Chapter 2

Current Hydrogen Demand and Supply

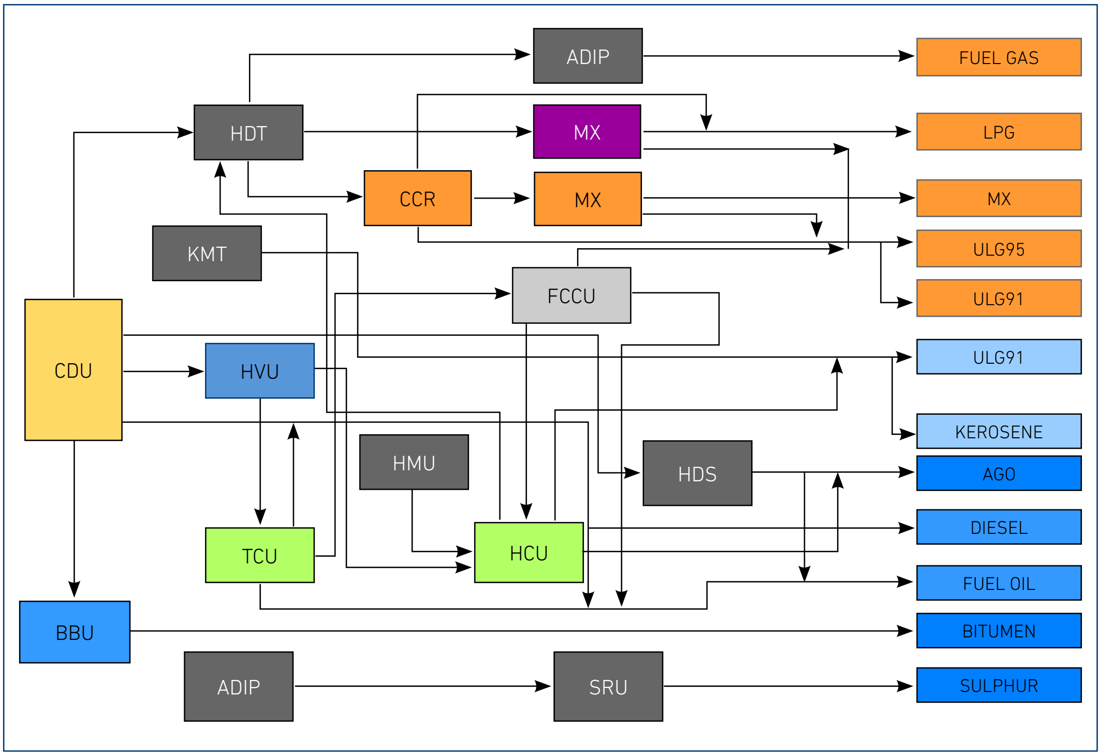
Alloysius Joko Purwanto
Ridwan Dewayanto Rusli
Hafis Pratama Rendra Graha
Sirichai Koonaphapdeelert
Reza Miftahul Ulum
Akhmad Zainal Abidin
Citra Endah Nur Setyawati
Dian Lutfiana
Badrul Munir
Deni Ferdian
Veradika Elsye
Ryan Wiratama Bhaskara
Nadiya Pranindita

Purwanto, A.J.,R.D. Rusli, H.P.R.Graha, S.Koonaphapdeelert, R.M.Ulum, A.Z.Abidin,C.E.N.Setyawati, D.Lutfiana, B.Munir, D.Ferdian, V.Elsye, R.W.Bhaskara and N.Pranindita (2024), 'Current Hydrogen Demand and Supply' in Purwanto, A.J. and R.D.Rusli (eds.) *Hydrogen Demand and Supply in ASEAN's Industry Sector*. Jakarta: ERIA, pp. 10-67.

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.

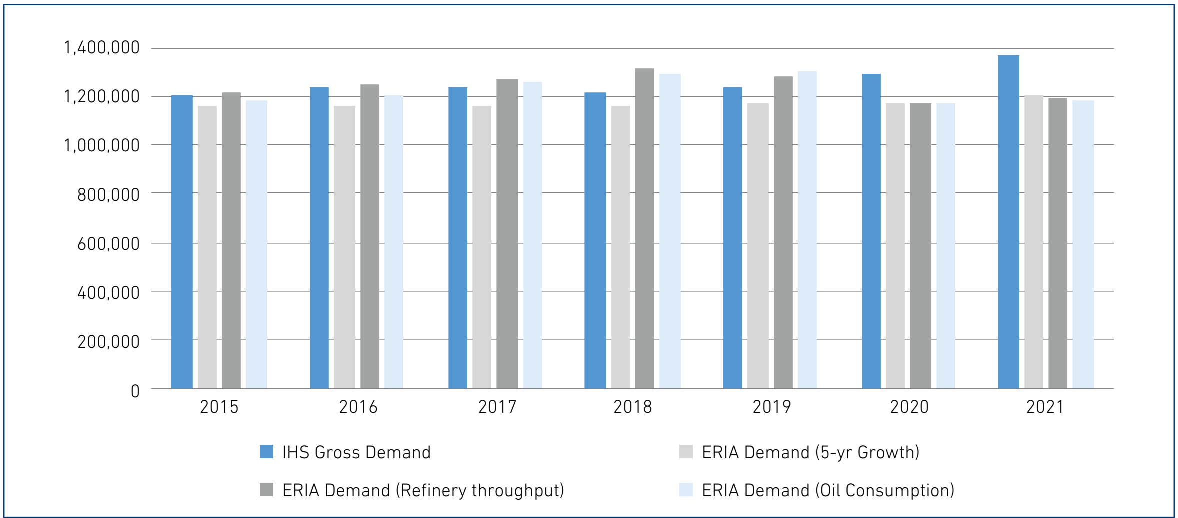
Sources: Author's estimates based on BP (2022), OGJ (2020), company websites, public information.

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)

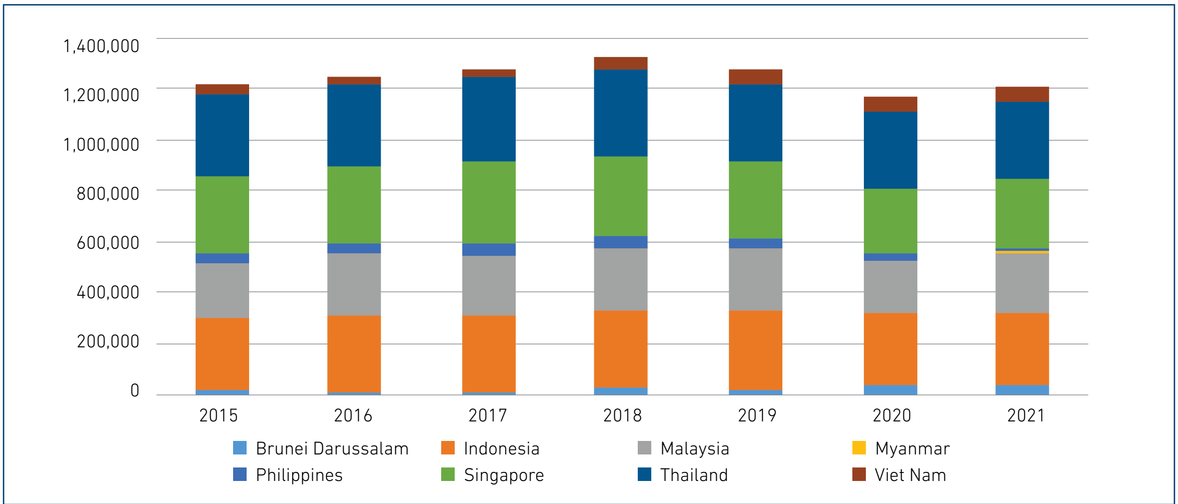


TPA = tons per annum.

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**

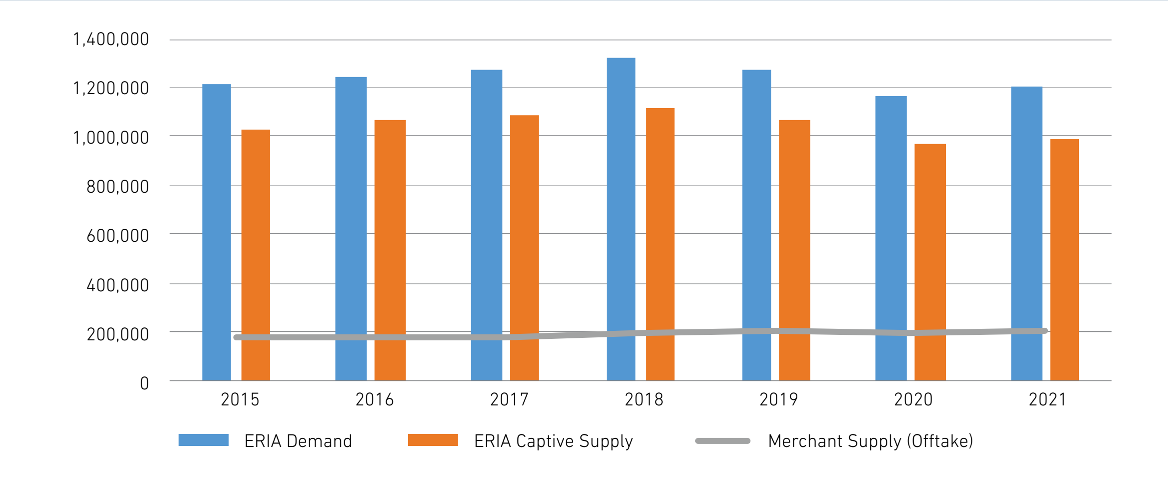
NA = not available, pa = per annum.

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.

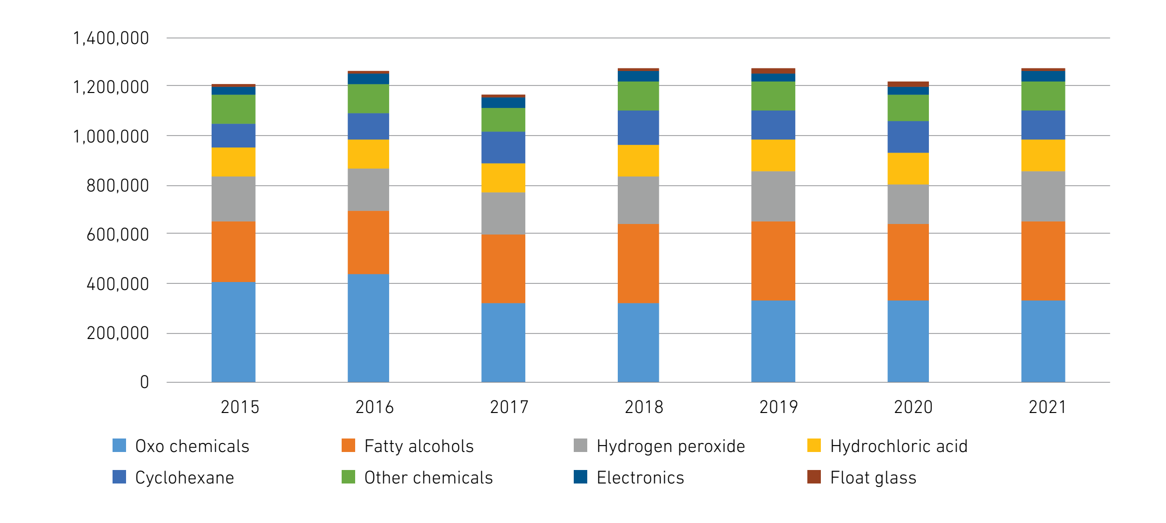
By comparison, oxo alcohols such as 2-ethylhexanol and butanol are important ingredients for plasticisers, which are additives used in the automotive industry, construction, consumer products applications, acrylates for the production of polymers for paints, adhesives, and for lube oil additives (GMI, 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)

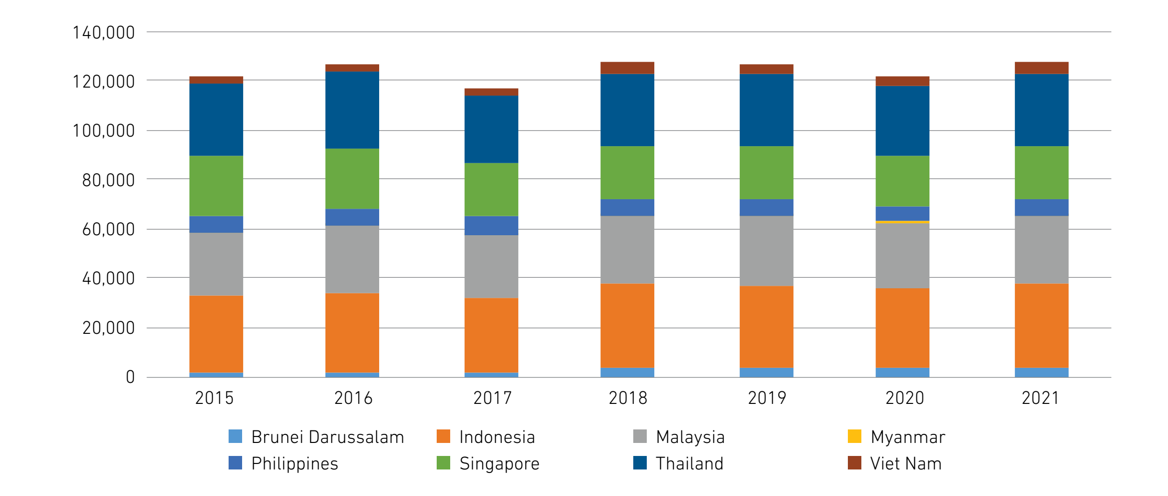


TPA = tons per annum.

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

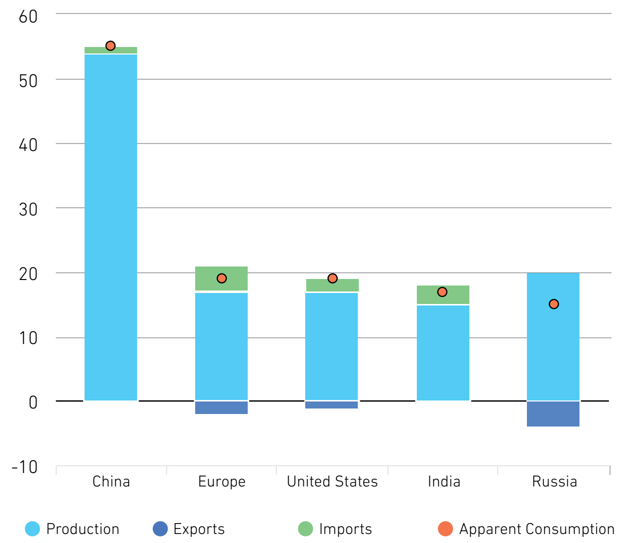
Property	Ammonia (NH_3)
Decomposition point (°C)	500
Flash point (°C)	11
Density, gas (g/L)	0.7710
Density, liquid (g/L)	0.6818
Vapor pressure (atm)	8.5
Vapour density	0.5697
Critical temperature (°C)	132.4
Critical pressure (atm)	111.3
Heat of fusion (kJ/mol)	58.1
Heat of Vapourisation (kJ/mol)	23.3
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



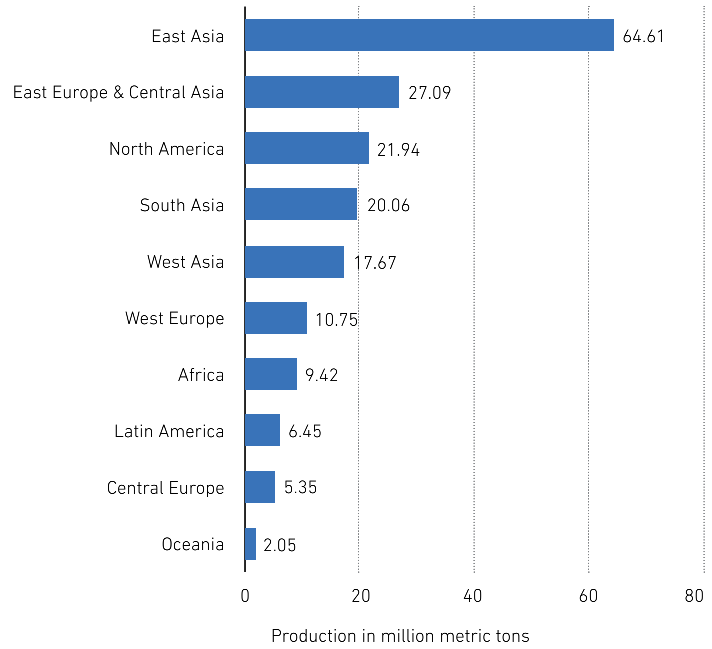
MT = million tons.
Source: IEA (2020).

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.

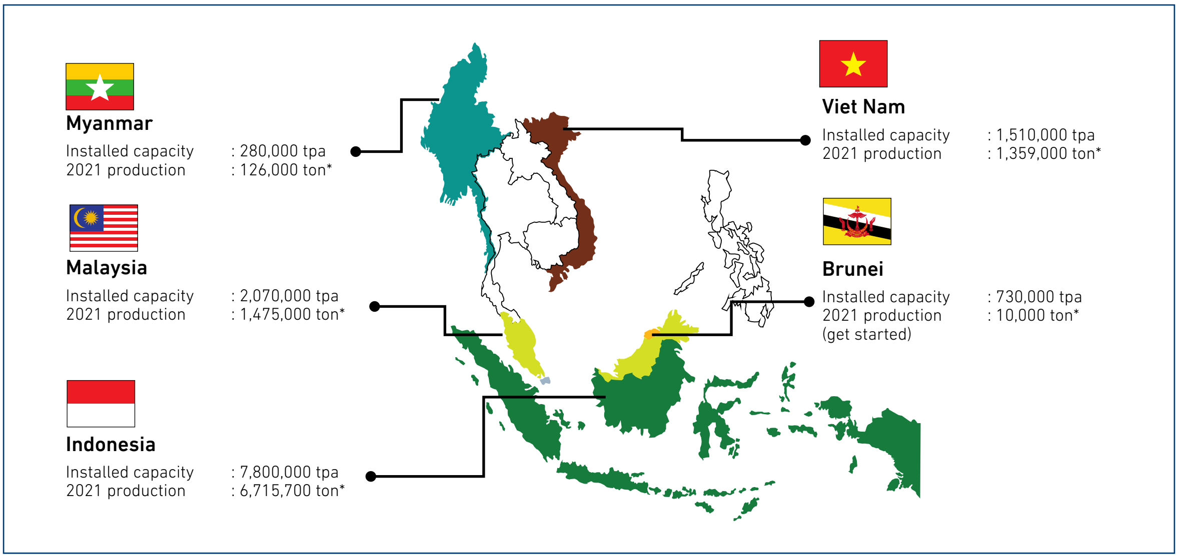
Figure 2.9. Production of Ammonia Worldwide in 2020 by Region



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.

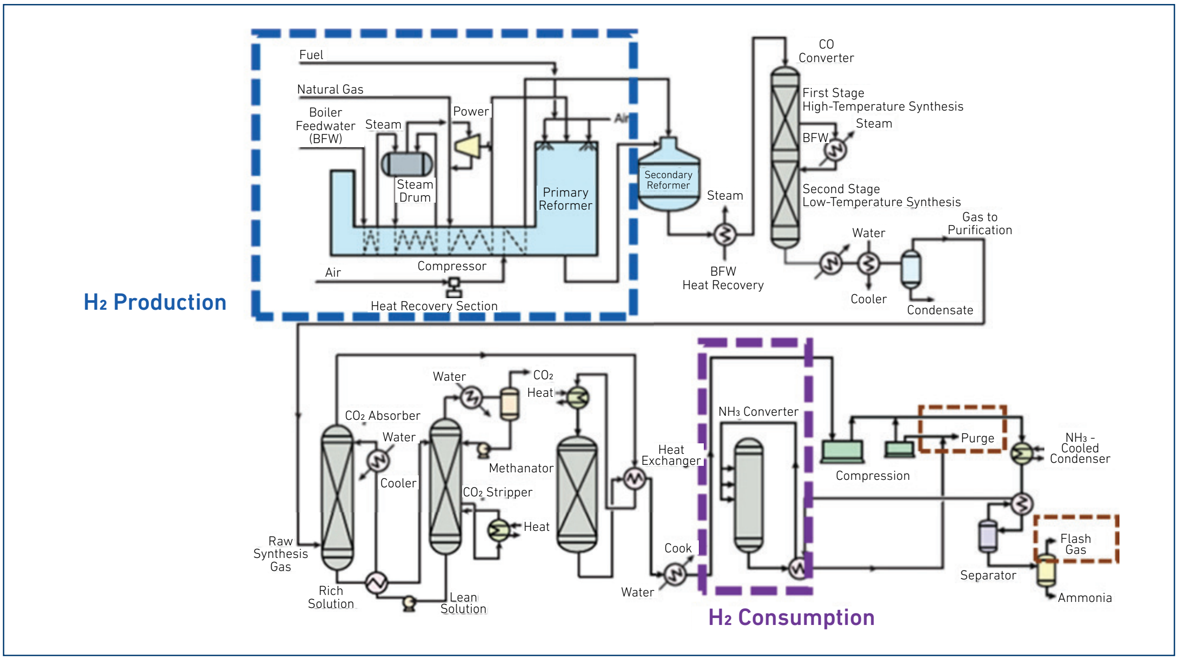
Source: Authors.

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.

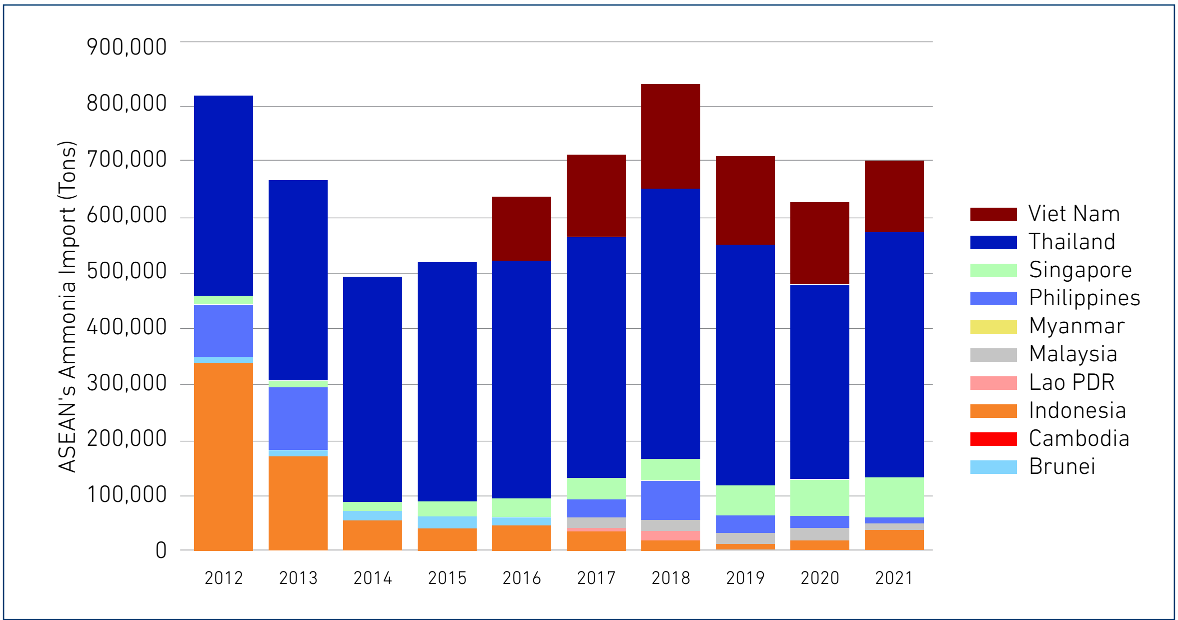
All ammonia production data were estimated using past plant utilisation data except for Indonesia. Data for Indonesia were based on real production data reported by companies.

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



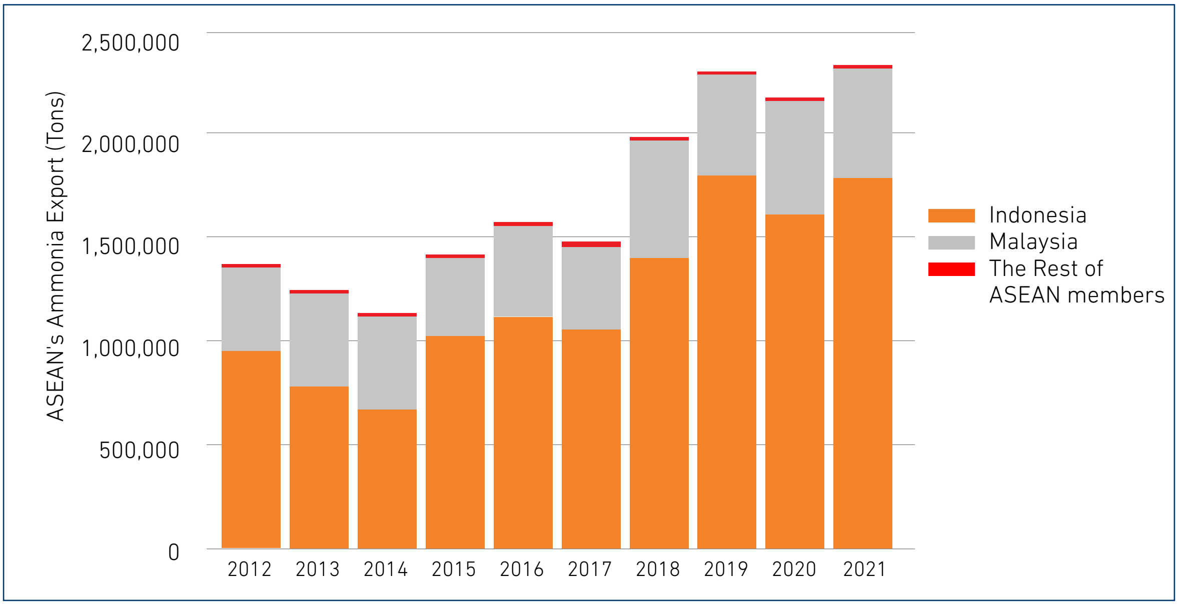
ASEAN = Association of Southeast Asian Nations.

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

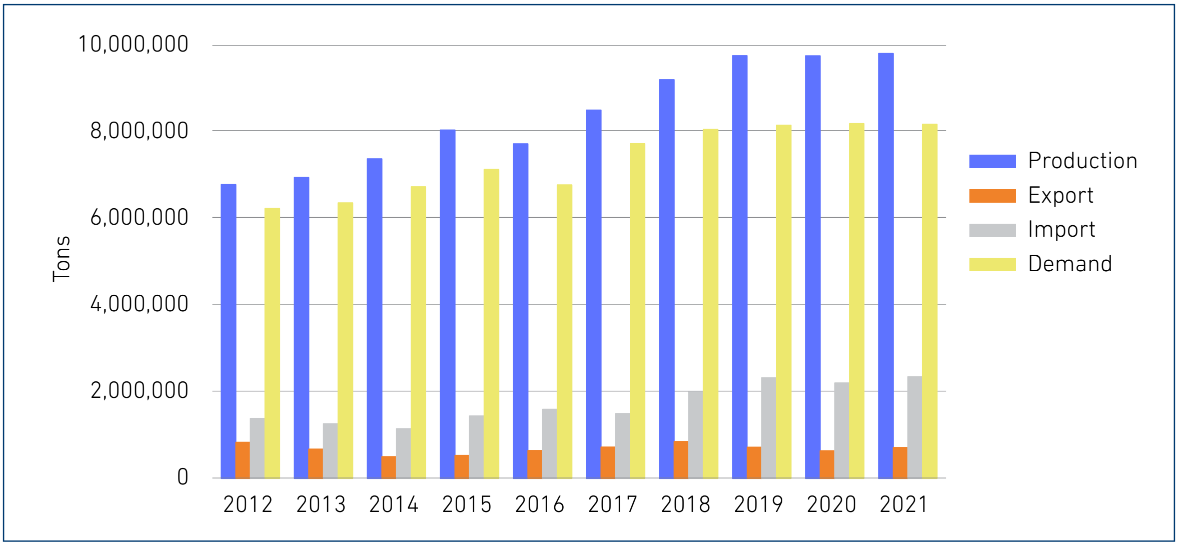


ASEAN = Association of Southeast Asian Nations.

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.

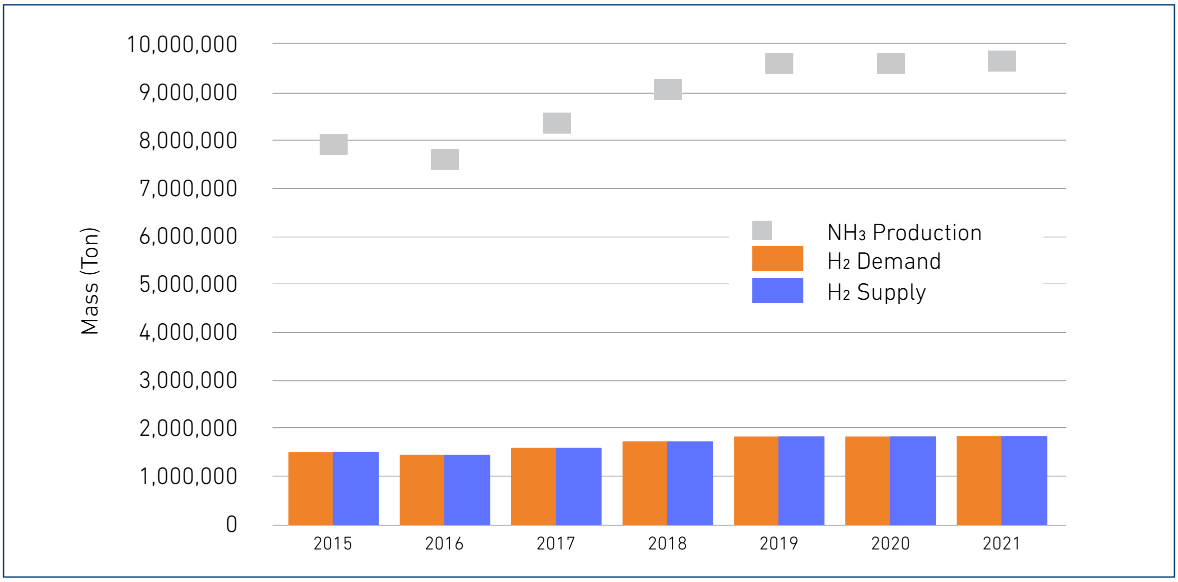
Figure 2.14. Southeast Asia's Ammonia Historical Supply and Demand



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

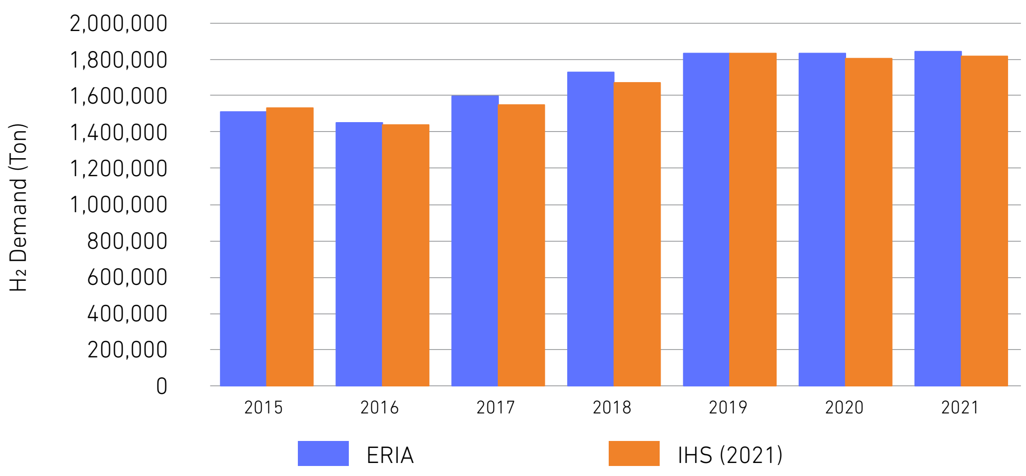


Source: Authors.

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).

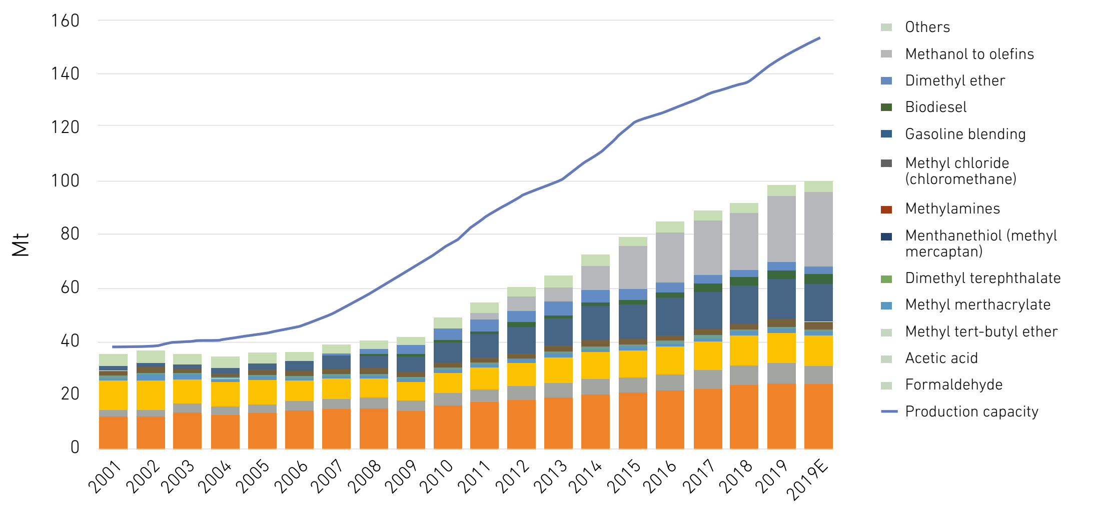
Product type	Industry type	Methanol Utilisation
9. Methyl methacrylate	Chemicals	Methanol is used as a raw material for the production of methyl methacrylate that has many applications: 1) Used for the production of polymethyl methacrylate (PMMA) as known as an acrylic. It is highly durable and transparent; 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.

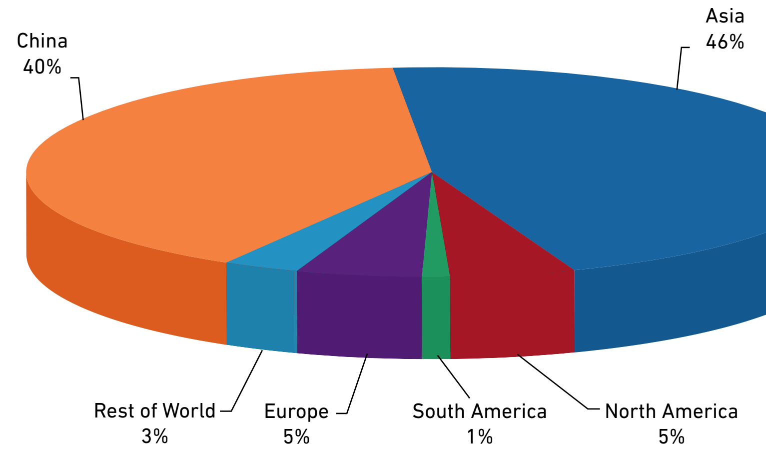
Figure 2.17. World Production and Consumption of Methanol, 2001–2020



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**



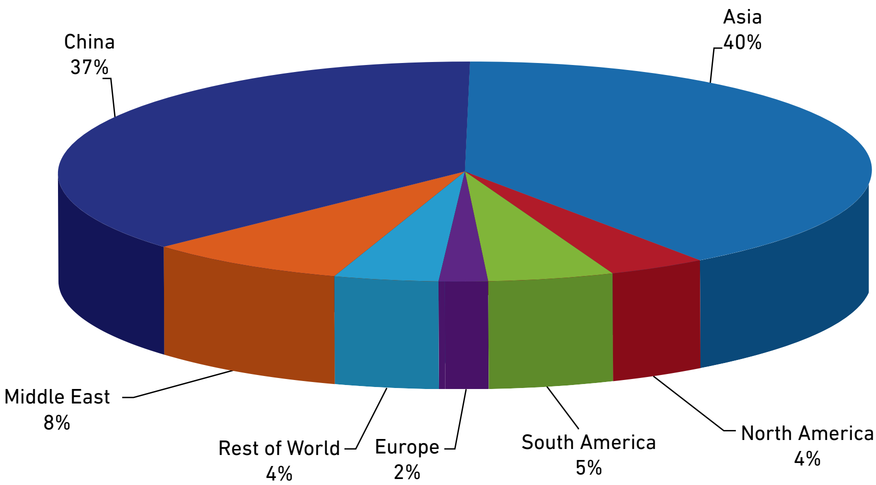
Source: Methanol Market Services Asia (2021).

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.

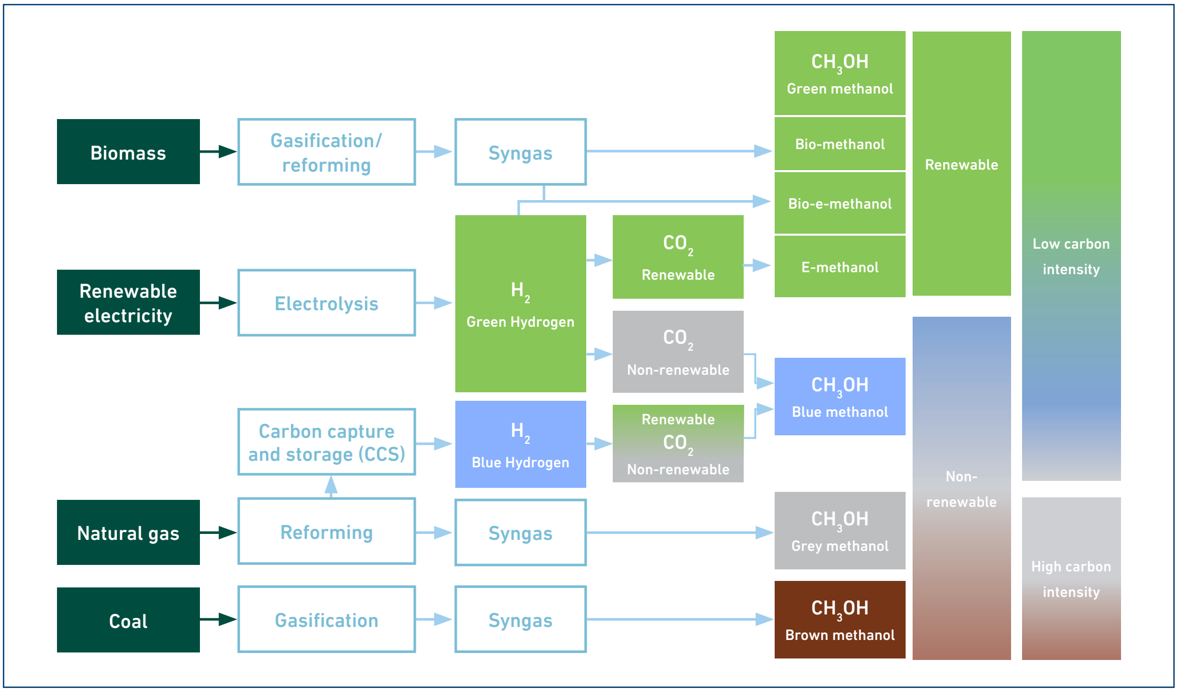
It can be stated that Southeast Asia, specifically Malaysia, Indonesia, and Brunei, have seen significant growth in their methanol industry, with several new methanol production plants being built or planned in these countries (Table 2.5). These plants are being constructed to meet the growing demand 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



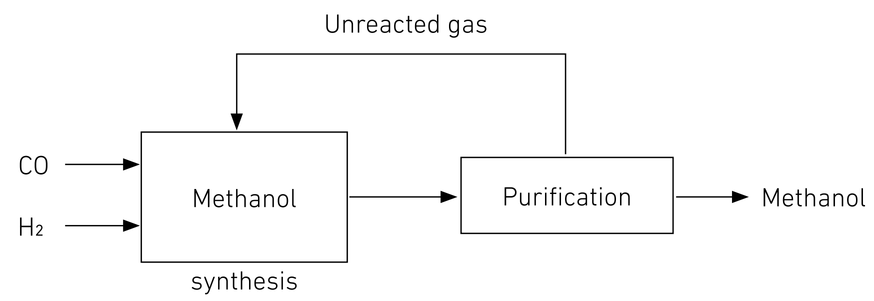
Source: IRENA and Methanol Institute (2021).

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).

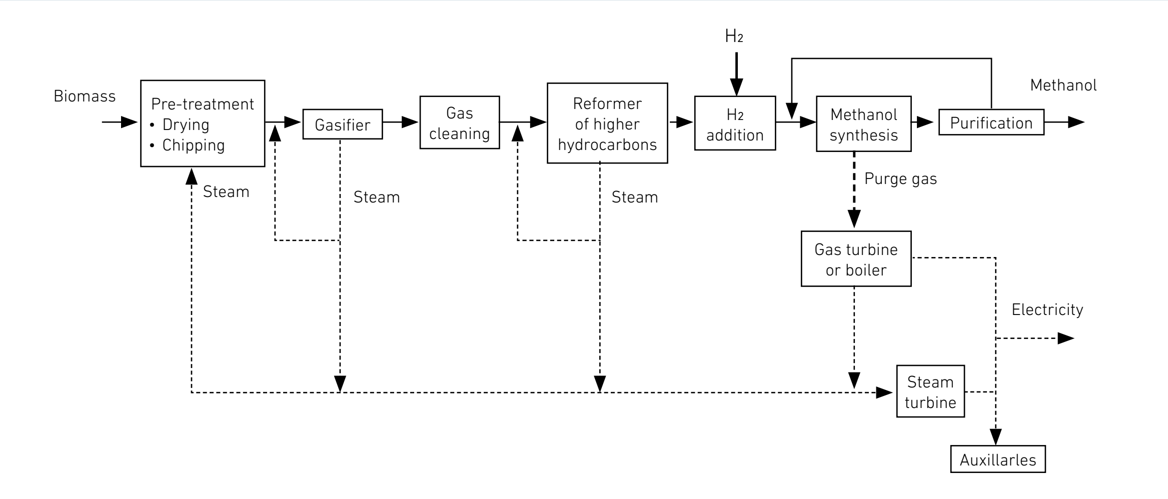
Synthetic gas (syngas) can be obtained via a number of routes. If the raw material is natural gas or biogas, methane reforming processes, such as steam methane reforming (SMR) and autothermal reforming (ATR), are the most common routes. The processes are conducted over a nickel-based catalyst at high 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.

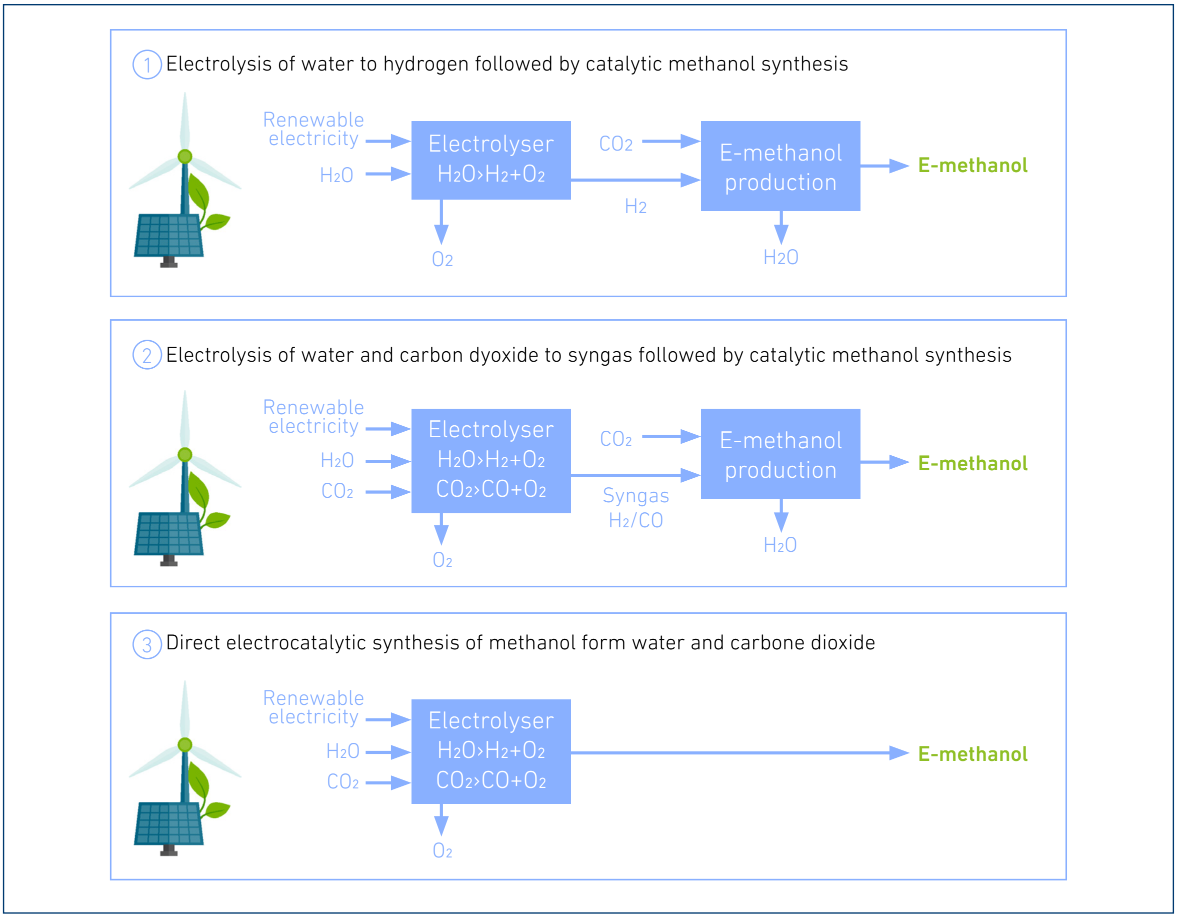
Figure 2.22. Biomass Methanol Synthesis Process



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

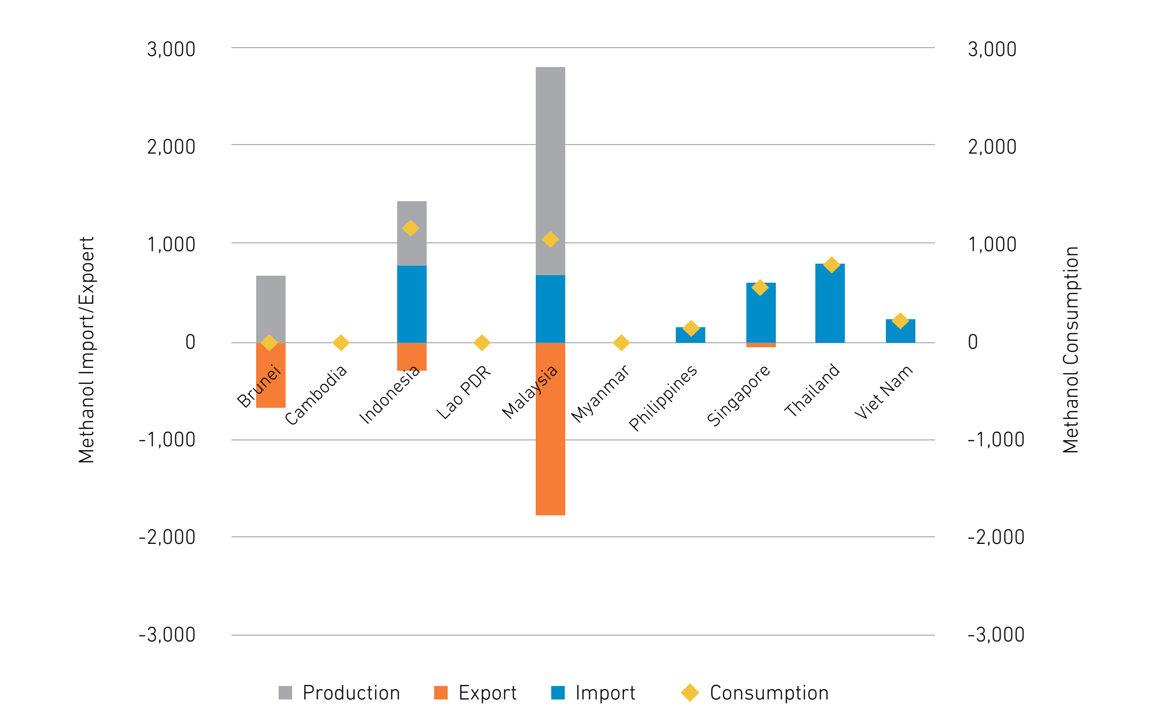
The yearly methanol consumption is calculated from the following equation:

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

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

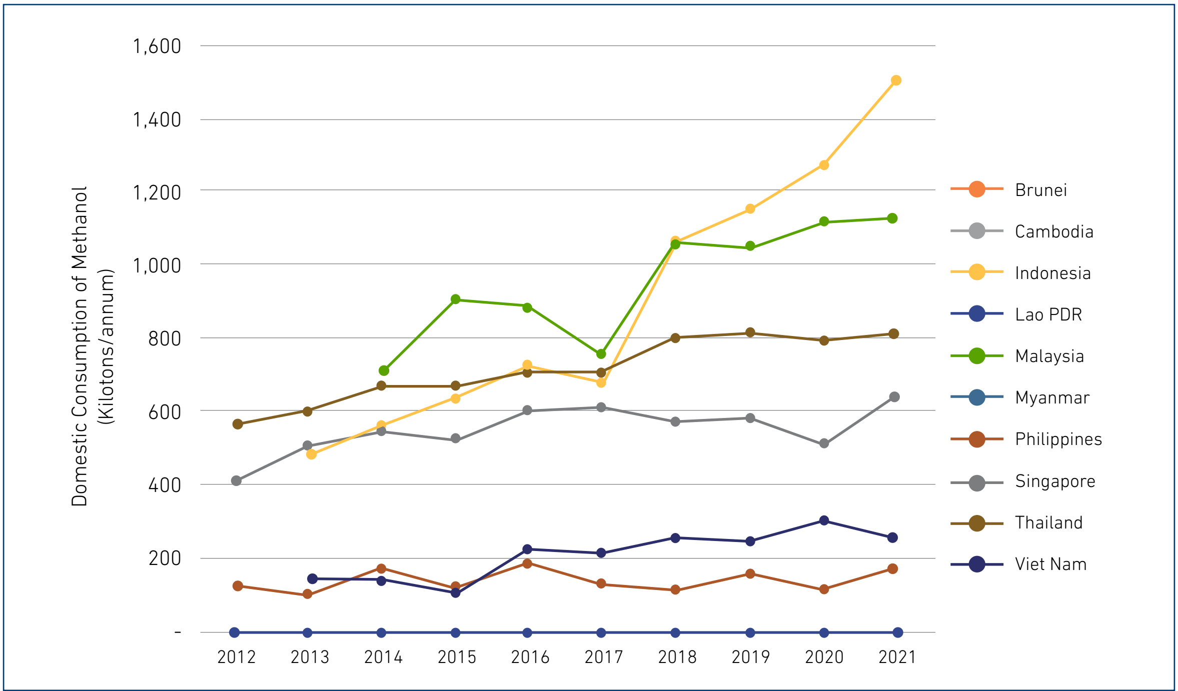
Figure 2.24. Methanol Trade Balance in Southeast Asia in 2019



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.

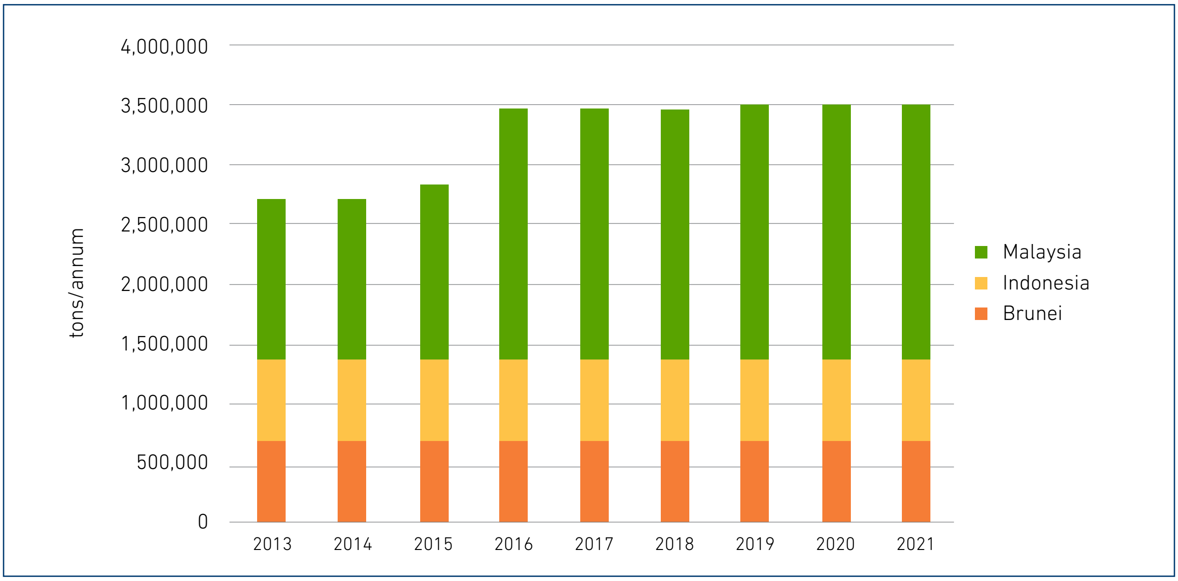
Figure 2.25. Domestic Consumption of Methanol between 2012 and 2021



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.

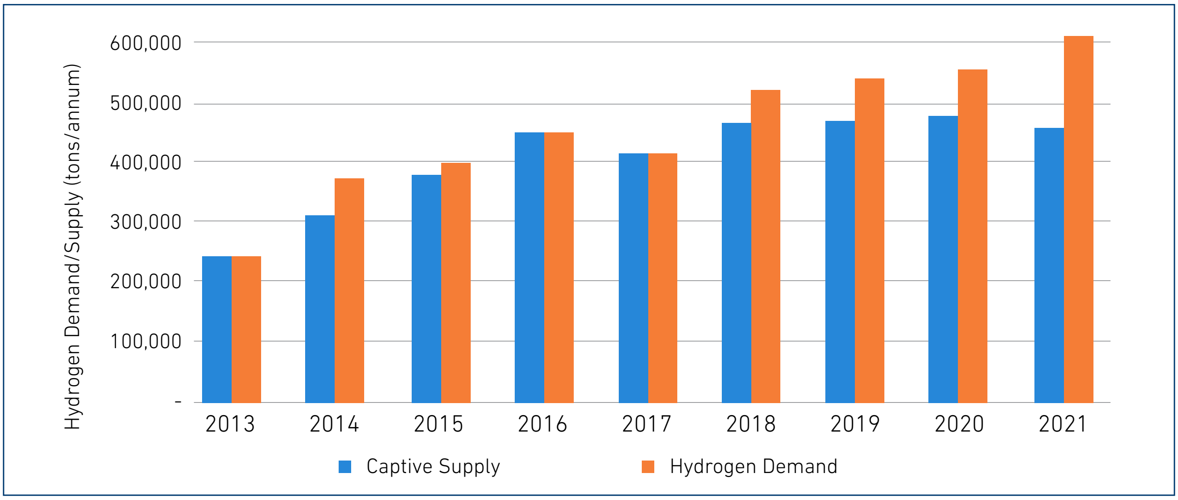
Figure 2.26. Production of Methanol in Brunei, Indonesia, and Malaysia



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 3.50 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.

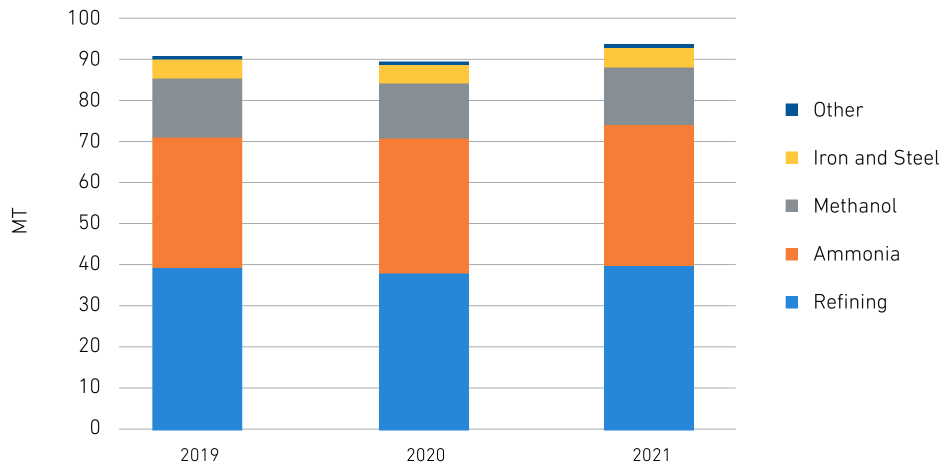
The steel industry requires sustainable technology by transitioning to low-carbon energy sources such as renewable energy and hydrogen, which can reduce the resulting gas emissions. Then, the implementation of carbon capture, utilisation, and storage (CCUS) technology can capture and store CO_2 emissions. 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.

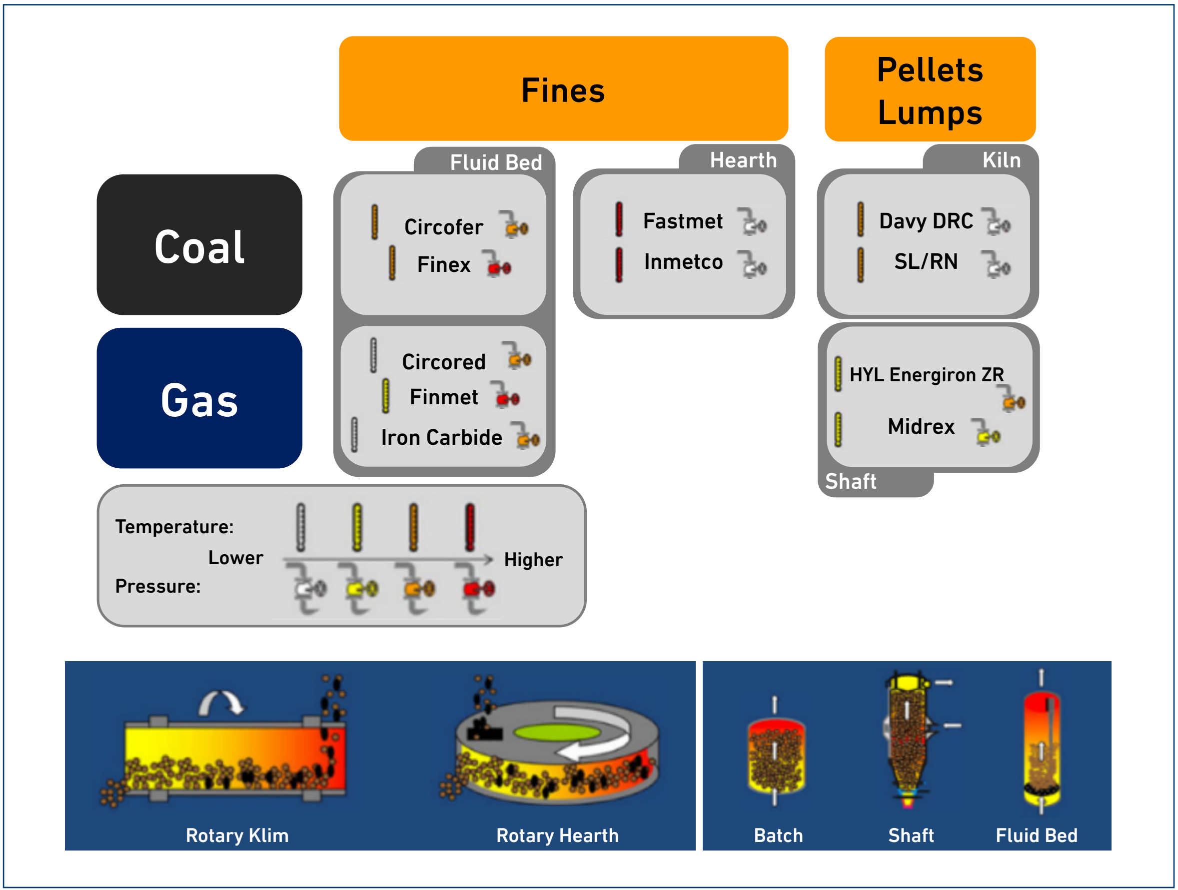
In the direct reduction process, there are several technologies that can be used such as MIDREX, HYL-I, HYL-II, HYL-III, Fion, Finmet, Circored, and others. This direct reduction process produces a product in the form of sponge iron in a solid state. Of the various technologies that can be used, the 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



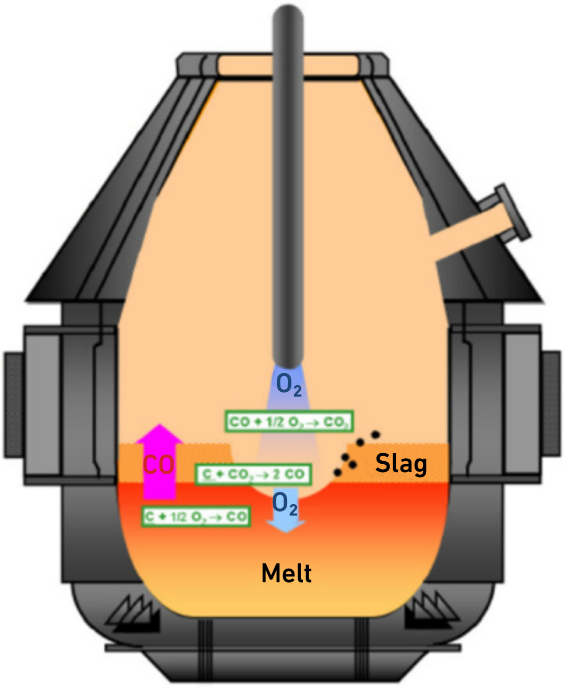
Source: International Iron Metallics Association. (n.d.)

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.

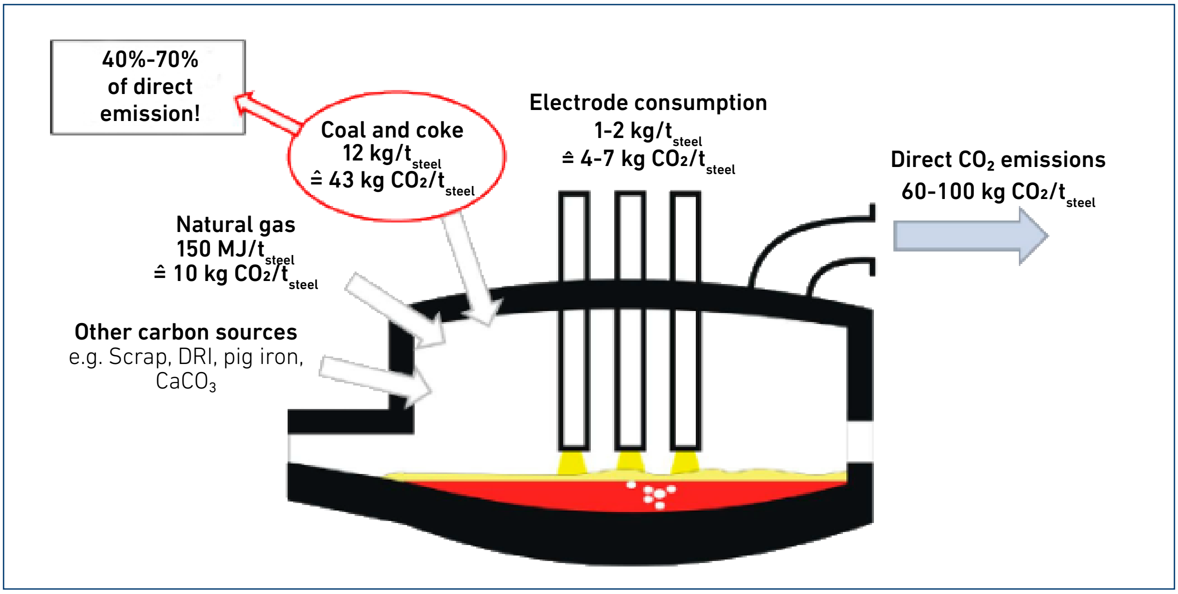
Figure 2.30. Schematic Process of Basic Oxygen Furnace



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

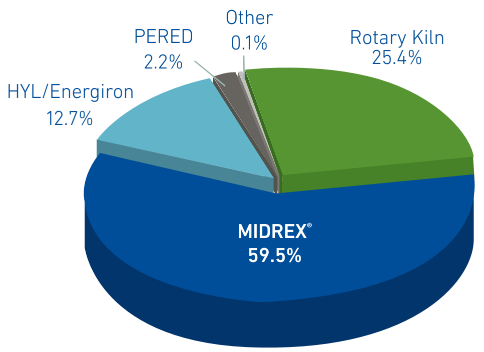


$CaCO_3$ = calcium carbonate, CO_2 = carbon dioxide, DRI = direct reduced iron, kg/t – kilogramme per ton, MJ = megajoule.
Source: Demus et al. (2012).

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.

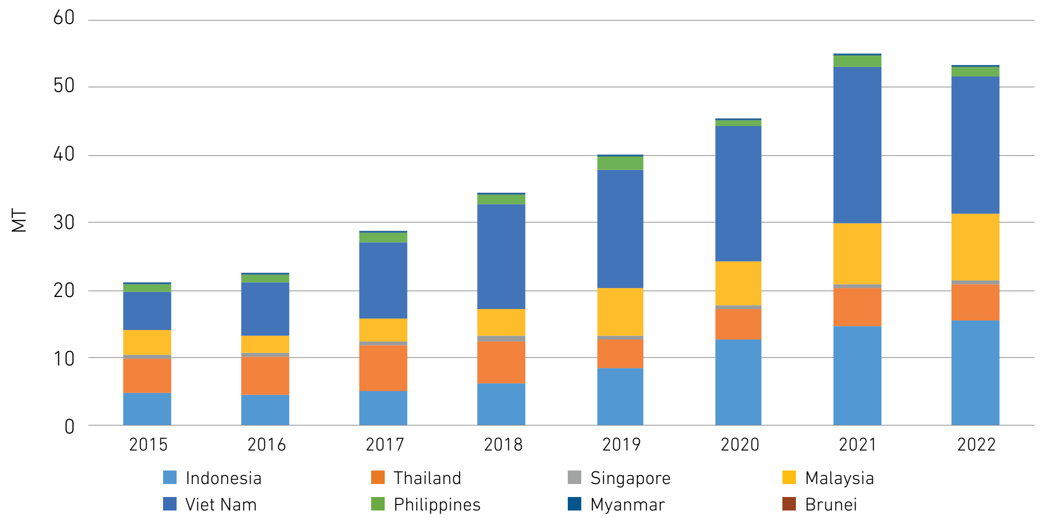
Source: MIDREX Technologies (2021).

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).

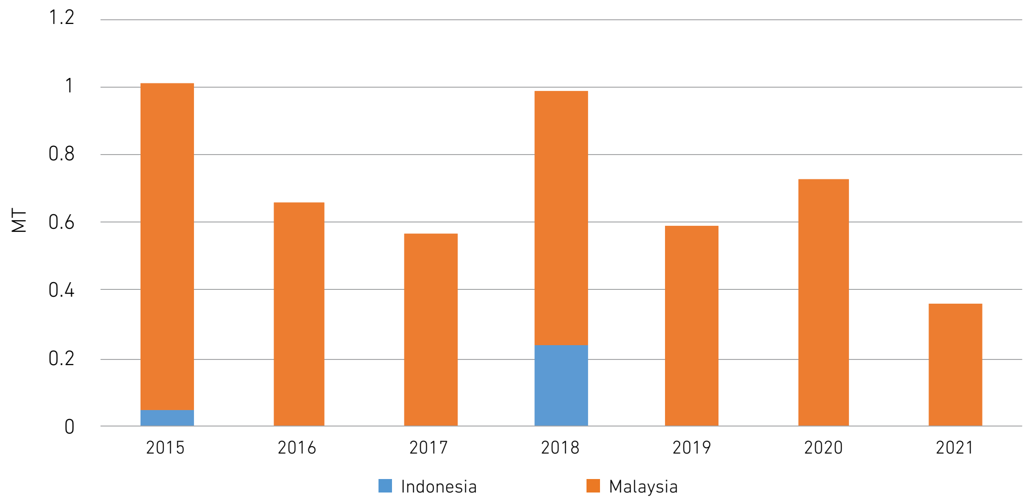
The ASEAN countries before the COVID-19 pandemic consumed more than 80 MTPA of raw steel, in 2021 the amount of consumption decreased to 72 MT. During 2023 it is expected to return to pre-pandemic levels, around 81 MT. This is based on the ASEAN countries such as Viet Nam, Indonesia, Singapore, Malaysia, 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).

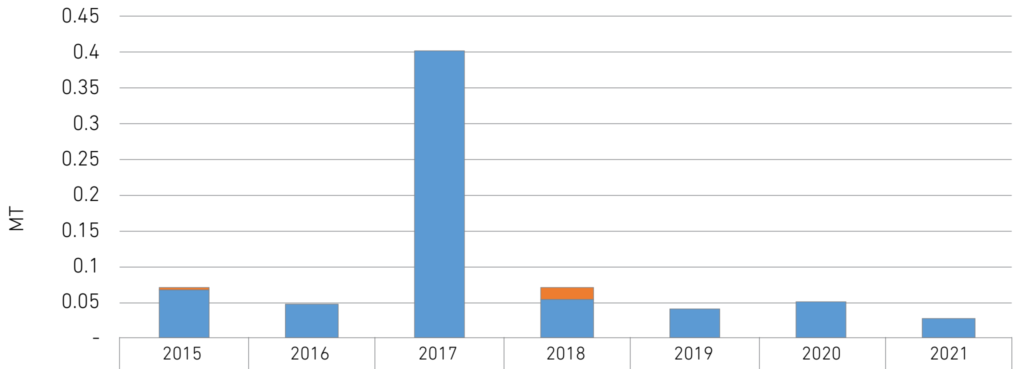
These DRI-based companies use hydrogen as the main raw material to reduce iron ore, except for PT Meratus Jaya because it uses rotary kiln technology. Companies such as PT Krakatau Steel, Antara Steel Mills, Lion DRI, and Perwaja Steel use hydrogen reducers supplied by other companies. PT Krakatau Steel 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).

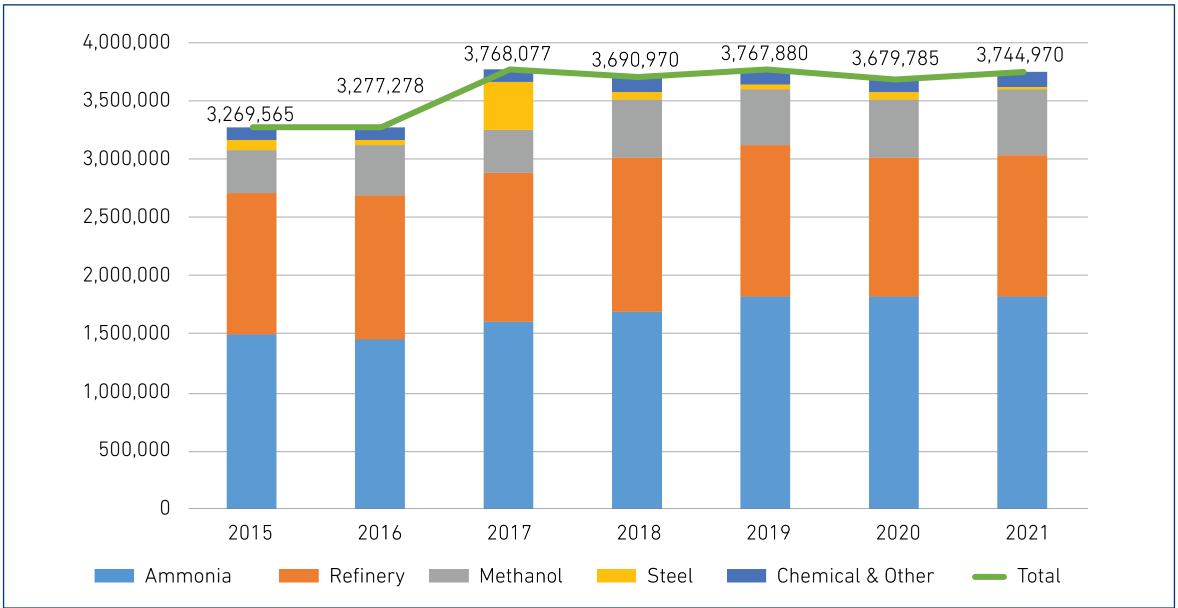
5. Total Hydrogen Demand and Supply in Industry Sectors

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)

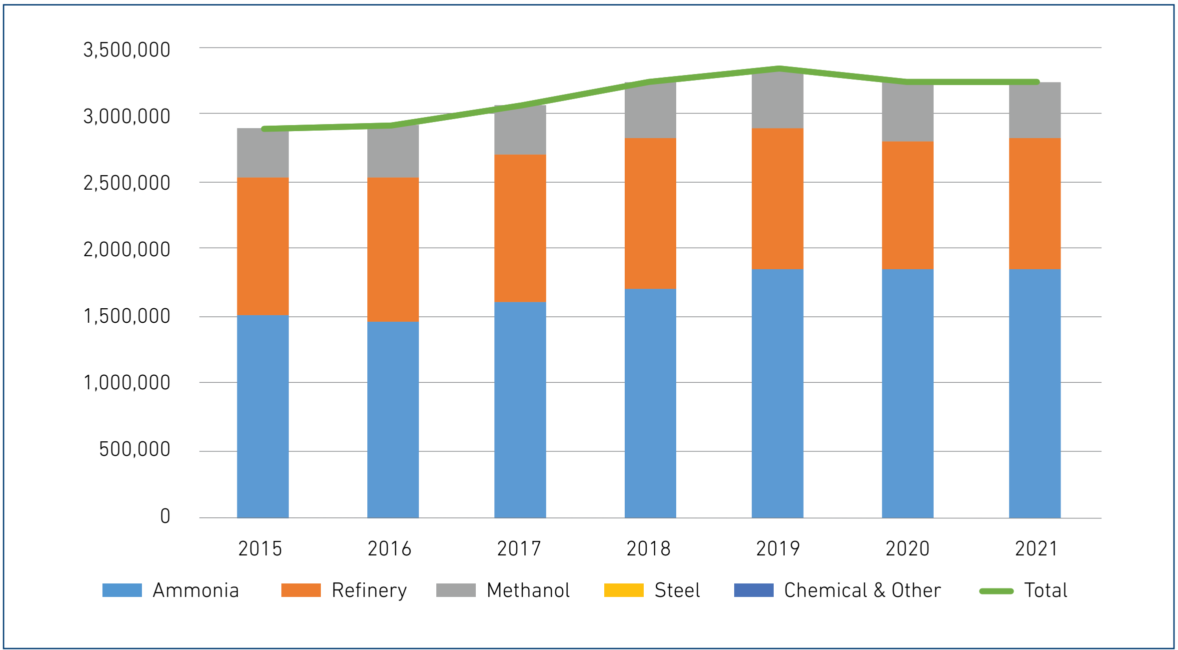


TPA = tons per annum.

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.