International Hydrogen Ramp-up Programme – H2Uppp

Green H_2 and Derivative Products in Southeast Asia: Regional Trade Dynamic Study

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Preface

Welcome to this in-depth study on the evolving landscape of green hydrogen (gH_2) and its derivative products in Southeast Asia, a region poised to play a crucial role in the global energy transition. As the Project Manager overseeing this initiative, I am pleased to present a comprehensive analysis that not only charts the current state of gH_2 in the region but also offers strategic insights into its future development.

This study, conducted under the auspices of the H2Uppp programme, reflects a collaborative effort aimed at fostering the growth of the gH_2 economy in Southeast Asia. The region's energy landscape is as diverse as its countries, each with unique challenges and opportunities in harnessing gH_2 and its derivatives. Countries like Vietnam, and Malaysia are emerging as players in gH_2 production, while others, such as Singapore, Indonesia, and Thailand, will see demand growth. This dynamic interplay between supply and demand underpins the region's potential to become a hub for gH_2, particularly as countries continue their paths towards decarbonisation.

Our study provides a detailed examination of the gH_2 and derivatives markets across Southeast Asia, focusing on each country's current and potential roles. We explore the diverse infrastructure, political ambitions, and economic drivers that shape the gH_2 market, while also identifying the critical sectors where gH_2 can have the most significant impact, such as the refinery, fertilizer and chemical, as well as the transportation sector.

This study is not merely an academic exercise; it is a comprehensive resource for policymakers, industry leaders, and stakeholders committed to advancing Southeast Asia's role in the global energy transition. Moreover, the findings should encourage leaders to foster strategic alignment and regional cooperation, as these are essential components in overcoming the challenges of infrastructure development, cost competitiveness, and regulation. By focusing on sectors where gH_2 is most viable and encouraging regional trade to optimize costs and resources, Southeast Asia can establish a strong position in the global gH_2 market.

I extend my deepest gratitude to all the contributors and collaborators who have made this study possible. It is my hope that this work will inspire informed decision-making and foster the collaborations necessary to achieve a sustainable and prosperous energy future for Southeast Asia.

Thank you for engaging with this important work.

Tim Nees
Project Manager, H2Uppp Southeast Asia

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Abbreviations and units

ASEAN	Association of Southeast Asian Nations
AEC	Alkaline Electrolysis Cell
BEV	battery electric vehicles
Bn.	Billion
BOE	Barrel of oil equivalent
BOF	Basic oxygen furnace
CAPEX	Capital expenditure
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon capture and storage
CCU/S	Carbon capture and utilisation and/or storage
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DAC	Direct air capture
DME	Dimethyl ether
EAF	Electric arc furnace
EGAT	Electricity Generation Authority of Thailand
EU	European Union
FCEV	Fuel cell electric vehicle
FLH	Full load hours
FQD	Fuel Quality Directive
FSRU	Floating storage and regasification unit
GO	Guarantees of Origin
gH_2	Green hydrogen
GHG	Greenhouse gas
GW	Gigawatt
GWh	Giga watt hour
H_2	Hydrogen
HDR	Hydrogen direct reduction
HETR	Hydrogen Economy and Technology Roadmap
Hpa	Hours per annum
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
kg	Kilogramme
km	Kilometer
kgpa	Kilogramme per annum
ktH_2pa	Kilo tonnes of hydrogen per annum
LCOE	Levelised cost of electricity
LCOH	Levelised cost of hydrogen
LOHC	Liquid organic hydrogen carriers
LNG	Liquefied natural gas
mil.	Million
MoU	Memorandum of understanding
Mt	Mega tonnes
MtH_2pa	Mega tonnes of hydrogen per annum
Mtoe	Mega tonnes of oil equivalent
Mtpa	Mega tonnes per annum

MW	Megawatt
MWh	Megawatt hour
N_2	Nitrogen
N_2O	Nitrogen dioxide
NH_3	Ammonia
NO_x	Nitrogen oxides
NREL	National Renewable Energy Laboratory
O_2	Oxygen
OPEX	Operational expenditure
PEM	Proton exchange membrane
PtL	Power-to-Liquid
PtX	Power-to-X
PV	Photovoltaic
RE	Renewable energy
RED II	Renewable Energies Directive II
RFNBO	Renewable fuels of non-biological origin
RFS	Renewable Fuel Standard
RNBFOs	Renewable Natural Gas (RNG), Biofuels, and Bioproducts
SAF	Sustainable Aviation Fuel
SEA	Southeast Asia
SMR	Steam methane reforming
SOEC	Solid oxide electrolysis cells
$tCO_{2\text{-}eq}/tH_2$	Tonne of CO_2 equivalent per tonne H_2
tH_2pa	Tonnes of hydrogen per annum
tpa	Tonnes per annum
TRL	Technology readiness level
US	United States of America
USD	US-Dollar
VSPP	Very small power producer
WACC	Weighted average cost of capital
Wt%	Weight percentage

1 Introduction

In the wake of the global climate crisis and the urgent need to transition to sustainable energy sources, green hydrogen (gH_2) has emerged as a beacon of hope globally. At its core, gH_2 is produced by electrolysis, using renewable energy (RE) sources such as solar and wind power to split water molecules into hydrogen (H_2) and oxygen (O_2). Unlike its fossil fuel-based grey counterpart, gH_2 emits no greenhouse gases during its production and use, making it a cornerstone of sustainable energy systems. As the Southeast Asian region grapples with rapid industrialisation, urbanisation and energy demand, the search for clean and reliable energy solutions has never been more critical. Southeast Asia (SEA) is at a crossroads, facing the dual challenge of meeting its growing energy needs while mitigating environmental degradation and reducing carbon emissions. Traditional fossil fuels continue to dominate the energy mix, posing myriad environmental and economic challenges. However, the emergence of gH_2 offers a compelling alternative that promises to decarbonise key sectors such as transport, industry and power generation.

The SEA region, with its abundant RE resources and strategic geographical location, provides a ripe environment for the deployment of gH_2 technologies. Countries such as Singapore, Malaysia and Vietnam have already made significant strides in advancing their H_2 agendas, recognising the immense potential of this clean energy vector in promoting economic growth, energy security and environmental stewardship. Moreover, the transformative impact of gH_2 goes beyond its use as a fuel. Its derivatives, such as green ammonia, green methanol, and other green synthetic fuels, hold the key to decarbonising hard-to-abate sectors like shipping, aviation, and heavy industry. By harnessing these innovative pathways, SEA can unlock new opportunities for sustainable development while accelerating its transition to a low-carbon future. However, realising the full potential of gH_2 in SEA will require concerted and informed efforts from policy makers, industry stakeholders and the wider community. This report explores the transformative potential of gH_2 and its derivatives in reshaping SEA's energy, transport and industrial landscapes, and aims to provide guidance for informed decision-making.

This study is conducted under the H2Uppp programme, which aims to support the H_2 and Power-to-X (PtX) markets in SEA. The focus countries selected for this report in consultation with the H2Uppp programme are Thailand, Singapore, the Philippines, Indonesia, Malaysia, Laos and Vietnam. In order to promote the development of gH_2 and green derivative products based on gH_2 such as green ammonia, green methanol and other green fuels within the region, it is necessary to gain a full understanding of the regional context and analyse the potential and roles in the SEA market landscape. This includes a thorough analysis of the regional status and explore the potential roles that SEA countries could play either as exporters, importers or self-sufficient in this new emerging market. This study provides an overview of global trends and developments in gH_2 and derivatives' markets, and then delves into the SEA perspective, starting with an overview of current markets. It then analyses potential future trends along the entire value chain of production, conversion, transport and end-use of gH_2 and derivative products in SEA. Opportunities for the region are analysed based on current drivers and barriers and the countries' potential roles within a gH_2 and derived products economy. Five high-potential use cases important to the region are highlighted as examples. The study concludes with recommendations and an outlook for the region.

The following chapter provides a brief overview of the most important aspects for understanding global trends and developments in a market for gH_2 and its derivatives. It is important to consider these global developments in the context of regional dynamics. The chapter describes demand and supply dynamics, current production volumes and sources, and the different applications of these products. As the gH_2 market has recently entered a new dimension, the technology status and cost competitiveness are discussed. The opportunities and benefits of using gH_2 are then described and an overview of existing policies and regulations in a global gH_2 and derivatives market and trade is given.

1.1 Current and future market of green hydrogen and derivatives

1.1.1 Demand and supply

As of 2022, the global H_2 use ranged around 95 Mtpa (see Figure 1) [1]. While this production volume is sufficient to cover the current demand, scenarios for a global sustainable development estimate the demand in 2050 to rise above 600 Mtpa. This rapid and strong increase sets out the challenge of scaling up H_2 production while simultaneously decarbonising the existing H_2 supply. Only a small fraction of around 0.1% of the current H_2 supply were produced with RE [1], and thus qualify as gH_2. However, global gH_2 production is growing rapidly. In 2022, the global capacity for gH2 production had increased by 20% compared to the previous year [1], a trend that is likely to continue. In terms of announced gH_2 production projects, the increase was even higher with around 30%. Compared to 0.7 GW electrolyser capacity operational today, an additional 3.9 GW is currently under construction or has reached the stage of a final investment decision; while the global capacity in 2030 could reach up to 420 GW [1], a 600-fold increase compared to the present capacity.

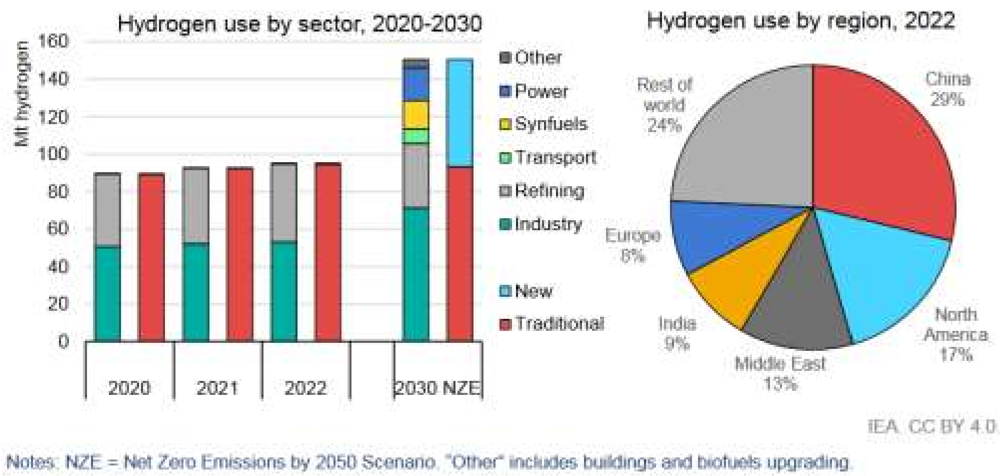


Figure 1: Hydrogen use by sector and by region: Historical and Net Zero Emissions (NZE) by 2050 Scenario, for 2020-2030, taken from IEA (2023)

1.1.2 Production

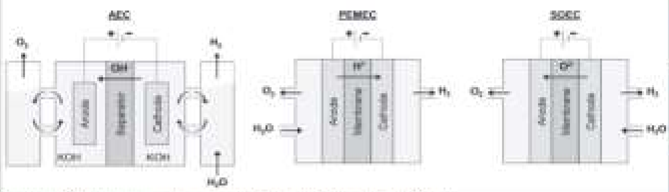
Currently, the vast majority of H_2 produced worldwide consists of fossil-based H_2, which is produced through steam methane reforming (SMR), or the gasification of coal or lignite, resulting in emissions of around 10 tCO_2-eq/tH_2 for SMR and 19 tCO_2-eq/tH_2 for coal gasification [2]. Two primary pathways are being considered to replace emission-intensive fossil-based H_2 with low-carbon production methods: green and blue H_2 [3]. Green H_2 production aligns fully with the net-zero trajectory, utilising water electrolysis technology powered by renewable electricity. Although currently limited, H_2 production from renewables is expected to expand given global interest in its potential. On the other hand, blue H_2, produced from fossil fuels with carbon capture and storage (CCS) technology, offers a way to lower greenhouse gas emissions by retrofitting CCS to existing grey H_2 facilities. However, it comes with risks associated with methane leakage and price volatility [3]. Green H_2 remains the ultimate zero-carbon solution in the long run, and thus will be the focus of this report. Other low-carbon pathways like turquoise H_2 (H_2 production based on thermal cracking of hydrocarbon fuels such as methane, which creates solid carbon particles instead of CO_2), pink H_2 (H_2 from electrolysis powered by nuclear energy), and biomass gasification with CCS exist, but are not addressed in this report.

When looking at the production of gH_2, different technology options for electrolysis exist; alkaline electrolysis cells (AEC), proton exchange membrane (PEM) electrolysers and solid oxide electrolysis cells (SOEC). Figure 2 provides and overview of these three technological option for gH_2 production and compares the technology readiness level (TRL), their water demand, efficiency, space requirements, capital expenditure (CAPEX) and operational expenditure (OPEX) [4]. While SOEC electrolysers are more energy efficient and have a longer lifetime, they also come with higher capital costs and water needs. With a TRL of 9 AEC is the most mature technology option with the lowest space requirements but has a slightly higher water demand than PEM electrolysers.

Water Electrolysis

Process

- Water is separated into hydrogen and oxygen emitting heat as a by-product
- Water needs to be purified before it gets into the electrolysis
- Input temperature and pressure vary between each technology
- Hydrogen output purity is in the range of 99.99 %



Source: OSCE, RLI: Promoting Green Ports and Connectivity (2022)

	AEC	PEM	SOEC
TRL:	9	5-8	4-6
Water demand:	180 kg/MWh	157 kg/MWh	209 kg/MWh
Efficiency:	63-70 %	56-60 %	74-81%
Area:	12.5 m²/MWh	20 m²/MWh	35 m²/MWh
CAPEX:	750 -1,400 €/kW	800 -1,800 €/kW	800 -2,300 €/kW
OPEX in % of CAPEX:	2-4	2-4	5-7

Figure 2: Overview of green hydrogen production technologies, taken from OSCE and RLI (2022)

The production of derivatives like ammonia and methanol are conventionally performed with grey H_2, usually relying on on-site production of H_2 through SMR. The production technologies of synthetic green fuels encompass a variety of methods including biofuels derived from biological materials like vegetable oils and animal fats, H_2 fuels synthesised by reacting H_2 with CO_2, power-to-liquid (PtL) fuels generated from renewable electricity converting water and CO_2 into liquid fuel. Another method involves capturing CO_2 from the air or industrial facilities and combining it with renewable H_2 to produce synthetic fuels, showcasing the versatility and potential for sustainability in synthetic fuel production. Common refinement methods include Fischer-Tropsch conversion and methanol conversion [5]. In the case of ammonia production, a reaction of H_2 and nitrogen is induced in the so-called Haber-Bosch process. While there are some aspects to the complex tightly integrated production steps of ammonia that are changed by the switch from SMR to electrolysis leading to an overall reduction of complexity (further explained in Section 2.3.3.1), the basic chemical process of the Haber-Bosch process remains the same [6]. Green methanol production combines CO_2 and H_2 through a chemical synthesis process, using H_2 derived from renewable electricity and biogenic CO_2 sources like those found in the paper and pulp industry, methanol production, biomass power plants, and waste-to-energy facilities [5].

1.1.3 Storage and transportation

The competitiveness of H_2 depends heavily on transport and storage costs. Long-distance H_2 transmission could potentially triple the cost of local H_2 production, and the efficient operation of extensive H_2 value chains relies heavily on ample storage capacities. The challenge of long-distance H_2 transmission and local distribution arises from its low energy density per volume. Options such as compression, liquefaction, or integration into larger molecules present potential solutions, each with its own set of advantages and disadvantages. The optimal choice depends on factors such as geography, distance, scale, and intended use. Integrating H_2 into existing natural gas pipelines could secure H_2 supply without requiring investment in new infrastructure. For overseas transport, H_2 transport options include the shipping of liquefied H_2, the conversion to ammonia prior to transport or transport in the form of liquid organic hydrogen carriers (LOHCs) [2]. The most feasible transport option depends on the distances and volumes of H_2 or derivatives to be transported. Pipeline transport is considered the most cost-effective option for distances below 1,500 km, while shipping as ammonia or LOHCs becomes more economically feasible for longer distances (e.g. intercontinental) [7]. Other studies state that pipelines remain competitive for even larger distances, up to 4,000 km or even 8,000 km if an already existing pipeline is being repurposed [8]. In any case, pipelines may emerge as the most cost-effective option for local H_2 distribution with sustained and localised demand. At present, distribution relies heavily on trucks transporting H_2 as gas or liquid, a trend likely to persist in the coming decade [2].

1.1.4 Applications

1.1.4.1 Current applications

Currently, the largest share of H_2 is used as a feedstock in industrial processes and refining, which together account for almost all of the worldwide use of H_2 (see Figure 1, Section 1.1.1). Of the global volume of 90 Mt H_2 produced each year, around 41 Mt are used by its largest consumer, the refining industry, followed by the production of basic chemicals like ammonia (32 Mt), and methanol (16 Mt) [1]. Around 80% of ammonia produced globally is used for the production of fertilisers [9]. Methanol on the other hand serves as a basic chemical for various products like synthetic fibres, plastics, resins or sugars [10]. The production of ammonia and methanol, as well as oil refining, are likely to be among the priority sectors for the use of gH_2, as these industries already use H_2 commercially and there is currently no real alternative to the use of H_2 [11]. While technologically feasible, the switch to gH_2 is currently associated with significantly higher costs. For example, the cost of gH_2-derived methanol is currently 960 €/t, which is more than double the price of fossil-based methanol [12]. The largest cost variable is the price of RE for electrolysis [12].

1.1.4.2 Future applications

In the future, gH_2 and derivatives will also have to be used in areas which are currently not relying on H_2 as a feedstock to achieve decarbonisation objectives. These new uses include the use of H_2 both a new feedstock, which plays a role in the industry sector, as well as an energy carrier, which plays a role across all sectors, including industry, transport, and power generation. H_2 as an energy carrier will be especially relevant in areas in which direct electrification is not a viable option. These may include transport (here, H_2 is mostly considered in form of derivatives like ammonia and synthetic fuels to decarbonise especially aviation and long distance cargo shipping), but also the use in the power sector (as a storage option for excess RE or as a fuel in gas power plants), or for district heating [13]. An overview of useful future applications of H_2 or derivatives is depicted in Figure 3 [14]. In the following, some examples of gH_2 application in the industrial sector (steel and aluminium production, process heat provision) as well as the power sector are given. More details can also be found in Section 2.3.3 where high-potential use cases for the SEA region are being analysed.

In the industrial sector, the steelmaking industry is currently the most advanced in decarbonisation through the replacement of coke with H_2 as a reacting agent for the reduction of iron oxide. The method most frequently used here is hydrogen direct reduction (HDR). HDR slightly changes the product of the reaction, producing so called sponge iron (due to its porosity), which must be fed into another furnace to be converted into crude steel [15]. This method of steelmaking is already applied, leading to a H_2 demand of the steel industry reaching around 5 Mtpa in 2022 [1]. Electric arc furnaces for recycling steel scrap also offers a cost-effective method for reducing emissions in steelmaking, potentially lowering costs by up to 49%. This approach uses significantly less energy than traditional methods and benefits from cheaper raw materials compared to primary steel production [16], [17].

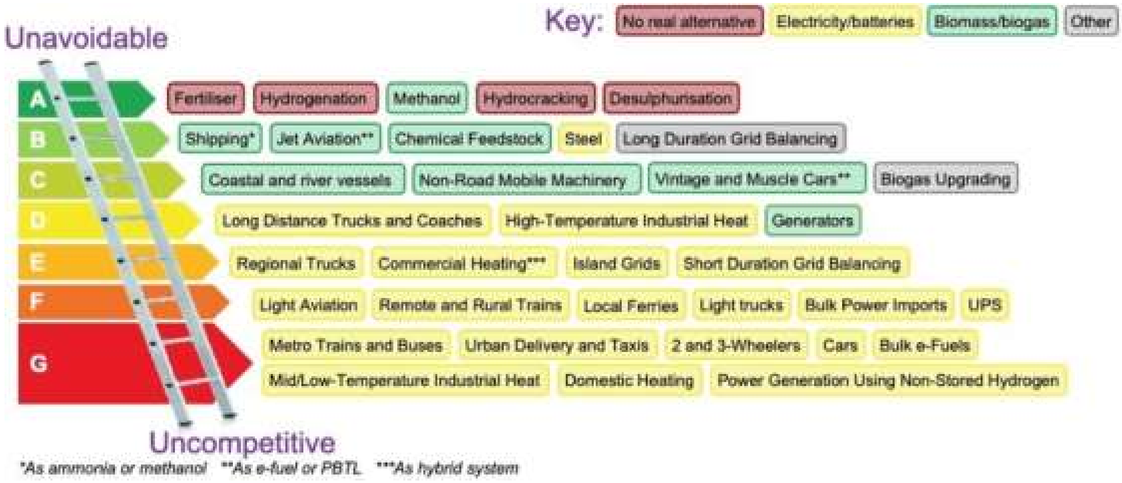


Figure 3: The "green hydrogen ladder": Useful applications for green hydrogen and hydrogen derivatives, taken from Michael Liebreich (2023)

Other potential fields of application in the industrial sector is the use of H_2 instead of natural gas for the calcination of alumina in the aluminium industry, which has been tested in industrial-scale trials [18]. Furthermore, the combustion of H_2 can replace coal and natural gas in the provision of high temperature heat in various industrial processes. This may be relevant in the cement industry, where the fossil fuels used to provide temperatures of up to 1,450°C might be replaceable through the use of H_2-fired kilns in the near future [19]. However, indirect electrification through gH_2 use can only reduce up to 40% of the emissions associated with cement production, since 60% of the emissions originate from unavoidable process emissions, which would require carbon capture and utilisation and/or storage (CCU/S) technology to be avoided. The potential of H_2 is furthermore called into question by the existence of other alternative fuels like biomass or municipal solid waste (MSW).

In the power sector, the use of H_2 and derivatives is under discussion, but contested due to the conversion losses when transforming and re-converting electricity to H_2, which come with high costs and energy losses. In contrast to pure H_2, which can only be blended with gaseous fuels, ammonia can be used to co-fire both gas and coal power plants. At present, there is no progress being made towards developing ammonia-fired power plants that operate solely on ammonia because of worries about emissions. Although ammonia does not contain carbon and therefore does not produce CO_2 upon combustion, it comprises a significant amount of nitrogen. When this nitrogen (N_2) is burned, it leads to the formation of nitrogen oxides (NO_X), which is an indirect contributor to climate change, and eventually can lead to the formation of nitrous oxide (N_2O). Nitrous oxide possesses a much stronger greenhouse effect than CO_2, being up to 298 times higher. [9]. With current technology, N_2O emissions become difficult to control for ammonia concentrations of above 70% [20]. Although several countries, spearheaded by Japan and South Korea are investing in green ammonia co-firing to lower emissions of coal-fired power plants, such policies are generally discouraged. The reasons are manifold: Electricity generated from ammonia co-firing is comparatively expensive, it extends the usage of coal, it may lead to food insecurities due to a shortage of ammonia available for fertiliser production, and it detracts funding from more efficient decarbonisation technologies [21].

1.1.5 Technology status and cost competitiveness

While the installed capacity of electrolysers shows technological feasibility and applicability on an industrial scale, supporting infrastructure such as RE deployment or transport routes required for decarbonisation still need to be improved. The current pace of new production site project announcements and developments lags behind ambitious production targets due to high production costs, lack of supporting renewable and CCU/S infrastructure, long lead times for final investment decisions, and challenges in securing financing and permitting [1]. Another current bottleneck is the technology readiness of long distance gH_2 transportation with regard to maritime H_2 trade, since there is only one prototype vessel that can transport liquid H_2 [3]. Several companies are engaged in the creation of liquefied H_2 tankers, with plans to have them operational by 2030. These tankers are designed to carry up to 160,000 m^3 of H_2, equivalent to approximately 9,600 tons of liquefied H_2 [1]. In the power sector recent developments show availabilities for gas turbines, which function without problems for H_2-natural gas blends and some even with 100% H_2.

The market readiness for green ammonia projects is still at an earlier stage of development. In 2023, the ACME Group embarked a pioneering venture by establishing a 4 MW alkaline electrolysis pilot plant in Bikaner, India, designed to significantly advance the de-risking of large-scale renewable ammonia production. This initiative, which commenced operations in November 2021, is projected to yield approximately 1,500 tonnes of ammonia annually, marking a significant milestone in the advancement of green ammonia technology. Simultaneously, Unigel took steps towards decarbonising its ammonia production processes at its facility in Camaçari, Brazil, by introducing 60 MW of alkaline electrolysis capacity. This expansion, set to commence in the current year, aims to harness the country's extensive RE generation capabilities through grid-connected electrolysers, potentially producing up to 60,000 tonnes of ammonia yearly. Furthermore, Yara and ENGIE made substantial progress with Project Yuri in Karratha, Australia, securing final investment decision approval in the preceding year. This project incorporates 10 MW electrolysers alongside 18 MW of combined solar photovoltaic and battery storage systems, facilitating the production of 3,600 tonnes of ammonia annually at the adjacent Yara Pilbara Fertilisers plant. The green ammonia production landscape is witnessing the emergence of numerous multi-gigawatt projects, underscoring the ambition to establish world-scale, electrolysis-based ammonia plants capable of producing one million tonnes of ammonia annually. Notably, the NEOM project in Saudi Arabia, with a contract secured for the provision of at least 2 GW of alkaline electrolysers by Thyssenkrupp, and the Australian Renewable Energy Hub, featuring over 14 GW of installed electrolyser capacity planned as combined gH_2 and green ammonia plant, stand out as prominent examples of these ambitious endeavours [22].

The main roadblock to the widespread adoption of gH_2, however, is the fact that it is still far more costly than its fossil alternatives. With strong regional variations, the current levelised cost of hydrogen (LCOH) for gH_2 ranges between 2.7–6.0 USD per kgH_2 under "best" and "average conditions, respectively, but could drop as low as 0.8–1.2 USD per kgH_2 in the future under optimal conditions [4]. Important cost drivers to be considered for the production of gH_2 are the cost of RE as well as CAPEX for electrolyser components and the construction works, the weighted average cost of capital (WACC) and the efficiency and lifetime of the electrolyser [23]. While these can be expected to drop due to technological improvements and scaling effects, it is unclear whether the optimistic assumptions for the low costs presented in the future scenario by IRENA will ever manifest. In particular, global inflation, which increases the cost of investment, is seen as a major problem, increasing the cost of projects already underway and slowing the development of new projects. [1]. Since the cost of electricity is a major determinant and since gH_2 requires all electricity input to come from renewable sources, the LCOH is expected to be the lowest where the most abundant and reliable RE sources are available. Thus, for certain regions, importing H_2 may prove more economical than domestic production. For instance, in Japan, importing H_2 from Australia could be cheaper than domestic production by 2030. Similar scenarios may unfold in Korea and parts of Europe [2]. Direct utilisation of ammonia in end-use sectors could further enhance the competitiveness of imports. In addition, energy-importing countries may consider H_2 imports to increase energy diversity and access to low-carbon energy sources, even if they are not the cheapest option [2]. The emergence of new patterns of import and export in a global H_2 economy might give rise to new geopolitical dynamics and opportunities, which have been widely discussed in the literature (see [3], [24]).

1.2 Opportunities of green hydrogen and derivatives

Green H_2, whether occurring in its pure form or as derivative product, is an important building block for an emission-free energy system and industry, as well as a potential fuel for carbon-neutral transport options and thus for global efforts to mitigate climate change. Since no CO_2 emissions emerge in the electrolysis of water and the operation of RE production facilities, gH_2 can be considered an emission-free gaseous energy carrier. Already replacing fossil-based H_2 with gH_2 has an enormous emissions saving potential, given that the production of H_2 currently emits around 830 tCO_2 every year [2]. When considering possible future applications of gH_2, the emission saving potential becomes significantly higher. Green H_2 is particularly viable as a decarbonisation option in sectors in which the simple switch from fossil to renewable sources or decarbonisation through direct electrification is impossible or not sufficiently developed. A particular field of interest might be the so-called energy-intensive industries which are currently responsible for roughly 20% of global CO_2 emissions [25] . As pointed out above (see Section 1.1.4), the steel industry, where direct reduction with green H_2 can eliminate the otherwise hard to avoid process emissions provides a technologically mature example for areas in which gH_2 can unfold its decarbonisation potential [26], [27], as well as the production of ammonia and methanol and their downstream products. Green ammonia and green methanol, for example, in addition to reducing emissions compared to their conventional production forms (see Sections 2.3.3.1 and 2.3.3.2), can replace fossil fuels in various industrial processes, including steelmaking and chemical production, significantly reducing their carbon footprint.

The opportunities of gH_2, however, are not limited to environmental benefits, but may also entail political and economic opportunities. Since RE resources are geographically less concentrated than fossil ones [24], gH_2 could provide an opportunity for countries previously dependent on imports of fossil fuels to increase their energy autonomy. On the other hand, setting up gH_2 infrastructure like electrolysers and solar PV or wind turbine technology, still depends on critical raw materials, which are rarer and thus even more geographically concentrated than fossil fuels. First trends regarding the role of some regions in the global gH_2 economy can already be observed. These include a stronger import-orientation of the European Union (EU), Japan and South Korea, parallel to the emergence of states in the gulf region and North Africa as strongly export-oriented gH_2 producers and the development of China and the United States as major prosumers of gH_2 [24]. Australia, India, North Africa, and the US are key ammonia exporters. Regions like Brazil, Canada, China, and Latin America are mostly self-reliant. Germany, Indonesia, Japan, SEA, and other parts of Asia are significant H_2 importers, influenced by high capital costs. The Middle East also imports due to costly domestic production. Ammonia supply is generally well-diversified across countries, offering a competitive edge to RE over fossil fuels. Future ammonia surpluses will likely come from Australia, India, North Africa, and the US, with Australia being a primary supplier to Asia. Countries like Morocco and Chile could transition from importers to exporters, while Brazil, Canada, China, Spain, and Latin America might achieve self-sufficiency. India's shift towards solar energy could boost its export potential [28]. However, the future of geopolitical developments related to gH_2 trade are facing great uncertainty. Pepe et al. (2022) outline three different scenarios for the future "geopolitics of hydrogen": Future developments might entail a realignment of global power associated with a shift towards a "Gulf-China hydrogen axis"; a manifestation of existing economic imbalances in a new "hydrogen imperialism", or an increasing global disintegration, in which states find themselves in a tension between striving for more energy autonomy through gH_2, while being locked in dependencies due to the requirement of critical raw materials [24]. While it is unlikely that one of these scenarios will play out in its pure form, these examples illustrate that the global transition to gH_2 represents a momentum for geopolitical transformations, and that whether and how the transition to a global gH_2 economy will pan out, depends on the interplay of future policy choices by multiple actors.

1.3 Policies and regulatory framework

In parallel to the rapid growth of gH_2 supply, the global policymaking on gH_2 is taking up pace as well. From September 2021 until September 2022, nine new countries published national H_2 strategies, raising the total number to 26 [1]. In November 2023 the German Society for Chemical Engineering and Biotechnology (DECHEMA) analysed 43 countries or regions with a strategy or roadmap including hydrogen [29]. In addition, during the UN conference on climate change 2023 (COP28), 37 countries (see **Fehler! Verweisquelle konnte nicht gefunden werden.**) signed the mutual recognition of certification schemes for renewable and low-carbon H_2 and derivatives [30].

Figure 4: Countries that signed COP28's UAE Declaration on Hydrogen and Derivatives

Hydrogen strategies are important at highlighting long-term political targets of countries. But the necessary policy framework that is relevant to the global H_2 economy goes far beyond these H_2 strategies, but spans across various policy sectors such as financing, research and development, regulatory standards, subsidies or trade agreements and international cooperation. As depicted in Figure 5, until 2024 more than 50 countries are either in preparation of a national H_2 strategy or it is already available [31].

Figure 5: Global overview on H_2 strategies, taken from COP28 (2023)

Policies for H_2 industry decarbonisation necessitate measures stimulating both supply and demand, alongside infrastructure support. Existing RE -focused policies may serve as a foundation, yet dedicated H_2-specific instruments are crucial. These policies encompass technology, research and development, regulatory incentives, and fiscal measures. Hydrogen technology research and development policies aim to support new technology maturation and scale-up, fostering commercial and industrial adoption [32]. Various nations allocate funds for research and development in academia and industry, exemplified by programs like Australia's CSIRO Hydrogen Roadmap and Europe's FCH 2 JU [32]. Public-private partnerships, such as Australia's ASME Hydrogen Energy Supply Chain, further drive scale-up efforts [32]. In the last years, the world has observed a strong increase in government spending on research and development in the field of H_2 technologies, amounting to more than 1.7 bn. USD in 2022 [1].

At the same time, certification schemes ensuring traceability and accountability of low-carbon H_2 and its derivatives production are critical. Guarantees of Origin (GO) schemes, akin to those for RE, enable gH_2 market functioning. However, there is currently a lack of globally harmonised definitions and assessment areas, which hinders international trade [33]. Nevertheless, this issue is gaining increasing attention, so that a positive development can be observed. In recent years, the sector encompassing gH_2 and its associated products, such as renewable natural gas (RNG), biofuels, and bioproducts, has witnessed substantial progress in terms of certification and regulatory frameworks. These advancements are pivotal in guaranteeing the sustainability, reliability, and safety of these energy carriers and commodities, thus facilitating the shift towards a decarbonised economy. Crucial certifications like ISO 14064 for managing GHGs, ISO 9001 for quality management systems, and ISO 50001 for energy management systems have been foundational in setting benchmarks for the manufacture and utilisation of gH_2 and its derivatives [34]. Concurrently, numerous national and international laws have surfaced to oversee the manufacturing, distribution, and usage of these fuels, with a focus on environmental conservation, energy efficiency, and achieving carbon neutrality objectives. For example, the European Union has enacted the Renewable Energy Directive II (RED II) and the Fuel Quality Directive (FQD) to foster the application of renewable and sustainable fuels, including gH_2 and RNG [35]. Similarly, the United States have initiated policies under the Clean Air Act Amendments and the Renewable Fuel Standard (RFS) programme to spur the advancement and adoption of biofuels and other RE resources [36]. As the market demand for gH_2 and RNBFOs expands, continuous efforts to enhance and broaden these certifications and regulations will significantly influence the trajectory of sustainable energy solutions. An accompanying visual representation in 6 provides an overview of the varying sustainability criteria applicable to H_2 and renewable fuels of non-biological origin (RFNBO). The figure categorises the criteria into several sections, including Regulation/Standard, Market, Purpose, Tracking Models, GHG Emissions, Eligible Carbon Sources, and Land Use. It further distinguishes between criteria that are covered (+), not covered (-), mentioned but not implemented (+/-), lack information (n/a), pending update (tbu), voluntary (V), and those based on the national framework for state benefits (R).

Sustainability criteria for hydrogen/RFNBO	Scheme							Funding programme	Regulations		
Regulation/standard	ISCC Plus	CertifHy	dena Biogas Register	TÜV süd CMS 70	China Hydrogen Alliance´s Standards	Certification Scheme (Japan)	Zero carbon Certification Scheme	H2 Global	LCFS	RED II	RTFO
Market	EU	EU	DE	DE	CN	JP	AU	DE	US/CA	EU	UK
Purpose	V	V	R	V	n/a	V	V	R	R	R	R
Renewable electricity	+	+	+	+	+	+	+	+	+	+	+
Tracking models	MB	B&C	MB	MB;B&C	n/a	B&C	MB	MB	B&C	MB	MB
GHG emissions	Well-to-Wheel	Well-to-Gate	According to demand	Well-to-Wheel	Well-to-Wheel	Well-to-Gate	Well-to-Gate	Well-to-Wheel	Well-to-Wheel	Well-to-Wheel	Well-to-Wheel
Eligible carbon sources	+	tbu	+	out of scope	out of scope	n/a	+	tbu	+	+	+
Land use	+	-	-	-	-	-	-	+	+	-	-

Figure 6: Overview on existing gH_2 and derivatives certifications and regulations

This detailed breakdown underscores the diversity of sustainability criteria for H_2 and RFNBOs and emphasises the necessity for harmonising these criteria to establish a fair competitive environment for both producers and consumers of H_2 and RFNBOs.

Decarbonisation through gH_2 can also be stimulated by carbon pricing or trading schemes. Carbon pricing mechanisms influence energy use and investment decisions, fostering broad adoption of low-carbon technologies. A major concern is the phenomenon of carbon leakage, referring to the relocation of industries to countries with lower or absent prices on emissions, however this can be avoided by border tax adjustments [37]. An example is presented by the EU's recently designed Carbon Border Adjustment Mechanism (CBAM), which requires companies who seek to import their goods from third countries to the EU to purchase a certificate, making sure that they pay a price equivalent to the carbon price that applies to products on the European single market [38].

The CBAM initially applies to selected energy-intensive products, namely cement, iron and steel, aluminium, fertiliser, electricity and H_2. A transitional phase for the introduction of the CBAM started in October 2021, which mainly serves to fine-tune the methodology to account for emission data. During the transitional phase, importers are obliged to document and report the emissions according to the EU's methodology, but do not need to buy certificates yet. From 2026 onwards, importers of products from the respective industries need to declare their emissions and submit emission certificates, which are purchased for the price of emissions equivalent to the one in the European Emission Trading System [39]. An overview of the general functioning of the CBAM mechanism is shown in Figure 7.

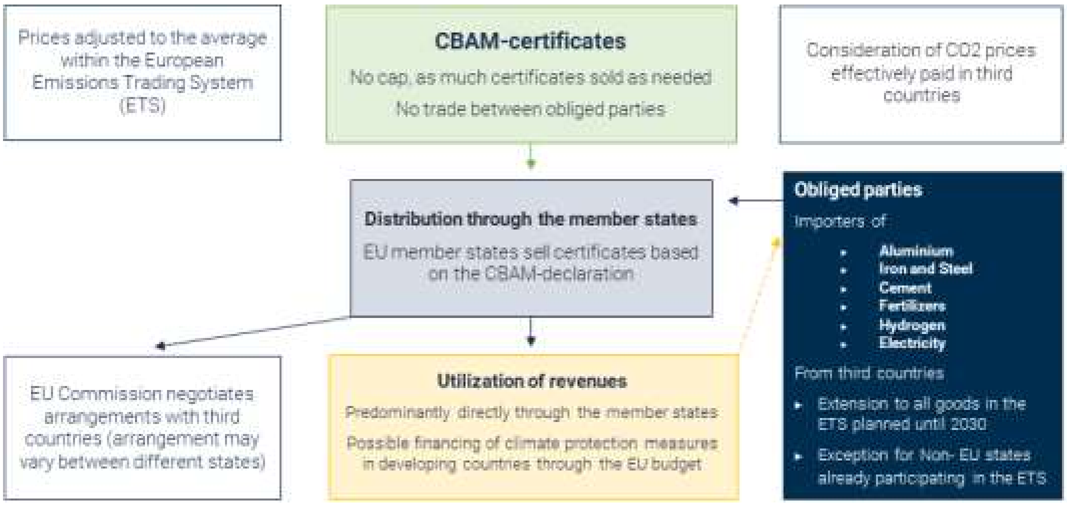


Figure 7: Overview of CBAM functionality

Implications of the CBAM on third countries have been widely discussed, as economic models have confirmed fears of negative economic impacts on countries exporting to the EU. Especially middle and low-income countries with strong economic ties to the EU are seeing a higher share of their domestic emissions covered by the CBAM, putting a stronger pressure on these economies to decarbonise [40]. The indirect impact of the CBAM might even grow as similar adjustments are adopted in countries worldwide. The United Kingdom is expected to adopt legislation analogous to the CBAM, similar policies are currently under debate in Canada and the United States [41]. In light of these developments, decarbonisation seems likely to become a key for current exporters of industrial products to sustain economic stability. gH_2 plays a role not only as a key component of decarbonisation for energy intensive products like steel or fertiliser, but also as a potential alternative export product to compensate for losses caused by carbon border taxing. The global interest in integrating gH_2 into economies is also present in the SEA region, for which the current status and prospects of gH_2 will be reviewed in the following section.

2 Southeast Asian perspective

After the global perspective was discussed in the previous chapter, this chapter is now dedicated to the SEA perspective on gH_2 and its derivatives. First, the current market dynamic of H_2 and its derivatives is summarised, followed by another look at future trend within the region. Last, the opportunities for SEA countries in a gH_2 and derivate economy are being analysed.

It is crucial to mention that the analysis of current trade flows and applications of H_2 are not limited to gH_2 but are currently largely shaped by H_2 derived from fossil fuels. When it comes to H_2 strategies, projects, and cost competitiveness, as well as future market trends, the focus will be on gH_2.

2.1 Current market of hydrogen and derivatives

As in most regions of the world, SEA's H_2 demand is currently primarily covered by H_2 derived from natural gas. With SEA being projected to become a net importer of natural gas by 2025 [42], gH_2 could play a crucial role not only in the transition to a RE system but also in terms of energy security. The overall demand for H_2 in the region, which is currently mainly driven by the industrial sector is estimated to be around 3.2 Mtpa but could grow to up to 11 Mtpa by 2050, if the countries pursue an energy transition pathway in line with the Paris Agreement [43]. Some outlooks prescribe a limited potential for the region to become a relevant player in the emerging global gH_2 economy due to a lack of technology, capital, and infrastructure [24]. However, a closer look at the current status of H_2 and derivative trade presents a more differentiated image. The region includes, on the one hand, traditional importers of gas, such as Thailand and Singapore which have a strong industry sector and limited natural resources. For these countries, a transition to gH_2 could be an opportunity to increase self-sufficiency and reduce imports of natural gas, H_2-derived chemicals like methanol or fertiliser or establish themselves as centres of innovation for new H_2-products, such as synthetic green fuels or green steel. On the other hand, for traditional exporters such as Malaysia, Myanmar, Indonesia, and Brunei Darussalam, a shift to gH_2 could be a chance to use already existing gas infrastructure and diversify their economy, but may also represent a threat to loose geopolitical relevance. But here as well, gH_2 production could help to onshore important industries such as the production of H_2-derived chemicals, which are currently imported by all countries in the region except for Singapore.

This chapter thus seeks to assess the starting conditions for a gH_2 economy to emerge in the given countries, looking at trade and applications of H_2 and its derivatives as well as available infrastructure, gH_2 projects under development, and the status quo of H_2 policy development.

2.1.1 Current applications and demand of hydrogen and derivatives

To determine the potential role of SEA countries in a gH_2 and derivatives economy, it is important to understand the current (mostly grey) H_2 demand and supply structures and applications. Therefore, available information on H_2, ammonia and methanol demand and application is given for each focus country and the information is summarised in the table below.

The highest H_2 demand within the region is found in **Indonesia** and ranges around 1.75 Mtpa. The largest share (88%) is used for the production of urea [44], one of the most frequently used nitrogenous fertiliser products synthesised from CO_2 and ammonia (NH_3), requiring H_2 as a feedstock [45]. A further 4 % of Indonesia's H_2 demand is driven by the production of ammonia (excluding the ammonia that is directly processed to urea), and around 2% for the refining of oil [44]. Indonesia additionally has an annual average methanol demand of around 1.77 million tonnes, for the production of various chemicals [46]. Its domestic production is currently covered by a single plant that produces methanol from H_2 from an on-site coal gasification plant but needs to be complemented by imports, which cover the biggest share of methanol demand [46].

At around 480 ktpa (own estimate based on [47]), **Vietnam**'s H_2 demand is less than a third of Indonesia's, but still one of the more significant in the region. In Vietnam, the largest share of the national H_2 demand traces back to the production of ammonia, which needs around 300,000 tonnes of H_2 per year. A lower, but still significant amount is used for oil refining (117,000 tpa). H_2 is furthermore used for the annealing of steel, however, the demand in this industry currently remains at a relatively low level of around 2,270 tH_2pa [47]. Looking at the derivative products, Vietnam has a high demand for ammonia, ranging around 674 ktpa (own estimate based on [48] and [49]). Around 88 % of the ammonia produced in Vietnam is used for the production of fertiliser [47]. As a country with a strong agricultural sector and a rapidly growing population, Vietnam's high fertiliser demand can only be covered by additional imports [50]. Demand is also high for methanol, which the country must import to supply its chemical, pharmaceutical and construction industries with the necessary raw materials due to a lack of domestic production [47].

With a demand of around 350 ktH_2pa [51] and a H_2 trade deficit for of around 250 million USD [49], **Thailand** can be expected to have a similar H_2 demand to Vietnam. Thailand's H_2 consumption has a strong emphasis on industrial purposes: Currently, H_2 is used for oil refining, iron smelting and by steel rolling mills as well as for glass production [52]. Concrete examples include the petrochemical industry in the industrial area Map Ta Phut and steel rolling mills in the province of Chonburi [52]. The Thai industry sector also has a strong demand for imports of methanol (around 550 ktpa in 2023), which serves as a basic chemical for the manufacturing of chemicals like formaldehyde and acetic acid, which together account for around 56% of the methanol demand. Currently the country has no domestic methanol production [53]. Thailand's ammonia demand stood at nearly 320.000 tonnes in 2023 and is expected to grow [54]. The main sectors contributing to this demand are fertiliser production (48%), chemical intermediates (20%) and refrigeration (18%) [54]. Looking beyond the industrial sector, there is also interest to explore the potential application of H_2 in fuel cell vehicles, as demonstrated by a pilot H_2 refuelling station operated by BIG and opened in 2022 [55].

Singapore's H_2 demand is expected to be high since the country, despite domestic production of H_2, remains among the top importers of H_2 within the region (see Table 2) [49]. A large share of the demand can be expected to trace back to the refining of oil, given that refined petroleum accounts for 11.6% of the country's exports, creating a revenue of around 40 billion USD [49]. Singapore is also a regional leader in testing applications for H_2 that can be used for a decarbonisation of the energy system. There are two separate gas networks in Singapore– the municipal gas network and the natural gas network. The municipal gas system, supplying 61% of the households with gas for cooking and water heating, partly uses H_2-methane blends with H_2 shares of up to 50% [56]. Similarly, the construction of a "H_2-ready" gas power plant has begun in 2023 [57].

Malaysia's H_2 demand is comparatively low, ranging at 50 ktpa, with H_2 being mainly used for ammonia production and petroleum refining [58]. Malaysia's first gH_2 plant, however, is directly connected to a refuelling station for H_2 fuel cell vehicles [59]. Having introduced the first H_2-powered buses in SEA in 2019 [59], Malaysia is a forerunner in terms of H_2-based mobility. Like in Singapore, there are also trial projects of using H_2 for electricity generation, although here ammonia is used for co-firing in coal power plants [60]. Malaysia's methanol demand accounts for 1,170 ktpa mainly used within the chemical industry [61].

In the **Philippines**, the H_2 demand currently is mainly driven by the petroleum industry, followed by the chemical industry producing ammonia, fertiliser, and methanol. Furthermore, H_2 is used for the generation of process heat in industrial applications [62].

For **Laos**, the trade data shows that the country exports fertilisers [49], although the source cited here does not differentiate between chemical and mineral fertilisers which makes it unclear whether H_2 is applied in the Lao fertiliser industry or not. Since 2020, Laos also operates a diesel hydro treatment plant, for which H_2 is also required [63]. Nonetheless, the overall demand is expected to be relatively low, as indicated by limited H_2 imports while lacking the gas reserves and infrastructure that would be necessary to produce and transport large amounts of H_2 [64]. This is also reflected by very low projections in a study from 2019 modelling the future H_2 demand for the region [65].

Table 1: Overview of current hydrogen and derivatives demand and application for Southeast Asian countries

Current demand and applications of hydrogen and derivatives			
Country	Hydrogen	Ammonia	Methanol
Indonesia	Demand: 1.75 Mtpa Sector: Urea, ammonia production, oil refinery Source: Domestic production and imports	Demand: no detailed information Sector: Fertiliser production and export Source: Domestic production	Demand: 1.77 mil. tpa Sector: Chemical industry Source: Domestic production and imports
Malaysia	Demand: 50 ktpa Sector: Ammonia production, oil refinery, fuel cell electric vehicles, export Source: Domestic production	Demand: Sector: Fertiliser production, energy sector, export Source: Domestic production	Demand: 1,170 ktpa Sector: Chemical industry Source: Domestic production and imports
Philippines	Demand: No detailed information Sector: Oil refinery, production of ammonia and methanol, process heat in industrial applications Source: Domestic production and imports	Demand: No detailed information Sector: Fertiliser production Source: Domestic production and imports	Demand: No detailed information Sector: Chemical industry Source: Imports
Singapore	Demand: No detailed information Sector: Oil refinery, supplying municipal gas network, energy sector Source: Domestic production and imports	Demand: No detailed information Sector: Chemical industry and export Source: Domestic production	Demand: No detailed information Sector: Chemical industry Source: Imports
Thailand	Demand: 350 ktpa Sector: Oil refinery, iron, steel and glass production, fuel cell vehicles Source: Domestic production and imports	Demand: 320 ktpa Sector: Fertiliser production, chemical industry, refrigeration Source: Domestic production and imports	Demand: 550 ktpa Sector: Chemical industry Source: Imports
Vietnam	Demand: 480 ktpa Sector: Ammonia production, oil refinery, steel production, exports Source: Domestic production	Demand: 674 ktpa Sector: Fertiliser production Source: Domestic production and imports	Demand: No detailed information Sector: Chemical, pharmaceutical and construction industries Source: Imports

Reviewing the current H_2 applications shows that H_2 demand in the region is mostly driven by industries that use H_2 as a feedstock, such as the refining of petroleum industry and the production of basic chemicals like ammonia, urea or methanol. Only Singapore, Malaysia and the Philippines are already involved in pilot projects using newer applications of H_2 as an alternative fuel in the municipal gas systems, for electricity supply, transport, or process heat.

2.1.2 Current hydrogen and derivatives trade flows within the region

The region as a whole is currently a net importer of H_2, with a trade deficit of around 200 million USD in the H_2 sector, as highlighted from the trade data presented in Table 2 below. However, a closer look at the trade dynamics within the region shows differences and characteristics of the analysed countries.

The major exporter of H_2 is **Malaysia**, exporting H_2 with a total trade value of 802 million USD, making it the 4th largest exporter of H_2 worldwide [66]. Followed by **Vietnam**, which has around half the H_2 export value of Malaysia [49], although simultaneously being a significant importer of derivative products, mainly fertilisers. The country's trade deficit for nitrogenous fertilisers in 2023 ranged at 216 million USD [49], another 44 million USD are added by the net imports of ammonia (Table 2), while methanol imports are also existing [47]. **Indonesia** is a net importer of H_2 but has traditionally been a major exporter of ammonia and urea, although there has been a recent drop in exports due to a sharp rise of domestic demand [67]. The biggest importers are **Thailand** and Singapore, both having an H_2 trade deficit of around 250 million USD [49]. In terms of derivatives, Thailand also imports ammonia and fertiliser products, while exporting refined petroleum [49]. **Singapore**, despite having high trade volumes in both exports and imports, shows a trade deficit for refined petroleum amounting to more than 10 billion USD, while net exporting fertiliser and alcohols [49]. **Laos** and the **Philippines** both show comparatively low export and import volumes for H_2, with a slight net export trade balance for Laos (of 8.6 million USD) and a slight trade deficit for the Philippines (of 9.2 million USD). When looking at the derivatives, the current role of the Philippines as an importer becomes more visible, showing a trade deficit of 437 million USD for nitrogenous fertilisers, and of 9.04 billion USD for refined petroleum, as well as trade deficits other chemicals that potentially rely on H_2 in their production, such as alcohols and other hydrocarbons [49].

Table 2: Current trade dynamics of H_2 and derivatives

Current trade dynamics of H_2 and derivatives			
Country	Current H_2 demand	Current H_2 production	Net imports/ exports of H_2 and derivatives
Indonesia	Around 1.75 Mtpa [68], mainly used for urea production [69]	Derivatives: estimated ca. 7 tonnes of ammonia	• H_2: net imports, value 115 million USD • Ammonia: net exports, value 865 million USD[49]
Laos PDR	No information	No information	• H_2: net exports, value of 8.6 million USD • Ammonia: net imports 64,000 USD [49]
Malaysia	50 ktpa, mainly used for ammonia production and refining [58]	No information	• H_2: net exports of 423 million USD • Ammonia: net exports 271 million USD[49]Ammonia: net exports 271 million USD [49]
Philippines	No information	No information	• H_2: net imports value 9.2 million USD

			• Ammonia: net import value 5.38 million USD [49]
Singapore	No information	No information	• H_2: net imports value 249 million USD • Ammonia: net exports value 35 million USD [49]
Thailand	400-500 ktpa (estimate)	Country – wide volume around 350,000 t of H_2, No methanol production	• H_2: net imports 250 million USD • Ammonia: net imports of 218 million USD [49]
Vietnam	Around 480 kt/a (own estimate based on [47]), mainly used for ammonia production and refining	N/A	• H_2: net exports value 225 million USD • Ammonia: net imports 66 million USD 66 million USD [49]

The export and import patterns of H_2 are currently coupled with the availability of natural gas, given that most H_2 is produced through steam methane reforming (SMR). Malaysia and Vietnam, the biggest exporters of H_2 within the region, have significant natural gas reserves [70]. Similarly, major importers of H_2, such as Thailand and Singapore are also importing natural gas from regional exporters, such as Malaysia, Indonesia or Brunei [24]. Although some exporters of natural gas such as Brunei Darussalam and Myanmar import H_2 (albeit in relatively low volumes), the reverse case can only be observed in the exceptional case of Laos, which seems to be a net exporter of H_2 [71], despite not having any natural gas reserves [64]. Since there are also no reported electrolyser plants operational, it can be assumed that the H_2 exported from Laos is produced from the gasification of coal or lignite. However, the demand potential in Laos itself is very small due to a lack of H_2 intensive industries and infrastructure as well as the volumes of H_2 being exported. Singapore has large trade volumes in both, imports as well as exports, and shows diverse trade partners, importing mostly from partners such as Qatar, Germany and the US, while exporting to a large extent within the region or to regional neighbours like China or India [49], serving as a regional transhipment point. Generally, trade data suggests a relatively low degree of regional integration of the H_2 market. One explanation are the geographical factors. All countries in the region (with the exception of Laos) are coastal or island states and thus may favour shipping over pipelines for H_2 trade, for which the marginal cost increase for larger distances is lower [72].

Generally, current costs for grey H_2 range around 2 – 2.5 USD per kg H_2 in the region, for blue H_2 between 3 and 4 USD per kg, and for gH_2 between 8 and 12 USD per kg, although the values are varying strongly between different sources. Another study estimates the LCOH in the region to range between 7.1 (in Myanmar) and 10.8 (in Indonesia) USD per kg H_2 [73] thus having considerably higher costs for gH_2 than many other countries in Europe, America or the Middle East [74]. Current average prices are mainly determined by the cost of natural gas, making Malaysia the country with the most cost competitive H_2 supply, with the LCOH lying at around 1.9 USD per kg H_2 for grey H_2 and 2.98 USD per kg for blue H_2 [75]. When specifically looking at gH_2, the LCOH in the SEA region is the lowest in Myanmar, Thailand and Vietnam, but still range around 7.1-7.5 USD per kgH_2 according to Kim et al.[73]. However, there are strong differences depending on the location within a country and seasonal variabilities when it comes to the LCOH of gH_2. Another study, conducted in the Philippines found lower overall values and even stronger variations, predicting a price range of 2.22 and 4.6 USD per kgH_2 for solar- and between 1.94 and 35.33 USD per kgH_2 for wind-based gH_2. [76]. While the data on cost aspects that was reviewed for this study showed large variations, the cost for the production of gH_2 in the region is consistently higher than for conventional, fossil-based H_2, suggesting that the competitiveness of gH_2 will, at least in the short term, hinge on subsidies or other price-cutting policies.

2.1.3 Availability of required infrastructure

In this section, the availability of infrastructure that can be used or repurposed for the transport of H_2 will be examined. A summarising table can be found at the end of this section. This mainly includes gas pipelines, LNG terminals and ports. However, as this infrastructure is limited to certain countries and others do not have this type of infrastructure, road and rail transport options within the region are also visualised.

First, Figure 8 shows an overview of existing LNG terminals and gas pipelines within the region and more information is given in the following paragraphs.

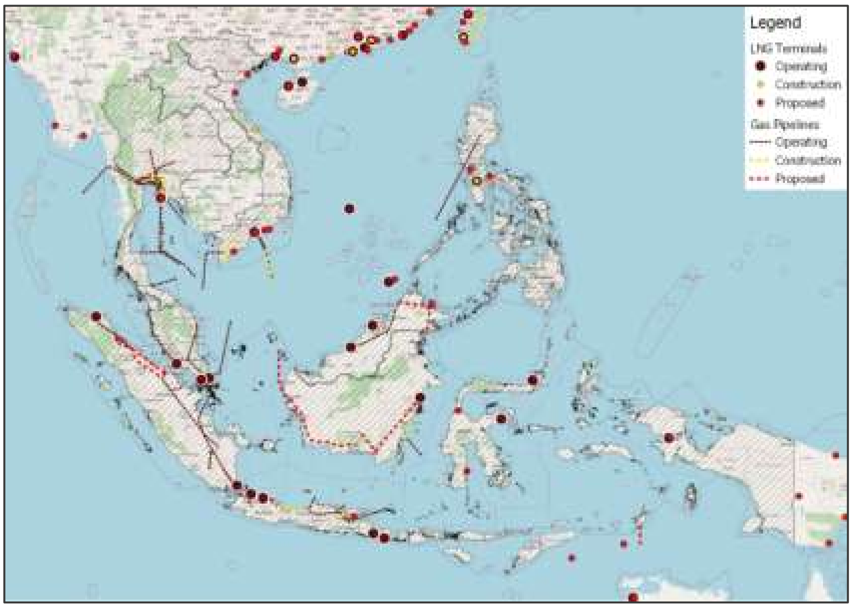


Figure 8: Overview of LNG terminals and gas pipelines in Southeast Asia

- **Singapore**'s infrastructure contains the Singapore LNG Terminal and the Jurong Island LNG Terminal as well as two natural gas pipelines. The first one, is the West Natuna Transportation System Gas Pipeline that runs offshore from Indonesia to Singapore. The second one is the Gresik-Batam-Singapore Gas Pipeline that brings gas from Indonesia's Sumatra Island to Singapore. Singapore is also the world's largest bunkering hub, supplying close to 50 million tonnes of marine bunker fuel in 2021 [77].
- **Indonesia** has in total eight major ports [78]. There are nine operating LNG terminals and FSRUs across the country. In May 2022, 18,687 km natural gas pipelines were completed across the country (target: 19,800 km) [79].
- **Malaysia** has seven major ports operating. Port of Bintulu, the western coastline of Sarawak, located near the PETRONAS LNG complex is one of the most important ports for oil and gas trading [80]. There are also four operating LNG terminals in Malaysia. One of them is used for imports, the others are mainly used for imports. The longest pipeline is Peninsular Gas Utilization (PGU) supplying gas to the energy sector, petrochemical plants and various industries and runs 2,623 km throughout Peninsular Malaysia, including exports to Singapore and is operated by Petronas [38]. Smaller pipelines are West Natuna Transportation System Gas Pipeline and Sabah–Sarawak Gas Pipeline [81].

- **Thailand** has an extensive gas transmission infrastructure. Map Ta Phut LNG Terminal is Thailand's first LNG regasification terminal. It started operating in 2011 and has a current capacity of 11.5 Mt/a [82]. The national gas pipeline system connects onshore and offshore gas fields to power plants, gas separation plants (GSPs), and industrial users. Pipeline imports from Myanmar started in 1998 with the Yadana Gas Pipeline 1.
- In **Vietnam**, the first LNG terminal, mostly used for import was inaugurated in 2023 in Ba Ria province located in the south of the country. Six further LNG terminals are planned until 2035 [83]. Nam Con Son 2 Pipeline is used to transport gas from offshore gas fields to onshore industrial zones and to transport gas imported from other ASEAN countries to meet the demand of southern and south-eastern Vietnam [44]. There are several gas pipelines operating in the Southern part of the country [81].
- In the **Philippines**, the main shipping port is Batangas, where most of crude oil and gas are processed and distributed within the country and which also serves as LNG terminal for imports. Malampaya Gas Pipeline is the operating natural gas pipeline in the Philippines which has a length of 504 km and connects the Malampaya offshore gas field with Luzon [81].

Among the SEA countries, Thailand appears to have the most developed gas infrastructure, which is concentrated around Bangkok. Indonesia also has a dense network of pipelines and LNG terminals, geographically concentrated in the west of the country. In Vietnam, most of the infrastructure is located in the south, while some LNG terminals are planned or under construction in the north of the country. Singapore also has a well-developed gas infrastructure for its small size, consisting of transnational pipelines and LNG terminals, both designed to import gas. Malaysia's infrastructure is designed to supply natural gas to neighbouring countries and to transport gas between different parts of the country. The following table summarises available port, LNG terminal and pipeline infrastructure within the region.

Table 3: Summary of available infrastructure for focus countries including ports, LNG terminals and gas pipelines

Availability of required infrastructure			
Country	Ports	LNG Terminals [81]	Pipelines [81]
Singapore	Singapore is the world's largest bunkering hub, supplying almost 50 million tons of marine bunker fuel in 2021 [77]	Singapore LNG Terminal and Jurong Island LNG Terminal Capacity: 3.5 Mt/a	West Natuna Transportation System Gas Pipeline (natural gas), offshore from Indonesia to Singapore Length: 640 km Gresik-Batam-Singapore Gas Pipeline (natural gas), from Indonesia's Sumatra Island to Singapore Length: 465 km
Indonesia	Eight major ports: Port of Jakarta, Port of Belawan, Port of Dumai, Port of Cirebon, Port of Gresik, Port of Jambi, Port of Teluk Bayur, and Port of Pontianak [78]	Arun LNG Terminal (formerly used for export, now import) Jawa Satu FSRU in West Java Bontang LNG Terminal (export) in East Kalimantan Senoro LNG Terminal (export) in Central Sulawesi Donggi	In May 2022, 18,687 km natural gas pipelines were completed across the country (target: 19,800 km) [79]: • Wampu-Belawa-Paya Pasir • Arun-Belawan (Trans-Central Sumatra Gas Pipeline) • Gresik-Batam-Singapore • Cambai-Simpang Y III • South Sumatra West Java Phase II

		Hua Xiang-Zaynep Sultan LNG Terminal in Amurang, Sulawesi Tangguh LNG Terminal (export) in West Papua Lampung FSRU offshore off Lampung Karunia Dewata FSRU in Bali Benoa FSRU (also known as Bali LNG) in Bali	• Nagrak - Bitung • Muara Karang-Muara Tawar • Gresik-Semarang • Kandang Haur Timur - Cilamaya II • Kalija • East Java (EJGP) • Gresik-PKG Looping • Ruby Field Gas Pipeline
Malaysia	The seven major ports in Malaysia are: Port Klang, Port Tanjung Pelepas, Port of Johor, Port of Penang, Port of Bintulu, Port of Kuantan, and Port of Labuan. Port of Bintulu, the western coastline of Sarawak, located near the PETRONAS LNG complex is one of the most important ports for oil and gas trading [80].	Pengerang Johor LNG Terminal (import) Export terminals: Petronas Bintulu LNG Complex, in Sarawak (including Tiga Malaysia LNG Terminal, Malaysia LNG Terminal Train 9, Satu Malaysia Terminal)	The longest pipeline is Peninsular Gas Utilization (PGU) supplying gas to the energy sector, petrochemical plants and various industries. It runs 2,623 km throughout Peninsular Malaysia, including exports to Singapore [38]. Smaller pipelines are West Natuna Transportation System Gas Pipeline and Sabah–Sarawak Gas Pipeline.
Thailand	Thailand's ports include [85]: • Bangkok • Bangpakong • Benchamas Terminal • Bongkot Terminal • Chanthaburi • Chongnonsri Marine Terminal • Erawan Terminal • Kantang	Map Ta Phut LNG Terminal is Thailand's first LNG regasification terminal Capacity: 11.5 Mt/a [82].	The national gas pipeline system connects onshore and offshore gas fields to power plants, gas separation plants (GSPs), and industrial users. Pipeline imports from Myanmar with the Yadana Gas Pipeline 1. Operating natural gas pipelines include among others: Nakhon Sawan, Nakhon Ratchasima, Rayong-Kaeng Khoi, Bang Phli-Saraburi, Ban I-Tong-Ratchaburi, Yetagun, Erawan-Khanom as well as Erawan-Rayon 3 [81].
Vietnam	Sea Ports include [86] • Ba Ngoi • Binh Duong Port • Cai Lan • Cai Mep • Campha • Can Tho • Cat Lai • Dai Hung	First LNG terminal opened in 2023 in Ba Ria province is located in the south of the country. Six further LNG terminals are planned until 2035 [83].	Nam Con Son 2 Pipelines to transport gas from offshore gas fields to onshore industrial zones and to transport gas imported from other ASEAN countries to meet demand of southern and south-eastern Vietnam [44]. Gas pipelines in the South: The Nam Con Son, the Su Tu Vang-Rang Dong–Bach Ho-Long Hai–Dinh Co, the Thi Vai Import Terminal, and the PM3 CAA – Ca Mau System [81]
Philippines	Main shipping port is Batangas, where the	Batangas LNG	Malampaya Gas Pipeline (natural gas), which has a length of 504 km and

	largest amount of crude oil and gas are processed and distributed within the country		connects the Malampaya offshore gas field with Luzon.

It is clear that not all countries in SEA have well-developed infrastructure for shipping and pipeline transport of H_2 within their own country or the region. Therefore, another look is taken at the road and rail network in SEA, as these modes of transport may be the only option for some countries now and in the near future.

The following figure shows these networks on a map. In particular, mainland SEA is connected by a rail network (black lines), with a slight concentration in Thailand, Myanmar and parts of Malaysia (mainland). The road network is very well developed, especially in the eastern part of mainland SEA (Thailand, Cambodia, Vietnam, Laos, parts of Malaysia). To compensate for the advantages of a solid road and rail transport network in mainland SEA, the island states (Indonesia, parts of Malaysia and the Philippines) benefit from a well-developed port system.

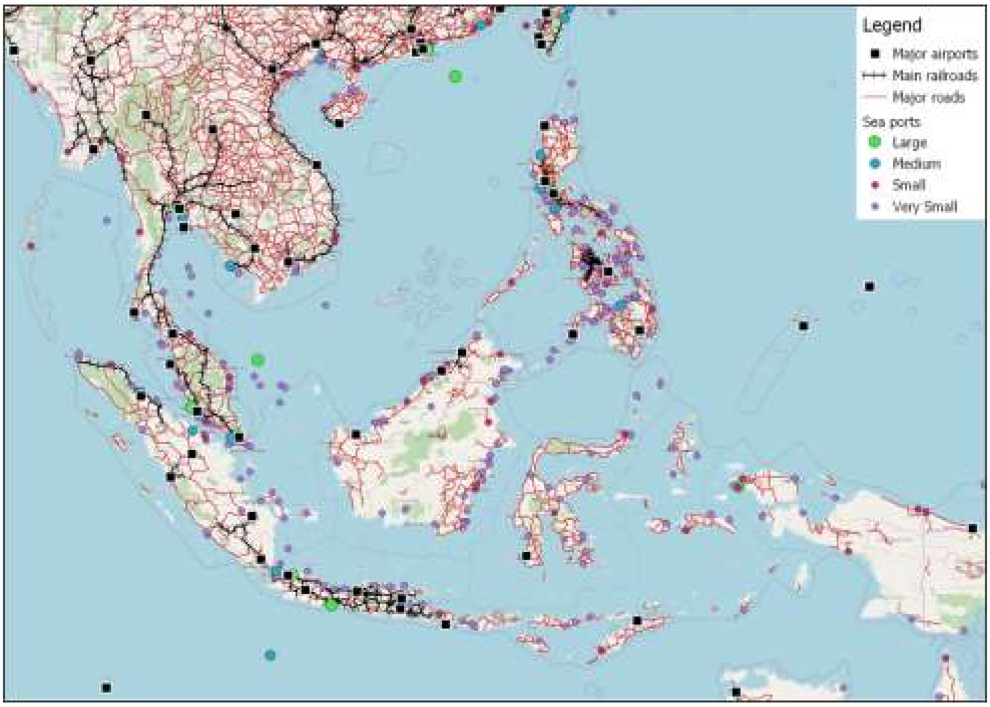


Figure 9: Overview about major airports, roads, railways and ports

2.1.4 Existing hydrogen strategies

There are many countries in the region which already published a H_2 strategy: Singapore, Indonesia, Malaysia, Thailand and Vietnam. Furthermore, H_2 policies and strategies are under development in the Philippines.

Singapore's Ministry of Trade and Industry published a H_2 strategy in October 2022 as first country in SEA [77]. The National Hydrogen Strategy speaks of "low carbon hydrogen", leaving undefined what the standards are, but presumably also including blue H_2 [87]. The strategy focuses on the energy sector, the industrial sector, maritime and air transport, as well as land transport and defines five key thrusts which include [77]:

- Experimenting with the use of advanced H_2 technologies at the cusp of commercial readiness,
- Investing in research and development,

- Pursuing international collaborations to enable "low-carbon hydrogen supply chains",
- Undertake long-term land and infrastructure planning,
- Support workforce training and development of a broader H_2 economy.

Indonesia published its detailed National Hydrogen Policy in December 2023. The strategy is based on a net zero emission model that was developed by the Ministry of Energy and Mineral Resources of Indonesia, the low carbon H_2 demand is projected to start growing from 2031 to 2060. Hydrogen consumption for the transportation sector is estimated to reach 26,000 barrel of oil equivalent (BOE) in 2031 and increases to 52.2 million of BOE in 2060.

The policy gives an outlook and strategic objectives for the following sectors:

- For the industry, H_2 consumption starts with 2.8 TWh in 2041 and increases to 79 TWh in 2060, mainly on metal, ceramic, and paper industry.
- By 2040, parts of the bus fleet will be converted to H_2, beginning with a demand of 6 GWh. By 2060, 20% of the bus fleet are estimated to be H_2-based. The consumption of H_2 for fuel cell electric vehicles (FCEV) based busses will increase into 930.6 GWh in 2060.
- The H_2 demand for the heavy freight sector is predicted to reach 161 GWh in 2040 and will increase to 930.6 GWh in 2060. For the train segment, PT KAI (Indonesia's state-owned rail company) plans to expand its locomotives to include electric rail which will be combined with H_2 fuels and/or battery.
- Hydrogen is also to be used in maritime shipping in 2060.
- There are 17 locations within the country that are identified suitable for H_2 production [69].
- For H_2 production, there is a Joint Study Agreement (JSA) to explore gH_2 and green ammonia development projects, using RE with main location in Sumatra, Indonesia [88].

In October 2023, the Ministry of Science, Technology, and Innovation of **Malaysia** published the Hydrogen Economy and Technology Roadmap (HETR). The HETR execution is separated into three phases [60]:

- Start by focusing on establishing a backbone for domestic H_2 demand and production and initiate export business to the targeted countries,
- Oversee the development of the domestic market while continuing to export,
- Expand and maintain domestic growth and export market share.

The HETR foresees blue H_2 using carbon capture and utilisation or storage (CCU and/or CCS) technology as a short- and mid-term solution. For 2050, the country aims to cover 40% of the market with blue, and 60% with gH_2.

In **Thailand**, the H_2 Development Plan Thailand includes short- (2020-2030), medium- (2030-2040), and long-term (2040-2070) planning, with only gH_2 from 2040 onwards For the short and medium term, grey, blue, and green H_2 are included [52]. According to the current "Power Development Plan" (2023-2037), EPPO aims to produce and use a maximum of 20% H_2 in power plants by 2037 [51], while EPPO has also announced intentions to use H_2 in the transport sector (especially for large trucks) and to explore its usage in industrial boilers [89].

Most recently, in February 2024, **Vietnam** published its H_2 strategy, which sets out production targets of 0.1-0.5 Mt/a by 2030 and 10-20 Mt/a by 2050, which shall be met by a mixture of green and blue H_2. It sets out the goal of covering 10% of the nation-wide energy demand with H_2 by 2050, cutting across multiple sectors including electricity generation, transport, and industry (steel, cement, and chemicals). With the publication of the strategy, announcements of further policies set out a legal framework for enterprises currently involved in the fossil industry to convert to H_2 as an energy carrier, as well as strategies to mobilise investments [90].

The Department of Energy of the **Philippines,** through its Energy Utilization Management Bureau, conducted a public consultation of the draft Department Circular Providing a National Policy and General Framework, Roadmap, and Guidelines for Hydrogen in the Energy Sector on 13 October 2023 [91]. The draft includes among general and final provisions also chapters on the role of H_2 in the energy sector (such as the exploration and development of native H_2 and the H_2 energy value chain) and on H_2 energy industry activity (such as research and development). It also contains fiscal and non-fiscal incentives in support of H_2 in the energy sector [92]. The main goals are to:

- Pursue policy and research development with initiating a Hydrogen Energy Industry Committee (HEIC) (now),
- HEIC shall advance the establishment of a National Policy Framework, define standards for H_2 and derivatives and develop a H_2 masterplan (until 2024),
- Institutionalise development and partnerships (2023 -2028), and
- Develop support infrastructures (2028 – 2035).

2.1.5 Current green hydrogen and derivatives projects

Parallel to the growing gH_2 policy landscape outlined above in Section2.1.4, in many countries in the SEA region companies have expressed plans to or are already developing gH_2 projects, ranging from pilot projects to larger production facilities to application or transport infrastructure. The following section will outline the different states of the development of gH_2 production and other projects related to the emerging gH_2 economy in the region.

Indonesia is one of the few countries in the region that already produces small volumes of gH_2. In 2023, PT PLN inaugurated the first gH_2 plant in Indonesia located at the Muara Karang Steam Gas Power Plant, Jakarta. The plant is powered 100 % from RE and able to produce 51 tonnes of gH_2 annually [93]. In addition to this pioneer project, several other gH_2 projects are planned. These include:

- Garuda Hidrogen Hijau Project (gH_2 production), operated by Saudi ACWA Power, has the goal to generate 150.000 tonnes of green ammonia annually. The project is scheduled for financial closure by the end of 2025, the commercial operation is expected to begin in 2026. Partners are PT PLN and PT Pupuk Indonesia [94].
- HDF Energy, a French Power Developer signed a MoU with PT Bukit Asam to do a feasibility study for gH_2 power generation installation in the country [95].
- PT PLN, PT Pupuk Iskandar Muda, and Augustus Global Investment plan to build a gH_2 power plant with a production capacity of 35,000 tonnes per year in SEZ Arun, Lhoksumawe, Aceh [44].
- Pertaina NRE, Krakatau Steel, and PT Rukun Raharja signed a MoU for gH_2 pipelines development [96].

Malaysia also takes a leading role in terms of gH_2 production in the region, having inaugurated the first commercial PEM electrolyser plant in SEA already in 2019, implemented in a cooperation between Petronas and Universiti Kebangsaan Malaysia (UKM) [97]. Other projects in the pipeline include:

- Eneos and Sumitomo Corp, two Japanese companies signed an agreement with SEDC Energy, to build hydroelectric plants in Malaysia which will produce gH_2 which will be shipped to Japan. It aims to produce 90,000 tonnes annually by 2030 [98].
- Asahi Kasei, Gentari Hydrogen Sdn Bhd, a wholly-owned subsidiary of PETRONAS clean energy arm Gentari Sdn Bhd (Gentari), and JGC Holdings Corporation (JGC) announced the completion of a detailed feasibility study for production of up to 8,000 tonnes of gH_2 per year using a 60 MW alkaline water electrolyser system [99].
- SK Group, a large industrial conglomerate from South Korea, agreed to work together with Gentari Sdn Bhd to advance the production of gH_2 in Malaysia [100]; Gentari planning to produce a total of 1.2 Mtpa H_2 by 2030 [101].

In the **Philippines**, private and public activities are observed in the development of blue and green H_2 projects and strategic development. These include:

- In 2019, Air Liquide signed a new long-term contract to supply H_2 to Shell Pilipinas' Tabangao refinery. Air Liquide will invest 32 million USD in the construction of a state-of-the-art blue H_2 manufacturing unit that will be built on the Tabangao refinery in Batangas [102], [103].
- HDF plans the construction of a gH_2 plant in Mindanao [104].
- Gen X Energy enters into a joint venture with ACE Enexor Inc., a subsidiary of AC Energy Corp., to develop Batangas Clean Energy, Inc.'s, a 1,100 MW combined cycle power plant project [105].
- The government considers to transform old coal plants to utilise gH_2 in the future [62].
- In a recent push of the Philippine government, the Department of Energy created the Hydrogen and Fusion Energy Committee [106].

Several gH_2 activities are also observed in **Thailand** which include pilot plants but also first large scale production plants:

- A wind-H_2-hybrid project by Thailand's Electricity Generation Authority (EGAT) is under development (PEM electrolyser), with 1.2 MWe, 4 MW wind power plants and fuel cells of 300 kW [107].
- The Hydrogen Learning Centre of EGAT was opened in March 2023 in collaboration with Enapter and H_2 Core Systems ; a total of 10 Enapter electrolysers were supplied and installed [107].
- EGAT also joined forces with five leading Japanese companies in March 2023 to jointly investigate and develop "complete clean hydrogen and ammonia, biofuel production and BESS" [52].
- Saudi Arabia's Aramco and Thailand's state-owned energy company PTT plan to expand their cooperation in areas such as LNG, blue, and green H_2 [52].
- In June 2022, Thai Oil, the largest oil refiner, acquired a stake in a US-based start-up (Versogen) specialising in the production of gH_2.
- PTT, BIG and Toyota have opened the country's first H_2 refuelling station in Pattaya (Chonburi province) by the end of 2022. Toyota will import two to three FCEVs and collect field data. PTT is using imported

FCEVs as transport vehicles for its own fleet. If the pilot project is successful, there are plans to build additional H_2 refuelling stations in other parts of the country [108].

- PTT, EGAT and ACWA have signed a MoU to produce ammonia at a volume of 1.2 Mtpa with electrolyser capacities of 2,494.5 MWe, and 432 ktpa H_2.

Also, **Vietnam** shows several activities in the gH_2 and derivate market including production sites but also infrastructure development [9], [61], [62:

- The first gH_2 plant is under construction since 2023. Located in Tra Vinh – the project has a total investment volume of 341 million USD and is implemented in collaboration by The Green Solutions and ThyssenKrupp. The project is planned to be operational as early as 2024 and is planned to achieve a capacity of 24,000 tonnes H_2, 150,000 tonnes ammonia and 195,000 tonnes of oxygen.
- Vietnam is also exploring options for transport and export, as demonstrated by the trials for jettyless LNG transfers, conducted by The Green Solutions (TGS) in cooperation with ECONNECT energy (Norway). Such LNG transfers are necessary for cost-efficient export of ammonia produced onshore [109].
- Another integrated gH_2 and green ammonia production connected to an offshore wind power plant in Ba Tri is planned. Construction is announced to start in 2024 and will be operational by 2028.
- Another offshore wind park with integrated PtX facility in Than Lang by Enterprise Energy (Singapore) will produce both electricity for the grid and H_2, which will be transported via pipelines and ammonia that can be shipped with a tanker.
- Additionally, a MoU has been signed between Vietnam Petroleum Institute and Großmann Ingenieur Consult GmbH to produce gH_2 and biomethane with offshore wind energy and desalinated seawater.
- The Hai Lang Green Hydrogen Centre with planned production capacities of 700 MW of solar power, 300 MW of wind power and 193,000 tonnes of green ammonia per year. The total cost for the project amounts to 7.46 bn. USD.
- In Chau Du, Ba Ria-Vung Tau province a H_2 generation facility coupled to an ammonia plant is planned with a capacity of 200,000 tonnes per year. The investor of the project is the Hung Hai Group, a Vietnamese infrastructure and RE company.
- At last, the Can Tho H_2 production plant, planned by SK Energy Co. will produce H_2 directly for transport purposes.

2.1.6 Conclusion: status quo and green hydrogen readiness in SEA countries

The above analysis of current activities and trade in H_2 and gH_2 shows the various stages of development towards a H_2 economy of SEA countries.

- **Malaysia**, for instance, is already a major exporter of H_2 [49] seeking to hold this position and has implemented first projects focusing on the production of H_2 from RE (e.g. solar power) instead of natural gas [98], [100]. Malaysia is also one of the few countries in the region which has published a H_2 strategy. Furthermore, it invested in innovative pilot projects such as H_2 buses and the region's first electrolyser plant in 2019, and thus has very favourable conditions for the expansion of gH_2 technology.

- **Indonesia**, is also one of the top countries in the region with regards to the development of a gH_2 economy, having its first operational electrolyser plant and several other projects pipelined. The supply of gH_2 could be a major opportunity to decarbonise the countries large fertiliser industry, an important sector of the country's economy and main driver of Indonesia's H_2 demand, currently the highest in the region.
- **Singapore**, which published the first H_2 strategy in the region is currently seen as a regional leader in H_2-development in terms of research and development and public acceptance, and has already started integrating H_2 in its national energy and transport system [110]. However, due to the challenges of limited land and RE availability, Singapore has low chances to become a major producer of gH_2. It rather aims at maintaining a position as regional trade, storage and logistics hub by leveraging its already significant role in connecting regional energy markets, as well as its high technological and infrastructural development [111], and could use gH_2 to decarbonise its significant industrial sector.

While these three countries currently seem to be the most advanced in terms of H_2 development within the region, others are catching up quickly.

- **Vietnam**'s first gH_2 plant is expected to start production this year, while large investment sums are planned for further gH_2 projects, targeting gH_2 production, but also exploring options for cost-effective shipping of derivatives, indicating ambitions to become an exporter. Vietnam is currently importing fertilisers, but gH_2 might be a chance to onshore fertiliser production. Since February 2024, the country also developed its H_2 strategy, setting out production targets for green (and blue) H_2 that foresee a steady increase reaching up to 20 Mt by 2050.
- **Thailand** with its H_2 development plan has the first pilot projects for gH_2 running. Currently, importing methanol as a feedstock for its chemical industry, as well as natural gas as a fuel and feedstock for H_2 production, the country could use gH_2 to fulfil strategic objectives of becoming less dependent on imports. Thailand could also benefit from its well-developed gas pipeline network that could potentially be repurposed for H_2.
- Similarly, the **Philippines** also have first H_2 projects planned, while also showing interest in new applications for H_2 and derivate products, such as ammonia co-firing for electricity production. Planned H_2 projects are connected to refineries, thus serving to replace grey H_2, which is currently being imported.
- **Laos**, although benefiting from an already strong RE sector, is faced with a lack of gas-related infrastructure and a weak logistics sector. While having one power-to-fertiliser project planned, these conditions make it unlikely that Laos will become a major player in international H_2 and derivate trade.

The following table is summarising main findings of the current market analysis for the seven focus countries within SEA.

Table 4: gH_2-readiness indicators

gH_2-readiness indicators				
Country	gH_2 projects and status	Gas-related infrastructure	Hydrogen/ green hydrogen strategy	Current RE capacity
Indonesia	First gH_2 plant operational with a relatively small capacity of 51 t/a [93]; several further projects in construction phase [94] or planned [95]; [44] [112];[113]	As in May 2022, 18,687 km natural gas pipelines was completed across the country (target: 19,800 km).[79], concentrated on Sumatra, Java and Borneo, several LNG terminals for both import and export [81]	Published 2023, aiming to reduce the share of fossil fuels and export H_2 and derivatives to the global market, naming transportation and metal and ceramic industry as future applications, identification of 17 suitable sites for gH_2 production [69]	Around 12.5 GW RE capacity (including biomass, around 17% of energy mix)[69]
Lao PDR	One planned electrolyser plant producing green ammonia with excess hydropower [114], no further projects known to be in the pipeline	No major gas pipelines [81]	Strategy for the use of green ammonia as energy carrier [115]	Around 8.9 GW RE capacity, mostly hydropower (83.5% of total capacity) [116]
Malaysia	First PEM electrolyser plant operational since 2019 [97], further projects with larger capacities are planned [98];[99]; Gentari SDN is planning to achieve a gH_2 production volume of 1,2 Mtpa by 2030 [101]	Major gas pipeline of 2,623 km along the cost of the Peninsula; shorter pipeline on Borneo, 1 further pipeline planned; 2 import- LNG terminals on Peninsula; 2 export LNG terminals on Borneo, 2 floating LNG terminals offshore (export) [81] H_2 pipeline planned for export to Singapore [117]	Hydrogen Economy and Technology Roadmap (HETR) published in October 2023 [60]. Plans to build a domestic demand for low-carbon H_2 first and become an exporter long-term. Blue H_2 seen as a bridge technology, by 2050 60% gH_2 are foreseen.	Around 8.8 GW (2021); around 23% of total capacity main sources are hydro, geothermal and solar [118]
Philippines	MoU signed for a combined electrolyser-reconversion system [119], a further project is planning to switch from coal to H_2 in existing power plant[62]; Planned H_2 power plants [104], [105], , feasibility studies for ammonia	1 Pipeline transporting gas from offshore gas field to the biggest island providing several power plants, 2 operational LNG terminals; 3 under construction, several further ones proposed (or unclear status), all for import [81]	"Draft Department Circular Providing a National Policy and General Framework, Roadmap, and Guidelines for Hydrogen in the Energy Sector", in draft stage, public consultation took place in October 2023 [91]	Around 8.4 GW; around 28% of total capacity, mainly hydro, solar and geothermal [121]

	co-firing in coal power plants [120]			
Singapore	One 9 MW electrolyser plant [122] and a green e-methanol plant planned [123]	2 Pipeline connections for import from Indonesia, LNG terminal for import, H_2 pipeline planned for H_2 import from Malaysia [117]	Hydrogen strategy exists, focus on research and development, international collaboration and infrastructure planning, speaks of low-carbon H_2, possibly including blue H_2 [77]; [87]	Around 1.1 GW, around 9.5% of total capacity, from solar and biomass [124]
Thailand	Several pilot gH_2 production plants and project sites for future applications (energy storage, fuelling stations); industrial scale under development/planned [52], [107]	Large network of gas pipelines around Bangkok, several pipelines transporting gas from offshore fields to the mainland, 2 LNG terminals for gas imports [81]	H_2 development plan Thailand under development, from 2040 onwards only gH_2 [52]	Around 17 GW, around 31.5% of total capacity [125], mainly biomass and solar
Vietnam	First gH_2 and green ammonia plant under construction[126], several other projects planned [47], [109]	Gas pipelines transporting Gas from offshore gas fields to the south of the country, 1 operational LNG terminal in the south of the country, further Terminal in central Vietnam under construction, several others proposed/planned [81]	H_2 strategy since February 2024, setting out production targets of 100-500 ktpa by 2030 and 10-20 Mtpa by 2050 [90]; further mention of H_2 in some energy and R&D policy documents [127], [128]	Around 46.8 GW, around 58 % of total capacity [129]

2.2 Future green hydrogen and derivatives market

To assess the future gH_2 and derivatives market in the region, it is important to understand the value chain first. It gives an indication of necessary prerequisites for market development. Figure 10 visualises the value chain for gH_2 and its derivatives from production to end use [33].

In order to understand the market potential for gH_2 and its derivatives along the entire value chain, it is therefore important to analyse the following aspects:

- **Production**: renewable energy potential and water availability for gH_2 production and associated cost,
- **Transformation**: CO_2 sources, synthetic fuels (including methanol, jet fuels, methane and other hydrocarbons) and green ammonia production and their cost structures,

- **Transport**: shipping (ports and terminals), pipeline and storage infrastructure as well as trucking potential and cost,
- **End use**: Current and future demand in the industrial, transport, heating and power generation sectors.

The following sections guide through these different steps of the value chain for SEA countries and assess the potential of specific countries and the region as a whole.

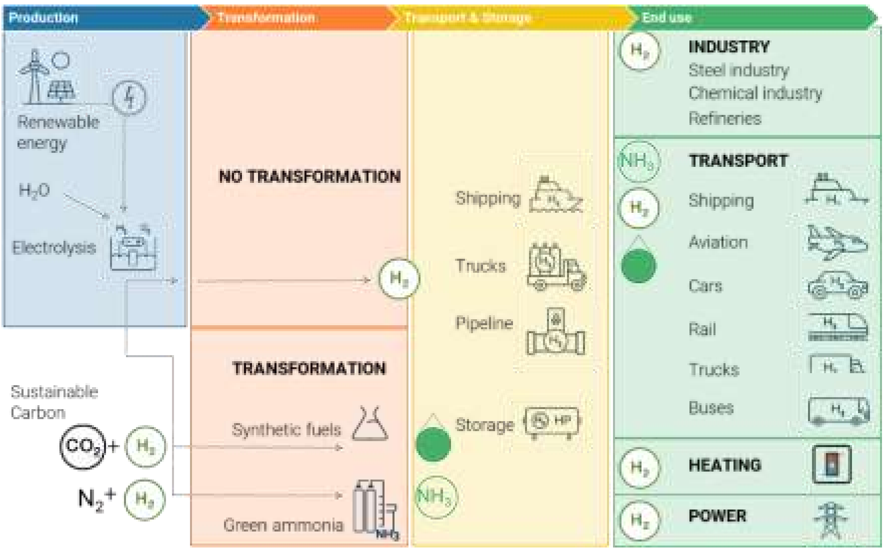


Figure 10: Green hydrogen and derivative products supply chain, taken from IRENA (2022)

2.2.1 Production: Green hydrogen

In order to produce gH_2, it is important to consider the RE potential, water availability, infrastructure, regulatory frameworks and potential production costs, among other factors. This section first examines the RE potential, production costs and policy targets, then delves into the water availability of SEA countries, and finally provides an overview of gH_2 production, trade and markets before concluding.

2.2.1.1 Renewable energy supply for green hydrogen production

2.2.1.1.1 Current electricity supply and renewable energy shares

Currently, the energy mix of SEA countries is dominated by fossil fuels for the majority of countries. Figure 11 shows the electricity generation sources of SEA countries in 2021 [130]. While looking at fossil fuel based sources, Vietnam and Laos are heavily dependent on coal power, Indonesia, Malaysia and the Philippines rely on both, natural gas and coal power. Other countries like Thailand and Singapore have a higher dependency on electricity generation based on natural gas. Laos shows the highest proportion of RE sources in the electricity generation sector, followed by Vietnam. The smallest proportion of RE sources for electricity provision is seen in Singapore.

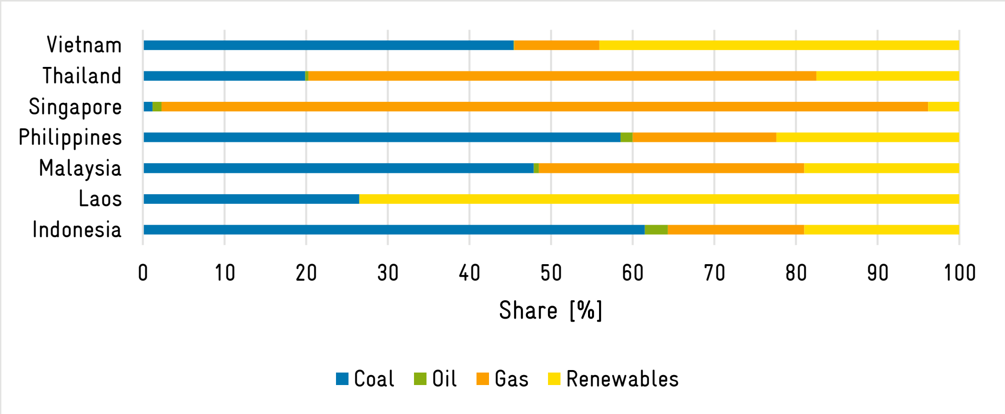


Figure 11: Electricity generation sources for Southeast Asian countries in 2021, taken from IEA (2024)

To produce gH_2, the electricity used in the production process must come from renewable sources. To date, the energy mix of SEA countries is mostly not based on renewables as shown above (Figure 11), so grid electricity is usually not an option for powering gH_2 production plants. Logically, new RE power plants will need to be installed and operated at the gH_2 production sites. In order to determine which RE source is most promising for the countries analysed, first a closer look is taken at the current share of different RE sources in Figure 12. Currently, hydropower plays an important role for all countries except for Singapore, where only solar power generation is used. Geothermal power is relevant for Indonesia and the Philippines, while solar power is currently an important pillar for Thailand and Vietnam. Thailand has the most diversified renewable electricity generation portfolio so far.

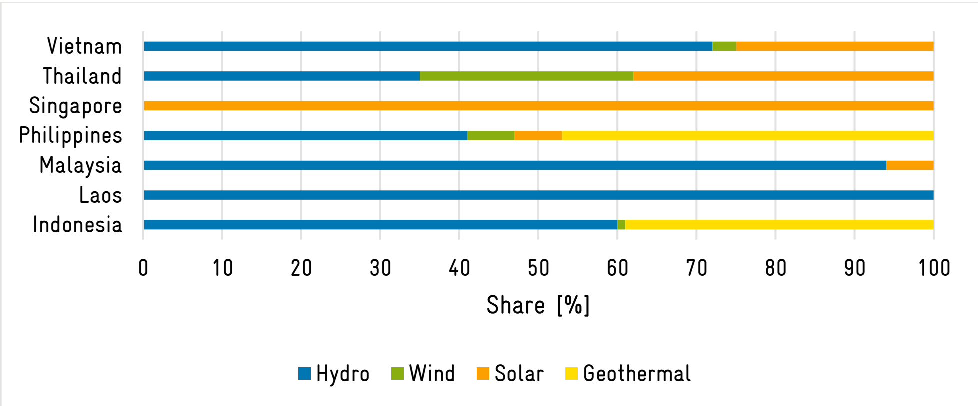


Figure 12: Contributions of different renewable energy sources to the renewable electricity generation for each country in 2019, taken from IEA (2021)

2.2.1.1.2 Renewable energy potential for electricity production

After analysing the current contributions of different RE sources within the countries, projections and future trends are important to determine most promising options to supply gH_2 production sites. Figure 13 shows the solar power potential expressed as global horizontal irradiation [131]. Overall the region has excellent solar resources with lesser potential in regions of Northern Vietnam and Northern Philippines.

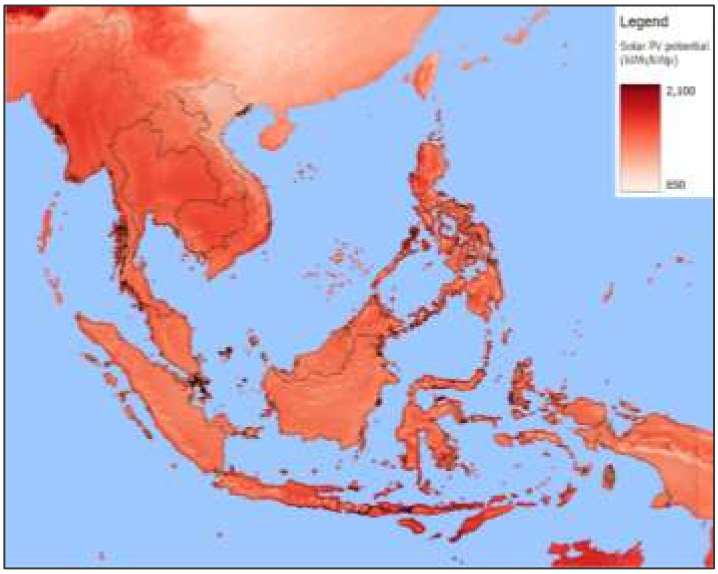


Figure 13: Overview about the solar power potential (expressed as potential yearly PV yield in kWh/kWp) in Southeast Asia, own visualisation based on data provided by Global Solar Atlas

Figure 14 provides the wind power potential in m/s at 100 m hub height. In contrast to solar resources wind resources are rather average [132]. Nevertheless, a significant potential can be overserved in regions with lower solar potential (Norther Vietnam and Northern Philippines). Here wind power can complement solar power.

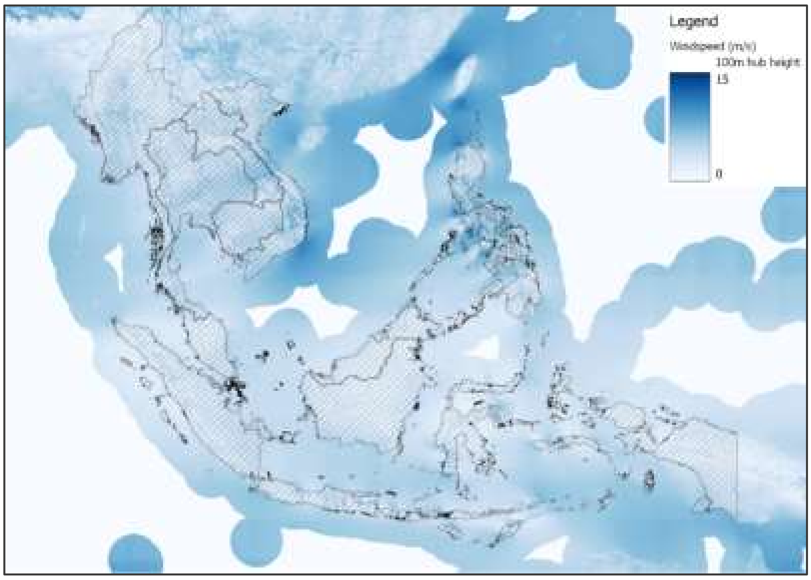


Figure 14: Overview about wind speed in m/s (at 100 m) in Southeast Asia, own visualisation based on data provided by Global Wind Atlas

Sakti et al. (2023) conducted an extensive geospatial review of RE potential in SEA. They analysed solar, wind and hydro power potential for the region and found that much of this potential remains untapped [133]. Figure 15 visualises areas of high suitability for RE power plant installation within SEA based on geographical factors such as elevation, slope, and land use among other[133]. It becomes clear that especially the central parts of Myanmar and Thailand are very suitable for solar power plant installations as well as the central parts of Indonesia (Java), and the Philippines (Luzon) which can be seen in picture a. Hydropower plant installation is recommended along the bigger river systems (like Mekong or Irrawaddy River), northern parts of the Philippines and western parts of Indonesia (picture b). Vietnam, Laos, Cambodia, Thailand, and Myanmar have large areas suitable for wind power plant installations as well as southern islands of Indonesia and Northern islands of the Philippines (picture c). Looking at the combined suitability (picture d), there is high suitability in a stretch from north-western to the south-eastern part of mainland SEA (highlighted in blue). Other hotspot areas are southern Indonesia and northern island groups of the Philippines. It becomes clear that SEA is a region rich is RE potential with a diverse mix of renewable resources. Its distribution varies and is country specific.

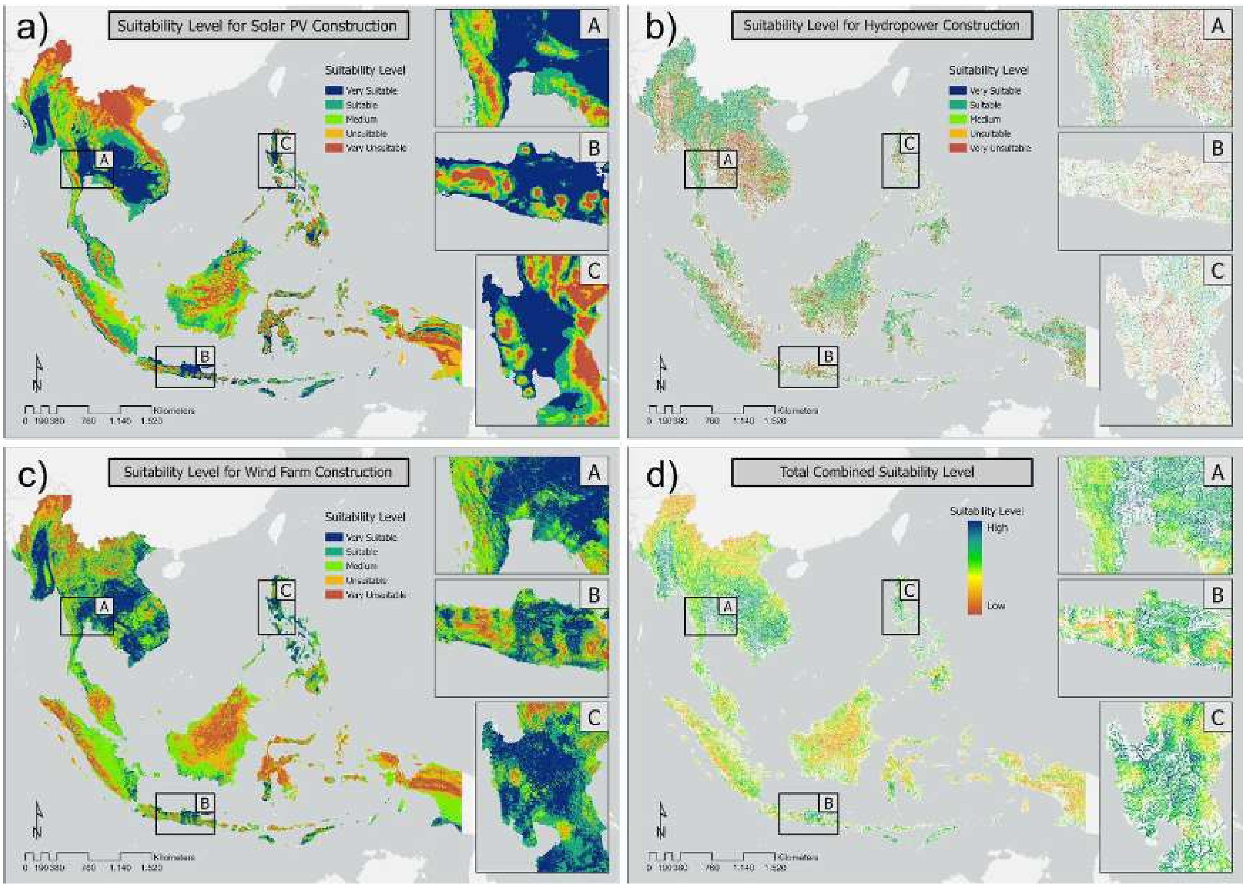


Figure 15: Suitability of renewable energy power plant installation a) for solar, b) for hydro power, c) for wind power plants, and d) combined suitability, taken from Sakti et al. (2023)

Having looked at the spatial distribution of RE potential in SEA, it is also important to understand the temporal distribution of this potential in order to draw conclusions about the most suitable RE resources for each country, which are also likely to be the main source for gH_2 production. Figure 16 provides an overview of the solar, wind and hydro power potential (in MW) in 2020 for SEA [133].

The monthly figures of the solar power potential (a) show a regional peak in October whereas lowest overall solar potential is found for April [133]. Wind potential (b) in contrast peaks between June and August and shows lowest production in April and October [133]. Hydropower potential (c) show two significant regional patterns: Southern regions have high hydropower potential during November to May, whereas hydropower potential in northern parts of SEA is highest between May to October.

Looking at the potential analysis, within the SEA region, hydro, wind and solar power will play an important role in gH_2 production in the future. However, at the country level, the source of electricity generation for gH_2 production may vary. While Indonesia, Myanmar and Vietnam benefit from combined high RE potential (solar, hydro and wind), other countries such as Thailand or Cambodia may focus on solar, Laos on hydro and the Philippines on solar and wind for gH_2 production. In addition, geothermal sources will play a role in the Philippines and Indonesia.

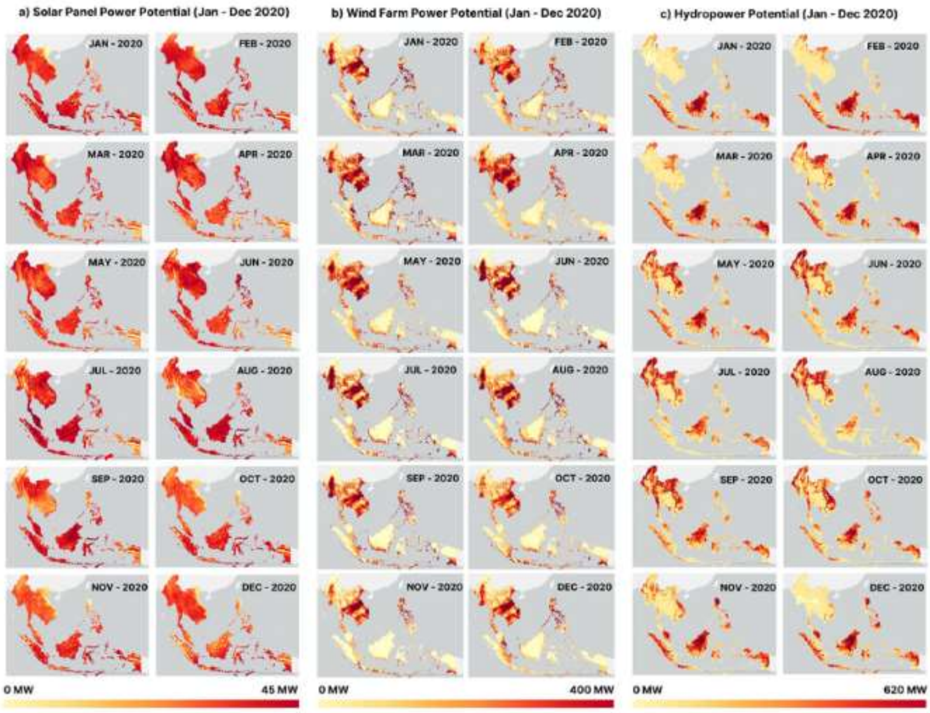


Figure 16: Monthly power potential in MW/MWp of renewable energy sources, a) solar, b) wind, c) hydro, taken from Sakti et al. (2023)

2.2.1.1.3 Renewable energy generation cost

Apart from already installed RE capacities and the overall potential within the region, generation cost are also playing an important role to assess the feasibility of in-country gH_2 production. The National Renewable Energy Laboratory (NREL) developed the REexplorer, where generation cost (levelised cost of electricity, LCOE) for different technologies are explored. For the SEA region, only LCOE for wind and solar power generation (utility scale) are analysed [134]. Both can be found in the following figures for the Moderate Technical Potential Scenario[1] and the country specific default values provided by NREL [134]. For solar PV it can be observed that the lowest values are in a range of 70 to 100 USD/MWh. Such low costs are possible in Myanmar, Thailand, Cambodia and parts of Vietnam. Slightly higher LCOE for solar PV in a range of 100 to 150 USD/MWh are projected for Laos, northern Vietnam, Malaysia and the Philippines. Highest costs for power from solar PV is projected for Indonesia based on higher investment cost assumptions. For wind power, many regions are excluded in a first place because the 15% capacity factor cannot be exceeded (due to technical constraints e.g. 15% capacity factor filter). However, lowest wind power LCOE in a range of 70 to

[1] Protected areas, water-bodies, forested areas as well as urban areas are excluded from the analysing; for solar PV areas with a slope of more than 5% were also excluded and a capacity factor filter of 10% applied; for wind areas with a slope of more than 20% were excluded and a capacity factor filter of 15% applied

100 USD/MWh can be achieved in Vietnam, central Myanmar and some regions of the Philippines. Higher LCOE of >100 USD/MWh for wind power can be found in eastern Thailand, Laos, Cambodia and further parts of the Philippines. Overall the wind power potential is much more scattered over the region. Low LCOEs are usually found in areas with high potential as analysed above (Section 2.2.1.1.2).

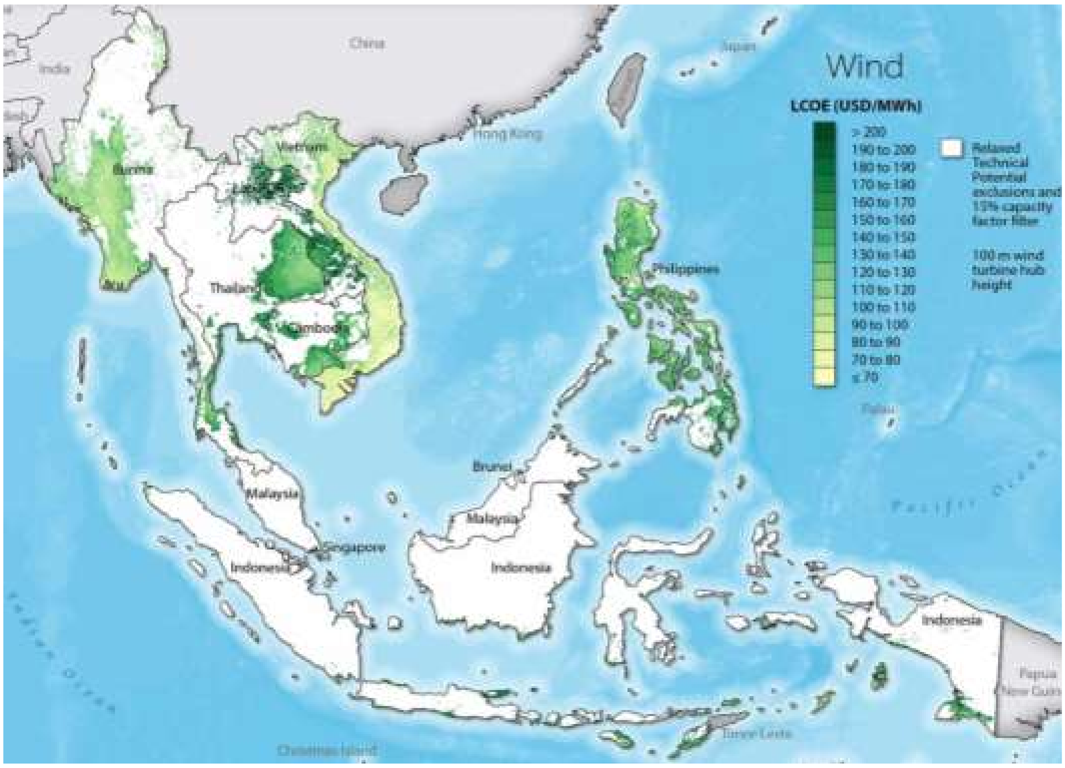


Figure 17: Levelised cost of electricity (LCOE) for solar PV (top) and wind generation (bottom) for the Moderate Technical Potential Scenario, taken from NREL (2023)

2.2.1.1.4 Renewable energy targets

As a next step, we provide information on RE policy objectives to understand current expansion plans and policy priorities in the application of RE technologies that may influence the dominant use of RE resources for gH_2 and its derived products.

- **Indonesia** aims to increase its RE share in its power generation to 44% by 2030 from around 12% in 2022. This is planned to be achieved by mainly installing geothermal and hydropower capacities, but also solar PV capacities [135].
- **Laos** plans to develop 7.5 GW of hydropower, 1 GW of wind & solar, and 300 MW biomass by 2030 to increase its RE share [136].
- **Malaysia** committed to increase its RE share to 70% of the total generation capacity by 2050. As part of the process, Malaysia is expected to expand renewable capacity from 6 to 14 GW with various technologies [137].
- **The Philippines** are planning to extend their RE share to 35% by 2030 and 50% by 2040, mainly achieving this through solar power plants, followed by hydro and wind [138].
- **Singapore** aims to increase the RE share, but space limitations are restricting RE share expansion. For example, Singapore's Green Plan 2023 foresees to add 1.5 GW of solar energy which can meet around 2% of the projected electricity demands 2025 and at least 2 GW until 2030, which can meet around 3% of its 2030 projected electricity demand [139].

- **Thailand's** RE targets are set to 30% by 2037 and 50% by 2050 with extension targets for solar power capacity of 12.1 GW in 2037, biomass capacity of 5.7 GW in 2037 and wind power (offshore) capacity of 2.9 GW in 2037. [52], [51].
- **Vietnam** is planning an RE share extension of 30.9 – 39.2% by 2030 and 67.5 – 71.5% by 2050, mainly through solar power plants (around 34% of planned RE extension), followed by land-based wind power (13% of planned RE extension), offshore wind (15% of planned RE extension) and some hydro (7% of planned RE extension) and biomass (1% of planned RE extension) [127].

This overview highlights significant RE expansion plans, with the exception of Singapore (due to space constraints). In the development of gH_2 projects, RE policy targets could provide an indication of priorities and existing support mechanisms. However, it is also highly relevant to assess where RE development for gH_2 production is competing with overall electricity supply and achieving RE shares, e.g. in national grid supply.

2.2.1.1.5 Summary

In summary, the currently installed renewable power capacity in SEA is not yet capable of providing sufficient power for gH_2 production. If renewable electricity generation is realised for gH_2 production in the SEA region it will come from a variety of RE sources and will be country specific. It will be a mix of currently installed dominant RE capacities (e.g. hydropower in Laos), country-specific overall potentials and connected to this their generation cost, and political plans to expand and diversify RE shares. According to our analysis the following RE mixes are most likely to play a role in future gH_2 production (also summarised and visualised in Figure 18):

- **Indonesia**: The country's untapped RE potential lays mainly in solar power, with hydro and geothermal power already playing a major role.
- **Laos**: Hydropower currently accounts for a significant share of the energy mix, with further expansion planned. To diversify its energy mix, Laos plans to develop its wind power potential.
- **Malaysia**: Currently hydropower and to a smaller extend solar energy plays a role in the RE mix. In the future, these sources will be complemented by bioenergy and geothermal power.
- **Philippines**: Due to its mature technology and the country's location in the Pacific Ring of Fire, geothermal power is the most abundant and cheapest RE in the Philippines. Apart from geothermal, hydropower dominates the RE in the Philippines, with wind and solar power also playing a role.
- **Singapore**: Due to its small size, Singapore has limited RE potential, with solar being the only viable RE source now and in the future.
- **Thailand**: At present, Thailand's dominant RE sources for electricity generation are almost evenly split between hydro power, wind power and solar power, looking at the overall energy mix, bioenergy is the dominating RE resource. This diversified RE mix will continue to play a role in Thailand's energy sector.
- **Vietnam**: Hydropower is currently the dominant RE source, but new projects will focus on solar PV and offshore wind, which are expected to be the dominant sources of electricity generation for gH_2 production.

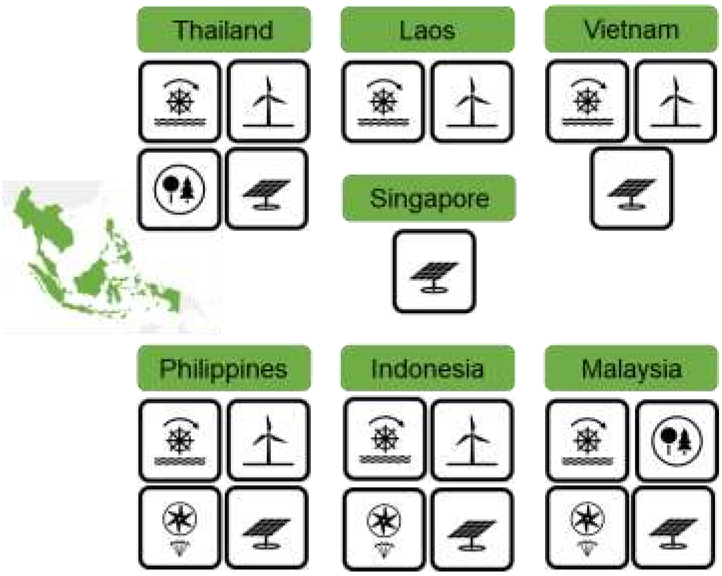


Figure 18: Renewable energy sources playing major roles in future green hydrogen production for each country

2.2.1.2 Water availability

In addition to electricity from renewable sources, the availability of water is crucial for the long-term sustainable production of gH_2. Therefore, potential water sources should be identified, and long-term supply ensured, taking into account future climate change impacts. Sustainable water management practices are therefore key. Figure 19 shows global water stress levels. According to this analysis, most SEA countries face low water stress levels, only Thailand and Indonesia show medium water stress levels.

Figure 19: Heat map of water stress levels, taken from IRENA (2022)

World Bank statistics allow a closer look at the water situation in the countries of SEA. Table 5 shows two key indicators for assessing water management and availability: the ratio of freshwater withdrawals to available resources (first column) and renewable internal freshwater resources. While the ratio of freshwater withdrawals to available freshwater resources is very high in Singapore (83%), it is moderate in countries such as Indonesia, the Philippines, Thailand and Vietnam (18-30%) and very low in countries such as Brunei, Cambodia, Laos, Malaysia and Myanmar (1-6%). For some countries, there is a direct correlation between freshwater withdrawal and available resources, such as Singapore (high abstraction rate, left column, due to low available resource volume, right column) or Brunei (low abstraction rate, left column, due to high available resource volume, right column). However, some countries have significantly higher extraction rates than others despite having similar resource volumes (e.g. Cambodia with 1% and Indonesia with 30%, both with resource volumes of around 7,000 m^3), implying higher stress levels due to more excessive extraction rather than limited resource availability as in Singapore. The highest resource availability is observed in Brunei, Laos, Malaysia and Myanmar, all of which appear to have relatively low levels of water stress (1-6%) due to their high resource availability. Medium levels of resource availability within the region are found in Cambodia, Indonesia, the Philippines, Thailand and Vietnam, with the highest extraction rates in Indonesia, the Philippines and Thailand.

Table 5: Water availability and resources based on World Bank statistics.

Water availability and resources based on World Bank statistics		
Country	Level of water stress: freshwater withdrawal as a proportion of available freshwater resources in 2020 [140] [%]	Renewable internal freshwater resources per capita in 2020 [141] [m^3]
Brunei	3.5	19,243
Cambodia	1.0	7,355
Indonesia	29.7	7,426
Laos	4.8	26,013
Malaysia	3.4	17,470
Myanmar	5.8	18,771
Philippines	26.3	4,270
Singapore	83.1	106
Thailand	23.0	3,141
Vietnam	18.1	3,719

Apart from freshwater resources, seawater desalination could be an opportunity (especially for countries with lower freshwater reserves such as Singapore, Thailand or Vietnam). Therefore, gH_2 production plants, with their water needs, could also provide an opportunity to develop a corresponding seawater desalination infrastructure, which, if done properly, could benefit the country's overall water management. Desalination can be costly for sectors such as agriculture or small industry, making water supply critical [3]. Desalination for gH_2 adds 1 – 2% to energy consumption and production costs, with electricity consumption being the most costly factor [3]. Green H_2 could therefore provide a boost to the desalination industry. It should be noted, however, that desalination plants produce brine that is enriched with salt and chemicals, which can cause environmental problems if discharged back into the sea or improperly disposed of.

In summary, the SEA region appears to be a relatively water-rich region with potential to develop further supply through seawater desalination. Southeast Asian countries show differences in current water consumption rates with tendencies of higher rates in more industrialised countries such as Indonesia, the Philippines and Thailand and lower rates in less developed countries like Cambodia or Laos. Only in Singapore water availability is an issue due to limited freshwater resources. It should also be noted that gH_2 production processes tend to be closed loops with water recovery, which limits the need for a constant supply of fresh water.

2.2.1.3 Green hydrogen production, trade and trends

Now that we have analysed the necessary inputs for gH_2 production (water and renewable electricity), it is important to consider technology readiness and availability as well as regulations related to gH_2 production and the associated production costs.

2.2.1.3.1 Promising sectors

As summarised in Section 2.1.5, several gH_2 projects are already being developed or planned in some SEA countries for various purposes, and in addition potential demand could arise from the replacement of blue and grey H_2 in different sectors, as well as other emerging sectors that drive decarbonisation:

- **Indonesia**: The country has one H_2 production site in operation (51 t/a) linked to a gas power plant site. Several gH_2 plants with different applications are planned. Examples are gH_2 production in the industrial sector (steel) or for green ammonia production (fertiliser). Future application of gH_2 is driven by the countries industry (metal, ceramic, paper, urea and petrochemical), transport sector especially shipping, buses and heavy freight as well as in its power sector and to replace current grey H_2 used in the methanol production.
- **Malaysia**: Japanese investors have developed a gH_2 production facility for export to Japan. Other gH_2 production plants are planned and under development for domestic use, especially in the power and transport sector. The country is also one of the biggest methanol producers in the region [142] and has some oil refinery, fertiliser, cement and steel production capacities that could drive a potential gH_2 demand.
- **Laos**: A gH_2 production plant is planned, using excess from hydro power generation. The gH_2 produced will be used to produce green ammonia. Future gH_2 demands could result from decarbonising its fertiliser and cement industry as well as the country's transport sector.
- **Philippines**: A H_2 production plant is under construction which should serve demand in refinery processes (oil industry). Within the power sector, there are also attempts to develop gH_2 production sites to start replacing current coal-based power generation. Future demand could be generally driven by replacing blue and grey H_2 in the petroleum and chemical industry of the country.
- **Singapore**: A first gH_2 production plant is planned with a capacity of 9 MW (electrolyser) as showcase project to supply a chemical company (Evenki). The gH_2 will be used to produce methionine (an essential component in animal feed). In addition, the plant will serve the local trading market as H_2 demands are constantly rising. This project is planned to be operational by 2024. The country's gH_2 demand will be driven by replacing conventional H_2 in their petroleum refining and chemical industry as well as their H_2-methane blends in the municipal gas systems. Application potential is also given in Singapore's power sector and transport sector. A first demonstration project for SAF was realized at Singapore's Changi airport.
- **Thailand**: Pilot plants were and are being developed for gH_2 production and its use in the electricity and transport sectors (learning centre developed by EGAT and refuelling stations for FCEVs). Further projects are planned, for example by stakeholders in the oil and gas sector. The country seems to have broader use cases for gH_2 (transport, industries such as iron smelting, chemical and petrochemical/refining or glass and power sectors as well as in the fertiliser industry through the production of green ammonia) and is currently developing production sites as pilots or for domestic use.

- **Vietnam**: The country is planning several gH_2 projects to supply green ammonia and bio-methane production in the future. The country's power sector as well as industry (mainly steel and cement) and to a smaller extend its transport sector will most likely drive its domestic gH_2 demand. Vietnam has only recently started its gH_2 activities but is already preparing to enter international trade.

These activities and forefront projects underline the general availability of technology within the region and are evidence of a growing market for gH_2 and derived products in SEA. Figure 20 summarises most promising applications for gH_2 and derivative products within the SEA region.

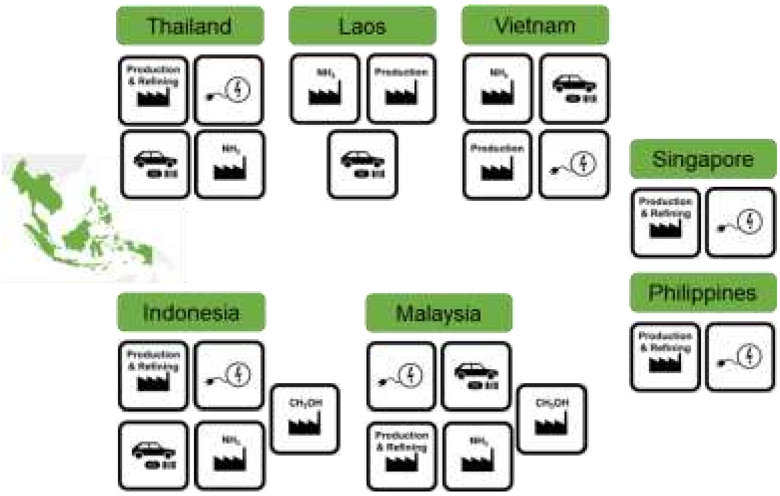


Figure 20: Overview of most promising fields of application for gH_2 production in Southeast Asian countries

2.2.1.3.2 Technology availability and gH_2 trade

While gH_2 production equipment and related technology (electrolysers, fuel cells and storage tanks) are available to SEA markets, either through imports from e.g. Japan, Germany or the US, or through technology providers within the region, such as electrolyser or PtX technology from Thailand or Singapore, the transport infrastructure may need a further boost, as discussed in Chapter 2.2.3. An important H_2 trading partner outside of the SEA region (export market) is currently Japan, which is already making the transition from conventional H_2 trade (grey and blue) to gH_2 by investing in its SEA trade partner countries (e.g. Malaysia, Brunei Darussalam).

2.2.1.3.3 Production cost

In terms of actual production cost of gH_2, a look into Figure 21 provides a first overview for projections for 2030 from two different sources (IEA to the left [143] and Agora to the right [144]) for the SEA region. IEA has projected LCOH based on production from solar PV and onshore wind with site-specific potentials and hourly capacity factors [143]. The weighted average cost of capital (WACC) is set at 6% for this study. As mentioned in Chapter 3.1.2, largest areas (higher quantity of sites) with comparably low LCOH are found in Thailand and Vietnam, as well as in the Philippines and some parts of Malaysia. Significantly larger areas with higher values than in other countries can be found in Indonesia. According to the map, the LCOH values range from approx. 2 – 4 USD/kgH_2 for the region. The Agora (2024) study projects higher values in the range of 4 – 14 USD/kgH_2 for the region. Lowest and most promising LCOH are expected for Thailand, Malaysia and the Philippines. The projections are subject to the underlying assumptions which explain the differences in the cost projections.

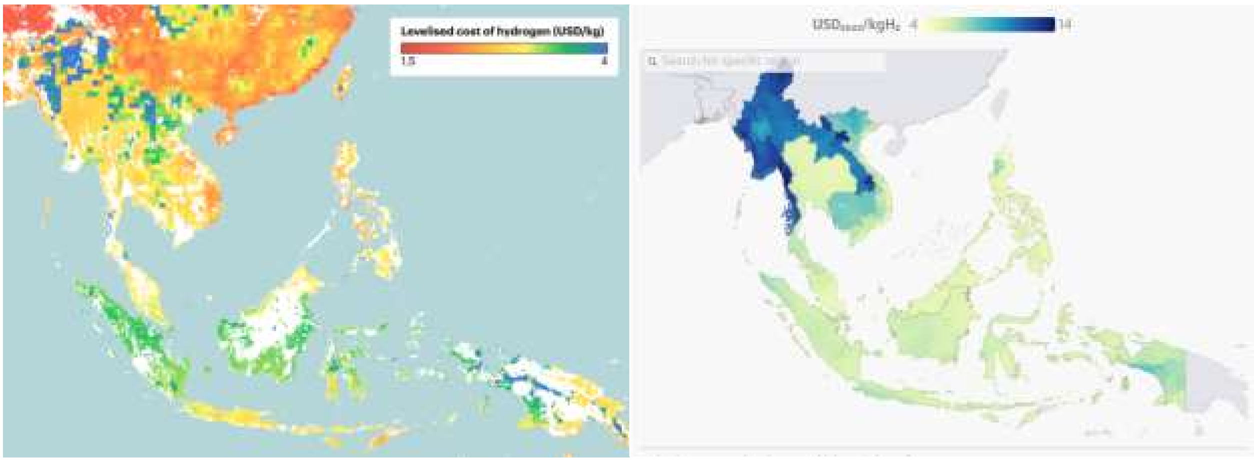


Figure 21: Overview of levelised cost of green hydrogen (LCOH) in Southeast Asia projected for 2030, taken from IEA (2023) on the left and taken from Agora (2024) to the right

A third study looked at LCOH for selected countries, covering five SEA countries [7]. Projections for 2030 result in the following LCOH:

- **Indonesia:** **2.4 – 4.1 USD/kg**
- **Malaysia:** **2.1 – 3.6 USD/kg**
- **Philippines:** **2.5 – 4.0 USD/kg**
- **Thailand:** **2.1 – 3.1 USD/kg**
- **Vietnam:** **2.3 – 3.9 USD/kg**

These figures match quite well with the analyses carried out by IEA (2023) and underline the fact that LCOH are very site-and region-specific. For example, in some parts of Vietnam LCOH are comparably low (southern part) while in the north LCOH's are higher, leading to price differences of more than 1.5 USD/kg. Thus site-specific and geospatial evaluations are key for the development of gH_2 projects.

2.2.1.3.4 Regulatory framework

Currently, gH_2 producers face the challenge of low or unclear regulatory frameworks within the region as the markets are just developing. To date, Laos, Malaysia and Indonesia have no gH_2 specific strategies or regulations in place, while some already developed or are developing gH_2 specific legal frameworks or defining gH_2 under their general gas or H_2 frameworks.

- **Philippines:** As of writing, there are no enacted laws that specifically deal with H_2 and fuel cells, and electrochemical energy storage in the Philippines. However, the Department of Energy published a Circular for Providing a National Policy and General Framework, Roadmap, and Guidelines for Hydrogen in the Energy Sector. These documents outline the next steps for establishing a "national policy framework for hydrogen and hydrogen derivatives".

- **Singapore:** The Energy Market Authority announced in October 2023 that from 2024, all new and repowered gas plants will need to be designed to be at least 30% H_2 compatible with the ability to be retrofitted to become 100% H_2-ready in the future [145]. It has to be noted that the National Hydrogen Strategy speaks of "low carbon hydrogen", leaving undefined what the standards are, but presumably also including blue H_2 [87].

- **Thailand**: Currently, there are no gH_2 specific regulations, but from the regulator's side, the Energy Regulatory Commission (ERC), has included H_2 in the definition of "renewable energy" to be purchased by the Provincial or Metropolitan Electricity Authorities (for very small power producer, or VSPP projects) and EGAT (for small power producer, or SPP projects) [146]. In addition, general regulations would apply to H_2 projects similarly to other power projects. For instance, in H_2 projects where electricity is generated to be used in the electrolysing process, an electricity generation licensing under the Energy Industry Act would be required. The operating site may also be subject to requirements under the Factory Act, depending on the activities being carried out. At the moment, the H_2 industry is not subject to the Fuel Control Act and Fuel Trading Act, as H_2 does not fall within the definition of fuel thereunder.
- **Vietnam**: The country is developing plans for piloting electricity generation using H_2 set out as a goal in Resolution No. 55-NQ/TW (2020)[127]. In addition, the Decision No. 38/2020/QD-TTg (30/12/20) sets out the following incentives for projects applying "hydrogen energy technology" (not limited to gH_2):
    - a preferential tax rate of 10% for a period of 15 years,
    - preferential value-added tax of 5%,
    - the exemption of land rental fees,
    - exemption from import tax on raw materials, supplies and components for a period of 5 years if they cannot be produced domestically [128].

  With the publication of its H_2 strategy, announcements of further policies set out a legal framework for enterprises currently involved in the fossil industry to convert to H_2 as an energy carrier, as well as strategies to mobilise investments [90].

Given recent market developments and the immense interest in gH_2 technologies across the region, the development of further regulatory frameworks can be expected. In particular, countries with a strong focus on the export market for gH_2 would need to comply with global standards and certifications as described in Section 1.3, requiring a supportive and clear regulatory framework.

2.2.1.4 Summary

At present, most SEA countries rely heavily on fossil fuels for electricity generation, but there is growing interest in tapping the potential of abundant RE sources, and there is ample potential to develop these for gH_2 production projects. Hydro, solar and wind are the main RE sources, for some countries complemented by geothermal energy. While most countries in SEA face little water stress, others such as Singapore or Indonesia may need to explore options such as seawater desalination to provide sufficient water resources for electrolysers. Several SEA countries are already involved in gH_2 projects, with applications ranging from pilot plants to industrial use. Japan is currently a major trading partner for (green) H_2. Vietnam, Malaysia and Indonesia are poised to export gH_2 in the future. While gH_2 production technology is available in the region, transport infrastructure development may be required, particularly for countries with little or no pipeline infrastructure. The lowest gH_2 production cost projections are seen in Thailand and Malaysia, followed by Vietnam and Indonesia. Regulatory frameworks for gH_2 production and trade are evolving, with some countries developing specific regulations or integrating H_2 into existing energy frameworks. Overall, SEA is a promising region for gH_2 production, with countries taking steps to harness their RE potential and develop a supportive regulatory environment.

2.2.2 Transformation: Derivative products

2.2.2.1 Green ammonia

Most ammonia worldwide (around 90%) is produced in the so-called Haber-Bosch process, in which nitrogen (N_2) and H_2 react to ammonia (NH_3) under high pressure and temperature (400-600 °C). While most Haber-Bosch ammonia plants today use grey H_2 sourced from steam methane reforming (SMR) [147], the H_2 used as a feedstock can be switched to green H_2 from electrolysis without effecting changes in the Haber-Bosch process. This switch from grey to green H_2 can be seen as the most effective options to decarbonise ammonia supply [148]. The technology for green ammonia is already fully developed, the current focus of the industry lies on the integration of gH_2 production into plants currently running on grey H_2 [149]. A major challenge remains the cost competitiveness, which mainly traces back to the higher LCOH for gH_2. While some studies expect that green ammonia could become cost competitive by 2030 [150], uncertainties remain due to fluctuations in gas prices[151]. Unlike synthetic fuels, ammonia production does not depend on the availability of sustainable carbon, since it only needs H_2 and nitrogen, which can be sourced from compressed air, as feedstock.

When looking at the developments in the SEA region, it can be seen that many gH_2 projects are combined with an integrated ammonia production facility. This applies to the Tra Vinh plant that is currently being constructed by The Green Solutions and ThyssenKrupp in southern Vietnam, as well as to another offshore wind park that is also planned to produce gH_2 and ammonia on-site, and two further planned H_2 production sites in the country [47], [109], [126], [152]. An example from Indonesia is presented by the Garuda Hidrogen Hijau Project (gH_2) Indonesia, which will generate 150,000 tonnes of green ammonia annually beginning in 2026 [94]. Lastly, Laos' only project involving green H_2 takes the power-to-fertiliser route [114] and thus will also synthesise ammonia as an interim product. In some of these projects, however, it is unclear whether the ammonia produced is later used for further downstream applications of ammonia (such as fertiliser production) or whether the ammonia is just synthesised for the purpose of more cost-efficient shipping and later reconverted to pure H_2.

The leading producer of ammonia in the region is Indonesia, followed by Vietnam and Malaysia. Currently, Indonesia alone transforms 1.2 Mt of H_2 to ammonia per year. The H_2 demand for Indonesia's ammonia industry is expected to grow up to 3.3 Mtpa in the "likely" scenario of a forecast by ERIA; the number for the entire region ranges at 5.2 Mt/a [153]. Since the decarbonisation of ammonia production using gH_2 does not require a change of existing plants, the geographical distribution of ammonia production in the region will likely remain similar to the current one, although new green ammonia plants will more likely be installed near sites of gH_2 production, hence favouring regions with a high RE potential. The multiple planned power-to-ammonia projects as well as the LNG terminals in Vietnam are hints that the country will increase its ammonia production in the near future and might take on a more central role in terms of ammonia production in the region. At the same time, Indonesia, the region's leading producer of ammonia is also ramping up its production (although not limited to green ammonia), expecting an annual increase of 2.4 % in the period 2020-2050 [154].

2.2.2.2 Synthetic green fuels

The group of chemicals that are here summarised as synthetic green fuels includes several derivatives of H_2, such as green methanol or dimethyl ether (DME), synthetic diesel, and certain sustainable aviation fuels (SAF) like green kerosene. This section will focus on power-to-liquid (PtL) variants of synthetic fuels, meaning fuels that are based on H_2 derived from electrolysis.

The most relevant product in this group is **methanol**, which, like ammonia, is conventionally produced from grey H_2, and thus also presents a likely no-regret use case for gH_2. However, the term of green methanol is ambiguous. While it is mostly used to refer to methanol synthesised from gH_2 and captured CO_2 [12] (e-methanol), it may also refer to a different production pathway, more frequently referred to as bio-methanol, which is based on organic matter like agricultural waste or food waste as a feedstock from which the syngas is derived. [155], [156] This process does not necessarily require gH_2, although H_2 might be added to make up for the typically higher CO to H_2 ratio in the syngas mix [156]. In this report we define green methanol as being produced with gH_2 as a feedstock replacing grey H_2. The current producers in the region are Malaysia, Indonesia and Brunei, the latter does not show high political will in transitioning to gH_2; thus, Indonesia and Malaysia are expected to be the main players in providing green methanol. The H_2 needed for methanol production in the region currently lies at around 0.4 Mt, but is expected to grow up to 1.5 Mt in 2050 according to ERIA's most likely scenario [153].

Methanol is also a feedstock for **DME**, a less widespread synthetic fuel which can replace diesel in certain engines, resulting in a reduction of CO_2, NO_X, SO_x and particulate matter emissions. While the production through the dehydration of methanol is already technically possible, the application in fuel cells is only at an early laboratory stage. Synthetic diesel, on the other hand, is already used as a replacement for conventional diesel in cars. Like other synthetic fuels, it is produced in a Fischer-Tropsch process using H_2 and CO as syngas, thus having the potential for reduced emissions if gH_2 is used.

Finally, green **kerosene** is also produced in a Fischer-Tropsch process using gH_2 and CO_2, sometimes combined with hydrocracking. It has been successfully tested in test flights as a blend with conventional jet fuel, but still faces challenges when it comes to commercial-scale production and is seen as an option on the long term [157].

Many low emission fuels still lack technological maturity or are not cost competitive yet, even with increasing prices of fossil fuels. Thus, investments in the production of synthetic green fuels are currently still associated with financial risks, which are a roadblock that needs to be addressed to scale up production. Nonetheless, first steps in the development of a green fuel industry can be observed in some SEA countries. Indonesia and Malaysia have joined hands with Japan in collaborative efforts aimed at advancing the development of H_2, ammonia, and CCUS supply chains possibly connected to other synthetic fuels. Concurrently, similar initiatives are being pursued in Thailand and Singapore. Notably, significant players in the oil and gas industry, including Petronas, Pertamina, and PTT, have devised strategies to invest in H_2 supply chains and carbon capture [158]. The growing demand for methanol and synthetic green fuels, combined with the need for a supply of decarbonised H_2, might encourage the development of new industrial zones. These are most likely to emerge in places which have (1) a high RE potential leading to a low LCOH for gH_2 and (2) favourable conditions of pre-existing infrastructure for the transport of feedstock and products. For synthetic green fuels, however, a third criterion becomes relevant, namely the availability of sources of sustainable carbon, which is needed as a feedstock for the production of such fuels, which will be discussed in the following section.

2.2.2.3 Potential CO_2 sources

When talking about synthetic fuels, it should be kept in mind that these are not automatically reducing carbon emissions, but the emission saving potential largely depends on the source of CO_2. Figure 22 visualises the production process of synthetic fuels and the required inputs. It can be seen that H_2, N_2 and CO_2 are essential inputs. Sourcing these inputs sustainably is crucial to produce sustainable or green synthetic fuels.

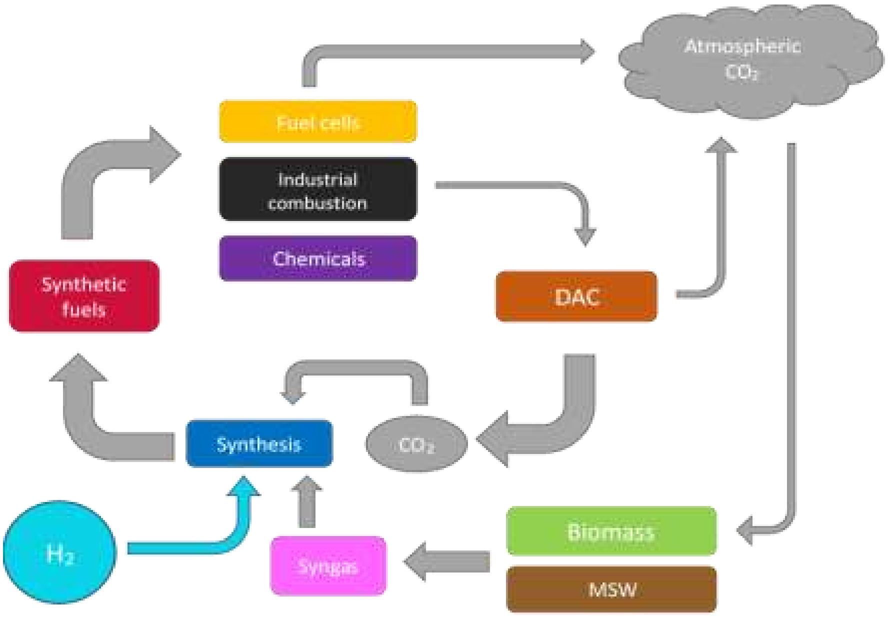


Figure 22: Carbon flows in synthetic fuel production and usage

There are three carbon sources that are usually considered for the production of green fuels. These include the sourcing of carbon from bio-resources, the recycling of waste materials (mainly plastic) and lastly, the use of CO_2 from direct air capture (DAC). While DAC-derived CO_2 can be seen as being compatible with circular approaches, the sustainability largely depends on the capture rate, as well as where it its applied and the end use of the product.

DAC is currently expensive, but comes with the benefit that it produces water as a by-product (around 1.4 kg H_2O per $kgCO_2$ captured) and requires heat [159]. Thus, it can provide cost-savings and enhanced sustainability due to a lower energy and water consumption when looped with the production of green H_2 through electrolysis, which requires water and produces heat. The utilisation of waste heat can bring down the cost of CO_2 capture from 242 to 145 USD/tCO_2 captured under present conditions [159]. Further savings are possible on the H_2 production site. This again favours the development of integrated industrial zones. It is expected that the operational costs for DACs could fall to 59 USD[2] per tCO_2 captured (without waste heat utilisation) by 2050. For the sustainability and profitability of the investment in combined DAC-electrolysis industrial complexes, it is important to apply DAC only to those CO_2-emitting facilities which can be expected to remain running for a long time and cannot cost-competitively decarbonised with state-of-the-art technology, so fossil-lock-in effects are avoided. A promising first step for DAC employment can be found in Thailand, where Thai Nippon Steel Engineering & Construction and Siam Cement Group have signed a memorandum to capture CO_2 emissions from cement factories in Thailand and other SEA [160]. Although the utilization of the captured CO_2 has not been discussed at present, CO_2 from cement factories would be a sensible source of CO_2 for the production of gH_2 derivatives due to the unavoidable process emissions in the production of clinker.

Another option for carbon sourcing is CCS/U where CO_2 is captured from industrial processes and stored and/or used. At least seven large-scale CCUS projects are planned in SEA, including several linked to enhanced oil recovery and natural gas processing with offshore storage [158]. Another example can be found in Singapore, where a multi-national partnership aims to establish a green methanol plant which converts

[2] 54 EUR/tCO_2, and converted on 24.05.2024 here: https://www.finanzen.net/waehrungsrechner/euro_us-dollar

captured biogenic CO_2 into green methanol, which would be the first one of its kind. The partnership includes Thailand's PTT Exploration & Production (PTTEP) [123]. Overall, synthetic fuel production with carbon sourcing from DAC or CCU/S is most likely to be deployed in areas that are already strongly industrialised. New facilities built in more rural areas are more likely to rely on biomass, which can be generated from agricultural waste. An example for this is a recently established biodiesel plant in Laos.

2.2.3 Transport

Hydrogen can be transported as gaseous H_2 via pipeline, as ammonia in refrigerated tanks, as liquefied H_2 in specially insulated and double-hulled tanks, and as liquid organic H_2 carriers (LOHCs) [161]. Due to the high demand centres in the region, H_2 trade would most likely be regional in order to reduce transportation costs [162]. To analyse possible as well as suitable transport options for green H_2 in SEA, a look at existing infrastructure for the transport of natural gas, which is described in more detail in Chapter 3.1.3, can give an idea of established gas infrastructure which could potentially be repurposed for H_2. Beyond the aspect of repurposing, the development of gas infrastructure can also give a hint on the status of research and development and knowledge about the transport of gases.

Among the SEA countries, Thailand, Indonesia, and Malaysia appear to have the highest development of gas transportation facilities. Thailand's infrastructure includes LNG terminals and a pipeline system connecting onshore and offshore gas fields to power plants, gas separation plants (GSPs), and industrial users. The infrastructure is mainly concentrated in the area around Bangkok [81]. Indonesia's network of natural gas pipelines is the largest in the region totalling a length 18,687 km [39].

However, the potential of repurposing gas infrastructure for the transport of H_2 has mixed prospects. For onshore pipelines, repurposing from fossil gas to H_2 is expected to cost around 10–35% of the construction of a new H_2 pipeline, thus making repurposing economically attractive, promising savings of up to 80% in regions with a highly developed gas infrastructure [163]. This economic advantage of repurposing only occurs in regions where the transport demand for H_2 increases while it decreases for fossil gas. Currently, the gas demand for the region is still increasing by around 3% every year [158], limiting the profitability of repurposing pipelines on the short term. On the long term, repurposing might become financially more attractive, depending on future energy policy choices. Globally, repurposing of gas pipelines is expected to start around 2030 [72]; conversely, the gas demand for the SEA region is not expected to peak before 2035 [158]. This means that all existing natural gas infrastructure will be needed at least until this point. The sooner the transport needs for fossil gas decrease, the more costs can be saved in the development of H_2 pipeline networks by repurposing.

For LNG terminals, on the other hand, significant doubts about their usability for H_2 remain. Using H_2-compatible materials might allow to maintain 50% of the initial CAPEX when transitioning to gH_2. The high investment needs, combined with uncertainty about the technical feasibility and the future market is likely to discourage the expansion of H_2-ready LNG terminals [21].

The statement made in Section 1.1.3 that pipeline transport is seen as more cost competitive for distances below 1,500 km [6] may vary in the local context. While the figure holds true in the context of flat areas with mostly agricultural use, which applies to some parts of mainland SEA, Cambodia Thailand, Malaysia and Vietnam, the construction in challenging terrain or offshore can add significantly to the CAPEX of pipelines (around 60% for forests; 130% for mountainous terrain; 70% for offshore and 160% for ultra-deep offshore) [164], lowering the cut-even distance of ammonia shipping compared to compressed H_2 pipelines. Thus, shipping might become a more favourable option for the transport of gH_2 in and between archipelagic states like Indonesia and the Philippines, between these states and continental SEA states like Thailand and Vietnam, or for interregional trade. For the latter, especially Japan and South Korea are potential destinations for the export of gH_2 from SEA. The two countries have a high energy demand, relatively low RE resources and policies in place that promote gH_2 [21]. Long-distance shipping to these countries will probably prioritise derivatives like green ammonia and methanol, which are more feasible and cost-effective for shipping given the current technological constraints. Which molecule is prioritised largely depends on the intended end-use in the country of destination. Derivate trade is the most cost effective if no chemical conversion after transport are needed. Re-converting ammonia or methanol back to H_2 is likely to double the total costs [21] and is therefore not expected to play a significant role.

Lastly, LOHCs are organic molecules which can bind additional H_2 and be reverted to their original form through dehydrogenation. Unlike ammonia, LCOHs can, after releasing the H_2 stored in them, be shipped back to an H_2-exporting port and recharged with new H_2 molecules. LOHC systems aim to include a variety of properties that make them suitable for H_2 storage and transportation, such as a low melting point, high H_2 storage capacities, low energy demand for dehydrogenation, long life cycles of charging and discharging, compatibility with existing infrastructure, low costs and high safety [165]. There are several alternatives to methanol and ammonia under discussion, however, each of the current LOHCs comes with a set of drawbacks, be it a high level of toxicity or the high energy demand for dehydrogenation [166]. Overall, several technical challenges still need to be addressed, which is the reason why LOHCs are not seen as a near-term feasible option and thus not discussed in detail in this report. Similarly, metal hydrides like magnesium hydride are assumed to have a limited commercialisation potential due to a relatively low storage density and relatively high costs [167]. Due to these limitations non-methanol LOHCs as well as metal hydrides are assumed to play a marginal role for the region in the near-term future and were thus excluded from the country-level analysis. The following section will briefly scope the prospects of H_2 and derivative transport in each country.

In **Malaysia** and **Singapore**, efforts to develop an H_2 transportation concept are among the most advanced in the region. Malaysian Gentari Sdn and Singapore's City Energy have announced a collaboration on a feasibility study for an H_2 pipeline between the two countries. The project is meant to contribute to achieving Singapore's vision of carbon neutrality by 2050 and Gentari's aim of producing up to 1.2 MtH_2pa [117]. If realised, the pipeline would parallel existing patterns of natural gas pipelines, since Singapore is dependent on gas imports from neighbouring Malaysia. It is possible that existing pipelines between the countries are repurposed once the transport needs for natural gas decline. This, however, is unlikely to happen soon, also because Singapore's H_2 strategy includes blue H_2 [77], which could be produced on site from imported natural gas. An H_2 pipeline to Singapore could also help not only cover domestic demand, but secures access to international trade flows. At the same time, Malaysia also shows interest in shipping H_2 on its own shores, as evidenced by a planned project that aims to produce H_2 for direct export to Japan [98]. Singapore, is currently a hub for international maritime trade and is strongly investing in research and development on H_2 and derivates storage and transport options. If there is an oversupply of H_2 imported through the Malaysia-Singapore pipeline, H_2 could be transformed into higher-value derivatives like synthetic fuels which can be used in Singapore's industrial or logistics sector.

In **Thailand**, which already seems to have relatively well-developed gas facilities, gas infrastructure is still being expanded. Current projects under development include a 430 km long gas transmission pipeline, which is already under construction [168], and an LNG Terminal with regasification unit which is expected to start in 2025 [169]. Given the extensive gas infrastructure, it is likely that parts of it will be repurposed for H_2 once gH_2 is widely available and natural gas transportation needs are declining. This, however, is a long-term prospect. Thailand also shows efforts to expand research and development on the shipping of H_2 and ammonia, as shown by an MoU signed between Thailand's Electricity Generation Authority, Japanese shipping company Mitsui O.S.K and other firms to develop a value chain and transport options for H_2 produced in the south of the country [170]. Such developments point towards interest in H_2 and derivate trade across larger distances. With two large ammonia terminals in the south [171], there are some capacities that can be used for this purpose if green ammonia is used as an H_2 carrier.

Indonesia owns an extensive system of gas pipelines, several more infrastructure projects are proposed or are already under construction, including a rapid development of LNG terminals. It is notable that both, the capacities for imports as well as for exports, are being expanded [81]. The gas demand for Indonesia is still strongly increasing, thus, a repurposing of gas pipelines seems unlikely in the near and medium-term future. However, the domestic extraction of natural gas is decreasing and the share of imported LNG growing, potentially changing the geographical distribution of gas transportation [172]. At the same time, Indonesia shows interest in gH_2 production and applications [69], giving rise to new transport needs. First interest in exploring H_2 pipelines has already been expressed by a MoU on H_2 pipeline development between the three companies Pertaina NRE, Krakatau Steel, and PT Rukun Raharja [96].

Like Singapore and Malaysia, Indonesia also benefits from a strategically important location at the strait of Malacca and is likely to evolve as a crossing point for H_2 transports between the gulf states as future exporters like Japan and South Korea [173] . Having a large fleet and workforce in the maritime sector [174], the country has the potential to establish itself as a major player in maritime transport of H_2 and derivates. Another potential advantage is the country's existing methanol storage facility in the port of Balikpapan, being one of the only ones in the region [175], bearing the potential for the region to develop as a centre for methanol trade and storage. Being one of the world's leading exporters of ammonia, Indonesia is likely to be able to take up the export of future gH_2-derived ammonia due to a wide availability of ammonia export and storage infrastructure, having the largest ammonia storage capacities in the region [171].

Looking at **Vietnam**, the country's political will to transition to an H_2 economy is also recognisable in the planned infrastructure projects. While the existing gas infrastructure is comparatively low developed and only located in the south, certain projects are either proposed or already under construction. There have been trials in jettyless LNG transfers, which are an important technology for shipping ammonia or liquid CO_2 from the shallow coastline of Vietnam [109]. Furthermore, several of the planned H_2 projects are planned as offshore wind parks which transport gH_2 or ammonia to the mainland via a pipeline and/or also supply ships [47], [109]. At the same time, Vietnam is rapidly expanding its LNG import capacities. Having inaugurated its first LNG terminal, there are 7 further LNG terminals or FSRUs in the pipeline, one of which has already reached the construction stage [81]. The relevance of these projects for gH_2, however is questionable due to doubts about the technological and economic feasibility of converting terminals for H_2 usage. Furthermore, investments in LNG favour long-distance transport over local supply, thus potentially driving up the price of gH_2 and introducing a market bias in favour of imported gH_2.

The Philippines are also rapidly expanding their LNG capacities; Vietnam and the Philippines together account for 70% of the LNG capacity under development in the region, although both countries have only started importing LNG very recently [21]. Here, the same constraints as mentioned in the section on Vietnam apply. The Philippines have only one gas pipeline with a length of 504 km [81]; there is no information on plans to repurpose this pipeline for the use of gH_2. The relatively remote geographical location makes it likely that international H_2 trade from the Philippines will take place in form of derivate shipping; in some cases this might even be the most feasible option for transportation within the country due to its archipelagic structure. The Philippines already have three existing ammonia terminals with relatively high storage capacities [171], which could be used for green ammonia without technological difficulties.

Laos is the only landlocked country assessed in this study, and thus has no options to use marine vessels for H_2 or derivate transport. Laos also does not have any existing or planed gas pipelines that could be repurposed for H_2 in the future [81]. Given its relatively weak transport and logistics sector [176], it can be expected that H_2 supply chains will be kept relatively short. Derivates and higher-value downstream products like fertilisers or synthetic fuels are likely to be produced where gH_2 production and RE generation occurs and find their end-use nearby. Excess downstream products can be exported by trucks, but the volumes and overall transportation needs for gH_2 and derivate products can be expected to be small for Laos.

2.2.4 End use: Green hydrogen and derivative products

2.2.4.1 Green hydrogen

2.2.4.1.1 Industry sector

Industry is currently, by far, the largest sector of application for H_2. Although forecasts like Malaysia's H_2 strategy see the relevance of other sectors increasing more rapidly, projections show that the demand for the industry is growing and still accounts for more than half of all H_2 demand in 2050 (around two thirds if the application of H_2 for industrial heat is considered as well) [60].

Industrial chemical processes that are already using H_2 as a feedstock present a no-regret option for introducing green H_2, since in these cases, switching from grey to gH_2 is, in most cases, the only option for decarbonisation, and the switch is easier than in other industries since only the infrastructure for the production of H_2 needs to be changed (e.g. replacing SMR plants with electrolysers), while other infrastructures and processes may sustain without any major adjustments. Chemical processes that rely on H_2 as a feedstock include the production of ammonia and urea (which were already discussed in detail in Section 2.2.4.2), alcohols and fatty acids (discussed in Section 2.2.4.3), and the refining of crude oil to petroleum products. Although the latter is still connected to fossil fuels, it is likely to remain relevant in the next decades, thus representing a potential application for gH_2. Assuming the countries will fully implement their emission reduction pledges announced at COP 26, the demand of H_2 in the refining sector will peak in 2030 and gradually decline until 2050, but still remain at a similar level as it is today with around 1.2 Mt /a [153].

While the main industrial purposes that use H_2 at present are the production of methanol and ammonia and the refining of oil, the potential of gH_2 as an option to decarbonise other industries has been recognised by industrial and public stakeholders.

Among those industries that have not always relied on the use of H_2, but for which a switch to gH_2 provides a viable decarbonisation option, the most advanced one in terms of research and development is the steel industry [26]. Here, the use of gH_2 as a feedstock in the so-called hydrogen direct reduction (HDR) process is the most promising pathway for a decarbonised primary production of steel [27]. Overall the region's H_2 demand for iron and steel is estimated to range between 40 and 60 ktpa [153]. However, the demand is rapidly growing, as well as the production capacities within the region which is currently a net importer of steel. This suggests that gH_2 may play a role in covering this growing demand. Although recent capacity expansions have focused on the coal-based blast furnace basic oxygen furnace route, the region historically produces comparatively low emission steel due to reliance on electric arc furnaces (EAF) [21]. The high presence of EAFs steel production sites enhance the region's suitability to become a centre for HDR-based steel reduction, since HDR needs to be coupled with EAF for secondary production. Thus, the HDR – EAF route can be achieved with a lower investment cost than in other regions, if this advantage is being leveraged. The interest in gH_2-based steel in the region seems high, suggesting that the demand for H_2 in the steel sector will grow rapidly in the next decades.

Aluminium production also plays a role in the region, especially in Indonesia, which has significant bauxite reserves. The use of H_2 in the aluminium industry has been tested for the refining of bauxite [18]; however, this only accounts for a small share of the total emissions of aluminium production. Approaches to decarbonise the aluminium sector exist in several countries in the region, but usually focus on other decarbonisation measures such as switching from fossil-based to renewable electricity [177]. Hence, the aluminium sector is expected to play a less significant role for future H_2 demand in the region and was excluded from our analysis.

Similarly, H_2 can be used to be blended with fossil gas in gas-fired cement kilns, although the emission reduction potential for this method is limited due to the high process emissions in the cement industry. This suggests that other pathways are more effective (see section 1.1.4.2). In our research, we were unable to find data on the distribution of coal- versus gas powered cement kilns in each country, but it can be assumed that gas-fired kilns are more common in the countries in which gas makes up a high share of industrial energy consumption. This is in particular the case for Malaysia, where gas is far more frequently used than coal (around 40% versus 10% of industrial energy consumption) [21]. The cement sector was not prioritised in the following review that lists the potential for H_2 end-use in the industry sector for each country.

Vietnam is a leading producer of steel products among ASEAN countries [178]. A pushing factor for the development of green steel using HDR might be given by the introduction of the CBAM. This might be particularly relevant for producers in Vietnam, which exports a large share (around 20%) of its iron and steel products to the EU [49].While green steel will likely be an important industrial product using gH_2,the H_2 strategy of Vietnam draws a broader picture of using H_2 in multiple industries, including steel, but also cement, chemicals and refining [90]. Among these sectors, especially the chemical industry will likely become another important area of application for gH_2. Investing in the production of green ammonia, in particular, presents an opportunity to reduce dependence on fertiliser imports, which the country currently relies on [47]. Although the country is the region's largest producer of cement with a volume of 117 Mtpa [179], it is unclear whether H_2 can be used for co-firing of cement kilns, since this depends on the current fuel that is used in the respective plant (see above).

Looking at gH_2 pilot projects, several projects taking place in Vietnam are planned to include power-to-ammonia applications. At the same time, these projects are often in offshore and coastal areas and the efforts are connected with the development of infrastructure to transfer liquid ammonia on ships [109]. This observation makes it unclear whether the ammonia produced will supply the domestic use or rather is produced for long-distance shipping, for example to Japan and South Korea, which are planning to import green ammonia from SEA countries to be used in power plants [21]. Nonetheless, the domestic market potential for green ammonia in Vietnam is estimated to be large due to the high demand for fertiliser with potential exports even increasing this demand.

Indonesia, on the other hand, is already the largest producer of ammonia and urea-based fertiliser products in the region. Although there are currently no shortages in terms of natural gas supply that would provide a direct economic pressure to replace natural gas, the perspective of more countries possibly introducing a carbon border tax in the future might provide an incentive to be an early adapter of gH_2 in the ammonia and urea industry, which is highly relevant for the country, which exports around 1.8 Mt of ammonia and the same amount of fertiliser[21]. Indonesia's H_2 strategy explicitly endorses replacement of fossil-based H_2 with gH_2 in the production of fertiliser, ammonia and oil refined products. Furthermore, the strategy sets out to replace fossil fuels with H_2 in the provision of high-temperature industrial heat by 2040 [69]. Indonesia has also announced its metal industry as a target sector for H_2 deployment [69], and is among the regions' four main players in terms of refining [153], which is another no-regret opportunity for a switch to H_2. The fact that there are cooperations between the Krakatau Steel company and players from the energy and petrochemical sector to expand H_2 production infrastructure in industrial areas is an indicator that gH_2 deployment in the steel industry will be taken up as well [96].

Malaysia's industrial structure is similar to that of Indonesia, characterised by a strong chemical sector. As the country is exporting around 2 Mtpa of urea[21], gH_2 will be an important component to meet national emission reduction targets and the criteria of potential future carbon border mechanisms. Additionally, Malaysia is also the fourth largest exporter of methanol in the world [21], which is comparable to ammonia in being a no-regret option for gH_2 use. Although the high availability and reliance on natural gas in Malaysia might be a challenge for the decarbonisation and use of H_2 in these sectors, the country also has one of the lowest production costs in the region for gH_2 due to its abundant RE potential (see Section 2.2.1.3.3). Thus, although present gH_2 pilot projects are focused on the transport sector [97], the potential for applying gH_2 in the methanol or refining industry is large and may provide a lower-risk alternative application for gH_2. Malaysia is also the second largest producer of cement and has an industry sector that largely relies on natural gas, which makes H_2 blends for cement kilns a possible option to reduce emissions (see above). However, we could not find any current attempts to employ gH_2 in the country's cement industry.

Singapore, on the other hand, has a strong industrial sector but is an importer of both natural gas and electricity. Like in Malaysia, Indonesia, the Philippines and Thailand, the refining sector plays an important role. Refined oil products make up for around 11% of the country's exports [49]. Singapore is well connected to neighbouring Malaysia with gas pipelines, which could be repurposed for green H_2 in the future, given Malaysia's high RE potential. The fact that Singapore is also strongly investing in research and development on innovative fuels like green kerosene and has a strongly developed port infrastructure makes it likely that it will remain a regional centre of the refining industry. Furthermore, Singapore is the only net exporter of chemical products in the region, but does not produce methanol [180], which is an important feedstock in that industry. Green H_2 production for green methanol might bear the potential to ameliorate the trade balance. There are plans to build a 9 MW electrolyser plant on Jurong Island, which will supply gH_2 for the production of methionine, which is planned to start operation in 2024 [122]. Methionine is an essential amino acid which is mostly produced to feed livestock, but also finds various pharmaceutical applications [181].

Thailand, for its part is the largest importer of ammonia in the region [153], as well as an importer of methanol with no domestic production. Both products are needed to supply Thailand's chemical industry [53]. Thus, gH_2 may provide an attractive opportunity to reduce the need for imports of ammonia and methanol. Hydrogen may also provide an alternative industrial fuel for the supply of high temperature heat that can replace natural gas, of which Thailand's domestic supply is gradually shrinking. However, the potential is limited since H_2 firing in industrial plants is only estimated to be economically feasible for concentrations of up to 20% H_2, since otherwise infrastructural adjustments drive up the price [182]. An area in which H_2 for process heat might nonetheless become relevant is the production of cement. Thailand has a combined cement production capacity of 60 Mtpa and a strong domestic demand pushed by public investment in the construction sector. The country's cement industry is also a regional leader in decarbonisation efforts. Although current efforts seem to focus on other reduction pathways such as alternative cement chemistries and CCU/CCS [183], gH_2 or green ammonia might become an additional building block to the decarbonisation of the country. A more accessible end-use for gH_2 might be the refining sector, which is also very strong in Thailand and expected to maintain a demand for H_2 between 0.2 and 0.3 Mtpa H_2 over the next decades. Political interest exists in green steel, as shown by policies that encourage the use of RE sources in the steel industry, as well as on the regional level, where the ASEAN Centre for Energy provides support for the adoption of RE technologies in the iron and steel industry [153]. One of first projects producing direct reduced iron from HDR has been announced for Thailand by Meranti and Danieli in 2022 [184].

In the **Philippines**, the largest driver of H_2 demand in the industry sector is the petroleum refining industry, followed by the production of basic chemicals like ammonia and methanol. H_2 is furthermore fired for the provision of process heat in some industries [62]. While these sectors which already rely on grey or blue H_2 are likely to be the first applications of gH_2, there is some potential in other sectors as well, in which the H_2 demand could grow in the future. While the country's steel industry is limited to the production of higher-value downstream steel products from imported semi-processed products, the demand for steel is rising [185]. Thus, the potential for H_2 applications currently seems low, although the rising demand may encourage investments in domestic production of crude steel, which could be based on green steel, if the country's H_2 supply appears reliable enough for investors. The cement industry presents a sector that already has a strong presence in the country, with 23 cement plants and a total production volume of 53 Mtpa cement, although the sector is currently recovering from overproduction [186]. Some cement companies operating in the Philippines, like Cemex, have announced a net-zero target for 2050 [187]. However, it is unclear how this objective will be achieved and to what extent H_2 will play a role in the transition. Looking at the energy data for the entire Philippine industry sector, natural gas is currently not used as an energy carrier [21], making H_2 blends in the cement industry a less viable option, and more likely that other alternatives like ammonia or biomass are used.

Laos' industry sector only takes up a relatively small share of the country's economy, which is dominated by the primary sector goods. The manufacturing sector is mainly structured around small and medium-sized enterprises, which have a lower emission level and lack the capital to invest in H_2 applications. The level of industry-related emissions is thus generally low, the only emission-intensive industry with a relevant presence in Laos is the cement industry [188]. It is highly unlikely that the cement industry will deploy H_2, since the use of H_2 for the provision of high temperature heat in cement production is generally contested due to a relatively low emissions saving potential and high CAPEX. Furthermore, Laos does not have any natural gas resources and infrastructure [64], which suggests that most cement kilns are fired with coal or lignite, and H_2 is currently only a technologically mature option when blended with natural gas. There might be some potential to use gH_2 to strengthen the domestic chemical fertiliser production through power-to fertiliser applications, which may become competitive due to the high availability and low cost of RE due to the country's abundant hydropower resources. Laos' only gH_2 project under development at present is led by Tsubame BHB and uses excess hydropower for the production of fertiliser [114]. Although similar projects might follow, the production and demand potential remains limited, since capital availability is a significant challenge and the logistics sector is relatively low developed [176], [188], limiting the prospects of exporting industrial products.

2.2.4.1.2 Transport sector

According to Galimova et al. (2023), H_2 and e-fuels should be mainly used in sectors where electrification is not possible [189]. Due to higher costs and the existence of battery electric vehicles (BEVs) as a technologically mature alternatives, light-duty vehicles are a questionable target for end uses of H_2 [189]. The energy losses for H_2-based FCEVs are higher than for BEVs, hence, H_2 is economically feasible only in those vehicles where battery technology is not a technologically mature option. This insight is mirrored by the observation that the market for H_2-based vehicles in SEA is shrinking. Potentially sensible applications of pure H_2 for the region may lie in the use for short-haul aviation and heavy-duty vehicles, especially trucks operating in ports or industrial areas where gH_2 will be widely available without additional transportation needs [21].

In accordance with these insights, **Singapore**'s H_2 strategy outlines that H_2 in the land transport sector should focus on vehicles with higher power and mileage demands, while emphasising the dominant role of BEVs for road transportation [77].

In **Malaysia**, on the other hand, there are some pilot projects that use H_2 in light-duty road vehicles. Malaysia's Sarawak Energy Berhad has started demonstrator projects for H_2-powered road vehicles and has been setting up first H_2 refuelling stations. Although the focus lies on buses here, the fuel is being tested in multiple types of vehicles, including light-duty ones. Similarly, the automotive company UMW is also investing in light passenger vehicles using H_2 [60]. Generally, H_2 as a fuel for road vehicles is emphasised as a sector in which many pilot projects are already taking place, making Malaysia a likely regional leader in developing an H_2-based road transport sector.

Indonesia also mentions the transport sector as a target sector in its National Hydrogen Strategy [69], without specifying which vehicle types shall be targeted, and whether pure H_2 or derivatives should be used.

Similarly, Thailand's H_2 Development Plan, also includes the road transport sector in the area of heavy-duty vehicles, although it is still unclear whether the focus will be on H_2 fuel cells or H_2-derived synthetic fuels. There is, however, a first H_2 refuelling station in Thailand, pointing towards some interest in H_2-based fuel cells While the discussions of the Power Development Plan seem to place an emphasis on heavy-duty vehicles, the ongoing FCEV trials in Thailand use light-duty vehicles [108].

In the railway sector the first tram powered by H_2 has entered the on-road trial stage and is expected to enter commercial operation by 2025 [190]. In **Indonesia**, a lab train operating on a hybrid system including a diesel engine, auxiliary batteries and 12 kW H_2 fuel cells has been launched in late 2023 [191], while feasibility studies on H_2-powered railway applications have been undertaken as early as 2010 [192].

For other applications in the transport sector, like maritime transportation or long-haul flights, derivatives like ammonia or synthetic fuels are currently the only technologically mature option. However, Singapore intends to promote research on the direct utilisation of H_2 for long-haul flights and aims to develop this as a decarbonisation option in the long term, while SAF will be the more relevant option in the near future [77].

The potential importance of green ammonia in the maritime sector will be further elaborated in Chapter 3.2.4.2. In Chapter 3.2.4.3 synthetic green fuels, which could become important for both shipping and aviation, are discussed.

2.2.4.1.3 Power and heat sector

According to Barrera et al. (2024), forecasts on the demand for H_2 in the power sector is the most uncertain due to the strong coupling effects with other sectors. However, it can be expected that in the near future, H_2 demand will be globally driven by the industry and mobility sector, while power and residential heat plays less of a role [21]. Reasons for this include higher doubts about economic viability and the availability of other technologically mature decarbonisation pathways. Nonetheless, there are some developments in the region that indicate a trend towards using H_2 also in energy sector.

In the case of residential use, **Singapore** is the only country in the region that shows interest in applying H_2 for decarbonisation, already using gas blends with an H_2 content of up to 50% in its municipal gas system, serving for residential heat, cooking and water heating [56].

Looking at energy production, the overall interest in applications of gH_2 seems to be higher. In the **Philippines**, for instance, HDF energy has signed an MoU to explore H_2 combustion plants for the replacement of diesel generators in ensuring baseload energy in off-grid systems [104]. **Singapore** is also planning to build an H_2-ready gas power plant [193]. In **Malaysia**, the use of H_2 has been explored as a storage option for the power supply to off-grid telecommunication towers powered by solar energy. Furthermore, its H_2 roadmap foresees exploring H_2 co-blends with fossil fuels as first, short-term steps towards an H_2 economy [60]. Similarly,

Vietnam's H_2 strategy aims at providing 10% of energy from H_2 combustion by 2050 [90]. A similar trend can be found in **Thailand**, where, EPPO proposed the utilisation of up to 20% H_2 in its power plants by 2037 [51].

In addition to the application as direct fuel in the power sector, gH_2 may serve as a long-term storage option that balances seasonal variabilities of RE supply [21]. This role of gH_2 may also become relevant for RE-based off-grid and small island energy systems. In these contexts, H_2 provides a cost-effective long-term energy storage option and allows for a stable energy supply without an oversizing of battery storages or RE power plants. However, the current costs of H_2 technology instalments makes a combination of battery storage and diesel generator more cost competitive in most cases [194]. Seasonal storage might be an interesting field of gH_2 application for all countries in SEA.

2.2.4.2 Green ammonia

2.2.4.2.1 Industry sector

The largest share of ammonia produced is used in the agricultural industry, namely in form of urea-based fertiliser, which makes up for around 80% worldwide [9]. In Indonesia, the region's largest producer of fertiliser, urea accounts for 88% of the total H_2 demand [69]. Since **Indonesia and Malaysia** are currently leading exporters of nitrogenous fertilisers in the region (both exporting nitrogenous fertiliser in a value of 0.9 – 1 bn. USD per year)[49] and also among the most advanced in the development of green H_2 projects (see Section 2.1.5), it is likely that their regional leadership in fertiliser production will be sustained in the future. In the face of continued population growth, the demand for intensive agriculture and thus for fertilisers is likely to continue growing.

For countries in the region which are currently importing fertiliser, such as the **Philippines, Thailand, or Laos** [49], the advancement of H_2, in the form of power-to-fertiliser might provide an opportunity to reduce the dependence on imports. This is especially true for **Laos**, which has a high installed RE capacity, is currently importing fertiliser and has no gas reserves [64] and a low development of its transport and logistics infrastructure, which makes imports more costly [176]. The fact that the first project involving gH_2 announced in Laos is a power-to-fertiliser facility [114] underlines the assumption. More importantly, current exporters of fertiliser, like Indonesia, will need to switch to gH_2 as a feedstock to maintain their relevance on the global market in the face of increasing carbon border taxes.

Other industrial uses of ammonia include the deployment as a feedstock of plastic, melamine resin, nylon fibre, and synthetic rubber production [9], which will not be discussed in detail in this report due to the relatively small share of end-uses of ammonia that they account for.

Ammonia furthermore can be used as a fuel due to its reactive properties with oxygen, which makes it suitable for process heat in industrial applications [9]. While it is associated with higher energy losses than H_2, it can be blended with coal, while H_2 has only been tested in natural gas blends. Ammonia co-firing has been successfully applied in cement kilns and for the degreasing of steel sheets [195]. **Vietnam and Indonesia** are the region's biggest cement producers, with annual production volumes of 118 Mt and 116 Mt, respectively [179], [196]. Although there are commitments to decarbonise the sector [196], both countries are currently experiencing an oversupply of cement [179], [196] which might discourage investments that would be necessary for the switch to ammonia. Secondly, there are alternative pathways to reduce emissions in cement industry, including the burning of biomass or waste, or the application of CCS technology, or combinations of both. These factors make the cement industry an overall less favourable field of application for green ammonia in comparison to the fertiliser industry, although ammonia can play a role in the future of the cement industry as well.

2.2.4.2.2 Transport sector

The International Maritime Organization (IMO) has announced the goal of halving emissions from shipping by 2050 and ammonia is currently the most promising decarbonised fuel option for maritime transport [130]. Given the long average vessel lifespan of around 25 and 30 years, stakeholders are in need to implement measures to facilitate shipping transition early on to minimise the risk of fossil-fuel powered ships becoming stranded assets [197] The key to decarbonise shipping is using low-CO_2 fuels, although these have not yet been produced on a large scale yet. Hydrogen and its derivatives such as ammonia, which are produced using RE, and liquid gas from biogenic raw materials are the main options [197]. Depending on the type of engine used in these vessels, the cost of retrofitting them to run on alternative fuels can be substantial. Although other synthetic fuels come with a higher compatibility with existing engines, green ammonia is likely to be the most cost-effective option for the near future, due the lower energy losses in its production. H_2 fuel cells, on the other hand, are not a technologically mature option for large ships and would require enormous storage capacities for long-haul transport, making ammonia the most feasible option for marine bunkering. There are estimates that green ammonia could supply more than 43% of the shipping sector. Although it is not market ready as a marine fuel yet, market uptake could be achieved as early as 2027. [21].

As the region comprises many coastal and island nations and major ports (namely Singapore as a regional hub for marine trade), marine transport is assumed to have great potential as an end-use application of green ammonia. Due to geographical factors, shipping and maritime transport plays a crucial role for many SEA countries, especially for the archipelagos like Indonesia and the Philippines, which have the second and third largest maritime workforce in the world and a large number of ships deployed in coastal and inter-island transport [198]. Indonesia alone has around 900,000 people employed in the local and international maritime economy [174]. Furthermore, the region is located along two of the most important shipping routes in the world, the Strait of Malacca and the Sunda Strait, making it a hub for international trade. The geographical location the importance of the trade and shipping sector as a source of employment and income presents an opportunity and necessity for investments in a diversified maritime market that needs to transition to lower carbon intensity and become a hub for international vessels passing between the world's largest economies [197]. Especially **Singapore** can be expected to be at the forefront of ammonia bunkering for marine vessels. The Port of Singapore is currently the world's busiest container transhipment port, with ship arrival tonnage exceeding 2.8 billion gross tonnages in 2021. Singapore is also the world's largest bunkering hub, supplying close to 50 million tons of marine bunker fuel to vessels that supplied international shipping routes in 2021 [81]. Singapore has also already started trials for ammonia bunkering. In a collaboration between the Maritime and Port Authority, multiple research institutes and industry partners, the combustion of ammonia-diesel blend was successfully tested in a platform supply vessel. The fuel was provided through existing terminal infrastructure. While **Indonesia** has not conducted such trials yet, it is likely to achieve decarbonisation of its shipping sector through ammonia. Causing 3.7% of global emissions from shipping (2018, trend increasing), Indonesia has a strong need to take measures to decarbonise the sector in light of the IMO targets. Having announced the vision of becoming a "Global Maritime Fulcrum", Indonesia will need to invest in low-carbon maritime transport to realise this goal [199]. To this end, Indonesian ports can harness the advantages of the large ammonia storage capacities with Indonesia being the 4^{th} largest exporter of the product worldwide.

2.2.4.2.3 Power sector

The combustion of green ammonia for electricity production is, like H_2-firing, associated with significant energy losses that occur during electrolysis, derivate production, transport, and combustion, which drives up the price. Nonetheless, like H_2 combustion, the combustion of ammonia still is subject of some interest in the region. In contrast to pure H_2, ammonia can be used to co-fire both, gas and coal power plants. Currently, there is no development of ammonia-firing plants that work on pure ammonia due to concerns about nitrous oxide (N_2O) emissions, which have a significantly higher global warming potential than CO_2 [9]. With current technology, N_2O emissions become difficult to control for ammonia concentrations of above 70% [20]. For the lower firing rates that are currently possible, the CO_2 emission reductions are very low. Ammonia co-firing indirectly increases emissions from fossil fuels on the short term by potentially extending the life of coal power plants. Ammonia co-blending with coal has between 44% (in Indonesia) up to 94% (in Malaysia) more emissions compared to an average gas power plant. Additionally, low ammonia concentrations have been shown to cause NOx emissions, which further questions the sustainability of ammonia combustion [21].

Ammonia co-firing might especially be promoted in those countries which are currently still expanding their coal-power capacities, namely **Indonesia, the Philippines and Vietnam** [9]. Here, a 2022 study projects a potential demand for coal-ammonia co-firing of 31 Mtpa for Indonesia, 38 Mtpa for Vietnam and 11 Mtpa for the Philippines, while the demand in Malaysia and Thailand ranges significantly lower with 3 and 1 Mtpa, respectively, if all coal power plants currently under construction will be operational and using a co-firing rate of 50% [9]. These high numbers confirm a further constraint to the practicability of widespread ammonia co-firing. The high demand from the power sector would put additional pressure on the SEA market which is already strained by occasional scarcities and supply chain issues, which can easily lead to rising food prices and insecurities since ammonia is needed as a fertiliser and, in the future, as a marine fuel [21].

Despite this Indonesia and Malaysia are conducting feasibility studies to co-fire ammonia in coal power plants, similar plans exist in Singapore, Thailand, the Philippines and Vietnam [158]. In both **Thailand and the Philippines**, feasibility studies in existing coal power plants testing co-firing rates of 20% are ongoing, combined with further developments of green ammonia value chains [120]. **Vietnam** has also committed to transition to ammonia or biomass by 2050 in all power units that are currently burning coal [20].

The cost of green ammonia and the availability of finance and technology for making the necessary infrastructural adjustments remain the main bottlenecks for the deployment of ammonia in the power sector; under present assumptions, co-firing coal power plants with green ammonia would almost double the LCOE [9]. Given the transport advantages of ammonia over H_2 in maritime transport, ammonia firing might be relevant for countries (or regions within a country) which have few available energy resources and cannot import electricity through a grid connection with a neighbouring, energy exporting state (or H_2 through a pipeline). In the SEA region, these criteria might apply to some islands in Indonesia and the Philippines. However, negative impacts of ammonia firing such as carbon-lock in's and fertiliser shortages must be taken into account as limiting factors for a widespread use of ammonia in the power sector (see Section 1.1.4.2).

2.2.4.3 Synthetic green fuels

2.2.4.3.1 Industry sector

Methanol is not only a potential fuel, but also an important feedstock for the production of a large variety of further chemicals. These for example include DME, which finds applications as a pesticide or polishing agent, acetic acid, formaldehyde or olefins, which find in turn precursors to various downstream products like synthetic fibres, plastics, resins or sugars [10]. The complexity of the methanol value chain makes it more difficult to forecast where future applications of gH_2 will emerge, however, it can be assumed that the production of green methanol will follow the distribution of downstream facilities (and existing methanol plants). Figure 23 visualises this complexity by showing current methanol production and other products based on methanol as a feedstock [156].

Based on trade data, the main players in the chemicals and fibres industry are **Malaysia, Singapore, and Thailand**, which are leading exporters of methanol downstream products like polymers, industrial acids, resins and other hydrocarbons [49]. Other important countries, although to a lesser extent, are **Vietnam and Indonesia**. Especially in these countries, in which the export of downstream products of methanol plays a central role, the increasing practice of carbon pricing and international certifications like the European CBAM are a strong incentive for the decarbonisation of methanol production through gH_2. For **Thailand**, which currently does not produce methanol, a switch to locally produced green methanol could additionally be a chance to become less dependent on imports of methanol as a feedstock to supply its chemical industry, without increasing the demand for natural gas imports.

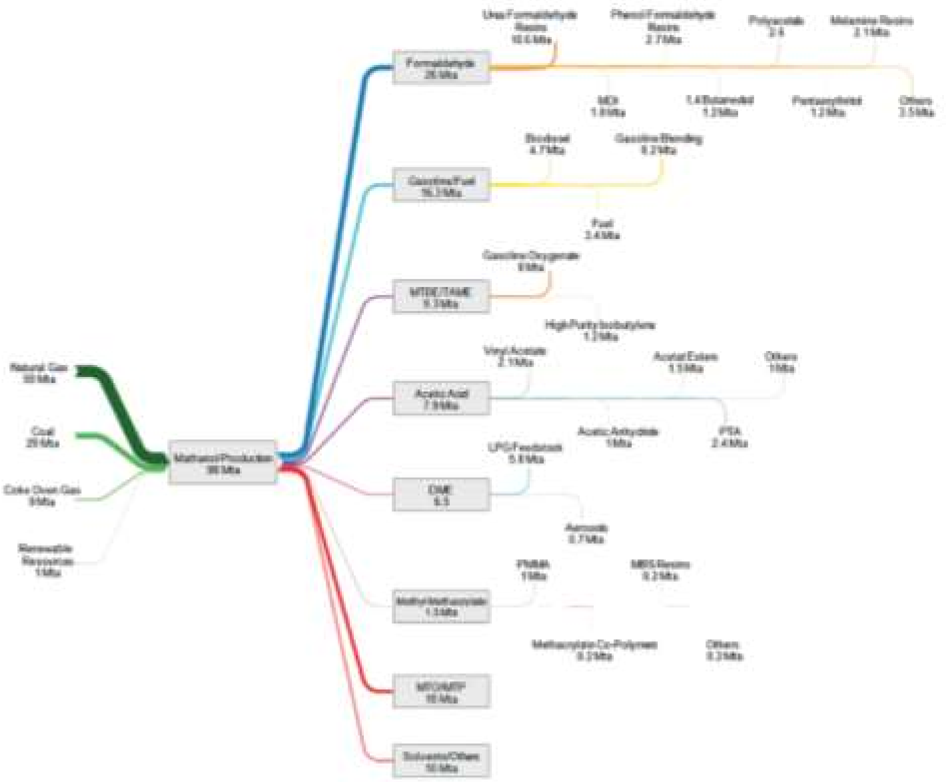


Figure 23: Overview of methanol and downstream products with global production volumes, taken from Tabibian et al. (2023)

Both, Thailand and Malaysia have a relatively high solar power potential which makes them favourable locations for gH_2. Singapore, on the other hand, has also good chances for access to gH_2, if the H_2 pipeline between Malaysia and Singapore, which is currently being studied [200], is to be realised.

Methanol is also used to produce further downstream low-carbon fuels, such as biodiesel. Indonesia, as one of the biggest producers of biodiesel worldwide, has observed increasing imports of methanol [154], and is thus also a likely driver of the future demand for methanol in the region. The switch to green methanol may be a driver for an onshoring of the chemical industry into countries that manage to timely ramp up the production of green methanol. Most likely, however, the transition to green feedstock in the chemical industry will overwhelmingly use existing infrastructure and rather switch the supply from fossil to green methanol.

2.2.4.3.2 Transport sector

New application for methanol and synthetic fuels can be found in the transport sector. PtL synthetic fuels in the transport sector are associated with higher energy losses compared to direct electrification and H_2, but can be expected to play an important role in applications for which the aforementioned alternatives are not available. These applications mainly include marine transportation and long-haul aviation. In shipping, synthetic fuels are tested in parallel to ammonia bunkering. Currently low-carbon aviation over long distances only seems feasible with SAF synthetic fuels. It should be mentioned that the term SAF refers to a variety of different products and production pathways, not all of which require H_2. However, the only SAF product commercially available today and used most frequently are hydrotreated esters and fatty acids (HEFA), which requires H_2 for the production process. Currently, a maximum blending rate of a 50% HEFA –SAF with fossil kerosene is possible [201]. A set of sustainability criteria for SAF are set out in the International Civil Aviation Organization's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Since January 2024, the CORSIA criteria include not only aspects of emission reduction and the source of the carbon stock, but also on aspects like water availability and rights, soil and ecosystem conversation, waste management, human rights or food security [202]. The aviation sector is important for several SEA countries. Although the aviation industry has suffered heavy losses internationally due to the corona virus pandemic in the early 2020s, the decarbonisation of the aviation sector continues to play a key role, as passenger numbers and air traffic growth are expected to increase again in the medium term [203].

- A country of particular interest when looking at aviation sector is **Singapore**. Singapore's Changi Airport is one of the world's major aviation hubs [204]. In February 2022, a working group, called the Singapore Hydrogen Cooperation Committee, was formed after Airbus, Changi Airport Group, the Civil Aviation Authority of Singapore (CAAS) and Linde signed a cooperation agreement. Since then, the committee has been looking at the supply of and demand for H_2 in the regional and local market, the supply chain and infrastructure requirements, as well as the potential factors to implement a successful H_2 system for aviation [205].On the supply side, Neste, a Finnish refining and renewable fuels company, expanded its refinery in Singapore in 2024. The facility is said to produce up to 1 Mtpa SAF, which is the largest capacity worldwide [206]. The operating plant already has an output of up to 1.3 Mt/a biofuel [207]. Although the SAF produced in Singapore is currently not H_2-based, the country's H_2 strategy foresees the integration of low-carbon H_2 into SAF production as a near-term target [77]. Furthermore, Singapore's "Sustainable Air Hub Blueprint foresees concrete targets for SAF blending", intending to make SAF blends of at least 1% mandatory from 2026 and raise the target to 3-5% for 2023, while setting the long-term goal of carbon neutrality of the aviation sector by 2050 [208].
- **Indonesia**, as a major palm oil producer, is also showing first steps in SAF production. Pertamina, an Indonesian company, uses refined, bleached, and deodorised palm kernel oil to produce SAF called Bioavtur. Garuda Indonesia, the national airline, launched its first commercial flight with Bioavtur in October 2023. Pertamina plans to market and distribute its SAF via PT Pertamina Patra Niaga [206]. The sustainability of palm-oil derived biofuel, however is unclear and not accepted by all certification schemes. The Sustainable Aviation Buyers' alliance, for instance, declared palm oil and its by-products as not eligible due to serious environmental risks associated with their production [209].
- **Thailand** has also announced SAF to be part of its national oil plan, analogous to Thai companies announcing to commence the production of SAF [210]. Although currently planned SAF capacities are based on the recycling of used cooking oil [211], it is possible that gH_2-derived SAF will play a role in the future.
- **Malaysia**'s Petronas and Japanese oil company Idemitsu Kosan Co, Ltd (Idemitsu), reached an agreement in October 2023 to work together to ensure a stable and efficient supply chain for the sustainable development of SAF. Petronas is also exploring the use of crude algae oil and palm waste for SAF. The company expects to have the capacity for large-scale production of SAF and other types of biofuels by 2026 through its biorefinery in Pengerang, Johor and co-processing in

Melaka [206]. Like in Singapore, Malaysia also set out SAF blending targets (47% by 2050) in its National Energy Transitions Roadmap [212].

Aviation, however, is not the only relevant area of interest when it comes to the use of gH_2-derived fuels in the transport sector. Especially methanol may provide an alternative to ammonia in maritime transport. Due to the higher volumetric energy density of methanol requiring a smaller tank and less overall space consumption in the vessel, it has an advantage as a marine fuel. Like ammonia, it can be blended with marine diesel at low levels, and can be used in conventional internal combustion engines. For higher levels of blending, a retrofitting of the engine would be necessary. Retrofitting is an essential point due to the long investment cycles of marine vessels [213]. Methanol still plays a rather marginal role, even among low-carbon options for marine transport, but is taking up pace.

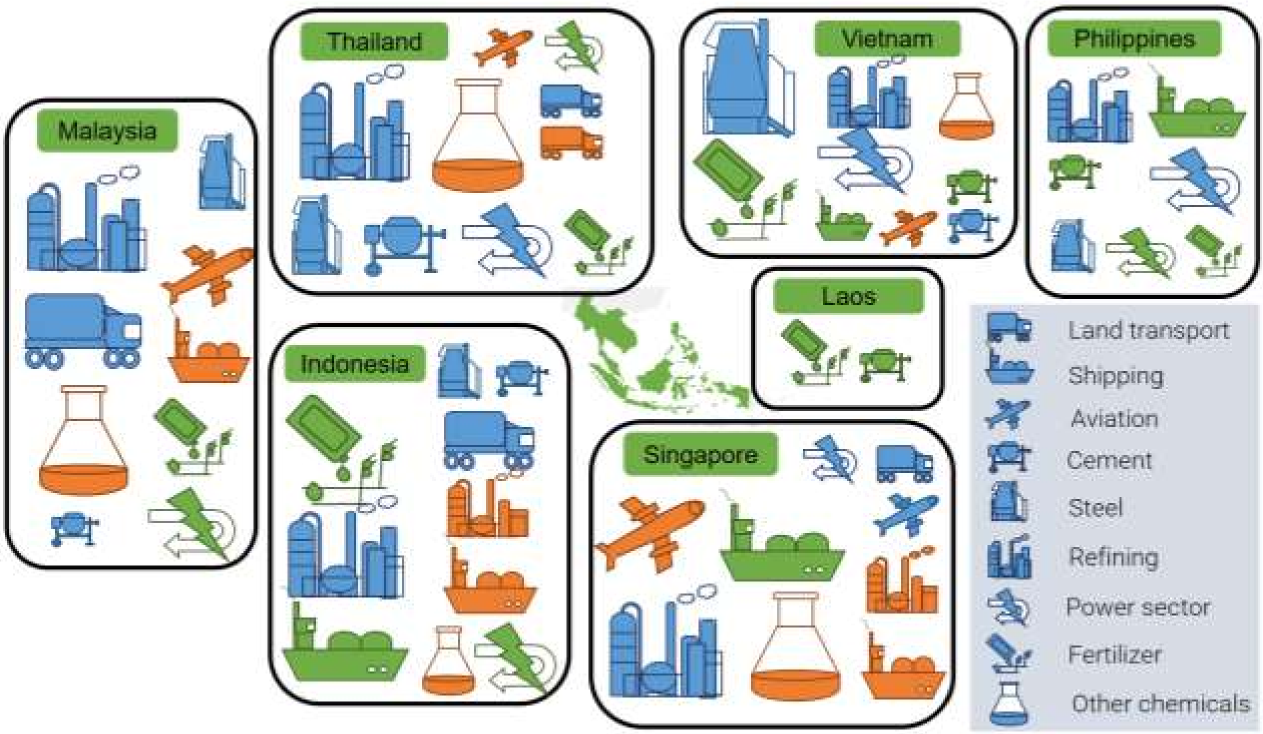
In the region, **Singapore and Indonesia**, with its future capital and major port city Balikpapan, are the two countries that already have significant methanol storage or bunkering facilities in their ports [175], and both are major shipping nations, making them likely to be at the forefront of development of green methanol as a marine fuel. Singapore's H_2 strategy considers methanol and synthetic fuel as possible options for the decarbonisation of shipping, while acknowledging that ammonia is currently the most promising alternative as marine fuel [77]. Nonetheless, there is a multiplicity of proposals using methanol bunkering in Singapore, which has carried out a first trial in ship-to-ship methanol bunkering in 2023. It is estimated that the country could reach a methanol demand for bunkering amounting to up to 1 Mtpa by 2030 [214]. However, there are still uncertainties about the relevance of methanol in the shipping sector in the future. While it has the advantage of easier storage and a higher level of safety compared to ammonia and H_2 (despite its toxic properties), it is associated with higher energy losses and might thus be less economically viable. It is expected that in the near future, the costs of using methanol as a fuel are higher than for ammonia [213].

2.2.5 Summary

The main end-use applications by country are summarised below and visualised in Figure 24. Within the figure, end uses are also marked and distributed to the different products (gH_2 in blue, ammonia in green and methanol/synthetic fuels in orange).

- **Indonesia**: Production potential of gH_2, transformation (mainly to ammonia)
  End uses: fertiliser industry, metal industry, transport (mainly marine transport)
- **Malaysia**: Production potential of gH_2 (very high RE potential and advanced in terms of H_2 policy and projects), transformation (both ammonia and methanol)
  End uses: fertiliser and chemical industry,
- **Thailand**: Production potential of gH_2 (high RE potential)
  End uses: producing industry (cement, steel, glass), refining, chemical industry (methanol), maybe power sector and cement industry
- **Vietnam**: High production potential of gH_2 (abundant solar and wind resources, transformation (mainly ammonia)
  End uses: fertiliser industry (ammonia), steel, potentially power sector and marine transportation
- **Philippines**: Production potential of gH_2 (high RE potential), transformation (Mainly to ammonia)
  End uses: refining, green ammonia in fertiliser industry, marine bunkering and co-firing in coal power plants, potentially to onshore steel production by setting up a domestic HDR-EAF production route

- **Singapore**: little potential for gH_2 production, but takes a role as a provider of technology, strongly involved in trade and storage options, high gH_2 imports expected (H_2 pipeline from Malaysia is planned), producer of derivatives (mainly synthetic fuels, e-kerosene), applications of ammonia and methanol in maritime transport, SAF in aviation and methanol chemical industry. Focus on methanol and synthetic fuels.
- **Laos**: Mainly production of RE, can support gH_2 development in neighbouring countries (mitigating conflicts between higher renewable shares in grid electricity and producing gH_2); some power-to-x applications mainly to make use of excess RE and supply domestic demands of fertiliser.



The colours of the Icons indicate the product used for the respective end-use: **blue= H_2; green = ammonia; orange = methanol/ synthetic fuels.**
The sizes indicate the relevance of the applications: Big = high potential/regional leadership, medium = likely field of application; small = some potential but uncertainties exist

Figure 24: Potential applications of H_2 and derivatives by country and product

2.3 Opportunities of Southeast Asian countries

2.3.1 Drivers and barriers

In the following section, the main drivers and barriers for a gH_2 development in SEA are presented and discussed. For a structured discussion, the drivers and barriers are discussed along the key points of energy, infrastructure, industry, regional market and framework conditions.

- **Energy**

A main driver for H_2 development is the high renewable resource availability in SEA, especially with regard to solar PV, and more location specific for hydropower, geothermal power, and for wind power (compare Section 2.2.1.1).

At the same time, the lack of currently developed renewable power capacities is one of the main barriers for the production of gH_2. Overall, the vast potential especially for variable RE (such as solar PV) is not harnessed yet. Only in Thailand and Vietnam a significant uptake of variable renewable capacities was observed in recent years.

Furthermore, the energy demand is still rapidly increasing in the region and is expected to triple by 2050 compared to the 2020 level [215]. Therefore, new renewable power capacities are likely to feed the growing hunger for power. A massive expansion of RE capacities would address the supressed demand, align with climate change mitigation targets and reduce renewable power costs on the long run which in turn would increase the economic feasibility of gH_2 in the region.

- **Infrastructure**

An advantage of southern SEA for a gH_2 development is the existence of a well-developed natural gas infrastructure in countries such as Malaysia and Vietnam. Furthermore, several terminals for the export of natural gas products are operational or under development [81]. This infrastructure could potentially be upgraded for gH_2 and its derivatives export but retrofitting includes major challenges (inspection of existing pipelines) and costs (material retrofitting) [216].

Nevertheless, the infrastructure for power transmission is still lacking in many parts of the region. The development of the grid infrastructure to integrate necessary large renewable power capacities for the gH_2 development needs significant investments.

- **Regional market**

The domestic demand for H_2 is expected to grow significantly which can stimulate the development of a regional gH_2 infrastructure. However, the demand can only be supplied with gH_2 if the costs can compete with grey and blueH_2 which are currently the main sources to address the regions H_2 demand. Pivotal for competitive gH_2 prices are low renewable power costs. Therefore it will be decisive to generate renewable power under low costs and high full load hours. Several locations show high potential especially with complementing solar, wind and hydropower potential.

On a wider regional scale, large potential export markets with Japan, South Korea, China and Taiwan exist with a favourable distance to SEA and may evolve as main drivers for a gH_2 development if foreign markets demand for entirely renewable H_2. On the other hand, the main competitor for gH_2 supply in the wider region is Australia, here it needs to be carefully assessed if it is possible to generate renewable power at similar costs to Australia.

- **Framework conditions**

Legal and regulatory framework conditions are under a rapid development in the region with Singapore, Indonesia, Malaysia, Thailand and Vietnam already published specific H_2 or gH_2 strategies. Nevertheless, legal frameworks are still not mature enough to attract major commercial interest. The regulatory and legal framework for a private sector driven RE expansion are not yet given in the region. Therefore, an enabling framework for a relevant renewable capacity growth is required as an initial step to develop a H_2 economy.

2.3.2 Roles of Southeast Asian countries

Currently, the role of SEA countries in a future global H_2 economy is yet to be defined and a large level of uncertainty exists regarding the role of the specific countries. A recent report which analysed potential roles of different countries in a future H_2 economy conducted by the World Energy Council (2022) highlights this uncertainty as visualised in Figure 25, [217]: The Philippines is projected to be a self-sufficient country while Indonesia is expected to be slightly-import oriented. However, for other countries in SEA, such as the technologically advanced and major economies of Singapore, Thailand, Vietnam, and Malaysia, no positioning is provided. The analysis also highlights that an important market for H_2 products may evolve in East Asia with Japan, South Korea, and Taiwan characterised as strongly-import oriented countries. While China is projected to be rather self-sufficient, it should be noticed that especially in the industrial zones of southern China, a significant H_2 demand may arise, which could potentially be supplied by SEA countries. On the other hand, the analysis highlights that SEA would compete with Australia as a strongly-export oriented country for supplying the East Asian markets with gH_2 and its derivatives.

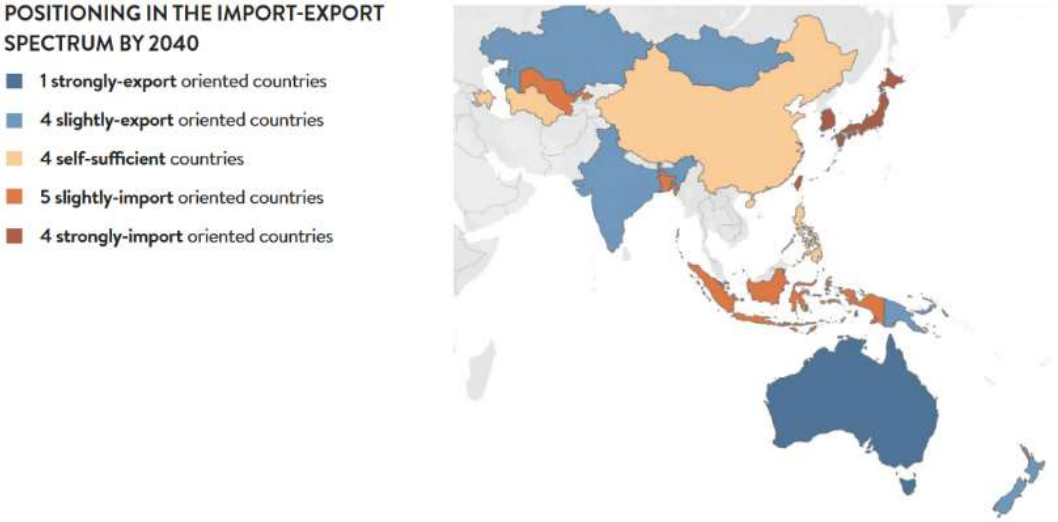


Figure 25: Anticipated role of countries in the Asia-Pacific region in the hydrogen economy by 2040, taken from World Energy Council (2022)

To shed light on the uncertainty of future roles of SEA countries in the H_2 market we have compiled the main information of this report characterising the future role in a global H_2 economy per country and present them in Table 6. We differentiate between ongoing gH_2 projects, future gH_2 market, infrastructure, policy support and RE capacity. Based on the assessment we provide for each country a position as frontrunner, progressive, prospective and potential as adapted from [218]. Furthermore, we define the potential future role as import-oriented/export oriented or self-sufficient.

Vietnam and Malaysia are the first group of countries which are positioned as frontrunners and characterised as rather export oriented. Currently, pilot projects for gH_2 production are already operational [97] or currently implemented [126]. An annual H_2 demand in Malaysia with 50 ktH_2pa [58] and Vietnam with 480 ktH_2pa [47], which is exceeded by Indonesia. Both, pilot projects for gH_2 production and a domestic demand, may stimulate a further development of the H_2 market in these countries. In terms of policy support Vietnam and Malaysia can be considered as progressive since Malaysia published its Hydrogen Economy and Technology Roadmap in October 2023 [54] and Vietnam recently published a Hydrogen Strategy in February 2024 [90]. Both policies set out production goals and initially prioritise the development of a domestic market mid-term and supplying the export market long-term. Notably blue H_2 is considered as "bridging technology" as both countries aim to transition and diversify their natural gas sectors. Based on the existing natural gas industry, both countries have a respective infrastructure in place with pipelines and ports. Here, Malaysia is well ahead but several infrastructure projects are planned for Vietnam. Finally, both countries have implemented RE technology with a RE capacity of 23% in Malaysia [118] and 58% in Vietnam [116]. Since electricity demand is still evolving in both countries it needs to be assessed how much of the planned capacities can actually be utilised for

gH_2 production. Both countries have as well ambitious RE expansion targets with a RE capacity share of 70% by 2050 [110], [127]. Especially for Malaysia it is important to consider the regional differences and perspectives. For example, a massive expansion of hydropower capacities is planned for Sarawak which could provide substantial renewable power for gH_2 generation.

Similar to the two aforementioned countries **Laos** is considered as export-oriented, but mainly for power provision as Laos, in contrast to the two frontrunners, has potential for improving its readiness towards gH_2. In principle, Laos's role in a regional H_2 economy could be to export affordable renewable power from its vast hydropower potential. Hydropower capacities are already intensively developed with the purpose of power exports mainly to China, Vietnam and Thailand [136]. However, recent national interests were directed towards harnessing more from the H_2 value chain. Therefore, a first pilot project for green ammonia production from hydropower excess is planned [114] and a strategy was published to use ammonia as an energy carrier [115].

Indonesia, Thailand and the Philippines can be defined as between progressive (Indonesia, Thailand) and prospective (Philippines) towards gH_2. The three countries are expected to be rather self-sufficient (Philippines, Thailand) to slightly export-oriented (Indonesia) with regard to gH_2. From the three countries, **Indonesia** has a unique role as one of the largest ammonia exporters worldwide. Consequently, Indonesia has the highest current H_2 demand of the region with 1.75 MtH_2pa [68]. Furthermore, a first gH_2 plant is already operational [93] and several projects are under development. Both, the existing H_2 demand and pilot projects, could trigger a substantial domestic demand for gH_2. Indonesia has published a National Hydrogen Policy in 2023 which states H_2 export as a key goal [69]. Potentially, locally produced gH_2 could serve as feedstock for green ammonia production and thus allow Indonesia to export gH_2 derivatives which comply with regulation of foreign markets (e.g. EU's CBAM). However, the implementation of RE in Indonesia is slow. Currently, only 17% of the power mix is renewable [69]. Indonesia targets to achieve 44% renewable power generation by 2023 [135], but rapidly increasing demand for electricity may consume all the added capacity. **Thailand** can be considered as progressive towards gH_2 since several projects even on industrial scale are under development [52], [107]. Furthermore the Hydrogen Development Plan foresees pure gH_2 production from 2040 onwards [52]. Thailand has one of the most diversified energy mixes of the region and aims to achieve 50% renewable generation by 2050. As of now the **Philippines** are considered as prospective towards gH_2 since several H_2 projects are planned [104], [105] and even a national policy is drafted [91]. However, the Philippines lack a substantial existing export infrastructure for natural gas, although several projects are under development [81].

Singapore's position finally can be described as advanced given a number of pilot projects [122], [123] and a published H_2 strategy [77]; [87]. However, the strategy is not clearly differentiating between H_2 and gH_2. In addition, space constraints in Singapore will not allow for significant domestic RE generation, which will have to be imported instead.

Table 6: Final assessment of Southeast Asian countries' role in the future green hydrogen market

Country	gH_2 projects	Future gH_2 market	Infrastructure	Policy support	Renewable energy capacity	Positioning and future role
Indonesia	• First gH_2 plant operational [93]; • Several projects in construction phase [94] or planned [95]; [44] [112];[113] • Current H_2 demand of around 1.75 MtH_2pa [68], mainly used for urea production [69]	• Methanol production • Cement production • Steel production • Green ammonia • Transport (mainly heavy duty)	• Large natural gas grid existing [79] • Several operational LNG terminals in Java, Sumatra, Borneo [81]	• National Hydrogen Policy published 2023, aiming to reduce the share of fossil fuels and export H_2 and derivatives to the global market identification of 17 suitable sites for gH_2 production [69]	• Around 12.5 GW RE capacity (including biomass, around 17% of energy mix)[69] • RE share of 44% by 2030 (mainly geothermal, hydro-power, solar PV) [135]	• Position: Progressive • Future role: Rather self-sufficient to slightly export oriented
Laos	• One planned project for green ammonia production with excess hydropower [114] • No information of H_2 demand or projects	• Potential supplier of renewable power for gH_2 production • Transport (mainly heavy duty)	• No major gas pipelines [81]	• Strategy published for the use of green ammonia as energy carrier [115]	• Around 8.9 GW RE capacity, mostly hydro (83.5% of total capacity) [116] • Expansion of 7.5 GW of hydropower, 1 GW of wind & solar, and 300 MW biomass planned by 2030 [136]	• Position: Potential • Future role: Export oriented[3]
Malaysia	• First PEM electrolyser plant operational since 2019 [97] • Current demand of 50 ktH_2pa, mainly used for ammonia production and refining [58]	• Methanol production • Cement production • Steel production • Transport (mainly heavy duty)	• Large gas network existing and export focused natural gas industry • Several LNG terminals for	• Hydrogen Economy and Technology Roadmap published in October 2023 [60] • Priority to stimulate domestic H_2 demand and evolve as exporter long-term	• Around 8.8 GW (2021); around 23% of total capacity, main sources are hydro, geothermal and solar [118] • Malaysia committed to increase its RE share to	• Position: Frontrunner • Future role: Rather export oriented

[3] Mainly renewable energy exports

			export operational [81]	• Blue H_2 as a bridge technology, by 2050 60% gH_2 planned	70% of the total generation capacity by 2050 [137]	
Philippines	• Planned H_2 power plants [104], [105], one project planning switch from coal to H_2 in existing power plant [62] • No information of H_2 demand or projects	• Cement production • Steel production	• 2 operational LNG terminals; 3 under construction, and further ones proposed, all for import [81]	• Currently a National Policy for Hydrogen in the Energy Sector", is in draft stage, and public consultation took place in October 2023 [91]	• Around 8.4 GW; around 28% of total capacity, mainly hydro, solar and geothermal [76] • The Philippines are planning to extend the RE share to 35% by 2030 and 50% by 2040, mainly achieving this through solar, followed by hydro and wind [138]	• Position: Prospective • Future role: Self-sufficient
Singapore	• One 9 MW electrolyser plant [122] and a green e-methanol plant planned [123]	• Marine and sustainable aviation fuels • Residential use (gas network for cooking) • Chemical industry	• Pipeline connections for natural gas import from Indonesia, LNG terminal for import	• Hydrogen strategy exists, focus on research and development, international collaboration and infrastructure planning, no clear definition of green H_2 ([77], [87]	• Around 1.1 GW, around 9.5% of total capacity, from solar and biomass [124] • Singapore's Green Plan 2023 foresees to add 1.5 GW and at least 2 GW until 2030, which can meet around 3% of its 2030 projected electricity demand [139]	• Position: Progressive • Future role: Import dependent
Thailand	• Several pilot gH_2 production plants and project sites for industrial scale under development or planned [52], [107]	• Cement production • Steel production • Transport (mainly heavy duty)	• Large network of gas pipelines operational and two LNG terminals for gas imports [81]	• Hydrogen Development Plan Thailand, from 2040 onwards only gH_2 shall be produced [52]	• Around 17 GW, around 31.5% of total capacity [125], mainly biomass and solar • RE targets are set to 30% renewable generation by 2037 and 50% by 2050	• Position: Progressive • Future role: Rather self-sufficient

Vietnam	• First gH_2 and green ammonia plant under construction[126], several other projects planned [47], [109] • Around 480 ktH_2pa [47]), mainly used for ammonia production and refining	• Cement production • Steel production • Transport (mainly heavy duty)	• One operational LNG terminal in the south of the country, further Terminal in central Vietnam under construction, several others proposed/ planned [81]	• Hydrogen strategy published in February 2024 • Production targets of 0.1-0.5 MtH_2pa by 2030 and 10-20 MtH_2pa by 2050, which shall be met by a mixture of green and blue H_2 • Further goal of supplying 10% of the nation-wide energy demand with H_2 by 2050 [90]	• Around 46.8 GW, around 58% of total capacity [129] • Vietnam is planning an RE share extension of 30.9 – 39.2% by 2030 and 67.5 – 71.5% by 2050 [127]	• Position: Frontrunner • Future role: Export oriented

2.3.3 High potential use cases

Southeast Asia's rapidly expanding economy presents an opportunity to develop a low-carbon industrial sector. Decarbonising industrial processes such as steel, ammonia, and fertiliser production will be essential to meet climate targets and access international trade markets. Direct electrification and the use of alternative fuels are crucial to drive this decarbonisation. Utilising gH_2 can position the region favourably in global low-carbon markets and significantly reduce emissions. In the following section, some high potential use cases for the application of gH_2 and derivative products in the SEA region are identified and analysed in terms of their technical, operational, and financial feasibility. These use cases have been selected based on the importance of the respective sectors to the country, but also to cover a diverse range of applications for gH_2 and derivative products to be analysed in this study. Use cases have not been selected for all countries, as some of the use cases are transferable to other countries (e.g. fertiliser industry in Indonesia which is also relevant for fertiliser industries in Malaysia, Laos, and Vietnam). The following use cases have been identified:

- **Indonesia: Largest fertiliser producer in SEA (5th largest producer worldwide) with PT Pupuk Indonesia (Persero) being one of the largest producers in the country** [219]

  Also relevant for fertiliser industry in Malaysia, Philippines, Thailand, Vietnam and Laos

  Pertamina (Persero), PT Pupuk Indonesia (Persero) and Mitsubishi Corporation have agreed to jointly develop the gH_2 and green ammonia value chain businesses with CCU/S in Indonesia [52]

- **Malaysia: Petronas Chemical Group as main producer of methanol in the Asian-Pacific region with Malaysia being one of the three methanol producers in SEA** [142]

  Also relevant for methanol production industry in Brunei Darussalam and Indonesia [142]

  Maersk, in collaboration with PTT Exploration and Production Public Company, Air Liquide, YTL PowerSeraya, Oiltanking Asia Pacific and Kenoil Marine Services has formed a joint venture to develop a green e-methanol plant in Singapore [220]

- **Philippines: The Bataan Refinery in the Philippines is the country's largest refinery plant running since 1961** [221]

  Also relevant for petrochemical industry in Thailand, Singapore, Indonesia, Vietnam and Malaysia

- **Thailand: Siam Cement Group (SCG) as ASEAN's largest cement producer** [222]

  Also relevant for cement production industry in Malaysia (mature cement market) as well as Indonesia, Vietnam, the Philippines (emerging cement markets) and Cambodia, Laos and Myanmar (frontier cement markets) [222]

- **Vietnam: The country has the largest steel production capacity in SEA, with the Hoa Phat Group being one of the biggest producers in Vietnam** [223]

  Also relevant for steel production industry in Malaysia, Indonesia, Thailand, and Philippines [223]

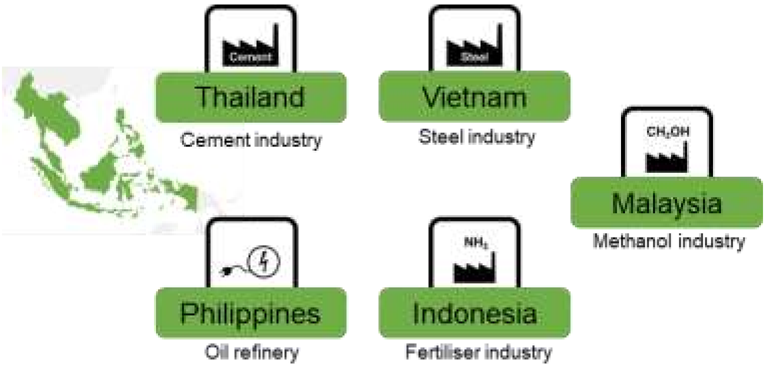


Figure 26: Selection of countries and applications for high potential use case analysis

For these identified use cases, traditional production technology and green alternative production processes are briefly summarised below, and the cost of gH_2 production is estimated with the "Regional green hydrogen production infrastructure optimisation tool" (OptiH2Infra) developed by the Reiner Lemoine Institut within the HyExpert H2VL project[4]. This tool is able to calculate the LCOH based on CAPEX and OPEX costs for different system components (PV and wind power plants, electrolyser, compressor, and storage), RE potential time series and given gH_2 production volumes (or demand volumes). Depending on domestic RE potentials, an optimal combination of PV, wind power and electrolyser capacities is provided to minimise the LCOH. The tool currently only includes wind and solar as RE sources. This means that hydro and geothermal energy, two very promising RE sources in SEA, cannot be included in the LCOH calculation. The real cost of H_2 production may therefore be lower than the calculated cost for specific sites, depending on their hydro and/or geothermal potential. The input data used was provided by GIZ and is summarised in the following table.

Table 7: Input parameter for LCOH calculation valid for the Southeast Asian region provided by GIZ for the year 2030

Input parameter for LCOH calculation			
Technology	Parameter	Unit	Value
Onshore wind	CAPEX	USD/kW	812.93
Onshore wind	OPEX	USD/(kW*year)	19.76
Onshore wind	Lifetime	year	30
Solar PV	CAPEX	USD/kW	524.58
Solar PV	OPEX	USD/(kW*year)	8.01
Solar PV	Lifetime	year	30
Electrolyser	CAPEX	USD/kW	976[5]
Electrolyser	OPEX	USD/(kW*year)	20
Electrolyser	Lifetime	year	25

[4] https://reiner-lemoine-institut.de/en/feasibility-study-hyexpert-h2vl/

[5] Electrolyser nit CAPEX of 722.93 USD/kW plus 35% EPC cost mark-up

The solar and wind potential data was derived from Renewables Ninja[6] with the following assumptions:

PV power plant:

- no tracking
- inclination 35° / 180°

Wind power plant:

- turbine: Vestas V90 2000
- hub height: 100 m.

The site-specific LCOH calculations are then compared with country-specific LCOH projections for 2030 (see Section 2.2.1.3.3) to assess whether on-site production is favourable for the specific cases. Transport costs are assessed based on a study conducted by Bloomberg (2020) and are shown in the graph below which is taken from their analysis [224].

It should be noted that the use of gH_2 as an alternative fuel is an option to reduce emissions in industrial processes currently caused by burning fossil fuels, e.g. to provide high temperatures. However, in most studies this is considered a secondary option as direct electrification is likely to be more economically viable ("no regret option"), whereas gH_2 utilisation is rated as "regret" application [144]. For this reason, the following use cases focus on so called 'non-energy' uses of gH_2.

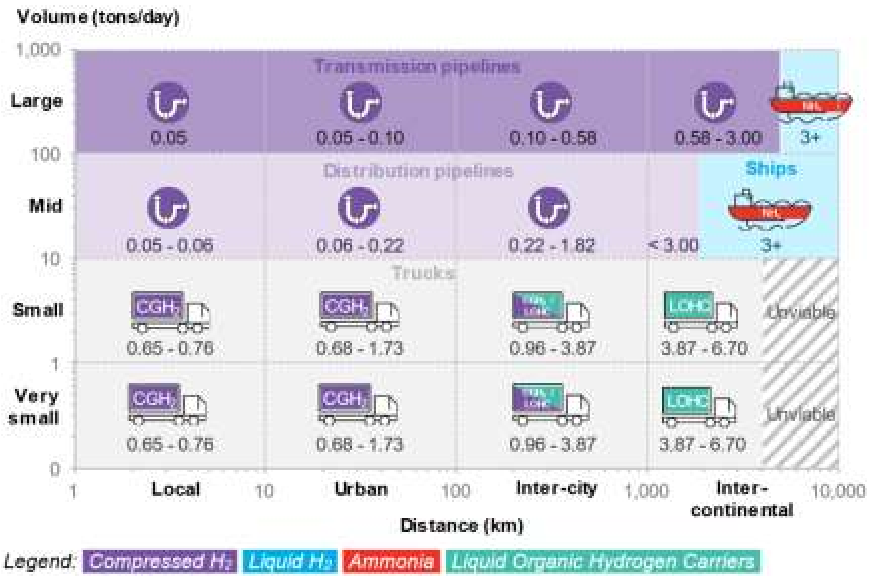


Figure 27: H_2 transport costs based on distance and volume in USD/kg

2.3.3.1 Indonesia – Green ammonia: PT Pupuk Indonesia fertiliser production

Indonesia holds a significant position in global fertiliser production, standing as the largest producer in the SEA region. Ammonia (NH_3) serves as the cornerstone for mineral nitrogen fertilisers, which are extensively utilised worldwide. To meet the challenge posed by the escalating demand for eco-friendly fertilisers and compete effectively with other global players, Indonesia and its neighbouring countries are under pressure

[6] https://www.renewables.ninja/

to transition their fertiliser industries, particularly ammonia production, towards fossil-free technologies. In the realm of fertiliser production, the pivotal factor in emission reduction lies in the procurement of ammonia. Therefore, it is imperative to delve into existing ammonia production methods and explore avenues for transitioning these processes to fossil-free alternatives. In general, there are three colours relating to ammonia production:

- Brown ammonia: based on fossil fuel feedstock without CCS
- Blue ammonia: based on fossil fuel feedstock with CCS
- Green ammonia: based on gH_2 as feedstock.

2.3.3.1.1 Traditional ammonia production

Traditional ammonia production involves several key steps as visualised in the figure below on the left side [6]. The process starts with H_2 production and air capture to gain nitrogen as feedstock ("production of the synthesis mixture", see figure below) culminating in the Haber-Bosch process ("production of ammonia", see figure below), which converts nitrogen and H_2 into ammonia.

The majority of ammonia production facilities utilise grey H_2 generated through steam methane reforming (SMR), a process that emits CO_2. SMR comprises two stages, the initial of which is allothermal and involves fuel emissions, typically from natural gas or coal used for process heat. Additionally, methane combustion during production releases CO_2 process emissions. Although subsequent steps like partial oxidation and water-gas shift reaction are less energy-intensive, they still result in CO_2 emissions.

During the second step of ammonia production, ammonia is synthesised from H_2 and compressed air (containing nitrogen as a feedstock, along with methane and argon as inert gases) via the Haber-Bosch process. While this process itself is devoid of process emissions, most conventional ammonia plants rely on natural gas for thermal energy and power in the Haber-Bosch reactor, necessitating a shift to fully reduce emissions.

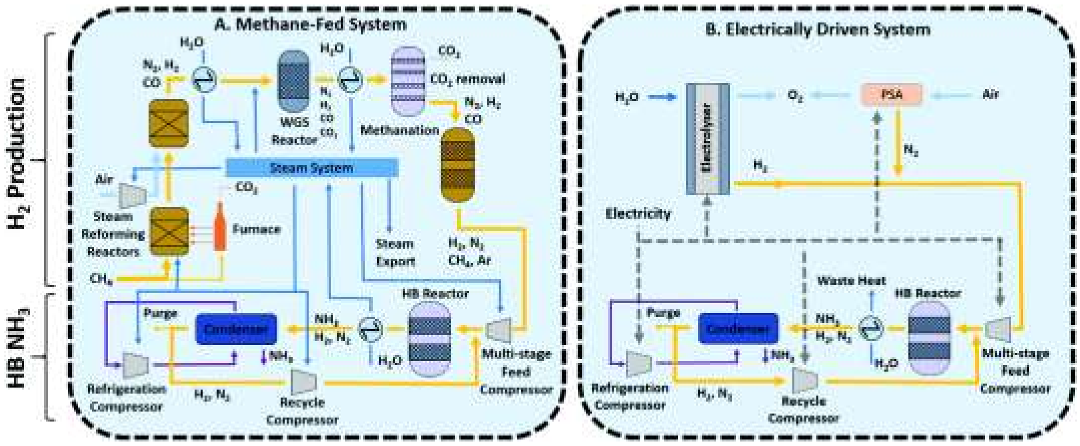


Figure 28: Traditional (left) versus green ammonia (right) production processes, taken from Smith et al. (2020)

2.3.3.1.2 Green ammonia production

The primary option for reducing emissions in ammonia production involves substituting grey H_2 with gH_2 (see figure above, right side). This necessitates a continuous supply of gH_2 through pipelines or an on-site electrolyser, replacing existing steam reformers. In this approach, the Haber-Bosch process, currently the sole method for ammonia production, would undergo minimal alteration. However, temperatures ranging from 800-900 °C must be sustained through direct electrification or alternative fuels to entirely supplement natural gas. Alternative emission reduction strategies include maintaining conventional H_2 production and mitigating emissions through CCS, also known as blue H_2, which faces sustainability challenges. Electrocatalytic nitrogen reduction, though limited to laboratory scale, may not be relevant for several decades. The optimal approach seems to be retaining the Haber-Bosch process while transitioning to gH_2 and electrifying process heat and compressors. Nonetheless, drawbacks include higher energy losses and a substantial land footprint due to the demand for renewable electricity. Cost competitiveness, estimated to be achievable by 2030, could improve in the future with rising natural gas prices and falling renewable electricity costs.

2.3.3.1.3 Cost estimation

In order to assess the feasibility of on-site gH_2 production to replace the currently used grey H_2 for ammonia and fertiliser production respectively, H_2 production costs were calculated for the selected case study "PT Pupuk" in Dumai, Indonesia. The ammonia production volume of this fertiliser plant is projected to be 8.07 million t/a in 2030 according to the National Hydrogen Strategy of Indonesia (page 34) [69]. According to Baharudin et al. (2017), 0.188 tonnes of H_2 is required to produce one tonne of ammonia, resulting in a H_2 demand of 1.45 million tonnes/year (in 2030) for the selected case study [225]. The following table summarises the H_2 and ammonia production volumes and main results of the applied OptiH2Infra tool for the first case study PT Pupuk Fertiliser Industry.

Table 8: Ammonia and H_2 production volumes as well as main results of OptiH2Infra for PT Pupuk case study (Indonesia)

PT Pupuk fertiliser plant in Dumai – production volume			
Ammonia production at PT Pupuk in 2030	**8.07**	**Mil. tpa**	
H_2 demand to produce ammonia	**1.45** 1,452,600,000	**Mil. tpa** kgpa	
OptiH2Infra outputs: Capacities, full load hours and production cost			
Installed components:	Capacity[7]	Full load hours	Production costs
Electrolyser:	31,736 MW	2,540 hpa	5.56 USD/kgH_2[8]
PV:	63,472 MW	1,357 hpa	4.70 USDct/kWh_el
Wind:	0 MW	332 hpa	32.01 USDct/kWh_el
OptiH2Infra outputs: CAPEX and LCOH			
Total CAPEX:	**71,730**	**Mil. USD**	
CAPEX electrolyser:	30,976	Mil. USD	
CAPEX compression & storage[9]:	7,431	Mil. USD	
CAPEX PV:	33,323	Mil. USD	
CAPEX Wind:	0	Mil. USD	
Total H_2 costs[10]:	**6.37**	**USD/kgH_2**	

[7] Theoretical capacities as calculated, in reality they have to be adjusted to the available technology (e.g. 30 GW or 32 GW if 31.7 GW was calculated)

[8] only production, without compression, cooling and storage

[9] compression to 350 bar, cooling and storage for one day of full production

[10] including compression to 350 bar, cooling and storage for one day of full production

Taking into account the site-specific RE potential (solar and wind), this case study shows the potential for gH_2 production based on solar energy only (limited wind resources). Massive investment would be required to produce the gH_2 on-site (total CAPEX of 71,730 million USD for H_2 technology and solar power plant) and space on the roofs and near the fertiliser plant for ground mounted systems to install a total of 63 GW of PV. Comparing the full load hours of the PV system (1,357 h/a) for this case study with an analysis by Sens et al. (2022) for Europe and North Africa, the results for Indonesia are comparable to those for Southern European countries [226]. Looking at the pure production cost of gH_2 for this site, 5.56 USD/kg H_2, and comparing this with the study by Sens et al. (2022), the on-site production costs (excluding storage and compression) are again comparable to those in Southern Europe. The calculated LCOH of 6.37 USD/kg H_2 is higher than the projections for 2030 described previously (2.4 – 4.1 USD/kg), which could be an indication that the high H_2 demand combined with the site specific RE potential makes the purchase of gH_2 more feasible than on-site production for this case study. Inner-country gH_2 transportation cost can be estimated with 0.10 – 0.58 USD/kgH_2 for shipping or 0.96 – 3.87 USD/kgH_2 for road transport (trucks) [224]. In this case, a combination of the two modes is likely; if a higher proportion of road transport is required, on-site production becomes more feasible due to higher transport costs. It should be also noted that this calculation, as well as the study cited above, is an initial assessment and certain assumptions have been made that need to be validated. The feasibility of on-site production will depend heavily on market trends in the coming years and will also be positively influenced if the feed-in of excess electricity generated by the RE plants installed at the H_2 production sites generates additional profit and if a mix of RE plants may guarantee high values for full load hours of electricity generation and H_2 production. In the vicinity of the analysed site, there is a river (about 23 km away) and access to the Strait of Malacca (about 2 km away), which may have hydroelectric potential. It is also close to a promising area for geothermal potential, as several geothermal power plants are close to the ammonia production facility (on the other side of the island, with access to the Indian Ocean, about 240 km away). Harvesting these potentials may further reduce resulting LCOH.

2.3.3.2 Malaysia – Green synthetic fuel: Petronas Chemical Group methanol production

Methanol (CH_3OH) is a colourless alcohol which serves as a versatile chemical feedstock for various industrial processes, including the production of plastics, adhesives, solvents, and fuels. It can be used as a clean-burning fuel for transportation, power generation, and heating applications, offering a sustainable alternative to conventional fossil fuels. As Malaysia is one of three countries in SEA with domestic methanol production, the country may feel the urge to convert its current fossil fuel-based production process to green production, especially to maintain global and regional trade options. The following is a brief overview of traditional versus green methanol production, followed by an analysis of production costs.

2.3.3.2.1 Traditional methanol production

Traditional methanol production primarily uses natural gas or coal as a feedstock through processes such as steam reforming or gasification to produce synthesis gas (syngas). When this synthesis gas is fed into a reactor with a catalyst, methanol and water vapour are produced. Various feedstock can be used to produce methanol, but natural gas is currently the most economical. The use of fossil fuels in traditional methanol production results in significant CO_2 emissions. Conventional methods require significant energy input, often from non-renewable sources, making the process even more environmentally unsustainable.

2.3.3.2.2 Green methanol production

Green methanol production involves using gH_2 derived from water electrolysis using RE sources such as solar or wind power. Another essential component for methanol production is CO_2 captured from industrial processes or directly from the atmosphere. This CO_2 is hydrogenated using gH_2 to produce methanol via a catalytic process. By utilising CO_2 as a feedstock and gH_2 as a reducing agent, green methanol production can be carbon-neutral or even carbon-negative, depending on the source of H_2 and the overall process efficiency. Scaling up green methanol production requires investment in RE infrastructure, carbon capture and utilisation technology, and efficient catalytic processes. However, the scalability potential is substantial, given the abundance of RE resources in SEA and the availability of CO_2 sources.

2.3.3.2.3 Cost estimation

In order to assess the feasibility of on-site gH_2 production to replace the currently used natural gas, H_2 production costs were calculated for the selected case study- The Petronas Methanol Plant in Labuan is one of the biggest methanol production units in the region and combines two plants in one industrial complex. The methanol production capacity of both plants is stated as 2,400,000 tpa (in 2020) [227]. Baharudin et al. (2017) estimate that 0.125 t of H_2 are needed in order to produce one tonne of methanol [225]. This results in a H_2 need of 300,000 tpa (300,000,000 kgpa) for this specific site. The following table summarises the H_2 and methanol production volumes and main results of the applied OptiH2Infra tool for the second case study.

Table 9: Methanol and H_2 production volumes as well as main results of OptiH2Infra for Petronas Methanol Production in Labuan (Malaysia)

Petronas Methanol Production (Plant 1 & 2) in Labuan – production volume			
Methanol production capacity in 2020	**2,400,000**	**tpa**	
H_2 demand to produce green methanol at this site	**300,000** **300,000,000**	**tpa** **kgpa**	
OptiH2Infra outputs: Capacities, full load hours and production cost			
Installed components:	Capacity	Full load hours	Production costs
Electrolyser:	6,288 MW	2,648 hpa	5.34 USD/kgH_2
PV:	12,576 MW	1,461 hpa	4.37 USDct/kWh_el
Wind:	0 MW	617 hpa	17.25 USDct/kWh_el
OptiH2Infra outputs: CAPEX and LCOH			
Total CAPEX:	**14,235**	**Mil. USD**	
CAPEX electrolyser:	6,137	Mil. USD	
CAPEX compression & storage[11]:	1,495	Mil. USD	
CAPEX PV:	6,602	Mil. USD	
CAPEX Wind:	0	Mil. USD	
Total H_2 costs[12]:	**6.13**	**USD/kgH_2**	

This case study evaluates the potential for gH_2 production solely from solar energy due to limited wind resources. It highlights the need for significant investment, totalling 4,235 million USD, to establish on-site production infrastructure, including H_2 technology and solar power plants. Installation of 12.5 GW of PV systems would be necessary, utilising space on roofs and near the methanol plants for ground-mounted systems if there are no space constraints. A comparison with the study by Sens et al. (2022) shows, similarly to the first case study, that full load hours of the PV plant (1,461 hpa, slightly higher than for the Indonesian site) and gH_2 production costs (5.34 USD/kg H_2, slightly lower than for the Indonesian site) for this specific case are comparable to those of Southern European countries [226].

[11] compression to 350 bar, cooling and storage for one day of full production

[12] including compression to 350 bar, cooling and storage for one day of full production

The calculated LCOH is 6.13 USD/kgH_2 and slightly lower than for the Indonesia case study. However, the LCOH is also exceeding the projected costs for 2030 outlined in Section 2.2.1.3.3 (2.1 – 3.6 USD/kg). This suggests that despite high H_2 demand and favourable RE potential at the site, purchasing gH_2 may be more economically viable than on-site production in this scenario. However, it is important to recognise the preliminary nature of this analysis and the need to validate some of the assumptions made. The use of a variety of RE sources, such as ocean or river power in addition to solar power, given that the production site is located directly on the sea and within 3 km of a river, has the potential to significantly reduce the LCOH at the site and improve cost competitiveness. It is also important to consider transport costs within the country and real cost developments in the future to clarify this. Inner-country transport cost depend on the mode of transportation and the volume, for this case most likely via truck transport (0.96 - 3.87 USD/kgH_2) and/or shipping (0.10 – 0.58 USD/kgH_2) through the close by port [224]. Therefore, if a large proportion of road transport costs can be avoided, which is likely to be the case due to the limited size of the island on which the site is located, transport costs could be negligible for this site. The location of the methanol plant on the island of Labuan, close to the port, has another strategic advantage. In the event of excess gH_2 production, the use of the port for sales and shipping could provide another avenue for long-term profitability. Currently, green methanol production may be more expensive than traditional methods due to the higher cost of necessary input gases (gH_2 instead of natural gas). However, as RE becomes more cost-effective and technology advances, the cost differential is expected to decrease.

2.3.3.3 Philippines – Green hydrogen: Bataan Refinery (Petron Corporation)

Green oil refineries, which use gH_2 in their oil processing, represent a sustainable shift away from traditional oil refineries, which rely heavily on fossil fuels not only as a raw material but also as an input in oil processing contributing significantly to CO_2 emissions. The SEA region is characterised by its oil and gas industries, and therefore processing facilities. Refinery greening has a large market potential in the SEA region. The Bataan Refinery, selected as a case study, is the largest oil refinery in the Philippines and is representative of many others in the region. Below is a brief overview of traditional oil refining processes and the green alternative based on gH_2 as an input source. The LCOH is then calculated for this case study.

2.3.3.3.1 Traditional oil refinery

Traditional oil refineries process crude oil obtained from fossil fuel sources such as petroleum wells. Crude oil is a non-renewable resource composed of hydrocarbons. The raw crude oil undergoes heating within a furnace before being directed to a distillation tower for separation based on boiling points (naphtha, light oils and heavy oils are separated). Subsequently, through processes involving heating, pressure adjustments, or catalyst utilisation, the separated components are transformed into a range of finished products [228]. As shown in Figure 29, many of these naphtha, light and heavy oil processing steps include H_2 (hydrotreating, hydrocracking) [229]. Final refined products encompass various fuels such as gasoline and diesel, as well as specialty items like asphalt and solvents. These refineries typically rely on fossil fuels such as natural gas, coal, or petroleum products for energy-intensive processes like distillation, cracking, and reforming as an external energy source and on H_2 for refining processes.

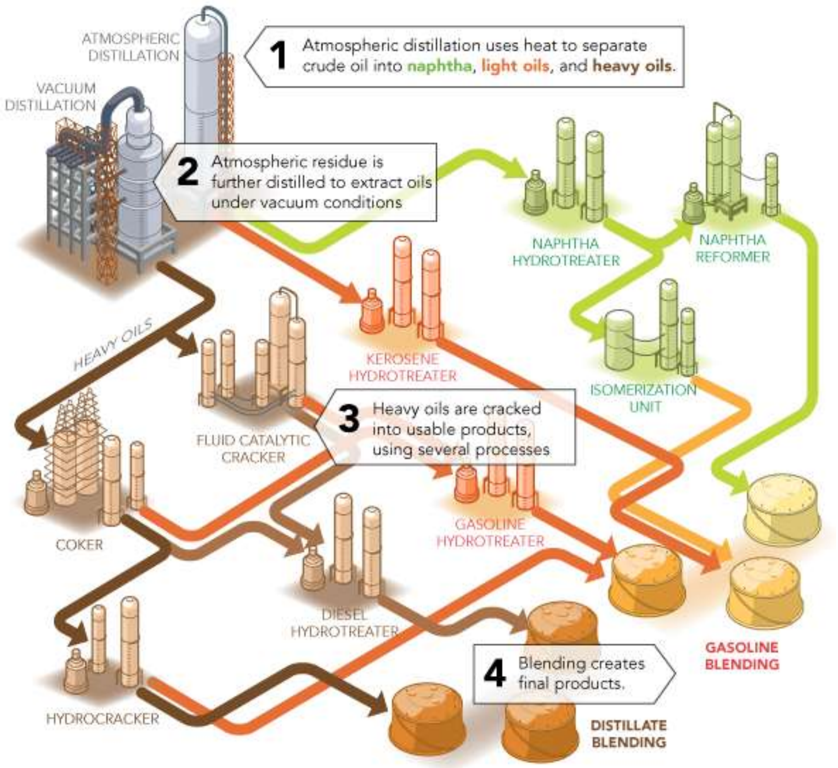


Figure 29: Overview of crude oil refinery processes, taken from GLT Products Blog (2024)

2.3.3.3.2 Green oil refinery

Green oil refineries use gH_2 for refining processes (hydrogenation) instead of grey or blue H_2. Processes include hydrocracking, hydrotreating and hydrodeoxygenation to upgrade crude oil fractions and remove impurities. In addition, oil refineries may look to other high-temperature provision sources than coal or gas to further decarbonise their production processes.

2.3.3.3.3 Cost estimation

To evaluate the viability of on-site gH_2 production as a replacement for the currently used conventional H_2 for hydrocracking and hydrofining, the production costs of H_2 were computed for the specific case study Bataan Refinery. This plant is processing a crude oil volume of 180,000 barrelspa [221]. According to Baharudin et al. (2017), hydrocracking requires 0.5-0.8 wt% H_2 relative to the crude oil feed and hydrofining requires 0.005 wt%, resulting in an average requirement of 10,306 tpa gH_2 for this plant [148]. The subsequent table provides a summary of the required H_2 and crude oil processing volumes, as well as the primary outcomes derived from the employed OptiH2Infra tool for the third case study.

Table 10: Crude oil processing and necessary H_2 production volumes as well as main results of OptiH2Infra for Bataan Refinery, Petron Cooperation (Philippines)

Bataan Refinery (Petron Cooperation) – processing volume			
Crude oil processing volume (2020)	180,000 24,552[13]	Barrel per annum tpd	
H_2 demand for hydrocracking and hydrofining	10,306[14] 10,305,702	tpa kgpa	
OptiH2Infra outputs: Capacities, full load hours and production cost			
Installed components:	Capacity	Full load hours	Production costs
Electrolyser:	155 MW	3,685 hpa	4.47 USD/kg H_2
PV:	155 MW	1,606 hpa	3.98 USDct/kWh_el
Wind:	155 MW	2,279 hpa	4.75 USDct/kWh_el
OptiH2Infra outputs: CAPEX and LCOH			
Total CAPEX:	399	Mil. USD	
CAPEX electrolyser:	151	Mil. USD	
CAPEX compression & storage[15]:	40	Mil. USD	
CAPEX PV:	81	Mil. USD	
CAPEX Wind:	126	Mil. USD	
Total H_2 costs[16]:	5.11	USD/kg H_2	

This case study assesses the feasibility of gH_2 production using solar and wind energy sources, both having a promising potential at the site. It underscores the substantial investment required, amounting to 399 million USD, to establish on-site production infrastructure, encompassing H_2 technology, solar and power plants. Compared to both previous case studies, the required H_2 volume is smaller, resulting in lower initial investment costs. The installation of 155 MW of PV systems and wind turbines would be necessary, utilising available space on roofs and in proximity to the refinery for ground-mounted PV systems and wind power plants, if space permits.

A comparison with the study conducted by Sens et al. (2022) reveals that the full load hours of the PV plant (1,606 hpa, significantly higher than for all other sites) can compete with those seen in the North African region [226]. In terms of wind power full load hours (2,279 hpa), the site is equally suitable as Northern European countries having similar full load hours [226]. The Philippines case study shows the lowest gH_2 production cost of all the sites analysed at 4.47 USD/kg H_2 comparable to those in North African countries [1]. The calculated LCOH stands at 5.11 USD/kg H_2, lower than for all other sites slightly exceeding the projected costs for 2030 as outlined in Section 3.2.1.3.3 (2.5 – 4.0 USD/kg). As the site is competitive with the North African region in terms of RE full load hours and projected H_2 production costs, on-site production of gH_2 to replace the current grey and blue H_2 could be beneficial for this site in the future. In particular, if additional RE sources such as hydropower (the refinery is located next to the sea and close to a river) or geothermal energy (the site is close to a geothermal power plant, app. 100 km distance) could be integrated for a diverse energy mix creating high full-load hours, production costs could be significantly reduced.

[13] Based on 0.1364 as crude oil conversion factor (barrels to tonnes), provided by Qatarenergy [230]

[14] Based on H_2 consumption in wt% relative to crude oil based on Baharudin et al. (2017) [225]

[15] compression to 350 bar, cooling and storage for one day of full production

[16] including compression to 350 bar, cooling and storage for one day of full production

2.3.3.4 Thailand – Green hydrogen: SCG cement production

Cement production is an important industry in many SEA countries, with Siam Cement Group (SCG) being the largest producer in the region. In the cement industry, gH_2 can be used in a number of ways to decarbonise the production process. It can either be used to replace the fossil fuels currently used to provide the high temperatures required for cement production, or it can be used as a reducing agent in the production of clinker (an essential component of cement) responsible for a large share of CO_2 emissions in the production process. To provide an overview, the production of conventional and green cement is described below, followed by the LCOH calculation for application in clinker production.

2.3.3.4.1 Traditional cement production

Cement primarily consists of clinker, which is intricately linked to a highly emission and energy-intensive production process. For clinker production, a mixture of clay, limestone, and sand is heated to temperatures near 1500 °C. Following limestone quarrying, the raw material undergoes crushing and grinding to ensure homogenisation. Subsequently, the raw material is fed into a preheater, where waste heat from other stages of the production chain is often harnessed. Approximately 40% of emissions in cement production originate from burning fossil fuels to achieve the high temperatures required - 900 °C for the calciner and 1450 °C for the rotary kiln. These being the two main components of a cement production facility [231]. However, a more substantial challenge to decarbonisation efforts in the cement industry lies in process emissions associated with clinker production, constituting about 60% of the total emissions in the sector. These emissions arise from the calcination process, where limestone ($CaCO_3$) undergoes decomposition into quicklime (CaO) and CO_2.

2.3.3.4.2 Green cement production

To mitigate the process emissions, which are currently deemed unavoidable, CCU/S emerges as a critical technology for emission reduction. CCU/S can be integrated with oxyfuel combustion, where fuels are burned with pure oxygen instead of air, thus minimizing NO_x emissions and other off-gases to yield pure CO_2, enabling a capture rate exceeding 90%. Pilot plants for the oxyfuel + CCS pathway already exist, but not in an operational scale. However, CCU/S entails increased energy demand and consequently a cost increase estimated at 78-104%.

An alternative approach to curbing process emissions without solely relying on CCS is to alter the chemical composition of cement. Since clinker is responsible for process emissions in cement production, reducing its share can significantly cut down GHG emissions. Supplementary cementitious materials (SCMs) like fly ash or blast furnace slag can compensate for a reduced clinker share [232]. However, both are by-products of coal burning for energy production or conventional steelmaking, respectively, remaining linked to fossil production pathways. Exploring other sustainable materials like magnesium (potentially enabling negative emissions), calcium silicate, or aluminate faces technical immaturity. In addition, H_2 can be used as a reducing agent in the raw material mix for cement production and offers a means to diminish the required amount of clinker by half, thus reducing CO_2 emissions by as much as 50% if gH_2 is applied [233]. For H_2 integration to contribute to decarbonisation goals, it is crucial that gH_2 becomes available and cost-competitive. Cost competitiveness may be achieved in the coming decades, contingent upon continued decreases in renewable electricity costs and increased availability. Other alternatives to fossil fuels instead or in combination with gH_2 encompass biomass or municipal solid waste (MSW) combustion, though the latter alone does not significantly reduce emissions and would require combination with CCU/S pathways.

In summary, substantial emission reduction potential in the cement production lies in a combination of fuel switching to a mixture of gH_2 with sustainable biomass or electrification to archive required high process temperatures, use of gH_2 as a reducing agent to reduce emission-intensive clinker requirements and CCU/S to mitigate both unavoidable process emissions and fuel-related emissions. Yet, as of now, there is no known operating plant that integrates these approaches. Two key technologies with sufficiently high TRL have been selected for comparison: hydrogen combustion for high-temperature heat in limestone calcination and rotary kiln, and oxyfuel combustion plus CCS, predominantly based on fossil fuels. The collected data on these technologies are presented in Table 11.

Table 11: Technology comparison for cement industry decarbonisation technologies.

Cement		
Criteria/ Technology	Hydrogen combustion for high-temperature heat for limestone calcination and in rotary kiln	Alternative: Oxyfuel combustion + CCS
Technological maturity	TRL < 4 for pure H_2 use, but applied in relevant environment with H_2 blending (40% of total fuel mix) – TRL 7	TRL 6-7 [234]
Safety	Moderate - concerns due to explosive properties of H_2 and little experience with H_2 as a fuel	High - no safety concerns known
CAPEX	93.5 USD/t[17], clinker for new production plants	102.9 USD/t[18], clinker for new production plants[19]
Specific energy consumption	1,111 kWh/t, clinker	1,257 kWh/t, clinker[20]
Energy costs (today)	High – gH_2 costs significantly higher than electricity price, mainly due to high CAPEX of electrolysers and conversion losses Energy carrier: H_2	Low – 24.5-36.9 USD/MWh_{coal} according to global market price [237] Energy carrier: coal/coke
Energy costs (future)	Low-Medium – decreasing costs of renewable electricity and electrolysers expected	High – Due to increasing carbon price
CO_2 reduction potential	40% reduction (all fuel-related emissions), no effect on process emissions [238]	90% reduction possible
Applicability	No existing project using or aiming to use pure H_2 today, but already tested for blending [239]	Requires CO_2 infrastructure (transport and storage) or specific CO_2 use-case (e.g., e-methanol production)
Sustainability	Moderate - Water impact of H_2 production: stoichiometrically 9l/kg H_2, in practice up to 30 l of water per kg H_2 [240]	Low - Air pollution, fossil lock-in, risk of carbon leakage, inequality increase, finiteness of resources

2.3.3.4.3 Cost estimation

In order to assess the feasibility of on-site gH_2 production versus gH_2 purchase, applying the produced H_2 as fuel for clinker production, LCOH for a Siam Cement Group plant in Nonthaburi is being analysed. This plant could produce the gH_2 required for all five of SCG's cement production plants, and therefore the full volume

[17] 86 EUR/t and converted to USD on 16.05.2024 here: https://www.finanzen.net/waehrungsrechner/euro_us-dollar

[18] 94.6 EUR/t and converted to USD on 16.05.2024 here: https://www.finanzen.net/waehrungsrechner/euro_us-dollar

[19] assuming 10% increase of CAPEX due to costs for CO_2 capture unit

[20] energy consumption for reference technology taken from [235], additional energy for oxyfuel-capture derived from [236]

of SCG's cement production in Thailand (23 Mtpa) is taken into account. The current average clinker-to-cement ratio over all cement types is 73.7%, resulting in a clinker demand of 16.95 Mtpa for the SCG. Within the clinker production, a study stated that 24 kg of H_2 are sufficient to produce one tonne of clinker, resulting in a gH_2 demand of 406,824 tonnes H_2 per year [241].

In addition to its use as a fuel in clinker production, gH_2 can be used as a reducing agent in the raw material mix, reducing the amount of clinker required for the cement process at SCG, providing additional benefits. The following table summarises the cement and clinker production volumes and main results of the applied OptiH2Infra tool for the second case study.

Table 12: Cement and required H_2 production volumes as well as main results of OptiH2Infra for SCG plants in Thailand (5 plants)

Siam Cement Group Cement Production Plants (5 sites) – production volume			
Cement production volume (5 plants)	23	Mtpa	
Clinker needed	16.95	Mtpa	
H_2 demand as fuel for clinker production	406,824 406,824,000	tpa kgpa	
OptiH2Infra outputs: Capacities, full load hours and production cost			
Installed components:	Capacity	Full load hours	Production costs
Electrolyser:	9,888 MW	2,284 hpa	5.42 USD/kg H_2
PV:	14,831 MW	1,558 hpa	4.10 USDct/kWh_el
Wind:	0 MW	1,475 hpa	7.28 USDct/kWh_el
OptiH2Infra outputs: CAPEX and LCOH			
Total CAPEX:	19,776	Mil. USD	
CAPEX electrolyser:	9,651	Mil. USD	
CAPEX compression & storage[21]:	2,339	Mil. USD	
CAPEX PV:	7,786	Mil. USD	
CAPEX Wind:	0	Mil USD	
Total H_2 costs[22]:	6.30	USD/kgH_2	

Similar to the case study in Indonesia and Malaysia, this case study evaluates the potential for gH_2 production solely from solar energy due to limited wind resources. It highlights the need for significant investment, totalling 19,776 million USD, to establish on-site production infrastructure, including H_2 technology and solar power plants. This investment cost is lower than for the Indonesian case, but higher than the Philippine and Malaysian case due to lower or higher H_2 demands respectively. Installation of 14.8 GW of photovoltaic (PV) systems would be necessary, utilising space on roofs and near the cement production plant for ground-mounted systems if there are no space constraints. A comparison with the study by Sens et al. (2022) shows, similarly to the first and second case study, that full load hours of the PV plant (1,558 hpa, slightly higher than for the Indonesian and Malaysian site) and gH_2 production costs (5.42 USD/kg H_2, slightly lower than for the Indonesian site and slightly higher than for the Malaysian and Philippines site) for this specific case are comparable to those of Southern European countries [226]. The calculated LCOH is 6.30 USD/kg H_2 and slightly lower than for the Indonesian case study. The use of RE sources other than solar is limited for this

[21] compression to 350 bar, cooling and storage for one day of full production

[22] including compression to 350 bar, cooling and storage for one day of full production

site, with no wind or geothermal potential, and the proximity of the close by Chao Phraya River to the Thai capital making energetic utilisation and integration difficult. However, the LCOH is also exceeding the projected costs for 2030 outlined in Section 2.2.1.3.3 (2.1 – 3.1 USD/kg). This suggests that the procurement of H_2 would make more sense for this case study than on-site production. Transport to the specific site within Thailand is most likely limited to road transport by truck with an estimated cost of 0.96 – 3.87 USD/kgH_2 [224], which makes on-site production favourable if gH_2 transport costs develop according to the upper range of this projection. In any case, it is important to recognise that this analysis is preliminary and certain assumptions made need to be validated. The gH_2 produced would have several potential on-site fuel applications as previously explained, only one of which is analysed. Considering combined applications and other uses, e.g. in nearby industries, combined with potential revenues from surplus electricity feed-in, may increase the feasibility of on-site production. In addition, approaches are being explored to combine on-site gH_2 production with captured CO_2 at cement production sites to produce hydrocarbons relevant to other applications, generating potential revenues and diversifying value chains.

2.3.3.5 Vietnam – Green hydrogen: Hoa Phat steel production

For Vietnam, the steel industry was selected as a high potential use case as the country has the largest steel production capacity in SEA. For the steel industry, switching from grey or blue H_2 to gH_2 is becoming an increasingly pressing issue, especially for steel export markets such as Vietnam. Emission reduction and trade mechanisms such as the European Union's CBAM set the framework for goods imported into the EU. Industries with high energy consumption (e.g. steel producers) and therefore high GHG emissions are mainly affected by this measure. Under the CBAM, certain imported goods are subject to a carbon price equivalent to the cost that EU producers would incur for the same level of carbon emissions. As a result, non-European producers, including those in Vietnam, are incentivised to reduce GHG emissions in their own production in order to ensure the competitiveness of local producers when exporting products to Europe. Therefore, global trends combined with emission reduction frameworks are setting the stage for a green transition of industries such as the steel industry in Vietnam. For this reason, we take a closer look at the transition opportunities for the steel industry for one specific steel production site of the Hoa Phat Group: Dung Quat Steel Production.

2.3.3.5.1 Traditional steel production

In conventional iron production from iron ore, the initial stage involves reducing iron oxide in a coke-fired blast furnace. Coke, typically produced on-site from fossil coal in a coking plant, serves as the reducing agent for this process. During this reduction, the iron oxide in the ore is transformed into iron, with coke oxidizing to CO_2. The CO_2 emissions from this reaction constitute approximately 55% of the total CO_2 emissions associated with primary steelmaking [16]. Furthermore, to achieve the high temperatures (up to 1600°C) required for the reaction, coke or natural gas is typically burned in the blast furnace, leading to additional emissions from fuel combustion.

In the subsequent step to produce crude steel, the carbon content of primary iron must be reduced. This occurs in a basic oxygen furnace (BOF), where oxygen is blown through pig iron. This BOF method is the primary production technology employed in Vietnam, accounting for 13 million tons in 2021 [242]. Other methods of current steel production include direct reduction using natural gas or coal, as well as secondary steelmaking from scrap in an electric arc furnace (EAF). The latter process is also utilized in Vietnam, with production totalling 7 million tons in 2021 [242].

2.3.3.5.2 Green steel production

Among all energy-intensive industries, steelmaking has been subject to extensive research on decarbonisation technologies [26]. The most promising pathway for achieving decarbonized primary steel production is through hydrogen direct reduction (HDR) combined with an EAF[27], [27]. In this process, gH_2 serves as a fossil-free reducing agent to convert iron ore into pig iron. This approach builds upon existing natural gas or coal-based direct reduction methods but employs gH_2 instead. It is anticipated that this technology will become commercially available within the next decade.

HDR involves replacing the conventional blast furnace with a shaft furnace that utilises gH_2 as the reducing agent. The required temperatures, around 800 °C, can be supplied using electricity. However, current prices for gH_2 result in significant increases in production costs. The competitiveness of this pathway is contingent upon decreasing electricity prices and/or high CO_2 emission costs. The sponge iron produced from HDR, named for its porosity, must then be processed in an EAF to convert it into crude steel [15]. HDR and EAF facilities do not necessarily have to be co-located; sponge iron can be transported as hot briquetted iron to an EAF at a different location [243].HDR involves replacing the conventional blast furnace with a shaft furnace that utilises gH_2 as the reducing agent. The required temperatures, around 800 °C, can be supplied using electricity. However, current prices for gH_2 result in significant increases in production costs. The competitiveness of this pathway is contingent upon decreasing electricity prices and/or high CO_2 emission costs. The sponge iron produced from HDR, named for its porosity, must then be processed in an EAF to convert it into crude steel [15]. HDR and EAF facilities do not necessarily have to be co-located; sponge iron can be transported as hot briquetted iron to an EAF at a different location [243].

Another commercially applied method for reducing emissions in steelmaking is through the utilisation of an EAF for recycling steel scrap, which operates solely on electricity [16]. This pathway is noted for its high potential for cost reduction (up to -49%) due to its high energy and material efficiency [17]. CO_2 emissions can be eliminated if the furnace exclusively uses recycled scrap and biochar as the carbon input, along with renewable electricity.

For comparison, three key technologies with sufficiently high TRL have been selected: hydrogen direct reduction for primary steelmaking, secondary steelmaking with an EAF, and the conventional BF-BOF route with additional carbon capture and storage (CCS). The collected data on these technologies are provided in Table 13.

Table 13: Technology comparison for steel industry decarbonisation technologies

Steel[23]			
Criteria/ Technology	Hydrogen Direct Reduction	Alternative 1: EAF scrap recycling and secondary production	Alternative 2: Conventional Production (BF-BOF route) + CCS
Technological maturity	TRL 7-9 [244]	TRL 9, fully commercially applied [26]	TRL 5 [245]
Safety	Moderate – explosive properties of H_2	Moderate – high currents and temperatures > 1500 °C	Moderate – large quantities of carbon monoxide
CAPEX	450 USD/t[24],crude steel [246]	200 USD/t[25],crude steel [246]	528.4 USD/t[26], crude steel[27] [246]
Specific energy consumption	3642 kWh/t,crude steel [247]	< 1000 kWh/t,crude steel [248]	4337 kWh/t,crude steel [247]
Energy costs (today)	High – gH_2 costs significantly higher than electricity price, mainly due to high CAPEX of electrolysers and conversion losses Energy carrier: H_2	Moderate – electricity price of 103 USD/MWh in 5-year average [249] Energy carrier: electricity	Low – 24.5-36.9 USD/MWh_{coal} according to global market price [237] Energy carrier: coal/coke
Energy costs (future)	Low-Medium – decreasing costs of renewable electricity and electrolysers expected	Low – decreasing costs of renewable electricity expected	High – Due to increasing carbon price
CO_2 reduction potential	100% emission reduction, if gH_2 is used, [246] Savings of 1.5 - 2.2 t CO_2/t,crude steel compared to conventional route [250]	75% emission reduction if powered by RE, process emissions remain, 100% if biochar is used as a carbon feedstock [246]	CO_2 capture rate: 70-80% [251]
Applicability	Moderate - dependent on gH_2 availability and H_2 infrastructure	Moderate - limited scrap availability [246], cannot produce all qualities of steel	Moderate - dependent on CO_2 infrastructure (transport, storage) or CO_2 utilisation opportunities
Sustainability Constraints	Moderate - land use, water consumption, export dependencies and potentially increasing inequalities	Low - due to resource and material efficiency	High – due to continued fossil fuel use and residual emissions

[23] crude steel, before rolling and casting

[24] 414 EUR/t and converted to USD on 16.05.2024 here: https://www.finanzen.net/waehrungsrechner/euro_us-dollar

[25] 184 EUR/t and converted to USD on 16.05.2024 here: https://www.finanzen.net/waehrungsrechner/euro_us-dollar

[26] 486 EUR/t and converted to USD on 16.05.2024 here: https://www.finanzen.net/waehrungsrechner/euro_us-dollar

[27] assuming 10% increase of CAPEX due to costs for CO_2 capture unit

2.3.3.5.3 Cost estimation

In order to assess the feasibility of on-site gH_2 production to replace the currently used natural gas, H_2 production costs were calculated for the selected case study of the Hoa Phat group in Vietnam. This calculation refers to the H_2 direct reduction as stated above. The Hoa Phat steel production plant Dung Quan produces 5.6 million tonnes of steel per year (projection for 2025) [252]. According to Bhaskar et al. (2022) 60 kg of H_2 are required for the production of one tonne of steel, which results in a gH_2 demand for this specific site of 336 tpa [253]. The following table summarises the gH_2 and steel production volumes and main results of the applied OptiH2Infra tool for the last case study.

Table 14: Steel and required H_2 production volumes as well as main results of OptiH2Infra for Hoa Phat's Dung Quat Steel Production (Vietnam)

Hoa Phat's Dung Quat Steel Production – production volume			
Methanol production capacity in 2020	5.6	Mil. tpa	
H_2 demand to produce green methanol at this site	336,000 336,000,000	tpa kgpa	
OptiH2Infra outputs: Capacities, full load hours and production cost			
Installed components:	Capacity	Full load hours	Production costs
Electrolyser:	8,163 MW	2,284 hpa	5.41 USD/kgH_2
PV:	12,245 MW	1,576 hpa	4.05 USDct/kWh_el
Wind:	0 MW	1,586 hpa	6.78 USDct/kWh_el
OptiH2Infra outputs: CAPEX and LCOH			
Total CAPEX:	16,331	Mil. USD	
CAPEX electrolyser:	7,968	Mil. USD	
CAPEX compression & storage[28]:	1,935	Mil. USD	
CAPEX PV:	6,429	Mil. USD	
CAPEX Wind:	0	Mil. USD	
Total H_2 costs[29]:	6.30	USD/kgH_2	

This case study assesses the feasibility of producing gH_2 solely from solar energy, given limited wind resources at this specific site. It underscores the significant investment required, totalling 16,331 million USD, to establish on-site production infrastructure, including H_2 technology and solar power plants. Installation of 12.2 GW of PV systems, very similar to the required capacity of the Malaysian case study, would be necessary, utilising available space on roofs and near the steel production plant for ground-mounted systems if space permits. Comparison with the study by Sens et al. (2022) reveals that full load hours of the PV plant (1,576 hpa, slightly higher than for the Indonesian, Thai and Malaysian site) and gH_2 production costs (5.41 USD/kg H_2, slightly lower than for the Indonesian and Thai site) for this specific case are comparable to those of Southern European countries [226]. The calculated LCOH stands at 6.30 USD/kg H_2, slightly lower than for the Indonesian and Thai case study but exceeding the projected costs for 2030 as outlined in Section 2.2.1.3.3 (2.3 – 3.9 USD/kg). This implies that, even with significant H_2 demand and favourable RE potential at the site, buying gH_2 might be more cost-effective than producing it on-site in this situation. Transport costs in this case are most likely to be driven by road transport (trucks) at 0.96 - 3.87

[28] compression to 350 bar, cooling and storage for one day of full production

[29] including compression to 350 bar, cooling and storage for one day of full production

USD/kgH_2. As road transport costs in Vietnam move towards the upper end of this range, local production becomes more economically attractive. Like for all other cases, it is important to recognise that the cited study and this analysis are projections and certain assumptions made need to be validated. The site is located close to the sea and a river, which may, for example, have some hydropower potential that could be assessed and integrated for this case study, ultimately leading to a potential reduction in LCOH. In general, production costs are expected to fall over the next decade and given the high pressure on the Vietnamese steel industry to compete with global players and maintain export volumes in the face of growing demand for green steel, investments in green production processes may pay off in the long run.

2.3.3.6 Summary

In summary, the production costs of gH_2 for the four case studies analysed are similar, with the Philippines showing the lowest LCOH for the specific site analysed. Of course, the LCOH depends on the RE sources and the investment assumptions for the technology involved (H_2 technology and solar and/or wind power plants), the respective operating costs and the demand for gH_2 for each site. Therefore, the LCOH may vary even within a country for specific sites and this analysis has to be taken as a first approach to provide production costs for different use cases. In addition, on-site gH_2 production may be more feasible if feed-in tariffs for specific sites and plant sizes are considered, which could generate revenue from the sale of excess electricity from RE plants installed for the gH_2 production facilities. Considering combined applications of gH_2 (as a fuel, reactant or essential component for reactions and processing) and additional demand and other uses, e.g. in nearby industries or selling and shipping it through nearby ports, may increase the feasibility of on-site production as gH_2 can be sold to these customers without high transportation costs. The following table is summarising main findings from the case studies for different sectors.

Table 15: Overview and summary of identified high potential use cases and application of green hydrogen or derivative products

Overview of high potential use cases				
Sector & product	Application /change made	Change in current production process: [30]	Cost estimation	Estimated CO_2 reduction
Fertiliser production Green ammonia	gH_2 as a feedstock, supplementing grey H_2	Production process remains the same, gH_2 utilisation for provision of heat demand as additional use case	CAPEX: 71,730 Mil. USD gH_2 production cost: 5.56 USD/kgH_2	Up to 100% for ammonia production[254] Up to 90% for fertiliser production[255] Around 5% for final food products [254]
Methanol production Green Methanol	gH_2 utilisation as reducing agent in methanol production as replacement for natural gas	Change from steam reforming (natural gas) or gasification (coal) to produce synthesis gas (syngas), which is then catalytically converted to methanol to the use of gH_2 and captures CO_2 via a catalytic process	CAPEX: 14,235 Mil. USD gH_2 production cost: 5.34 USD/kgH_2	For methanol production up to 100% reduction or even carbon negative (if CCS technology is applied as carbon sourcing)

[30] If on-site gH_2 production: Renewable energy power plant, electrolyser, storage, pipelines are needed

Oil refinery gH_2	gH_2 utilisation in hydrotreating and hydrocracking	If gH_2 is applied for hydrocracking and hydrotreating (replacement of grey H_2), refining process keeps the same, gH_2 utilisation for provision of heat demand as additional use case	CAPEX: 399 Mil. USD gH_2 production cost: 4.47 USD/kgH_2	Up to 100% as replacement of fossil-based H_2 with gH_2 Overall emission reduction depends on applied sources for high temperature provision
Cement production gH_2	gH_2 combustion for high-temperature heat	Depending on the gas mixture and percentage of gH_2 utilisation, firing equipment needs to be adapted	CAPEX: 19,776 Mil. USD gH_2 production cost: 5.42 USD/kgH_2	40% reduction (all fuel-related emissions), no effect on process emissions [238]
Steel production gH_2	gH_2 direct reduction (gH_2 is used as fossil free reducing agent)	Blast furnace needs to be replaced with shaft furnace	CAPEX: 16,331 Mil. USD gH_2 production cost: 5.41 USD/kgH_2	Up to 100% as replacement of fossil-based H_2 with gH_2 Savings of 1.5 - 2.2 t CO_2/t,crude steel compared to conventional route [250]

3 Conclusion and recommendations

3.1 Summary

The gH_2 and derivative products' landscape in SEA is diverse and dynamic, with multiple countries exploring various applications and strategies. Many use cases transcend borders, offering opportunities for shared learning and collaboration through pioneering case studies across the region. Currently, Laos, Vietnam, and Malaysia are among the key H_2 exporters, while Indonesia, the Philippines, and Thailand are exhibiting the highest demand for H_2. Political targets in Vietnam, Malaysia, and Indonesia show a tendency for export-orientation, indicating that these nations are positioning themselves as future gH_2 export leaders in the region. However, the current scenario largely revolves around grey H_2, indicating a need for a transition towards cleaner alternatives. Four countries have established H_2 strategies (Singapore, Indonesia, Malaysia and Vietnam), while two are still in the development phase (Thailand and the Philippines), signalling a concerted effort towards a sustainable gH_2 economy. These H_2 strategies are also affecting the gH_2 derivatives market development. Ammonia, a crucial component in industries such as agriculture and chemical manufacturing, sees currently significant export activity in Indonesia, Malaysia, and Singapore. Moreover, methanol finds high demand in the chemical industries of Thailand, Malaysia, and Singapore. The region's diverse infrastructure presents both challenges and opportunities. While countries like Thailand, Indonesia, Singapore, and Malaysia boast relatively developed gas pipeline networks with various LNG and pipelines in stages of planning and construction, other countries like Laos or the Philippines are lacking behind. Projections for gH_2 production costs by 2030 based on studies provided by IEA (2023) and Bhashyam et al. (2023) show lowest LCOH in Thailand and Malaysia, followed by Vietnam and Indonesia with the Philippines having the highest cost among these five analysed countries [143], [7].

Table 16 summarises the main market roles of gH_2 and derivative products for SEA countries and lists current and potential future applications. Indonesia is likely to be either self-sufficient or export-oriented in a future gH_2 economy, with current applications mainly in the fertiliser industry and future applications in the producing industry and transport sector. Laos will play a minor role in a gH_2 and derivatives economy but will be an important provider of renewable electricity within the region (also to meet renewable electricity demand for gH_2 production). Malaysia, a more gH_2 export-oriented country, uses gH_2 in the refinery, chemical and fertiliser industries and has potential applications in the methanol, cement, steel production as well as the transport sector. The Philippines is likely to become self-sufficient in a gH_2 and derivatives market and currently has applications in the refinery and fertiliser industries. The country's potential demand lies in cement and steel production. Singapore, being H_2 import-dependent, eyes H_2 applications in marine and aviation fuels, chemical industries, and residential use with current application in refinery and ammonia production. Thailand's future focus lies in hard-to abate industries like cement and steel production as well as in the transport sector with current application in the chemical and refinery industry. Vietnam emphasises the fertiliser industry, eyeing potential application in the green steel and cement production and transport sector. In the future, gH_2 could play a pivotal role in decarbonising shipping and aviation, particularly crucial for island nations like Indonesia and the Philippines. With Singapore serving as a major maritime hub, the region's potential for green ammonia in the maritime sector and synthetic green fuels in the aviation sector is substantial.

Table 16: Summary of key gH_2 and derivative products market roles as well as current and future applications for Southeast Asian countries

Summary of key roles and fields of gH_2 and derivatives application			
Country	Role	Current H_2 and derivatives application	Future gH_2 and derivatives application
Indonesia	Rather self-sufficient to slightly export oriented	• Urea/fertiliser industry • Refinery	• Methanol production • Cement production • Steel production • Transport (road vehicles)
Laos	Export oriented[31]	• Refinery (small scale) • Fertiliser industry	• Transport (road vehicles)
Malaysia	Rather export oriented	• Refinery • Chemical industry • Fertiliser industry	• Methanol production • Cement production • Steel production • Transport (road vehicles)
Philippines	Self-sufficient	• Refinery • Fertiliser industry	• Cement production • Steel production
Singapore	Import dependent	• Refinery • Ammonia production	• Marine and aviation fuels • Residential use (gas network for cooking) • Chemical industry
Thailand	Rather self-sufficient	• Refinery • Chemical industry	• Cement production • Steel production • Transport (road vehicles)
Vietnam	Export oriented	• Fertiliser industry	• Cement production • Steel production • Transport (road vehicles)

Recognising the region's high demand centres, there is a growing consensus that H_2 trade would likely be regional, to reduce transportation costs and promote economic efficiency. This regional approach aligns with the potential role of gH_2 decarbonising critical and hard-to-abate sectors like chemical and fertiliser industry, steel and cement production or shipping and aviation fuelling (so called no-regret sectors).

The concentration of gH_2 trade within the broader region due to the relatively high resulting LCOH compared to other exporting regions is also recommended and thus underlined by another study on H_2 carried out by Agora (2024) for the SEA region, which states that: "Embracing a "global gas hub" strategy, as advocated by some SEA countries, could risk stranding infrastructures. Nevertheless, proximity to East Asian markets could increase SEA's potential for PtX trade through strategic partnerships" [144].

[31] Mainly renewable energy exports

Based on this analysis, a number of key recommendations and areas for action have emerged:

- **Prioritise sectors for gH_2 use**

When prioritising the use of gH_2, it is important to target sectors where there are no mature technological alternatives. Building strategies around these sectors offers low-risk approaches with no regrets. To identify these sectors, another glimpse at the "clean hydrogen ladder" as shown in Section 1.1.4 (Figure 3) helps to get an overview [14]. Sectors in red boxes (such as fertilisers or hydrogenation and hydrocracking as part of the refining process) have no real alternative to gH_2 application and should be prioritised over other sectors. These sectors rely heavily on H_2 as a feedstock, making them pivotal in the transition towards a H_2 economy. Other sectors show biomass use or electrification as alternatives to the use of gH_2, prioritising the most economical alternative for each site and context is useful. However, some sectors make more sense for gH_2 use than others (shown as a ranking, the higher the sector on the ladder, the more feasible the use of gH_2 in that sector). Other sectors relevant to the SEA region and highlighted in this study, such as shipping and aviation fuels, or the chemical and steel industries, but also high-temperature industrial heating demands, such as in the cement industry, are high on the list and appear to be a useful future application for gH_2. Targeting no-regret sectors first, as recommended here, is also highlighted as one of the four key findings of the Agora (2024) study, which looked at the H_2 outlook for SEA - highlighted this as a key strategic element for policy makers in the region [144].

It is essential that each country, based on its current economy and future goals, assesses which sectors need to be prioritised for gH_2 application and which can be better served by other alternatives (e.g. biomass/biogas or electricity/batteries). While determining these priority sectors for gH_2 utilisation, it is also important to consider the timeframe for implementation. This involves deciding which sectors to address first, which to target later, and which have to be explored with alternative options such as biomass or electricity. This approach should encompass short-term, mid-term, and long-term perspectives for sector deployment. Based on this sectoral analysis with clear timelines, streamlined targets, roadmaps, regulations and supportive policies have to be developed.

- **Create competitive LCOH through strategic mix of RE sources**

The viability of gH_2 production depends on achieving a competitive LCOH. This entails a strategic blend of RE sources, such as photovoltaic (PV), hydropower, and geothermal energy. Given the limited availability of wind power in many countries, a smart combination of these renewables becomes imperative to drive down LCOH and ensure the economic feasibility of H_2 production. Yet, achieving sufficient full-load hours (FLH) for electrolysers poses a challenge. If FLH falls short of the optimal threshold (> 3500 h/a), local gH_2 production may prove more expensive than importing it from countries with lower LCOH, such as Australia. To address this, a hybrid RE approach, integrating PV with hydropower and/or geothermal sources, becomes essential. This not only enhances the reliability of RE supply but also drives down LCOE, thus facilitating cost-effective H_2 production. To achieve this, support mechanisms and an enabling environment for RE deployment in SEA is needed to guarantee affordability of electricity and gH_2 as also highlighted as key finding by Agora (2024) [144]. This includes promoting the development of RE and the necessary infrastructure and considering flexibility options in cross-sectoral planning and in the development of policy frameworks for RE and H_2, taking into account environmental and social aspects to attract and accelerate investment [144].

- **Address regulatory barriers**

An appropriate legal framework and regulations are key to creating a sustainable gH_2 economy. There are two aspects to this: the way in which policies and regulations are developed and their actual content.

First it is important to take local and cultural aspects into account when developing these frameworks and to allow all parties involved to participate in shaping them. In addition, international dialogues and cooperation are necessary to develop and promote sustainable framework conditions, because establishing a gH_2 economy is an international challenge. Regional cooperation should take centre stage in order to avoid competition and political tensions. Regional dynamics and circumstances should be taken into account in the design of national regulations, standards and legal frameworks. Second, policies must be clear, barrier-free and long-term to enable the further development of the gH_2 economy. These clear rules and policies need to be embedded in countries' climate and energy plans to avoid investment uncertainty.

- **Implement support schemes and stimulate demand**

Financial support schemes and mechanisms to facilitate the market introduction of gH_2 technologies and production are useful tools for fostering a gH_2 economy. This can serve multiple purposes, from reducing the cost of production and infrastructure development to creating market incentives and ensuring regulatory support. Long-term prospects help to stimulate demand, for example through long-term public procurement contracts as one support mechanism, thereby encouraging suppliers to invest in production capacity.

- **Public awareness and education**

In order to implement gH_2 projects sustainably and to benefit from the creation of jobs in and around H_2 production sites, people along the entire value chain (production, transport and use of green hydrogen) and at all levels (from unskilled labour to scientists) must be educated and trained. To support this process, international cooperation, exchange programmes and special training curricula could be developed and established. Actions to increase public awareness addressing misconceptions and highlighting the role of gH_2 in reducing carbon emissions are needed to get the people on board. Jointly conducted studies on the national and regional potential of gH_2 and its utilisation (e.g. national use in industry, as a fuel for transport and integration into the electricity system) could also promote visibility and understanding in SEA countries.

- **Support commercialisation**

Pilot projects and demonstration programmes are important pillars for further market development. It is only through these showcase initiatives that practical application and viability in different sectors can be demonstrated and misconceptions fully dispelled.

- **Foster international cooperation**

International cooperation and exchange are important in many ways: It helps to develop sustainable production and trade rules and regulations for all stakeholders, promotes public awareness and local job creation, as well as technological and safety improvements. It is therefore crucial for accelerating sustainable market growth and stimulating technological development and innovation.

In summary, policy plays a pivotal role in shaping the transition to a gH_2 economy. Clear targets, subsidies, and supporting schemes are essential to incentivise investment in necessary RE and gas infrastructure as well as H_2 technologies. Potential exporters such as Vietnam and Malaysia will need massive investment along the whole value chain, from RE plants over pipeline and port infrastructure to H_2 technology, while potential RE suppliers such as Laos will need more transmission capacity. It is important to sharpen the objective of each country based on its role in a future gH_2 economy and to direct all efforts at the policy level towards achieving these roles. By sharpening policy frameworks and reducing insecurities, governments can catalyse innovation and investment and thus drive market adoption of gH_2 and derivatives in SEA. Looking ahead, future roles and business models in the H_2 sector will hinge on factors such as infrastructure needs, international cooperation, and the evolving cost dynamics of RE. Regional trade in RE, gH_2 or its derivatives presents opportunities for collaboration and economic growth. By fostering regional partnerships and aligning strategies, countries can leverage their comparative advantages to accelerate the transition towards a sustainable energy future.

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Annex

Country Factsheets

Disclaimer: The facts and figures presented in these factsheets are based on a literature review. It should be noted that different sources sometimes give figures or projections, which may differ or even contradict each other. Due to time constraints, not all facts could be verified with experts in the region.

I. Indonesia

Hydrogen		
Parameter	Information	Source
Current H_2 demand	• The highest demand in the SEA region with around 1.75 Mt/a [68] • Current H_2 consumption: Urea (fertiliser) production 88%, ammonia production 4%, refinery 2% [68] • Resulting from the following industries: Fertiliser (urea), refinery, metal industry, ceramic and paper [69]	[68], [69]
Current H_2 derivate demand	• High ammonia/urea/fertiliser demand (see above) • Estimated methanol demand of around 1.77 mio t/a, for the production of various chemicals [46]	[68], [46]
Current H_2 production source, volume and price	• Mainly produced from natural gas (grey hydrogen)	[69]
Current H_2 derivate production process, volume and price	• Estimated production capacity of around seven tonnes of ammonia annually [69] • Domestic methanol production is covered by a single plant producing hydrogen from an on-site coal gasification plant, complementary imports are needed, which cover the main share of methanol demand [46]	[69], [46]
Current H_2 and derivate product trade	• Hydrogen: net imports, value $115 million [49] • Ammonia: net exports, value $865 million, the third largest exporter after Russia and Trinidad and Tobago [69] • Within the region, Indonesia is a net importer of hydrogen but has traditionally been a major exporter of ammonia and urea, although there has been a recent drop in exports due to a sharp rise in domestic demand [67]	[49], [69], [67]
Current H_2 & gas infrastructure	Current infrastructure: • There are eight major ports in the country: Port of Jakarta, Port of Belawan, Port of Dumai, Port of Cirebon, Port of Gresik (mainly for agricultural trading including Ammonia), Port of Jambi, Port of Teluk Bayur, and Port of Pontianak [78] • There are nine operating LNG terminals and FSRUs across the country: the Arun LNG Terminal, which was formerly used for export and has been repurposed for import. Jawa Satu FSRU is operating in West Java and started in 2021. Bontang LNG Terminal is an export terminal in East Kalimantan. Another export LNG	[78], [81], [79], [54], [129], [130], [132]

	terminal, the Senoro LNG Terminal, is in Central Sulawesi Donggi. The Hua Xiang-Zaynep Sultan LNG Terminal is in Amurang, Sulawesi. The Tangguh LNG Terminal which is used as an export terminal is located in West Papua. The Lampung FSRU is located offshore off Lampung. Based in Bali are the Karunia Dewata FSRU as well as Benoa FSRU, also known as Bali LNG [81] • In May 2022, 18,687 km of natural gas pipelines were completed across the country (target: 19,800 km). This includes the Wampu-Belawa-Paya Pasir Gas Pipeline, Arun-Belawan Gas Pipeline, Trans-Central Sumatra Gas Pipeline, the Gresik-Batam-Singapore Gas Pipeline, Cambai-Simpang Y Gas Pipeline III, South Sumatra West Java Phase II Gas Pipeline, the Nagrak - Bitung Gas Pipeline, the Muara Karang-Muara Tawar Gas Pipeline, Gresik-Semarang Gas Pipeline, Kandang Haur Timur - Cilamaya Gas Pipeline II, Kalija Gas Pipeline, East Java Gas Pipeline (EJGP), Gresik-PKG Looping Gas Pipeline and Ruby Field Gas Pipeline [79] Proposed infrastructure: • Notable here is the Sengkang LNG Terminal in the middle of the country, which will be used for exports. The construction already began but progress has been stalled [129] • Both used for exports and proposed are the Madura FLNG Terminal and the West Papua FLNG Terminal [54] • A project used for imports is the Palu LNG Terminal, which is proposed to be located in the Palu Special Economic Zone, adjacent to the Port of Pantaloan [130] • Abadi LNG Terminal, a LNG export terminal, is proposed to lie in front of Australia [54]. There are also numerous proposed gas pipelines. The KEK Sei Mangke - Dumai Gas Pipeline and Dumai–Medan Gas Pipeline are both located in North Sumatra. The West Kalimantan-Central Kalimantan Gas Pipeline and Natuna-West Kalimantan Gas Pipeline are proposed to run through West and Central Kalimantan. The Central Kalimantan-South Kalimantan Gas Pipeline and the East Kalimantan – South Kalimantan Gas Pipeline are supposed to run from Central Kalimantan to the South and up in the North-East. In West Java, the Cirebon-KHT Gas Pipeline is proposed [54] • Two projects in Java are already under construction: the Cirebon-Semarang Gas Pipeline in Central Java, which is expected to start in 2024 [131] and the Teluk Lamong LNG Terminal, which was expected to start in 2023 [132] • Also under construction is the Senipah-Balikpapan Gas Pipeline, running from South to North Kalimantan [54]	
Most suitable H_2 transport option	• Gas pipelines and through shipping ports	
General H_2 strategy and goals	• Indonesia published its National Hydrogen Policy in December 2023. Based on a Net Zero Emission model that was developed by the Ministry of Energy and Mineral Resources of Indonesia, the low carbon hydrogen	[69], [88]

	demand is projected to start growing from 2031 to 2060. Hydrogen consumption for the transportation sector is estimated to reach 26.000 barrels of oil eq in 2031 and increase to 52.2 million of oil eq in 2060. For the industry, hydrogen consumption starts at 2,8 TWh in 2041 and increases to 79 TWh in 2060, mainly in the metal, ceramic, and paper industry which is predicted to reach 29 TWh in 2060. By 2040, parts of the bus fleet will be converted to hydrogen, beginning with a demand of 6 GWh or 0.21 million tonnes of hydrogen. By 2060, 20% of the bus fleet is estimated to be hydrogen-based. The consumption of hydrogen for hydrogen-based buses will increase to 930.6 GWh or 28.2 kilo tonnes of hydrogen in 2060. The hydrogen demand for the Heavy Freight Sector is predicted to reach 161 GWh (4.88 kilo tonnes of hydrogen) in 2040 and will increase to 930.6 GWh (28.2 kilo tonnes H_2) in 2060. For the train segment, PT KAI plans to expand its locomotives to include electric rail which will be combined with hydrogen fuels and/or battery. Hydrogen is also to be used in Ship transportation (Maritime) in 2060. 17 locations within the country are identified for hydrogen production [69] • There is a Joint Study Agreement (JSA) to explore gH_2 and green ammonia development projects, using renewable energy with a main location in Sumatra, Indonesia [88]	
Value chain for H_2 and derivates	• Activities along the whole value chain: production, consumption and trade	
Green hydrogen		
Parameter	**Information**	**Source**
Relevant stakeholders	Public stakeholders • PT PLN [93] • PT Pupuk Indonesia [94] • Pertamina NRE [88] • PT KAI [69] Private stakeholders • ACWA Power [94] • Chevron [88] • Keppel Infrastructure [88] • PT Bukit Asam • Hydrogene de France Energy (HDF) [95] • PT Pupuk Iskandar Muda [44] • August Global Investment (AGI) [44]	[69], [44], [88], [93], [94], [95], [96], [112], [113]

<table>
<tr><td></td><td>

- Krakatau Steel [96], PT Rukun Raharja [96]
- Tokyo Electric Power Company Holdings (TEPCO HD) [112]
- Marubeni Corporation [113]

</td><td></td></tr>
<tr><td>Dominant RE source to produce gH_2</td><td>
<table>
<tr><th>Tipe</th><th>Potensi (GW)</th><th>Pemanfaatan (MW)</th></tr>
<tr><td>Surya solar</td><td>3.295</td><td>283,2</td></tr>
<tr><td>Air hydro</td><td>95</td><td>6.689</td></tr>
<tr><td>Bioenergi bioenergy</td><td>57</td><td>3.089,9</td></tr>
<tr><td>Bayu wind</td><td>155</td><td>154,3</td></tr>
<tr><td>Panas Bumi geothermal</td><td>24</td><td>2.360,3</td></tr>
<tr><td>Laut sea</td><td>63</td><td>0</td></tr>
<tr><td>TOTAL</td><td>3.689</td><td>12.616</td></tr>
<tr><td colspan="3">Note: *) Capaian realisasi Desember 2022 until Dec 2022
1 GW = 1000 MW</td></tr>
</table>

- RE potential is estimated to be 3.689 GW, of which so far only 0,3% has been tapped until 2022

</td><td>[69]</td></tr>
<tr><td>Potential gH_2 demand</td><td>

Current demand:

- Industry: Urea/fertiliser industry
- Refinery
- Ceramic, oleochemical and paper

Future demand:

- Methanol production
- Cement production
- Steel production
- Transport (road vehicles and ships)
- Power generation and storage solution

</td><td>[69]</td></tr>
<tr><td>Future gH_2 generation potential</td><td>

- Worldwide trade
- Exporter: New Zealand, Australia, Portugal, Norway, France, Russia, Spain, Chile, US, Canada, Brazil, Morocco, UK
- Importer: Japan, South Korea, Germany, EU, Italy, Rep. Czech, Columbia
- Self-production/Exporter Hub: Netherlands, Finland, China, Ukraine, Hungary, Poland

</td><td>[69]</td></tr>
<tr><td>H_2/PtX production and transport cost</td><td>

- Projection for 2030, show production cost of gH_2 around 2.4 – 4.1 USD/kg

</td><td>[7]</td></tr>
</table>

gH_2 roadmap and targets	• Three pillars of hydrogen expansion in the country: reducing the high reliance on fossil fuel to ensure energy sovereignty and energy security; achieving the decarbonisation target by expanding the domestic hydrogen market; and exporting the hydrogen also its derivatives to the global market by using the country uniqueness as a maritime country.	[69]
gH_2 regulatory framework	• No official regulation yet	
gH_2 programmes or partnerships		[69]
gH_2 projects and knowledge	• PT PLN inaugurated the first Green Hydrogen Plan (GHP in Indonesia located in Muara Karang Steam Gas Power Plant, Jakarta. The GHP is 100% comes from renewable energy and able to produce 51 tonnes of hydrogen annually [93] • Joint Study Agreement (JSA) to explore green hydrogen and green ammonia development projects, using renewable energy with a main location in Sumatera, Indonesia [88] • Garuda Hydrogen Hijau Project (gH_2), ACWA Power (Saudi Arabia-based developer) agreed to develop a green hydrogen facility that will generate 150.000 tonnes of green ammonia annually. Target achieved by the end of 2025, commercial begin in 2026. Partners: PT PLN and PT Pupuk Indonesia [94] • HDF Energy, a French Power Developer signed an MoU with PT Bukit Asam to do a feasibility study for hydrogen power generation installation in the country [95] • PT PLN, PT Pupuk Iskandar Muda, and Augustus Global Investment plan to build a Green Hydrogen Power Plant with a production capacity of 35.000 tons per year in SEZ Arun, Lhoksumawe, Aceh, Indonesia [44]	[93], [88], [94], [95], [44], [96], [112], [113]

	• Pertaina NRE, Krakatau Steel, and PT Rukun Raharja signed a MoU for the development of green hydrogen pipelines. The distribution pipelines project plans in Banten and West Java regions [96] • Pertamina NRE and TEPCO HD signed a MoU on hydrogen and green ammonia development in Indonesia [112] • Green Hydrogen Pilot Project by Pertamina NRE in the Ulubelu geothermal area with a production target of 100 kg/day [112] • Marubeni Corporation will start production of green hydrogen in South Australia which will be transported to Java Island, Indonesia [113]	
Land and water availability		
Parameter	Information	Source
Fresh water situation/scarcity	• Level of water stress (freshwater withdrawal as a proportion of available freshwater resources): 29,7 (2020) [140] • Annual freshwater withdrawals, total (billion cubic meters): 222,6 (2020) [256] • Annual freshwater withdrawals, total (% of internal resources): 11 (2020) [257]	[140], [256], [257]
Water consumption	• Daily water consumption per capita (litres): 2,329	[258]
Land availability	• 51,2% Forest, 48,8% Non-Forest (2022)	[259]
Resource conflicts (electricity, land, water, land use etc.)	There are a few territorial conflicts with Malaysia such as: • Sebatik Island, the Northern part of the island is in the border with Malaysia while the Southern part is on Indonesia's territorial • Ambalat, rich in mineral resources specifically for oil and natural gas • Sipadan and Ligitan Island in Borneo area • Oecusse district, bordering with East-Timor In addition: • Natuna Islands, maritime borders with China, Taiwan, Brunei Darusalam and Vietnam	[260]
CO_2 sources for derivate production	Coal-fired power plants, geothermal power plants, industrial processes	[261]
Energy situation		

<table>
<tr><th>Parameter</th><th>Information</th><th>Source</th></tr>
<tr><td>Energy mix (electricity generation)</td><td>• 2021: Coal (61.5%), crude oil (2.8%), natural gas (16.7%), renewables and others (19%)</td><td>[130]</td></tr>
<tr><td>RE share (electricity generation)</td><td>• 2021: Hydropower (59.9%), geothermal (38.6%), solar (0,4%), wind (1.1%)</td><td>[262]</td></tr>
<tr><td>Planned capacity expansion</td><td>
Power Plant Capacity Expansion Plan in Indonesia (MW)
based on RUPTL 2021-2030
<table>
<tr><th></th><th>Year</th><th>2021</th><th>2022</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>Total</th></tr>
<tr><td></td><td>PP (Power Plant) Type</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>PLN</td><td>Steam Fired Power Plant (Coal) / PLTU</td><td>488</td><td>306</td><td>228</td><td>50</td><td>231</td><td></td><td>24</td><td></td><td>20</td><td></td><td>1.347</td></tr>
<tr><td>PLN</td><td>Geothermal Power Plant / PLTP</td><td></td><td></td><td></td><td>5</td><td>155</td><td>120</td><td>25</td><td>195</td><td>15</td><td></td><td>515</td></tr>
<tr><td>PLN</td><td>Combined Cycle Power Plant /PLTGU</td><td>350</td><td>1.279</td><td></td><td></td><td></td><td>80</td><td></td><td></td><td></td><td>100</td><td>1.809</td></tr>
<tr><td>PLN</td><td>Gas Fired Power Plant</td><td>260</td><td>543</td><td>316</td><td>240</td><td>370</td><td>60</td><td>95</td><td></td><td>10</td><td>70</td><td>1.964</td></tr>
<tr><td>PLN</td><td>Diesel Fired Power Plant /PLTD</td><td></td><td>5</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>5</td></tr>
<tr><td>PLN</td><td>Micro-Hydro Power Plant / PLTM</td><td></td><td></td><td></td><td>13</td><td>35</td><td>22</td><td></td><td>2</td><td>11</td><td></td><td>83</td></tr>
<tr><td>PLN</td><td>Hydro Power Plant / PLTA</td><td>110</td><td>43</td><td>132</td><td>87</td><td>258</td><td>177</td><td>44</td><td>201</td><td>568</td><td>100</td><td>1.720</td></tr>
<tr><td>PLN</td><td>Pumped Storage / PS</td><td></td><td></td><td></td><td></td><td>1.040</td><td></td><td></td><td>943</td><td>250</td><td>1.250</td><td>3.483</td></tr>
<tr><td>PLN</td><td>Solar Power Plant /PLTS</td><td>59</td><td>126</td><td>237</td><td>266</td><td>773</td><td>17</td><td>8</td><td>25</td><td>33</td><td>157</td><td>1.701</td></tr>
<tr><td>PLN</td><td>Other Power Plant</td><td></td><td>2</td><td></td><td>165</td><td>155</td><td></td><td></td><td>10</td><td></td><td>300</td><td>632</td></tr>
<tr><td>PLN</td><td>PP Based on Renewables</td><td></td><td></td><td></td><td></td><td></td><td>100</td><td>265</td><td>215</td><td>280</td><td>150</td><td>1.010</td></tr>
<tr><td></td><td>Total</td><td>1.267</td><td>2.304</td><td>913</td><td>826</td><td>3.017</td><td>576</td><td>461</td><td>1.591</td><td>1.187</td><td>2.127</td><td>14.269</td></tr>
<tr><td>IPP (Independent Power Producer)</td><td>Steam Fired Power Plant (Coal) / PLTU</td><td>4.200</td><td>938</td><td>414</td><td></td><td>1.660</td><td>1.660</td><td></td><td></td><td></td><td></td><td>8.872</td></tr>
<tr><td>IPP (Independent Power Producer)</td><td>Steam Fired Power Plant (Lignite) / PLTU MT</td><td></td><td>1.200</td><td>600</td><td>300</td><td></td><td>600</td><td>600</td><td></td><td></td><td></td><td>3.300</td></tr>
<tr><td>IPP (Independent Power Producer)</td><td>Geothermal Power Plant / PLTP</td><td>136</td><td>108</td><td>190</td><td>136</td><td>715</td><td>170</td><td>98</td><td>255</td><td>225</td><td>808</td><td>2.841</td></tr>
<tr><td>IPP (Independent Power Producer)</td><td>Combined Cycle Power Plant /PLTGU</td><td>2.035</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>2.035</td></tr>
<tr><td>IPP (Independent Power Producer)</td><td>Gas Fired Power Plant</td><td></td><td></td><td></td><td></td><td></td><td>20</td><td></td><td></td><td></td><td></td><td>20</td></tr>
<tr><td>IPP (Independent Power Producer)</td><td>Micro-Hydro Power Plant / PLTM</td><td>144</td><td>154</td><td>277</td><td>276</td><td>154</td><td>22</td><td></td><td></td><td>2</td><td>6</td><td>1.035</td></tr>
<tr><td>IPP (Independent Power Producer)</td><td>Hydro Power Plant / PLTA</td><td>290</td><td>10</td><td></td><td></td><td>1.180</td><td>150</td><td>412</td><td>467</td><td>200</td><td>600</td><td>3.309</td></tr>
<tr><td>IPP (Independent Power Producer)</td><td>Pumped Storage / PS</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>760</td><td></td><td>760</td></tr>
<tr><td>IPP (Independent Power Producer)</td><td>Solar Power Plant /PLTS</td><td>1</td><td>162</td><td>1.070</td><td>358</td><td>858</td><td>110</td><td>140</td><td>140</td><td>140</td><td></td><td>2.979</td></tr>
<tr><td>IPP (Independent Power Producer)</td><td>Other Power Plant</td><td>12</td><td>43</td><td>121</td><td>365</td><td>221</td><td>90</td><td></td><td>5</td><td></td><td></td><td>855</td></tr>
<tr><td></td><td>Total</td><td>6.818</td><td>2.615</td><td>2.672</td><td>1.433</td><td>4.788</td><td>2.822</td><td>1.250</td><td>867</td><td>1.327</td><td>1.414</td><td>26.006</td></tr>
<tr><td>IUPTL Owner</td><td>Steam Fired Power Plant (Coal) / PLTU</td><td></td><td></td><td>300</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>300</td></tr>
<tr><td>IUPTL Owner</td><td>Total</td><td>0</td><td>0</td><td>300</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>300</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>40.575</td></tr>
</table>
[135]
• Around 12.5 GW RE capacity (including biomass, around 17% of energy mix) [69]</td><td>[69], [135]</td></tr>
<tr><td>RE policy target</td><td>• By 2030: [262]</td><td>[262], [135]</td></tr>
</table>

	• Reduce 31,89% of total GHG emission (compared to the base year 2010) unconditionally or 43,20% conditionally, • Targeted to have renewable energy resources installed 20.923 MW unconditionally • Targeted to have a solar rooftop, PV, hydro, and off-grid RE Installed 15.483 MW unconditionally • Reaching NetZero Emission by 2060 or sooner and increasing the portion of renewable energy in power generation to 44% by 2030 [27] • Indonesia aims to increase its renewable energy share in its power generation to 44% by 2030 from around 12% in 2022. This is planned to be achieved by mainly installing geothermal and hydropower plant capacities, but also some solar PV capacities [135]	
Existing energy trade	• Importing electricity from Malaysia	[135]
Electrification rate	• 99,63% (2022)	[263]
Reliability of electricity supply	• SAIDI: power outage or interruption occurs six hours per customer per year • SAIFI: power outage or interruption occurs four times per customer per year	[264]
Electricity cost/tariff	Electricity Tariff: • Households in the 3,500 to 5,500 VA category (R2) and households using 6.600 VA or more (R3): IDR 1699,53/kWh • Tariffs for Government class using 6,600 VA – 200 kVA (P1) and P3 customers: IDR 1444,70/kWh • P2 customers (Government using more than 200 kVA): IDR 1522,88/kWh	[265]
RE investment	• Overall score 1.67 of 5 / fundamentals (policies, market structures etc.) 2.55 of 5, opportunities (market potential growth) 1.17 of 5, experience 0.43 of 5 • Global rank: 95	[116]
Social, political and economic indicators		
Parameter	Information	Source
Socio-economic data	• GDP per capita: $4,777.5 [266] • Unemployment rate: 5,9% (2022) [267] • Poverty headcount ratio: 9,5 (2022) [268] • GINI index: 37,9 (2022) [269]	[266], [267], [268], [269]

Worldwide Governance Index	Percentile rank: indicates the rank of the country among all other countries in the world, 0 corresponds to the lowest rank and 100 to the highest rank, all 2022 values • Voice and Accountability: 52.66 • Political Stability and Absence of Violence/Terrorism: 29.25 • Government Effectiveness: 66.04 • Regulatory Quality: 59.43 • Rule of Law: 45.28 • Control of Corruption: 37.74	[270]
Trade indicators		
Parameter	Information	Source
Exported goods	• In 2021, Indonesia was the world's biggest exporter of Palm Oil ($27.3 billion), Ferroalloys ($7.16 billion), Large Flat-Rolled Stainless Steel ($6.68 billion), Stearic Acid ($5.5 billion), and Lignite ($5.29 billion). • The top exports of Indonesia are Coal Briquettes ($28.4 billion), Palm Oil ($27.3 billion), Petroleum Gas ($8.06 billion), Ferroalloys ($7.16 billion), and Large Flat-Rolled Stainless Steel ($6.68 billion).	[49]
Export partners	China, USA, Japan, India and Singapore	[49]
Imported goods	• In 2021, Indonesia was the world's biggest importer of Soybean Meal ($2.37 billion), Industrial Furnaces ($404 million), Steam Boilers ($233 million), Refractory Cements ($226 million), and Artificial Filament Tow ($177 million) • The top imports of Indonesia are Refined Petroleum ($14.5 billion), Crude Petroleum ($6.03billion), Petroleum Gas ($4.27 billion), Vaccines, blood, antisera, toxins and cultures ($3.42 billion), and Motor vehicles; parts and accessories (8701 to 8705) ($3.19 billion),	[49]
Import partners	China, Singapore, Japan, US, Malaysia	[49]

II. Laos

Hydrogen		
Parameter	Information	Source
Current H_2 demand	• No demand data is available, but export statistics show some products that potentially need hydrogen as a feedstock, e.g. chemicals and fertilizer [71] • Some demand for oil refining, the first diesel hydrotreatment plant opened in 2020 [63] • Demand is expected to be relatively low due to low projections in a study modelling future demand [65] • 88% of current oil and gas imports are used in the transport sector, suggesting that this sector bears the largest H_2 application potential [271]	[1], [63], [65], [271]
Current H_2 derivate demand	Ammonia for fertilizer production (presumably), makes up around 3% of exports (share of ammonia-based fertilizers unknown) [71] The advancement of H_2, in the form of power-to-fertiliser might provide an opportunity to reduce the dependence on imports Laos has a high installed RE capacity, is currently importing fertilizer and has no gas reserves [64], and low development of its transport and logistics infrastructure, which makes imports more costly [176]	[71], [64], [176]
Current H_2 production source, volume and price	Volume is unknown, trade volume for exports at $12.5 million and production volume is probably relatively small Presumably from lignite gasification, since the country does not have any natural gas reserves and no recorded green H_2 production facilities	[71]
Current H_2 derivate production process, volume and price	Not operational yet, but planned production of green ammonia-based fertilizer derived from hydrogen produced with excess hydropower	[114]
Current H_2 and derivate product trade	Laos shows comparatively low export and import volumes for H_2, with a slight net export trade balance of $8.6 million Ammonia: net imports $64,000	[49]
Current H_2 & gas infrastructure	The lack of gas-related infrastructure is assumed to be a significant hurdle to major PtX production in Laos	[64]

Most suitable H_2 transport option	No information, but most likely trucks due to lack of pipelines and ports	
General H_2 strategy and goals	Hydrogen strategy being drafted, but no results are public yet [9] Oral affirmation that hydrogen-based ammonia will play a role in the country's energy transition, no specific goals defined yet [10]	[115], [272]
Value chain for H_2 and derivates	Mostly renewable electricity generation (not so much hydrogen production and consumption compared to the other countries)	
Green hydrogen		
Parameter	Information	Source
Relevant stakeholders	Public stakeholders Ministry of Energy and Mines Ministry of Natural Resources and Environment Ministry of Industry and Commerce National University of Laos Laos-Korea Institute of Technology Private stakeholders Electricite du Laos (EDL) Nam Theun 2 Power Company	[64], [272]
Dominant RE source to produce gH_2	Hydropower (already accounts for a significant share of the energy mix [116], expansion planned [273]) Wind power could play a more significant role in the future, as the country seeks to diversify its RE sources [274] Among the region, Laos shows the highest proportion of renewable energy sources in the electricity generation sector [130]	[116], [273], [274], [130]
Potential gH_2 demand	Current demand [71], [188] • Refinery (small scale) • Fertiliser Industry • Chemicals • Cement • Metal	[65], [71], [188]

	Future demand [65] • Transport (road vehicles) • 0-0.2 Mtoe projected by EIRA, if it all comes from the transport sector	
Future gH_2 generation potential	No data available, but high RE potential (especially hydropower); 30 GW of the country's hydropower potential would not be needed to cover the electricity demand of Laos and its neighbouring countries and thus could be used to produce H_2	[275]
H_2/PtX production and transport cost	No data available	
gH_2 roadmap and targets	No specific green H_2 targets	
gH_2 regulatory framework	Non-existent yet with specific regards to gH_2, general lack of legal framework related to gas Generally, hydrogen projects could benefit from the Green Growth Promotion Fund, which provides loans to businesses for expenditures related to "implementing the plans, programmes, and activities which have the characteristics of promoting green growth"	[64]
gH_2 programmes or partnerships	Sustainable energy partnership with Australia, including the development of green hydrogen in Laos as one of its objectives	[276]
gH_2 projects and knowledge	Tsubame BHB planning to produce low-carbon fertilizer from ammonia derived from hydrogen generated with surplus hydropower electricity, MoU signed with AgriLaos and State Enterprise for agriculture Service (SAS)	[114]
Land and water availability		
Parameter	Information	Source
Fresh water situation/scarcity	• 26,013 cubic meters of renewable internal freshwater resources available per capita [13], • Proportion of freshwater withdrawal to available resources: 4.79 [18], • stable supply of freshwater but might get more scarce in the future due to hydropower expansion and more frequent droughts [19]	[140], [141], [273]
Water consumption	• 1,635 l/day per capita	[258]

Land availability	• General shortage of land accessible for economic use due to geographic factors and contamination through unexploded ordnances [277] • 21% of the land is leased or conceded (as of 2021), most concessions for mining or agriculture (mostly rubber) [278] • Maximum lease term is 99 years; the minimum term for concessions is 5 years, state land leases for industrial facilities have a duration of 15-30 or 50 years with the possibility of the lease being extended [278] • Project owners responsible for carrying out investigations and providing compensation for people negatively affected by the activities carried out on the conceded land [278] • However, generally a low level of compliance of land deals with Lao legal obligations, more than 50% of land deals are happening without concession contract [278]	[277], [278]
Resource conflicts (electricity, land, water, land use etc.)	• Dispossession of small-scale (often ethnic minority) farmers by industrial rubber and pulpwood plantations, denied access to land and resources, often met with community resistance, results ranging from violence to concessions[279] • Hydropower expansion was criticised for lacking consideration of socio-environmental impact assessment, lack of community involvement and transparency, displacement of communities, and destroying fish feedstock which account for a significant share of the local population's nutrition intake and exacerbate the consequences of droughts. Protests are rare but happening. Ethnic minorities are often disproportionately affected [280] • Interpersonal conflicts within communities displaced or negatively impacted by hydropower development due to limited availability of resources [280] • If hydropower is expanded for green H_2 production, water availability in regions downstream of the Mekong River (southern Laos, southern Vietnam, and eastern Thailand) might be affected by less available freshwater [281]	[279], [280], [281]
CO_2 sources for derivate production	• Potentially cement industry (most other industries are driven by SMEs with less concentrated CO_2 emissions and lacking capital to invest in infrastructure to process CO_2 into derivates), electricity generation (often lignite-based)	[188]
Energy situation		
Parameter	Information	Source

Energy mix (electricity generation)	• Overall installed capacity: 8.8 GW Hydropower (82.9%); 1.9 GW Coal/Lignite (17.5%); Solar PV: 0.032 GW Solar PV (0.3%); 0.025 GW Biomass/Waste (0.2%) [116] • Generation mix 2021: 26.5% coal, 73.2% hydro, 0.2% biofuels, 0.1 % solar [130]	[116], [130]
RE share (electricity generation)	• Capacity (GW): 83.5% [116] • Generation (GWh). 56.31% [116] • Share of different RE sources in electricity generation in 2021: 99.8% hydro, 0.2% solar [262]	[116], [262]
Planned capacity expansion	• Plans to develop 7.5 GW of hydropower, 1 GW of wind & solar, and 300 MW biomass by 2030	[136]
RE policy target	• 65% being sourced from hydropower, 30% from coal thermal energy and 5% from other renewable energy sources (already more hydropower in the current mix) • Achieving a share of 30% electric Vehicles by 2030	[24]
Existing energy trade	• Exporting of electricity to Vietnam; two-way energy trade with China; Power Integration Grid with Thailand, Malaysia, and Singapore operational since 2022, Laos as the biggest exporter within this grid [273] • Current total exports: 25 TWh, account for $1.96 million trade volume, expected to grow to 43.8 TWh by 2030 • Imports of fossil fuels for transport and industry (total imports of fuel amount to a value of $803 million in 2021) [272]	[64], [71] [272], [273]
Electrification rate	• 100%	[282]
Reliability of electricity supply	• Increasing droughts might impact hydropower supply and lead to disruption of supply chains in the future	[273]
Electricity cost/tariff	• LCOE around $65/MWh Tariff (2022) • Residential: $0.039/kWh; Industrial: $0.048/kWh; Commercial: $0.068/kWh	[116]
RE investment	Currently (2023) 38 hydropower dams are under development, total investment sum of $18B [273] Climatescope index [283]: • Overall scoring: 1.29/5 • Fundamentals: 1.51/5 • Opportunities: 1.03/5	[273], [283]

	• Experience: 1.1/5 • Ranking: 121 (global); 27 (Asia-Pacific)	
Social, political and economic indicators		
Parameter	Information	Source
Socio-economic data	• GDP per capita: $9,387.4 [266] • Unemployment rate: 2.6% [267] • Poverty headcount ratio: 6.5% absolute poverty (2024), 18.3 at national poverty lines (2018) [284] • GINI index: 38.8 (2018) [269]	[266], [267], [284], [269]
Worldwide Governance Index	Voice and Accountability: – 1.66 Political Stability and Absence of Violence/Terrorism: 0.8 Government Effectiveness: -0.6 Regulatory Quality: – 0.99 Rule of Law: – 0.81 Control of Corruption: – 0.97 (all on a scale from -2.5 to 2.5)	[270]
Trade indicators		
Parameter	Information	Source
Exported goods	Top export goods: Electricity ($1.69 billion), Gold, Paper, Copper and Iron Ore, Rubber, Cassava	[71]
Export partners	Exports total: $9.22 billion (1240 per capita) Imports total: $7.67 billion (1030 per capita)	[71]
Imported goods	Refined petroleum ($734 million), gold, cars, broadcasting equipment, trucks	[71]
Import partners	Mainly Thailand, China, Vietnam,	[71]

III. Malaysia

Hydrogen		
Parameter	Information	Source
Current H_2 demand	• Malaysia's hydrogen demand is comparatively low, ranging at 50 kt/a, with hydrogen being mainly used for ammonia and methanol production and petroleum refining [60] • Current green hydrogen usage: Fuel cell electric vehicles [58]	[60], [58]
Current H_2 derivate demand	• Ammonia and methanol (no detailed information)	[60]
Current H_2 production source, volume and price	• Mainly grey hydrogen • First green hydrogen production based on hydropower • Sarawak Energy through its integrated Hydrogen Production and Refuelling Station produces 130 kg/H_2 per day with 99.99% purity	[60]
Current H_2 derivate production process, volume and price	• One of the three countries in Southeast Asia with domestic methanol production	[142]
Current H_2 and derivate product trade	• One of the major exporters of hydrogen, export has a total trade value of $802 million, making it the 4th largest exporter of hydrogen worldwide • Hydrogen: net exports of $423 million • Ammonia: net exports $271 million • With Indonesia, Malaysia is currently a leading exporter of nitrogenous fertilizers in the region (both exporting nitrogenous fertilizer in a value of 0.9 – 1 bn. USD per year)	[60], [66], [4]

Current H_2 & gas infrastructure	Current infrastructure: • There are 7 major ports in Malaysia: Port Klang, Port Tanjung Pelepas, Port of Johor, Port of Penang, Port of Bintulu, Port of Kuantan, and Port of Labuan. Port of Bintulu, the western coastline of Sarawak, located near the PETRONAS LNG complex is one of the most important ports for the oil and gas industry trading [80] • There are several operating LNG terminals in Malaysia: The Pengerang Johor LNG Terminal has been commercially operating since 2017 and is used for imports. The Petronas Bintulu LNG Complex, which is located in Sarawak consists of the Tiga Malaysia LNG Terminal, which started in 2017, the Malaysia LNG Terminal Train 9, operating since 2016, as well as the Satu Malaysia Terminal, operating since 1983. All of the terminals are used for export. The Brunei LNG Terminal, started in 1973 is an export terminal as well. The longest pipeline is Peninsular Gas Utilization (PGU) supplying gas to the energy sector, petrochemical plants, and various industries and runs 2.623km throughout Peninsular Malaysia, including exports to Singapore, and is operated by Petronas. Smaller pipelines are West Natuna Transportation System Gas Pipeline and the Sabah-Sarawak Gas Pipeline [81] • Malaysia's first green hydrogen plant is directly connected to a refuelling station for H_2 fuel cell vehicles. Malaysia introduced the first H_2-powered buses in Southeast Asia in 2019 [59] • Gas Transportation and Regasification of Petronas runs 2.623km Peninsular Gas Utilization (PGU) pipelines network transport sales gas to power sectors, petrochemical plants, and various industries across Peninsular Malaysia, including export to Singapore [285] • Malaysia's infrastructure is designed to supply neighbouring countries with natural gas, and transport gas between different regions within the country. Proposed infrastructure: • The Trans Sabah Gas Pipeline, the Tiga FLNG Terminal in Sabah, and the Petronas ZFLNG Terminal near the Rotan Gas Field are proposed [81]	[80], [81], [59], [285],
Most suitable H_2 transport option	• Trucks, ships and pipelines	[60]
General H_2 strategy and goals	• In October 2023, the Ministry of Science, Technology, and Innovation published the Hydrogen Economy and Technology Roadmap (HETR). The HETR execution is separated into three phases. Start from focusing on establishing a back-bone for domestic hydrogen demand and initiating an export business to the targeted countries, then look over the development of the domestic market with the continuation of the export, and the last phase is to see the expanding and sustaining domestic growth and export market share.	[60]

Value chain for H_2 and derivates	• Activities along the whole value chain: production, consumption and trade	[60]
Green hydrogen		
Parameter	**Information**	**Source**
Relevant stakeholders	Public stakeholders [60] • PETRONAS • TNB • Sarawak Energy Berhad Private stakeholders [98] • Gentari Sdn Bhd • ENEOS • Sumitomo Corp • Asahi Kasei • JGC Holding Corp • SK Group • Linde • Air Liquide • AirProducts	[60], [98]
Dominant RE source to produce gH_2	• POME as biogas feedstock, energy from solar, large and small hydropower and ocean thermal energy conversion	[60]
Potential gH_2 demand	Current demand • Refinery • Chemical industry • Fertiliser industry Future demand Methanol production • Cement production • Steel production • Transport (road vehicles) • Power sector	[60]

	• Industrial heat provision	
Future gH_2 generation potential	• Exports to Australia, the Middle East, China, Japan, South Korea and Singapore	[60]
H_2/PtX production and transport cost	• Production price for green hydrogen stands at $6/kg [60] • Projections for 2030 also foresee LCOH of $2.1-4.1/kg [7]	[60], [7]
gH_2 roadmap and targets	• Target: 200.000 tonnes per year by 2030 • 10% fuel on Marine switching to green hydrogen by 2050 • The share of green hydrogen is projected to be 23,14% in 2040 and 49,53% by 2050 • Hydrogen production volume is projected at 2 MTPA by 2030, 8 MTPA by 2040, 16 MTPA by 2050 • Hydrogen share in Final Energy Consumption is projected at 1.1% in 2030, 3.6% in 2040, and 6% in 2050	[60]
gH_2 regulatory framework	• No specific regulation in place	
gH_2 programmes or partnerships	• NanoMalaysia's Malaysia Hydrogen EcoNanoMY Programme, Sarawak's Lead Hydrogen Projects, Decarbonising Urban Transportation System, Project H_2ornbill	[60]
gH_2 projects and knowledge	• Eneos and Sumitomo Corp, two Japanese companies signed an agreement with SEDC Energy, to build hydroelectric plants in Malaysia which will produce green hydrogen and ship to Japan. It aims to produce 90.000 tonnes annually by 2030. [98] • Asahi Kasei, Gentari Hydrogen Sdn Bhd, a wholly-owned subsidiary of PETRONAS clean energy arm Gentari Sdn Bhd (Gentari), and JGC Holdings Corporation (JGC) today announced the completion of a detailed feasibility study for production of up to 8,000 tonnes per year of green hydrogen using a 60 megawatt (MW) class alkaline water electrolyser system. [99] • SK Group, the largest conglomerate from South Korea, agreed to cooperate with Gentari Sdn Bhd to produce up to 1.2 mtpa of hydrogen in Malaysia. [100], [286] • Malaysia and the Philippines are already involved in pilot projects using newer applications of H_2 as an alternative fuel in the municipal gas systems, for electricity supply, transport or process heat. • Having inaugurated the first commercial PEM electrolyser plant in Southeast Asia already in 2019, implemented in cooperation between Petronas and Universiti Kebangsaan Malaysia (UKM). [97]	[98], [99], [100], [286], [97], [60].

	• Sarawak Energy Berhad (SEB) has started demonstrator projects for H_2-powered road vehicles, including buses and has been setting up the first H_2 refuelling stations. Similarly, the automotive company UMW is also investing in light passenger vehicles using hydrogen. [60]	
Land and water availability		
Parameter	Information	Source
Fresh water situation/scarcity	• Level of water stress (freshwater withdrawal as a proportion of available freshwater resources): 3,44 (2020) [140] • Annual freshwater withdrawals, total (billion cubic meters): 6,7 (2020) [256] • Annual freshwater withdrawals, total (% of internal resources): 1(2020) [257]	[140], [256], [257]
Water consumption	• Daily water consumption per capita (litters): 1184 [258] • Level of water stress: freshwater withdrawal as a proportion of available freshwater resources in 2020: 3.4 [140] • Renewable internal freshwater resources per capita in 2020: 17,470 [141]	[258], [140], [141]
Land availability	• Forest Area: 58% (2021) [287] • Agricultural Land: 26,21% [288] • Others: 15,71%	[287], [288]
Resource conflicts (electricity, land, water, land use etc.)	• Tensions in the South China Sea for maritime coastline with China, Vietnam, Malaysia, Brunei and the Philippines	[289]
CO_2 sources for derivate production	• Petrochemical industry by-product	[290]
Energy situation		
Parameter	Information	Source

<table>
<tr><td>Energy mix (electricity generation)</td><td>• Electricity generation mix (2021): Gas (32.5%), coal (47.9%), oil (0.6 %), RE (19.1%)</td><td>[130]</td></tr>
<tr><td>RE share (electricity generation)</td><td>RE generation (2023): [291]
• Biogas: 452,211 MWh (35%)
• Biomass: 107,908 MWh (8%)
• Biomass (Solid Waste) 59,876 MWh (5%)
• Small Hydro: 324.872 MWh (25%)
• Solar PV: 352.919 MWh (27%)
RE electricity generation in 2021: 93.9% hydro, 6.1% solar [262]
Current RE capacity [69]
• Solar Around 12.5 GW RE capacity (including biomass, around 17% of energy mix)</td><td>[291], [262], [69]</td></tr>
<tr><td>Planned capacity expansion</td><td>Table 1: Generation Development Plan (2021-2030)
<table>
<tr><th>Year</th><th>Generation Capacity (31% RE Capacity Mix for Malaysia)</th><th>Retiring Plants</th></tr>
<tr><td>2021</td><td>Edra Energy (CCGT) (3x747 MW)
RE (860 MW)</td><td>YTL Power (CCGT) (585 MW)</td></tr>
<tr><td>2022</td><td>RE (652 MW)</td><td>TNB Pasir Gudang (CCGT) (275 MW)
GB3 (CCGT) (640 MW)</td></tr>
<tr><td>2023</td><td>RE (663 MW)</td><td>Panglima (CCGT) (720 MW)</td></tr>
<tr><td>2024</td><td>TADMAX (CCGT) (2x600 MW)
RE (855 MW)</td><td>SKS Prai CCGT (341 MW)
TTPC (CCGT) (650 MW)
TNB Gelugor (CCGT) (310 MW)</td></tr>
<tr><td>2025</td><td>RE (818 MW)</td><td>TNB Putrajaya GT4 & GT5 (OCGT) (249 MW)</td></tr>
<tr><td>2026</td><td>THB (CCGT) (2x600 MW)
RE (117 MW)</td><td>KLPP (CCGT) (675 MW)</td></tr>
</table></td><td>[292]</td></tr>
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<tr>
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<table>
<tr><th>Year</th><th>Generation Capacity (31% RE Capacity Mix for Malaysia)</th><th>Retiring Plants</th></tr>
<tr><td>2027</td><td>Nenggiri (Hydro) (300 MW)
RE (184 MW)</td><td>Segari Energy Ventures (CCGT)
(1,303 MW)</td></tr>
<tr><td>2028</td><td>RE (192 MW)</td><td>TNB Tuanku Jaafar PD1 (CCGT)
(703 MW)</td></tr>
<tr><td>2029</td><td>CCGT (1x700 MW)
CCGT (1x500 MW)
RE (199 MW)</td><td>KEV Gas U1 & U2 (Thermal Gas)
(578 MW)
KEV Coal U3-U6 (Coal) (1,474 MW)</td></tr>
<tr><td>2030</td><td>CCGT (4x700 MW)
RE (207 MW)
BESS (1X100MW)</td><td>TNB Tuanku Jaafar PD2 (CCGT)
(708 MW)
TNB Janamanjung (Coal) (2,070 MW)</td></tr>
</table>
Note: CCGT = Combined Cycle Gas Turbine; OCGT = Open Cycle Gas Turbine.
BESS = Battery Energy Storage System
</td>
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<tr>
<td>RE policy target</td>
<td>

45% of carbon intensity reduction (unconditional) by 2030 with the base year 2005. [293]
Malaysia plans to have 31% renewable energy resources in its total installed capacity by 2030. [294]
The government has further committed to achieving net zero greenhouse gas emissions as early as 2050 by implementing clean, sustainable, and renewable energy (RE). Malaysia has committed to increase renewable energy composition to 70 percent of the total generation capacity by 2050. Malaysia is expected to expand its renewable capacity from 6 to 14 GW. [137]

</td>
<td>[293],
[294],
[137]</td>
</tr>
<tr><td>Existing energy trade</td><td>Thailand, Indonesia, Singapore</td><td>[295]</td></tr>
<tr><td>Electrification rate</td><td>100%</td><td>[282]</td></tr>
</table>

Reliability of electricity supply [296]

SAIDI, SAIFI, CAIDI

Year	SAIDI (Minutes/Customer/Year)		SAIFI (Disruptions/Customer/Year)		CAIDI (Minute/Disruption)	
	Peninsular	Sabah	Peninsular	Sabah	Peninsular	Sabah
2011	0.3630	0.0000	0.0039	0.0000	90.9600	0.0000
2012	0.7489	0.0000	0.0029	0.0000	260.9000	0.0000
2013	0.1480	0.0000	0.0022	0.0000	66.8300	0.0000
2014	0.1492	0.0000	0.0021	0.0000	70.7100	0.0000
2015	0.0874	0.0000	0.0016	0.0000	54.0500	0.0000
2016	0.3812	0.0000	0.0010	0.0000	375.2300	0.0000
2017	0.1067	0.0000	0.0025	0.0000	42.5100	0.0000
2018	0.3060	0.0000	0.0008	0.0000	404.8200	0.0000
2019	0.1780	0.0000	0.0007	0.0000	259.5600	0.0000
2020	5.7775	0.0000	0.0041	0.0000	1381.6300	0.0000

Year	SAIDI (Minutes/Customer/Year)		Network Integrity (Disruptions/Customer/Year)		Customer Service	
	Peninsular	Sabah	Peninsular	Sabah	Peninsular	Sabah
2021	1.4393	N/A	2	N/A	47	N/A
2022	0	N/A	1.2	N/A	35	N/A

Electricity cost/tariff [138]

region	subregion	industry	generation	unit	currency	2010	2011	2012	2013	2014	2015	2016	2017	2018
Malaysia	Sabah	Agricultur	Electricity	kWh	MYR	0	0	0	0	0	0	0	0	0
Malaysia	Sabah	Househol	Electricity	kWh	MYR	0,2295	0,247	0,2508	0,2508	0,2791	0,2914	0,2886	0,2839	0,2931
Malaysia	Sabah	Public	Electricity	kWh	MYR	0	0,2838	0,1851	0,1851	0,2161	0,2254	0,2309	0,2327	0,2481
Malaysia	Sabah	Services	Electricity	kWh	MYR	0,2884	0,2905	0,3298	0,3298	0,3719	0,3763	0,3821	0,3828	0,3939
Malaysia	Sabah	Industry	Electricity	kWh	MYR	0,2331	0,2377	0,2813	0,2813	0,3119	0,308	0,3136	0,3109	0,3136
Malaysia	Sarawak	Agricultur	Electricity	kWh	MYR	0	0	0	0	0	0	0	0	0
Malaysia	Sarawak	Househol	Electricity	kWh	MYR	0,3119	0,3117	0,3122	0,3125	0,3125	0,2825	0,283	0,2821	0,2827
Malaysia	Sarawak	Public	Electricity	kWh	MYR	0,4709	0,4708	0,4704	0,4709	0,4709	0	0,4712	0,4718	0,4717
Malaysia	Sarawak	Services	Electricity	kWh	MYR	0,32	0,3119	0,3197	0,3195	0,3195	0,3172	0,3053	0,3054	0,305
Malaysia	Sarawak	Industry	Electricity	kWh	MYR	0,2462	0,2466	0,249	0,2507	0,2507	0,2488	0,2415	0,2386	0,2369
Malaysia	Semenanjung	Agricultur	Electricity	kWh	MYR	0,3703	0,3724	0,3982	0,3944	0,4315	0,4586	0,4578	0,4554	0,4583
Malaysia	Semenanjung	Househol	Electricity	kWh	MYR	0,2766	0,2761	0,2876	0,2918	0,3123	0,3267	0,3321	0,3287	0,3309
Malaysia	Semenanjung	Public	Electricity	kWh	MYR	0,2058	0,2049	0,215	0,2154	0,2332	0,2549	0,2557	0,2553	0,2557
Malaysia	Semenanjung	Services	Electricity	kWh	MYR	0,3769	0,3819	0,4074	0,4086	0,4493	0,4768	0,4676	0,4756	0,4728
Malaysia	Semenanjung	Industry	Electricity	kWh	MYR	0,2844	0,2894	0,3091	0,3096	0,3417	0,3656	0,3713	0,3697	0,373

RE investment [116]

- Overall score 2.05 of 5 / fundamentals (policies, market structures, etc.) 3.21 of 5, opportunities (market potential growth) 1.21 of 5, experience 0.55 of 5
- Global rank: 45

Social, political and economic indicators

Parameter	Information	Source
Socio-economic data	• GDP: M$1,79 trillion (MYR) • GNI per capita: $11,780 (2022) [290] • Population: 32,7 million (2022) • GDP per capita: 11.993,2 (2002) [266] • Unemployment rate: 3,7 (2002) [267] • Poverty headcount ratio: 6,2 (2021)[268] • GINI index: 41,2 [269]	[266], [267], [268], [290], [269]
Worldwide Governance Index	• Voice and Accountability: 47,34 • Political Stability and Absence of Violence/Terrorism: 51,89 • Government Effectiveness: 79,25 • Regulatory Quality: 72,64 • Rule of Law: 68,40 • Control of Corruption: 62,26	[270]
Trade indicators		
Parameter	Information	Source
Exported goods	The top exports of Malaysia are Integrated Circuits ($71B), Refined Petroleum ($29.3B), Palm Oil ($15B), Rubber Apparel ($13.3B), and Petroleum Gas ($10.7B)	[49]
Export partners	Singapore, China, USA, Hong Kong and Japan	[49]
Imported goods	The top imports of Malaysia are Integrated Circuits ($34.4B), Refined Petroleum ($18.7B), Crude Petroleum ($4.92B), Coal Briquettes ($4.36B) and Gold ($4.01B)	[49]
Import partners	China, Singapore, Japan, USA and Taiwan	[49]

IV. Philippines

Hydrogen		
Parameter	Information	Source
Current H_2 demand	• Currently, the main hydrogen demand is from the petroleum industry, followed by the chemical industry (ammonia, fertiliser, methanol) and as an industrial heat source [62] • The government plans to transform the old coal plants with the HERO systems into green hydrogen plants. The MOU with Star also explores the possibilities of co-producing electricity and green hydrogen at onshore wind farms. With the expected penetration of RE, energy storage should also be developed at equal magnitudes. [62] • Hydrogen demand potential in the Philippines is estimated to be 0.4 Mtoe in Scenario 1, 0.9 Mtoe in Scenario 2, and 1.4 Mtoe in Scenario 3 in 2040 [65]	[62], [65]
Current H_2 derivate demand	• Ammonia, fertilisers and methanol are demanded by the chemical industry and as an industrial heat source but to a lesser extend	[62]
Current H_2 production source, volume and price	• In 2019, Air Liquide signed a new long-term contract to supply hydrogen to Pilipinas Shell's Tabangao refinery. Air Liquide will invest 30 million euros in the construction of a state-of-the-art Hydrogen Manufacturing Unit (HMU) that will be built on the Tabangao refinery in Batangas. [102] • Pilipinas Shell Petroleum Corporation (Pilipinas Shell), in partnership with Air Liquide Philippines, Inc. (Air Liquide), held its ground-breaking ceremony for its Integrated Hydrogen Manufacturing Facility at the Shell Refinery in Batangas City last August 29. Expectation: complete the project by the end of 2020 and reap the benefits from this venture starting in 2021, said Paolo Barredo, Pilipinas Shell Refinery's Business Opportunity and Business Development Manager. [103] • Hydrogen is produced from Gas. No info on volume and price.	[102], [103]
Current H_2 derivate production process, volume and price	• No information found	
Current H_2 and derivate trade	• Import: 141.37 in Trade Value $1000 (2019) [297] • Export: N/A	[297], [298], [49]

	• The Philippines show comparatively low export and import volumes for hydrogen, with a slight trade deficit of $9.2 million [298] • Derivatives: the current role of the Philippines as an importer becomes more visible, showing a trade deficit of $437 million for Nitrogenous fertilizers, and of $9.04 billion for refined petroleum, as well as trade deficits other chemicals that potentially rely on hydrogen in their production, such as alcohols and other hydrocarbons [49]	
Current H_2 & gas infrastructure	Current Infrastructure • The main shipping port is Batangas, where most of the crude oil and gas are processed and distributed within the country. • Philippines LNG Terminal is the only liquefied natural gas (LNG) import terminal operating in the Philippines. • Malampaya Gas Pipeline is the operating natural gas pipeline which has a length of 504km. Proposed infrastructure: • The Philippines are planning to expand their already existing infrastructure around Batangas with the Filipinas LNG Gateway Project FSRU, Vires FSRU, Tabangao FSRU and the Batangas Clean Energy LNG Terminal. In the same area, the FGEN Batangas FSRU and the FGEN Batangas LNG Terminal are already under construction. • The Atimonan LNG Terminal is a proposed terminal, near Pagbilao Grande Island LNG Terminal. • The proposed Mariveles LNG Terminal would be constructed in Bataan.	[81]
Most suitable H_2 transport option	• Trucks, pipelines and shipping	
General H_2 strategy and goals	• The Department of Energy of the Republic of the Philippines, through its Energy Utilization Management Bureau, conducted a public consultation of the draft Department Circular Providing a National Policy and General Framework, Roadmap, and Guidelines for Hydrogen in the Energy Sector on 13 October 2023 [91]. The draft includes among general and final provisions also chapters on the role of hydrogen in the energy sector (such as the exploration and development of native hydrogen and the hydrogen energy value chain) and on hydrogen energy industry activity (such as research and development). It also contains fiscal and non-fiscal incentives to support hydrogen in the energy sector. [92] • The government-academic partnership realized the importance of establishing a white paper or roadmap that focuses on hydrogen fuel cell technology to (1) determine the status of hydrogen energy storage both globally and locally; (2) propose future scenarios; (3) identify challenges and gaps that can be addressed through research and development; (4) capacity and institution building; and to (5) identify research areas	[91], [92], [106]

	and formulate an action plan. It was identified that internationally, hydrogen and fuel cell technologies are in the early stages of commercialization and struggle to compete with alternative options due to high cost. [91] • The Philippine Council for Industry, Energy, and Emerging Technology Research and Development of the Department of Science and Technology (DOST-PCIEERD) initiated the crafting of an action plan that identified three focus areas for future fuel cell development between 2019 and 2022. The roadmap details the fuel cell and electrolyser research and development program between 2020 and 2025. [106]	
Value chain for H_2 and derivates	• Activities along the whole value chain: production, consumption and trade	
Green hydrogen		
Parameter	Information	Source
Relevant stakeholders	Public stakeholders • Department of Energy (DoE), including the Hydrogen Energy Industry Committee (HEIC) and the Alternative Fuels and Energy Technology Division (EUMB-AFETD). • Department of Science and Technology • National Economic and Development Authority • University of the Philippines Diliman • University of Santo Tomas • De La Salle University • Philippine Nuclear Research Institute • Energy Research and Testing Laboratory • Philippine Council for Industry, Energy, and Emerging Technology Research and Development Private stakeholders • Energy Development Corporation • First Gen Corporation • Philippine National Oil Company • Manila Electric Company (MERALCO) • Visayan Electric Company (VECO)first gen Associations: • Philippine Hydrogen Association • Renewable Energy Association of the Philippines	[106]

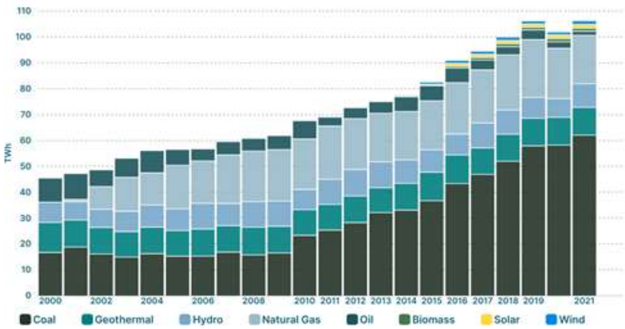
Dominant RE source to produce gH_2	Cheap and low emission: • Geothermal • Hydropower • Solar and Wind • Biomass • Ocean Energy • Renewables accounted for 21% of the country's total energy mix, which includes hydropower, geothermal, wind, solar, and biomass. • Given its geographic advantage in the Pacific, the country has a huge potential for RE generation with 170 GW from the ocean, 76.6 GW wind, 10 GW hydropower, 4 GW geothermal, 1528 MW solar, and 500 MW biomass. The government aims to tap this potential and increase the RE capacity to 60% in 2030 by developing localized RE sources. [299] • Due to its mature technology and the country's location in the Pacific Ring of Fire, Geothermal is the most abundant and cheapest RES in the Philippines. • Apart from geothermal, hydropower dominates the RES in the Philippines because of its mountainous terrain and abundance of rainwater. • Currently, wind energy, albeit with huge potential, makes up a small percentage of the total energy generation mix in the Philippines. With the archipelagic nature of the country, islands with high potential for wind energy production are not connected to the national grid limiting the mass development of wind infrastructures. [299] • While the neighbouring countries in Asia embraced solar energy, the Philippines still underutilized this energy source despite its location advantage in the tropics and great potential to harness solar energy. • Ocean energy could be another source of green hydrogen, however, it seemed to be delayed in development in terms of capacity as compared with other renewables. • Biomass is another renewable and sustainable source of energy that can replace fossil fuels for hydrogen production. • As an agricultural country, the Philippines has a great potential to produce hydrogen from biomass as the country is abundant in various agricultural wastes such as livestock manure and plant residues of rice, corn, sugarcane, and coconut; as well as agro-industrial and municipal organic wastes with millions of tons generated per year. [62]	[299], [62]
Potential gH_2 demand	Current demand • Refinery	

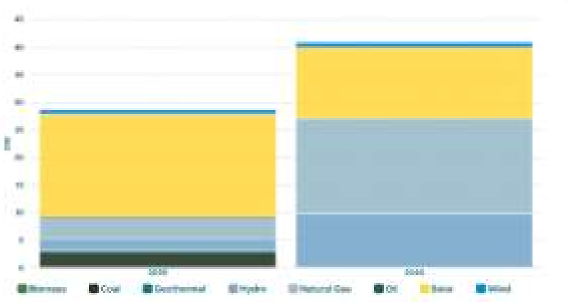
	• Fertiliser industry Future demand • Cement production • Steel production • Replacing current H2 demand in refinery and fertilizer industry as well as future demand in cement and steel production	
Future gH_2 generation potential	No data	
H_2/PtX production and transport cost	• Grey:< $2.5/kg [7] • Blue: $3-3.5/kg [7] • Green: $2.5 – 4/kg [7] • Solar $2.22 -4.6/kg [76] • Wind $1.94 – 35.33/kg [76] • Projections for 2030 foresee green hydrogen production costs of $2.5-4.0/kg [7]	[7], [76]
gH_2 roadmap and targets	• The Philippines is one of the signatories to the Paris Agreement – promising to reduce carbon emissions to 75% from 2017 to 2030 [76] • Achieve net-zero emissions by 2050 [299] • The National Renewable Energy Program (NREP) of the Department of Energy was established and created a roadmap towards reliable, affordable and resilient energy supply powered by independent indigenous resources. The program aims to triple current capacity by 2030, and endeavours to meet half of the electricity demand through renewables. [106]	[76], [299], [106]
gH_2 regulatory framework	• Power crisis in the 1880ies/1990ies, where the generation sector was not able to keep up with the demand caused by a quadrupling population: Power losses could reach 10 h daily and the supply-demand gap reached 48% in 1992. The economic impact on the industrial and commercial sectors was severe with the estimated loss in the same year alone to about $1.6 billion or 1.5% of the GDP.	[106]

	• The Electric Power Industry Reform Act of 2001 (Republic Act 9136), also EPIRA Law aimed to aid the country in its economic development efforts. The Law provides that the power sector will be unbundled, that is, power generation, transmission and distribution are separated and can be fully private enterprises. This led to the additional 5000 MW or 70% increase in generation capacity between the years of 1992–1998. • Following EPIRA, the Biofuels Act was enacted in 2007, providing the legal mandate for blending bio-liquid fuels such as bio-ethanol and bio-diesel into liquid transport fuels. Blending requirements have increased progressively to current levels of 10% for bioethanol and 2% for biodiesel, up from an initial 5% and 1%, respectively. This increase is associated with improved production and feedstock capacity and has driven growth in the domestic sugar industry as well as in the cultivation of coconut and other oil-rich plants for biofuel production. Incentive schemes such as tax exemption and financing were also made available. Biofuels can also be instrumental in providing the energy input needed for a 'green' hydrogen production process. • The next significant regulatory effort for alternative power generation was the enactment of the Renewable Energy Act of 2008. This officially signified the national position to encourage the development and use of renewable energy as a solution to the increasing energy needs. • The Philippines also officially recognized the consequences of climate change and the country's vulnerability through the enactment of the Climate Change Act of 2009. The law mandates the state to cooperate with the global community to resolve climate issues. The Executive branch has also endorsed the Paris Agreement, which the Philippine Senate then ratified. It has so far committed to the United Nations a Nationally Determined Contribution (NDC) of 70% below business-as-usual (BAU) levels by 2030. • In 2019, the Republic Act 11393 was signed into law, known as the "Advanced Energy and Green Building Technologies Curriculum Act". The law mandates the Commission on Higher Education (CHED), in consultation with the Department of Energy (DOE) and different Higher Education Institutions (HEI) to develop curricula that will focus on design resilience, natural resource conservation, sustainable design and practices, among others. This is done to enable future professionals such as engineers, architects, and urban planners to incorporate principles of advanced energy and green building technologies in the design of high-performance buildings. Additionally, both institutions were also mandated to develop graduate level curricula for advanced energy technology research, development, demonstration and commercial application of activities about energy infrastructure. • In July 2021, the consolidated bill that sought to establish the Philippine Energy Research and Policy Institute (PERPI) has been signed into law (Republic Act 11572). PERPI was proposed as a tool by which decision-makers could keep pace with the rapidly changing technologies in the energy sector and aims to enhance the country's capabilities for energy research and policy development. The institute will support	

	education and training, including advanced degrees, as well as short-term programs that focus on energy research. • As of writing, there are no enacted laws that specifically deal with hydrogen and fuel cells, and electrochemical energy storage in the Philippines. There are, however, attempts to pursue legislation through bills that particularly promote the use of hydrogen for Philippine use. These bills specifically identify the possibility of hydrogen to reduce dependency on foreign oil imports and the market volatility that it entails.	
gH_2 programmes or partnerships	German-Philippine Chamber of Commerce and Industry, Inc. (GPCCI / AHK Philippines) activities - Green Hydrogen Knowledge Hub	
gH_2 projects and knowledge	• The government plans to transform the old coal plants with the HERO systems into green hydrogen plants [62] • HDF plans the construction of a hydrogen plant in Mindanao [104] • Gen X Energy enters into a joint venture with ACE Enexor Inc., a subsidiary of AC Energy Corp., to develop Batangas Clean Energy, Inc.'s ("BCE") 1,100 MW combined cycle power plant project [105] • In a recent push of the Philippine government, the Department of Energy (DOE) created the Hydrogen and Fusion Energy Committee [106]	[62]; [104], [105], [106]
Land and water availability		
Parameter	Information	Source
Fresh water situation/scarcity	• In 2019, out of 1489 municipalities, 331 were included in the list of waterless communities. The Philippine Department of Interior and Local Government defines communities as waterless when at least 50% of the total poor population have no access to a safe water supply and is susceptible to waterborne diseases with high morbidity and mortality rates. [300] • Level of water stress: freshwater withdrawal as a proportion of available freshwater resources in 2020: 26.3 [140] • Renewable internal freshwater resources per capita in 2020: 4,270 [141]	[300], [140], [141]
Water consumption	• Each person in Metro Manila uses about 48 to 108 litres of water per day • Annual freshwater withdrawals, industry (2020): 12% of total freshwater withdrawal	[301]
Land availability	No information	

Resource conflicts (electricity, land, water, land use etc.)	The country also lies within the typhoon belt and Pacific Ring of Fire and is vulnerable to extreme weather events such as typhoons, floods and rising sea levels	[106]
CO_2 sources for derivate production	By-product of industrial and refinery processes	
Energy situation		
Parameter	Information	Source
Energy mix	**Capacity by fuel (GW) (2021)**[138]: • Biomass 0,489 • Geothermal 1,928 • Hydro 3,752 • Natural Gas 3,453 • Oil 3,847 • Solar 1,317 • Wind 0,427 • Coal 11,669 **Generation by fuel in GWh (2021)**[138]: • Coal 62,052 • Geothermal 10,681 • Hydro 9,185 • Natural Gas 18,675 • Oil 1,616 • Biomass 1,165 • Solar 1,47 • Wind 1,27	[138], [106], [130]

	 • The Philippines' total primary energy supply (TPES) in 2018 reached 59.7 million tons of oil-equivalent (mtoe), from 58.0 mtoe the previous year. Of the TPES, about 50% is supplied through imported energy source, namely, oil (32.5%), coal (17%), and biofuels (0.3%). The other half is chiefly supplied by available local renewable and indigenous energy sources. Natural gas supply contribution grew to 6.0% with the other shares of renewables as subsequently: 15% geothermal, 3.9% hydropower, 12.9% biomass, and about 1% total contribution for biofuels, wind and solar. [106] • Electricity generation shares in 2021: 58.5% coal, 1.5% oil, 17.6% gas, 22.4% RE [130]	
RE share	Generation by fuel in TWh (2022) • Coal: 59.61% • Geothermal: 10.27% • Hydro: 8.82% • Natural Gas: 17.96% • Oil: 1.55% • Biomass: 1.12% • Solar: 1.41% • Wind: 1.22% Capacity by fuel (2021) in GW • Biomass: 1.90% • Coal: 45.31% • Geothermal: 7.50% • Hydro: 14.56%	[138], [262]

	• Natural Gas: 13.40% • Oil: 14.94% • Solar: 5.12% • Wind: 1.66% • Renewable energy electricity generation shares in 2021: 40.6% hydro, 5.6% wind, 6.5% solar, 47.2% geothermal [262]	
Planned capacity expansion		[138]
RE policy target	35% 2030 50% 2040 mainly achieving this through solar power plants, followed by hydro and wind	[138]
Existing energy trade	• In-country • Regional	
Electrification rate	97.5%	[283]
Reliability of electricity supply		
Electricity cost/tariff	Cost: generation Tariff: Residential, commercial, industrial Very tough because there are many tariffs, we could use the MERALCO tariff though	[106]

	The Philippines has some of the most expensive electricity in Southeast Asia which has affected the investment climate negatively. This is a challenge as (1) the archipelagic geography makes electricity more costly in some areas; (2) the generation, transmission, and distribution sectors are inefficient; and most importantly, (3) the country has limited fossil fuel reserves, rendering it highly dependent on renewables and imported fossil fuel resources.	
RE investment	Rank 16 in Climatescope	[283]
Social, political and economic indicators		
Parameter	Information	Source
Socio-economic data	• Gross Domestic Product (GDP) of $360 billion with a growth rate of 9.5% in 2020 due to pandemic and is expected to bounce back by 6.5-10% in the coming years. The economy is driven by the services sector with the highest GDP share of 57.2%, followed by agriculture, hunting, forestry and fishing (24.5%), and industry (18.3%) [299] • Unemployment rate: 4,5% (2023) [302] • In the Philippines, 18.1% of the population lived below the national poverty line in 2021 [303] • Philippines's Gini Coefficient Index is 40.2 (2021)[269]	[299], [302], [303], [269]
Worldwide Governance Index	• Voice and Accountability: 43,96 • Political Stability and Absence of Violence/Terrorism: 20,28 • Government Effectiveness: 56,13 • Regulatory Quality: 53,77 • Rule of Law: 33,49 • Control of Corruption: 33,49 * all numbers from 2022	[270]
Trade indicators		
Parameter	Information	Source
Exported goods	The top exports of Philippines are Integrated Circuits ($27.5 billion), Office Machine Parts ($11.1 billion), Insulated Wire ($3.05 billion), Electrical Transformers ($2.49 billion) and Semiconductor Devices ($2.44B).	[49]

	In 2021, Philippines was the world's biggest exporter of Nickel Ore ($1.5 billion) and Gold Clad Metals ($62.5 million).	
Export partners	Exporting mostly to China ($15.1 billion), United States ($13.3billion), Japan ($11.5 billion), Hong Kong ($11.4 billion), and Singapore ($6.19 billion).	[49]
Imported goods	The top imports of Philippines are Integrated Circuits ($14 billion), Refined Petroleum ($9.04 billion), Office Machine Parts ($3.11 billion), Broadcasting Equipment ($2.84 billion), and Cars ($2.77 billion). In 2021, Philippines was the world's biggest importer of Iron Sheet Piling ($284 million) and Copra ($32.8 million)	[49]
Import partners	Importing mostly from China ($48.9 billion), Japan ($10.4 billion), South Korea ($9.23 billion), Indonesia ($9.21 billion) and USA ($8.16 billion)	[49]

V. Singapore

Hydrogen		
Parameter	Information	Source
Current H_2 demand	• Hydrogen demand potential in Singapore is estimated to be 0.1 Mtoe in Scenario 1, 0.3 Mtoe in Scenario 2, and 0.5 Mtoe in Scenario 3 in 2040 [65] • Current applications of hydrogen include: Hydrogen-methane blends in the town gas system (cooking and water heating) [56] • Refined petroleum accounts for 11.6% of Singapore's export revenue and is a product that requires hydrogen in its production process [304] • No exact data was found but demand is expected to be high since Singapore was the 3rd largest importer of hydrogen worldwide in 2021 (trade volume of $18 million)[305] • Industry sector contributes to 44.4% of primary emissions. Singapore implemented energy efficiency and resource optimization measures to reduce the sector's carbon footprint and continue to explore low-carbon technologies such as carbon capture, utilization and storage, and low-carbon hydrogen. [77] • Transport contributes to 13.7% of primary emissions. Aim to have all vehicles run on cleaner energy by 2040. [77]	[65], [56], [304], [305], [77]
Current H_2 derivate demand	• Domestic ammonia production (for industrial and fertiliser industry)	
Current H_2 production source, volume and price	• SMR plant operated by Air Liquide operational on Jurong Island since 2010 • No concrete output numbers are available but H_2 production is assumed to mostly rely on imported natural gas	[306]
Current H_2 derivate production process, volume and price	• No information	

Current H_2 and derivate product trade	• Hydrogen Import: 692.87 in Trade Value $1000 [297] • Hydrogen Export: 777.19 in Trade Value $1000 [298] • Despite having high trade volumes in both exports and imports, shows a trade deficit for refined petroleum amounting to more than $10 billion, while net exporting fertilizer and alcohols [49] • H_2: net imports value $249 million [49] • Ammonia: net exports value $35 million [49]	[297], [298], [49]
Current H_2 & gas infrastructure	Current infrastructure: • West Natuna Transportation System Gas Pipeline is an operating natural gas pipeline that runs from the Anoa, Kakap, Belida, Buntal, Tembang and Belanak territories in block B of the Natuna Sea Gas Field in the South China Sea offshore from Indonesia and delivers it to Singapore. Length: 640 kilometres, operating since 2001. • The Gresik-Batam-Singapore Gas Pipeline is an operational natural gas pipeline that brings gas from Indonesia's Sumatra Island to Singapore. Length: 465 km, operating since 2003. • Singapore LNG Terminal, also SLNG Terminal and Jurong Island LNG Terminal is a liquefied natural gas import terminal operating in Singapore. The starting year was 2013, Capacity: 3.5 mtp. Singapore LNG, owner and operator of the Jurong LNG terminal, is performing studies to build additional jetty capacity to support future small-scale LNG and LNG bunkering demand. In July 2020 the Energy Market Authority of Singapore issued a Request-for-Proposal (RFP) to appoint up to two additional LNG term importers for Singapore. • The Port of Singapore is currently the world's busiest container transshipment port, with ship arrival tonnage exceeding 2.8 billion gross tonnage in 2021. Singapore is also the world's largest bunkering hub, supplying close to 50 million tonnes of marine bunker fuel to vessels that plied international shipping routes in 2021.	[81]
Most suitable H_2 transport option	• Pipeline and shipping	
General H_2 strategy and goals	The Ministry of Trade and Industry Singapore published a hydrogen strategy in October 2022 [77]. The National Hydrogen Strategy speaks of "low carbon hydrogen", leaving undefined what the standards are, but presumably also including blue H_2 [87]. The strategy focuses on the energy sector, the industrial sector, maritime transport, air transport, as well as land transport and defines five key thrusts which include: 1. Experimenting with the use of advanced H_2 technologies at the cusp of commercial readiness; 2. Investing in R&D; 3. Pursuing international collaborations to enable "low-carbon hydrogen supply chains"; 4. Undertake long-term land and Infrastructure planning; 5. Support workforce training and development of the broader hydrogen economy.	[77], [87], [307]

	• Efforts to advance Ammonia Bunkering • Co-develop ammonia bunkering standard • Work with industry • Establish green and digital corridors [307]	
Value chain for H_2 and derivates	• Activities along the whole value chain: production (limited!), consumption and trade	
Green hydrogen		
Parameter	Information	Source
Relevant stakeholders	Public stakeholders • Energy Market Authority (EMA) • National Environment Agency (NEA) • Economic Development Board (EDB) • National Research Foundation (NRF) • Energy Research Institute @ NTU (ERI@N) • Institute of Materials Research and Engineering (IMRE) • National University of Singapore (NUS) • Nanyang Technological University (NTU) Private stakeholders • Singapore Power Group • Keppel Corporation • Sembcorp Industries • SP Group • Senoko Energy • Sustainable Energy Association of Singapore (SEAS) • Singapore Chemical Industry Council (SCIC) In February 2022, a working group called the Singapore Hydrogen Cooperation Committee, was formed after Airbus, Changi Airport Group, the Civil Aviation Authority of Singapore (CAAS) and Linde signed a cooperation agreement. Since then, the committee has been looking at the supply and demand for H_2 in the regional and	[205]

	local market, the supply chain and infrastructure requirements as well as the potential factors to implement a successful H_2 system for aviation. [205]	
Dominant RE source to produce gH_2	• Solar is the only feasible RE source, generally scarce RE sources due to small surface area, not suitable for wind or hydropower generation, and no geothermal power resources [308] • In the update of the solar photovoltaic roadmap by the Solar Energy Research Institute of Singapore, the maximum technical potential for solar deployment was estimated to be around 8.6 Gigawatt peak, meeting about 10% of the projected electricity demand in 2050 if it materialises [77] • Electricity imports are estimated to meet about 30% of the projected electricity demand by 2035, and Singapore may consider more imports if doing so can meet the needs [77]	[308], [77]
Potential gH_2 demand	Current demand • Refinery • Ammonia production Future demand • Marine and aviation fuels • Residential use (gas network for cooking) • Chemical industry • "Given recent developments in the global energy market and further acceleration in momentum behind hydrogen, we assess that hydrogen has the potential to supply up to 50% of our projected electricity demand by 2050." • Petroleum refining and chemical industry are important sectors of Singapore's industry and will potentially require H_2 • Replacement of current grey hydrogen usage in refinery and ammonia production as well as potential demand in maritime and aviation fuels, residential gas networks or chemical industry	[77]
Future gH_2 generation potential	• Estimated to be low due to low RE potential (see above), no concrete data available	
H_2/PtX production and transport cost	No data found	

gH_2 roadmap and targets	• To achieve net zero emissions by 2050 [77] • Singapore aims to peak its absolute emissions at 65 $MtCO_2e$ around 2030, which represents a reduction of greenhouse gas emissions intensity by 36% below 2005 levels [309] • Singapore has published a National Hydrogen Strategy that looks at targeted demand in industry, shipping, aviation, and hydrogen imports due to limited land availability. The strategy doesn't expect to build significant infrastructure in the short term but looks at import and storage facilities and shipping routes, learning from the country's experience in the LNG market. [162] • Five key thrusts from the Hydrogen Strategy: [77] 1. Experimenting with the use of advanced hydrogen technologies at the cusp of commercial readiness; 2. Investing in R&D; 3. Pursuing international collaborations to enable low-carbon hydrogen supply chains; 4. Undertake long-term land and 5. infrastructure planning; 6. Support workforce training and development of a broader hydrogen economy	[77], [309], [162]
gH_2 regulatory framework	• In 2019, the Singapore Energy Story was announced and plans to decarbonise the power sector and help Singapore achieve its climate commitments while ensuring energy security were laid out. Four supply "switches" were identified to transform the fuel mix –natural gas, solar paired with Energy Storage Systems (ESS), regional power grids, and low-carbon alternatives. [77] • Maritime Singapore Decarbonisation Blueprint in March 2022. [145] • Energy Market Authority announced in October 2023 that from 2024, all new and repowered gas plants will need to be designed to be at least 30% hydrogen compatible with the ability to be retrofitted to become 100% H_2-ready in the future [145] • Procurement of consortia for a project developing a 55-65 MW plant for the combustion of imported low or zero-carbon ammonia [310] • National Hydrogen strategy speaks of "low carbon hydrogen", leaving undefined what the standards are, but presumably also including blue H_2 [87]	[77], [145], [310], [87]
gH_2 programmes or partnerships	• "green shipping corridor" between Japan and Singapore, two countries working together in pilot projects for alternative fuels such as ammonia, development of infrastructure and regulations	[311]
gH_2 projects and knowledge	• A multi-national partnership aims to establish a green e-methanol plant, which converts captured biogenic carbon dioxide into green e-methanol located in Singapore, the first Southeast Asia. The partnership includes Thailand's PTT Exploration & Production (PTTEP). [123]	[123], [312], [313], [122],

	• In December 2022, EMA and the Maritime and Port Authority of Singapore (MPA) launched a call for Expression of Interest (EOI) to build, own and operate low or zero-carbon power generation and bunkering solutions in Jurong Island. [312] • H_2One – SP Group • Semakau island microgrid Engie (SPORE) [313] • Agreement between Irish industrial gas engineering company Linde and Chemical company Evonik to build a 9 MW electrolyser plant on Jurong Island, which will supply gH_2 to Evonik, which will be used for the production of methionine [122] • Neste, a refiner and producer of renewable fuels from Finland, expanded its refinery in Singapore in 2024. The facility is said to have produced up to one million tons of Sustainable Aviation Fuel, which is the largest capacity worldwide. [206] • The operating plant already has an output of up to 1.3 Mt/a biofuel. [207]	[206], [207]
Land and water availability		
Parameter	**Information**	**Source**
Fresh water situation/scarcity	• Water scarcity due to a limited land area on which freshwater can be stored and a high population density, but is managed by freshwater imports, rainwater catchment policies, desalination plants and wastewater recycling • Within the region only in Singapore water availability is an issue due to limited freshwater resources	[314]
Water consumption	• Singapore currently consumes about 440 million gallons of water per day [315] • Renewable internal freshwater per capita: 106 m^3 (2020) [316] • Annual freshwater withdrawals, industry (2020): 51% of total freshwater withdrawal [140] • The ratio of freshwater withdrawals to available freshwater in 2020 was very high with 83 [140] • Renewable internal freshwater resources per capita in 2020 were 106 [141]	[315], [316], [140], [141]
Land availability	• 78% of the land area is used	[317]
Resource conflicts (electricity, land, water, land use etc.)	Singapore is facing space constraints	

CO_2 sources for derivate production	• Emissions from gas combustion for power generation, industrial processes	
Energy situation		
Parameter	Information	Source
Energy mix (electricity generation)	Capacity by fuel (2021): [138] • Biofuels and waste 0,2568 • Crude, NGL, refinery feedstock 10,49141 • Gas Engine 0,18 • Solar photovoltaic 0,3415 • Steam Gas 0,7636 Generation by fuel in TWh (2020): [138] • Natural Gas 86,499288 • Oil 0,070943 • Other 7,30364 • Coal 2,912152 • Biofuels and waste 0,81875 • Electricity generation shares in 2021: 93.9% gas, 1.2% coal, 0.9 oil, 4% RE [130]	[138], [130]
RE share (electricity generation)	Capacity by fuel (2021): [138] • Biofuels and waste: 2.33% • Crude, NGL, refinery feedstock: 95.16% • Gas Engine: 1.63% • Solar photovoltaic: 3.10% • Steam Gas: 6.94% Generation by fuel in TWh (2020): [138] • Natural Gas: 88.64% • Oil: 0.07% • Other: 7.48% • Coal: 2.98% • Biofuels and waste: 0.84%	[138], [262], [124]

	• Renewable electricity generation shares in 2021: 100% solar [262] • Current RE capacity is around 1.1 GW, around 9.5% of total capacity, from solar and biomass [124] • Singapore aims to increase the renewable energy share, but space limitations are restricting RE share expansion.	
Planned capacity expansion	• Singapore's Green Plan 2023 foresees adding 1.5 GW of solar energy which can meet around 2% of the projected electricity demand in 2025 and at least 2 GW until 2030, which can meet around 3% of its 2030 projected electricity demand.	[139]
RE policy target		
Existing energy trade		
Electrification rate	100%	[282]
Reliability of electricity supply	Very reliable	
Electricity cost/tariff	Tariff: Average electricity price $176.27/MWh (2022)	
RE investment	Climatescope index 1,92 (2022) Investment in clean energy was around $145.82 million in 2022. Rank 63 in the global power ranking, and rank 38 in the emerging markets power ranking (2022)	[283]
Social, political and economic indicators		
Parameter	Information	Source
Socio-economic data	• GDP per capita (2022): 127,606.8, (current international $) [266] • GDP per capita (2022): 82,807.6 (current US $) [318] • Unemployment rate(2022): 2,8 (Unemployment, total) (modelled ILO estimate)[267] • Poverty headcount ratio: N/A • GINI index: N/A	[266], [318], [267]

Worldwide Governance Index (2022)	• Voice and Accountability: 44,44 Percentile Rank • Political Stability and Absence of Violence/Terrorism: 97,17 Percentile Rank • Government Effectiveness: 100 Percentile Rank • Regulatory Quality: 100 Percentile Rank • Rule of Law: 99,06 Percentile Rank • Control of Corruption: 98,58 Percentile Rank	[270]
Trade indicators		
Parameter	Information	Source
Exported goods	Integrated Circuits ($77 billion), Refined Petroleum ($40.8 billion), Gold ($18.6 billion), Packaged Medicaments ($10.4 billion), and Machinery Having Individual Functions ($8.33 billion) (2021)	[49]
Export partners	China ($56.8 billion), Hong Kong ($54.5 billion), United States ($28.1 billion), Malaysia ($27.7 billion), and Indonesia ($18.4 billion) (2021)	
Imported goods	Integrated Circuits ($65.2 billion), Refined Petroleum ($50 billion), Crude Petroleum ($22.5 billion), Gold ($15.1billion), and Gas Turbines ($7.43 billion) (2021)	
Import partners	China ($53.9 billion), Malaysia ($49.6 billion), Chinese Taipei ($34.1 billion), United States ($32.5 billion), and Japan ($18.2 billion) (2022)	

VI. Thailand

Hydrogen		
Parameter	Information	Source
Current H_2 demand	• Sectors: Iron smelting, chemical and petrochemical (refining) industry, glass production [52] • Examples: petrochemical industry in the industrial area Map Ta Phut, steel rolling mills in the province of Chonburi [52] • Demand projection: 6 Mt/year (2050) [319] • Producing around 350 kt of H_2 annually [51], and a trade deficit for H_2 of around $250 million [49], Thailand can be expected to have an H_2 demand similar to Vietnam. Thailand's H_2 consumption has a strong emphasis on industrial purposes.	[52], [319], [51], [49]
Current H_2 derivate demand	• Methanol: [53] The demand of 450,910 tonnes in 2020, expected demand of 695.220 t in 2030, growth driven by its excessive consumption in the chemical and petrochemical industry to manufacture Formaldehyde and Acetic Acid • Ammonia: [54] Ammonia market demand stood at nearly 320 thousand tonnes in 2023 and is expected to grow at a CAGR of 3.4% during the forecast period until 2034 Sector: Fertiliser production (48%), 20% chemical intermediates, 18% refrigeration, 14% other (in 2023)	[53], [54]
Current H_2 production source, volume and price	• Main H_2 producing companies: Bangkok Industrial Gas (BIG) dominating (grey hydrogen), other companies such as Air Liquide (Thailand), Linde (Thailand), Air Products Industry • Source: natural gas (grey hydrogen) dominating, some as by-product of industrial processes [52] • Volume: 350,000 tonnes of hydrogen per year country-wide; BIG has three production plants with a volume of 500 Nm^3/h, 13,000 Nm^3/h, 15,000 Nm3/h [51] • Price: US$2.0-5.0/kg (2022) [51]	[52], [51]
Current H_2 derivate production process, volume and price	• Methane: Producer: 2012 Hitachi Zosen - PTTEP CO_2 Conversion to Methane Project R&D • Methanol: Producer: Asia Pacific Petrochemical Co., Ltd (Bangkok) Price: methanol export price stood at $592 per ton in 2022	[320]

Current H_2 and derivate product trade	• H_2: [52] Export: In 2020, Thailand exported hydrogen to Cambodia (US$54,000), Laos (US$32,000), Myanmar (US$17,500) and Hong Kong Import: Totalled just US$12,000 in 2019 (USA, Japan, Singapore, UK and Vietnam) • Methanol: [321] Exports are expected to reach 2.2 million kilograms by 2026, an increase of 3.8% per year on average from 1.75 million kilograms in 2021; imports of methanol are expected to reach 2.8 billion kilograms by 2026, an increase of 3.6% per year on average from 2.27 billion kilograms in 2021 • Ammonia: [322] In 2022 1,329,327 $/a export mainly to Malaysia and Cambodia and 304,391,696 $/a mainly Malaysia and Indonesia	[52], [321], [322]
Current H_2 & gas infrastructure	Current infrastructure: • Thailand has extensive gas transmission infrastructure. The national gas pipeline system connects onshore and offshore gas fields to power plants, gas separation plants (GSPs), and industrial users. • The national gas pipeline system connects onshore and offshore gas fields to power plants, gas separation plants (GSPs), and industrial users. Pipeline imports from Myanmar started in 1998 with the Yadana Gas Pipeline 1. Operating natural gas pipelines include among others Nakhon Sawan Gas Pipeline, Nakhon Ratchasima Gas Pipeline, Rayong-Kaeng Khoi Gas Pipeline, Bang Phli-Saraburi Gas Pipeline, Ban I-Tong-Ratchaburi Gas Pipeline, Yetagun Gas Pipeline, Erawan-Khanom Gas Pipeline as well as Erawan-Rayon Gas Pipeline 3 and are in the south of the country. • Map Ta Phut LNG Terminal is Thailand's first LNG regasification terminal. It started operating in 2011 and has a current capacity of 11.5 mtpa. A second onshore LNG import terminal at Nong Fab was expected to be commissioned by the end of 2022; however, as of January 2023, there was no confirmation of commissioning. Proposed infrastructure: • Two more gas infrastructure projects are planned: The already proposed Gulf MTP LNG Terminal for imports and the Fifth Gas Transmission Pipeline Project, which is already under construction. The pipeline is planned to be 430 km long and run from Rayong, Thailand to Sai Noi, Nonthaburi, while passing through Chonburi, Chachoengsao, Prachinburi, Bangkok, Pathumthani, and Pra Nokorn Sri Ayudhaya and was expected to start in 2023.	[82]

Most suitable H_2 transport option	• In-country: Pipelines and trucks • Regional: Pipeline (Myanmar), trucks or shipping to other countries • International: Shipping • Gas and liquid	
General H_2 strategy and goals	"H_2 Development Plan Thailand" is under development (CMU, Chulalongkorn, and EPPO) including: • Short (2020-2030), medium (2030-2040), and long-term (2040-2070) planning • From 2040 onwards only green hydrogen • Short-term and medium-term grey, blue, and green hydrogen [52] According to the current "Power Development Plan" (2023-2037), EPPO aims to produce and utilise a maximum amount of hydrogen usage of up to 20% in power plants by 2037 [51]	[52], [51]
Value chain for H_2 and derivates	• Activities along the whole value chain: production, consumption and trade	
Green hydrogen		
Parameter	Information	Source
Relevant stakeholders	Public stakeholders • EGAT • EPPO Private: • BIG • PTT • Thai Oil • Hydrogen Thailand Group • Air Liquide Thailand • Enapter • H_2 Core Systems • Thyssenkrupp • Linde	

Dominant RE source to produce gH_2	RE mix: 30% biomass, 25% hydropower, 24% solar power, 13% wind power, and 8% other sources such as waste and geothermal power (2023)	[323]
Potential gH_2 demand	Current demand • Refinery • Chemical industry Future demand • Cement production • Steel production • Transport (road vehicles) Application: [52] • Industrial park operators are increasingly interested in green hydrogen solutions in transport and logistics (e.g. Industrial Estate Authority of Thailand (IEAT) in Rayong) • Seasonal storage for island electrification • Transport sector • In general: replacement of currently used grey hydrogen in refinery and chemical industry as well as potential application in the cement and steel industry and transport sector Volume: • By 2050, the expected demand for gH_2 to fully decarbonise gas-fired power plants is 3.38 Mt [52] • Blue and green hydrogen demand projection 2050: 6 Mt/year [319] Location: [324] • Central, East and Bangkok regions are the most likely future demand centres for hydrogen[324]	[52], [319], [324]
Future gH_2 generation potential	• Self-sufficient regions: the North, Central and East regions are classified as self-sufficient though demand and supply potential in the Central and East regions are higher. Should sufficient low-cost renewables be available in both regions, it may be possible to export to other regions cost-effectively. • Export potential regions: This export potential likely exists for the Northeast region as well, due to access to low-cost wind but with limited domestic demand. • Import dependent: Import dependency will mostly exist in the Bangkok area, with a large potential demand in Industry and Transport but with limited access to local hydrogen production – especially green hydrogen from local renewables	[324]

H_2/PtX production and transport cost	Projections for 2023: gH_2 LCOE of \$2.1 – 3.1/kg (compared to \$2.1/kg for grey and \$3.0/kg for blue H_2) [7] Green hydrogen generation cost estimations: [324] • Short-medium term (2025-2030): solar PV electrolysis, which is estimated to be around \$5.7 - 5.8/kg H_2 in 2025 and \$4.3 - 4.8/kg H_2 in 2030 across all regions – with minimal differences across regions, but significant differences in production cost from wind. • In the medium to long-term (2030-2050): onshore wind in the central and northeast regions, which is estimated to be around \$3.6 - 3.7/kg H_2 in 2035 and \$2.5 – 2.6/kg H_2 in 2050.	[324], [7]
gH_2 roadmap and targets	"H_2 Development Plan Thailand" (developed by CMU, Chulalongkorn, and EPPO) including short, medium and long-term planning, from 2040 onwards only green hydrogen [52]. As part of this, the following sectors are discussed to be included [324]: Power sector: H_2 could be used as direct fuel in fuel cell stacks or blended with natural gas in gas-fired generators Industrial heating sector: H_2 could be used as direct fuel in combustion chambers or blended with natural gas. Transport sector: H_2 could be used to produce synthetic fuel for the internal combustion engine (ICE) or used in the Fuel Cell Electric Vehicle (FCEV), especially on heavy-duty and long-haul vehicles including buses and trucks. "Long Term Low Greenhouse Gas Emission Development Strategy" aims for carbon neutrality by 2050 and net zero GHG emissions by 2065 [51] Under the "Alternative Energy Development Plan (AEDP)" hydrogen is included as part of the "Alternative Fuels" category with a set target goal of 10 Kilotons of oil equivalent (KTOE) in total by 2036 [146]	[52], [51], [324], [146]
gH_2 regulatory framework	No hydrogen specific regulations, but from the regulator's side, the Energy Regulatory Commission (the "ERC") has included hydrogen in the definition of "renewable energy" to be purchased by the Provincial or Metropolitan Electricity Authorities (for very small power producers or VSPP projects) and EGAT (for small power producers or SPP projects), according to the ERC Notification re purchase of power from SPP operators of renewable energy by Feed-in Tariff (B.E. 2560) and the ERC Notification re purchase of power from VSPP operators of renewable energy (B.E. 2561). General regulations would apply to hydrogen projects similarly to other power projects. For instance, in hydrogen projects where electricity is generated to be used in the electrolysing process, an electricity generation licensing under the Energy Industry Act would be required. The operating site may also be subject to requirements under the Factory Act, depending on the activities being carried out. Meanwhile, at	[146]

	the moment, the hydrogen industry is not subject to the Fuel Control Act and Fuel Trading Act, as hydrogen does not fall within the definition of fuel thereunder.	
gH_2 programmes or partnerships	International Hydrogen Ramp-up Programme (H2Uppp) Hydrogen Thailand Working Group	
gH_2 projects and knowledge	Phi Suea House in Chiang Mai (100% self-sufficient, solar-powered building complex with gH_2 storage solution) [52] Wind-hydrogen hybrid project by EGAT (PEM electrolyser), 1.2 MWe, 4 MW wind power plants, fuel cell 300kW [107] EGAT signed a cooperation agreement with the electrolyser manufacturer Enapter in August 2019; at the beginning of March 2023, the hydrogen learning centre of EGAT was opened; a total of 10 Enapter/H_2 Core Systems electrolysers were supplied and installed [107] EGAT also joined forces with five leading Japanese companies in March 2023 to jointly investigate and develop "complete clean hydrogen and ammonia, biofuel production and BESS" [52] Saudi Arabia's Aramco and Thailand's state-owned energy company PTT plans to expand their cooperation in areas such as LNG, blue and green hydrogen [52] In June 2022, Thai Oil, the largest oil refiner, acquired a stake in a US-based start-up (Versogen) specialising in the production of green hydrogen PTT, BIG, and Toyota have opened the country's first hydrogen refuelling station in Pattaya (Chonburi province) by the end of 2022; Toyota will import two to three fuel cell electric vehicles (FCEVs) and collect field data; PTT company is also planning to use imported FCEVs as transport vehicles for its fleet; if the pilot project is successful, there are plans to build additional hydrogen refuelling stations in other parts of the country Future ammonia production: PTT - EGAT – ACWA (MoU) volume of 1.2 Mt NH3/y (production), capacities of 2494.5 MWel and 554324 Nm^3 H_2/h and 432 kt H_2/y	[52], [107]
Land and water availability		
Parameter	Information	Source
Fresh water situation/scarcity	Level of water stress (freshwater withdrawal as a proportion of available freshwater resources): 23.01 (2020) [140] Annual freshwater withdrawals, total (billion cubic meters): 57.3 (2020) [256] Annual freshwater withdrawals, total (% of internal resources): 26 (2020) [257]	[140], [256], [257]

Water consumption	Daily water consumption per capita: 2,350 l	[258]
Land availability	Land used by (2013): 54% agriculture 34% forest 5% community 3% water 4% others	[325]
Resource conflicts (electricity, land, water, land use etc.)	Challenge with land use and land acquisition: There are many laws relating to natural resources and environment management with different legal definitions, and many different agencies and Ministries involved [325] Territorial conflicts at the border with Malaysia and Cambodia Agricultural land ownership: According to Protection International, while 57% of Thai farmland is publicly owned, 43% is privately owned and 90% of this land – or more than 127 million rai – is owned by just 50 individuals. Half of the land in Thailand is used for agriculture and a third of the workforce is employed as farmers. Many of Thailand's 5.9 million farming households do not own land – many of which are deeply in debt. Protection International maintains that there are at least 1.5 million families who have to rent the land that they till. [326] Thailand has been facing problems related to its water resources, including water shortage, drought, floods, decreased groundwater levels, and saltwater intrusion in its groundwater sources [327] Thai people have been able to sufficiently access drinking water; the proportion of household members with access to clean drinking water has increased from 97% in 2012 to 98% in 2016 and 99.5% in 2019. However, the quality of water available remains a challenge for the country. Data from the Ministry of Public Health's Report on Drinking Water Quality from 2009-2019 showed that only 40.8% of water available to households was appropriate for consumption. [327]	[325], [326], [327]
CO_2 sources for derivate production	Biomass Industrial processes Coal-fired, natural gas-fired, and waste-to-energy power plants Stationary CO_2 sources from the industry sector include cement factories, refineries, iron and steel mills plants, and power plants	[328]
Energy situation		
Parameter	Information	Source

Energy mix (electricity generation)	• Electricity generation shares in 2021: 19.9% coal, 0.4% oil, 62.2% gas, 17.5% RE	[130]
RE share (electricity generation)	• Renewable electricity generation shares in 2021: 35.3% hydro, 26.8% wind, 37.8% solar, 0.1%geothermal	[262]
Planned capacity expansion	• Solar power target capacity of 12,129 MW in 2037 • Biomass target capacity of 5,790 MW in 2037 • Wind power (offshore) target capacity of 2,989 MW in 2037	[51]
RE policy target	Overall RE targets: [52] • 30% by 2037 • 50% by 2050 Technology-specific targets: [51] • Solar power target capacity of 12,129 MW in 2037 • Biomass target capacity of 5,790 MW in 2037 • Wind power (offshore) target capacity of 2,989 MW in 2037 GHG emission reduction targets: [324] • At COP26, Thailand committed to increasing its conditional GHG reduction from 25% to 40% by 2030 in addition to re-confirming a 20% unconditional GHG reduction	[52], [51], [324]
Existing energy trade	• Gas imports from Myanmar • LNG imports from Qatar, Malaysia and Oman	[52]
Electrification rate	Almost 100 % App. 180 islands depend on diesel generator supply (by private operators or at household level)	[282]
Reliability of electricity supply	Reliable and sustainable electricity supply network: minimal power outages, with an average of only 7 minutes of unplanned outage per year	[329]
Electricity cost/tariff	Tariff structure: • Three parts: Base tariff, fuel adjustment mechanism (is adjusted every four months by ERC), value added tax [52] • Depends on demand, time of usage and voltage level of connection [52]	[52], [51]

	• In general from $0.138/kWh for residential use to $0.143/kWh for industrial use [52] • ERC has set new electricity charges, ranging from 4.68 baht ($0.13/kWh) to 5.95 baht/unit ($0.17/kWh) from January until April 2024 [51]	
RE investment	• Overall score 2.01 of 5, fundamentals (policies, market structures etc.) 3.24 of 5, opportunities (market potential growth) 0.09 of 5, experience 0.59 of 5 • Global rank: 30 • Asia-Pacific rank: 11	[283]
Social, political and economic indicators		
Parameter	Information	Source
Socio-economic data	• GDP per capita: 20,679.1 (2022) [318] • Unemployment rate: 0.9% (2022) [267] • Poverty headcount ratio: 6.3% (2021) [268] • GINI index: 35.1 (2021) [269]	
Worldwide Governance Index	Percentile rank: indicates the rank of the country among all other countries in the world, 0 corresponds to the lowest rank and 100 to the highest rank, all 2022 values • Voice and Accountability: 31.4 • Political Stability and Absence of Violence/Terrorism: 31.6 • Government Effectiveness: 58.0 • Regulatory Quality: 58.5 • Rule of Law: 54.7 • Control of Corruption: 35.9	[270]
Trade indicators		
Parameter	Information	Source
Exported goods	Machinery is an important manufactured export, along with chemicals and chemical products, telecommunications equipment, road vehicles and clothing and accessories	[330]
Export partners	The United States is among Thailand's largest export markets, followed by Japan, Singapore and Malaysia	[330]

Imported goods	The most important import categories by value are machinery; chemicals and related products; petroleum; iron, steel and other metals; and raw materials of various types	[330]
Import partners	Japan is among the country's biggest sources of imports, followed by the United States, China, Singapore and Malaysia	[330]

VII. Vietnam

Hydrogen		
Parameter	Information	Source
Current H_2 demand	• Ranging around 480 kt/a (own estimation based on [47]), Vietnam's H_2 demand is less than a third of that of Indonesia, but still among the more significant ones within the region. A lower, but still significant amount is used for oil refining (117,000 t/a) • H_2 is furthermore used for the annealing of steel, however, the demand in this industry currently remains at a relatively low level of around 2,270 t/H_2 per year • Oil refinery (177,000 t/a) • To a lesser extent for annealing steel (estimated demand: 2270 t/a) • Other applications: float glass and as a carrier gas in the production of semiconductors	[47]
Current H_2 derivate demand	• In Vietnam, the largest share of the national hydrogen demand traces back to the production of Ammonia, which needs around 300,000 t of H_2 per year [47] • Looking at the downstream side of the value chain, Vietnam has a high demand for ammonia, ranging around 674 kt/a (own estimate based on [48] and [49]). Around 88% of the ammonia produced in Vietnam is used for the production of fertilizer [47]. As a country with a strong agricultural sector and a rapidly growing population, Vietnam has a high demand and currently still needs to import fertilizer. [50] • A high demand also exists for methanol, which the country needs to import to supply its chemical, pharmaceutical, and construction industries with the required feedstock [47] • Imports of Methanol and Ammonia account for 99% of the total imported value of hydrogen and derivate products [5]Current demand for ammonia around 673,835 t/ year (domestic production + imports – exports, based on [331] and [49]) • Methanol: Imports – exports = 299, 183 t /year, no data on production volume (demand unclear) [5]	[1], [2], [49], [4], [5]
Current H_2 production source, volume and price	• Source: mainly grey hydrogen from steam reforming of natural gas (around 95% of Hydrogen [332]) • Volume: up to 500,000 t/a [333] • Price: Grey hydrogen from natural gas: \$1.4-\$2.3/kg [7] Green H_2: \$2.3-\$4.0/kg [7]	[7], [332], [333]

Current H_2 derivate production process, volume and price	• Process: Mostly from steam reforming of natural gas and from coal gasification, SR process is oftentimes supplied by offshore gas fields; hydrogen is usually produced at the same site where it is processed to derivates [4] • Volume: 540,000 t/a ammonia -> insufficient to cover domestic demand [9] • Price	[50], [334]
Current H_2 and derivate product trade	H_2: • H_2: net exports value 225 million USD in 2019 (own calculation based on [297] and [298]) Ammonia: • Imports total 133,999 t in 2021 (trade value: $73,386,470), mostly from Indonesia and Malaysia • Exports: 164t in 2021 (trade volume: $44, 460) Methanol: • 300,333 t import (trade value: $ 120.3 M, mostly from Malaysia, Saudi Arabia and Brunei [49]) 1150 t export (trade Value: $ 671,640, mostly to Iceland and Cambodia[49])Ammonia: net imports 66 million USD [49]	[297], [298], [49]
Current H_2 & gas infrastructure	Current infrastructure: • In Vietnam, the first LNG terminal, mostly used for import was inaugurated in 2023 in Ba Ria province located in the south of the country. Six further LNG terminals are planned until 2035. • Nam Con Son 2 Pipelines to transport gas from offshore gas fields to onshore industrial zones and to transport gas imported from other ASEAN countries to meet the demand of southern and south-eastern Vietnam • The Nam Con Son Gas Pipeline, the Su Tu Vang-Rang Dong-Bach Ho-Long Hai-Dinh Co Gas Pipeline, the Thi Vai Import Terminal Gas Pipeline, and the PM3 CAA – Ca Mau Gas Pipeline System are all operating pipelines located in the south • Nam Con Son 2 Pipelines to transport gas from offshore gas fields to onshore industrial zones and to transport gas imported from other ASEAN countries to meet the demand of southern and south-eastern Vietnam. Proposed infrastructure: • While the existing infrastructure is comparatively less developed and only located in the south, certain projects are either proposed or already under construction. This includes several proposed LNG terminals and FSRU across the country: the Bac Lieu LNG Terminal, the Thi Vai LNG Terminal, the Mui Ke	[81]

	Ga FSRU and the Son My LNG Terminal, all located in the South, as well as the Thanh Hóa LNG Terminal and the Thai Binh FSRU in the North. In the centre of the country, the Hai Lang LNG Terminal is already under construction. Gas pipelines are neither planned nor constructed.	
Most suitable H_2 transport option	• In-country: pipeline • Regional: Pipeline for distances of up to 1,500 km from H_2 production site and up to 7,000 km where an already existing gas pipeline can be repurposed for H_2, ship (Liquid Ammonia) for all other destination • International: shipping of derivates (ammonia)	[72]
General H_2 strategy and goals	• Hydrogen strategy published in February 2024, setting out production targets for 2030 (100-500 kt) and 2050 (10-20 Mt), developing both green and blue H_2 • Generating around 10% of electricity from H_2, deployment in industrial (including steel, cement, chemicals and refining), transport and residential sector • Target of peak emissions by 2030 and achieving net zero by 2050	[90]
Value chain for H_2 and derivates	• Activities along the whole value chain: production, consumption and trade	
Green hydrogen		
Parameter	Information	Source
Relevant stakeholders	Public stakeholders • Ministry of Planning and Investment • Ministry of Industry and Trade Private stakeholders • RE project developer The Green Solutions (TGS)- multiple agreements for renewable hydrogen and ammonia production • PetroVietnam, national oil and gas group, Petrovietnam Fertilizer and Chemicals Corporation currently a major producer of ammonia, research and assessment of opportunities for hydrogen industry development • Vietnam Petroleum Institute (VPI) • Hung Hai Group	[109], [335]

Dominant RE source to produce gH_2	• Currently hydropower is the dominant RE source [336], new projects will be focused on solar PV and offshore wind, which are expected to be dominant sources of energy for H_2 production [332] • Offshore wind technical potential estimated at 162.2 GW [332]	[332], [336]
Potential gH_2 demand	Current demand • Fertiliser industry Future demand • Cement production • Steel production • Transport (road vehicles) Potential gH_2 demand by 2050: • 2200 kt/a (2.2 Mt)for electricity generation; 1000 kt/a (1 Mt) for steelmaking; 2800 kt/a (2.8 Mt) for the cement industry • H_2 use for private vehicles is expected to be comparatively low, due to a high price for H_2 fuel cell vehicles and insufficient distribution of H_2 stations • In general: replacement of currently used grey hydrogen in fertilizer production and future application in steel and cement production as well as in the transport sector	[332]
Future gH_2 generation potential	• 22 Mt by 2050	[332]
H_2/PtX production and transport cost	• LCOH for gH_2: € 7-13/kg, with the lower prices (~€8)being geographically concentrated in the southern part of the country [47] • Other estimates are lower at $2.3 - $3.9/kg [7]	[7], [47]
gH_2 roadmap and targets	• Most recently, in February 2024, Vietnam published its Hydrogen strategy, which sets out production targets of 0.1-0.5 Mt by 2030 and 10-20 Mt by 2050, which shall be met by a mixture of green and blue H_2. It sets out the goal of covering 10% of the nation-wide energy demand with H_2 by 2050, cutting across multiple sectors including electricity generation, transport, and industry (steel, cement, and chemicals). With the publication of the strategy, announcements of further policies set out a legal framework for enterprises currently involved in the fossil industry to convert to H_2 as an energy carrier, as well as strategies to mobilize investments. • Hydrogen strategy published in 2024, speaks of "clean hydrogen" but explicitly includes H_2 from fossil sources	[90]

	• Plan to take advantage of existing infrastructure, plans to create mechanisms for currently fossil-based producers and consumers to convert to H_2 • gH_2 utilisation o achieving 10% of energy mix from H_2 by 2050 • gH_2 production targets: o 100,000 – 500,000 t/a by 2030; o 10-20 Mt /a by 2050	
gH_2 regulatory framework	• Developing plans for piloting electricity generation using hydrogen set out as a goal in Resolution No. 55-NQ/TW (2020)[128] • Further policies regulating investment in Re-based H_2 production projects [90] • Decision No. 38/2020/QD-TTg (30/12/20) sets out the following incentives for projects applying "hydrogen energy technology" (not limited to gH_2) [21]: o a preferential tax rate of 10% for a period of 15 years o preferential value-added tax of 5%; o the exemption of land rental fees o exemption from import tax on raw materials, supplies and components for a period of 5 years if they cannot be produced domestically [128]	[90], [128], [337]
gH_2 programmes or partnerships	• PtX hub [333] • Just energy transition partnership with EU and G7 countries, green hydrogen named as a key priority in the joint declaration [338]	[333], [338]
gH_2 projects and knowledge	• Trials for jettyless LNG transfers, necessary for cost-efficient export of hydrogen/ammonia produced onshore due to the shallow coastal line of Vietnam, developed by Vietnamese The Green Solution (TGS) in cooperation with ECONNECT energy (Norway) [109] • Tra Vinh: green H_2/ ammonia plant under construction since 2023, also planned to be operational by 2024, total investment of $341 M, Collaboration between TGS and ThyssenKrupp, initially generation capacity: 24,000 tonnes of green hydrogen, 150,000 tonnes of ammonia and 195,000 tonnes of oxygen (status: under construction) [109]; [126] • Ba tri offshore wind power plant, construction starts 2024, operational by 2028 [152] • Thang long: construction of an offshore wind part with Ptx by Enterprise Energy (Singapore), production targets: 330,000 tonnes per year. The project will produce both electricity for the onshore grid, hydrogen	[47], [109], [126], [152]

	which will be transported via pipelines, and ammonia that can be shipped with a tanker (construction start: 2023)[47] • Collaboration between Vietnam Petroleum Institute and Großmann Ingenieur Consult GmbH to produce hydrogen and bio methane with offshore wind energy and desalinated seawater (Status: MoU signed) [47] • Hai Lang Green Hydrogen Center, planned production capacities:: 700 MWp of solar power, 300 MW of wind power, and 193,000 tons of Ammonia; total cost: $7.46 Bn [47] • Chau Du, Ba Ria-Vung Tau province: hydrogen generation facility coupled to an ammonia plant planned, planned capacity of 200,000t/a. Investor: Hung Hai Group (Vietnamese infrastructure and RE company) [47] • Can Tho hydrogen production plant, planned by SK Energy Co. planned to produce hydrogen directly utilizable for transport [47]	
Land and water availability		
Parameter	Information	Source
Fresh water situation/scarcity	• Level of water stress (proportion of freshwater withdrawal to available resources): 18,13% [140] • 3,719 cubic meters of renewable internal freshwater resources available per capita [316]	[140], [316]
Water consumption	• Daily water use: 2,703 l per capita	[258]
Land availability	• Land availability/use [339]: High population density, 0.3 ha agricultural land per person; 81% is agriculturally used (including forestry) rapid expansion of residential and commercial land use, additional pressures due to enduring contamination from the war, such as landmines and herbicides • Regulatory framework [340] All land is public property and managed by the state, the 2013 land law reform has decentralized the administration, lease prices are now determined on the province and district levels	[339], [340]
Resource conflicts (electricity, land, water, land use etc.)	• Occasional conflicts between small-scale farmers and rural villagers and State Forest Companies due to overlapping land claims and labour agreements perceived as exploitative [341] • Displacement and food insecurity through a loss of land and fish abundance associated with hydropower expansion in the Mekong river basin [342]	[31], [32]

CO_2 sources for derivate production	• Steel production (122.5 Mt by 2025)[47] • Electricity generation[332] • Cement (and other CO_2 intensive) industries[332]	[47], [332]
Energy situation		
Parameter	Information	Source
Energy mix (electricity generation)	• **Fossil:** [336] 115.026 MWh coal; 26.312 MWh natural gas; 298 MWh oil • **Renewable:** [336] 78.553 hydropower; 27.791 MWh Solar PV; 3344 MWh wind; 2093 MWh biofuels • Electricity generation shares in 2021: 45.4% coal, 10.4% gas, 0.9% oil, 43.3% RE [130]	[336], [130]
RE share (electricity generation)	• 23% (Total energy supply) , 43% (Electricity generation) [336] • Current RE capacity is around 46.8 GW, around 58% of total capacity[336] • Renewable electricity generation shares in 2021: 71.6% hydro, 3.0% wind, 25.3% solar [262]	[336], [262]
Planned capacity expansion	• Capacity expansion by 2050: + 60.050 - 77.050 MW of land-based wind power (12.2 – 13.4%); + 70.000 - 91.500 MW of offshore wind power (14.3 – 16.0%); + 168.594 - 189.294 MW of solar power (33.0 – 34.4%); + 6.015 MW of biomass electricity and electricity produced from waste (1.0 – 1.2%); + 36.016 MW of hydroelectricity (6.3 – 7.3%)	[127]
RE policy target	• RE share: around 30.9 – 39.2% by 2030; 67.5 – 71.5% by 2050	[127]
Existing energy trade	• Import of fossil energy carries ($9Bn worth of oil, mostly from Malaysia, South Korea and Kuwait; $1.5Bn worth of coal, mostly from Indonesia and Australia; $0.4 Bn worth of gas) • Import of electricity play a role to a lesser extent; $78.5M, mostly from Laos)	[343]
Electrification rate	100%	[282]
Reliability of electricity supply	No data	

Electricity cost/tariff	• Tariff: Residential: $0.073 – $0.13 /kWh Commercial: $0.06 – $0.2 /kWh Industrial: $0.041 -0.13 VND/ kWh	[344]
RE investment	• Climatescope index: • overall score 2.21/5; fundamentals 2.86/6; opportunities 1.6/5; experience 1.52/5 • Rank (global): 30 • Rank (Asia-Pacific): 5	[283]
Social, political and economic indicators		
Parameter	Information	Source
Socio-economic data	• GDP per capita: 13,461 international $ [266] • Unemployment rate: 1.9% [267] • Poverty headcount ratio: 0.4% absolute poverty (2024) 4.8% at national poverty lines (2020) [268] • GINI index: 36.8 (2020) [269]	[266], [267], [268], [269]
Worldwide Governance Index	• Voice and Accountability: – 1.29 • Political Stability and Absence of Violence/Terrorism: -0.03 • Government Effectiveness: 0.18 • Regulatory Quality: -0.43 • Rule of Law: – 0.16 • Control of Corruption: – 0.29	[270]
Trade indicators		
Parameter	Information	Source
Exported goods	Broadcasting Equipment ($51.1B), Telephones ($25.3B), Integrated Circuits ($18.2B), Office Machine Parts ($11.7B), and Textile Footwear ($9.79B) Biggest exporter of: Nuts ($3.37 B); Fuel Wood; Cement ($1.19 B)	[343]
Export partners	Export total: $356B (3560 per capita) Imports: $331B (3400 per capita)	[343]

Imported goods	Integrated Circuits ($39.8B), Telephones ($20.7B), Light Rubberized Knitted Fabric ($6.29B), Broadcasting Accessories ($5.38B), and Refined Petroleum ($4.76B)	[343]
Import partners	Exports: United States ($99.3B), China ($57.8B), South Korea ($22.6B), Japan ($21.3B), and Hong Kong ($12.5B), Imports: China ($129B), South Korea ($56.5B), Japan ($18.2B), Taiwan ($14.8B), and Thailand ($12.5B).	[343]

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