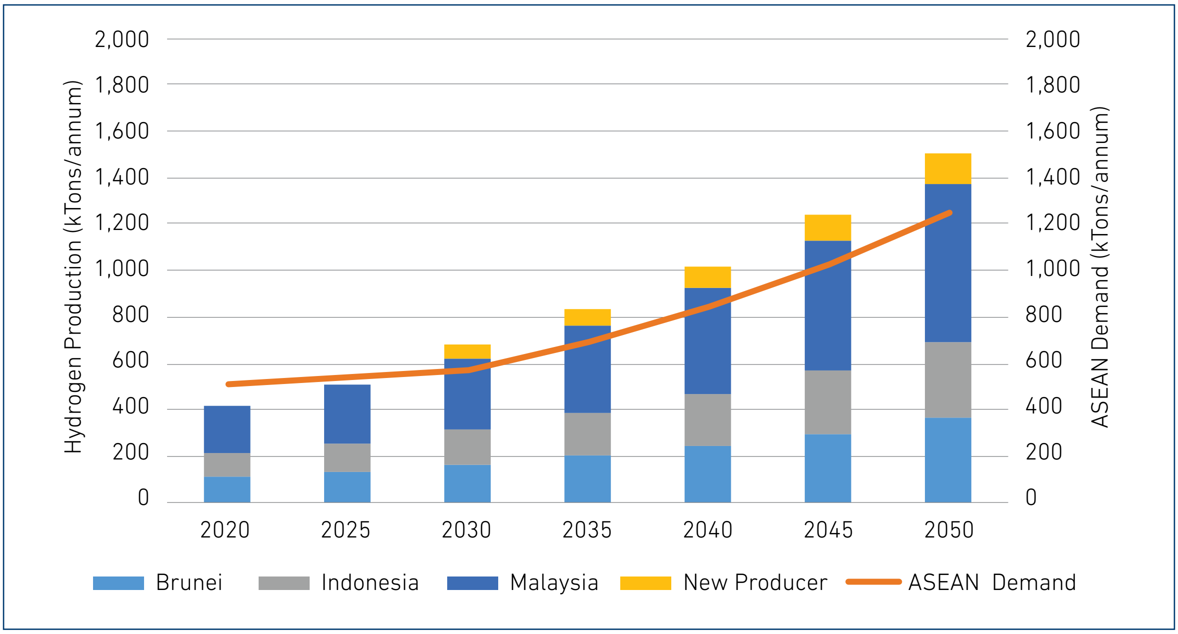
Figure 4.23. The Methanol Demand in the Region in the ERIA Likely Scenario



Source: Authors.

Figure 4.23 shows the methanol demand in the region in the ERIA likely scenario. In this scenario, methanol demand experiences moderate growth, with a more conservative increase compared to the APS scenario. Until 2030, methanol consumption in ASEAN countries is expected to resemble the demand in the STEPS, as developing countries are likely to adapt more slowly compared to the developed world. After 2030, the compound annual growth rate (CAGR) is estimated to be 4% per annum until 2050. Figure 4.23 indicates that Indonesia and Malaysia are the largest consumers of methanol in the region, with their demand continuing to increase steadily throughout the entire period. Singapore, Thailand, and the Philippines also exhibit a consistent growth pattern in methanol demand. The total ASEAN methanol demand increases from 4,074 kilotons per annum in 2020 to 10,034 kilotons per annum in 2050. This growth rate, although more conservative than the APS, is still higher than the growth rate predicted by the STEPS. The moderate increase in demand is influenced by the potential market saturation and technological advancements that may impact methanol consumption over time.

Figure 4.24. Hydrogen Demand from Methanol Production in the Most-likely Scenario



Source: Authors.

In the ERIA–Likely Scenario as shown in Figure 4.24, hydrogen demand for methanol production increases moderately, in line with the methanol demand discussed earlier. The hydrogen demand in Indonesia, Malaysia, and Brunei rises steadily throughout the period, reflecting their increased methanol consumption.

A new producer emerges by 2030, contributing to the overall growth of hydrogen demand in the region. This addition might be due to the need to serve the emerging green methanol market, particularly as a marine transport fuel. A multinational partnership aims to establish the first green e-methanol plant in Southeast Asia was announced (PTTGC, 2022). The hydrogen demand in the ASEAN region grows from 421.8 kilotons per annum in 2020 to 1,500 kilotons per annum in 2050, with a CAGR of approximately 4% per annum after 2030. The Most-Likely Scenario takes into account potential market saturation and technological advancements that may impact methanol demand, leading to a more moderate growth rate in hydrogen demand for methanol production compared to the APS.

5. Raw Steel Production

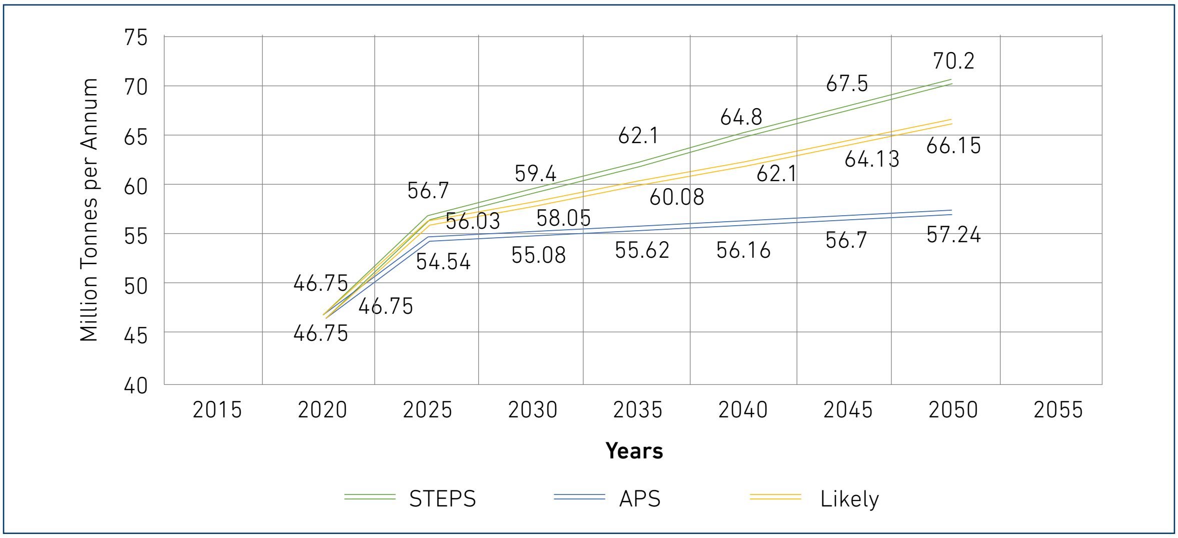
In recent years, ASEAN countries have implemented policies and initiatives to encourage the development of renewable energy sources, such as solar, wind, and hydroelectric power, and to promote the use of these sources in the iron and steel industry. One example of this is the ASEAN Plan of Action for Energy Cooperation, which sets out a framework for the development of renewable energy sources in the region (ACE, 2022b). Another initiative is the ASEAN Centre for Energy, which is a regional intergovernmental organisation that promotes energy cooperation and supports the development of renewable energy sources in the ASEAN region. The centre provides technical assistance, training, and research support for the adoption of renewable energy technologies in the iron and steel industry and other sectors (ACE, 2021a). In addition, many ASEAN countries have implemented their own policies and incentives to promote the use of renewable energy in the iron and steel industry. For example, Indonesia has launched a program to encourage the development of solar power plants in the iron and steel industry, whilst Thailand has provided tax incentives for companies that invest in renewable energy sources (MEMR, 2021b; Asia Pacific Energy, 2015).

The increasing demand for iron and steel for the future as well as the transition to renewable energy is expected to be the right solution without affecting the world's demand for and supply of steel and iron. Renewable energy infrastructure, such as wind turbines and solar panels, requires large amounts of steel and iron for construction. In addition, there is an increasing trend to use sustainable and low-carbon steel production methods, such as hydrogen-based direct reduction iron (DRI) technology. This technology uses renewable energy sources to produce steel, which reduces greenhouse gas emissions and environmental impact.

Hydrogen-based DRI technology is a new and innovative method of producing iron that has been gaining popularity in the iron and steel industry. The process involves using hydrogen gas to reduce iron oxide pellets, producing high-quality iron with low impurity levels, resulting in a cleaner and more sustainable iron production process. Hydrogen gas can be produced from renewable energy sources, such as wind and solar power. The hydrogen gas is then fed into the reduction reactor, where it reacts with iron oxide pellets to produce metallic iron and water vapour. The iron produced through this process has a purity level of up to 98%, making it suitable for use in high-quality steel production. Then, hydrogen-based DRI technology is its low carbon footprint. As it uses renewable energy sources and produces water vapour as the only by-product, it is a clean and sustainable iron production method. It also has a higher energy efficiency compared to traditional iron production methods, reducing energy consumption and costs. In addition, by using renewable energy sources for hydrogen production and incorporating carbon capture and storage (CCS) technologies, the entire iron and steel production process can become more sustainable and environmentally friendly (Ramakgala and Danha, 2019; Kim, 2022). Until now, there has been no steel plant In ASEAN that uses pure hydrogen as a reductant. The current MIDREX or HyL plant uses natural gas, reformed into CO and H2 gases (a mixture of CO and H_2) inside the reformer. The illustration of hydrogen production in this case is shown in Figure 2.34.

Demand for iron and steel will continue to increase to meet the needs of various sectors. Predictions related to iron and steel production, especially in the ASEAN region, can be seen in Figure 4.25. There are various prediction methods used, including the STEPS, APS, and Likely Scenario methods. In each method, iron and steel production reaches around 57.24 million tons per year for the APS, 70.20 million tons per year for the STEPS, and 66.15 million tons per year in 2050. Thus, for meeting the demand for iron and steel and the pressures associated with the renewable energy transition to achieve net-zero emissions by 2050 will be a challenge for countries that produce iron and steel. With this also, the use of hydrogen-based direct reduction iron (DRI) technology will also require increased demand and supply of hydrogen in the future.

Figure 4.25. Demand and Supply of Iron and Steel in the ASEAN Region Using the STEPS, APS, and Likely Scenario Methods



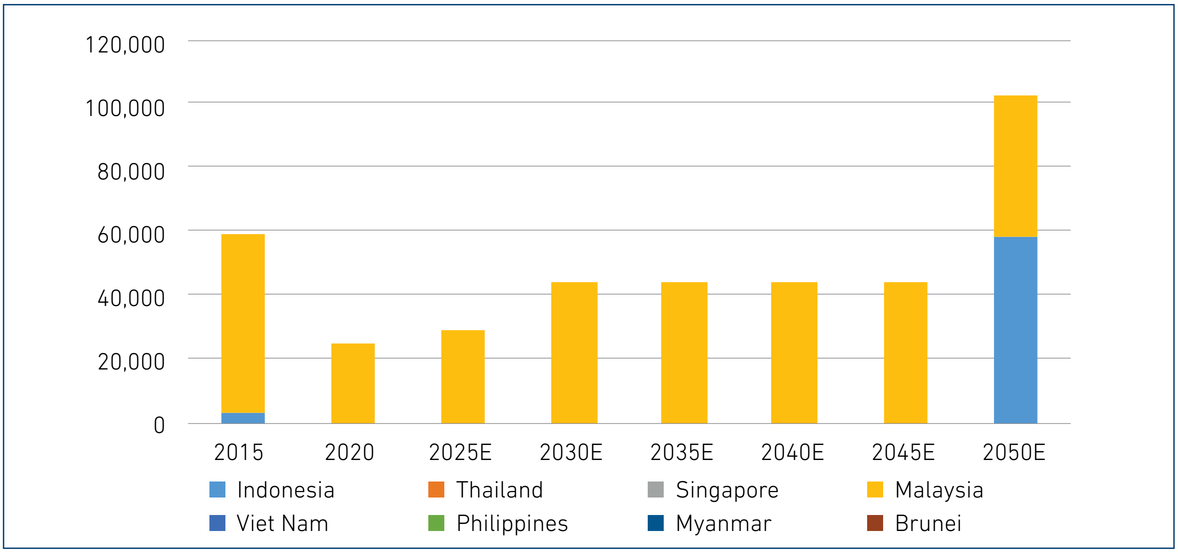
APS = Announced Pledges Scenario, STEPS = Stated Policies Scenario.

Source: Authors.

ERIA–Frozen Scenario

Figure 4.25 shows that in the Frozen scenario, regional demand for hydrogen from the iron and steel industry increases. From 2025E to 2030E, demand for hydrogen will increase at a CAGR of around 8%. Then, the demand for hydrogen will be stable until 2045E and increase again in 2050E with a CAGR of 18%. The high demand in 2050E is supported by Indonesia's high demand for hydrogen in crude steel production.

Figure 4.26. **ASEAN-8 Raw Steel Hydrogen Demand– Frozen Trend (TPA)**

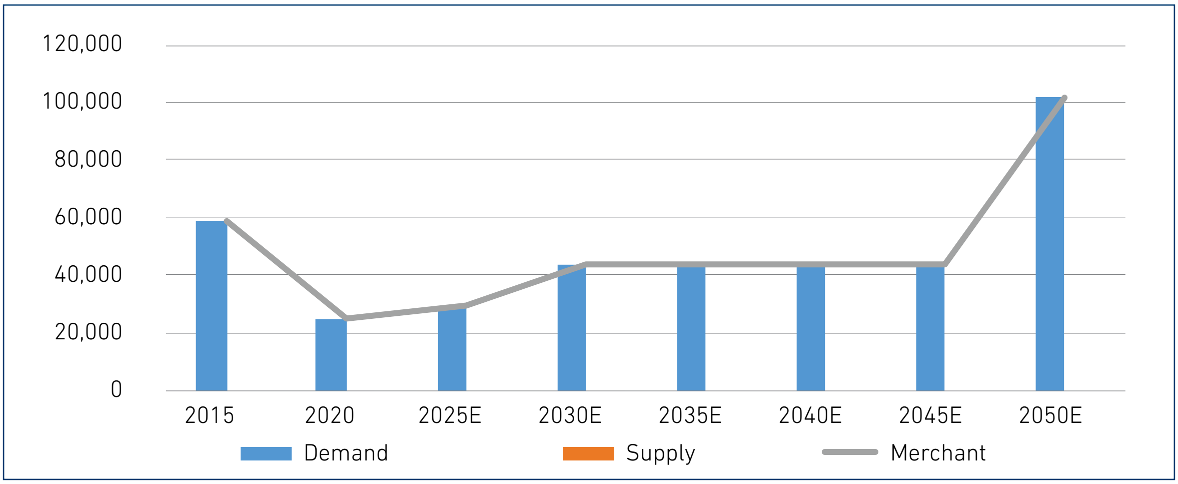


E = estimate, TPA = tons per annum.

Source: Authors.

Figure 4.26 shows the related demand and supply of hydrogen in the raw steel sector under the Frozen scenario. It can be seen that the captive supply is zero from year to year. The supply of traders has increased as well as the demand for hydrogen. Demand and supply of hydrogen in raw steel production is only seen in two countries – Indonesia and Malaysia.

Figure 4.27. **ASEAN-8 Raw Steel Hydrogen Demand-Supply– Frozen Trend (TPA)**



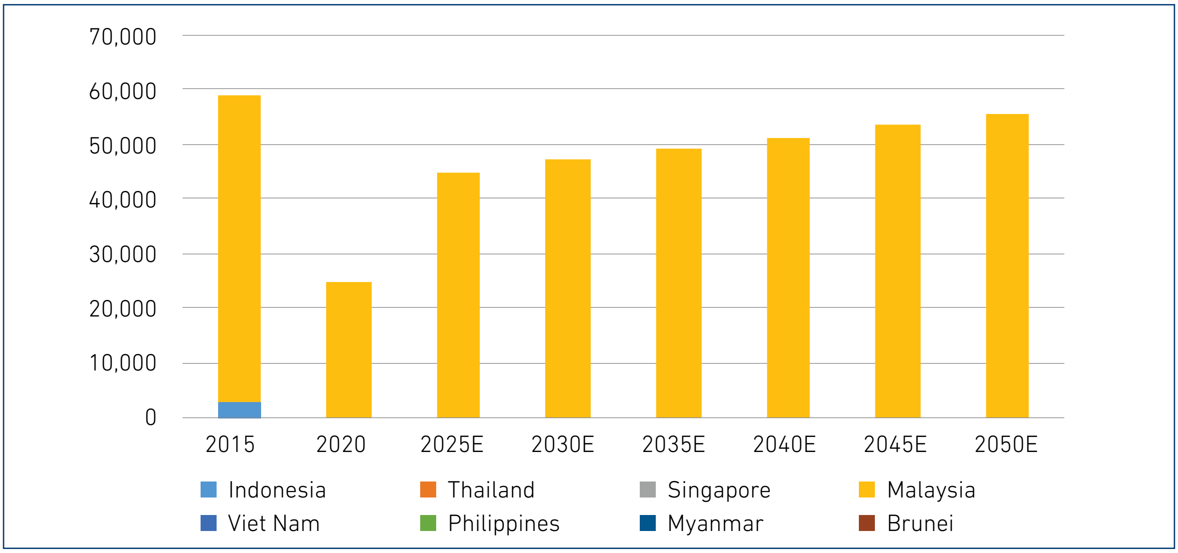
TPA = tons per annum.

Source: Authors.

ERIA–STEPS

Figure 4.28 shows the demand for hydrogen in the raw steel sector using the STEPS. It is estimated that hydrogen demand will increase from year to year with a CAGR of 13% from 2020 to 2025E and a CAGR of 1% from 2025E to 2050E. In this STEPS, it is estimated that Indonesia has demand related to H2 for crude steel production as in the Frozen scenario. Growth in demand for hydrogen will continue to be dominated by Malaysia from year to year.

Figure 4.28. ASEAN-8 Raw Steel Hydrogen Demand– STEPS (TPA)

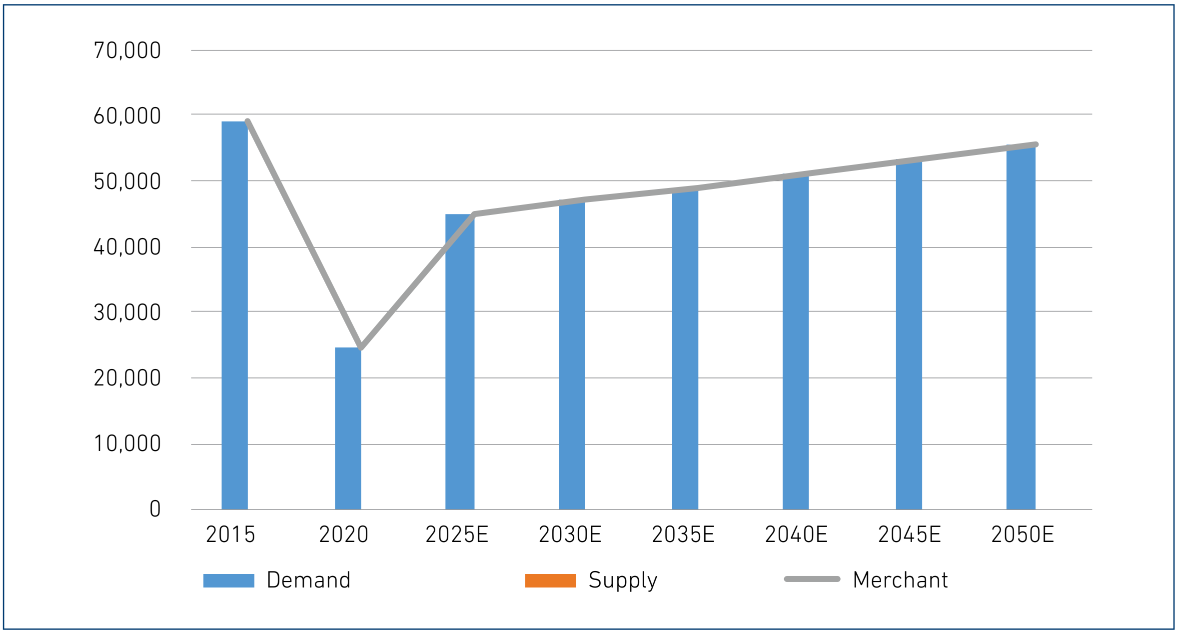


STEPS = Stated Policies Scenario, E= estimate, TPA = tons per annum.

Source: Authors.

Figure 4.29 illustrates the supply and demand for hydrogen in the iron and steel sector using the STEP. In this scenario, the demand for hydrogen will increase year by year. It can be seen that the captive supply is zero year to year. Hydrogen requirements do not rule out the possibility for countries in ASEAN to import to meet hydrogen needs. Merchant supply increases at 1% CAGR from 2025E to 2050E.

Figure 4.29. ASEAN-8 Raw Steel Hydrogen Demand and Supply – STEPS (TPA)



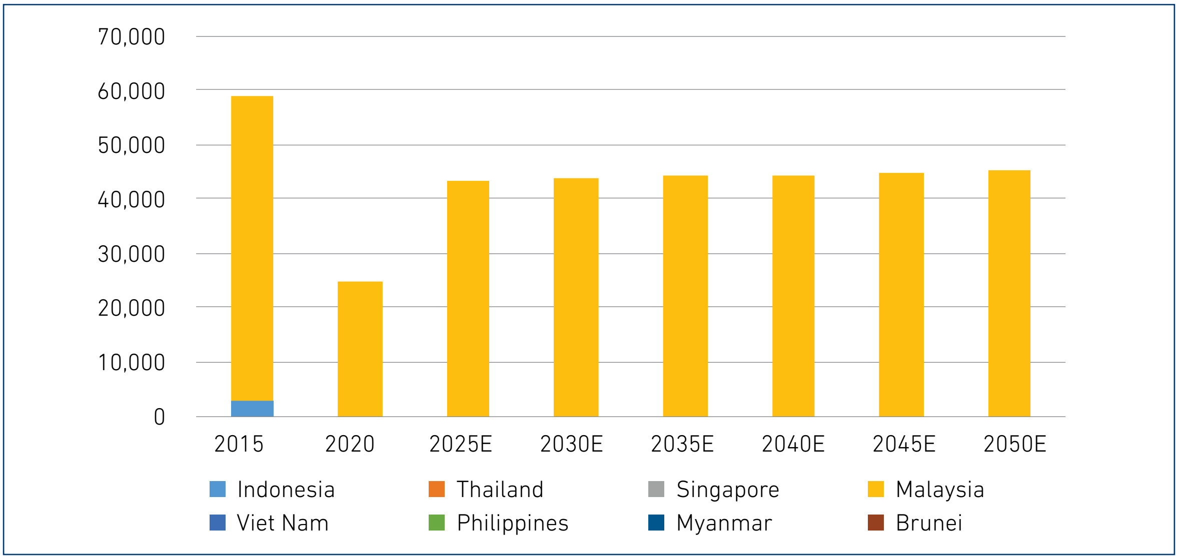
STEPS = Stated Policies Scenario, E= estimate, TPA = tons per annum.

Source: Authors.

ERIA–APS

Figure 4.30 shows data related to hydrogen demand in the raw steel sector using the APS. In this scenario, the demand for hydrogen will increase from year to year until 2050E, where the CAGR from 2025E to 2050E is 0.2%. Hydrogen demand in this scenario has the smallest growth compared to other scenarios. Malaysia is a country with the largest amount of hydrogen demand for raw steel production.

Figure 4.30. SEAN-8 Raw Steel Hydrogen Demand – APS (TPA)

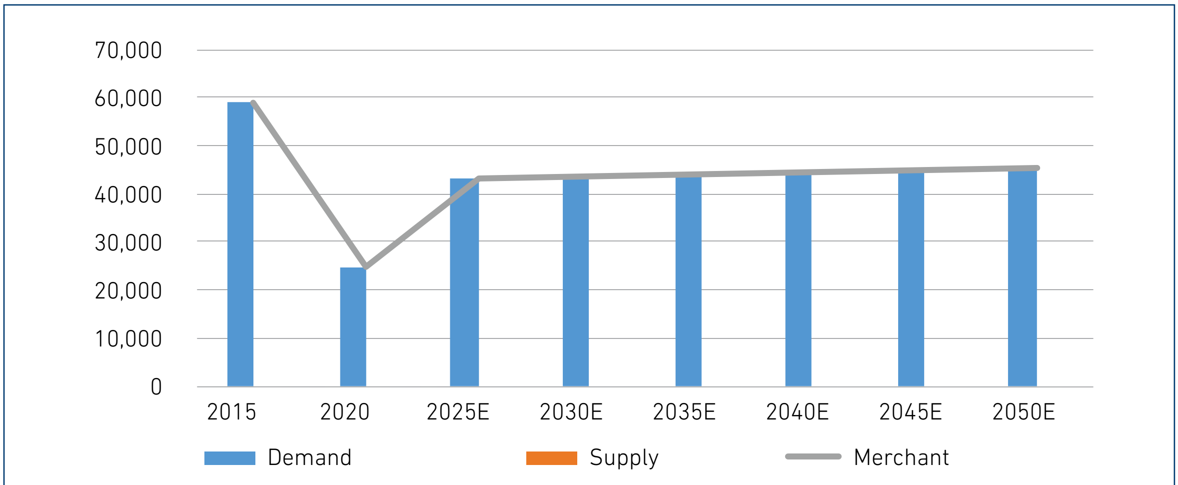


APS = Announced Pledges Scenario, E = estimate, TPA = tons per annum.

Source: Authors.

Figure 4.31 shows data related to demand and supply from the hydrogen scenario with APS in the raw steel production industry. The hydrogen demand in this scenario is the demand with the smallest CAGR compared to other scenarios. The captive supply is assumed to be zero year to year. On the other hand, Merchant supply of hydrogen continues to increase in proportion to the demand for H_2 for raw steel production.

Figure 4.31. ASEAN-8 Raw Steel Hydrogen Demand-Supply – APS (TPA)



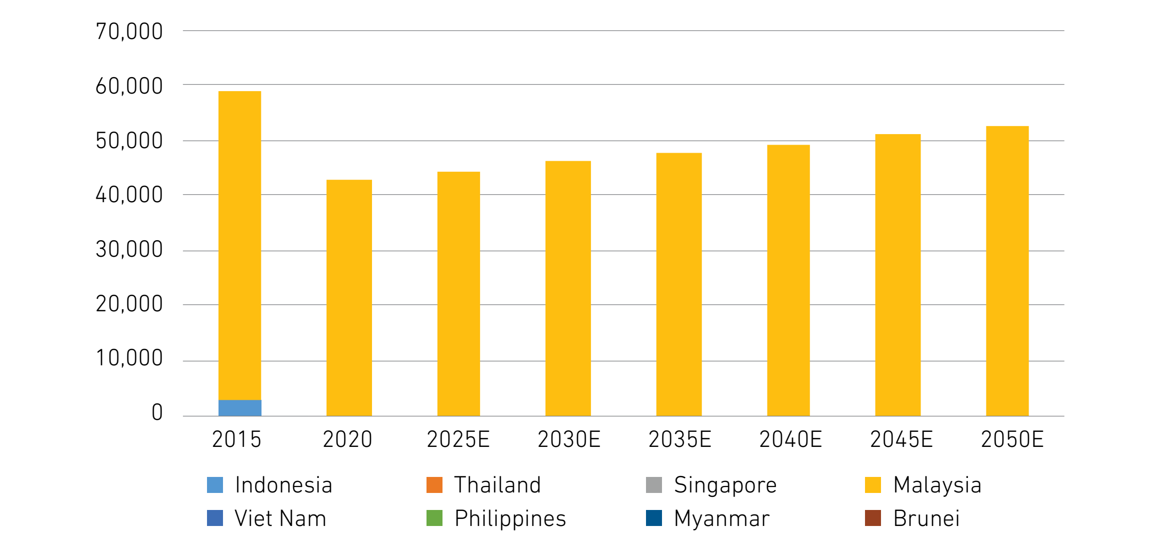
APS = Announced Pledges Scenario, E = estimate, TPA = tons per annum.

Source: Authors.

ERIA–Likely Scenario

Figure 4.32 presents the Likely scenario of regional demand for hydrogen in the iron and steel industry. Demand for hydrogen in this scenario has increased year to year. Hydrogen demand will increase from 2025E to 2050E with a CAGR of 0.7%. Again, the demand for hydrogen in raw steel production is dominated by Malaysia.

Figure 4.32. ASEAN-8 Raw Steel Hydrogen Demand – Likely Scenario (TPA)

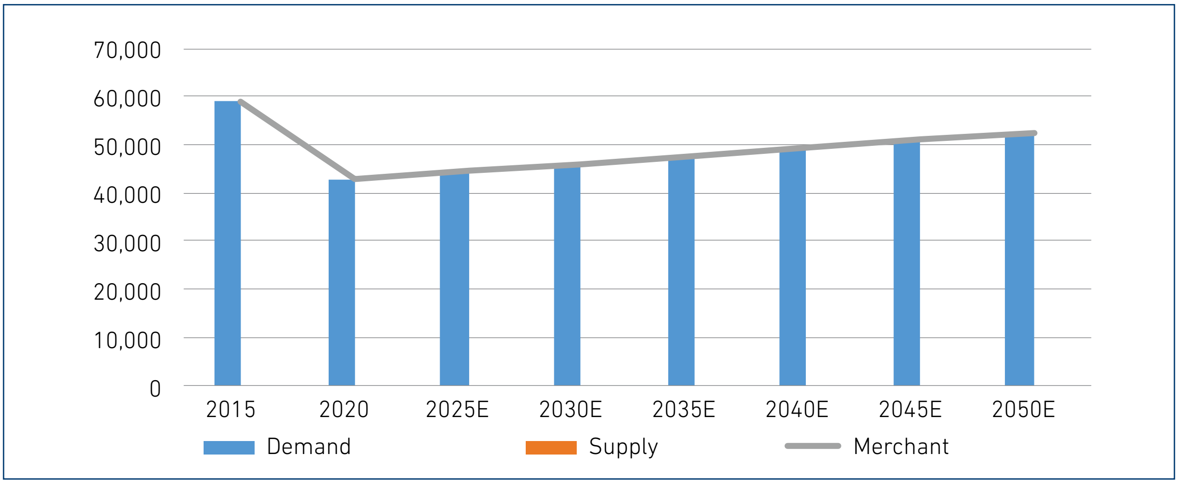


E= estimate, TPA = tons per annum.

Source: ERIA estimates.

Figure 4.33 shows data related to the demand and supply of hydrogen with the ERIA-Likely scenario in the raw steel production industry. Hydrogen demand growth in this scenario obtains a CAGR of 0.7% from 2025E to 2050E. Likewise with the increase in merchant supply from 2025E to 2050E with a CAGR of 0.7%. This scenario also assumes a zero year-to-year supply of captive hydrogen.

Figure 4.33. ASEAN-8 Raw Steel Hydrogen Demand and Supply – Likely Scenario (TPA)



E= estimate, TPA = tons per annum.

Source: Authors.

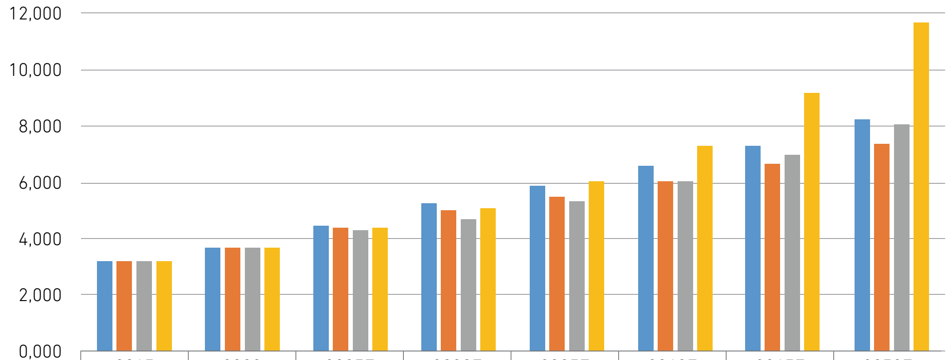
6. Total Hydrogen Demand and Supply for Industry Sector in ASEAN

The ERIA–APS appears to be the scenario where total hydrogen demand for the industry sector in ASEAN will increase the fastest during the simulated 2020–2050 period. As shown in Table 4.3, the CAGR of the hydrogen demand in the ERIA-APS between 2020 and 2050 reaches 3.9%. During the 2020–2030 period, the CAGR of the ERIA–APS is 3.3%, i.e. below ERIA–Frozen Scenario whose CAGR would reach 3.6%. During this period, the need for hydrogen in the oil refining of the ERIA–APS decreases as the use of electric vehicles is getting intensified and at the same time the production of hydrogen needed as feedstock for methanol production for new applications in the energy sector, such as using it as a low-carbon fuel starts to slowly kick in, therefore 2020–2030 ERIA–APS hydrogen demand growth rate is slightly higher than that of ERIA–STEPS (3.1%). The CAGR of the ERIA-APS would take off starting from the 2030–2040 period as the use of hydrogen to produce e-fuels and ammonia carriers start to really take place commercially and this strong CAGR can be expected to continue until the end of the simulation period, i.e. 2050. In the meantime, together with electric vehicles, hydrogen fuelled vehicles, such as fuel cell electric vehicle (FCEV) will also kick in during the 2040–2050 decade which will reduce the need for conventional transport fuel such as gasoline and diesel fuel even more. The share of oil refining's hydrogen demand will drop to reach a level below 10% by 2050.

In this scenario where net-zero emissions targets are assumed to be reached by ASEAN Member States (AMS) by mid 21st century, the hydrogen demand for the industry sector in ASEAN would increase from around 3.7 million tons per annum (MTPA) in 2020 to 11.7 MTPA in 2050. The use of hydrogen as energy carrier as feedstock to produce e-methanol, ammonia fuels, and e-kerosene is the main driving factor of this fast growth and the used hydrogen in this scenario must be low-carbon (intensity) hydrogen and only the use of low-carbon hydrogen will lead to net-zero emissions.

As shown in Table 4.3, the CAGR of the hydrogen demand in the ERIA-APS between 2020 and 2050 reaches 3.9%. During the 2020–2030 period, the CAGR of the ERIA–APS is 3.3%, i.e. below ERIA–Frozen Scenario whose CAGR would reach 3.6%. During this period, the need for hydrogen in the oil refining of the ERIA–APS decreases as the use of electric vehicles is getting intensified and at the same time the production of hydrogen needed as feedstock for methanol production for new applications in the energy sector, such as using it as a low-carbon fuel starts to slowly kick in, therefore 2020–2030 ERIA–APS hydrogen demand growth rate is slightly higher than that of ERIA–STEPS (3.1%). The CAGR of the ERIA-APS would take off starting from the 2030–2040 period as the use of hydrogen to produce e-fuels and ammonia carriers start to really take place commercially and this strong CAGR can be expected to continue until the end of the simulation period, i.e. 2050. In the meantime, together with electric vehicles, hydrogen fuelled vehicles, such as fuel cell electric vehicle (FCEV) will also kick in during the 2040–2050 decade which will reduce the need for conventional transport fuel such as gasoline and diesel fuel even more. The share of oil refining's hydrogen demand will drop to reach a level below 10% by 2050.

Figure 4.34. Total Hydrogen Demand for Industry Sector in ASEAN by Scenario (million tons per annum)



	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ERIA-Frozen Scenario	3,216	3,657	4,445	5,212	5,830	6,520	7,302	8,227
ERIA-STEPS	3,216	3,657	4,367	4,961	5,444	5,990	6,610	7,319
ERIA-Likely Scenario	3,216	3,657	4,245	4,687	5,272	6,009	6,933	8,088
ERIA-APS	3,216	3,657	4,406	5,060	5,978	7,292	9,130	11,669

ERIA-Frozen Scenario ERIA-STEPS ERIA-Likely Scenario ERIA-APS

APS = Announced Pledges Scenario, E = estimate, STEPS = Stated Policies Scenario.

Source: Authors.

Table 4.3. Compound Annual Growth Rate of Hydrogen Demand for Industry Sector in ASEAN by Period and Scenario

Scenario	2015–2020	2020–2030	2030–2040	2040–2050	2020–2050
ERIA-Frozen	2.61%	3.61%	2.26%	2.35%	2.74%
ERIA-STEPS	2.61%	3.10%	1.90%	2.02%	2.34%
ERIA-Likely	2.61%	2.46%	2.52%	3.02%	2.66%
ERIA-APS	2.61%	3.30%	3.72%	4.81%	3.94%

APS = Announced Pledges Scenario, STEPS = Stated Policies Scenario.

Source: Authors.

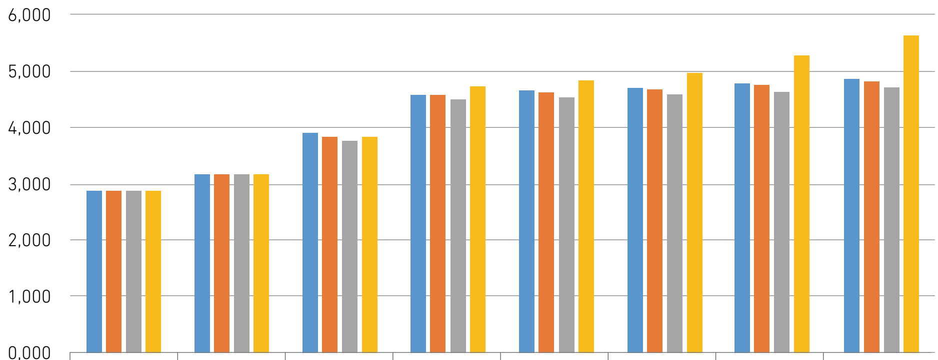
It is interesting to remark how close the 2050 total hydrogen demand of ERIA-Frozen and ERIA-Likely scenarios appears. It is the composition and sequence of the two scenarios that matters. In the ERIA-Likely scenario, traditional demand in oil refining, ammonia, and methanol industries decrease over the simulated period but demand for ammonia for energy carrier and methanol e-fuels overcompensates. Between 2020 and 2030, the CAGR of the total hydrogen demand in ERIA–Likely is lowest of all scenarios as traditional hydrogen demand, especially in oil refining due to the mobility electrification declines, whilst at the same time ammonia-energy and e-fuels technology have not been introduced yet. During the same period, the ERIA–Frozen scenario's hydrogen demand, grows faster as traditional demand for hydrogen such as in oil refining increases strongly. The hydrogen demand growth in the ERIA–Likely scenario is expected to catch up relative to ERIA–Frozen starting from 2030–2040 as the use of e-fuels and ammonia carriers start to contribute to decarbonisation. Therefore, even if in term of total hydrogen demand, the two scenarios, ERIA–Frozen and ERIA–Likely reach about similar levels by 2050, carbon emissions in the ERIA–Likely decrease much more significantly than in the ERIA–Frozen scenario.

The ERIA–STEPS is the scenario where hydrogen demand in the industry sector in ASEAN grows with the weakest CAGR, i.e. 2.3% during the 2020–2050 period. This slow growth results in the weakest hydrogen consumption by 2050 compared to other scenarios, i.e. 7.3 million MTPA or less than two-thirds of hydrogen demand in the ERIA–APS. This is caused by two factors. The first factor is the reduction of hydrogen use in oil refining due to the limited mobility electrification and the second one is the very limited use of hydrogen in the production of e-fuels and ammonia carriers. In this scenario, no significantly impacting policy measure is implemented in the ammonia, methanol, and iron and steel industries so that the changes in the total hydrogen demand is mainly caused by the changes in the oil refining sector.

6.1. Total Hydrogen Production

Total hydrogen produced onsite in the four scenarios is shown in Figure 4.35. Hydrogen production will increase in all four scenarios, with ERIA–APS being the scenario where hydrogen produced in the four sectors shall increase at the fastest rate from around 3.2 MTPA of hydrogen in 2020 to 5.6 MTPA of hydrogen in 2050. This means that the produced hydrogen in this ERIA–APS follows the growth of demand which is also the fastest. On the other hand, the ERIA–Likely scenario is the scenario where hydrogen produced in the four sectors grows at the slowest rate, i.e. from 3.2 MTPA in 2020 to 4.6 MTPA in 2050.

Figure 4.35. Total Hydrogen Production in Industry Sector in ASEAN by Scenario (million tons per annum)



	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ERIA-Frozen Scenario	2,844	3,148	3,826	4,554	4,612	4,677	4,750	4,833
ERIA-STEPS	2,844	3,148	3,805	4,542	4,591	4,645	4,706	4,773
ERIA-Likely Scenario	2,844	3,148	3,696	4,474	4,509	4,554	4,608	4,671
ERIA-APS	2,844	3,148	3,812	4,658	4,782	4,968	5,229	5,587

ERIA-Frozen Scenario ERIA-STEPS ERIA-Likely Scenario ERIA-APS

APS = Announced Pledges Scenario, E= estimate, STEPS = Stated Policies Scenario.

Source: Authors.

The ratios or proportions of onsite or captive hydrogen production to the total hydrogen demand in the industry sectors increase from 2020 to 2030 and then decrease to the horizon 2050. By 2020, the ASEAN ratio of the onsite and/or captive production to the total hydrogen demand was recorded at around 86%. By 2030, the ratio varies from 87.5% in the ERIA–Frozen scenario to more than 95% in the ERIA–Likely. By 2050, these ratios range from around 58% in ERIA–Frozen and ERIA–Likely scenarios to around 65.2% in the ERIA–STEPS.

The relatively low onsite and/or captive hydrogen production in the ERIA–Likely scenario after 2030 compared to other scenarios is presumably caused by the need to produce low-carbon hydrogen to meet higher hydrogen demand in the industry sector in the scenario in comparison to ERIA–Frozen scenario and ERIA–STEPS. The need for hydrogen feedstock to produce e-fuels and ammonia carriers in the ERIA–Likely scenario starts to kick-in after 2030 but the quantity is less than in ERIA–APS so that the economy of scale of producing low carbon hydrogen is not high enough to decrease low-carbon hydrogen prices. Therefore, the onsite and/or captive of (low-carbon) hydrogen production in the ERIA–Likely scenario becomes lower than in ERIA–Frozen and ERIA–STEPS, the two scenarios where carbon intensities of hydrogen are higher.

On the other hand, the ratios of onsite production to hydrogen demand in the ERIA–APS are the highest. What happens in this scenario is the strong increase of hydrogen demand as feedstock that triggers an economy of scale high enough to reduce the low carbon hydrogen price.

6.2. Supply from Merchants

As shown in Table 4.4, the role of hydrogen merchants in the ASEAN industry sector will become more important after 2030 as the demand for hydrogen will grow but supply from onsite and/or captive production and by-products are yet to be announced.

The first source of growth is the ammonia sector where supply from onsite production and by-products increases only until 2030 and then remains at the same level between 2030 and 2050 regardless of the scenarios. The oil refining sector is generally less dependent on hydrogen supplied by merchants, whilst the methanol sector shows an important increase only in the ERIA-APS. Iron and steel and chemical industries on the other hand are often dependent on supply of hydrogen from merchants.

Decarbonisation imperative grows from ERIA–STEPS to ERIA–Likely to ERIA–APS, which is followed by the increasing share of supply from the merchants. The increasing merchant supply therefore indicates the important roles expected from the hydrogen merchants to supply low-carbon hydrogen.

Table 4.4. Part of Supply from Merchant in Total Hydrogen Demand in Industry Sector in ASEAN

Scenario	2015	2020	2025E	2030E	2035E	2025E	2025E	2025E
ERIA-Frozen	5.3%	8.0%	7.6%	5.1%	11.1%	16.5%	21.3%	26.2%
ERIA-STEPS	5.3%	8.0%	6.7%	1.0%	7.7%	13.9%	19.9%	25.5%
ERIA-Likely	5.3%	8.5%	7.2%	1.8%	12.3%	22.3%	31.7%	40.3%
ERIA-APS	5.3%	8.0%	7.7%	3.2%	17.1%	30.0%	41.2%	50.5%

APS = Announced Pledges Scenario, E= estimate, STEPS = Stated Policies Scenario.

Source: Authors.

7. Potential Carbon Emissions from Hydrogen Production and Supply from Merchants

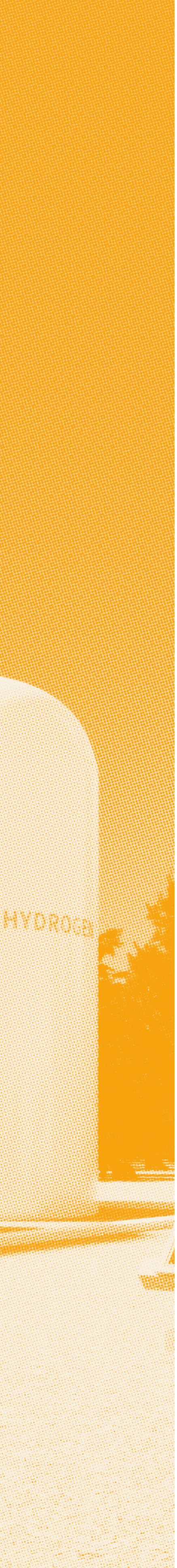
Looking only at hydrogen demand and supply might hide the significance of the composition of the demand and supply forecasts from the perspective of hydrogen uses and their sequence that are essential in analysing their impacts on carbon emissions. One of the examples that has already been shown briefly in the previous section are the very similar mid-century total hydrogen demand estimates under the ERIA–Frozen and ERIA–Likely scenarios. These hide the fact that fundamental hydrogen demand composition and sequences should result in very different patterns of CO_2 emissions under these scenarios.

Different emissions factor or emission intensity estimates are available to calculate carbon dioxide emission from grey hydrogen production routes. For example, Bassani et al. (2020) estimate that 1 kg of hydrogen production from SMR should emit 7 kg of CO_2, while the average emission intensity of global hydrogen from the use of unabated natural gas ranges around 10–13 kg CO_2 eq per kg H_2 according to IEA (2023). Taking these values, ASEAN's 2020 hydrogen demand (and supply) would emit up to 48 million tons of CO_2-eq. Assuming that hydrogen continue to be produced from unabated natural gas, emissions under the ERIA Frozen scenario should reach 107 tons of CO_2-eq by 2050.

IEA (2023) estimates that the use of partial oxidation of natural gas with carbon capture and storage (CCS) will bring down the emission intensities to reach 0.8–4.6 kg CO_2 eq per kg H_2. IEA's Announced Pledges Scenario (APS) and Net-Zero Emissions (NZE) by 2050 Scenario see levels of emission intensities in 2050 of 3 kg CO_2 eq per kg H_2 and under 1 kg CO_2 eq per kg H_2, respectively by 2050E.

By 2050, ERIA–APS should be the scenario that reaches the lowest average emissions factor or intensity followed by the ERIA–Likely scenario and then ERIA–STEPS as more hydrogen uses that require low- or lower carbon intensive hydrogen will penetrate the strongest in ERIA–APS followed by ERIA–Likely scenario and then ERIA–STEPS. However, the quantification of emissions will need a more detailed description of the sequence of the appearance of those uses and a dissection of hydrogen production routes in each of the scenarios that are beyond the scope of this study.


H2
HYDROGEN
H2



Chapter 5

Hydrogen Economics for Southeast Asian Industries

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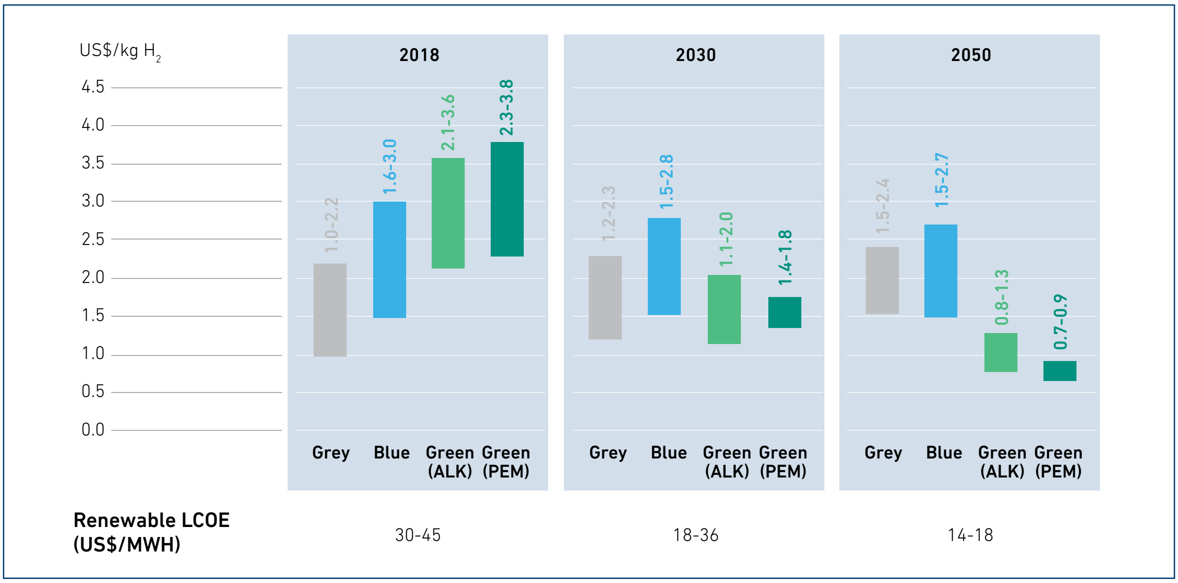
In this chapter, the economics of hydrogen across industries such as ammonia, refineries, methanol, and steel are discussed. Following a summary of current and future hydrogen business models and applications across these sectors, the economics of several production, storage, and transport alternatives are examined. The comparative economic analysis allows formulating potential hydrogen development pathways for these key industries across the relevant ASEAN countries.

1. Global Hydrogen Economics

The majority of hydrogen currently used as feedstock for ammonia and methanol in Southeast Asia is produced via steam methane reforming (SMR). In the region's major refining centres, SMR hydrogen is produced simultaneously with captive hydrogen from reforming and platforming and by products from various refining processes. By contrast, the steel industry still relies mainly on traditional basic oxygen furnace technology. Considering medium- and long-term process optimisation, technology synergies and scale effects, Figure 5.1 demonstrates the current cost advantage of SMR versus blue and green hydrogen alternatives, which is expected to reverse by 2040E–2050E (IESR, 2022b).

Figure 5.1. Hydrogen Cost by Production Type



ALK = alkaline, LCO = levelized cost of electricity, PEM = proton exchange membrane, US$/MWh = US dollars per megawatt hour.

Source: IESR (2022b).

Electrolyser costs are thus expected to decrease due to learning and economy of scale, reaching US$200–US$300 per kW by 2030E. The cost of electricity makes up 30%–60% of hydrogen levelized cost of energy (LCOE). As a result, when the LCOE of solar and wind power decreases to US$20 per MWh by 2030E, the cost of green hydrogen will fall to US$1.1–US$2 per kg by 2030E (IESR, 2022b). By 2050E the cost of green hydrogen could fall below US$1 per kg, with proton exchange membrane (PEM) electrolysis being even cheaper than alkaline electrolyser costs by then.

Other studies reach similar results with regard to the cost competitiveness of various hydrogen production pathways in Southeast Asia. Li and Taghizadeh-Hesary (2020) compare the cost of green hydrogen production and supply versus lithium batteries and pumped hydropower for road transport fuel applications. Similar cost comparison results are observed by Li et al. (2023), who study hydrogen production and supply for power generation via hydrogen fuel cells or mixed combustion in coal or gas power plants. As will be elaborated in section 5.4, these studies combine green hydrogen production technologies with various storage and transport alternatives to derive reasonable estimates of landed, i.e. onsite hydrogen costs. For electrolysis hydrogen, both studies compare the use of selected countries' electricity grids, solar photovoltaic (PV), wind, and geothermal, and assume curtailment to take advantage of the variability in renewable power generation (Chang and Han, 2021). The storage and transport solutions include technologies from gas pipelines, compressed hydrogen trucks and ships, liquid hydrogen shipping, compressed hydrogen trucks and ships, and liquid organic hydride trucks and ships.

2. Global Green Ammonia, Methanol, and Steel Economics

Neuwirth and Fleiter (2020) report on their studies of the potential of and production cost estimates for green hydrogen in the German chemical industry. Assuming electricity prices of EUR0.05/kWh and onsite alkaline electrolysis technology the authors estimate the production costs of hydrogen, ammonia and methanol between 2020, 2030E, and 2050E to reach levels as summarised in Table 5.1.

Table 5.1. Hydrogen, Ammonia, and Methanol Production Costs in Germany

Product	Parameter	Technology	Unit	2020	2030E	2050E
Hydrogen	CAPEX	SMR Electrolysis	EUR/kWh	710 1,100	710 700	710 300
	Production costs	SMR Electrolysis	EUR/kg	2.0 3.4	2.0 3.2	2.0 2.8
Ammonia	CAPEX	SMR Electrolysis	EUR/kW	870	830	750
	Production costs	SMR Electrolysis	EUR/ton	960 1,250	960 1,170	960 1,030
Methanol	CAPEX	Methanol synthesis	EUR/kW	750	730	700
	Production costs	SMR Electrolysis	EUR/ton	1,120 1,340	1,120 1,280	1,120 1,120

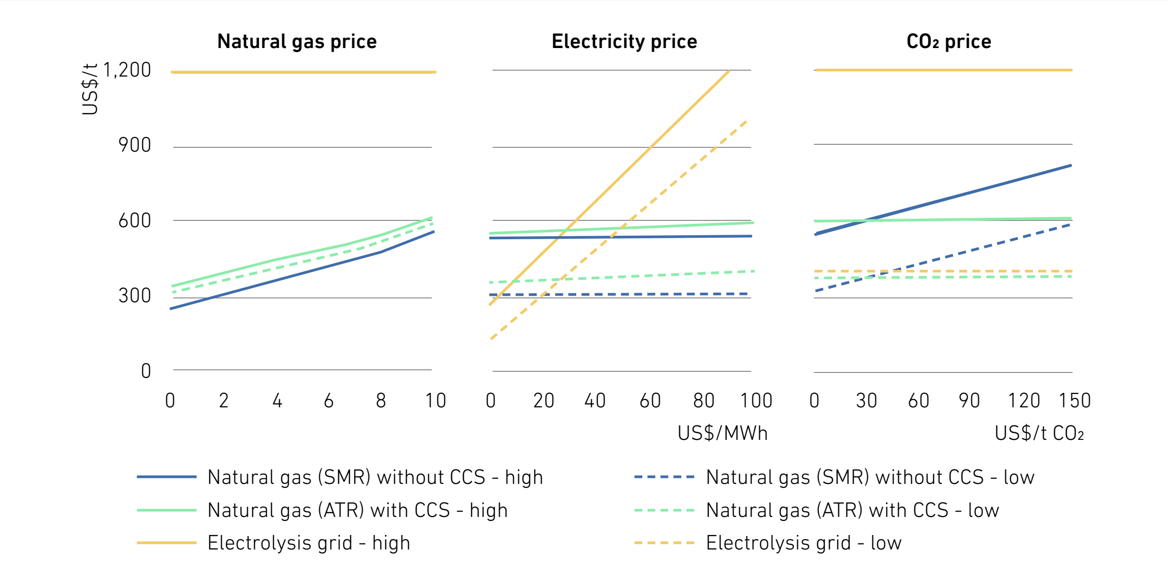
Capex= capital expenditure, E = estimate, kg = kilogramme, kW = kilowatt, SMR = steam methane reforming.

Source: Neuwirth and Fleiter (2020).

Neuwirth and Fleiter (2020) calculate the 2020 production cost of green ammonia in Germany to be around EUR1,250 per ton, higher than SMR-based production costs of about US$960 per ton. They anticipate the cost of green ammonia to decline to US$1,030 per ton in 2050, as economy of scale and learning gain importance.

By comparison, IEA's Ammonia Technology Roadmap (2021b) estimates green and blue hydrogen-based ammonia production costs to depend very much on electricity, i.e. energy costs and technology capital expenditures (CAPEX), as well as on future carbon prices. Figure 5.2 shows that SMR with and without CCS is still cheaper than green hydrogen, even at moderate natural gas prices and low carbon prices.

Figure 5.2. Levelized Cost of Ammonia Production



ATR = autothermal reforming, CCS = carbon capture and storage, SMR = steam methane reforming.

Source: IEA (2021b).

IEA (2021b) observes that the US$600 per ton production cost of blue hydrogen-based ammonia breaks even with SMR hydrogen at a carbon price of about US$30 per ton. Moreover, electrolysis-based ammonia production cost ranges from US$600–US$1,200 per ton, depending on electricity and electrolyser costs. Green hydrogen is clearly more likely to be competitive with SMR when electricity prices are low, natural gas prices are high and electrolyser costs low. Nevertheless, even at low electrolyser costs, electricity costs of lower than US$0.04 per kWh are required to render green hydrogen competitive. Moreover, electrolyser costs must decline by 60% to reach about US$400 per kW electrolyser capacity costs to become comparable to the level of grey hydrogen. By contrast, according to IEA's Global Hydrogen Review (2021a), Hydrogen Council and McKinsey & Company (2022), and IRENA (2020), electrolyser CAPEX estimates still range from about US$1,000 per kW to US$1,750 per kW. Only in 2030E is electrolyser system CAPEX expected to fall to US$230–US$380 per kW. Nevertheless, uncertainties in technology innovation affects the feasibility and timing of the necessary cost reductions (IEA, 2021b).

More recently, Egerer et al. (2023) estimate the cost of ammonia produced via a hybrid solar PV and wind powered electrolyser in Australia and its transport to Germany. The goal is to reconvert the carrier ammonia into hydrogen, the feedstock and fuel of interest. If one strips away the overseas transportation and storage costs, the authors' estimate of the cost of carrier green ammonia sums up to approximately EUR509 per ton (Egerer, et al., 2023). This production cost includes EUR458 per ton of solar PV and wind electricity generation plus a small amount of EUR51 per ton of ammonia synthesis costs.

When it comes to methanol, the study by IRENA and Methanol Institute (2021) estimates current production costs of green methanol to be in the range of US$800–US$1,600 per ton, the upper bound being the case of bioenergy with CCS, or up to US$1,200–US$2,400 per ton in case of CO_2 from direct air capture. Table 5.2 depicts selected production cost estimates fort green methanol based on the choice of renewable power for electrolysis, the choice of carbon to be captured and capacities.

Table 5.2. Selected Studies on Methanol Production Cost by Carbon and Electricity Sources

Carbon source	Electricity source	Electricity US$/kWh	Carbon cost US$/ton	Capacity TPA	CAPEX US$/TPA	OPEX US$/ton	Carbon cost US$/ton
Flue gas	Renewable energy	0.01–0.06	44	1.8 million	1,385–2,770		430–910
CPP flue gas	Grid/renewable energy	0.11–0.13	0	440,000	1,260	740	805
CPP flue gas	Grid/renewable energy	0.044	43	110,000			645
Purchased	Grid	0.024-0.073	59	100,000	1,340		365–826
Flue gas	Renewable energy	0.03		100,000	620	880	810–1,190
Flue gas	Grid			4,000-50,000	1,670–2,780		555–780

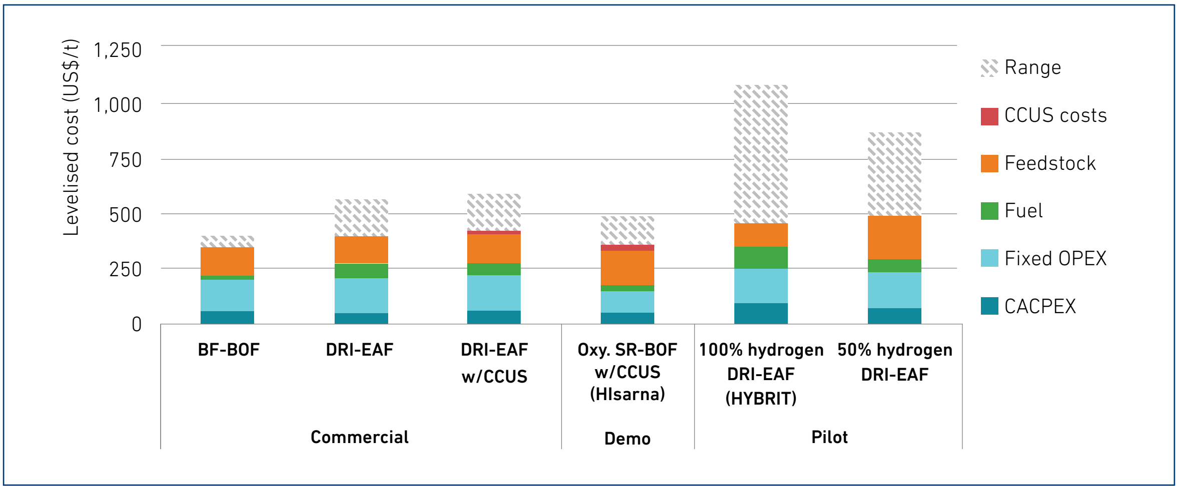
CAPEX = capital expenditure, CPP = coal-fired power plant, kWh = kilowatt per hour, OPEX = operating expenses, TPA = tons per annum.

Source: Adapted from Table 21 in IRENA and Methanol Institute (2021), p.77.

The studies listed in Table 5.2 estimate grid-electricity-based methanol production costs in the range of US$830 per ton, whilst the corresponding production costs for green methanol vary around US$650–US$1,190 per ton. Only the largest 1.8 million tons green methanol plant is estimated to come close to the grid-electricity-based costs. One thus observes that currently the main barrier to green methanol is its higher cost compared to SMR. The IRENA and Methanol Institute study (2021) anticipates decreasing renewable power prices, with green methanol production costs reaching US$250–US$630 per ton by 2050. Noteworthy are also methanol production cost estimates of around US$300–US$1,300 per ton (IEA, 2019).

Not unlike ammonia and methanol, IRENA (2022) estimates that investment and operating costs for DRI steelmaking are 30%–50% higher compared to the traditional SMR route. Particularly the electricity costs will be the key factor determining the future competitiveness of green hydrogen-based DRI. Early estimates were also made by IEA's *The Future of Hydrogen* (IEA, 2019), as can be seen in Figure 5.3, where steel production costs for 50%–100% DRI–EAF reach almost double the hitherto SMR-based, even including CCUS.

Figure 5.3. Estimated Costs of Steel (2018)



Notes: Oxy. SR-BOF = oxygen-rich-smelt reduction. CCUS costs includes the costs of capturing, transporting and storing CO_2. Range refers to the range of total levelised costs across regions, with the lower end of the range disaggregated for each technology. An availability factor of 95% is applied to all equipment and an 8% discount rate is used throughout. It is assumed that the electrolysis route is supplied with 100% renewable electricity. Natural gas-based and 100% hydrogen-based DRI-EAF considers 95% DRI charge to the EAF. More information on the assumptions is available at www.iea.org/hydrogen2019.

BF–BOF= blast furnace–basic oxygen furnace, CAPEX = capital expenditure, CCUS = carbon capture utilisation and storage, DRI–EAF = direct reduced iron–electric arc furnace, OPEX = operating expenses, Oxy. SR–BOF = oxygen-rich smelt reduction.

Source: IEA (2019).

3. Green Hydrogen Transition in Southeast Asia

According to IEA (2021a) up to 850 GW of aggregate renewable electricity capacity is required to produce the world's demand for 80 MTPA green hydrogen by 2050. The hydrogen supply required to feed a midsize 400 KTPA ammonia or 600 KTPA methanol plant ranges from approximately 75 to 85 KTPA. Southeast Asia's largest refineries in Indonesia, Thailand, and Singapore produce approximately 30–70 KTPA of hydrogen, net of their own captive hydrogen from reforming and platforming processes, hitherto supplied by their own captive SMR. We shall show below that to supply these industrial facilities requires about 1,000–2,200 megawatts (MW) single-site, dedicated peak solar PV generation capacity, and up to 700–1,500 MW of electrolyser capacity.

In the Pacific region Australia, China, and the Republic of Korea are currently planning GW-scale single site electrolyser facilities. To date not sufficiently large single-site solar PV, wind, or geothermal electricity generation capacity exist in Southeast Asia. Amongst the announced GW-scale solar PV projects in the region are the Singapore's Sunseap's plans for up to 7 GW capacity around the Indonesian Riau Islands, which include a 2.2 GW floating solar PV project in Batam Island, Australia's ReNu, and Anantara's 3.5 GW project in Riau. Li et al. (2023) quotes the ASEAN Centre for Energy's (ACE, 2020a) 6th ASEAN outlook for renewable electricity generation capacity in the region as summarised in Table 5.3. Thus, significant production, storage, and transport capacity expansion and investments are required.

Table 5.3. Current and Projected Installed Renewable Capacity in ASEAN

Renewable Energy (GW)	2020	2030	2040
Hydro	59.4	81	132
Solar	22.9	31	56
Wind	2.7	7	14
Geothermal	4.1	10	17
Biomass, biogas, waste	6.4	14	23

GW = gigawatt.

Sources: Li et al. (2023) and ACE (2020a).

A transition towards decarbonised hydrogen in industry can be expected to follow a path of staggered blue and green production and infrastructure development. Initially, the more incremental increase in CAPEX and operating costs (OPEX) of introducing CCS technology limits the loss in competitiveness and moderates any fiscal support necessary to incentivise and support the large industrial users and gas merchants. Fossil fuel companies are anticipated to favour the blue hydrogen route, at least in the near term, as we shall discuss in the next chapter. By contrast, the development of green hydrogen production and infrastructure projects will be much costlier and will require significant participation of the electricity sector, as the required power generation capacities will be larger than many solar PV, wind, geothermal, and other renewable power projects hitherto built or planned, even in industrialised Europe and North America. Therefore, whilst government and industry are working on multiple CCS projects across the region, plans must be made to initiate and implement several flagship green hydrogen projects to gain economy of scale and critical mass in green hydrogen production, storage and transport infrastructure, to help kickstart the green transition for all major hydrogen-consuming sectors.

Beyond replacing grey with blue and green hydrogen for the traditional industrial feedstock applications, the ERIA–APS and ERIA–Likely scenarios introduce the utilisation of green hydrogen via green ammonia as energy carrier for storage and transport as well as complementary fuel for coal and natural gas combined cycle power generation. Moreover, in future decarbonisation scenarios, methanol can be used a feedstock for e-fuels, to replace traditional higher emission diesel and gasoline across road transport applications.

4. Economics of Hydrogen in ASEAN

Several studies have analysed potential green hydrogen production, and storage and transport costs in Southeast Asia. The most important cost component is the renewable electricity cost. The solar PV electricity prices that Li and Taghizadeh-Hesary (2020) assume a range from US$0.04 per kWh in Indonesia and Malaysia, US$0.038 per kWh in Thailand, and US$0.041 per kWh in Viet Nam. These electricity costs contrast to Li et al.'s (2023) higher estimated solar PV electricity prices of US$0.165 per kWh in Indonesia, US$0.108 per kWh in Malaysia, US$0.145 per kWh in Thailand, and US$0.092 per kWh in Viet Nam (Table 5.4).

Table 5.4. Cost of Electricity (2020 US$)

Country	Grid Electricity (US$/kWh)	Solar PV (US$/kWh)	Wind (US$/kWh)	Hydropower (US$/kWh)	Woody Biomass (US$/kg)	Gasoline (US$/litre)	Diesel (US$/litre)	Natural Gas (US$/MMBtu)	Coal (US$/kg)[c]
Brunei Darussalam	0.069	0.118	NA	NA	NA	1.44	1.21	8.3	N.A.
Cambodia	0.202	0.087	0.147	0.046	NA	0.87	0.64	10.7	0.091
Indonesia	0.063	0.165	0.146	0.046	0.042	0.65	0.7	5.6	0.094
Lao PDR	0.124	0.111	0.186	0.046	NA	0.94	0.79	8.3	0.091
Malaysia	0.11	0.108	0.135	0.046	0.035	0.39	0.42	8.2	0.103
Myanmar	0.125	0.079	0.111	0.046	NA	0.53	0.46	8.3	N.A.
Philippines	0.12	0.117	0.128	0.046	0.058	0.99	0.69	10.7	0.091
Singapore	0.156	0.123	N.A.	N.A.	0.042	1.44	1.21	8.6	N.A.
Thailand	0.087	0.085	0.145	0.046	0.042	0.98	0.66	10.7	0.091
Viet Nam	0.101	0.087	0.092	0.046	0.020	0.64	0.47	8.3	0.102

g = kilogramme, kWh= kilowatt hour, MMBtu = metric million British thermal unit, NA = not available.

Source: Adopted from Table 6 of Li et al. (2022), p.7.

According to Li et al. (2023) regional grid and wind power prices are higher than solar PV except in Indonesia, where grid prices are subsidised. By contrast, hydropower and woody biomass prices are generally lower. Additionally, the Institute for Essential Services Reform (IESR) (2022b) uses Ministry of Energy and Mineral Resources (MEMR) data to estimate renewable electricity costs in Indonesia of US$0.07–US$0.16 per kWh (for onshore wind), US$0.06–US$0.10 per kWh (large scale solar PV), US$0.05–US$0.09 per kWh (geothermal) and US$0.05–US$0.11 per kWh (biomass). We thus estimate the resulting costs of green hydrogen in Southeast Asia in three ways:

4.1. IESR (2022b) and IEA (2019)

IESR (2022b) combines MEMR electricity costs with IEA's (2019) electrolyser cost, efficiency, and stack lifetime assumptions to compare green hydrogen production costs in Indonesia for the three different types of electrolysis technologies (Figure 5.4).

Figure 5.4 Green Hydrogen Production Estimates

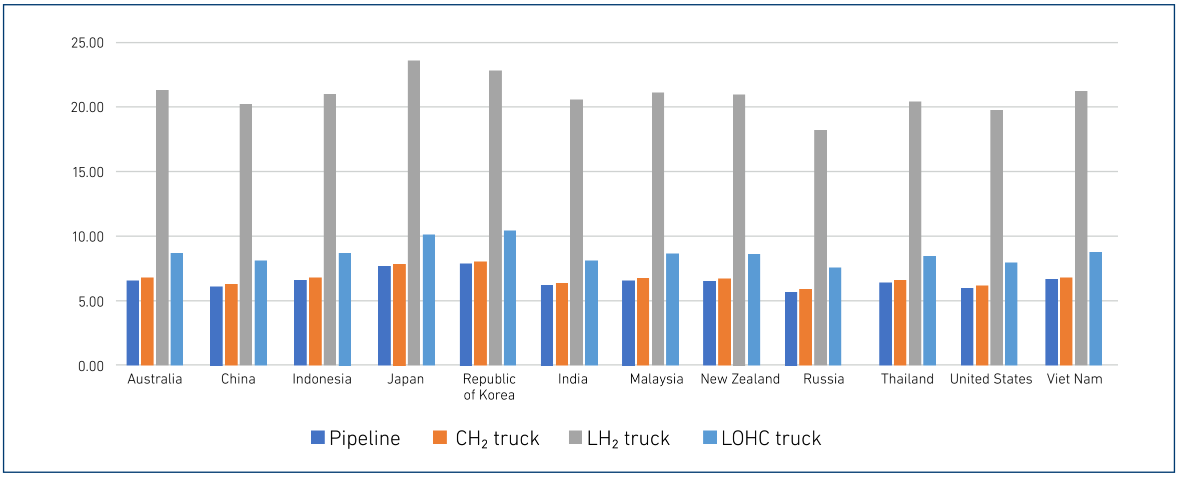
AE = alkaline electrolysis, PEM = proton exchange membrane, PV = photovoltaic, SOEC = solid oxide electrolyser cell.
Source: IESR (2022b).

IESR (2022b) assumes solar PV electricity costs of US$60–US$100 per MWh. The authors calculate the production cost of solar PV-based green hydrogen and expect costs to decrease to US$2.6–US$4.7 per kg by 2050E for alkaline, US$2.8–US$5.7 per kg for PEM respectively US$3.1–US$5.3 per kg for solid oxide electrolyser cell electrolysis. The lower cost of geothermal and location-constrained hydropower reduces these costs to about US$2.0–US$3.2 per kg by 2050E.

4.2. Li and Taghizadeh-Hesary (2020)

Li and Taghizadeh-Hesary (2020) assume multiple stacks of 1,000 MW solar PV, a 25% curtailment rate of annual generation out of 1,752,000 MWh of power, alkaline vs. PEM electrolyser CAPEX of US$1,102 per kW respectively 1,808 per kW capacity and OPEX of about 4.7% of CAPEX, pipeline CAPEX of US$400,000 per kilometre and corresponding OPEX of 8%, various storage, and transport costs ranging from short and medium distance trucking to long distance regional shipping of about 2,000 kilometres. Assuming alkaline electrolysis technology they calculate the cost of producing, 7-day storing, and delivering green hydrogen to a refuelling station 100 kilometres away (Figure 5.5).

Figure 5.5 Cost of Green Hydrogen at Refuelling Station at 500 km Trucking Distance (US$/kg)



CH_2 = compressed hydrogen, kg = kilogramme, km = kilometre, LH_2 = liquid hydrogen, LOHC = liquid organic hydrogen carrier
Source: Li and Taghizadeh-Hesary (2020).

Clearly, apart from the extremely expensive cost of transporting compressed hydrogen, their study indicates prices of US$6–US$10 per kg of hydrogen at delivery point.

4.3. ERIA (2023)

For sufficiently sizeable industrial facilities it would be beneficial to locate a large-scale renewable energy and green hydrogen production facility inside-battery-limit or directly adjacent to a refinery, ammonia, methanol, or steel facility. A synthesis of selected assumptions from third parties, i.e., Li and Taghizadeh-Hesary (2020), IESR (2022), Chang and Han (2021) and Li et al. (2023) solar PV, electricity, and electrolyser cost studies is made. It should be noted that this study itself does not explicitly analyse the economics of the solar PV facilities. By locating the solar PV and electrolyser facilities next to the industrial plant, it is assumed that there is no major pipeline or trucking transport CAPEX and OPEX, storage and refuelling or downstream power generation costs. This helps us estimate the effective costs of delivering green hydrogen at the target industrial site.

The starting point is a 2,000 MW solar PV electricity generation facility with a capacity factor of 20%. We consider a multi-stack electrolyser of 1,500–2,000 MW, closer to the combined capacity of 1,330 MW typically required for a 2,000 MW solar PV farm. A 16-year effective electrolyser lifetime, energy consumption rates of 3.98 kWh per Nm^3 hydrogen for alkaline electrolysers, and 3.48 kWh per Nm3 for PEM electrolysers and a system utilisation rate of 80% are utilised. Additionally, capital costs, i.e. discount rates of 8% are used across Southeast Asia. The electrolyser and electricity cost estimates are summarised in Table 5.5:

Table 5.5. Onsite Solar PV-based Green Hydrogen Production Assumptions

Southeast Asia	Electrolyser CAPEX (US$/kW)	Electrolyser Annual OPEX (% CAPEX)	Electrolyser Energy Consumption (kWh/Nm^3)	Electricity
Today	Alkaline 1,102	4.7%	3.98	Li et al. (2023)
	PEM 1,808	4.6%	3.48	
2030E	Alkaline 400	4.7%	3.98	0.06–0.10
	PEM 650	4.6%	3.48	
2050E	Alkaline 200	4.7%	3.98	0.04–0.08
	PEM 300	4.6%	3.48	

CAPEX = capital expenditure, E =estimate, kW = kilowatt, kWh= kilowatt hour, Nm3 = normal cubic metre, OPEX = operating expense, PEM = proton exchange membrane.

Source: Authors based on the above studies.

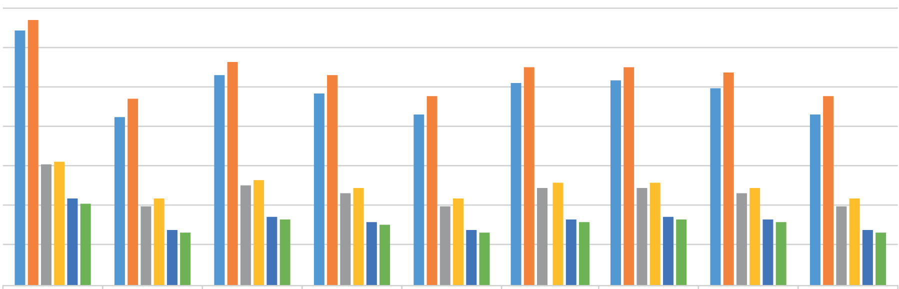
Starting with Li and Taghizadeh-Hesary's (2020) electrolyser CAPEX for a project today, roughly 20%–30% regional cost buffers are added to IEA's (2019) and IESR's (2022b) future 2030E and 2050E CAPEX estimates. Thus CAPEX estimates of approximately US$500 per kW for alkaline and US$800 per kW for PEM electrolysers by 2030E, and about US$300 per kW respectively US$400 per kW by 2050E, are calculated. Electrolyser CAPEX, the corresponding OPEX as well as solar PV electricity costs decline further beyond 2030E towards 2050E. As per Chang and Han (2021) and others, running an electrolyser at high load factors, i.e. high full load hours decreases the annualised cost of electrolyser CAPEX, thus lowering the unit production cost of hydrogen. These assumptions lead to a 1,330 MW alkaline electrolyser producing about 63,300 tons per annum of green hydrogen and consuming about 55.4 kWh electricity for every kg of hydrogen, and a PEM electrolyser producing about 72,400 TPA of green hydrogen and consuming 48.4 kWh per kg green hydrogen.

Between 700–1,500 MW of electrolyser capacity are required to serve a medium or large-scale ammonia, methanol or refinery facility. This necessitates electrolyser investment costs of almost US$0.9–US$2.7 billion (at today's CAPEX levels), US$0.3–US$1.0 billion (2030E), or US$0.2–US$0.5 billion (2050E) for the electrolyser facility alone, the lower and upper ranges corresponding to alkaline versus PEM electrolysis systems, respectively. This assumes the availability of 1 to 2 GW of solar PV or other equally large renewable electricity generation capacities in the vicinity of the electrolyser and target industrial facilities, which may cost another US$0.6–US$1.2 billion of upfront CAPEX plus associated OPEX.

Importantly, current renewable solar PV-based electricity input prices are assumed to follow Li et al. (2023). For 2030E, by contrast, IESR's (2022b) estimated prices in Indonesia of US$0.06–US$0.10 per kWh are used, combined with proportional reductions for other ASEAN countries in line with to Li et al.'s (2023) estimates. Finally, this study estimates price reductions towards US$0.04–US$0.08 per kWh electricity by 2050E in Indonesia, whilst assuming region-wide price reductions proportional to Li et al.'s (2023) country-by-country variations.

The resulting hydrogen production and onsite delivery costs are shown in Figure 5.6.

Figure 5.6 Hydrogen Production Cost (US$/kg): Onsite Solar PV Electrolyser



	Indonesia	Thailand	Singapore	Malaysia	Viet Nam	Philippines	Brunei	Myanmar	Cambodia
Alkaline (today)	12.85	8.42	10.52	9.69	8.53	10.19	10.24	9.86	8.53
PEM (today)	13.28	9.41	11.25	10.52	9.50	10.96	11.00	10.67	9.50
Alkaline (2030E)	6.11	3.97	4.99	4.58	4.02	4.82	4.85	4.66	4.02
PEM (2030E)	6.21	4.34	5.23	4.88	4,38	5.09	5.11	4.95	4.38
Alkaline (2050E)	4.33	2.72	3.49	3.18	2.76	3.37	3.39	3.25	2.76
PEM (2050E)	4.07	2.67	3.34	3.07	2.70	3.23	3.25	3.12	2.70

Alkaline (today) PEM (today) Alkaline (2030E) PEM (2030E) Alkaline (2050E) PEM (2050E)

PEM = Proton Exchange Membrane.

Sources: ERIA calculations based on IEA (2019), Li and Taghizadeh-Hesary (2020), Chang and Han (2021), Li et al. (2023).

Whilst current costs of producing green hydrogen in the ASEAN region reach as high as US$8–13 per kg, levelized production costs of US$4.0–US$6.2 per kg and US$2.7–US$4.3 per kg are anticipated by 2030E and 2050E, respectively. As electrolyser and renewable energy capacity and operating costs decrease, we thus anticipate green hydrogen to become more competitive towards 2030E and especially towards 2050E. Note that, if the PV solar capacity factor is reduced from 20% to 15%, the levelized green hydrogen production costs increase to US$10–US$14 per kg at today's cost levels, US$4.5–US$7.0 per kg by 2030E, and US$3.1–US$4.7 per kg by 2050E.

It should also be noted that the above cost estimates exclude the cost of short-distance hydrogen pipeline transport and storage systems, which could mean an additional cost of US$500,000 per km of pipeline CAPEX plus associated OPEX (Li and Taghizadeh-Hesary, 2020). Of course, optimal future transportation options must be studied in greater detail, by comparing hydrogen transport routes via pipelines, compressed or liquid hydrogen trucks, or liquid organic hydrides. Furthermore, a 1 GW single-side solar PV facility would require approximately 10 square kilometres of land space. This represents land area the size of 1,400 football fields, which may not be available in the vicinity of the typical refinery, ammonia, methanol, and steel facilities. Any distance between the solar farm and electrolyser site would require additional power transmission lines and contracting with the responsible power transmission and grip operators.

Clearly some combination of public sector co-financing, subsidies, or tax breaks, optimal carbon prices, and collaboration with multiple regulators, public and private companies are necessary to plan and implement the production of green hydrogen in the near term. As a consequence, the feasibility of implementing a green hydrogen transition in ASEAN industries hinges on an analysis of the political economy of hydrogen in the region.

Last but not least, per Figure 5.1 based on IESR (2022b) the cost of CCUS is expected to increase the production cost of grey hydrogen by only US$0.6–US$0.8 per kg today, US$0.3–US$0.5 per kg by 2030E and only US$0.1–US$0.3 per kg by 2050E. As a result, blue hydrogen is expected to play a significant interim role throughout the transition towards green hydrogen, i.e. until green hydrogen technology can become truly competitive in the ASEAN region.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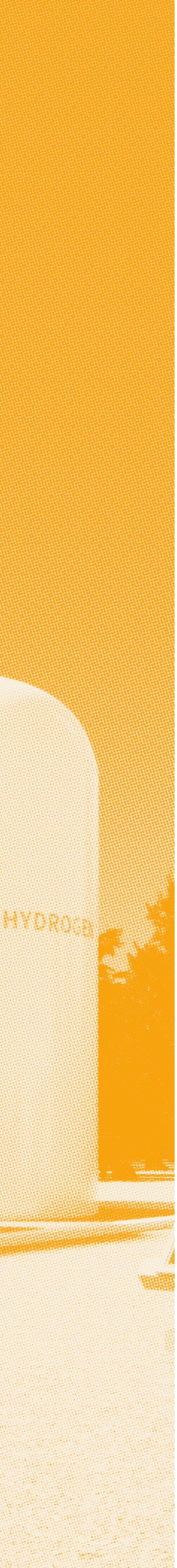

Chapter 6

Political Economy of Hydrogen in ASEAN

Ridwan Dewayanto Rusli
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Alloysius Joko Purwanto

Forcing private industry, domestic and multinational, to plan, finance and implement the greening of hydrogen production on their own merit is not feasible. There is ample evidence in the literature that companies' incentives to invest in innovative projects are driven by two main factors. First, competitive pressure and the increased profit potential (including cost reduction or revenue increase) and value enhancement potential of new technologies, products and processes (See for example, Belleflame and Peitz, 2010). Second, climate change and pollution regulation and/or carbon prices, which often exert necessary pressure for companies to innovate to avoid future costs of penalties and fines (Hemous, 2021, Popp, 2022; Aghion et al., 2016). Furthermore, financing costly green projects often requires public sector co-financing.

Considering how costly a transition towards green hydrogen will be for Southeast Asia's emerging and transition economies, one thus expects the need for strong pressure and incentives from international and domestic, public and private, political and economic institutions for ASEAN governments to stand a chance of realising their ambitious decarbonisation objectives. Robinson (2009) writes that industrial policy '…has been successful when those with political power who have implemented the policy have either themselves directly wished for industrialization to succeed, or been forced to act in this way by the incentives generated by political institutions.' In the context of the region's aim to transition the economies and key industries to green hydrogen, the term 'political and economic institutions' capture two dimensions of interaction. First, the horizontal interaction between ASEAN governments and policymakers with foreign partner governments, multilateral agencies, and nongovernment organisations. Second, the vertical interaction between government, policymakers, and regulators with domestic companies and international industrial interests in the region.

Each of these concurrent and complex interactions can be supportive or hampering the transition to green hydrogen. In turn, the interactions with a multitude of domestic and international industrial, government, international and multilateral interest groups will jointly determine the chances of ASEAN governments successfully implementing their stated policies and announced pledges optimally and in a timely manner. Thus any political economy study of a green (or blue) hydrogen transition process must start with an analysis of the key parties involved and how these are anticipated to support or hamper the governments' policies.

1. Role of Governments, Multilaterals, and Nongovernment Organisations ('Horizontal Interactions')

Table 6.1 and Table 6.2 depict a selected, albeit incomplete, list of governmental, international, and multilateral parties with interest in promoting decarbonisation and clean transition and the green and blue hydrogen transitions in Southeast Asia.

Table 6.1. Decarbonisation Recommendation and Projects

Institutions	Decarbonisation recommendations and efforts
International Energy Agency (IEA)	Indonesian Ministry of Energy and Mineral Resources (MEMR) and IEA unveiled Indonesia's 2060 Net-Zero Emissions (NZE) Roadmap.
Just Energy Transition Partnership (JETP) Indonesia 2022 (including International Partners Group)	US$20 billion public and private financing for energy transition, adoption of renewable energy, and coal phase-out, including concessional vs. market loans, grants, guarantees, plus private funds.
United States–Indonesia Strategic Partnership	ExxonMobil and Pertamina inked US$2.5 billion regional CCS hub to decarbonise industry including refining, chemicals, cement, steel.
Asian Development Bank (ADB) 2022	US$15 million technical assistance for climate change adaptation and mitigation in Southeast Asia.
Cleaner Energy Future Initiative for ASEAN (CEFIA)	Government–private platform to accelerate development of cleaner energy and decarbonisation technologies in ASEAN.

Source: Authors compilation.

Table 6.2. Hydrogen Proposals and Projects

Institutions	Green and Blue Hydrogen Proposal and Projects
International Renewable Energy Agency (IRENA)	Published 'Indonesia Energy Transition Outlook' in 2022, in cooperation with MEMR, PT PLN, etc.
World Bank	Hydrogen for Development Partnership (H4D) to accelerate deployment of low-carbon hydrogen in developing countries with public and private funding.
ASEAN Action Plan for Energy Cooperation 2021–2025	Regional integration and connectivity through deployment of renewable technologies, e.g. hydrogen, battery and storage, CCUS.

Institutions	Green and Blue Hydrogen Proposal and Projects
Brunei–Japan (AHEAD) Cooperation[a]	Pilot hydrogen supply chain project, hydrogen supply from Brunei to Japan.
POSCO, Lotte Chemical, Sarawak Economic Development Corporation (SEDC), SEDC Energy, and Samsung Engineering	Sarawak H2biscus green hydrogen and ammonia project. Expected to produce 7,000 TPA green hydrogen, 600 KTPA blue and 630 KTPA green ammonia, 460 KTPA green methanol.
Sarawak Energy – Linde, Germany	Pilot hydrogen electrolysis plant, hydrogen refuelling station and buses. Fuel cell light rail transit system by 2024.
Asia Zero Emission Community (AZEC)	Regional integration and connectivity through deployment of renewable technologies, e.g. hydrogen, battery and storage, CCUS.
(11 energy ministers from Japan, Australia, ASEAN, plus international organisations)	Cooperation for carbon neutrality, energy transition and decarbonisation incl. renewable energy, biomass, hydrogen, LNG.
Germany's TGS Green Hydrogen	Planning green hydrogen plant in Viet Nam (24 KTPA hydrogen, 150 KTPA ammonia) in Mekong Delta province, estimated US$848 million.
Singapore in cooperation with Australia, Chile, New Zealand	Multiple memorandums of understanding to collaborate on hydrogen technologies.
ASEAN Action Plan for Energy Cooperation 2021–2025	Regional integration and connectivity through deployment of renewable technologies, e.g. hydrogen, battery and storage, CCUS.

CCUS = carbon capture utilisation and storage, KTPA = kilotons per annum, LNG = liquefied natural gas, MEMR = Ministry of Energy and Mineral Resources, MOU = memorandum of understanding, TPA = tons per annum.

Note: [a] Japan's Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD).

Sources: Public and company information.

On the levels of government-to-government, multilateral agencies, and nongovernment organisations, i.e. horizontal interactions, it appears that ASEAN governments are encouraged by diverse multilateral organisations, development banks, and partner governments to decarbonise ASEAN economies and achieve their stated policies and announced pledges. A multitude of discussions, joint studies, and pilot projects are progressing or being planned.

International Partners Group, co-led by the United States and Japan, also involving Canada, Denmark, the European Union, France, Germany, Italy, Norway, and the United Kingdom have mobilised US$20 billion funding for Indonesia's energy transition and decarbonisation. The Secretariat of Just Energy Transition Partnership (JETP) was launched by the Ministry of energy and Mineral Resources (MEMR) and relevant stakeholders in February 2023. JETP-financed projects include early retirement of coal-fired power plants, deployment of renewable energy and related infrastructure, energy efficiency, and just transition.

Japan's AHEAD, which comprises Chiyoda Corporation, Mitsubishi Corporation, Mitsui & Co., Ltd. and Nippon Yusen Kabushiki Kaisha, has launched a demonstration project for by-product hydrogen to be shipped as liquid organic hydrogen between Brunei and Japan. The first shipment was completed in April 2020. In addition, initiated by Japan's Ministry of Economy, Trade, and Industry (METI) the Asia Zero Emissions Community Ministerial Meeting and public–private investment forum was held in March 2023. The forum provided support and policy coordination to accelerate clean energy projects including hydrogen, energy transition financing, and decrease costs for new technology implementation.

Also noteworthy is a one-stop online portal for green hydrogen business-related information and activities in Indonesia called the Hydrogen Business Desk Indonesia. The Hydrogen Business Desk was launched by the German–Indonesian Chamber of Industry and Commerce in May 2022 and intends to be the leading source of information on future green hydrogen commercial operations in Indonesia (AHK, 2022).[1]

Moreover, ASEAN member states receive significant support from the Japanese government and companies that play a leading role in hydrogen research, feasibility studies, technical assessments, and production. Focus areas include the blue ammonia project with Mitsubishi in Sulawesi, Indonesia, and the hydrogen pilot project in Brunei in cooperation with Japan. Additionally, the special reports on energy transition pathways in Indonesia supported by IRENA and IEA are also imperative in providing critical analysis and insights on projected energy and decarbonisation trends.

2. ASEAN Hydrogen Policies vs. Frozen, STEPS, Likely, and APS Scenarios

Notwithstanding the implementational challenges and costs involved, and despite the fact that pledges of financial assistance are yet to translate into firm commitments, ASEAN governments seem to have started introducing hydrogen into their decarbonisation policies for the next decades.

Table 6.3. Hydrogen Policies and Emission Reduction Targets of ASEAN Governments

Country	Government Policy and Targets
Brunei	• National Energy Policy 2022–2040: Leader in high growth renewable energy, energy storage, hydrogen economy, etc. • 10% share of renewables in national energy mix by 2035.
Cambodia	• Study of hydrogen and other zero-carbon fuels for the trucking sector, announced hydrogen R&D and studies. • Reduce GHG emissions by 27% through aggregate reductions from energy, transport, manufacturing.

1 Japan's Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD).

Country	Government Policy and Targets
Indonesia	• 23% new and renewable energy portion in the National Energy Mix. • 29% GHG emissions reduction by 2030. • Energy sector net-zero emissions by 2060. • Emissions reduction by 388 million ton CO_2e: Green hydrogen for transport by 2031. • Emissions reduction by 1,043.8 million ton CO_2e. Green hydrogen to replace natural gas for high temperature heating processes in industry by 2041.
Lao PDR	• 60% reduction in GHG emissions (unconditional).
Malaysia	• Reduce GHG emissions intensity of GDP by 45% by 2030.
Myanmar	• Emissions reduction of 244.5 million ton CO2e (unconditional) and 414.8 million ton CO_2e (conditional) by 2030
Philippines	• 2.7% reduction in GHG emissions (unconditional), 72.3% (conditional) by 2030.
Singapore	• Reduce GHG emissions intensity by 36% from 2005 to 2030. • Singapore's long-term low-emissions strategy (2020): hydrogen as a low-carbon alternative, the country plan to become a hydrogen hub for the Asian region.
Thailand	• 20% reduction in GHG emissions (unconditional), 25% (conditional) vs. BAU by 2030. • Alternative Energy Development Plan includes hydrogen. Target of 10 ktoe (3.5 kt of hydrogen) by 2036. • Energy Regulatory Commission stipulates that 'renewable energy' to be purchased by Provincial or Metropolitan Electricity Authorities and Electricity Generating Authority of Thailand (EGAT).
Viet Nam	• 7.3% and 9% (unconditional) reductions in GHG emissions, 27% reduction (conditional). • Hydrogen to be developed under Viet Nam's Power Development Plan 8.

BAU = business-as-Usual, CO_2e = carbon dioxide equivalent, GHG = greenhouse gas, GDP = gross domestic product, ktoe = kiloton of oil equivalent, R&D = research and development.

Sources: Public and company information.

3. Company and Industry-level Dynamics ('Vertical Interactions')

Horizontal interaction has led ASEAN governments to introduce green and blue hydrogen transition projects across the region. What is important for successful implementation is to assess the potential support for a green transition that governments may expect from key domestic and foreign industrial interests. To this end we examine the relevant companies and activities and their anticipated support for a green and blue hydrogen transition in the region.

3.1. Relevant Parties and Projects

Several ASEAN and foreign companies have announced plans or initiated preparations to shift their industrial hydrogen infrastructure towards blue or green hydrogen in Southeast Asia. Table 6.4 lists the relevant hydrogen-related activities of several companies originating from or taking place in Southeast Asia.

Table 6.4. Hydrogen-related Activities of Companies in Southeast Asia

	State Controlled vs. Private, Domestic, Multinational	Green and Blue Hydrogen Transition
Refineries		
Exxon Singapore Refinery (592 KBPD)	• Private, multinational	• 1 billion cubic feet per day of blue hydrogen at Baytown (2027) • Green hydrogen and ammonia study (Norway)
Pertamina and ExxonMobil	• State controlled • Private, multinational	• US$2.5 billion regional CCS hub to decarbonise refining, chemicals, cement, steel
Shell Pulau Bukom Refinery (458 KBPD)	• Private, multinational	• Europe's largest renewable hydrogen plant from wind (2025)
PetroChina (Singapore Refining Corporation Jurong Island Refinery – 285 KBPD)	• State controlled • Domestic, multinational	• Blue hydrogen with CCUS (2021) • First Asian state-owned company to set near-zero emissions target by 2050
Pertamina's Cilacap (348 KBPD) and Balikpapan (260 KBPD) refineries	• State controlled • Domestic, multinational	• Green hydrogen study with Keppel Infrastructure, Chevron, Tokyo Electric Power Company • Green hydrogen with geothermal (2023) • Green hydrogen for mobility project in West Java (on-going technical assessment)

	State Controlled vs. Private, Domestic, Multinational	Green and Blue Hydrogen Transition
Ammonia		
Pupuk Indonesia	• State controlled • Domestic	• 2023–2030: Hydropower, reduce emissions • 2030–2040: Blue ammonia with CCS • 2040–2050: Green ammonia with hydropower • Feasibility studies for hybrid green ammonia in Aceh and West Java.
Pertamina and Mitsubishi	• State controlled • Private, multinational	• Invest US$11 billion to accelerate clean energy transition incl. hydrogen • Brownfield blue ammonia project from 338 tons per day hydrogen plant in central Sulawesi
Petronas Chemical Ammonia	• State controlled • Domestic, multinational	• Building a 'zero-emissions' Aframax dual-fuel tanker running on green ammonia
Methanol		
PT Kaltim Methanol Industri	• State controlled • Domestic	• Cooperation with Pupuk Indonesia, Pertamina, PLN, developing green hydrogen
PTT Exploration and Production plc (PTTEP)	• State controlled • Domestic, multinational	• Green hydrogen with Electricity Generating Authority of Thailand and the Saudi government
Petronas, Malaysia	• State controlled • Domestic, multinational	• Partnership with ENEOS to explore low carbon hydrogen production (2021)
Steel		
Krakatau Steel	• State controlled • Domestic, multinational	• Green hydrogen pipelines plan with Pertamina and PT Rukun Raharja (RAJA)
Hoa Phat, Viet Nam	• Private, domestic.	• Green, energy-saving technology in steel
Power and Multi-industries		
Fortescue Metals Group (Australia)	• Private, multinational	• Memorandum of understanding for green hydrogen, green ammonia, and renewable power in North Kalimantan
AEDP Power, Saudi Arabia	• Private, multinational	• Green hydrogen from hydropower with PLN
HDF Energy, Paris	• Private, multinational	• Green hydrogen storage and transport solutions with Indonesian state electricity company PLN and US Development Finance Corporation

AEDP = Alternative Energy Development Plan, CCS = carbon capture and storage, CCUS = carbon capture utilisation and storage, KBPD = thousand barrels per day, PLN = Perusahaan Listrik Negara.

Sources: Public and company information.

Whilst Exxon, PetroChina, and Shell, oil supermajors with refinery presence in Singapore, Malaysia, and Thailand are planning blue and green hydrogen projects in the United States, Europe, and China, they have yet to release details of their hydrogen plans in ASEAN. It is interesting to note that ExxonMobil is engaging in a major collaboration project with Pertamina to develop a carbon capture and storage (CCS) hub to serve multiple industries. Concurrently, Pertamina is engaging with Keppel Infrastructure, Chevron Corporation, and Tokyo Electric (Cariaga, 2022, Shetty, 2022, Chandak, 2023) on blue and green hydrogen projects for its Balikpapan and Cilacap refineries. The Indonesian state-controlled oil, gas, and chemicals company has also announced joint studies with the state-controlled fertiliser and electricity companies, Pupuk Indonesia and PT Perusahaan Listrik Negara (PLN), to develop future green hydrogen solutions. A Joint Study Agreement and memorandum of understanding (MOU) has been signed by Pertamina Power Indonesia with several companies to investigate the development of green hydrogen and green ammonia in Indonesia.

Additionally, consistent with their track records of technology and market diversification and internationalisation, Malaysia's Petronas and Thailand's PTT are already planning projects in green hydrogen incl., in the case of Petronas Chemical, ammonia for future shipping and energy applications. Concurrently, state-controlled Krakatau Steel in Indonesia and private Hoa Phat in Viet Nam are planning green hydrogen infrastructure and technology solutions for the future.

Several private multinationals have been actively identifying green hydrogen opportunities in Southeast Asia. In 2021, Fortescue Metals Group, Australia, agreed with the Indonesian government on a plan to develop a green hydrogen industry in North Kalimantan (Heynes, 2021). During the Indonesia Group of Twenty (G20) presidency in 2022, the government of Indonesia received a bilateral and multilateral support in financing transition, with one of its initiatives being the country's hydrogen development. HDF Energy Paris, a pioneer in hydrogen power plants and a manufacturer of high-power fuel cells, has formalised a collaboration with Indonesian state-controlled electricity company PLN and the United States Development Finance Corporation to support the development of Renewstable® green hydrogen power plants in Indonesia (Hydrogen Central, 2022). In November 2022, ACWA Power (Saudi Arabia) signed an MOU with PLN on the development of a green hydrogen facility that is powered by hydroelectricity (ACWA, 2022).

3.2. Industry-level Political Economy

When it comes to the vertical interactions with industrial players including national oil companies, fertiliser and steel companies as well as domestic and international private corporations we must examine their ownership structures, assess the revenue and cost impacts, i.e. incentives of transitioning to green or blue hydrogen and study how unified, i.e. concentrated or fragmented a political force they may be, in terms of either supporting or resisting this transition.

Table 6.5 depicts a selected list of industrial, government, international, and multilateral parties relevant to our study.

Table 6.5. Characteristics of and Potential Support from Industrial Actors

Countries and firms	State-Owned	Public Private*	Private Domes-tic	Private Interna-tional	Financial	Fragmenta-tion	Expected Support/ Resistance
Indonesia							
Pertamina	√		√	√	Cost ++,Rev. -	Conc.**	Support (long term)
Natural gas producers	√	√	√	√	Rev. - -	Fragm.	Resistance
Fuel product importers		√	√		0	Conc.	Resistance
Pupuk fertiliser	√	√			Cost +++	Conc.	Support (long term)
Sojitz			√	√	Cost +++	Conc.	Support
Krakatau Steel	√				Cost +++	Conc.	Support (long term)
Chemical industry			√	√	Cost ++	Fragm.	Support (long term)
Gas merchants				√	Cost ++	Conc.	Support
Thailand							
PTT		√	√	√	Cost +, Rev. -	Conc.	Support (long term)
Thai Oil, refineries		√	√	√	Cost ++	Conc.	Support (long term)
Natural gas producers		√	√	√	Rev. - -	Fragm.	Resistance
Gas merchants			√	√	Cost ++	Conc.	Support

Countries and firms	State-Owned	Public Private*	Private Domes-tic	Private Interna-tional	Financial	Fragmenta-tion	Expected Support/ Resistance
Singapore							
Exxon		√		√	Cost ++	Conc.	Support
Shell		√		√	Cost ++	Conc.	Support
PetroChina		√		√	Cost ++	Conc.	Support
Gas merchants				√	Cost ++	Conc.	Support
Malaysia							
Petronas	√	√	√	√	Cost +, Rev. -	Conc.	Support
Natural gas producers		√	√	√	Rev. - -	Conc.	Resistance
Gas merchants		√	√	√	Cost ++	Conc.	Support
Philippines							
PNOC gas	√	√			Rev. -	Conc.	Support
Petron	√	√			Cost ++	Conc.	Neutral
Viet Nam							
PetroVietnam	√				Cost +, Rev. -	Conc.	Support (long term)
Hoa Phat DQ Steel			√	√	Cost +++	Conc.	Resistance
Brunei							
Brunei LNG		√			0	Conc.	Neutral
Myanmar							
Natural gas producers		√			0	Fragm.	Neutral

Notes: * Including partially privatised national oil and gas, state-owned companies, and public–private partnerships (PPP). projects.
** Concentrated vs. fragmented political negotiation power to support or resistance a green transition.

Source: Authors' own analysis.

Each of the aforementioned groups have their distinct strategic and financial interests in the relevant sectors, and their inherent demands for and captive supply of hydrogen. Generally, whilst natural gas producers may lose part of their natural gas revenues, the refineries, fertiliser (i.e. ammonia, methanol), and steel companies must incur additional costs to invest either in carbon capture (in case of blue hydrogen) or renewable power capacity (for green hydrogen), unilaterally or in partnership with domestic and multinational companies. Moreover, the degree of support or resistance from each group of companies depends on how concentrated or fragmented their decision making and political lobbying powers are.

The combined effects of these special interests and interactions can be expected to drive their medium and long-term incentives in supporting a transition towards green hydrogen production and usage. The group of national oil, gas and petrochemical companies. The four largest ones – PTT, Petronas, Pertamina, and PetroVietnam – are fully integrated, encompassing upstream oil and gas production including liquefied natural gas (LNG) exports, midstream gas pipeline operations, downstream oil refining, and fuel marketing as well as petrochemical production. On the one hand, whilst PTT and Petronas are partially privatised on holding level and or subsidiary levels and Pertamina is still fully state-owned, they produce natural gas through partnerships with domestic and large multinational oil and gas corporations, with Petronas and Pertamina being amongst the world's largest LNG exporters. We anticipate that their upstream gas production subsidiaries and private partners would prefer to maintain gas production levels and promote a transition towards blue hydrogen, making use of carbon capture technologies, rather than fully abolishing steam reforming to make way for a completely green hydrogen supply chain. This is a motivating factor for companies like ExxonMobil, as can be observed from their planned CCS collaboration with Pertamina.

On the other hand, refinery, methanol and, in the case of Petronas, ammonia subsidiaries may be willing to help promote green hydrogen as feedstock, as long as the costs are not too high, no ongoing projects are jeopardised, and provided they are offered fiscal incentives or enter partnerships with financially strong multinationals. Whilst Brunei's National Petroleum Company's public–private partnership with Mitsubishi is an important LNG exporter, Philippine National Oil Company (PNOC), Myanmar Oil and Gas, and Singapore's oil companies and their partners have comparatively smaller upstream gas production presence and focus on their downstream oil refining operations. We anticipate that these will support a transition to green hydrogen in the long-run, as long as the cost impact is not too high or sufficient fiscal support is offered over time.

In terms of political and institutional strength particularly vis-à-vis their domestic and international private sector partners and competitors, the Singaporean government-linked entities Temasek, GIC and EDB, national oil, gas, and chemical companies PTT, Petronas, and PetroVietnam are strong policy drivers and often dominate their counterparty relationships. Thus, once they are on board and support the green hydrogen transition, the private sector might be more easily persuaded to support climate change policies.

By contrast, PNOC and Brunei with their strong upstream partners Shell and Mitsubishi may follow their partners' long-term strategies with regards to greening hydrogen, whilst Pertamina and Petronas may be supportive as long as the cost impact can be mitigated. Whilst the Japanese conglomerates follow METI in supporting hydrogen transitions in general, Shell may be pursuing a strategy of balancing its upstream gas, LNG and future green business interests, modernising and decarbonising its refineries, whilst setting the stage for a stronger future focus on renewables and hydrogen.
The most extreme cost increases of transitioning to green hydrogen will be experienced by the fertiliser, methanol and, depending on the proportional capacity shifts intended, steel producers.

Whilst Pupuk Indonesia (in Indonesia), Petronas (in Malaysia), and Brunei Fertilizer Industries Sdn Bhd (BFI) (in Brunei) are state controlled, the Sojitz methanol joint venture is partially Japanese-owned. We thus expect limited resistance and support in the long term, as long as the costs increases can be compensated for through some combination of fiscal incentives or in partnership with hydrogen-supportive multinationals. Many Japanese conglomerates are keen to engage in such endeavours. Additionally, shifting traditional basic oxygen furnace (BOF) steelmaking to direct reduced iron-electric arc furnace (DRI–EAF) will require huge investments and necessitates sufficient supply of scrap iron in the region. The cost increase will be significant, which is countered by the fact that state-owned steel companies like Krakatau Steel and private groups and partners like POSCO and Hoa Phat may be open to compromises to a gradual, fiscally mitigated transition.

On the fuel and energy side, the fuel import interests in the region may be somewhat indifferent to a green or blue transition for industry. They may me motivated to resist or slow down the overall process of electrification of road transport but may largely support or be indifferent to cleaner refined fuel products in the region. A green hydrogen transition may affect the long-term demand for hydrogen across the region's refineries and slow down the declining demand for refining capacity and thus hydrogen beyond 2030E but may not directly reduce fuel import and trade volumes. By contrast, the shipping and airline industries, which are more concentrated, can be expected to resist the significant cost increases associated with the use of ammonia as energy carriers and methanol for e-fuels. Again, this may affect the long-term demand for hydrogen in the ERIA–Likely scenario and the ERIA–APS.

Last but not least, whilst the cost impact for fatty alcohols, oxo alcohols, hydrochloric acid, cyclohexane, and other chemical producers might deter a speedy transition to green hydrogen, we anticipate limited resistance from these sectors given the fragmented nature of these sectors. By contrast, the large multinational gas merchants and producers may deem it too expensive to rapidly transition to only producing green hydrogen to serve the chemical and processing industries, notwithstanding their awareness and, in some cases, proactive initiatives towards greening their operations in general and hydrogen production in particular. As a consequence, significant fiscal support will be welcomed and necessary, as governments in the region may wish to ensure the continued survival and continue implementing their respective industrial policies and economic development.

Next, it is noteworthy that, the region's primarily state-controlled electricity companies will be watching the technological developments and pilot projects in Japan, Europe, China, and North America with regard to the potential co-firing of ammonia and hydrogen in their natural gas and coal power plants. Any medium-term cost impact will be low or moderate, unless the proportion of ammonia or hydrogen grows to make-up significant proportions of their electricity generation capacities.

4. Determinants of Success

In summary, ASEAN governments should leverage on their financially strong national oil and gas, fertiliser, and state-controlled power, and in the case of Indonesia, steel companies to help promote decarbonisation and a more rapid transition to green hydrogen-based refinery, ammonia, methanol, and steel sectors. The region's energy, industrial, state-owned enterprises, power, infrastructure, and finance ministries should empower coherent 'green hydrogen-for-industry transition' taskforces with mandates to work with both domestic and multinational private sector companies and their regional counterparts. These ministries, led by the finance, energy, environmental and industrial ministries should coordinate with relevant multilateral agencies, partner governments and nongovernment organisations to explore possible public and private financing alternatives, including taking advantage of carbon pricing and credit instruments. The objective is to incentivise state-controlled and private companies to support ASEAN governments' green hydrogen transition.

Particularly private sector ammonia, methanol, steel, and industrial gas companies must be encouraged to seek all possible financing alternatives and, if necessary, fiscally supported to either purchase costlier green hydrogen or to collaborate with renewable electricity companies to co-invest in the kind of large-scale solar PV, wind, or geothermal power-based electrolysis technologies and infrastructures discussed in chapter 5. The fiscal support can partially be sourced directly from each country's public budget. However, domestic public co-financing must be augmented by external financings promised throughout the United Nations Climate Change Conference (COP) negotiations and following bilateral or multilateral discussions with partner governments, multilateral development banks and institutions, and nongovernment organisations. Additionally, private companies and their investors, shareholders, and lenders require well thought-through and credible regulation to better assess their investment risks and returns.

Finally, in terms of sequencing the green transition, the lowest cost and immediate focus should be on selected and coordinated CCS technology and infrastructure investments to produce blue hydrogen. The cost increases are moderate and the infrastructure and technological requirements more incremental. Concurrently detailed cross-industry plans must be formulated to ensure timely development of large-scale solar PV, geothermal, and other renewable electricity capacities critically necessary to produce the green hydrogen volumes required. Cross-country regional coordination and cooperation are required to find the optimal regional mix of hydrogen capacities and supply chains, to maximise economies of scale and scope. By contrast, given the significant costs involved in transitioning the shipping and airline sectors to a future with ammonia- and e-fuels, significant multilateral and fiscal efforts must be expanded. It is not a coincidence that international energy and environmental agencies and their stakeholders only integrate the use of ammonia for fuel and e-fuels into their long-term APS.


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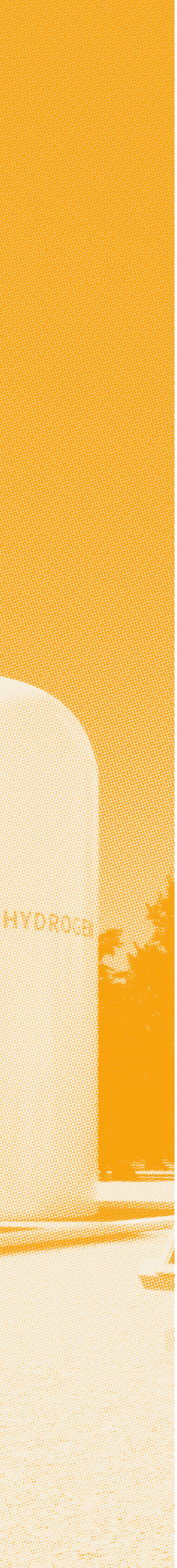

Chapter 7

Conclusions, Policy Recommendations, and Way Forward

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Ridwan Dewayanto Rusli

This chapter provides conclusions, recommendations, and the next steps of research that can be done in the future to explore more insights based on this study's findings.

1. Conclusions

Departing from the facts that current hydrogen use in ASEAN countries is entirely absorbed in the industry sector, and that this hydrogen is almost fully produced by conventional steam methane reforming pathway with high carbon intensity, this study analyses the historical use of hydrogen in the industry sector, i.e. oil refining, methanol, ammonia, and iron and steel industries in ASEAN countries and makes projections to the horizon 2050 in several scenarios.

Several conclusions can be elaborated as follows:

- **Between 2015 and 2021, hydrogen demand increased in ASEAN countries with two industry sectors, i.e. ammonia and oil refining being its drivers.**

Hydrogen demand in industry sectors in ASEAN grew from around 3.270 million tons per annum (MTPA) in 2015 to around 3.745 MTPA in 2021. The most important share of hydrogen demand in ASEAN came from the ammonia industry, which increased steadily from around 46% in 2015 to 49% in 2021. Oil refining's share, the second biggest, dropped from around 37% in 2015 to around 32% in 2021. By 2021, hydrogen demand from the methanol industry share reached almost 15% in 2021, increasing from around 11% in 2015. The iron and steel industry on the other hand, saw its small hydrogen demand share drop from 2.2% in 2015 to 0.7% in 2021. The chemical industry's hydrogen demand share remained below 4% during the 2015–2021 period.

During the 2015–2021 period, the methanol industry demand for hydrogen grew the fastest, with a compound average growth rate (CAGR) of 7.2%, followed by the ammonia industry (3.4% CAGR). The oil refining industry hydrogen demand remained stable as its CAGR approached 0%, whilst the iron and steel industry saw a strong drop in hydrogen demand, i.e. from 70,700 tons per annum (PA) in 2015 to 25,200 TPA in 2021.

Most of the hydrogen demand in the industry sector in ASEAN was supplied by captive onsite production in each sector. In 2015, around 88% of the demand was met by captive hydrogen supply and by 2021 this percentage dropped slightly to 86.5%.

- **Future situations, from now to the horizon 2050 the demand and supply of hydrogen in ASEAN countries can be represented in scenarios that differ in their climate ambitions.**

Four scenarios are defined in the study to describe future scenarios: ERIA–Frozen, ERIA–STEPS, ERIA–Likely, and ERIA–APS.

The ERIA–Frozen scenario relates to a future situation where the trend as shown in the demand and supply of hydrogen by the historical trend of the 2015–2021 period will continue as it is. It assumes that ASEAN countries only maintain a business-as-usual approach without any national CO_2 or renewable energy (RE) or energy efficiency (EE) targets to meet. Here hydrogen demand and supply in the future would grow at the same average rate of the 2015–2021 period, and supply including announced capacity expansion will be able to meet demand using the same supply structure as it is during the 2015–2021 period.

The ERIA–STEPS is inspired by the Stated Policies Scenario (STEPS) described in IEA (2022a) and IEA (2022b). Basically, it retains current and the latest ASEAN Member States' (AMS) policies, including those related to the Intended Nationally Determined Contribution (INDC). The scenario has no particular outcome to achieve, meaning that there is no additional policy implementation apart from the implementation of those based on INDC, e.g. shifting to a certain percentage of renewable use in power generation at a certain point in time, or increasing energy efficient in several final sectors. The scenario explores where the energy system might go without additional policy implementation and takes a granular, sector-by-sector look at existing policies and measures and those under development without any guarantee that the intended CO_2 emissions reduction will be achieved.

The ERIA–APS is based on the Announced Pledges Scenario (APS) of IEA (2022b) that assumes that all aspirational targets announced by governments are met on time and in full, including their long-term net-zero and energy access goals. Government targets in the scenario are assumed to be achieved on time and in full. The scenario includes all the climate commitments made by governments around the world including INDC as well as longer-term NDC targets and assumes that they will be met in full and on time and fills the 'implementation gap' that needs to be closed by countries from the STEPS to achieve their announced decarbonisation targets. The scenario includes net-zero pledges as announced by countries, in this case ASEAN countries' pledges.

The ERIA–Likely scenario represents the most likely future situation in the supply and demand of hydrogen in the four industrial sectors in ASEAN from the present time to the horizon 2050. It is inspired by the forecast of hydrogen demand in DNV (2022). In this scenario, hydrogen produced globally to be used as feedstock would grow from around 90 million tons (MT) in 2020 to reach 195 MT in 2050, whilst the Southeast Asian region's demand would reach 4.1% of the total global hydrogen and its derivatives demand by 2050. ERIA's 2050 estimate of ASEAN's hydrogen demand share is thus higher than DNV's (2022) estimated 3.9% share, presumably due to faster electrification and decarbonisation, and thus a reduction in hydrogen demand from refineries in the industrialised Western economies.

Grid-based electrolysis costs will decrease significantly towards 2050 averaging around US$1.5 per kg. Globally, green hydrogen will reach cost parity with blue hydrogen within the next decade. The scenario also assumes that green hydrogen will increasingly be the cheapest form of production in most regions and that hydrogen demand for ammonia and methanol production will be diversified, not only as feedstock for conventional production for industrial use (e.g. fertiliser and chemicals), but also as energy carriers and e-fuel that will show their penetration in the late 2030s or during the 2040–2050 decade.

The main inputs to obtain future estimates of hydrogen demand and supply in each country and industry sectors are socio-demographic trends, external policy measures that might include more stringent climate change and environmental requirements, and the effects of those policy measures on the technological costs. Based on those inputs spread along the modelled period to the horizon 2050, the development of demand and supply for hydrogen as feedstock are estimated.

- **The most ambitious scenario will require the highest quantities of hydrogen compared to others and the hydrogen must be low-carbon or green hydrogen. Less climate-ambitious scenarios might show high demand for hydrogen, albeit with carbon intensities higher than in the more ambitious scenarios.**

The ERIA–APS appears to be the scenario where total hydrogen demand for the industry sector in ASEAN will increase the fastest during the simulated 2020–2050 period. In this scenario where net-zero emissions targets are assumed to be reached by the AMS by the mid 21st century, the hydrogen demand in the industrial sector in ASEAN would increase from around 3.7 MTPA in 2020 to 11.7 MTPA in 2050. The use of hydrogen as energy carriers and fuels as feedstock to produce e-methanol, ammonia fuels, and e-kerosene is the main driving factor of this fast growth and the used hydrogen in this scenario must be low-carbon (intensity) hydrogen, as only the use of low-carbon hydrogen will lead to net-zero emissions.

Total hydrogen demand in 2050 in the ERIA–Frozen and ERIA–Likely scenarios are found to reach almost similar levels, but the composition and sequence of hydrogen use in the two scenarios differ. In other words, carbon emissions in the ERIA–Likely scenario should go down much more significantly than in the ERIA–Frozen scenario even when the total volumes of hydrogen demand are similar.

In the 2020–2030 period, the CAGR of the total hydrogen demand in the ERIA-Likely scenario is weakest of all scenarios as traditional hydrogen demand declines especially in oil refining due to mobility electrification, whilst at the same time ammonia-energy and e-fuels technology have not been initiated yet. By contrast, ERIA–Frozen scenario's hydrogen demand grows faster as traditional demand for hydrogen such as in oil refining increases strongly. The hydrogen demand growth rate in the ERIA–Likely scenario is expected to catch up relative to the ERIA–Frozen rate starting from the 2030–2040 period as the use of e-fuels and ammonia carriers start to take place as part of decarbonisation.

The ERIA–STEPS is where hydrogen demand in the industry sector in ASEAN grows at the weakest rate, i.e. 2.3% CAGR caused by the reduction of hydrogen use in oil refining due to the limited mobility electrification and to the limited use of hydrogen in the production of e-fuels and ammonia carriers.

The ERIA–APS is also where hydrogen produced onsite or captive hydrogen production in the four sectors shall increase at the fastest rate. On the other hand, the ERIA–Likely scenario is where hydrogen produced in the four sectors grows at the slowest rate. This can be explained using the economy of scale argument, i.e. the cost of onsite or captive hydrogen production should drop when production is higher as it tries to catch up with demand. In term of low-carbon hydrogen, for example, the need for hydrogen feedstock to produce e-fuels and ammonia carriers in the ERIA–Likely scenario starts to kick-in after 2030 but the quantity is less than in the ERIA–APS scenario so that the economy of scale of producing low-carbon hydrogen is not high enough to decrease low-carbon hydrogen prices. Therefore, the onsite or captive (low-carbon) hydrogen production in the ERIA–Likely scenario may turn-out lower than in the ERIA–Frozen scenario and ERIA–STEPS, the two scenarios with higher carbon intensities.

- **Configuration and sequencing of hydrogen use, and production are keys for the decarbonisation of hydrogen use in the ASEAN industry sector.**

The forecast hydrogen demand and supply might hide the significance of the composition or configuration of such demand and supply levels from the perspective of hydrogen uses and their appearance sequence, which are essential in analysing their impacts on carbon emissions.

For example, in the ERIA–Frozen scenario, the current conventional use of hydrogen as feedstock in the ASEAN industry sector is assumed to remain the same until the mid 21st century. Under the ERIA–Frozen scenario, such uses do not require that hydrogen be produced from low-carbon intensive routes. The ERIA2APS, on the other extreme, shall see an early appearance of application or uses that require low and low-hydrogen production routes such as ammonia fuels, e-methanol, etc. Moreover, under ERIA–APS, structural changes in hydrogen use and production routes are anticipated, for instance, strong and early mobility electrification that will reduce the need for hydrogen in oil refineries.

ASEAN's 2020 hydrogen use is estimated to emit up to 48 million tons of CO2-eq. Assuming that hydrogen will be produced from unabated natural gas, emissions in the ERIA–Frozen scenario by 2050 would reach 107 tons of CO_2-eq.

By 2050, ERIA–APS should be the scenario that achieves the lowest average emissions factor or intensity followed by ERIA–Likely and then ERIA–STEPS, as more low carbon intensive hydrogen will penetrate the strongest under ERIA–APS compared to the ERIA–Likely scenario and respectively the ERIA–STEPS. However, quantification of the emissions will need a more detailed description of the sequence of the appearance of those uses and a dissection of hydrogen production routes in each of the scenarios, which are beyond the scope of this study.

- **Production of low-carbon or green hydrogen would become much greater when its price is low. Low prices of low-carbon hydrogen will happen when the low-carbon electricity and hydrogen production pathways can reach economies of scale in the most climate-ambitious scenario.**

The ratio of onsite production to hydrogen demand in the ERIA–APS is projected to be highest. What happens in this scenario is the strong increase of hydrogen demand as feedstock that triggers an economic of scale high enough to reduce low carbon hydrogen price.

The decarbonisation imperative that grows from the ERIA–STEPS to ERIA–Likely to ERIA–APS is followed by the increasing share of supply from the merchants. The increasing share of merchants' supply in the decarbonisation function shows therefore the important roles expected from the hydrogen merchants to supply low-carbon hydrogen, which cannot be self-supplied by the studied industry sector.

- **The price of renewable electricity, the necessary land and infrastructure needs, and the price of electrolysers are key factors in estimating the future price of low-carbon or green hydrogen. Other important factors are the price of competing fossil fuels, especially natural gas, and the policies to set prices on carbon.**

Production costs of lower and low-carbon intensive such as blue and green hydrogen in Southeast Asian countries is currently high compared to grey hydrogen. Optimistically, if prices of electricity and electrolysers would go down significantly, it would be only during the 2030–2040 decade, when blue and green hydrogen production costs can be expected to reach comparable levels to those of grey hydrogen. It would be only during the 2040–2050 decade that the production costs of blue and green hydrogen would become cheaper than those of grey hydrogen.

In fact, it is not only the prices of electricity and electrolysers that play important roles in defining lower or low-carbon hydrogen competitiveness. Three other factors include the price of natural gas, a carbon tax, and the necessary land and infrastructure for renewable electricity production. Natural gas prices determine both the competitiveness of steam methane reforming (SMR)-based and electrolysis-based hydrogen. Competitive natural gas prices are amongst the reasons for players in the price-sensitive industry sector to keep on using SMR-based hydrogen.

A carbon tax defines how the different carbon capture technologies will penetrate commercially, which will decrease the carbon intensity of SMR-based hydrogen production. Currently the ASEAN region has no sufficient large-scale single site renewable electricity generation capacity such us solar PV, wind power, or geothermal power. A path of staggered lower and low-carbon hydrogen production such as blue and green hydrogen production and infrastructure development might be the most adequate path in decarbonising hydrogen use in industry. The role of the development of various carbon capture technologies such as carbon capture and sequestration (CCS), carbon capture, utilisation, and storage (CCUS), direct air carbon capture and storage (DACCS) in this pathway is crucial and determining and the implementation of carbon tax is amongst the most effective ways to trigger the development of such technologies.

Nevertheless, the main basic assumptions that need to be considered when estimating the future of hydrogen costs are the price development of the different types of electrolyser technologies and capacities, the development of the different renewable electricity generation costs, and the costs of hydrogen storage and transportation.

In this study, 2,000 MW solar PV and a multi-stack electrolyser facility of 1,500–2,000 MW are assumed to be located next to the industrial plant. Assuming decreases in electrolyser capital and operational expenditure (CAPEX and OPEX), decreasing solar PV-based electricity costs, onsite solar PV based hydrogen production cost might drop from the current US$8–US$13 per kg to reach US$4–US$6 per kg by 2030 and US$2.5–US$ 4 per kg by 2050.

It is important to note, however, that the large land area required for 1–2 GW-scale solar PV farms may necessitate the choice of locations further away from the industrial facilities. In turn, this will require power transmission or hydrogen transport infrastructure and additional contracting costs.

- **Multilateral horizontal and vertical institutional interactions are the two kinds of concurrent and complex interactions that must be considered whilst defining the political economy of hydrogen in ASEAN.**

Finally, a transition towards low-carbon or green hydrogen for Southeast Asia's emerging and transition economics is costly and also requires coordination across governments, multilateral organisations, and industry. Two kinds of concurrent and complex interactions are key determinants of the success or failure of this transition. First, the horizontal interaction between ASEAN governments and policymakers with foreign partner governments, multilateral agencies, and nongovernment organisations. Second, the vertical interaction between government, policymakers, and regulators with domestic companies and international industrial interests in the region.

Horizontally, AMS' governments are encouraged and supported by diverse multilateral organisations, development banks, and partner governments to decarbonise ASEAN economies and achieve their stated policies and announced pledges. Despite the implementational challenges and costs involved and the fact that financial assistance is yet to translate into firm commitments, ASEAN governments have introduced hydrogen into their decarbonisation policies for the next decades.

Whilst horizontal interaction has led ASEAN governments to promote green and blue hydrogen transition projects across the region, vertically, several ASEAN and foreign companies also have announced plans or initiated preparations to shift their industrial hydrogen infrastructure towards blue or green hydrogen in Southeast Asia.

Vertical interactions are nevertheless determined by the characteristics of the involved industrial players including national oil companies, fertiliser and steel companies, as well as domestic and international private corporations, including their ownership structure, financial interests, fragmentation, and their behaviour, i.e. degree of support or resistance towards their low-carbon or green hydrogen transition. These characteristics form different players' strategic and financial interest in their respective sector, and their inherent demands for low-carbon hydrogen and its development.

For instance, national natural gas, oil, and petrochemical companies might show some similarities in their support (or resistance) in terms of low-carbon hydrogen transition, but also differences in their strategies as a function of their domestic natural resources, their degree of state ownership, organisational structure, and international partnerships. The same dynamics also occurs across stakeholder groups such as methanol, ammonia, and steel companies, chemical producers, hydrogen merchants, and different transport sector players, for instance the more dispersed automotive industry in contrast to the more concentrated shipping and airline industries.

2. Recommendations

Based on the above findings, the following list of recommendations are synthesised:

- **ASEAN Member State governments need to reduce renewable electricity costs.**

The price of renewable electricity is one of the key parameters that determine the competitiveness of low-carbon or green hydrogen. Policymakers in ASEAN countries need therefore to elaborate on a set of policy measures to reduce the levelized cost of electricity (LCOE) of renewable resources including related grid infrastructure such as feed-in-tariffs (FIT) that can be considered as amongst the most effective tools. Together with FIT, these policy measures should aim at increasing the domestic industry's capability to produce modules, panels, and other components of renewable-based power plants and at building the skills and capacity of domestic human resources – in other words, reducing the region's dependency on foreign entities or organisations.

Other measures to reduce the LCOE are equally important, for instance, those which enable or ease deployment policies or reduce non-technical costs, such as licensing, permits, grid connection, land management, land acquisition, etc.

In the absence of FIT, one of the most effective ways to reduce the renewable LCOE is to introduce a reverse auction without further price negotiation. Viet Nam is considering replacing their FITs with an inverse auction, whilst the Philippines has just started auctioning their first green energy-based electricity. Indonesia, on the other hand, still equips its maximum purchase price setting with the selection or appointment process of providers followed by a final purchase price negotiation.

- **In the perspective of the political economy, ASEAN Member State governments should build strategies and work on their horizontal and vertical interactions.**

The region's energy, industrial, state-owned enterprises, power, infrastructure, and finance ministries should coordinate and set coherent 'green hydrogen-for-industry transition' taskforces with mandates to work with both domestic and multinational private sector companies and their regional counterparts. With the goal of incentivising state-controlled and private companies to support ASEAN governments' green hydrogen transition, these ministries should work with relevant multilateral agencies, partner governments, and nongovernment organisations to explore possible public and private financing alternatives, including taking advantage of carbon pricing and credit instruments.

ASEAN governments should support their state-controlled companies, including those in the oil and gas, fertiliser, power, and steel sectors, to help promote decarbonisation and a more rapid transition to green hydrogen-based refinery, ammonia, methanol, and steel sectors.

- **ASEAN Member State governments need to elaborate policies to combine public sector co-financing, subsidies, and/or tax breaks with optimal carbon pricing to incentivise the production of low-carbon (green) hydrogen in the near term.**

ASEAN Member State governments should encourage private sector ammonia, methanol, steel, and industrial gas companies to seek all possible financing alternatives, and if necessary, fiscal support to either purchase costlier green hydrogen or to collaborate with renewable electricity companies to co-invest in the large-scale renewable-based electrolysis technologies and infrastructure. Country public budgets can be the practical source of fiscal support, whilst external financing must be considered to increase domestic public co-financing. These must be augmented by external financing promised throughout the United Nations Conference of the Parties (COP) negotiations and following bilateral or multilateral discussions with partner governments, multilateral development banks and institutions, and nongovernment organisations.

Finally, ASEAN Member State governments need to collaborate to accelerate investments in CCS technology and infrastructure based on the least-cost principles to produce blue hydrogen. The cost increases of CCS are in fact moderate, whilst the infrastructure and technological requirements are more incremental. In the meantime, governments need to build detailed cross-industry plans to ensure timely development of large-scale solar PV, wind, geothermal, and other renewable electricity capacities critically necessary to produce the required volume of low-carbon or green hydrogen. In this regard, cross-country regional coordination and cooperation are required to find the optimal regional mix of hydrogen capacities and supply chains, to maximise economies of scale and scope.

- **ASEAN Member States should soon launch low-carbon hydrogen pilot projects, such as producing hydrogen from the surplus electricity generated by variable renewable energy (VRE) resources, including solar photovoltaic and wind or producing it from electricity generated by VRE in remote areas where electricity demand is negligible. In this production pathway, hydrogen plays the role of batteries and/or transportable batteries, thus facilitating penetration of VRE.**

Renewable electricity generated by VRE consists of some surplus electricity in some period of the day. The surplus power can be saved in the battery energy storage system and can also be transformed into hydrogen via electrolysis. In other cases, a lot of less populated remote regions in ASEAN have high renewable energy potential where generated renewable electricity can be fully tapped and transformed into hydrogen. Pilot projects focusing on this 'unused' renewable electricity should be soon conducted by ASEAN Member States to gain techno-economic knowledge on low-carbon hydrogen production, storage, and transportation that should give the information and data needed to elaborate strategies to continuously reduce low-carbon hydrogen production, storage, and transportation costs leading to more commercialised level of production and use.

3. Way Forward

More important details, however, remain to be elaborated. Those details might be addressed by the following research questions, amongst others: How can the costs of the different colour (carbon intensity) of hydrogen be reduced in each scenario during the observed period? Which renewable energy type, project location, and infrastructure configuration stand the best chance to most rapidly decrease the levelized cost of hydrogen for the major industrial facilities in ASEAN? How will the average prices of hydrogen be developed in each scenario during the observed period? How will the average carbon or carbon dioxide (CO_2) emissions factors develop in each scenario during the observed period? How will CO_2 emissions evolve in each scenario during the observed period? Indeed, whilst the greening of hydrogen in the industry sector will significantly reduce CO_2 emissions, the huge amounts of energy and fossil fuels used as inputs across the entire refinery, chemical, steel, and metal processing industries continue producing huge quantities of greenhouse gas emissions. The use of renewable energy and electrification thus play critical roles across all sectors.

These questions lead to a more quantitative modelling or research where demand for hydrogen dependent commodities – whether they are traditional such as fertilisers, transport fuel (gasoline and diesel), methanol, direct reduced iron, and derivative chemistry products – or advanced such as ammonia carriers and e-fuels, be determined as functions of the socio-economic and demographic level of the ASEAN Member States, the prices of the different colours (carbon intensities) of hydrogen, the prices of fossil fuels, and the assumed energy and climate change policies.

Quantitative bottom-up hydrogen economy modelling will be then an ideal follow-up research step. This kind of modelling needs extensive data and estimates, especially on the techno-economic and geographic characteristics of the related technologies, fuels, and energy resources. Therefore, some preliminary data collection activities can be set as preliminary research activities. The inclusion of complete ASEAN Member States' data and information will be indispensable, supported by more extensive literature studies on pricing mechanisms from cases of developed countries.

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Appendices

Appendix 1 – ERIA–Frozen Scenario

Appendix 1.1: ERIA–Frozen Scenario – Ammonia

Appendix 1.1.1. ASEAN-8 Ammonia Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Ammonia Demand/Consumption	**1,511,206**	**1,833,763**	**2,182,618**	**2,491,191**	**2,843,388**	**3,245,380**	**3,710,350**	**4,227,894**
Indonesia	1,052,120	1,270,759	1,421,651	1,622,640	1,852,045	2,113,882	2,412,738	2,753,845
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	176,347	280,799	312,133	356,262	406,629	464,117	529,733	604,625
Viet Nam	258,210	258,210	287,023	327,601	373,917	426,780	487,117	555,985
Philippines	0	0	0	0	0	0	0	0
Myanmar	24,529	23,995	26,673	30,444	34,748	39,661	45,268	51,668
Brunei	0	0	135,138	154,243	176,050	200,939	235,494	261,772

Source: Authors.

Appendix 1.1.2. ASEAN-8 Ammonia Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Ammonia Production Volumes	**1,511,818**	**1,834,291**	**2,144,340**	**2,525,670**	**2,525,670**	**2,525,670**	**2,525,670**	**2,525,670**
Indonesia	1,052,732	1,271,287	1,333,800	1,504,800	1,504,800	1,504,800	1,504,800	1,504,800
Thailand	-	-	-	-	-	-	-	-
Singapore	-	-	-	-	-	-	-	-
Malaysia	176,347	280,799	353,970	564,300	564,300	564,300	564,300	564,300
Viet Nam	258,210	258,210	283,860	283,860	283,860	283,860	283,860	283,860
Philippines	-	-	-	-	-	-	-	-
Myanmar	24,529	23,995	47,880	47,880	47,880	47,880	47,880	47,880
Brunei	0	0	124,830	124,830	124,830	124,830	124,830	124,830

Source: Authors.

Appendix 1.1.3. ASEAN-8 Ammonia Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Ammonia Merchant Supply (Offtake)	**-612**	**-528**	**49,177**	**-46,457**	**279,631**	**651,820**	**1,076,628**	**1,561,495**
Indonesia	-612	-528	87,851	117,840	347,245	609,082	907,938	1,249,045
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	-41,837	-208,038	-157,671	-100,183	-34,567	40,325
Viet Nam	0	0	3,163	43,741	90,057	142,920	203,257	272,125
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	-21,207	-17,436	-13,132	-8,219	-2,612	3,788
Brunei	0	0	10,308	29,413	51,220	76,109	110,664	136,942

Source: Authors.

Appendix 1.2 : ERIA–Frozen Scenario – Ammonia

Appendix 1.2.1. ASEAN-8 Refineries' Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Refineries Demand/Consumption	**1,157,234**	**1,167,870**	**1,546,092**	**1,931,152**	**2,142,621**	**2,377,245**	**2,637,562**	**2,926,385**
Indonesia	260,682	279,447	359,951	528,877	586,791	651,047	722,339	801,438
Thailand	281,532	301,799	313,638	363,592	403,407	447,582	496,593	550,972
Singapore	191,563	205,354	312,211	361,938	401,572	445,546	494,334	548,466
Malaysia	311,917	261,701	349,607	405,290	449,671	498,912	553,544	614,160
Viet Nam	53,088	56,910	70,687	81,945	90,918	100,874	111,920	124,176
Philippines	19,982	21,421	33,672	39,035	43,309	48,051	53,313	59,151
Myanmar	36,146	38,748	92,809	126,065	139,870	155,186	172,179	191,034
Brunei	2,323	2,490	13,517	24,409	27,082	30,048	33,338	36,989

Source: Authors.

Appendix 1.2.2. ASEAN-8 Refineries' Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Refineries Production Volumes	**976,792**	**974,439**	**1,282,387**	**1,594,511**	**1,595,163**	**1,595,343**	**1,595,343**	**1,595,343**
Indonesia	281,650	301,925	388,904	571,418	571,418	571,418	571,418	571,418
Thailand	202,019	216,562	225,057	301,663	301,663	301,663	301,663	301,663
Singapore	120,839	129,538	196,944	212,357	212,357	212,357	212,357	212,357
Malaysia	295,038	243,606	325,435	338,342	338,342	338,342	338,342	338,342
Viet Nam	16,913	18,131	22,520	21,584	21,584	21,584	21,584	21,584
Philippines	32,346	34,674	54,505	58,770	58,770	58,770	58,770	58,770
Myanmar	27,421	29,395	65,725	84,422	84,422	84,422	84,422	84,422
Brunei	567	608	3,298	5,956	6,608	6,788	6,788	6,788

Source: Authors.

Appendix 1.2.3. ASEAN-8 Refineries' Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Refineries Merchant Supply (Offtake)	**180,442**	**193,432**	**263,705**	**336,642**	**547,458**	**781,902**	**1,042,219**	**1,331,041**
Indonesia	-20,968	-22,477	-28,953	-42,540	15,374	79,629	150,921	230,020
Thailand	79,513	85,237	88,581	61,929	101,744	145,919	194,930	249,309
Singapore	70,725	75,816	115,268	149,582	189,215	233,189	281,978	336,109
Malaysia	16,879	18,094	24,172	66,948	111,329	160,570	215,202	275,818
Viet Nam	36,175	38,779	48,167	60,361	69,334	79,290	90,336	102,592
Philippines	-12,364	-13,254	-20,833	-19,736	-15,461	-10,719	-5,457	381
Myanmar	8,725	9,353	27,084	41,644	55,448	70,764	87,758	106,612
Brunei	1,756	1,882	10,219	18,453	20,474	23,260	26,550	30,201

Source: Authors.

Appendix 1.3: ERIA–Frozen Scenario – Methanol

Appendix 1.3.1. ASEAN-8 Methanol Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Methanol Demand/Consumption	**367,000**	**509,000**	**538,000**	**572,000**	**598,000**	**618,000**	**635,000**	**650,000**
Indonesia	79,000	157,000	158,000	173,000	184,000	193,000	200,000	207,000
Thailand	83,000	99,000	105,000	109,000	112,000	114,000	116,000	118,000
Singapore	65,000	63,000	72,000	73,000	74,000	75,000	75,000	76,000
Malaysia	112,000	139,000	149,000	160,000	168,000	174,000	180,000	184,000
Viet Nam	13,000	37,000	37,000	40,000	42,000	44,000	46,000	47,000
Philippines	15,000	14,000	17,000	17,000	18,000	18,000	18,000	18,000
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 1.3.2. ASEAN-8 Methanol Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Methanol Production Volumes	**355,300**	**339,300**	**399,700**	**434,300**	**491,400**	**556,000**	**629,100**	**711,600**
Indonesia	82,500	82,500	93,300	105,600	119,500	135,200	153,000	173,000
Thailand	-	-	-	-	-	-	-	-
Singapore	-	-	-	-	-	-	-	-
Malaysia	182,500	166,500	188,400	213,100	241,100	272,800	308,700	349,200
Viet Nam	-	-	-	-	-	-	-	-
Philippines	-	-	-	-	-	-	-	-
Myanmar	-	-	-	-	-	-	-	-
Brunei	90,300	90,300	118,000	115,600	130,800	148,000	167,400	189,400

Source: Authors.

Appendix 1.3.3. ASEAN-8 Methanol Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Methanol Merchant Supply (Offtake)	**11,700**	**169,700**	**138,300**	**137,700**	**106,600**	**62,000**	**5,900**	**-61,600**
Indonesia	-3,500	74,500	64,700	67,400	64,500	57,800	47,000	34,000
Thailand	83,000	99,000	105,000	109,000	112,000	114,000	116,000	118,000
Singapore	65,000	63,000	72,000	73,000	74,000	75,000	75,000	76,000
Malaysia	-70,500	-27,500	-39,400	-53,100	-73,100	-98,800	-128,700	-165,200
Viet Nam	13,000	37,000	37,000	40,000	42,000	44,000	46,000	47,000
Philippines	15,000	14,000	17,000	17,000	18,000	18,000	18,000	18,000
Myanmar	0	0	0	0	0	0	0	0
Brunei	-90,300	-90,300	-118,000	-115,600	-130,800	-148,000	-167,400	-189,400

Source: Authors.

Appendix 1.4: ERIA–Frozen Scenario – Iron and Steel

Appendix 1.4.1. ASEAN-8 Iron and Steel Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Iron and Steel Demand/Consumption	**59,006**	**24,648**	**29,211**	**43,816**	**43,816**	**43,816**	**43,816**	**102,238**
Indonesia	2,921	0	0	0	0	0	0	58,422
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	56,085	24,648	29,211	43,816	43,816	43,816	43,816	43,816
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 1.4.2. ASEAN-8 Iron and Steel Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Iron and Steel Production Volumes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Indonesia	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 1.4.3. ASEAN-8 Steel Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Steel Merchant Supply (Offtake)	**59,006**	**24,648**	**29,211**	**43,816**	**43,816**	**43,816**	**43,816**	**102,238**
Indonesia	2,921	0	0	0	0	0	0	58,422
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	56,085	24,648	29,211	43,816	43,816	43,816	43,816	43,816
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 1.5: ERIA–Frozen Scenario – Chemical and Other

Using IHS 2020-2021 aggregate estimates.

Appendix 1.5.1. ASEAN-8 Chemical and other Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Chemical and Other Demand/ Consumption	**121,158**	**121,608**	**149,291**	**173,911**	**202,591**	**236,000**	**274,920**	**320,257**
Indonesia	30,387	31,855	38,339	50,339	58,641	68,311	79,577	92,700
Thailand	27,161	28,726	28,669	31,380	36,555	42,584	49,607	57,787
Singapore	15,950	17,005	23,975	25,921	30,195	35,175	40,976	47,733
Malaysia	34,653	30,385	37,545	41,488	48,330	56,300	65,585	76,401
Viet Nam	4,420	4,713	5,428	5,869	6,836	7,964	9,277	10,807
Philippines	5,385	5,509	7,171	8,137	9,479	11,042	12,863	14,984
Myanmar	3,010	3,209	7,127	9,028	10,517	12,252	14,272	16,626
Brunei	193	206	1,038	1,748	2,036	2,372	2,763	3,219

Source: Authors.

Appendix 1.5.2. ASEAN-8 Chemical and other Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Chemical & other Production Volumes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Indonesia	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 1.5.3. Chemical and Other Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Chemical & other Merchant Supply (Offtake)	**121,158**	**121,608**	**149,291**	**173,911**	**202,591**	**236,000**	**274,920**	**320,257**
Indonesia	30,387	31,855	38,339	50,339	58,641	68,311	79,577	92,700
Thailand	27,161	28,726	28,669	31,380	36,555	42,584	49,607	57,787
Singapore	15,950	17,005	23,975	25,921	30,195	35,175	40,976	47,733
Malaysia	34,653	30,385	37,545	41,488	48,330	56,300	65,585	76,401
Viet Nam	4,420	4,713	5,428	5,869	6,836	7,964	9,277	10,807
Philippines	5,385	5,509	7,171	8,137	9,479	11,042	12,863	14,984
Myanmar	3,010	3,209	7,127	9,028	10,517	12,252	14,272	16,626
Brunei	193	206	1,038	1,748	2,036	2,372	2,763	3,219

Source: Authors.

Appendix 2 – ERIA–STEPS

Appendix 2.1: ERIA–STEPS – Ammonia

Appendix 2.1.1. ASEAN-8 Ammonia Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Ammonia Demand/Consumption	**1,511,206**	**1,833,763**	**2,088,857**	**2,237,150**	**2,605,518**	**3,034,656**	**3,534,519**	**4,116,690**
Indonesia	1,052,120	1,270,759	1,360,993	1,457,614	1,697,651	1,977,319	2,303,079	2,682,456
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	176,347	280,799	300,796	322,190	375,329	437,229	509,346	593,369
Viet Nam	258,210	258,210	276,540	296,140	344,812	401,498	467,523	544,427
Philippines	0	0	0	0	0	0	0	0
Myanmar	24,529	23,995	25,698	27,521	32,047	37,318	43,457	50,606
Brunei	0	0	124,830	133,685	155,679	181,292	211,115	245,832

Source: Authors.

Appendix 2.1.2. ASEAN-8 Ammonia Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Ammonia Production Volumes	**1,511,818**	**1,834,291**	**2,144,340**	**2,525,670**	**2,525,670**	**2,525,670**	**2,525,670**	**2,525,670**
Indonesia	1,052,732	1,271,287	1,333,800	1,504,800	1,504,800	1,504,800	1,504,800	1,504,800
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	176,347	280,799	353,970	564,300	564,300	564,300	564,300	564,300
Viet Nam	258,210	258,210	283,860	283,860	283,860	283,860	283,860	283,860
Philippines	0	0	0	0	0	0	0	0
Myanmar	24,529	23,995	47,880	47,880	47,880	47,880	47,880	47,880
Brunei	0	0	124,830	124,830	124,830	124,830	124,830	124,830

Source: Authors.

Appendix 2.1.3. ASEAN-8 Ammonia Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Ammonia Merchant Supply (Offtake)	**-612**	**-528**	**-33,301**	**-277,016**	**64,832**	**463,086**	**926,988**	**1,467,292**
Indonesia	-612	-528	27,193	-47,186	192,851	472,519	798,279	1,177,656
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	-53,174	-242,110	-188,971	-127,071	-54,954	29,069
Viet Nam	0	0	-7,320	12,280	60,952	117,638	183,663	260,567
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	-22,182	-20,359	-15,833	-10,562	-4,423	2,726
Brunei	0	0	0	8,855	30,849	56,462	86,285	121,002

Source: Authors.

Appendix 2.2: ERIA–STEPS Scenario – Refinery

Appendix 2.2.1. ASEAN-8 Refineries' Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Refineries Demand/Consumption	**1,157,234**	**1,167,870**	**1,546,092**	**1,931,152**	**1,989,786**	**2,050,201**	**2,112,449**	**2,176,588**
Indonesia	260,682	279,447	359,951	528,877	544,935	561,481	578,528	596,094
Thailand	281,532	301,799	313,638	363,592	374,632	386,006	397,726	409,802
Singapore	191,563	205,354	312,211	361,938	372,928	384,251	395,917	407,938
Malaysia	311,917	261,701	349,607	405,290	417,596	430,275	443,339	456,800
Viet Nam	53,088	56,910	70,687	81,945	84,433	86,997	89,638	92,360
Philippines	19,982	21,421	33,672	39,035	40,220	41,441	42,699	43,996
Myanmar	36,146	38,748	92,809	126,065	129,893	133,837	137,900	142,087
Brunei	2,323	2,490	13,517	24,409	25,150	25,914	26,701	27,511

Source: Authors.

Appendix 2.2.2. ASEAN-8 Refineries' Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Refineries Production Volumes	**976,792**	**974,439**	**1,282,387**	**1,594,511**	**1,594,692**	**1,595,343**	**1,595,343**	**1,595,343**
Indonesia	281,650	301,925	388,904	571,418	571,418	571,418	571,418	571,418
Thailand	202,019	216,562	225,057	301,663	301,663	301,663	301,663	301,663
Singapore	120,839	129,538	196,944	212,357	212,357	212,357	212,357	212,357
Malaysia	295,038	243,606	325,435	338,342	338,342	338,342	338,342	338,342
Viet Nam	16,913	18,131	22,520	21,584	21,584	21,584	21,584	21,584
Philippines	32,346	34,674	54,505	58,770	58,770	58,770	58,770	58,770
Myanmar	27,421	29,395	65,725	84,422	84,422	84,422	84,422	84,422
Brunei	567	608	3,298	5,956	6,136	6,788	6,788	6,788

Source: Authors.

Appendix 2.2.3. ASEAN-8 Refineries' Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Refineries Merchant Supply (Offtake)	**180,442**	**193,432**	**263,705**	**336,642**	**395,095**	**454,857**	**517,106**	**581,245**
Indonesia	-20,968	-22,477	-28,953	-42,540	-26,483	-9,937	7,111	24,676
Thailand	79,513	85,237	88,581	61,929	72,969	84,343	96,063	108,139
Singapore	70,725	75,816	115,268	149,582	160,571	171,894	183,561	195,581
Malaysia	16,879	18,094	24,172	66,948	79,254	91,933	104,997	118,458
Viet Nam	36,175	38,779	48,167	60,361	62,849	65,413	68,054	70,776
Philippines	-12,364	-13,254	-20,833	-19,736	-18,551	-17,329	-16,071	-14,775
Myanmar	8,725	9,353	27,084	41,644	45,471	49,415	53,479	57,666
Brunei	1,756	1,882	10,219	18,453	19,014	19,126	19,913	20,723

Source: Authors.

Appendix 2.3: ERIA–Frozen Scenario – Methanol

Appendix 2.3.1. ASEAN-8 Methanol Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Methanol Demand/Consumption	**367,000**	**509,000**	**538,208**	**572,034**	**597,513**	**617,955**	**635,031**	**649,694**
Indonesia	79,000	157,000	157,957	172,728	183,856	192,782	200,240	206,643
Thailand	83,000	99,000	104,564	108,591	111,624	114,058	116,091	117,836
Singapore	65,000	63,000	72,406	73,448	74,233	74,862	75,388	75,840
Malaysia	112,000	139,000	149,203	159,812	167,802	174,214	179,569	184,168
Viet Nam	13,000	37,000	36,909	40,090	42,486	44,409	46,015	47,394
Philippines	15,000	14,000	17,169	17,365	17,512	17,630	17,728	17,813
Myanmar	-	-	0	0	0	0	0	0
Brunei	-	-	-	-	-	-	-	-

Source: Authors.

Appendix 2.3.2. ASEAN-8 Methanol Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Methanol Production Volumes	**355,300**	**339,300**	**378,316**	**421,802**	**470,287**	**524,346**	**584,618**	**651,819**
Indonesia	82,500	82,500	91,983	102,556	114,345	127,489	142,143	158,482
Thailand	-	-	-	-	-	-	-	-
Singapore	-	-	-	-	-	-	-	-
Malaysia	182,500	166,500	185,639	206,978	230,769	257,295	286,871	319,846
Viet Nam	-	-	-	-	-	-	-	-
Philippines	-	-	-	-	-	-	-	-
Myanmar	-	-	-	-	-	-	-	-
Brunei	90,300	90,300	100,694	112,268	125,173	139,562	155,604	173,490

Source: Authors.

Appendix 2.3.3. ASEAN-8 Methanol Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Methanol Merchant Supply (Offtake)	**11,700**	**169,700**	**159,893**	**150,232**	**127,226**	**93,609**	**50,413**	**-2,124**
Indonesia	-3,500	74,500	65,974	70,172	69,511	65,293	58,097	48,161
Thailand	83,000	99,000	104,564	108,591	111,624	114,058	116,091	117,836
Singapore	65,000	63,000	72,406	73,448	74,233	74,862	75,388	75,840
Malaysia	-70,500	-27,500	-36,436	-47,166	-62,967	-83,081	-107,302	-135,678
Viet Nam	13,000	37,000	36,909	40,090	42,486	44,409	46,015	47,394
Philippines	15,000	14,000	17,169	17,365	17,512	17,630	17,728	17,813
Myanmar	0	0	0	0	0	0	0	0
Brunei	-90,300	-90,300	-100,694	-112,268	-125,173	-139,562	-155,604	-173,490

Source: Authors.

Appendix 2.4: ERIA–STEPS – Iron and Steel

Appendix 2.4.1. ASEAN-8 Iron and Steel Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Iron and Steel Demand/Consumption	**59,006**	**24,648**	**44,780**	**46,913**	**49,045**	**51,178**	**53,310**	**55,442**
Indonesia	2,921	0	0	0	0	0	0	58,422
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	56,085	24,648	44,780	46,913	49,045	51,178	53,310	55,442
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 2.4.2. ASEAN-8 Iron and Steel Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Iron and Steel Production Volumes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Indonesia	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 2.4.3. ASEAN-8 Steel Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Steel Merchant Supply (Offtake)	**59,006**	**24,648**	**44,780**	**46,913**	**49,045**	**51,178**	**53,310**	**55,442**
Indonesia	2,921	0	0	0	0	0	0	58,422
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	56,085	24,648	44,780	46,913	49,045	51,178	53,310	55,442
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 2.5: ERIA–STEPS – Chemical and Other

Using IHS 2020-2021 aggregate estimates.

Appendix 2.5.1. ASEAN-8 Chemical and Other Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Chemical and Other Demand/ Consumption	**121,158**	**121,608**	**149,291**	**173,911**	**202,591**	**236,000**	**274,920**	**320,257**
Indonesia	30,387	31,855	38,339	50,339	58,641	68,311	79,577	92,700
Thailand	27,161	28,726	28,669	31,380	36,555	42,584	49,607	57,787
Singapore	15,950	17,005	23,975	25,921	30,195	35,175	40,976	47,733
Malaysia	34,653	30,385	37,545	41,488	48,330	56,300	65,585	76,401
Viet Nam	4,420	4,713	5,428	5,869	6,836	7,964	9,277	10,807
Philippines	5,385	5,509	7,171	8,137	9,479	11,042	12,863	14,984
Myanmar	3,010	3,209	7,127	9,028	10,517	12,252	14,272	16,626
Brunei	193	206	1,038	1,748	2,036	2,372	2,763	3,219

Source: Authors.

Appendix 2.5.2. ASEAN-8 Chemical and Other Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Chemical and Other Production Volumes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Indonesia	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 2.5.3. ASEAN-8 Chemical and Other Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Chemical & other Merchant Supply (Offtake)	**121,158**	**121,608**	**149,291**	**173,911**	**202,591**	**236,000**	**274,920**	**320,257**
Indonesia	30,387	31,855	38,339	50,339	58,641	68,311	79,577	92,700
Thailand	27,161	28,726	28,669	31,380	36,555	42,584	49,607	57,787
Singapore	15,950	17,005	23,975	25,921	30,195	35,175	40,976	47,733
Malaysia	34,653	30,385	37,545	41,488	48,330	56,300	65,585	76,401
Viet Nam	4,420	4,713	5,428	5,869	6,836	7,964	9,277	10,807
Philippines	5,385	5,509	7,171	8,137	9,479	11,042	12,863	14,984
Myanmar	3,010	3,209	7,127	9,028	10,517	12,252	14,272	16,626
Brunei	193	206	1,038	1,748	2,036	2,372	2,763	3,219

Source: Authors.

Appendix 3 – ERIA–LIKELY Scenario

Appendix 3.1: ERIA–LIKELY Scenario – Ammonia

Appendix 3.1.1. ASEAN-8 Ammonia Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Ammonia Demand\Consumption	**1,511,206**	**1,833,763**	**2,070,152**	**2,196,013**	**2,736,397**	**3,409,939**	**4,249,348**	**5,295,336**
Indonesia	1,052,120	1,270,759	1,348,036	1,429,994	1,781,921	2,220,622	2,767,365	3,448,628
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	176,347	280,799	297,924	316,071	393,979	491,086	612,142	763,060
Viet Nam	258,210	258,210	273,908	290,534	361,891	450,798	561,581	699,627
Philippines	0	0	0	0	0	0	0	0
Myanmar	24,529	23,995	25,454	27,000	33,635	41,903	52,204	65,039
Brunei	0	0	124,830	132,413	164,970	205,530	256,056	318,981

Source: Authors.

Appendix 3.1.2. ASEAN-8 Ammonia Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Ammonia Production Volumes	**1,511,818**	**1,834,291**	**2,144,340**	**2,525,670**	**2,525,670**	**2,525,670**	**2,525,670**	**2,525,670**
Indonesia	1,052,732	1,271,287	1,333,800	1,504,800	1,504,800	1,504,800	1,504,800	1,504,800
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	176,347	280,799	353,970	564,300	564,300	564,300	564,300	564,300
Viet Nam	258,210	258,210	283,860	283,860	283,860	283,860	283,860	283,860
Philippines	0	0	0	0	0	0	0	0
Myanmar	24,529	23,995	47,880	47,880	47,880	47,880	47,880	47,880
Brunei	0	0	124,830	124,830	124,830	124,830	124,830	124,830

Source: Authors.

Appendix 3.1.3. ASEAN-8 Ammonia Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Ammonia Merchant Supply (Offtake)	**-612**	**-528**	**-51,762**	**-316,361**	**184,831**	**809,546**	**1,588,128**	**2,558,355**
Indonesia	-612	-528	14,236	-74,806	277,121	715,822	1,262,565	1,943,828
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	-56,046	-248,229	-170,321	-73,214	47,842	198,760
Viet Nam	0	0	-9,952	6,674	78,031	166,938	277,721	415,767
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	-22,426	-20,880	-14,245	-5,977	4,324	17,159
Brunei	0	0	0	7,583	40,140	80,700	131,226	194,151

Source: Authors.

Appendix 3.2: ERIA–LIKELY Scenario - Refinery

Appendix 3.2.1. ASEAN-8 Refineries' Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Refineries Demand/Consumption	**1,157,234**	**1,167,870**	**1,404,953**	**1,619,893**	**1,548,298**	**1,479,868**	**1,414,462**	**1,351,946**
Indonesia	260,682	279,447	326,336	454,577	434,486	415,283	396,929	379,385
Thailand	281,532	301,799	280,964	295,296	282,245	269,770	257,847	246,451
Singapore	191,563	205,354	283,054	297,493	284,344	271,777	259,765	248,284
Malaysia	311,917	261,701	318,126	334,354	319,576	305,452	291,952	279,048
Viet Nam	53,088	56,910	64,085	67,354	64,377	61,532	58,812	56,213
Philippines	19,982	21,421	30,527	32,084	30,666	29,311	28,015	26,777
Myanmar	36,146	38,748	88,614	115,803	110,685	105,793	101,117	96,648
Brunei	2,323	2,490	13,247	22,932	21,918	20,950	20,024	19,139

Source: Authors.

Appendix 3.2.2. ASEAN-8 Refineries' Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Refineries Production Volumes	**976,792**	**974,439**	**1,167,666**	**1,513,874**	**1,491,920**	**1,472,612**	**1,452,781**	**1,433,827**
Indonesia	281,650	301,925	352,585	491,141	469,434	448,686	428,856	409,901
Thailand	202,019	216,562	201,611	301,663	301,663	301,663	301,663	301,663
Singapore	120,839	129,538	178,551	212,357	212,357	212,357	212,357	212,357
Malaysia	295,038	243,606	296,131	338,342	338,342	338,342	338,342	338,342
Viet Nam	16,913	18,131	20,417	21,584	21,584	21,584	21,584	21,584
Philippines	32,346	34,674	49,415	58,770	58,770	58,770	58,770	58,770
Myanmar	27,421	29,395	65,725	84,422	84,422	84,422	84,422	84,422
Brunei	567	608	3,232	5,595	5,348	6,788	6,788	6,788

Source: Authors.

Appendix 3.2.3. ASEAN-8 Refineries' Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Refineries Merchant Supply (Offtake)	**180,442**	**193,432**	**237,288**	**106,019**	**56,379**	**7,256**	**-38,319**	**-81,881**
Indonesia	-20,968	-22,477	-26,249	-36,564	-34,948	-33,403	-31,927	-30,516
Thailand	79,513	85,237	79,353	-6,367	-19,418	-31,893	-43,816	-55,212
Singapore	70,725	75,816	104,503	85,136	71,988	59,420	47,409	35,928
Malaysia	16,879	18,094	21,996	-3,988	-18,766	-32,890	-46,390	-59,294
Viet Nam	36,175	38,779	43,669	45,770	42,793	39,948	37,228	34,629
Philippines	-12,364	-13,254	-18,888	-26,686	-28,104	-29,460	-30,755	-31,993
Myanmar	8,725	9,353	22,889	31,382	26,263	21,371	16,696	12,227
Brunei	1,756	1,882	10,015	17,337	16,571	14,162	13,236	12,351

Source: Authors.

Appendix 3.3: ERIA–LIKELY Scenario – Methanol

Appendix 3.3.1. ASEAN-8 Methanol Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Methanol Demand/Consumption	**367,000**	**509,000**	**575,985**	**651,674**	**737,309**	**834,197**	**943,818**	**1,067,843**
Indonesia	79,000	157,000	177,695	201,046	227,465	257,356	291,175	329,437
Thailand	83,000	99,000	112,123	126,857	143,527	162,387	183,726	207,869
Singapore	65,000	63,000	71,433	80,820	91,441	103,457	117,052	132,434
Malaysia	112,000	139,000	156,924	177,545	200,876	227,273	257,138	290,928
Viet Nam	13,000	37,000	41,843	47,341	53,562	60,601	68,564	77,574
Philippines	15,000	14,000	15,727	17,794	20,132	22,777	25,771	29,157
Myanmar	-	-	239	271	306	347	392	444
Brunei	-	-	0	0	0	0	0	0

Source: Authors.

Appendix 3.3.2. ASEAN-8 Methanol Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Methanol Production Volumes	**355,300**	**339,300**	**383,901**	**434,349**	**491,426**	**556,003**	**629,066**	**711,731**
Indonesia	82,500	82,500	93,341	105,607	119,485	135,186	152,950	173,049
Thailand	-	-	-	-	-	-	-	-
Singapore	-	-	-	-	-	-	-	-
Malaysia	182,500	166,500	188,379	213,134	241,142	272,830	308,682	349,245
Viet Nam	-	-	-	-	-	-	-	-
Philippines	-	-	-	-	-	-	-	-
Myanmar	-	-	-	-	-	-	-	-
Brunei	90,300	90,300	102,180	115,608	130,799	147,988	167,434	189,437

Source: Authors.

Appendix 3.3.3. ASEAN-8 Methanol Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Methanol Merchant Supply (Offtake)	**11,700**	**169,700**	**192,084**	**217,325**	**245,883**	**278,194**	**314,751**	**356,112**
Indonesia	-3,500	74,500	84,354	95,439	107,980	122,170	138,224	156,388
Thailand	83,000	99,000	112,123	126,857	143,527	162,387	183,726	207,869
Singapore	65,000	63,000	71,433	80,820	91,441	103,457	117,052	132,434
Malaysia	-70,500	-27,500	-31,456	-35,589	-40,266	-45,557	-51,544	-58,317
Viet Nam	13,000	37,000	41,843	47,341	53,562	60,601	68,564	77,574
Philippines	15,000	14,000	15,727	17,794	20,132	22,777	25,771	29,157
Myanmar	0	0	239	271	306	347	392	444
Brunei	-90,300	-90,300	-102,180	-115,607	-130,799	-147,987	-167,434	-189,436

Source: Authors.

Appendix 3.4: ERIA–LIKELY Scenario – Iron and Steel

Appendix 3.4.1. ASEAN-8 Iron and Steel Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Iron and Steel Demand/Consumption	**59,006**	**42,648**	**44,290**	**45,932**	**47,574**	**49,216**	**50,858**	**52,500**
Indonesia	2,921	0	0	0	0	0	0	58,422
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	56,085	42,648	44289.95	45,932	47,574	49,216	50,858	52,500
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 3.4.2. ASEAN-8 Iron and Steel Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Iron and Steel Production Volumes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Indonesia	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 3.4.3. ASEAN-8 Steel Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Steel Merchant Supply (Offtake)	**59,006**	**42,648**	**44,290**	**45,932**	**47,574**	**49,216**	**50,858**	**52,500**
Indonesia	2,921	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	56,085	42,648	44,290	45,932	47,574	49,216	50,858	52,500
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 3.5: ERIA–Likely Scenario – Chemical and other

Using IHS 2020-2021 aggregate estimates.

Appendix 3.5.1. ASEAN-8 Chemical and other Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Chemical & other Demand/Consumption	**121,158**	**121,608**	**149,291**	**173,911**	**202,591**	**236,000**	**274,920**	**320,257**
Indonesia	30,387	31,855	38,275	51,273	59,729	69,579	81,054	94,420
Thailand	27,161	28,726	28,328	30,553	35,591	41,461	48,298	56,263
Singapore	15,950	17,005	23,919	25,399	29,588	34,467	40,151	46,773
Malaysia	34,653	30,385	37,581	41,009	47,772	55,650	64,828	75,519
Viet Nam	4,420	4,713	5,415	5,751	6,699	7,804	9,091	10,590
Philippines	5,385	5,509	7,165	8,080	9,413	10,965	12,774	14,880
Myanmar	3,010	3,209	7,488	9,887	11,518	13,417	15,630	18,207
Brunei	193	206	1,119	1,958	2,281	2,657	3,095	3,605

Source: Authors.

Appendix 3.5.2. ASEAN-8 Chemical and other Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Chemical & other Production Volumes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Indonesia	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 3.5.3. ASEAN-8 Chemical and Other Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Chemical & other Merchant Supply (Offtake)	**121,158**	**121,608**	**149,291**	**173,911**	**202,591**	**236,000**	**274,920**	**320,257**
Indonesia	30,387	31,855	38,275	51,273	59,729	69,579	81,054	94,420
Thailand	27,161	28,726	28,328	30,553	35,591	41,461	48,298	56,263
Singapore	15,950	17,005	23,919	25,399	29,588	34,467	40,151	46,773
Malaysia	34,653	30,385	37,581	41,009	47,772	55,650	64,828	75,519
Viet Nam	4,420	4,713	5,415	5,751	6,699	7,804	9,091	10,590
Philippines	5,385	5,509	7,165	8,080	9,413	10,965	12,774	14,880
Myanmar	3,010	3,209	7,488	9,887	11,518	13,417	15,630	18,207
Brunei	193	206	1,119	1,958	2,281	2,657	3,095	3,605

Source: Authors.

Appendix 4 – ERIA–APS

Appendix 4.1: ERIA–APS – Ammonia

Appendix 4.1.1. ASEAN-8 Ammonia Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Ammonia Demand/Consumption	**1,511,206**	**1,833,763**	**2,074,107**	**2,204,679**	**3,004,786**	**4,095,570**	**5,582,470**	**7,609,082**
Indonesia	1,052,120	1,270,759	1,350,775	1,435,812	1,956,950	2,667,512	3,636,142	4,956,315
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	176,347	280,799	298,531	317,360	432,735	590,045	804,569	1,097,128
Viet Nam	258,210	258,210	274,465	291,715	397,373	541,342	737,532	1,004,903
Philippines	0	0	0	0	0	0	0	0
Myanmar	24,529	23,995	25,506	27,110	36,935	50,324	68,569	93,430
Brunei	0	0	124,830	132,682	180,793	246,347	335,659	457,305

Source: Authors.

Appendix 4.1.2. ASEAN-8 Ammonia Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Ammonia Production Volumes	**1,511,818**	**1,834,291**	**2,144,340**	**2,525,670**	**2,525,670**	**2,525,670**	**2,525,670**	**2,525,670**
Indonesia	1,052,732	1,271,287	1,333,800	1,504,800	1,504,800	1,504,800	1,504,800	1,504,800
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	176,347	280,799	353,970	564,300	564,300	564,300	564,300	564,300
Viet Nam	258,210	258,210	283,860	283,860	283,860	283,860	283,860	283,860
Philippines	0	0	0	0	0	0	0	0
Myanmar	24,529	23,995	47,880	47,880	47,880	47,880	47,880	47,880
Brunei	0	0	124,830	124,830	124,830	124,830	124,830	124,830

Source: Authors.

Appendix 4.1.3. ASEAN-8 Ammonia Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Ammonia Merchant Supply (Offtake)	**-612**	**-528**	**-47,859**	**-308,073**	**434,098**	**1,445,939**	**2,825,283**	**4,705,386**
Indonesia	-612	-528	16,975	-68,988	452,150	1,162,712	2,131,342	3,451,515
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	-55,439	-246,940	-131,565	25,745	240,269	532,828
Viet Nam	0	0	-9,395	7,855	113,513	257,482	453,672	721,043
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	-22,374	-20,770	-10,945	2,444	20,689	45,550
Brunei	0	0	0	7,852	55,963	121,517	210,829	332,475

Source: Authors.

Appendix 4.2: ERIA–APS – Refinery

Appendix 4.2.1. ASEAN-8 Refineries' Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Refineries Demand/Consumption	**1,157,234**	**1,167,870**	**1,474,139**	**1,768,653**	**1,590,582**	**1,430,440**	**1,286,421**	**1,156,902**
Indonesia	260,682	279,447	342,814	490,089	440,746	396,371	356,464	320,575
Thailand	281,532	301,799	296,981	327,891	294,878	265,189	238,490	214,478
Singapore	191,563	205,354	297,347	328,295	295,242	265,516	238,784	214,742
Malaysia	311,917	261,701	333,558	368,275	331,197	297,851	267,863	240,894
Viet Nam	53,088	56,910	67,321	74,328	66,845	60,115	54,062	48,619
Philippines	19,982	21,421	32,068	35,406	31,841	28,636	25,752	23,160
Myanmar	36,146	38,748	90,671	120,720	108,566	97,635	87,805	78,965
Brunei	2,323	2,490	13,379	23,649	21,268	19,127	17,201	15,469

Source: Authors.

Appendix 4.2.2. ASEAN-8 Refineries' Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Refineries Production Volumes	**976,792**	**974,439**	**1,223,902**	**1,552,418**	**1,498,525**	**1,452,179**	**1,409,062**	**1,370,286**
Indonesia	281,650	301,925	370,388	529,510	476,198	428,254	385,136	346,360
Thailand	202,019	216,562	213,104	301,663	301,663	301,663	301,663	301,663
Singapore	120,839	129,538	187,567	212,357	212,357	212,357	212,357	212,357
Malaysia	295,038	243,606	310,495	338,342	338,342	338,342	338,342	338,342
Viet Nam	16,913	18,131	21,447	21,584	21,584	21,584	21,584	21,584
Philippines	32,346	34,674	51,910	58,770	58,770	58,770	58,770	58,770
Myanmar	27,421	29,395	65,725	84,422	84,422	84,422	84,422	84,422
Brunei	567	608	3,264	5,770	5,189	6,788	6,788	6,788

Source: Authors.

Appendix 4.2.3. ASEAN-8 Refineries' Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Refineries Merchant Supply (Offtake)	**180,442**	**193,432**	**250,237**	**216,236**	**92,058**	**-21,739**	**-122,641**	**-213,384**
Indonesia	-20,968	-22,477	-27,574	-39,420	-35,452	-31,882	-28,672	-25,785
Thailand	79,513	85,237	83,876	26,228	-6,785	-36,474	-63,173	-87,185
Singapore	70,725	75,816	109,780	115,938	82,885	53,160	26,427	2,386
Malaysia	16,879	18,094	23,063	29,933	-7,145	-40,491	-70,479	-97,448
Viet Nam	36,175	38,779	45,874	52,744	45,261	38,531	32,478	27,035
Philippines	-12,364	-13,254	-19,841	-23,364	-26,929	-30,135	-33,018	-35,611
Myanmar	8,725	9,353	24,945	36,299	24,144	13,214	3,384	-5,457
Brunei	1,756	1,882	10,115	17,879	16,079	12,339	10,413	8,681

Source: Authors.

Appendix 4.3: ERIA–APS – Methanol

Appendix 4.3.1. ASEAN-8 Methanol Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Methanol Demand/Consumption	**367,000**	**509,000**	**665,356**	**869,593**	**1,136,523**	**1,485,391**	**1,941,346**	**2,537,262**
Indonesia	79,000	157,000	205,267	268,276	350,626	458,254	598,919	782,763
Thailand	83,000	99,000	129,520	169,277	221,239	289,150	377,908	493,910
Singapore	65,000	63,000	82,517	107,847	140,951	184,218	240,765	314,670
Malaysia	112,000	139,000	181,273	236,916	309,640	404,687	528,909	691,264
Viet Nam	13,000	37,000	48,335	63,172	82,563	107,907	141,030	184,320
Philippines	15,000	14,000	18,167	23,744	31,032	40,558	53,008	69,279
Myanmar	-	-	277	361	472	617	807	1,055
Brunei	-	-	0	0	0	0	0	1

Source: Authors.

Appendix 4.3.2. ASEAN-8 Methanol Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Methanol Production Volumes	**355,300**	**339,300**	**443,468**	**579,595**	**757,507**	**990,032**	**1,293,932**	**1,691,117**
Indonesia	82,500	82,500	107,824	140,922	184,179	240,715	314,605	411,176
Thailand	-	-	-	-	-	-	-	-
Singapore	-	-	-	-	-	-	-	-
Malaysia	182,500	166,500	217,609	284,406	371,707	485,807	634,930	829,828
Viet Nam	-	-	-	-	-	-	-	-
Philippines	-	-	-	-	-	-	-	-
Myanmar	-	-	-	-	-	-	-	-
Brunei	90,300	90,300	118,035	154,267	201,621	263,510	344,397	450,113

Source: Authors.

Appendix 4.3.3. ASEAN-8 Methanol Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	2015	2020	2025E	2030E	2035E	2040E	2045E	2050E
ASEAN-8 Methanol Merchant Supply (Offtake)	**11,700**	**169,700**	**221,888**	**289,998**	**379,016**	**495,359**	**647,415**	**846,145**
Indonesia	-3,500	74,500	97,443	127,354	166,446	217,539	284,314	371,587
Thailand	83,000	99,000	129,520	169,277	221,239	289,150	377,908	493,910
Singapore	65,000	63,000	82,517	107,847	140,951	184,218	240,765	314,670
Malaysia	-70,500	-27,500	-36,336	-47,490	-62,068	-81,120	-106,020	-138,564
Viet Nam	13,000	37,000	48,335	63,172	82,563	107,907	141,030	184,320
Philippines	15,000	14,000	18,167	23,744	31,032	40,558	53,008	69,279
Myanmar	0	0	277	361	472	617	807	1,055
Brunei	-90,300	-90,300	-118,035	-154,267	-201,620	-263,510	-344,397	-450,112

Source: Authors.

Appendix 4.4: ERIA-APS – Iron and Steel

Appendix 4.4.1. ASEAN-8 Iron and Steel Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Iron and Steel Demand/Consumption	**59,006**	**24,648**	**43,074**	**43,501**	**43,927**	**44,354**	**44,780**	**45,207**
Indonesia	2,921	0	0	0	0	0	0	58,422
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	56,085	24,648	43,074	43,501	43,927	44,354	44,780	45,207
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 4.4.2. ASEAN-8 Iron and Steel Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Iron and Steel Production Volumes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Indonesia	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 4.4.3. ASEAN-8 Steel Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Steel Merchant Supply (Offtake)	**59,006**	**24,648**	**43,074**	**43,501**	**43,927**	**44,354**	**44,780**	**45,207**
Indonesia	2,921	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	56,085	24,648	43,074	43,501	43,927	44,354	44,780	45,207
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 4.5: ERIA–APS – Chemical and other

Using IHS 2020-2021 aggregate estimates.

Appendix 4.5.1. ASEAN-8 Chemical and other Industry's Hydrogen Demand/Consumption

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Chemical & other Demand/Consumption	**121,158**	**121,608**	**149,291**	**173,911**	**202,591**	**236,000**	**274,920**	**320,257**
Indonesia	30,387	31,855	38,308	50,786	59,161	68,918	80,283	93,523
Thailand	27,161	28,726	28,503	30,981	36,090	42,042	48,975	57,052
Singapore	15,950	17,005	23,948	25,672	29,905	34,837	40,582	47,274
Malaysia	34,653	30,385	37,562	41,261	48,065	55,992	65,225	75,982
Viet Nam	4,420	4,713	5,422	5,812	6,771	7,887	9,188	10,703
Philippines	5,385	5,509	7,168	8,110	9,447	11,005	12,820	14,934
Brunei	3,010	3,209	7,302	9,440	10,997	12,810	14,923	17,384
Myanmar	193	206	1,078	1,849	2,154	2,509	2,923	3,405

Source: Authors.

Appendix 4.5.2. ASEAN-8 Chemical and other Industry's Hydrogen Production Volumes

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Chemical & other Production Volumes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Indonesia	0	0	0	0	0	0	0	0
Thailand	0	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0	0
Malaysia	0	0	0	0	0	0	0	0
Viet Nam	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0
Myanmar	0	0	0	0	0	0	0	0
Brunei	0	0	0	0	0	0	0	0

Source: Authors.

Appendix 4.5.3. ASEAN-8 Chemical and Other Industry's Hydrogen Merchant Supply (Offtake)

Unit: tons per annum

ERIA 2022–2023 Study	*2015*	*2020*	*2025E*	*2030E*	*2035E*	*2040E*	*2045E*	*2050E*
ASEAN-8 Chemical & other Merchant Supply (Offtake)	**121,158**	**121,608**	**149,291**	**173,911**	**202,591**	**236,000**	**274,920**	**320,257**
Indonesia	30,387	31,855	38,308	50,786	59,161	68,918	80,283	93,523
Thailand	27,161	28,726	28,503	30,981	36,090	42,042	48,975	57,052
Singapore	15,950	17,005	23,948	25,672	29,905	34,837	40,582	47,274
Malaysia	34,653	30,385	37,562	41,261	48,065	55,992	65,225	75,982
Viet Nam	4,420	4,713	5,422	5,812	6,771	7,887	9,188	10,703
Philippines	5,385	5,509	7,168	8,110	9,447	11,005	12,820	14,934
Myanmar	3,010	3,209	7,302	9,440	10,997	12,810	14,923	17,384
Brunei	193	206	1,078	1,849	2,154	2,509	2,923	3,405

Source: Authors.