This sector analysis was commissioned by the German Energy Solutions Initiative of the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

Sector Analysis – Vietnam

Green hydrogen for the commercial and industrial (C&I) sector

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Berlin

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Abbreviations /Acronyms

AC	Alternating Current
AEL	Alkaline electrolysis
AEM	Anion exchange membrane
AHK	German Chambers of Commerce Abroad
ASU	Air Separation Unit
bar	Metric unit of pressure
barg	Absolute pressure and gauge pressure
BF	Blast furnace
BMWK	German Federal Ministry of Economics and Climate Action
CAPEX	Capital Expenditures
CCU	Carbon Capture and Utilization
CH_3OH	Methanol
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DAP	Diammonium phosphate
DC	Direct Current
DRI	Direct-reduced iron
EAF	Electric arc furnace
EIB	European Investment Bank
ESMAP	Energy Sector Management Assistance Program
ETS	Emmision Trading System
EU	European Union
EVN	Electricity Vietnam
GDP	Gross Domestic Product
GHG	Greenhouse gases
GICON	Großmann Ingenieur Consult GmbH
GIS	Geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GW	Gigawat
GWh	Gigawatt-hour
H_2	Hydrogen
H2-PDP	Project Development Programme for Green Hydrogen Projects
H2Uppp	International Hydrogen Ramp-up Programme
IPA	Vietnam Investment Promotion Agency
IPCS	Investment Promotion Centers
IPP	Independent Power Producers
KFW	Kreditanstalt für Wiederaufbau
kWh	Kilowatt hour
LCoA	Levelized cost of Ammonia
LCoH	Levelized Cost of Hydrogen
LEP	Law on Environmental Protection
LOHC	Liquid organic hydrogen carriers
MOIT	Ministry of Industry and Trade
MoU	Memorandum of understanding
MPI	Ministry of Planning and Investment
$mtCO_2e$	Million tonnes of carbon dioxide equivalent
MTHP	Maximum Technical H_2
MW	Mega Watt
MWp	Mega Watt peak
N_2	Nitrogen
NCCS	National Climate Change Strategy
NH_3	Ammonia
Nm_3	Normal cubic meter
OPEX	Operational expenditures
PDP	Project Development Programme
PEM	Proton Exchange Membrane
PPP	Public-Private Partnership
PtX	Power-to-X
PV	Photovoltaics
PVN	Vietnam Oil and Gas Group
R&D	Research and Development
RES	Renewable energy sources
SME	Small and medium-sized enterprises
SMR	Steam methane reforming
SOEC	Solid Oxide Electrolysis
TIC	Total installed cost
ton	Imperial unit of mass equivalent to 1,016.047 kg or 2,240 lbs
tonne	Metric unit of mass equivalent to 1,000 kg or 2,204.6 lbs
tpa	Tons per annum
tpd	Tons per day
VAT	Value Added Tax
VPI	Vietnam Petroleum Institute
VRE	Variable renewable energy

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Currency Units

EUR Euro
USD United States Dollar
VND Vietnamese Dong

Conversion 29-06-2023: EUR 1 = VND 24,645 State Bank of Vietnam (Exchange Rate (sbv.gov.vn))

The German Energy Solutions Initiative

Energy solutions – made in Germany

Launched in 2002 by the German Federal Ministry for Economic Affairs and Climate Action (BMWK), the German Energy Solutions Initiative is primarily aimed at small and medium-sized enterprises (SMEs) and supports suppliers of climate-friendly energy solutions in finding new markets abroad. The initiative is active in around 140 countries and aims to disseminate German and European energy technologies more extensively across the globe.

The initiative includes the Project Development Programme (PDP) which is carried out by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and promotes climate-friendly energy solutions in selected emerging and developing countries in sub-Saharan Africa, South and Southeast Asia and the Middle East. Since 2007, the PDP has been supporting the energy transition in its cooperation countries by developing concrete renewable energy and energy efficiency projects. The focus was recently expanded to include green hydrogen projects through the Project Development Programme for Green Hydrogen Projects (H2-PDP), as the German Energy Solutions Initiative is increasingly promoting green hydrogen as a crucial energy carrier for achieving a climate-neutral economy.

Project Development Programme for Green Hydrogen Projects (H2-PDP)

Green hydrogen (H2) is needed to reduce the industry carbon footprint. At present, however, countries such as Ghana, Kenya, Jordan and Vietnam primarily use 'grey hydrogen' derived from fossil fuels. The sustainability of a product and its carbon footprint will play a greater role in determining its competitiveness in future, so it is worthwhile for companies to switch from grey to green hydrogen at an early stage. This solution is hardly cost-effective at the moment, but it is expected to become more competitive with the ramping up of this new market. Moreover, German and European technology suppliers and project developers are not currently particularly active in the selected countries. The market is still being established.

The objective of the project is to enable Ghana, Kenya, Jordan and Vietnam to progressively produce green hydrogen at competitive prices. In order to achieve this, the project identifies local companies that are able to switch from producing or consuming grey hydrogen to producing green hydrogen within a short period. It advises them on plant design, financial models and how they can cover the funding gap when compared with grey hydrogen. With a view to accelerating the transition to green hydrogen, the project facilitates access to funding instruments such as the public-private partnership (PPP) under the International Hydrogen Ramp-up Programme (H2Uppp), international funds and to suitable technology partners from Germany and elsewhere.

The project analyses industry segments that would be suitable for pilot projects and facilitates contact with German/European companies. Additional training sessions raise awareness among local hydrogen consumers, producers and project developers with the involvement of German solution providers. Local companies gain access to suppliers, who are made aware of specific opportunities. Due to their pioneering role, they may profit from financial support measures for pilot projects.

The project is thus supporting the energy transition in the partner countries. At the same time, German and European companies can benefit from this approach as it supports the better understanding of markets and the study project opportunities whilst strategic contacts are also acquired in developing countries and emerging economies.

The series of sector analyses available explore the green hydrogen market potential of Ghana, Kenya, Jordan, and Vietnam and can be downloaded from GIZ's H2-PDP project website: Changing from grey to green hydrogen production – giz.de

Executive Summary

Why start a hydrogen business in Vietnam?

The objective of this sector analysis is to provide German and European business with an overview of the hydrogen (H_2) market in Vietnam. It aims to offer simplified cost estimations and orientations for establishing a new business in the country. This report targets companies seeking partnerships with local entities that utilise hydrogen as the primary feedstock for their industrial processes. Vietnam presents numerous opportunities for international investors, including a well-established industrial sector, political and economic stability and a strong commitment from the government to reach its climate objectives.

Establishing a business in Vietnam brings several advantages, such as forming partnerships with local companies and creating decarbonised solutions for its well-developed industries by leveraging the country's renewable resources. This enables the production of affordable and carbon-free energy for green hydrogen generation. Producing hydrogen locally serves as an attractive alternative to reduce the country's reliance on fossil-based hydrogen commodities and enhance energy independence. Furthermore, the market prospects for green hydrogen are expected to grow as electrolysis technology costs decline and the demand for decarbonised products increases among customers willing to pay a premium.

Green hydrogen and ammonia opportunities

Green hydrogen and its derivative products offer multiple benefits such as the decarbonisation of processes and end products, energy storage, renewable energy integration, energy security and economic opportunities. These technologies can play an essential role in the transition to a sustainable and low-carbon economy. The analysis explains green hydrogen and ammonia production processes, input product requirements and associated costs in detail. Additionally, a brief overview describing the import and export balance of hydrogen-based commodities in the country is provided. Furthermore, the local industries with the highest potential for transitioning to green hydrogen applications are also highlighted.

Zusammenfassung

Warum sollte man ein Wasserstoff-projekt in Vietnam starten?

Diese Sektoranalyse skizziert, welche Perspektiven der Wasserstoffmarkt in Vietnam deutschen und europäischen Unternehmen bietet. Sie liefert vereinfachte Kostenschätzungen für die Herstellung von grünem Wasserstoff mit Photovoltaik (PV) und Orientierungshilfen für die Umsetzung eines Projekts in Vietnam. Dieser Bericht wendet sich an deutsche und europäische Firmen mit Interesse an einer Partnerschaft mit vietnamesischen Unternehmen, die Wasserstoff als Hauptrohstoff für ihre industriellen Prozesse nutzen. Vietnam bietet internationalen Investor*innen gute Voraussetzungen wie zum Beispiel einen etablierten Industriesektor, politische und wirtschaftliche Stabilität und ein starkes Engagement der Regierung für Klimaziele.

Ein Projekt in Vietnam ermöglicht den Aufbau von Partnerschaften zu lokalen Unternehmen und die Entwicklung kohlenstoffarmer Lösungen für die Industrie, mithilfe erneuerbarer Energien. Die erschwingliche und kohlenstofffreie Energie lässt sich für die Erzeugung von grünem Wasserstoff nutzen. Die lokale Produktion von Wasserstoff ist eine attraktive Alternative, um die Abhängigkeit des Landes von fossilen Rohstoffen zu verringern und die Energieunabhängigkeit zu verbessern. Darüber hinaus dürften die Marktaussichten für grünen Wasserstoff steigen, da die Technologiekosten für die Elektrolyse sinken und immer mehr Kund*innen bereit sind, einen Aufpreis für kohlenstofffreie Produkte zu zahlen.

Chancen für grünen Wasserstoff und Ammoniak

Grüner Wasserstoff und seine chemischen Derivate bieten zahlreiche Vorteile, darunter die Dekarbonisierung von Prozessen und Produkten, Energiespeicherung, Integration erneuerbarer Energien, Energiesicherheit und neue wirtschaftliche Chancen. Diese Technologien können eine wesentliche Rolle beim Übergang zu einer nachhaltigen und kohlenstoffarmen Wirtschaft spielen. Die Analyse erläutert im Detail die Verfahren zur Herstellung von grünem Wasserstoff und grünem Ammoniak, die Anforderungen an die Vorprodukte und die damit verbundenen Kosten. Darüber hinaus bietet sie für Wasserstofferzeugnisse einen kurzen Ausblick auf Angebot und Nachfrage in Vietnam. Die Analyse nennt ebenfalls die lokalen Industrien mit dem größten Potenzial für den Übergang zu grünen Wasserstoffanwendungen.

Benefiting from Vietnam's well-established industry to implement green hydrogen solutions

The country's chemical, refining and steel industries are well-established and positioned to take the next step by embracing green hydrogen-based solutions to decarbonise and diversify the current supply chain. The specific focus is put on green hydrogen produced from solar photovoltaics (PV), with cost details presented in the case studies. Interviews with local manufacturers in Vietnam supplemented by informal discussions and a detailed sector analysis were conducted to gauge potential interest in producing their own green hydrogen. Business cases were developed based on the interviews and represent typical sector scenarios for replacing grey hydrogen with green hydrogen. The business cases focus on current grey hydrogen consumers, where hydrogen is either a production feedstock or an element in the current manufacturing process. The analysis estimates the system sizing, cost including the electrolyser system and solar PV plant, as well as calculating the levelised cost of hydrogen (LCoH) as per the local solar resource. Two business cases are presented for illustrative purposes, where green hydrogen is used for green ammonia and food production.

Establishing hydrogen policies to support investments

The country primarily relies on fossil-based commodities to meet its energy needs and actively seeks to diversify its energy mix. The key document governing Vietnam's transformation into a net-zero economy is the country's National Climate Change Strategy 2050 (NCCS), which sets detailed objectives for Greenhouse gases (GHG) reduction targets by 2030 and 2050. One of the main objectives is the reduction of energy sector emissions by 91.6 % and increasing renewable energy shares up to 33 % of total electricity generation by 2050. There is no specific target for hydrogen implementation; however, there are several policies and guidelines for renewable energy sources (RES) and industrial sectors which include guidance on green hydrogen.

Nutzen der etablierten vietnamesischen Industrie für die Einführung grüner Wasserstofflösungen

Die vietnamesische Chemie-, Raffinerie- und Stahlindustrie ist gut etabliert und bereit für grünen Wasserstoff zur Dekarbonisierung und Diversifizierung ihrer Lieferketten. Der Schwerpunkt liegt auf grünem Wasserstoff, der mit PV hergestellt wird. Die entsprechenden Kosten werden in den Fallstudien dargestellt. Interviews mit lokalen Hersteller*innen in Vietnam, informelle Gespräche und eine detaillierte Sektoranalyse geben Aufschluss über das Interesse an der Produktion von grünem Wasserstoff.
Auf der Grundlage der Interviews entstanden typische Branchenszenarien für den Ersatz von grauem durch grünen Wasserstoff. Die Geschäftsszenarien konzentrieren sich auf die derzeitigen Verbraucher*innen von grauem Wasserstoff, bei denen Wasserstoff entweder ein Produktionsrohstoff oder ein Element im Herstellungsprozess ist. Die Analyse liefert eine Einschätzung der Systemgröße und der Kosten. Berücksichtigt werden dabei auch die Kosten für das Elektrolyseursystem, die PV-Anlage und die nivellierten Wasserstoffkosten (LCoH) in Abhängigkeit der lokalen Solarressourcen. Zwei Fallbeispiele machen die Nutzung von grünem Wasserstoff für die Herstellung von grünem Ammoniak und Lebensmitteln anschaulich.

Einführung einer Wasserstoffpolitik zur Förderung von Investitionen

Vietnam deckt seinen Energiebedarf derzeit hauptsächlich mit fossilen Rohstoffen und bemüht sich, seinen Energiemix zu diversifizieren. Das Schlüsseldokument für den Wandel in eine Netto-Null-Wirtschaft ist die Nationale Strategie zum Klimawandel 2050 (NCCS). Sie legt detaillierte Ziele für die Reduzierung von Treibhausgasen (THG) bis 2030 und 2050 fest. Hauptziele sind die Verringerung der Emissionen im Energiesektor um 91,6 Prozent und die Erhöhung des Anteils erneuerbarer Energien an der gesamten Stromerzeugung auf 33 Prozent bis 2050. Es gibt zwar kein konkretes Ziel für die Einführung von Wasserstoff, aber mehrere Politiken und Maßgaben für erneuerbare Energiequellen (EE) und Industriesektoren enthalten Leitlinien für grünen Wasserstoff.

1 CURRENT SITUATION OVERVIEW

1. Current Situation Overview

Hydrogen is a promising energy carrier that has the potential to play a significant role in Vietnam‘s efforts to diversify its energy mix and transition to a low-carbon economy. The rapid economic development, population growth and expansion of existing industrial sectors have placed additional strain on the energy system. The country‘s chemical, refining and steel industries are well-established and positioned to take the next step by embracing green hydrogen-based commodities. Vietnam requires additional sources of energy, and clean hydrogen production emerges as one of the solutions that can transform the energy sector and help the country achieve its ambitious climate goals.

The key document governing Vietnam's transformation into a net-zero economy is the country's NCCS, which sets detailed objectives for GHG reduction targets by 2030 and 2050. One of the main objectives is the reduction of energy sector emissions by 91.6% and capping them at 101 million mtCO2e by 2050. The country also declared an ambitious agenda to phase out coal by 2040 and increase renewable energy shares to have at least 33% of hydro, solar and biomass power within the total electricity generation mix. There is no specific target for hydrogen implementation, but the country demonstrates its strong intention to achieve the set climate targets.

While the hydrogen sector in Vietnam is still in its early stages of development, the country has taken proactive measures to explore its potential as a clean energy source and align it with its energy and climate policies. Vietnam has not yet issued a national strategy for green hydrogen; however, there are several policies and guidelines for RES and industrial sectors which already include guidance on hydrogen. The country has experienced very high economic growth over the last 10 years and needs to focus on the new energy streams that will reduce its dependency on fossil fuel imports, particularly coal and natural gas. Industries such as chemical production, refining or steel production are already well developed in the country; therefore, moving towards the use of green hydrogen and its derivatives creates an opportunity for sectors to decarbonise, implement innovative processes and increase Vietnam's energy independence.

1.1 Assessment of the energy landscape

Vietnam has an extensive and robust energy system but with challenging local conditions characterised by a long narrow energy corridor. Most of the baseload coal and hydropower generation is in the north of the country, the most promising renewable energy potential in the central regions, and there are major load centres in the south. In recent years the government of Vietnam, Electricity Vietnam (EVN) and the Ministry of Industry and Trade (MOIT) have carried out an extensive expansion of the energy system including a second north-south 500 KV transmission line to ease bottlenecks and improve network reliability.

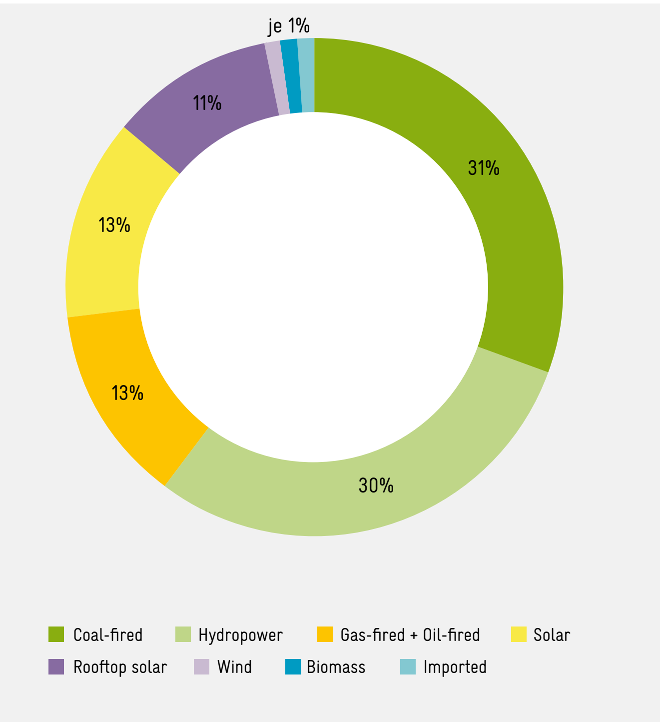
The Vietnamese electricity system is currently dominated by hydropower in the north and central parts of the country, as well as coal in the north and gas in the south. The detailed location of power plants in Vietnam with their capacities can be found in Figure 18, Locations of generation capacity in Vietnam, in the Appendix.

The electricity sector in Vietnam is run by the vertically integrated government-owned company EVN. EVN owns and manages the generation, transmission and distribution companies as well as the national dispatch centre. In addition, there are a number of either fully or partially privately owned power generation companies, including independent power producers (IPP) for wind and solar accounting for over 50% of the total generation capacity (NLDC, Annual Report, 2021).

1.1.1 Electricity generation

Vietnam's energy generation capacity is dominated by coal and gas, with fossil fuels accounting for around 47% of installed capacity and 64% of production in 2020. However, Vietnam rapidly increased its installed generation capacity, from 55.9 GW in 2019 to 78.1 GW in 2021, much of this in the form of renewables (around 55%) (NLDC, Annual Report, 2021). In 2020, hydropower and coal each represented around 30% of its installed capacity. The remaining 40% was more or less equally split between other thermal (gas & oil), utility-scale solar and rooftop solar. Negligible quantities of wind and biomass are installed.

FIGURE 1. INSTALLED ELECTRICAL GENERATION CAPACITY IN 2021



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on NLDC, Annual Report (2021)

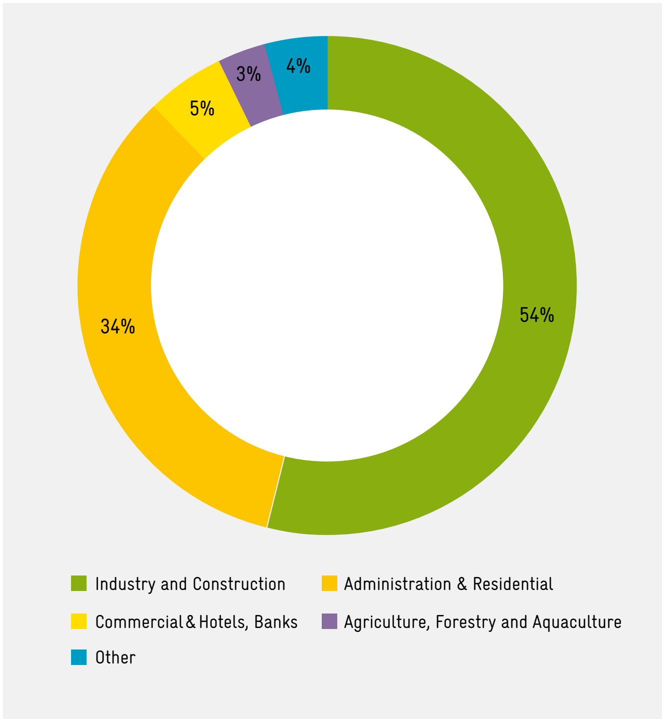
Since 2018, coal generation has increased, reaching almost half of the total production in 2020. At the same time, the contribution from other thermal sources (gas and oil) fell to 15% in 2020. Renewable energy (excluding hydro) grew steadily in the period 2016-2020, increasing from almost zero to over 5%.

Vietnam has experienced explosive growth over the last 10 years and the GDP – and thus energy demand – is expected to continue to grow strongly in the future. Vietnam experienced GDP growth of an average of 6.6%/year in the period 2021–2030; the forecast for 2031–2045 is an average of 5.7%/year.

1.1.2 Electricity demand composition

Vietnam has well-developed industrial and construction sectors, which account for more than half the total electricity demand. One third of the electricity consumed in the country is for residential and administration consumption, while the remaining electricity supplies the other sectors, e.g. commercial, agriculture.

FIGURE 2. ELECTRICITY SALES BY SECTOR IN 2020



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (EVN, 2021)

1.2 Energy prices

1.2.1 Electricity prices

The retail electricity price in Vietnam is regulated by the Ministry of Industry and Trade. According to Decision No. 648/QD-BCT dated 20 March 2019, the current average is VND 1,864.44/kWh (Value Added Tax (VAT) exclusive) (EUR 0.08/kWh). Electricity tariffs in Vietnam follow a time-of-use scheme (standard, peak and off-peak hours), which applies to industrial, business and administrative clients and varies based on the voltage level, while the residential tariff varies based on consumption and type of settlement (e.g. rural areas, towns).

Table 1 shows the tariff for industrial customers. As mentioned above, commercial customers are subject to the same tariff structure; however, electricity is, on average, around 50% more expensive. Residential customers are subject to an increasing tariff as their consumption grows. On average, the lowest tariff (that paid for the first 50 kWh of consumption) is VND 1,403–1,678/kWh (EUR 0.060–0.72/kWh), rising in subsequent brackets.

TABLE 1. RETAIL ELECTRICITY PRICES FOR MANUFACTURING INDUSTRIES

	Standard		Off-peak		Peak	
	VND/kWh	EUR/kWh	VND/kWh	EUR/kWh	VND/kWh	EUR/kWh
Voltage ≥ 110 kV	1,536	0.062	970	0.039	2,759	0.112
22 kV ≤ Voltage < 110 kV	1,555	0.062	1,007	0.041	2,871	0.238
6 kV ≤ Voltage < 22 kV	1,611	0.065	1,044	0.042	2,964	0.121
Voltage < 6 kV	1,685	0.068	1,100	0.045	3,076	0.125

Source: (Ministry of Industry and Trade (MOIT), 2019), exchange rate: EUR 1 = VND 24,645 (Central Bank of Vietnam, 2023)

1.2.2 Coal prices

Vietnam's energy composition is dominated by coal consumption, which accounted for 53.52 million tons in 2021 sourced both domestically and internationally. Domestically, most of the country's coal is mined in the north, with mining mainly undertaken by the state-owned enterprise Vietnam National Coal-Mineral Industries Group. The rest of the demand, accounting for around 70% of total coal consumption, is imported from Indonesia, Australia and China, which makes the country highly vulnerable to spikes in coal prices and the broader worldwide commodities basket (Koty, 2022). For illustrative purposes, two major coal price indexes are presented in Table 16 in the Appendix.

1.2.3 Natural gas price

In 2019, gas demand in Vietnam was 2,303,980 tons, of which 38.5% was domestic and 61.5% from imports. Gas supply is managed by the state-owned vertically integrated oil and gas company PVN (Vietnam Oil and Gas Group) along with its affiliate companies. Petroleum products are subject to price controls; however, gas prices are not publicly available. There is currently no active gas market, although the creation of a gas market is under discussion. According to the Roadmap for Natural Gas Market Development, wholesale gas prices for industrial and power-generation users are based on bilateral agreements between project proponents and PVN (Intelligent Energy Systems and Energy Market Consulting, 2017).

1.3 Legislative and regulatory framework

Vietnam has not yet issued a “Roadmap” or “Strategy” for green hydrogen; however, there are a number of policies and guidelines for RES and industrial sectors which include guidance on hydrogen. The key examples are:

- Resolution No. 55-NQ/TW dated 11 February 2020 on Vietnam’s National Energy Development Strategy to 2030 and Outlook to 2045 includes guidelines and objectives such as prioritising full and efficient exploitation and use of renewable energies, new and clean energies, promoting the remarkable development of renewable energy sources towards maximal replacement of fossil energy sources and conducting technology research and developing plans for piloting electricity generation using hydrogen and encouraging the use of hydrogen consistent with global trends.

- Resolution No. 140/NQ-CP dated 2 October 2020 of the Government announcing the implementation plan of Resolution No. 55-NQ/TW, which includes studying and planning a number of local renewable energy centres with preferential mechanisms to promote the development of RE, as well as developing plans for hydrogen pilot plants and encouraging the use of hydrogen.

Specific hydrogen incentive mechanisms are stipulated in the legislation below:

- Resolution No. 55-NQ/TW dated 11 February 2020 of the Politburo on strategic orientations for national energy development to 2030, with a vision to 2045 (Section III.1).

- Decision No. 1658/QD-TTg dated 1 October 2021 of the Prime Minister on the approval of the National Green Growth Strategy 2021-2030 with a vision to 2050.

- Through Decision No. 38/2020/QD-TTg (30/12/20) issued by the Prime Minister, projects applying hydrogen energy technology will enjoy investment incentives including:

  - a preferential tax rate of 10% for a period of 15 years;
  - preferential value-added tax of 5%;
  - the exemption of land rental fees for the entire land rental period;
  - exemption from import tax on raw materials, supplies and components that cannot be produced domestically for 5 years.

There are no regulatory frameworks in place for PtX nor specifically for green H_2.

1.4 Pilot projects and enabling infrastructure

There are a number of research and announced development projects taking place throughout the country. Some examples include:

- Vietnam Petroleum Institute (VPI) and Großmann Ingenieur Consult GmbH (GICON) signed a memorandum of understanding (MoU)) on 29 March 2021 to collaborate on research and development (R&D), focusing on offshore wind for hydrogen production from seawater, biological methanation and then hydrogenation of biomass to biomethane (VPI and GICON® Collaboration in the R&D of New Technologies in Vietnam, 2021).
- Hai Lang Green Hydrogen Center in the Southeast Quang Tri Economic Zone is being studied. “The Hai Lang Green Hydro Center Project is planned to be divided into three phases. They will have production capacities of 700 MWp of solar power, 300 MW of wind power and 193,000 tons of Ammonia (NH3; 1,800 MWp of solar power, 700 MW of wind power and 465,000 tons of NH3; and 1,800 MWp of solar power, 700 MW of wind power and 82,000 tons of liquid hydrogen in the first, second and third phases, respectively. Total investment for all three phases is estimated at VND 175,600 billion ($7.46 billion), of which Phase 1 will cost more than VND 31,300 billion ($1.33 billion)” (Dung, 2022).
- Hung Hai Group, a Vietnamese infrastructure and renewable energy development company, wants to build a battery plant and hydrogen generation factory in Chau Duc district, Ba Ria-Vung Tau province. The 500-hectare hydrogen factory’s output is set to continue into ammonia production, with a designed capacity of 200,000 tons per year (Tri Duc, 22).
- SK Energy Co., Ltd. is planning a hydrogen production plant in Can Tho. The project aims to supply hydrogen for public transport and heavy vehicles.
- TGS (The Green Hydrogen Solution) has announced plans to develop a green hydrogen plant in the Mekong Delta province of Tra Vinh. When complete, it will initially generate 24,000 tonnes of green hydrogen, with an annual capacity of 150,000 tonnes of ammonia and 195,000 tonnes of oxygen (Vietnam Investment Review, 2022). As of September 2022, operation was pushed back to Q1 2024 (Dung, 2022).

Although a number of pilot projects have been announced, none of which have yet reached implementation.

In Vietnam, hydrogen is mainly produced close to where it is used (e.g. fertiliser plants, refinery plants), with limited dedicated infrastructure such as transmission pipelines, refuelling stations, port systems, etc.

2 GREEN HYDROGEN TECHNOLOGY AND ESTIMATION OF COSTS IN THE VIETNAMESE CONTEXT

2. Green hydrogen technology and estimation of costs in the Vietnamese context

2.1 Introduction to hydrogen and hydrogen-based products

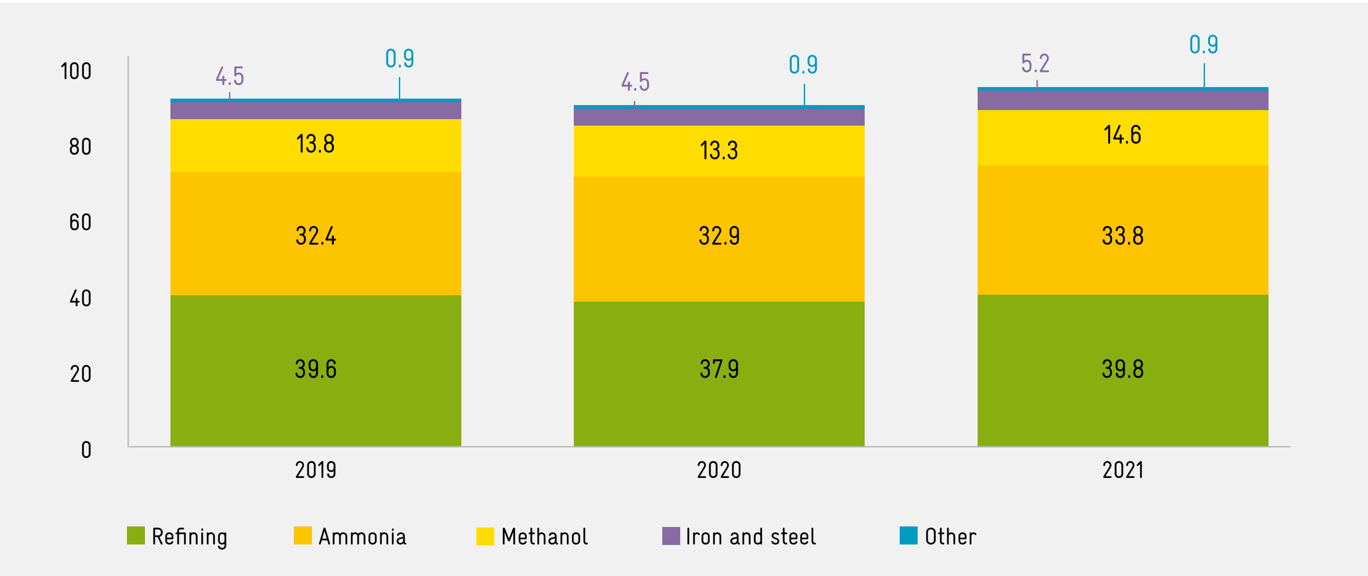
Hydrogen is the most abundant element on earth and an important chemical building block for numerous production processes, including the refining of petrochemicals, industrial processes such as glass and semiconductor production and in food production. Hydrogen is also a feedstock used in the production of downstream products such as ammonia and methanol.

Hydrogen has been produced on a significant industrial scale for decades. Currently, 95% of global hydrogen is produced using fossil fuels (grey hydrogen) (IRENA, 2018), primarily through the natural gas-based steam reforming process which is used to produce around 69 million tons of hydrogen annually (Statista). For the production of hydrogen, a typical natural gas-based steam reforming plant with 607 tons perday (tpd) capacity results in a H_2 production cost of USD 1.22/kg, depending on natural gas prices (A.O. Oni, 2022). The primary drawback to this process are the significant Carbon Dioxide (CO_2) emissions, which range on average between 8-9 kg CO_2/kg H_2. Global demand for hydrogen in 2021 was 94 Mt, a 5% increase compared to 2020 (IEA, 2022).

Hydrogen is predominantly used in refining as well as in the production of downstream products such as ammonia and methanol. Only about 6% of hydrogen produced is used for pure hydrogen demand (IEA, 2019). This share of hydrogen goes into the manufacturing processes of a wide variety of petrochemical products (PU foams, oxo-alcohols, nylon, etc.), pharmaceuticals, food production, electronics, etc. Hydrogen is mainly produced on-demand and on-site for treatment purposes or the production of chemicals.

In the context of the decarbonisation of industrial processes, green hydrogen is one of the favoured commodities. There are several utilisation routes for green hydrogen. One is the replacement of fossil-based hydrogen in synthesis or treatment processes. It is also used as a reduction gas, for example, in the steel industry. Another is the replacement of fossil energy sources for heating purposes, as well as an energy carrier for electrical storage purposes.

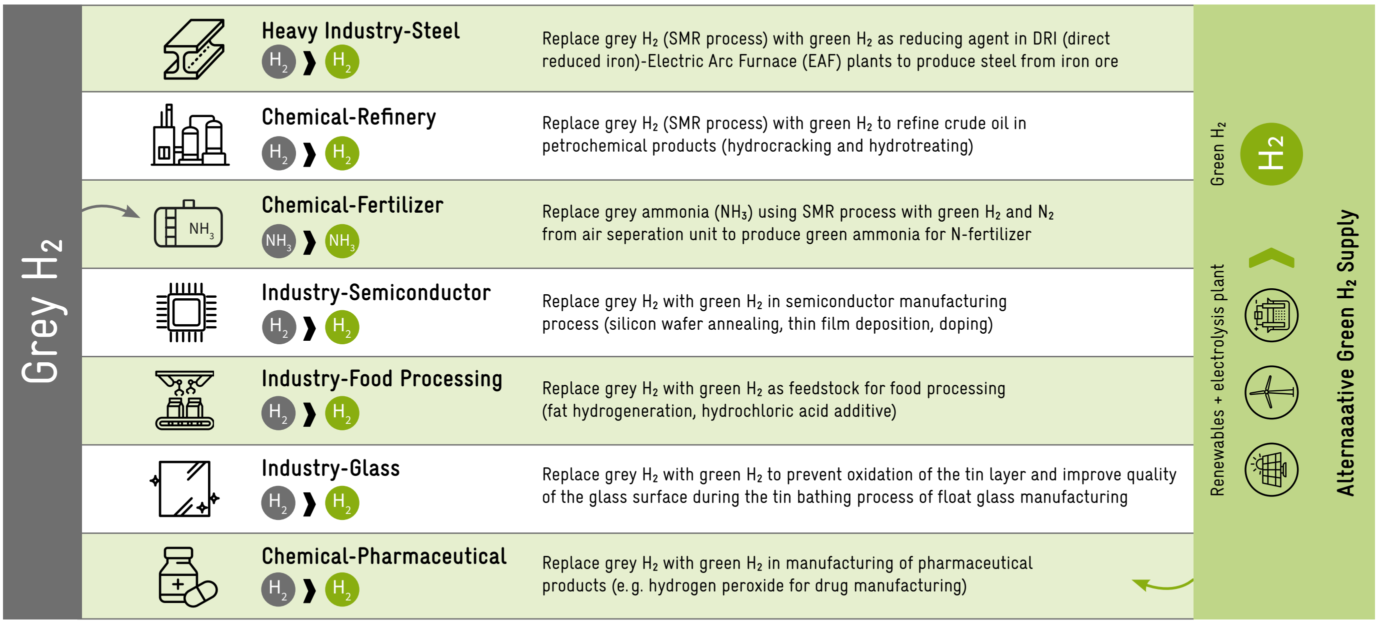
FIGURE 3. HYDROGEN DEMAND BY SECTOR



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (IEA, 2022)

Numerous sectors currently use hydrogen (or hydrogen-based products) as part of their production processes. These include heavy industry, for example, in steel production, in the chemical sector in refineries, for fertiliser production and pharmaceuticals, and in the industrial sector, for example, in float glass, semiconductor or food production. Figure 4 shows a selection of current industrial uses of hydrogen and how these can be replaced with carbon-free green hydrogen alternatives.

FIGURE 4. CURRENT INDUSTRIAL USES OF GREY HYDROGEN



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

As described above, hydrogen is extremely versatile and green hydrogen unlocks new possibilities for industry decarbonisation as well as contributing to energy security. However, hydrogen is a gas under atmospheric conditions and therefore needs to be processed either through compression or conversion to make it suitable for transport. The most attractive options for shipping hydrogen are ammonia, liquid hydrogen and liquid organic hydrogen carriers (LOHC) (Blanco, 2022).

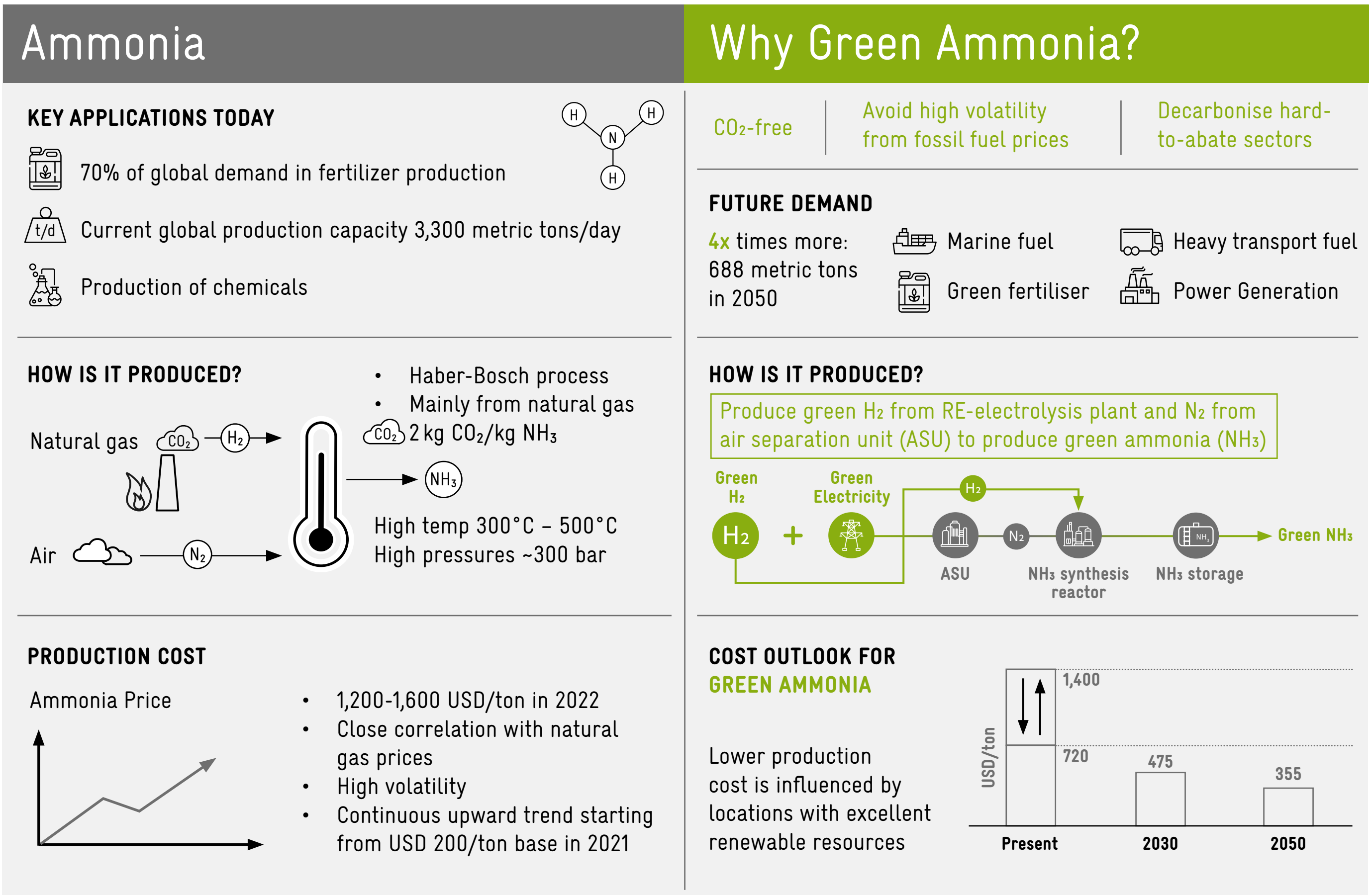
2.2 Hydrogen downstream products

The two primary downstream hydrogen-based products are methanol and ammonia. Methanol is a highly versatile commodity which is used as a fuel and in the production of plastics, silicone, acetic acid and formaldehyde, among others. Ammonia is primarily used as a chemical to create fertilisers, including urea and diammonium phosphate (DAP).

2.2.1 Ammonia

NH_3 is the largest hydrogen-based downstream chemical by volume, representing around 43% of global hydrogen demand, with around 236 million tons produced worldwide in 2021 (Statista, 2022) (IEA, 2022). It is the primary feedstock for nitrogen fertilisers, which account for around 70% of global ammonia demand. The production of NH_3 is a chemical synthesis process which requires H_2 and nitrogen (N_2), at a ratio of 18% H_2 and 82% N_2 as feedstock. As most current ammonia production is dependent on natural gas, ammonia prices are strongly correlated to those of natural gas. Conventional ammonia production is an emission-intensive process as it primarily relies on fossil fuels with over 70% of production using natural gas and the remaining 30% using coal. This most common fossil fuel-based Haber-Bosch process emits CO_2 in the order of 2 kg per kg of ammonia (Ghavam, 2021). Switching to green ammonia can significantly reduce greenhouse gas emissions in agriculture and transportation as it could be used as carbon-free fuel or fertiliser.

FIGURE 5. GREY AND GREEN AMMONIA PROPERTIES

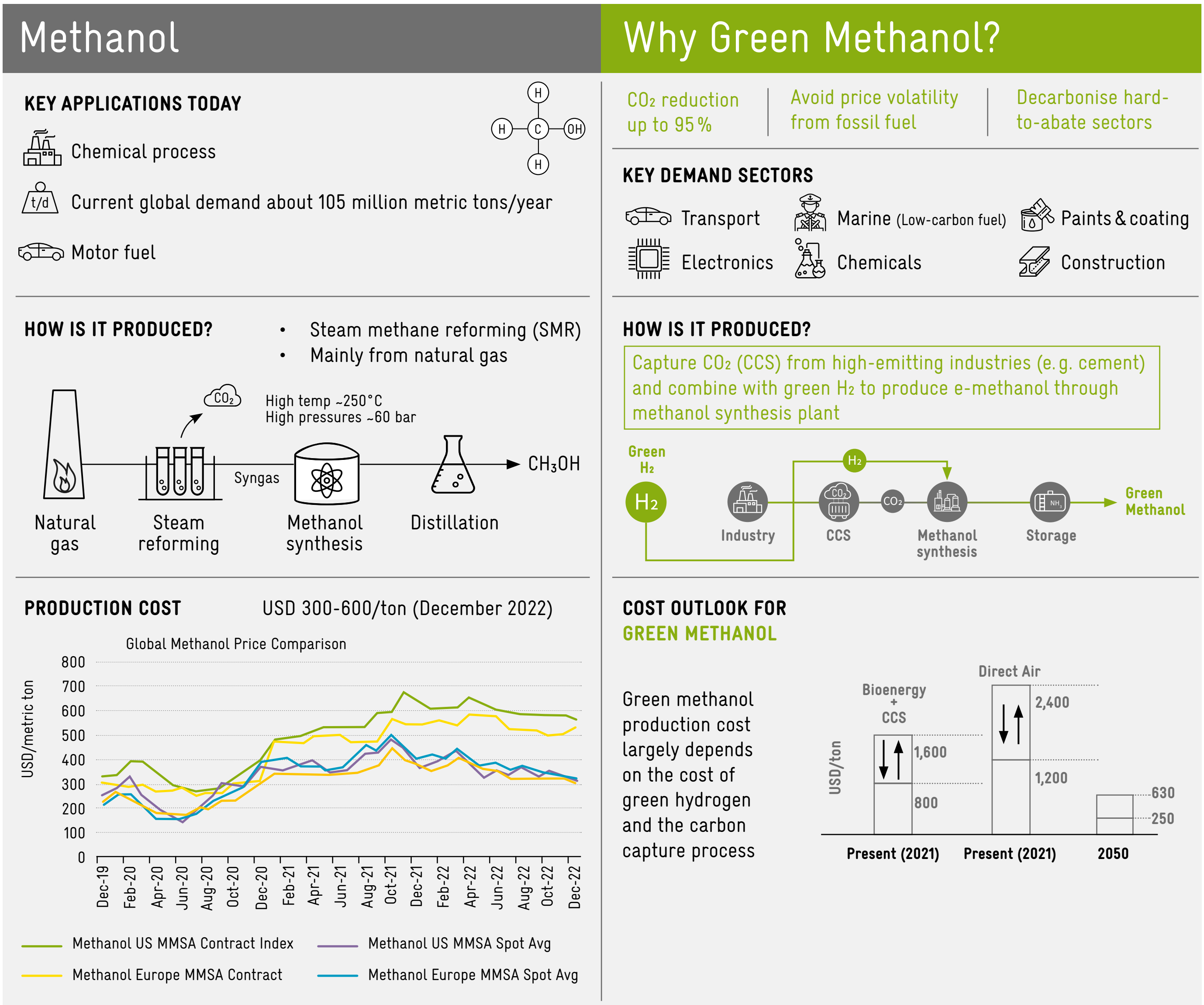


Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (Fasihi, M. et al., 2021) and data from Bloomberg

2.2.2 Methanol

Methanol (CH_3OH) is a simple water-soluble alcohol which can be used as a fuel for combustion engines or in methanol fuel cells, as a solvent, an anti-freeze, and a base chemical in the production of various downstream chemicals such as polymers, formaldehyde and acetic acid. The predominant methanol consumer is the automotive sector where it is mainly used as a motor fuel offering multiple advantages due to its high-octane content, which improves engine efficiency. Methanol is typically produced through the process of catalytic reduction of carbon monoxide Carbon Monoxide (CO) with H_2, called syngas, with a catalyst used at high pressures (up to 60 bar) and high temperatures (about 250°C), in a process known as „methanol synthesis". Green methanol is gaining significant interest as its production methods could cut up to 95% of CO_2 emissions compared to traditional methods (Methanol Institute, 2021).

FIGURE 6. GREY AND GREEN METHANOL PROPERTIES



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (Methanol Institute, 2023) and (IRENA, 2021)

2.3 Industrial use of hydrogen in Vietnam

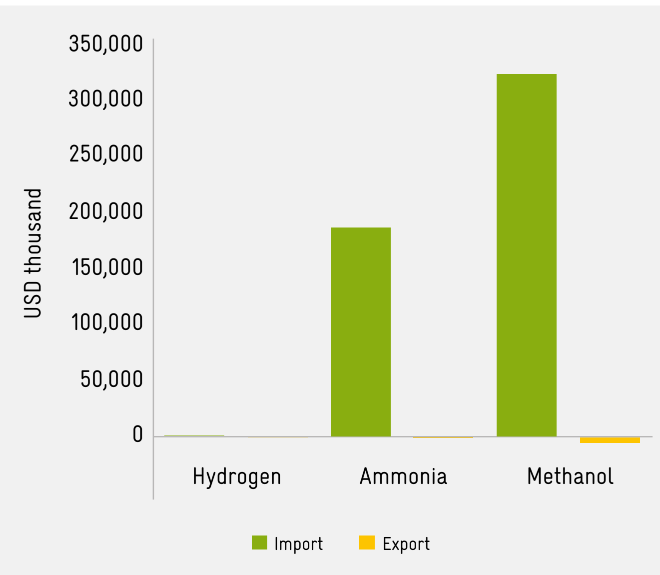
The main hydrogen-producing and hydrogen-consuming industries in Vietnam are the refinery and fertiliser sectors as well as, to a lesser extent, the steel, float glass, semiconductor, pharmaceutical and food industries. Refineries and fertiliser plants generally produce grey H_2 locally for their own consumption using natural gas and coal as the feedstock.

Chemical – fertiliser. Vietnam has several fertiliser plants where grey hydrogen is used to synthesise ammonia fed for urea production. Hydrogen demand in local fertiliser plants is met by a hydrogen source coming from a steam reforming process as well as a coal gasification process. Currently, the four main fertiliser plants (Phu My, Ca Mau, Ninh Binh, Ha Bac) produce and consume over 300 thousand tons of grey hydrogen per year (Vietnam Petroleum Institute (VPI) and Power Engineering Consulting Joint Stock Company 4 (PECC4), 2021). At present, up to 88% of the total ammonia demand is for urea fertiliser plants, and 12% of the market share is for other consumers such as thermal power, rubber production, freezing, for research and experimental purposes, etc., which is currently about 32–35 thousand tons/year (Ministry of Industry and Trade (MOIT), 2021).

- Chemical – refinery. Hydrogen is produced and consumed on site at local refineries where grey hydrogen produced through steam reforming technology is used in the hydro treatment processes. Vietnam has two operating refinery plants (Dung Quat Refinery and Nghi Son Refinery. Hydrogen demand for these kinds of plants is up to 177 thousand tons per year (Vietnam Petroleum Institute, 2021).
- Industry – steel. Vietnam has 11 steel plants with a combined annual production capacity of 27,780 million tons per year. Local steel industries mainly use grey hydrogen in the annealing of steel after cold rolling. Current hydrogen demand in steel annealing is estimated at 16.7 million Nm^3 or 2,270 tons/year (Vietnam Petroleum Institute (VPI) and Power Engineering Consulting Joint Stock Company 4 (PECC4), 2021) .
- There is high potential for hydrogen use in the steel-making process either via the primary blast furnace (BF) route or via the electric arc furnace (EAF) route.
- Industry – glass production. Hydrogen is used in the annealing process of float glass production. There are 8 float glass production plants in Vietnam.
- Industry – semiconductor industry as a carrier gas. There are 2 semiconductor manufacturing plants in Vietnam.

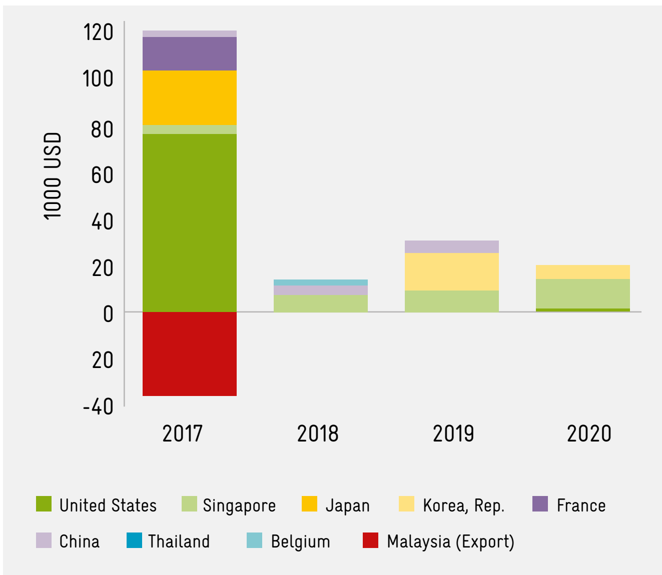
Over the 4-year period form 2017-2020, on average, Vietnam imported about USD 50 k p.a. of hydrogen with 2017 being an exception due to very high imports from the US and exports to Malaysia. As shown in the following figures, Vietnam is a net importer of ammonia with an estimated 150,000 ton/year, amounting to about USD 45,000 m/year with rather stable volumes coming from Indonesia and Malaysia (World Bank, 2022). Most significantly, Vietnam is an importer of methanol, primarily from Malaysia and Brunei, with an annual volume of around 250,000 tons, which represents about USD 80,000 m of methanol imports per year (World Bank, 2022).

FIGURE 7. VIETNAM'S TOTAL TRADE BALANCE BY FEEDSTOCK 2017–2020



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2022)

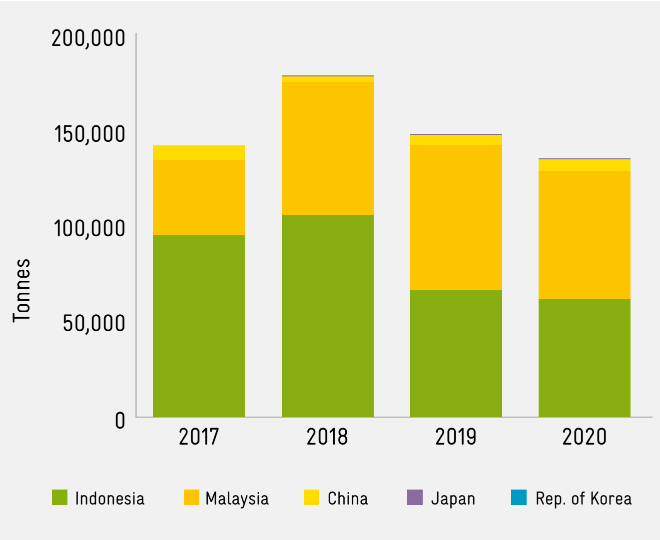
FIGURE 8. VIETNAM'S HYDROGEN IMPORTS/EXPORTS BY COUNTERPARTY 2017–2020



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2022)

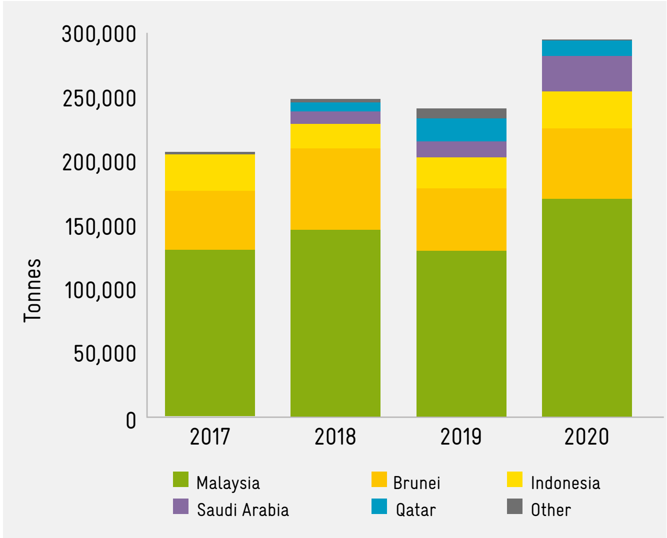
Trade volumes for hydrogen are not available. However, assuming hydrogen costs of around USD 3/kg, annual hydrogen imports of USD 50 k represent approximately 16 tons of imported H_2 annually (World Bank, 2022).

FIGURE 9. AMMONIA IMPORTS TO VIETNAM BY COUNTERPARTY **2017–2020**



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2022)

FIGURE 10. METHANOL IMPORTS TO VIETNAM BY COUNTERPARTY 2017–2020



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2022)

The main imported hydrogen-based products to Vietnam are pure hydrogen, ammonia and methanol, with the latter two accounting for almost 99% of the total imported value. Key derivative products where ammonia is used are mostly found in urea for fertiliser production. There are currently 4 main fertiliser plants operating in Vietnam, which consume over 300,000 tons of grey hydrogen per year. Given the country's ambitious targets to phase out the coal plants before 2040 and become net-zero in 2050, diversification of the energy sources is crucial to achieving the set objectives. In addition, producing green ammonia on-site would bring multiple benefits to the country's economy, including reduced dependency on imports and risks associated with the market price fluctuations, and will help to reduce GHG emissions. In addition, methanol could also be used for power generation purposes to move further away from fossil-fuelled plants.

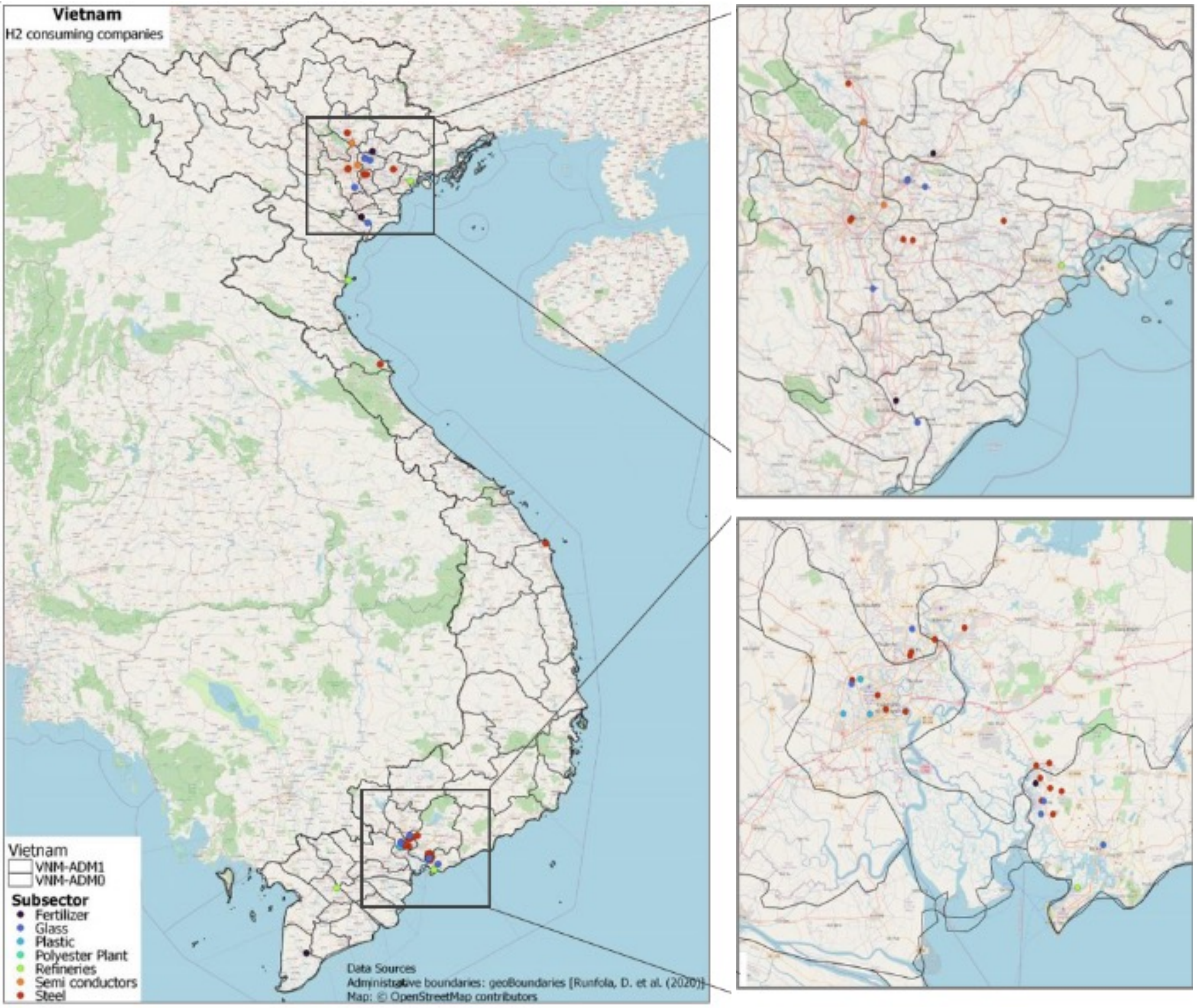
While pure hydrogen volumes represent the smallest share of imports, there is considerable potential to develop green hydrogen production capacities for both the refinery and steel sectors. Vietnam has 11 steel plants with a combined annual production capacity of 27,780 million tons per year, with the steel sector being a significant contributor to industrial emissions and the environmental impact. There is high potential for hydrogen use in the steel-making process, either via the primary BF route or via the EAF route. In the case of the BF route, around 90% of emissions comes from the coke plant and blast furnace that uses pulverised coal or natural gas as reducing agents. Alternatively, green hydrogen could be used in these processes and partially replace coke or natural gas in the steel-making process. In the EAF process, iron ore could be reduced directly by hydrogen while in solid state to "direct reduced iron" (DRI) instead of coke (Roland Berger, 2020). Today there are no plants using hydrogen for steel production processes; switching to green hydrogen use in the sector could be a major innovative achievement, significantly reducing plants' carbon footprints.

Pure hydrogen is also widely used in refining processes, mainly in hydrocracking and hydrotreating, to convert crude oil into refined petroleum products. In Vietnam, most of the grey hydrogen used is produced through steam methane reforming (SMR) or coal gasification processes, with the average hydrogen plant demand reaching up to 177,000 tons per year. Given the highly fluctuating prices of natural gas and coal, and very high GHG emissions during the hydrogen production process, hydrogen generated via water electrolysis using wind, solar or the country's abundant hydropower resources could be a viable alternative.

Vietnam imports significant volumes of methanol to meet the needs of its chemical, pharmaceutical and construction industries. This indicates the potential for local production of green methanol and its development for use in the transportation and chemical sectors. The automotive sector accounts for the largest share of global green methanol end-use as the government places more focus on switching to sustainable fuels and achieving climate goals. It is difficult to estimate the potential demand at this stage, but introducing green methanol as an additive to fossil-based fuels could be an initial step towards reducing the country‘s dependence on imported fossil fuels for transportation. The second main use of methanol is in the chemical industry, namely plastics, paints and solvents, and green methanol could serve as a sustainable alternative to traditional fossil-based methanol.

The primary hydrogen-using sectors are clustered in the north and south of the country (see Figure 11). The following section will provide a more detailed view of the hydrogen processes used in selected key sectors within the country.

FIGURE 11. INDUSTRIAL SECTORS CURRENTLY USING HYDROGEN-BASED PRODUCTS



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

2.4 P-to-X technology

In this analysis, the PtX technologies green hydrogen and green ammonia will be considered from a techno-economic viewpoint.

2.4.1 Green hydrogen production process

In the context of Power-to-X systems, green hydrogen is produced via the electrolysis of water, using electricity and water as input to produce hydrogen as the main product. The electrolysis of water is an electrochemical process in which water is electrochemically dissociated into its molecular components – hydrogen and oxygen.

The main inputs for the electrolysis process are pure water – which needs to be supplied in demineralised quality – and electricity – which needs to be supplied as direct current either from a Direct Current (DC) power source or an Alternating Current (AC) power source after conversion. Depending on the electrolyser type, the average pure water demand is 14 litres of water per kg of hydrogen produced. The main product of the electrolysis process is hydrogen in gaseous form. Oxygen and waste heat are produced as by-products, which can be utilised for external applications.

There are different water electrolysis technologies, of which alkaline electrolysis (AEL) and proton exchange membrane (PEM) electrolysis are currently the most mature technologies for low-temperature systems. Other electrolysis technologies include anion exchange membrane (AEM) and high-temperature solid oxide (SOEC) electrolysis which are currently in the prototype (AEM) and demonstration phase (SOEC), respectively.

The electrolysis process itself is dependent on technology and is characterised by different electrochemical and process parameters.

The main hydrogen production process takes place in the electrolysis cell stacks, which are composed of multiple individual cell modules. At plant level, electrolysis plants include various subsystems for the supply of utilities to the cell stacks. These subsystems include, for example, water treatment, gas treatment, cooling, power conversion and distribution as well as instrumentation and control systems.

Electrolysis plants are characterised by a modular design approach, with currently available designs in the range of 1 MW (small-scale) and 100 MW or more (large-scale). Small-scale electrolysis plants can be delivered as turnkey units based on standardised solutions, while large-scale electrolysis plants are developed as project-specific solutions based on predefined subsystems.

TABLE 2. OVERVIEW OF MAIN CHEMICAL REACTIONS OF ALKALINE AND PEM ELECTROLYSIS CELLS

Technology	Cathodic reaction (hydrogen evolution reaction)	Charge carrier	Anodic reaction (oxygen evolution reaction)
Alkaline electrolysis	$H_2O + 2e^- \rightarrow H_2 + 2OH^-$	OH^-	$2OH^- \rightarrow 0.5\ O_2 + H_2O + 2e^-$
PEM electrolysis	$2H^+ + 2e^- \rightarrow H_2$	H^+	$H_2O \rightarrow 0.5\ O_2 + 2H^+ + 2e^-$

Source: Authors' own table, ENGIE Impact GmbH (2023)

TABLE 3. OVERVIEW OF MAIN PERFORMANCE VALUES OF ALKALINE AND PEM ELECTROLYSIS

	Alkaline electrolysis	PEM electrolysis
Stack efficiency range at full load (LHV)	48–50 kWh/kg ~67–70%	48–52 kWh/kg ~64–70%
Operating temperature range	50–80°C	50–80°C
Operating pressure range	0.15–30 barg	0.15–40 barg
Operating range per module	20–100%	10–100%

Source: Authors' own table, ENGIE Impact GmbH (2023)

2.4.2 Green ammonia production process

Wind- or solar-based green ammonia production requires the separate production of both hydrogen and nitrogen. Within the scope of this study, hydrogen is generated by electrolysis. Nitrogen is obtained from ambient air and, from a technical point of view, can be produced in three different ways: cryogenic distillation (ASU – air separation unit), pressure swing adsorption or separation using a membrane process. All processes are commercially viable and primarily require electrical energy. The process of cryogenic distillation has the lowest specific energy consumption. Hydrogen and nitrogen are then introduced downstream into an ammonia synthesis loop. With a starting material ratio of 18% by hydrogen weight to 82% by nitrogen weight, ammonia is produced by means of catalytic synthesis – also known as Haber-Bosch synthesis – at temperatures between 300°C and 500°C and high pressures of up to 300 bar. Full conversion to ammonia cannot be achieved in a single pass due to the equilibrium conditions of the Haber-Bosch reaction. Consequently, the overall yield of the plant can be increased by implementing a so-called recycling loop to recycle unreacted reactants.

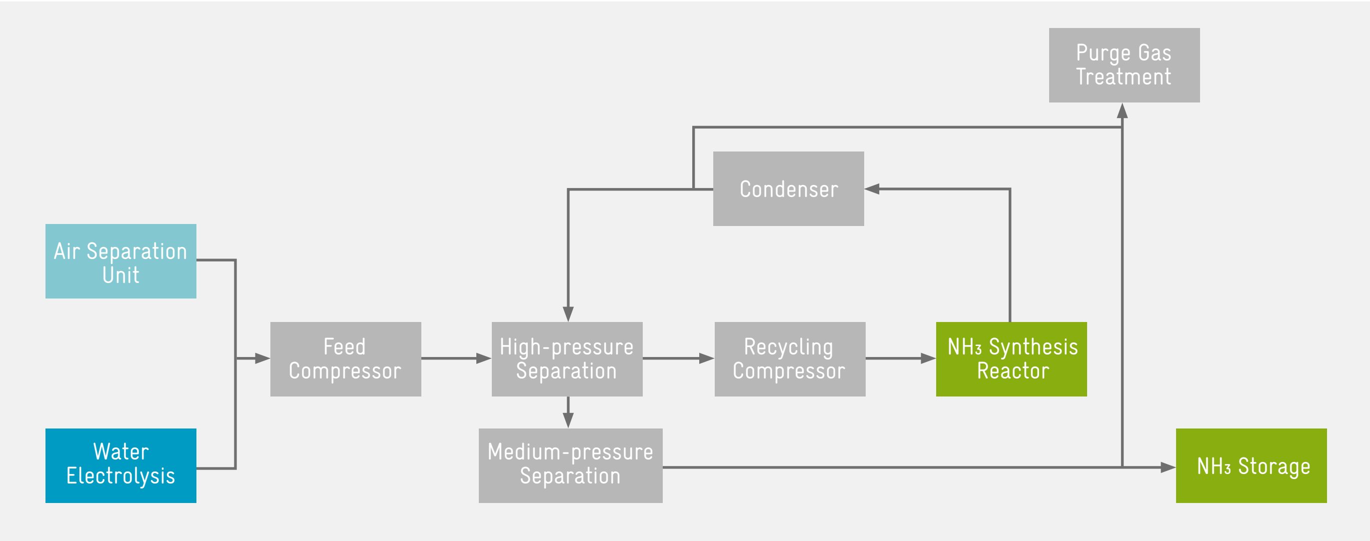
TABLE 4. OVERVIEW OF HABER-BOSCH SYNTHESIS CONDITIONS

Technology	Reaction	Process conditions	Specific consumption for 1 kg NH_3
Haber-Bosch synthesis	1.5 H_2+0.5 $N_2 \leftrightarrow NH_3$	300°C to 500°C up to 300 bar	0.18 kg H_2 0.82 kg N_2

Source: Authors' own table, ENGIE Impact GmbH (2023)

During green ammonia production, attention should be paid to ensure that Haber-Bosch synthesis is effected in a constant operating mode when possible. The same applies to cryogenic air separation for the supply of nitrogen. In contrast, PEM electrolysis can be "ramped up or down" under changing current loads. Therefore, when developing the overall process, appropriate compensation of load changes on the upstream side must be taken into account. Consideration should also be given to how constant production quantities can be ensured for the consumer market. The figure below provides an overview of the green ammonia production process.

FIGURE 12. GREEN AMMONIA PROCESS



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (EPCM, 2023)

2.5 PtX costs

A set of technical and economic assumptions are defined for the calculation of the levelised cost of hydrogen as well as for the business case calculations, which are summarised in Table 5 and Table 6. The cost assumptions are differentiated between medium (5 MW) and large-scale (100 MW) system sizes in order to show economies of scale. Note that the capital expenditures (CAPEX) assumptions are based on the total installed cost (TIC), including direct costs for equipment supply and indirect costs for plant installation and design.

The technical assumptions are based on average values, common per technology, without differentiation between plant scale.

TABLE 5. TECHNICAL AND ECONOMIC ASSUMPTIONS FOR THE ELECTROLYSIS SYSTEM

		PEM		Alkaline		AEM	SOEC
		Large-scale	Medium-scale	Large-scale	Medium-scale	Small-scale	Small-scale
Spec. CAPEX	EUR/kW	1,300	2,700	840	1,900	4,683	3,650
Spec. fixed OPEX	EUR/kW/year	15	20	20	25	19	32
System efficiency	% LHV	62%	62%	62%	62%	62%	81%
Efficiency degradation	%/year	1.3%	1.3%	1%	1%	1.3%	4%
Stack operational lifetime	hours	65,000	65,000	60,000	60,000	35,000	20,000
Spec. tap water consumption	L/kg H_2	14	14	14	14	14	14
Operating pressure	barg	30	30	0.15	0.15	35	0.15

Source: Authors' own table, ENGIE Impact GmbH (2023)

TABLE 6. TECHNICAL ASSUMPTIONS FOR THE HYDROGEN COMPRESSION AND STORAGE SYSTEM

		PEM		Alkaline		AEM	SOEC
		Large-scale	Medium-scale	Large-scale	Medium-scale	Small-scale	Small-scale
Delivery pressure	barg	100	100	100	100	100	100
Spec. compression power	kWh/kg	0.7	0.7	2.8	2.8	0.7	2.8
Max. storage pressure	barg	100	100	100	100	100	100
Max. storage autonomy	hours	72	72	72	72	72	72

Source: Authors' own table, ENGIE Impact GmbH (2023)

2.5.1 Green ammonia production costs

The following provides an illustrative example of the cost of green ammonia production when considering a capacity of a 300 tpd ammonia synthesis plant. Table 7 summarises the technical assumptions. Based on the Haber-Bosch reaction, the hypothesis is that a complete conversion of hydrogen and nitrogen into ammonia takes place via the ammonia synthesis cycle. Green hydrogen is produced using PEM electrolysis with a specific consumption of 50 kWh/kg H_2. The total specific consumption for the ammonia synthesis loop, including nitrogen generation, is about 1.2 kWh/kg NH_3. Hence a total of approx. 10 kWh of energy is required to produce 1 kg of NH_3, of which H_2 production is a major component.

TABLE 7. TECHNICAL ASSUMPTIONS FOR GREEN AMMONIA PRODUCTION

Specific Technical Assumptions		
H_2 demand	0.18	kg H_2 /kg NH_3
N_2 demand	0.82	kg N_2 /kg NH_3
PEM electrolysis (50 kWh/kg H_2)	8.8	kWh/kg NH_3
NH_3 synthesis (incl. ASU)	1.2	kWh/kg NH_3
Total energy demand	**10** 36	**kWh/kg NH_3** MJ/kg NH_3

Source: Authors' own table, ENGIE Impact GmbH (2023)

Table 8 summarises the capacity and price assumptions. To produce 300 tpd of ammonia, 53 tpd of hydrogen and 247 tpd of nitrogen are required. The production cost calculation considers levelised hydrogen production costs of EUR 8/kg H_2. The energy required for the NH_3 synthesis including ASU is assumed to be provided via grid electricity at EUR 0.16/kWh. As noted previously, due to the cryogenic process, ASU cannot be "ramped up and down" depending on the availability of renewable energy, but must remain relatively constant 24 hours a day. The total investment cost for the NH_3 synthesis loop including the ASU is approx. EUR 82 million.

TABLE 8. GREEN AMMONIA CAPACITY AND PRICING ASSUMPTIONS

Capacity and Pricing Assumptions	
NH_3 capacity	300 tpd NH_3
H_2 demand	53 tpd H_2
N_2 demand	247 tpd N_2
CAPEX NH_3 synthesis (incl. ASU)	EUR 82 m
LCoH	EUR 8/kg
Grid electricity cost	EUR 0.16/kWh

Source: Authors' own table, ENGIE Impact GmbH (2023)

Table 9 shows the specific production costs separated according to the shares for H_2 and NH_3 synthesis. Both shares consider operating costs and TIC. When calculating the specific cost shares for NH_3 synthesis, a depreciation period of 10 years and 8,000 annual operating hours are assumed.

TABLE 9. GREEN AMMONIA SPECIFIC PRODUCTION COSTS

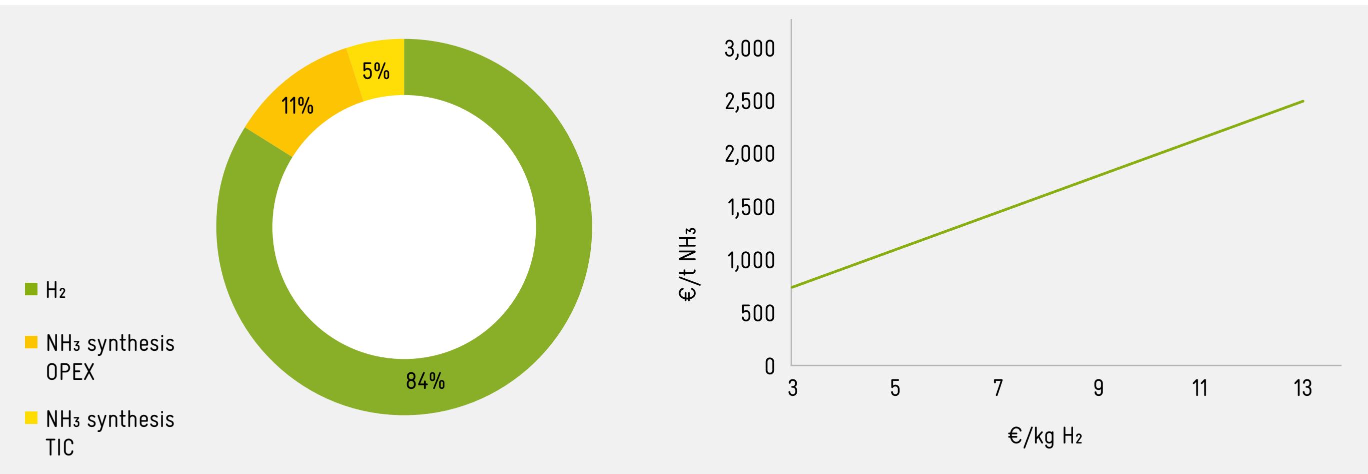
Specific Production Costs

	H_2	NH_3 synthesis	Total
EUR/t NH_3	1,412	274	1,686
	84%	16%	100%

Source: Authors' own table, ENGIE Impact GmbH (2023)

As with the specific energy requirement, the calculation shows that the main cost driver is hydrogen production. At around 84%, this is more than three quarters of the total production costs of ammonia. The 16% NH_3 synthesis cost is divided into 11% operating costs and 5% TIC. The influence of the levelised cost of hydrogen on NH_3 production is shown in Figure 13.

FIGURE 13. IMPACT OF H_2 PRICE ON THE LCOA



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

2.5.2 Levelised cost of hydrogen

The green hydrogen production potential from solar PV energy in Vietnam and the associated levelised cost of hydrogen production were estimated. For this purpose, a high-level geographical analysis has been performed, estimating the regional hydrogen production potential and specific cost based on the local solar potential. A map of the solar PV capacity factor with assumptions can be found in the Appendix in Figure 14 and Table 17.

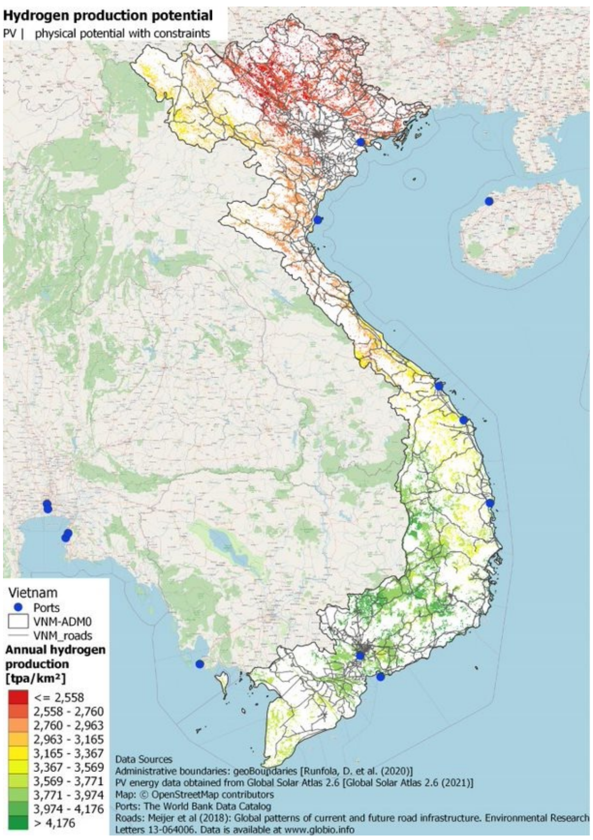
In the geographic information system (GIS) analysis, the technical hydrogen production potential is estimated. The technical production potential describes the maximum annual hydrogen quantity that can be produced in a defined area, considering the local PV energy yield, conversion efficiencies (electrolysis) as well as land-use constraints. Land-use constraints are applied according to the level 2 constraints based on the Energy Sector Management Assistance Program (ESMAP) (ESMAP Global Solar Atlas, 2020), which considers areas with rugged terrain, extreme remoteness, built-up environments, dense forests and, additionally, cropland and conservation areas as exclusion areas for the installation of solar PV plants. Therefore, areas with these land-use constraints are excluded from the analysis and the overall production potential (for electricity and hydrogen) is reduced accordingly.

Due to the land-use constraints applied, in regions with high population densities, complex terrain or large nature reserve areas, locally large areas are considered as unsuitable for hydrogen production. The exclusion areas are shown as white space on the following colour maps. Due to the land-use constraints, several areas were not considered for the production of hydrogen, including the northeastern region of Vietnam (Hà Giang, Lào Cai and Yên Bái provinces), north central coast region (Hà Tĩnh and Quảng Bình provinces) and Mekong Delta region.

Figure 14 gives an indication of the maximum technical H_2 potential (MTHP) for a specified area, taking into account the land-use restrictions. The average specific H_2 potential for Vietnam is 3,300 tpa/km². The specific MTHP for the Ninh Thuận province is 4,116 tpa/km². Other areas with significant potential in the southern part of the country are the Bình Thuận and the Tây Ninh provinces, with estimated specific MTHP of 4,113 tpa/km² and 4,116 tpa/km², respectively. Note that local water constraints are not considered on the hydrogen potential maps and must be assessed on a case-by-case basis.

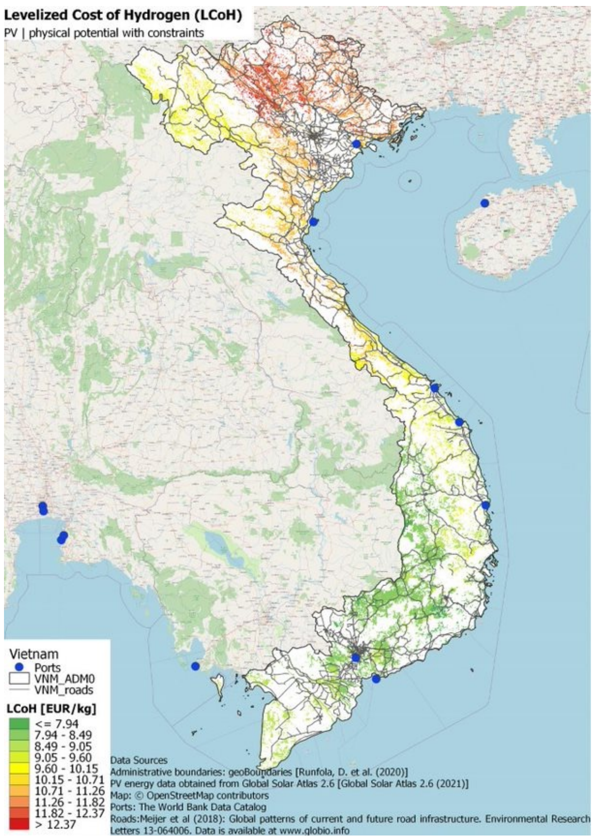
As can be seen, the areas with the greatest potential are located in the southern parts of the country. The proximity of the Bà Rịa–Vũng Tàu province would be advantageous if a project were to be set up to produce green hydrogen for export. The areas with most land without constraints can be observed in the central highlands and southeast regions.

FIGURE 14. HYDROGEN PRODUCTION POTENTIAL



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 15. LEVELISED COST OF HYDROGEN (LCOH)



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

Figure 15 shows the spatial distribution of the levelised cost of hydrogen (in EUR/kg) in Vietnam taking into account land-use constraints (level 2 constraints). The spatial distribution of the LCoH is directly proportional to the local irradiance and power yield of the PV plants.

The lowest LCoH level of EUR ≤ 7.94/kg can be observed in the southern regions (Lâm Đ ồng, Bình Phước, Ninh Thuận and Bình Thuận provinces), while the highest LCoH level of USD > 12.37/kg can be observed in the northern regions in the Hà Giang, Lào Cai, Yên Bái, Tuyên Quang, Bắc Kạn and Thái Nguyên provinces. In the Appendix, Figure 20 and Figure 21 show the H_2 production potential and LCoH without land-use constraints and H_2 production potential.

The capacity factor for PV, the average specific hydrogen production potential per region, the total hydrogen production potential per region and the calculated average levelised cost of hydrogen per region are shown in the table below. The top 5 locations in terms of renewable energy and hydrogen production potential in Vietnam are shown in Table 10; the complete table with all locations can be found in the Appendix.

TABLE 10. SUMMARY OF PV AND GREEN HYDROGEN PRODUCTION POTENTIAL BY REGION

Region	PV capacity factor [%]	Theoretic green hydrogen production potential		LCoH
		Area-specific potential [tpa/km²]	Total potential [tpa]	[EUR/kg]
Ninh Thuận	17.50%	4,116	926,135	7.84
Bình Thuận	17.44%	4,113	3,039,529	7.87
Tây Ninh	17.16%	4,045	1,201,444	7.98
Bình Phước	17.01%	3,997	12,804,988	8.06
Bà Rịa–Vũng Tàu	16.98%	3,941	1,820,711	8.22

Source: Authors' own table, ENGIE Impact GmbH (2023)

3 POTENTIAL GREEN HYDROGEN BUSINESS CASES

3. Potential Green Hydrogen Business Cases

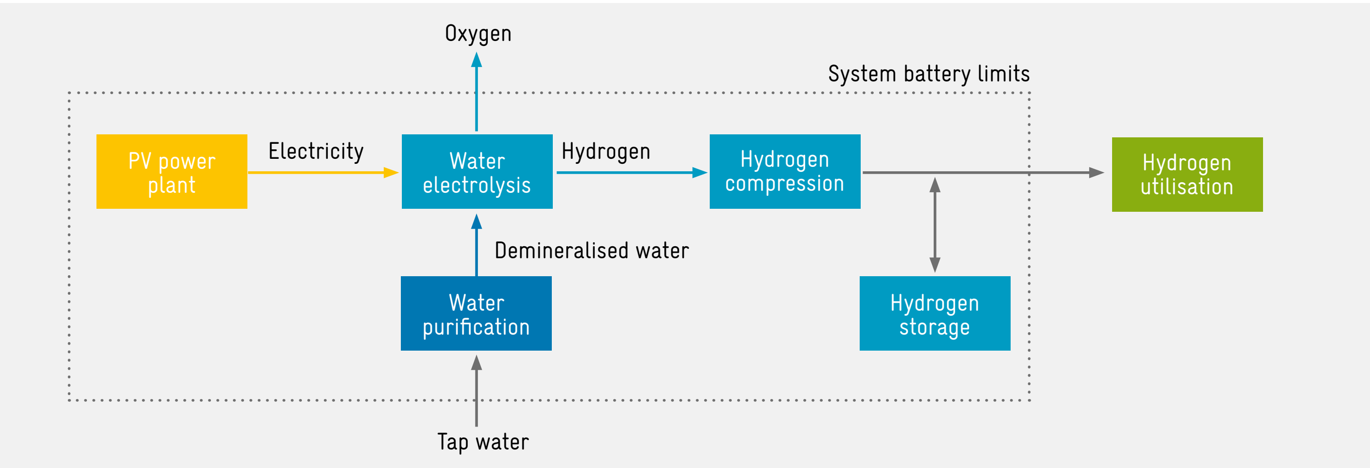
To understand the potential interest of local businesses in Vietnam in converting from current conventional hydrogen consumption to producing their own green hydrogen, detailed research was conducted with private sector representatives. The main source of information were industry interviews with current grey hydrogen users, during which they were asked about their hydrogen processes, motivation for interest in green hydrogen production, perceived challenges in converting to local green hydrogen production, hydrogen (or derivative product) demand and cost levels, land availability for PV and access to sufficient water. A list of topics discussed can be found in the Appendix in Table 19. The attached list is not exhaustive and additional informal discussions, e-mail exchanges and literature reviews were used to gain a full picture of the private sector in Vietnam and its willingness to convert to green hydrogen. This was further supplemented by a detailed industry sector analysis. Based on this information, illustrative business cases were developed which represent typical sector scenarios replacing grey hydrogen used in the manufacturing process with green hydrogen.

The premise of the business cases is the replacement of current grey hydrogen with locally produced green hydrogen, which would be created solely using carbon-free electricity supplied from on-site solar PV. These business cases focus on current grey hydrogen consumers where the hydrogen, or hydrogen derivative product, is either a production feedstock or an element in the current manufacturing process (e.g. process gas). Use cases for hydrogen as a thermal or energy carrier or as a transportation fuel are not considered within this study. The production concept for the business cases is shown in Figure 16.

For each business case, a high-level cost-benefit analysis was carried out based on estimated sizing and cost of the electrolyser system and solar PV plant, as well as the LCoH as per the local solar resource. To estimate the system cost, the PV and the electrolysis system are sized to meet the H_2 demand, and it is assumed that both are implemented as a combined greenfield project without pre-existing equipment. The methodology for the calculation is described in the Appendix and the key assumptions used are shown in Table 20.

When considering green hydrogen production solely powered by PV electricity, due to the variable nature of the solar resource, the sizing of system components will be influenced by the operational mode of the H_2 used in the end production process. Although the same volume in annual tons of H_2 produced is the same, for business operations where a constant or baseload supply of hydrogen is required, the PV plant must be oversized to ensure minimum baseload production even during non-peak solar resources. In cases where flexible production is possible, i.e. production scheduled following the solar resource, then PV plants could be significantly smaller, but the electrolyser would need to be oversized to fully utilise solar peak production. The choice between flexible and baseline H_2 production also has a significant impact on system costs and the resulting LCoH, particularly in cases where extra electricity from the PV plan can be sold back to the grid, which can account for substantial additional revenue. Please see the Appendix for a detail explanation.

FIGURE 16. GREEN HYDROGEN PRODUCTION CONCEPT



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (Gulf Energy, 2023)

For each case, the complete LCoH is calculated. In addition, the "effective" LCoH is calculated by adding back the discounted value of electricity sales revenue and oxygen sales revenue, which are benefits which would not accrue without the project. Finally, the effective LCoH is also provided for informational purposes, also taking into account the value of avoided GHG emissions.

The LCoH presented in the case studies varies from the global specific LCoH presented on the GIS maps as the GIS maps represent simplified costs of production, which is a common standard methodology, and are comparable to what is found on the LCoH in literature and other studies. The LCoH in the business cases, on the other hand, include additional costs which the company will likely incur, for example, import taxes (when applicable), inflation on operational expenditures (OPEX), capitalised financing costs and increased CAPEX and OPEX related to system sizing (or oversizing) required to achieve the specified H_2 production profile, as well as additional oversizing of the PV field to ensure a minimum level of annual production taking into account degradation of both the PV and the electrolyser system over time, which requires adding significant additional PV capacity. Together, these result in an LCoH which can, in some cases, vary significantly from the simplified specific production costs.

Given the comparatively low plant utilisation rates, due to the variable solar resource and lack of economies-of-scale production, small-scale local green hydrogen is not currently cost-competitive with conventional sources on a specific cost-of-production basis. However, as electrolyser technology costs come down and the decarbonisation of industry takes on a more important role with financial consequences, for example, through carbon tax, this could change. Therefore, the business cases set out to determine what it would take in terms of financial support to make the local production of green hydrogen, powered by solar PV, cost-effective for local businesses in Vietnam.

Note: the business cases are intended for illustrative purposes only and do not represent an actual company.

3.1 Case 1. Green hydrogen to ammonia for fertiliser

A fertiliser production company located in the Ca Mau region of Vietnam currently produces hydrogen through the SMR process, utilizing natural gas as the feedstock, which it further processes into ammonia and urea for fertiliser production.
For its corporate decarbonisation strategy, it intends to convert a share of its production to green ammonia produced from green hydrogen. Over the first two phases this will require a volume of 5,000 tons of green hydrogen annually (~77.66 tons/day) to produce 28,333 tons NH_3 annually.

Given that ~18% hydrogen, and ~82% nitrogen is required to produce ammonia is required, for 28,333 tons/year of NH_3 production, 5,000 tpa H_2 is required.

Given the solar resource in the southern region of Vietnam, to produce 5,000 tpa of H_2 in baseload operational mode a 405 MW PV plant and a 107 MW electrolyser would be required. In flexible operation mode, the PV plant would only need to be 246 MW and the electrolyser system would need to be sized at 185 MW. The upfront investment cost for baseload operation is around 15% higher than that for flexible operation. About 40,000 tons of oxygen per year would be produced as a by-product of the hydrogen production process, which could be sold to industrial users (assumed price EUR 0.40/kg). The table below shows system sizing for both flexible and baseline operational modes.

TABLE 11. BUSINESS CASE 1. GREEN HYDROGEN TO AMMONIA FOR FERTILISER PRODUCTION SYSTEM SIZING

System Sizing	Flexible Operation	Baseload Operation
Installed PV power (kWp)	246,546	405,659
Design power electrolysis (kW)	185,525	107,897
Annual net electricity generation PV (kWh/year)	357,199,064	587,723,703
Annual net electricity consumption EL (kWh/year)	268,790,323	268,790,323
Total investment cost (EUR thousand)	377,601	438,197

Source: Authors' own table, ENGIE Impact GmbH (2023)

The complete assumptions are show in Table 20 in the Appendix.

Using the cost assumptions as described in Section 3.2 for AEL technology, the resulting specific LCoH is EUR 12.16/kg in baseload operation and EUR 10.3/kg with flexible operation sizing. However, when considering the equivalent value of the surplus PV electricity which could be sold back to the grid, as well as revenue from oxygen sales, the resulting effective LCoH is EUR 4.71/kg with baseload operation compared to EUR 6.4/kg with flexible operation sizing.

The key difference is the volume of extra electricity which could be sold, effectively lowering the LCoH by EUR 4.3/kWh. In the baseload case, revenue from the sale of extra electricity and oxygen would cover more than 2/3 of the green H_2 production cost.

Given the target LCoH of EUR 3.09/kg to achieve price parity with conventional H_2 sources, subsidies equalling EUR 3.31/kg or the equivalent of a CAPEX grant of EUR 164 m would be required with flexible operation sizing and EUR 1.62/kg or the equivalent of a EUR 80 m CAPEX grant with baseload operation sizing would be required.

The breakdown of the LCoH for the business case is presented in the following table.

TABLE 12. BUSINESS CASE 1. GREEN HYDROGEN FOR AMMONIA PRODUCTION LCOH BREAKDOWN

Levelised Cost of Hydrogen	Flexible Operation	Baseload Operation
	EUR/kg	EUR/kg
Levelised Cost of Hydrogen	**10.30**	**12.16**
Equivalent levelised value of benefits per kg H_2 produced		
Equivalent value of oxygen revenue per kg H_2 produced	3.20	3.20
Equivalent value of electricity revenue per kg H_2 produced	0.70	4.26
Effective LCoH (incl. electricity and oxygen sales)	6.40	4.71
Effective LCoH (incl. revenue + CO_2 avoided costs)	5.61	3.92
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Required Subsidies		
Effective green H_2 LCoH	6.40	4.71
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Price gap between effective green LCoH and target LCoH [EUR/kg]	3.31	1.62
Subsidy required to achieve target (investment subsidy in EUR)	164,486	79,912

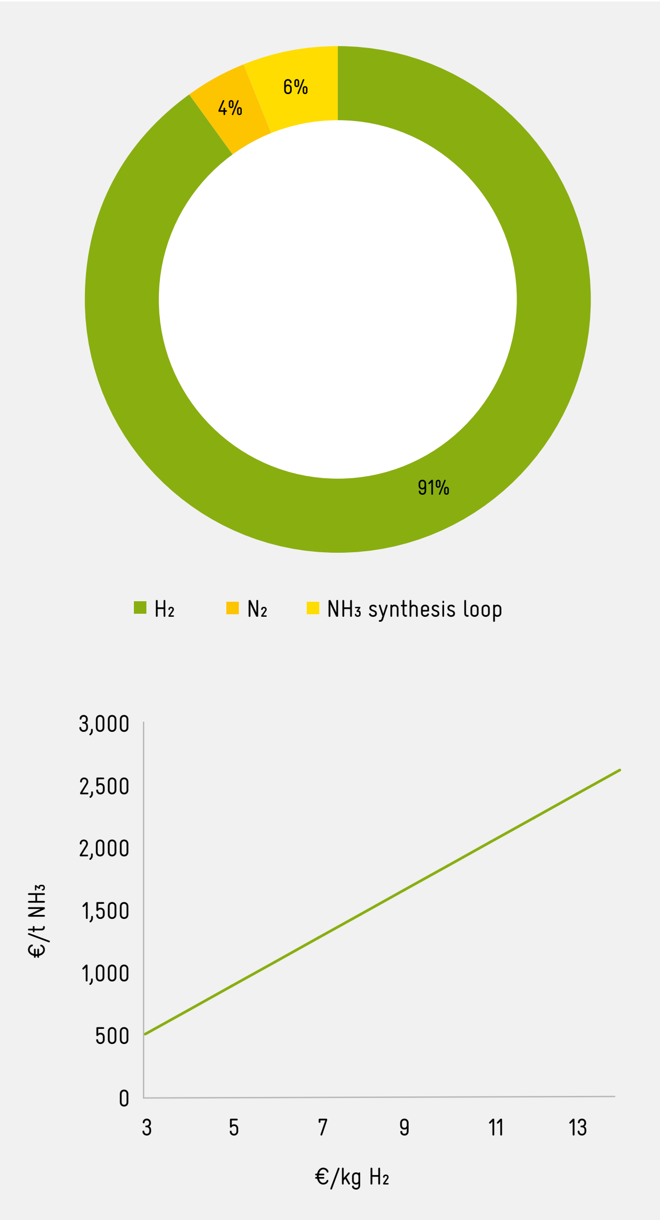
Source: Authors' own table, ENGIE Impact GmbH (2023)

The replacement of conventional H_2 with green H_2 would result in a reduction of 50,000 tpa in CO_2 emissions, which has a cost of carbon of over EUR 100 million (assuming High-Level Commission on Carbon Prices) over the 25-year lifetime of the plant.

The next step in the process is to convert the green H_2 to NH_3.

Given the small size of the ammonia plant, the CAPEX is estimated to be EUR ~34.04 m (around EUR 131/ton annual capacity). Applying the previously calculated LCoH of EUR 12.16/kg H2 and the local cost of electricity of EUR 0.07/kWh for the ASU, the resulting levelised cost of ammonia (LCoA) would be EUR 2,362/ton and would range from EUR 745-2,686/ton, based on the different effective LCoH presented.

FIGURE 17. IMPACT OF THE H_2 PRICE ON LCOA FOR CASE 1



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

3.2 Case 2. Green hydrogen as a process gas

A glass manufacturing company located in the region of Phu My, in southern Vietnam, currently uses hydrogen as a process gas in its production process. It requires a volume of 95 tpa, purchased from local suppliers.

Given the solar resource in the southern region of Vietnam, to produce 95 tpa of H2 in flexible mode a 4.86 MW PV plant and a 3.52 MW electrolyser would be required. As the PV would produce around 6.79 GWh electricity per year and the electrolyser system uses only 5.11 GWh, the remaining 1.98 GWh per year could be sold to the grid or used to offset electricity consumption in other parts of the production facility.

In addition, 760 tons of oxygen per year would be produced as a by-product of the hydrogen production, which could be sold to industrial users (assumed price EUR 0.40/kg). If baseline operation sizing was used, then to ensure consistent minimum production throughout the day the PV plant would need to be oversized at 7.71 MW and the electrolyser system size could be reduced to 2.05 MW. This would result in nearly 60% more electricity production for almost the same initial investment cost and the resulting "extra" electricity could be sold, generating an additional revenue stream, or used to offset electricity consumption in other parts of the production facility.

TABLE 13. BUSINESS CASE 2. GREEN HYDROGEN AS A PROCESS GAS

System Sizing	Flexible Operation	Baseload Operation
Installed PV power (kWp)	4,684	7,708
Design power electrolysis (kW)	3,525	2,050
Annual net electricity generation PV (kWh/year)	6,786,782	11,166,750
Annual net electricity consumption EL (kWh/year)	5,107,016	5,107,016
Total investment cost (EUR thousand)	10,925	10,548

Source: Authors' own table, ENGIE Impact GmbH (2023)

The complete assumptions are show in Table 20 in the Appendix.

Using the cost assumptions as described in Section 3.5 for AEL technology, the resulting specific LCoH is EUR 14.73/kg in baseload operation and EUR 14.60/kg with flexible operation sizing. However, when considering the equivalent value of the surplus PV electricity which could be sold back to the grid, as well as revenue from oxygen sales, the resulting effective LCoH is EUR 7.28/kg with baseload and EUR 10.69/kg with flexible operation sizing. As both methods have nearly the same investment costs and produce the same volume of H_2 annually, the difference is in the value of the sales of the extra electricity, which in the baseload case contributes an equivalent value of EUR 4.26/kg of H_2 produced.

Given the target LCoH of EUR 3.09/kg to achieve price parity with conventional H_2 sources, subsidies equalling EUR 7.61/kg or the equivalent of a CAPEX grant of EUR 7,362 k would be required with flexible operation sizing and EUR 4.19/kg or the equivalent of a EUR 3,931 k CAPEX grant with baseload operation sizing would be required.

The breakdown of the LCoH for the business case is presented in the following table.

TABLE 14. BUSINESS CASE 2. GREEN HYDROGEN AS A PROCESS GAS LCOH BREAKDOWN

Levelised Cost of Hydrogen	Flexible Operation	Baseload Operation
	EUR/kg	EUR/kg
Levelised Cost of Hydrogen	**14.60**	**14.73**
Equivalent levelised value of benefits per kg H_2 produced		
Equivalent value of oxygen revenue per kg H_2 produced	3.20	3.20
Equivalent value of electricity revenue per kg H_2 produced	0.70	4.26
Effective LCoH (incl. electricity and oxygen sales)	10.69	7.28
Effective LCoH (inc. revenue + CO_2 avoided costs)	9.91	6.49
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Required Subsidies		
Effective green H_2 LCoH	10.69	7.28
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Price gap between effective green LCoH and target LCoH [EUR/kg]	7.61	4.19
Subsidy required to achieve target (investment subsidy in EUR)	7,362	3,931

Source: Authors' own table, ENGIE Impact GmbH (2023)

The replacement of conventional H_2 with green H_2 would result in a reduction of 950 tons/year in CO_2 emissions, which has a cost of carbon of over EUR 2 million over the 25-year lifetime of the plant.

3.3 Business case conclusions

As can be seen in the illustrative business cases, the production of green hydrogen solely by means of solar energy will require significant financial incentives over the short, medium and long term to become cost-competitive with conventional H_2 sources. This is due to the required system "oversizing" needed to enable the constant production of H_2, as well as a lack of economies of scale due to the small production sizes compared to large centralised production. Alternative sources of green energy could be harnessed to reduce the required system size and increase plant utilisation enabling 24/7 production, thus significantly lowering the overall LCoH.

The business cases further demonstrate the significant impact of system sizing on the overall financial feasibility due to operational method, tapping into additional revenue streams and financial support structure. Although oversizing the PV system increases the overall initial investment cost, in most cases the resulting revenue from the sale of "extra" green energy more than offsets this cost and serves to subsidise the cost of H_2 production. Furthermore, financial incentives such as grants for the PV or electrolyser system could help to enable small-scale decentralised production of green H_2 to become financially viable in the medium term.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4 THE WAY FORWARD

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4. The Way Forward

4.1 Challenges and considerations for hydrogen implementation

Considerations for the implementation of renewable energy and electrolysis facilities for hydrogen production at existing industrial facilities include:

- **Investment costs.** High investment costs leading to production costs that are higher than market costs and a lack of sufficient accessible financing.
- **Regulatory framework and approval process.** As decentralised production of green hydrogen is relatively new, the regulatory, environmental requirements and permitting regulations are non-existent or unclear. This adds significant uncertainty and additional time and overheads to the project development process.
- **Operation staff.** Trained staff available for operations & maintenance activities.
- **Supply chain shortages.** In recent years there have been a number of factors (COVID, Ukraine, etc.) impacting supply chain components, parts and materials leading to long lead times for delivery of equipment.

- **Area requirements.** Availability of sufficient space for installation of an electrolysis plant, hydrogen storage and balance-of-plant equipment as well as the PV plant. The average space requirement for 1 MWp solar PV generating capacity requires at least 5 acres (Land Use & Solar Development, n.d.).
- **Logistical issues.** Potential issues in carrying out construction while the existing operations continue, as well as potential impacts on production and what types of tie-ins are necessary.
- **Design of the plant equipment.** Hydrogen is highly flammable and requires strict safety protocols to ensure safe handling and storage. Special attention should be given to the location of storage equipment, separation distances, potential for dominos effects, integrated design safety functions.
- **Power supply.** Is a reliable power supply as well as back-up power supply secured? There will be increased metering requirements to demonstrate the use of green electricity for green H_2 production.
- **Water supply.** Availability of water in required quality and quantity (tap water or demineralised water). Hydrogen production requires significant quantities of water. It is crucial to build a green hydrogen industry in such a way that it will not negatively affect water security. Water desalination is one of the proposed solutions that can reduce the impact of the hydrogen water footprint.
- **Safety aspects.** Integration of hydrogen production and storage facility into existing safety concept of the existing industrial plant site.
- **Control and operation.** Integration of hydrogen production and storage facility into existing control systems.
- **Supply considerations.** Is a constant hydrogen supply necessary for operations and is this possible given local renewable resources?
- **Storage facilities.** Adequate hydrogen and electricity storage facilities are required if production relies on variable renewable energy (VRE) to ensure uninterrupted production.

4.2 Opportunities and supporting frameworks for hydrogen implementation

The key document governing Vietnam's transformation into a net-zero economy is the country's NCCS which sets detailed objectives for GHG reduction targets by 2030 and 2050. The Vietnamese government expects to achieve the following decarbonisation targets by 2050 (S&P Global, 2022):

- Energy sector emissions will be reduced by 91.6%, and capped at 101 million $mtCO_2e$
- Agriculture sector emissions will be cut by 63.1%, and capped at 56 million $mtCO_2e$
- Forestry sector and land-use emissions will be cut by 90%, increase in carbon sequestration by 30%, with total emissions and removals reaching at least -185 million $mtCO_2e$
- Waste sector emissions will be cut by 90.7%, and capped at 8 million $mtCO_2e$
- Industrial process emissions will be cut by 84.8%, and capped at 20 million $mtCO_2e$.

Vietnam declared an ambitious agenda to phase out coal by 2040 and increase renewable energy shares to have at least 33% of the total hydro, solar and biomass power in total electricity generation. There is no specific target for hydrogen implementation, but the country demonstrates its strong intention to achieve the climate targets. The development of green hydrogen may be one of the solutions that can:

- Reduce GHG emissions and support the country's clean energy transmission policies, through the decarbonisation of hard-to-abate industrial sectors.
- Decarbonise the agriculture sector through more sustainable production of fertilisers using green ammonia.
- Reduce the country's dependency on hydrogen derivative imports such as ammonia and methanol and could be a starting point for developing local production capacities for industry.
- Accelerate investment and speed up the country's technological development. In addition, new skilled jobs will be created providing new opportunities to its population.

4.3 Local Vietnamese financing instruments

Vietnam does not yet have green hydrogen sector-specific financial and policy incentives or preferential mechanisms. In some existing industrial policies (e.g. chemical industry comprising fertiliser, basic chemicals, petrochemicals, industrial gases, etc.), the use of hydrogen is seen as a way to decarbonise the industry, along with other non-fossil alternatives such as biomass, carbon capture and utilization (CCU) , etc. The most relevant is Decision No. 38/2020/QD-TTg (30/12/2020) which stipulates that „Hydrogen energy technology (Hydrogen energy)" belongs to the list of high technologies prioritised for development investment and, accordingly, may enjoy investment incentives such as preferential tax rates.

Carbon pricing/emissions trading system (ETS) in Vietnam
Carbon pricing in the form of an emissions trading system (ETS) for greenhouse gases is legalised under a new Law on Environmental Protection (LEP) (DO, 2021) . A carbon tax could also be developed under the overall framework provided by this law. The law stipulates that the government will establish a carbon emissions trading scheme that suits the local context and complies with international climate change treaties. Details such as targets, timelines and regulated industries will be specified later in a government decree.

Carbon credit trading and carbon taxes will generate significant revenue flows that could also be used to support technology demonstrations and bridge the economic gap for some of the initial green hydrogen plants in Vietnam. According to the World Bank, carbon pricing regimes will help Vietnam attract more foreign direct investment and improve its export competitiveness (World Bank, 2021).

Once fully implemented, carbon pricing will help Vietnam to make a case for its exclusion from any carbon border adjustments imposed by other nations, allowing it to take full advantage of trade programmes like the European Union (EU)-Vietnam Free Trade Agreement or future EU carbon tariffs on a number of imports, including steel, cement and fertiliser by 2026.

4.4 Green hydrogen financing opportunities for German companies

There are four categories of financing opportunities for German companies active in green hydrogen technologies:

EU-level funding opportunities
The Clean Hydrogen Partnership (public-private partnership) aims to provide research and innovation funding for hydrogen projects for European companies (Hydrogen Europe, 2023). The funding comes in the form of grants and EU co-funding for green hydrogen production, storage, distribution, transportation, heat and power application, hydrogen valley development, etc.

Another example is the ETS Innovation Fund (European Union, 2023) for H_2 demonstration projects, where money raised via the EU ETS (European Union Emissions Trading System) is reinvested into the Innovation Fund (public-private partnership). Under grant agreements, the fund can be used for the demonstration of innovative low-carbon technologies including green hydrogen. For example, one of the hydrogen projects that received funding from the ETS Innovation Fund is the fossil-free steel production "HYBRIT" project in Sweden.

National public funding for hydrogen projects specific to the EU Member State
Examples of national public funding include the German H2Global instrument (H2 Global Stiftung, 2022). H2Global is an auction-based financing mechanism for green hydrogen which will conclude long-term purchase contracts on the supply side and short-term resale contracts on the demand side, ensuring planning and investment security for green H_2 investments, given the current lack of fully functioning green H_2 markets. The concept provides for the compensation of the difference between the purchase price (production plus transport costs) and the sales price (currently the market price for fossil hydrogen) for green H_2 and H_2-based derivatives. The first tender was launched in November 2022 as an auction for green ammonia, e-methanol and sustainable aviation fuel from international producers (outside EU and EFTA countries). The concept is developed with funding from the German Federal Ministry for Economic Affairs and Climate Action.

In addition, in 2022 the Federal Government launched the "Hydrogen Pilot Office" website, which provides combined information for hydrogen funding opportunities at national, EU and international level. The „International Hydrogen Ramp-up Programme" (H2Uppp) supports German small and medium-sized enterprises (SMEs) in identifying, preparing and implementing pilot projects for the production and use of green hydrogen in developing and emerging countries (BMWK, 2023). Guidance on sources of funding can be found on the BMWK website "Funding advice – Hydrogen Guidance Service" One-Stop-Shop – Wasserstoff – Funding advice (bmwk.de).

National and European banks
European and national banks such as the European Investment Bank (EIB) and Kreditanstalt für Wiederaufbau (KFW) leverage private capital investments in green hydrogen projects. A wide variety of financing instruments – including debt and equity finance, as well as investment guarantees – are available in addition to previously mentioned EU support programmes.

For instance, the EIB will provide financing advisory support as well as dedicated EIB financing products (European Investment Bank, 2021) for green hydrogen projects introduced through Hydrogen Europe – the association representing European industry, research and national and regional associations in the hydrogen and fuel cell sectors.

Private finance such as venture capital funds
Private finance such as venture capital funds (e.g. Breakthrough Energy founded by Bill Gates) and private banks are also showing interests in investing in the hydrogen sector. With over $1 billion raised in committed capital, Breakthrough Energy, through its Energy Catalyst platform, funds and invests in project companies utilising emerging climate technologies including clean hydrogen, storage, sustainable aviation fuel, etc. (Breakthrough Energy, 2022). A special programme in Europe has recently been established (Breakthrough Energy Europe) to support research and innovation in clean technology, including green hydrogen (Breakthrough Energy, 2022).

However, hydrogen projects solely based on private financing are yet to gain momentum given that there are no fully functioning markets yet for offtakers or pricing green hydrogen products.

4.5 Where to go for more information

The following resources are available to learn more about investing in H_2 in Vietnam:

Vietnam Investment Promotion Agency (IPA) operates under the Ministry of Planning and Investment (MPI) and has a close relationship with the central government, ministries and agencies, local authorities, international organisations, business associations and offers help to foreign investors to set up a business in Vietnam.

Ministry of Industry and Trade (MOIT) is responsible for energy policy and development in Vietnam. It oversees the renewable energy sector and can provide information on regulations, incentives and investment opportunities related to renewable resources.

Ministry of Planning and Investment (MPI) is the primary government agency responsible for investment-related matters in Vietnam. It formulates investment policies, manages investment promotion activities and oversees the implementation of investment projects. The MPI's website provides comprehensive information on investment guidelines, laws and regulations.

Investment Promotion Centers (IPCs). Each province in Vietnam has an IPC responsible for attracting investment in their region. Contacting the IPC of a specific province can provide you with localised information on renewable energy opportunities, incentives and investment procedures within that province.

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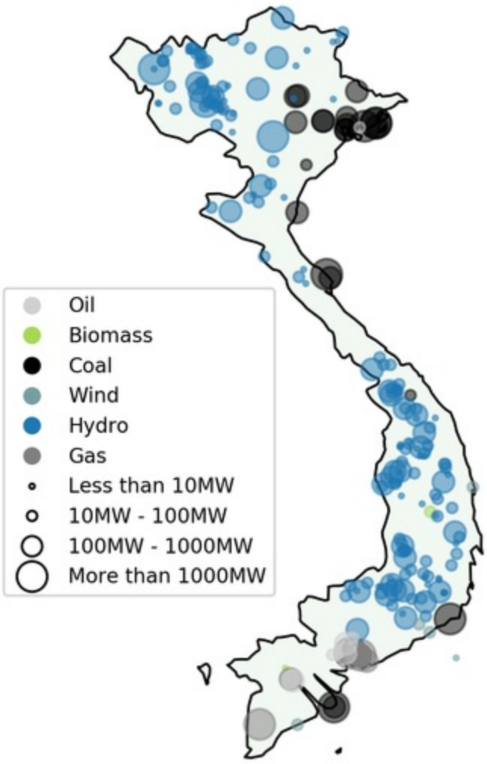
Appendix

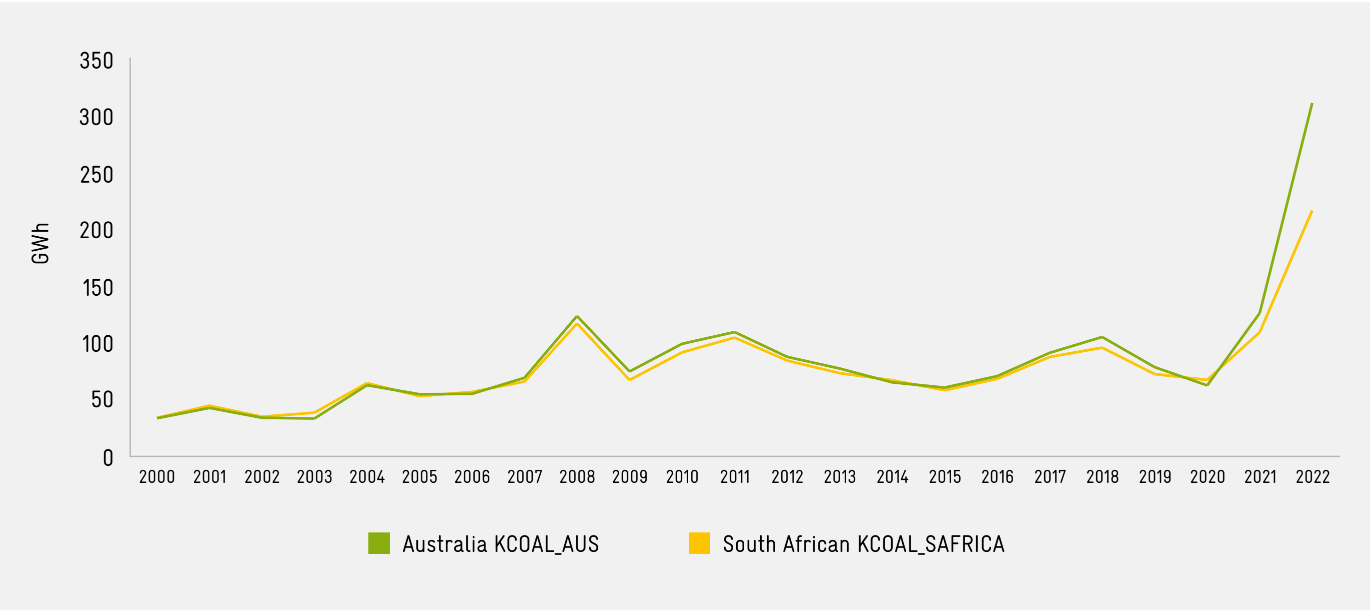
Locations of generation capacity in Vietnam

FIGURE 18. LOCATIONS OF GENERATION CAPACITY IN VIETNAM



Source: Greening the Grid (Greening the Grid, 2022)

FIGURE 19. ANNUAL COAL PRICES FOR AUSTRALIA AND SOUTH AFRICA



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2023)

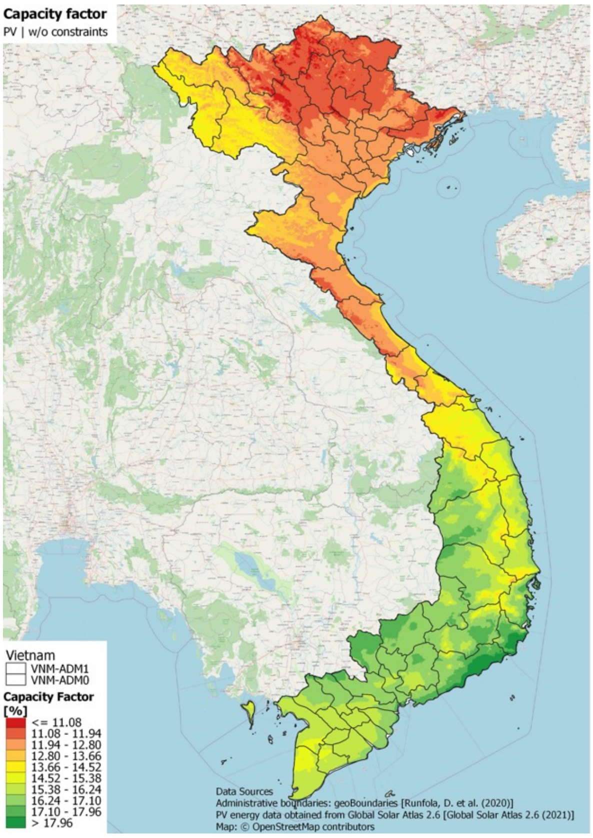
TABLE 15. FORECASTED INSTALLED GENERATION CAPACITY

Type of Source	2025	2030	2035	2040	2045	2050
Coal-fired	30,067	36,327	29,337	21,537	9,835	0
Coal-fired TPP with support firing of biomass/ammonia	0	0	6,990	14,790	18,642	0
Coal-fired TPP fully converted to biomass	0	0	0	0	6,990	28,832
Gas combined cycle + gas-fired TPP	9,176	14,930	7,900	7,900	7,900	7,900
Gas-fired TPP converted to LNG/Hydrogen	0	0	7,030	7,030	0	0
Gas-fired TPP fully converted to hydrogen	0	0	0	0	7,030	7,030
New GCC using LNG	3,500	15,400	25,500	13,600	0	0
New GCC using LNG with support of hydrogen	0	0	3,500	15,400	25,500	13,600
New GCC using LNG fully converted to hydrogen	0	0	0	0	3,500	15,400
Flexible power source	0	300	2,100	10,500	17,100	24,300
Oil-fired turbine	1,221	0	0	0	0	0
Hydro (small hydro included)	25,829	27,353	30,891	32,384	33,869	35,571
Wind	11,196	11,905	20,920	30,620	41,270	49,170
Offshore wind	0	0	9,000	21,000	31,000	46,000
Solar	8,736	8,736	20,819	41,786	66,505	100,651
Biomass and other RE	980	1,230	3,290	4,960	5,210	6,015
Pump-storage hydro/ESS	0	1,500	5,100	9,900	16,500	22,950
Import	3,853	4,076	7,742	7,742	9,742	11,042
Rooftop solar	7,755	7,755	11,207	14,540	18,721	26,333
Co-generation	1,450	2,700	3,300	4,500	4,500	4,500
Total	**103,763**	**132,212**	**194,626**	**258,189**	**323,814**	**399,294**

Source : (MOIT, Nov, 2022), Table 4 - page 23

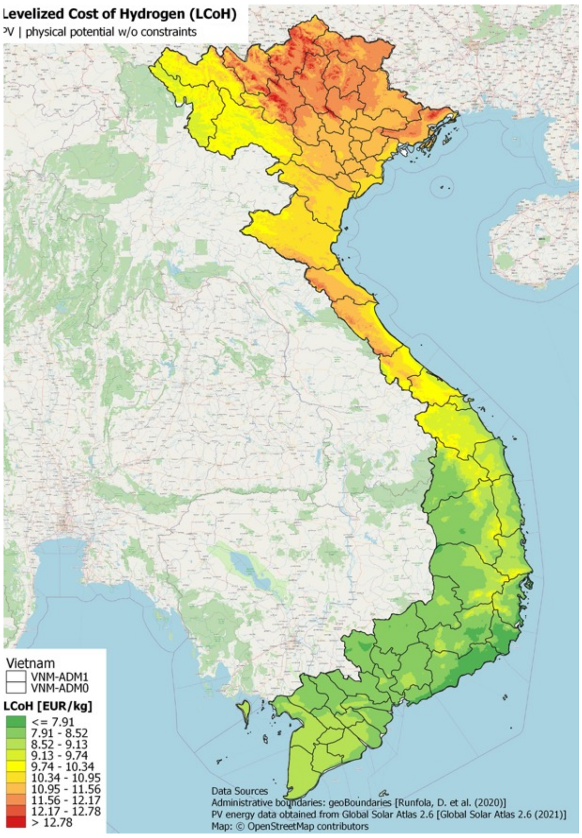
LCoH GIS maps and cost assumptions

FIGURE 20. SOLAR CAPACITY FACTOR



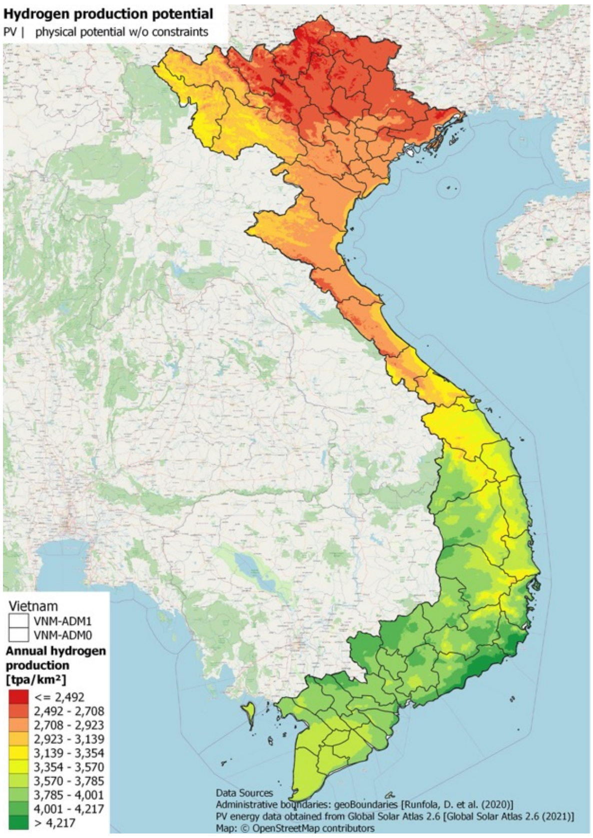
Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 21. LEVELISED COST OF HYDROGEN (LCOH)



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 22. HYDROGEN PRODUCTION POTENTIAL



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

TABLE 16. GIS MAP LCOH ASSUMPTIONS

Levelised Cost of Hydrogen Assumptions (GIS maps)		
Water price	4	EUR/m3
Electrolysis efficiency	62	%
CAPEX PV	713	EUR/kWi
CAPEX Electrolysis	1,300	EUR/kW
fixOPEX PV	20	EUR/kW/a
fixOPEX Electrolysis	15	EUR/kW/a
varOPEX PV	0	EUR/kWh/a
varOPEX Electrolysis	0	EUR/kg/a

Source: Authors' own table, ENGIE Impact GmbH (2023)

TABLE 17. COMPLETE SUMMARY OF PV AND GREEN HYDROGEN PRODUCTION POTENTIAL BY REGION

Region	PV capacity factor PV [%]	Theoretic green hydrogen production potential		LCoH
		Area-specific potential [tpa/km²]	Total potential [tpa]	[EUR/kg]
An Giang	16.43%	3,884	625,391	8.33
Bà Rịa–Vũng Tàu	16.98%	3,941	1,820,711	8.22
Bắc Giang	12.09%	2,690	1,977,411	11.37
Bắc Kạn	11.55%	2,579	3,002,210	11.79
Bạc Liêu	15.64%	3,689	793,095	8.8
Bắc Ninh	12.28%	2,734	147,613	11.21
Bến Tre	16.48%	3,841	3,348,970	8.44
Bình Định	15.68%	3,681	2,738,759	8.68
Bình Dương	16.65%	3,906	531,239	8.27
Bình Phước	17.01%	3,997	12,804,988	8.06
Bình Thuận	17.44%	4,113	3,039,529	7.87
Cà Mau	15.51%	3,686	4,228,132	8.82
Cần Thơ city	15.93%	3,744	408,117	8.65
Cao Bằng	11.62%	2,587	3,914,317	11.72
Đà Nẵng city	14.74%	3,452	348,662	9.17
Đắk Lắk	16.21%	3,828	15,856,864	8.39
Đắk Nông	16.67%	3,914	12,669,545	8.22
Điện Biên	13.96%	3,146	7,244,501	9.72
Đồng Nai	16.60%	3,873	7,954,656	8.35
Đồng Tháp	16.68%	3,910	695,972	8.28
Gia Lai	16.08%	3,795	14,288,733	8.44
Hà Giang	11.50%	2,564	4,631,110	11.83
Hà Nam	12.28%	2,730	103,754	11.27
Hà Nội city	12.29%	2,740	824,761	11.2
Hà Tĩnh	12.31%	2,827	2,433,858	11.05
Hải Dương	12.14%	2,673	523,970	11.47
Hải Phòng city	12.55%	2,814	928,714	10.91
Hậu Giang	15.55%	3,658	340,221	8.86

Hồ Chí Minh City	16.54%	3,906	2,117,273	8.28
Hòa Bình	12.33%	2,768	4,728,033	11.11
Hưng Yên	12.26%	2,745	74,127	11.19
Khánh Hòa	16.37%	3,923	2,506,679	8.21
Kiên Giang	15.80%	3,722	3,495,095	8.71
Kon Tum	15.80%	3,752	7,702,026	8.52
Lai Châu	13.27%	2,972	3,061,062	10.25
Lâm Đồng	16.55%	3,924	11,802,983	8.22
Lạng Sơn	11.85%	2,644	5,837,557	11.53
Lào Cai	11.74%	2,626	4,470,047	11.58
Long An	16.71%	3,902	4,550,002	8.29
Nam Định	12.67%	2,901	298,783	10.64
Nghệ An	12.84%	2,911	8,147,165	10.67
Ninh Bình	12.44%	2,792	731,454	11.05
Ninh Thuận	17.50%	4,116	926,135	7.84
Phú Thọ	11.93%	2,657	3,311,104	11.52
Phú Yên	15.56%	3,668	2,952,785	8.75
Quảng Bình	12.50%	2,971	3,517,089	10.57
Quảng Nam	14.47%	3,384	5,857,101	9.38
Quảng Ngãi	15.28%	3,543	2,834,677	8.98
Quảng Ninh	11.86%	2,697	3,290,159	11.37
Quảng Trị	13.22%	3,072	5,025,850	10.27
Sóc Trăng	15.89%	3,767	1,081,147	8.62
Sơn La	13.53%	3,055	9,835,848	10.05
Tây Ninh	17.16%	4,045	1,201,444	7.98
Thái Bình	12.51%	2,874	123,575	10.72
Thái Nguyên	11.67%	2,590	2,867,261	11.78
Thanh Hóa	12.70%	2,846	6,417,217	10.86
Thừa Thiên-Huế	13.62%	3,202	3,291,780	9.86
Tiền Giang	16.39%	3,830	2,137,074	8.45
Trà Vinh	16.22%	3,825	1,082,484	8.48
Tuyên Quang	11.47%	2,572	5,214,182	11.84
Vĩnh Long	16.05%	3,776	622,994	8.58
Vĩnh Phúc	11.94%	2,648	383,991	11.57

Source: Authors' own table, ENGIE Impact GmbH (2023)

Potential business cases questionnaire

TABLE 18. CASE STUDIES QUESTIONNAIRE

Question	
1	Does the Company have decarbonisation goals/objectives? Are these major factors in your current investment planning?
2	Current use of hydrogen/ammonia (processes used, volume, source)
3	How do you currently transport/store your hydrogen?
4	Have you installed, or do you plan to install, PV at your facility? If not, why not?
5	Do you face challenges in the supply chain (reliable grid electricity, sourcing feedstock since COVID and Ukraine, etc.)?
6	Have you considered local green H_2 production? What aspects are you in favour of? What against?
7	Opportunities for improvement. What regulatory/policy changes would make it easier for you to do business? What types of incentives or financial support for modernisation/decarbonisation do you wish were available?

Source: Authors' own table, ENGIE Impact GmbH (2023)

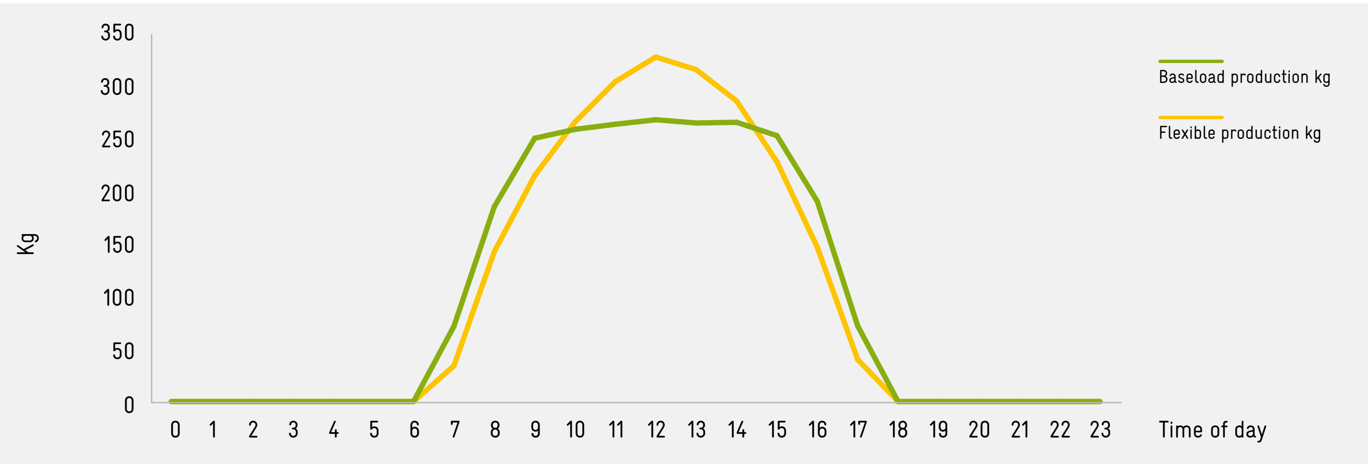
Baseload vs flexible operation

It is necessary to keep in mind that oversizing of both PV and EL for a baseload H_2 supply is always required when operating hydrogen production from PV. For example:

- Consider a H_2 demand of 800 tpa, with a baseload hourly demand of approx. 91 kg/h.
- This requires, at minimum, an electrolyser of approx. 5 MW if it the electrolyser would be running 24/7/365 at full load.
- Considering an average capacity factor of PV systems of 20%, a PV system of 5x the electrolyser capacity is required, at minimum, to supply enough electricity over the course of the year (without matching hourly demand).
- Considering the day/night characteristics of sun light and no electricity storage, the electrolyser needs to be oversized by a factor of approx. 2 (charging H_2 storage during the day).
- In this example, the electrolyser capacity would be at least ~10 MW and the PV capacity would be at least 25 MW.

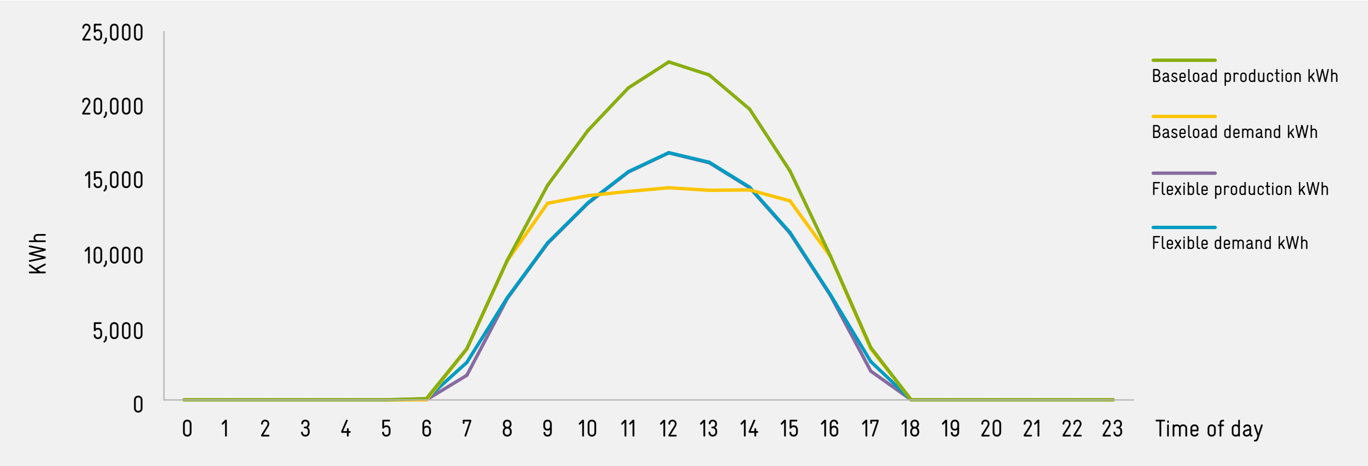
Since, from an optimisation point of view, the installation of a PV system is less expensive than the installation of an electrolysis system, the PV system is more strongly oversized than the electrolyser. The following two figures show the same annual volume of H_2 production, in flexible and baseload mode. The first figure shows the production of H_2 in flexible mode. In this case, the electrolyser needs to be oversized to be able to take full advantage of the solar peak. Whereas the green line shows production under baseload where more H_2 is produced during off-peak times, filling the H_2 storage for use when needed. However, in order to be able to produce this extra H_2 outside of the solar peak, the PV plant must be scaled up to provide the power. This can be seen in the second figure where the green and yellow lines show the electrical demand of the eletrolysers in baseload and the energy production of the PV field. To provide the extra energy during off-peak, the solar field must be oversized. This also results in significant "extra" electricity (the difference between the green and yellow lines) during peak solar production.

FIGURE 23. FLEXIBLE VS BASELOAD H_2 PRODUCTION



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 24. FLEXIBLE VS BASELOAD ELECTRICITY PRODUCTION AND CONSUMPTION



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

Business case financial calculation methodology

The business cases presented are illustrative of the conversion to green hydrogen for current conventional hydrogen consumers. As the business cases focus on the grey-to-green H_2 conversion, the indicative financial assessment is based on the LCoH and the "effective" LCoH. The LCoH represents the cost to produce 1 unit (1 kg) of hydrogen, taking into account the time value of money in the form of the applied discount rate. It is calculated by dividing the total discounted lifetime system costs by the lifetime discounted volume of hydrogen production.

The first step in calculating the LCoH for the selected business is the choice of investment location, electrolyser technology and required hydrogen production volumes. The CAPEX and OPEX assumptions for the different electrolyser technologies are described in Section 3.2. One of the key aspects of the model is the choice of electrolyser operating mode: baseload or flexible operation mode. Most key calculation assumptions for the business cases are in Table 22.

TABLE 19. VIETNAM LCOH BUSINESS CASE ASSUMPTIONS

Business Case Assumptions		
Prices		
Tap water price	EUR/m³	1.00
Electricity tariff (sell)	EUR/kWh	0.07
Oxygen tariff (sell)	EUR/kg	0.40
Taxes		
Import tax rate on PV	%	-
Import tax rate on electrolyser system	%	-
Operation		
Oxygen production volume per 1 kg of H_2	kg	8.0
Annual inflation rate (Local)	%	1.8
Water tariff escalation rate	%	2.0
Electricity tariff escalation rate	%	2.0
Oxygen escalation rate	%	0.0
Hydrogen storage	hrs	72.0
Financing		
Depreciation method		Straight-line depreciation
Operation period	years	25.0
Discount rate	%	8.0
Debt/equity ratio	%	60.0
Repayment period	years	10.0
Up-front fee	% of debt capital	1.0
Commitment fee	% of undrawn debt	1.5
Applied interest rate	%	9.0

Source: Authors' own table, ENGIE Impact GmbH (2023)

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