Federal Ministry for Economic Affairs and Climate Action

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Renewable Energy and Energy Efficiency in Viet Nam – Assessment of green hydrogen export potential of Viet Nam

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Abbreviations

4E	Renewable Energy and Energy Efficiency project
ASEAN	Association of Southeast Asian Nations
BOG	Boil-off Gas
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CF	Capacity Factor
CUF	Capacity Utilisation Factor
ESP	Energy Support Programme
EU	European Union
EUR	Euro
EVN	Viet Nam Electricity
GH2	Green Hydrogen
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiance
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GO	Guarantee of Origin
GSA	Global Solar Atlas
GW	Gigawatt
GWA	Global Wind Atlas
GWh	Gigawatt-hour
IEA	International Energy Agency
IPP	Independent Power Producer
IRENA	International Renewable Agency
kg	Kilogram
kt	Kilotons
LCOA	Levelized Cost of Ammonia
LCOE	Levelized Cost of Electricity
LCOH	Levelized Cost of Hydrogen
LH2	Liquid hydrogen
LOHC	Liquid Organic Hydrogen Carrier
MOIT	Ministry of Industry & Trade
Mt	Million tons
MW	Megawatt
MWh	Megawatt-hour
NH3	Ammonia
NZE	Net-Zero Emissions
OPEX	Operational Expenditure
PEM	Polymer/proton electrolyte membrane
PtX	Power-to-X (hydrogen derivatives)
PV	Photovoltaic
PVN	Petro Viet Nam
RE	Renewable Energy
TWh	Terawatt-hour
UK	United Kingdom
US$	US Dollar
VRE	variable Renewable Energy
WACC	Weighted Average Cost of Capital

Executive Summary

Green hydrogen (GH2) is poised to play an increasingly important role in the energy transition worldwide. One main area where green hydrogen is expected to be needed is to facilitate the decarbonisation of "hard-to-decarbonise" sectors such as steel production, shipping, and the production of chemical feedstocks. Grey and blue hydrogen (i.e., hydrogen derived from fossil fuels) currently dominate the global market. However, GH2 based on electricity produced from renewable energy (RE) sources is needed to reach global net zero targets. As of early 2022, less than 1% of the hydrogen used around the world today is derived from water electrolysis; the vast majority is still produced using fossil fuels.

With appropriate policy and financing supports, Viet Nam could become an important exporter of GH2, serving the regional market in Asia or potentially even the global market in the future. This study was conducted to explore the possibilities of Viet Nam to participate in the rapidly growing international GH2 market.

In addition to export opportunities, many countries will need to start engaging in the production of green hydrogen in order to decarbonize their own local industrial sectors; this makes GH2 a crucial element for Viet Nam's own domestic energy transition.

Hydrogen production potential and levelized cost

The levelized cost of hydrogen (LCOH) is highly dependent on the cost of the available RE resources since electricity alone represents 30% to 60% of the total LCOH. The simulation results of the study showed that LCOH in Viet Nam depends significantly on the underlying financing conditions.

Table 1: LCOH in 2030 for different technologies and financing conditions

TECHNOLOGY	SCENARIO	MIN	MEDIAN	MAX
Solar PV	Local conditions	3.76	4.86	6.88
	Concessional	2.84	3.63	5.14
Onshore wind	Local conditions	2.79	3.63	5.44
	Concessional	2.09	2.65	3.97
Offshore wind	Local conditions	4.73	6.08	8.43
	Concessional	3.45	4.43	6.02

Note: for details on the financing assumptions, see Annex 1.

Under a case with privileged or concessional financing, the LCOH in Viet Nam is expected to range from 2.84 - 5.14 US$/kg H2 if derived from solar PV and 2.09 - 3.97 US$/kg H2 for GH2 produced from onshore wind power in 2030. Due to the significantly higher CAPEX and OPEX for offshore wind, the LCOH for hydrogen produced via dedicated offshore wind plants, under concessional financing, ranges from 3.45 - 6.02 US$/kg H2. Without concessional financing, the LCOH increases by between 0.7 – 2.41 US$/kg H2, depending on the case.

Figures 1 and 2 present LCOH according to the geographic location of power generating plant for solar and onshore wind respectively.[1]

1 It was not possible to generate a comparable map for offshore wind due to data availability issues.

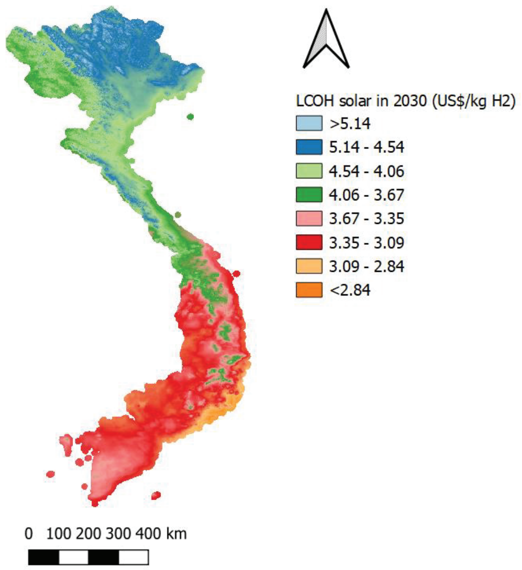


Figure 1: LCOH for GH2 from solar PV by 2030 (with concessional financing)

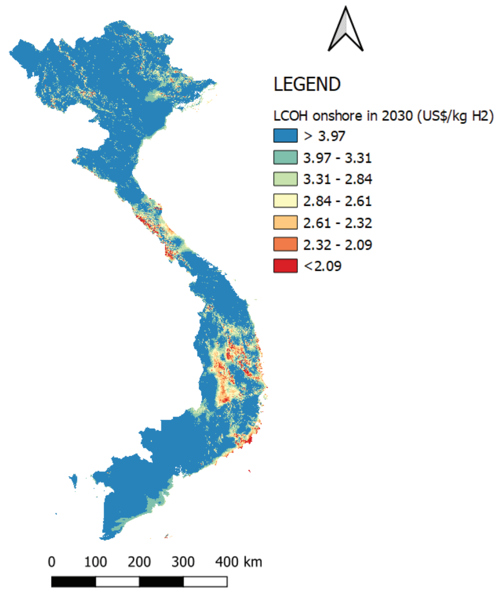


Figure 2: LCOH for GH2 from onshore wind by 2030 (with concessional financing)

In terms of GH2 production potential, the estimated GH2 potential is 38 236 kilotons for solar PV and 1 631 kilotons for onshore wind. The corresponding green ammonia quantities are 217,250 kilotons from solar PV and 9,270 kilotons from onshore wind.

For the transportation of hydrogen, three hydrogen carriers were assessed: liquid hydrogen (LH2), Ammonia and liquid organic hydrogen carrier (LOHC). The transportation cost of hydrogen depends on both the electricity cost in exporting and importing countries for conversion and reconversion respectively. Of the three analysed shipping options, ammonia is the most economic, except for importing countries with low electricity prices where LOHC becomes the preferred option. Figures 3 and 4 show the shares of different shipping cost elements to Japan and South Korea in 2050.

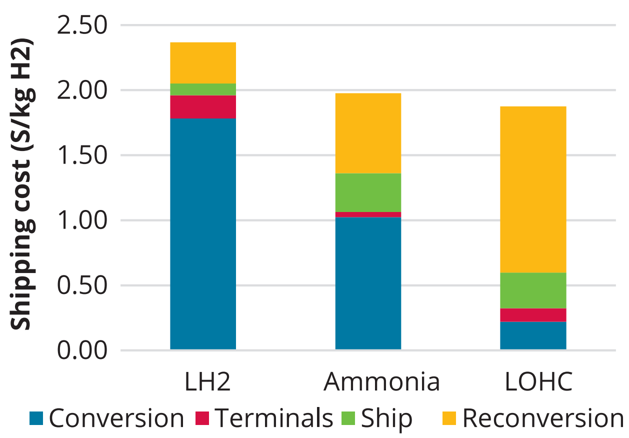


Figure 3: Shipping cost to South Korea in 2050

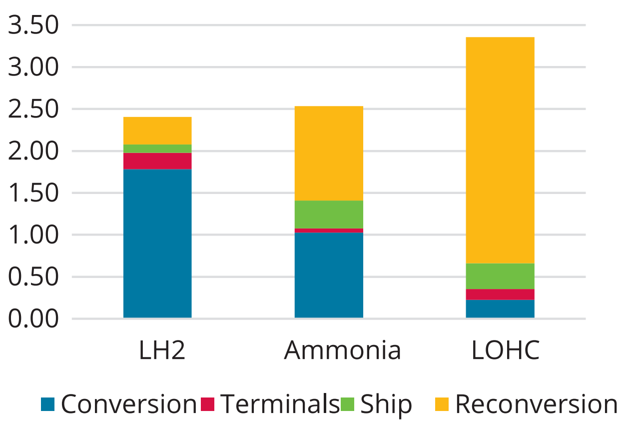


Figure 4: Shipping cost to Japan in 2050

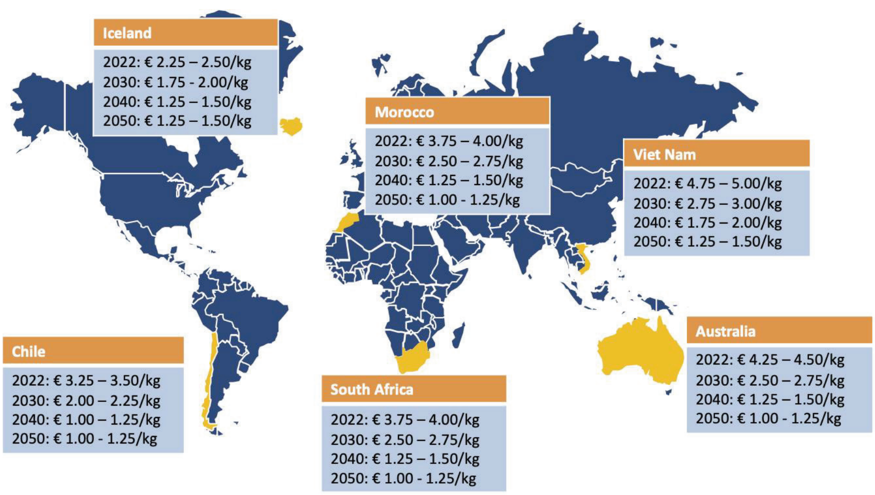
Five key variables will determine the competitiveness of Vietnamese green hydrogen on the global market in comparison with competitors like Chile, Morocco and Australia as described in the table below.

Table 2: Key variables for green hydrogen competitiveness

Key Variable	Viet Nam's relative position
Renewable energy resource quality	Viet Nam has good overall RE resource quality. However, on an international level, Viet Nam's relative position is weaker in solar than other potential competitors such as Australia, Morocco, and Chile. With regard to wind power, Viet Nam's resources are among the best in Southeast Asia.
Proximity to target market	Viet Nam is located roughly 2 700 nautical miles (approx. 5 050 km) from ports in South Korea, and just over 3 000 nautical miles (approx. 5 720 km) from major ports in Japan. Due to the significant costs of shipping, serving these markets might be more realistic than exporting to European countries.
Land availability	Viet Nam has a total land surface of 331 690 km2, significantly less that potential competitors such as Morocco (446 550 km2), Australia (7 692 000 km2) and Chile (756 950 km2). In addition, Viet Nam has a significantly higher population density (311 inhabitants/km2) compared to its competitors: 83 inhabitants/km2 for Morocco and 383 inhabitants/km2 for Australia. Note that the land requirements for GH2 production are not due as much to the electrolyser facilities, but rather to the land required for the dedicated renewable energy plants.
Cost of capital	The cost of debt provided for renewable energy projects in Viet Nam ranges from between 6.5% and 10%. By contrast, lending for major RE energy projects in countries like Australia and Chile benefit from a cost of debt as low as 2-3%.
Political stability	Overall Viet Nam benefits from a high degree of political stability. In addition, it ranked relatively well on the World Bank's ease of doing business report in 2020, at 70 out of 190, but behind other competitors such as Australia (14th), Chile (59th), and Morocco (53rd).

Compared to Viet Nam, the four major competitors considered here currently have certain competitive advantages in terms of green hydrogen production (see the figure below). These competitive advantages are reflected in the current estimated cost of green hydrogen production. Looking ahead to 2030, 2040, and 2050, significant cost reductions are anticipated, brining green hydrogen costs down from a range of EUR 3 - 6/kg in much of the world today to EUR 1,00 - 1,50/kg by 2050 (see Figure 5 below).

Figure 5: International GH2 production cost range among potential exporting (Present to 2050)



Viet Nam is expected to continue having a slightly higher production cost than other markets with higher resource quality, more abundant land, a lower cost of capital, or all three. However, this slightly higher production cost does not necessarily mean that Viet Nam will be unable to compete: much hydrogen production built for exports is likely to be developed in the context of bilateral partnerships, with preferential financing conditions and long-term supply contracts. Under such an approach, Viet Nam's production costs are likely to remain sufficiently competitive to be able to secure bilateral agreements for green hydrogen supply.

However, given the substantial impact of shipping costs, it is likely in the next decade that the international trade in green hydrogen will occur primarily on a regional basis, with regional trading hubs between markets that are close to one another geographically.

A further factor that needs to be overcome in countries like Viet Nam that wish to export green hydrogen is the cost of capital. As highlighted above, the cost of capital in Viet Nam is notably higher than the cost of capital in other competitor markets like Australia.

Policy Recommendations:

In order to participate and compete in this growing market, there are a number of policy measures that Viet Nam can implement. The policy recommendations are broken into three major areas: policies for encouraging GH2 production, policies for encouraging GH2 demand within Viet Nam, and policies to help reduce the cost of capital.

1. Policies for encouraging GH2 production and policies:

- Establish clear long-term targets for the production of green hydrogen in Viet Nam
- Introduce favourable taxation and fiscal rules for green hydrogen production
- Explore the introduction of feed-in tariffs for green hydrogen production fed into the natural gas network
- Develop monitoring and certification protocols to ensure compliance with international norms and standards.
- Establish a designated industrial cluster for hydrogen production and research.

2. Policies for Encouraging Green Hydrogen Demand in Viet Nam

In addition to green hydrogen support policies, it is important to develop specific policies aimed at creating greater domestic demand for green hydrogen, in order to help accelerate Viet Nam's own energy transition. This includes a set of policies specifically to encourage hydrogen adoption in the natural gas pipeline network, shipping, and in the industrial sector:

- Introduce standards for the injection of green hydrogen into natural gas infrastructure.
- Provide fiscal incentives for industries to shift their hydrogen or ammonia consumption to green hydrogen.
- Provide public financing to support the construction of green hydrogen storage infrastructure.
- Introduce requirements for key domestic users of hydrogen (e.g., refineries) to meet a minimum share of their hydrogen needs with certified, domestically produced green hydrogen (similar to a Renewable Electricity Standard or "Renewable Portfolio Standard")
- Introduce policies to encourage green hydrogen use in key sectors such as shipping.
- Adopt carbon pricing in order to improve the economics of low- and zero-carbon technologies like green hydrogen.

3. Policies to reduce the cost of capital

- Establish export-oriented partnerships with importing regions (e.g., the EU, Germany) to bring lower-cost, long-term financing to support the development of green hydrogen production infrastructure in Viet Nam
- Explore the creation of a green hydrogen export initiative to encourage multi-lateral lenders to support the build-out of green hydro production.
- Explore providing sovereign backing, or direct government investment, for strategic green hydrogen investments
- Explore introducing guaranteed offtake agreements or establishing a government-backed "buyer-of-last-resort" for green hydrogen to reduce market risk.

Based on current economics and the important role played by shipping costs, the more viable opportunities for Viet Nam to export green hydrogen are likely to be concentrated in the Asia Pacific region. By focusing first on meeting growing demand in Asia, Viet Nam can actively support the emergence of regional trade in green hydrogen, which could flourish into a truly global trade by the 2040s.

Chapter 1

Introduction

A growing number of countries are pledging to be carbon neutral by 2050, which requires a rapid transformation of the energy sector by shifting away from the consumption of fossil fuels towards cleaner and renewable energy (RE) sources. Green hydrogen (GH2) and GH2 derivatives known as Power-to-X (PtX) products are regarded as a key element of this transformation, thanks to their role in decarbonizing the so-called hard-to-abate sectors, such as steel, cement, chemicals, long-haul road transport, maritime shipping, and aviation.

GH2 is obtained by splitting water into hydrogen and oxygen using electricity from RE, which makes the process free or low Greenhouse Gases (GHG) emissions. Direct applications of GH2 include its usage as a raw material in the industrial sector, as a fuel in the transport sector, or as an energy storage medium that can later be used for re-electrification. Indirect applications of GH2 consists of combining it with nitrogen (N2) to produce ammonia or with a sustainable carbon (CO and CO2) to produce methanol, jet fuels, methane, and other hydrocarbons, which can be used to replace their fossil fuel-based counterparts.

To lay out the foundation for hydrogen development and enhance its contribution to their carbon neutrality, several countries worldwide have developed or are developing mid- and long-term hydrogen strategies, including national production, import or export plans as well as financing and cooperation opportunities. These countries can be classified into three groups depending on their domestic GH2 production potential, their expected hydrogen demand, and the cost of import or export. These groups comprise (1) **net exporters:** countries with large RE potential and low-cost green hydrogen production, (2) **self-sufficient:** countries with sufficient production potential to cater to their own needs without resorting to imports, and (3) **net importers:** countries that will need imports to satisfy domestic demands.

In order to explore its possibilities of participating in the rapidly growing international GH2 market, GIZ, on the behalf of the Government of Viet Nam, has commissioned the study “Assessment of green hydrogen export potential of Viet Nam”. The objective of the study is to conduct a quantitative and qualitative analysis to identify and evaluate the export potential of GH2 and green ammonia from Viet Nam to international markets, to Europe in general and to South Korea, Japan, and Germany in particular.

The specific objectives of this assignment are to:

- Estimate GH2 production potential and its levelized cost of production (LCOH)
- Estimate the shipment cost of GH2 and green ammonia (NH3) from Viet Nam to potential importing countries
- Conduct a quantitative and qualitative analysis to identify and evaluate the potential export for GH2 and green NH3 from Viet Nam to potential importing countries.

This report, structured into six chapters, presents the results of the assignment. Chapter 2 provides an overview of the progress and prospect of green hydrogen; Chapter 3 presents the assessment methodology and results on the LCOH production while Chapter 4 describes the methodology and presents the results of GH2 and green NH3 shipping cost from Viet Nam to potential importing countries. Chapter 5 presents an analysis of the Vietnamese exporting opportunities of GH2 and green NH3 from Viet Nam to potential importing countries; Chapter 6 presents the conclusions of the study and formulated recommendations to effectively develop the national exporting capability in the future.

Chapter 2

Prospects and progress of hydrogen

With the continuous decrease in RE costs combined with the global commitment to the Paris Agreement, GH2 has gained interest among the international community, as a solution for a deep decarbonisation of the economy. Hence, several countries are positioning themselves in GH2/PtX and investing in research and technology development (R&D) by implementing demonstration and pilot projects in the field.

2.1 Past and present global hydrogen demand and supply

The demand for hydrogen has risen slowly but steadily over the past two decades to reach 90 Mt in 2020, up from approximately 60 Mt in 2000, a compound annual growth rate of 2% (Figure 6-a). Of the total hydrogen demand in 2020, refineries consumed about 44% while the industrial sector consumed 56% (IEA, 2021): 37.5% for ammonia production, 12.5% for methanol production, and 6% in the iron and steel industry (Figure 6-b).

Currently, natural gas is the main source of hydrogen production, accounting for about 60% of the world's annual hydrogen production. Coal-based hydrogen represents 19% of the total global hydrogen supply, while the remaining 21% is by-product hydrogen produced in facilities designed primarily for other products, mainly refineries in which the reformation of naphtha into gasoline results in hydrogen (Figure 6-c).

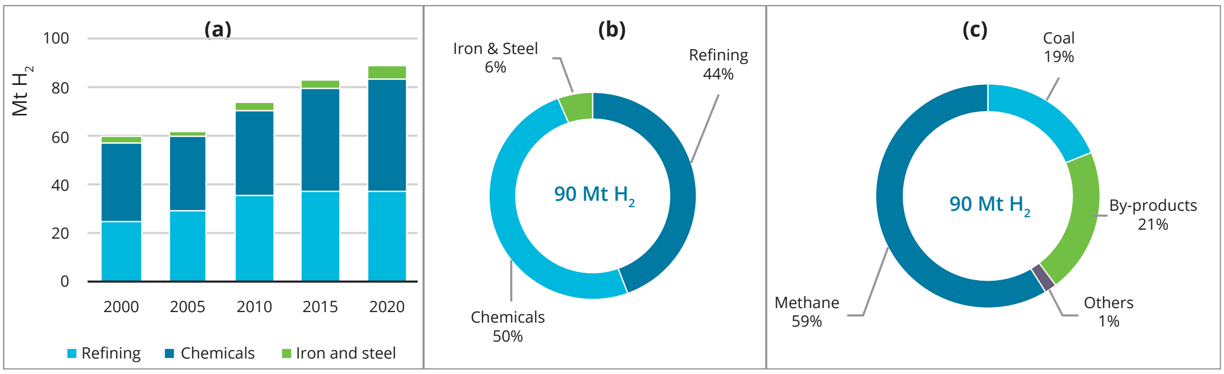


Figure 6: Hydrogen demand and its distribution by sector and by source (IEA, 2021)

2.2 Hydrogen role in the energy transition

Several governments are increasingly rallying behind the target of net zero emissions (NZE) by 2050, in order to limit the global temperature, rise to 1.5°C by 2100 as laid out in the 2015 Paris Agreement. Being responsible of over three-quarters of the total global emissions, the energy sector requires a rapid transformation by shifting the consumption away from fossil fuels towards cleaner and RE sources. However, not all sectors of the economy (e.g., steel, cement, chemicals, road transport, maritime shipping, and aviation) can easily make a direct switch from fossil fuels to electricity. Hydrogen has emerged as a key option for decarbonizing these sectors and a key element of the energy transition where its shares to the total final energy demand in 2050 vary between 12% and 22% as presented in Figure 7 below.

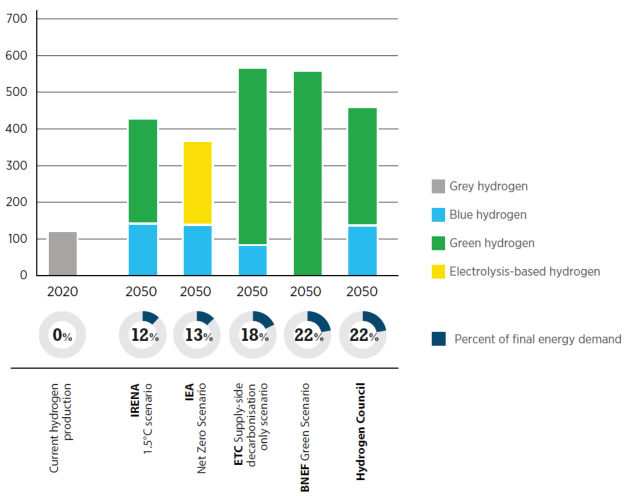


Figure 7: Estimates for global hydrogen demand in 2050 (IRENA, 2022)

2.3 Hydrogen production and transportation

Hydrogen from coal and natural gas without Carbon Capture and Storage (CCS) facilities is referred to as "grey hydrogen", while hydrogen production with CCS is given a "blue" colour. Hydrogen from the electrolysis of water using 100% renewable electricity is referred to as "green hydrogen" and is the most suitable one for a fully sustainable energy transition.

Key colours of hydrogen:

- Grey H2: Steam methane reforming (SMR) or coal gasification
- Blue H2: Grey H2 with CCS
- Green H2: Electrolysis of water with renewable electricity

Concerning the transportation of large amount of hydrogen, gas in pipelines or as liquid by ships are the most economic hydrogen transportation options. Unlike pipelines, transporting hydrogen by ships requires converting it into Liquid Hydrogen (LH2), ammonia or Liquid Organic Hydrogen Carriers (LOHCs). [1],[2]

- Liquid hydrogen: LH2 occupies over 50% less volume than compressed hydrogen. However, the conversion of hydrogen gas to a liquid state requires cooling its molecules to -253°C, and this process is energy intensive since it consumes energy equivalent to 25-35% of the initial hydrogen quantity. Furthermore, transporting and keeping LH2 in liquid state requires highly insulated tanker ships, which are currently not many.
- Ammonia: ammonia is the most promising hydrogen carrier; it has a much higher energy density per unit volume than LH2 and compressed hydrogen, and it is already a well-established internationally traded commodity. However, the conversion of hydrogen to
- Liquid organic hydrogen carriers: LOHCs are organic compounds that can absorb and release hydrogen through chemical reactions. They can serve as a storage and transportation medium for hydrogen liquids without further cooling requirements. LOHCs are very similar to crude oil and oil products, so the existing oil transport infrastructure could even be adapted to transport LOHCs. However, as with ammonia, there are costs associated with the conversion and reconversion processes. These processes would require energy equivalent to between 35% and 40% of the initial quantity of hydrogen.

1 Estimates for global hydrogen demand in 2050 (IRENA, 2022)
2 IEA (2019) – The Future of Hydrogen: Seizing today's opportunities

2.4 Green hydrogen enabling frameworks

In order to make GH2 competitive, the creation of a green hydrogen value chain and appropriate regulatory framework is vital. GH2 faces competition in terms of efficiency and cost that need to be overcome. For the penetration of GH2 in the long term, milestones such as deployment targets, cost reduction and scaling up should be reflected in policies. Broadly speaking, it is possible to distinguish three major phases of GH2 market development: (1) the market activation phase (2) the market penetration phase, and (3) the market growth phase.

- First phase: The first phase until 2030 can be considered as the market activation phase. This phase is characterised by running trials, executing pilots, and launching demonstration projects to evaluate the technology, gain skills and expand the local knowledge base. Hydrogen clusters, hubs or valleys can be established to strengthen the overall GH2 supply chain. The main role of policy in this phase is to activate the development of electrolysis capacity and to gain knowledge.
- Second phase: In the second phase until 2040, most countries expect the market penetration of green hydrogen to grow as GH2 exits the early market activation phase and starts to compete with alternative carriers (such as grey hydrogen) in a growing number of end-uses. The commercialisation of green hydrogen starts to occur in a number of applications. Policy in this phase can support by establishing projects to foster domestic demand while providing targeted incentives to support export-related infrastructure.
- Third phase: In the third phase until 2050, hydrogen markets are expected to mature and to enter the market growth phase. During this phase, green hydrogen starts to play a growing role in a number of end-uses and becomes an important building-block of the global energy mix. GH2 is widely used to replace natural gas in the pipeline distribution network, and several industries use green hydrogen to meet their needs. By this stage, it is expected that green hydrogen is fully cost-competitive and is being exchanged on the global market. At this stage, policy is about providing stability and predictability to the market.

2.5 Green hydrogen production opportunity in Viet Nam

Viet Nam is endowed with various RE resources, especially solar PV, and wind. In the Association of Southeast Asian Nations (ASEAN) region, Viet Nam has emerged as the leader in solar PV and wind electricity adoption since 2019. Viet Nam's total capacity of solar PV reached about 16,500 MW by the end of 2020, with approximately half of this capacity coming from rooftop installations as shown in the table/figure below.

While solar PV has seen the greatest expansion in Viet Nam, installed wind power capacity has also grown quickly. Installed wind power capacity has reached nearly 4.000 MW by the end of Q1:2022, surpassing all other countries in the ASEAN region. Despite these improvements, Viet Nam still has a huge amount of untapped solar PV and wind potential. By the end of 2020, for instance, of the estimated 309 GW solar PV potential, only 5.4% was developed while for wind only 0.3% of the country's 184 GW (24 GW for onshore and 160 GW for offshore) potential was developed .[1]

The huge amount of untapped RE potential presents an opportunity for Viet Nam to take advantage of the growing GH2 global market. Viet Nam also has good shipping access to several rapidly growing markets, particularly in the Asia Pacific region. However, Viet Nam also faces a number of constraints for scaling up GH2 production and competing with other exporting countries on the global market, as will be described later in this report (see Chapter 5).

Technology	Installed capacity (MW)	Percentage share
Hydropower	20 774	29.98%
Coal fired	21 554	31.10%
Gas & oil fired	8 858	12.78%
Wind	518	0.75%
Solar PV	8 871	12.80%
Rooftop solar	7 785	11.23%
Biomass	365	0.53%
Imports	572	0.83%
Total	62 297	100%

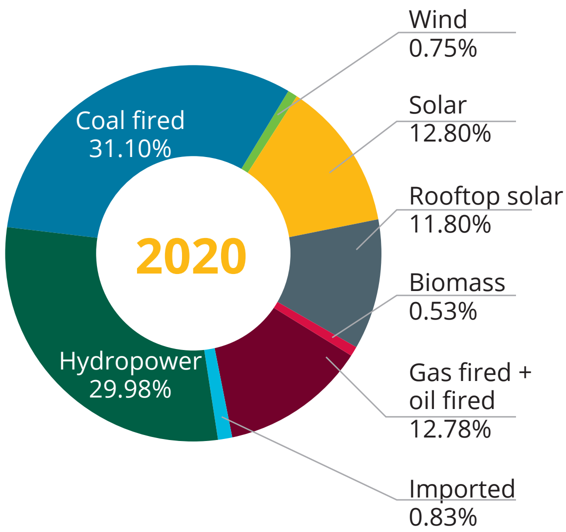


Figure 8: Installed capacity by type in 2020 (EVN, 2021)

1 EVN (2021), Annual Report 2021

Chapter 3

GH2 production potential and costs in Viet Nam

This chapter describes the applied methodology and presents the results of the estimated GH2 and green ammonia (NH3) production potentials in Viet Nam and their corresponding levelized costs. The levelized cost of hydrogen (LCOH) and levelized cost of green ammonia production (LCOA) are the average cost per kg (in discounted real terms) of building and operating a GH2 and green NH3 production asset over the project lifetime. LCOH and LCOA cover all relevant project related costs, including capital, operating, fuel, and financing costs.

3.1 Methodology

The estimation of the potentials for GH2 and green NH3 together with the LCOH and LCOA for the 2050-time horizon was conducted in five consecutive steps listed below:

- Analysis scope: definition of RE technologies to be considered, techno-economical parameters and assessment period;
- Geospatial analysis: RE resource evaluation and their geographical distribution;
- LCOE assessment: estimation of the levelized cost of electricity (LCOE) for different RE technologies and financing options;
- GH2 potential and cost assessment: estimation of GH2 and green NH3 production costs and potential.

3.1.1. Analysis scope

The analysis covered solar PV, onshore and offshore wind technologies for the whole Vietnamese territory based on technology (efficiency) improvements and cost reductions expected by 2050. For GH2 production, alkaline and Polymer Electrolyte Membrane (PEM) electrolysers are the two main technologies currently commercially available. The alkaline technology is more mature, and its supply chain already established (i.e., fast deployment). However, its limited operation window of 10 – 100% loading (Thyssen Krupp, 2022) combined with its slow dynamic response makes it less suited for H2 production from variable RE (IRENA, 2022). On the other hand, the PEM electrolyser has a fast response ramp-up and ramp-down capability, as well as a wide dynamic operating window ranging from 0 to 100%, which makes it ideal for H2 production using variable RE (IRENA, 2022). As such, this study assumes the use of a PEM electrolyser for analysing the GH2 production.

3.1.2. Geospatial analysis

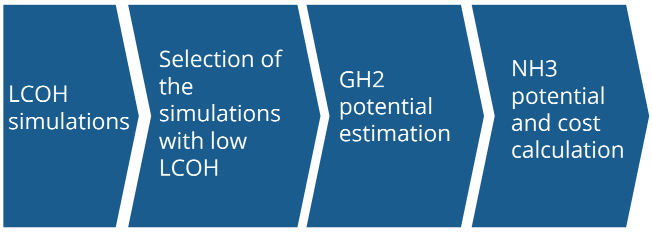
The geospatial analysis dealt with modelling the geographical distribution of the country's RE resources (i.e., wind and solar) and respective covered areas. For solar PV, the analysis used the data from the Global Solar Atlas 2.0 (GSA) of the World Bank Group. The GSA provides different solar data set types; this study used the global horizontal irradiance (GHI). Concerning wind, its geospatial analysis was performed using data from the Global Wind Atlas 3.1 (GWA), which is the product of a partnership between the Technical University of Denmark (DTU Wind Energy) and the World Bank Group. Similar to GSA, the GWA provides different wind data types, such wind speed, capacity factor and power density at different hub heights and rotor diameters. This study used the wind resource potential at a 100 m hub height and rotor diameter of 126 m.

3.1.3. LCOE potential assessment

This step consisted of estimating the LCOE for solar PV and wind installable on the land areas determined in the previous section. To calculate the LCOE for each technology (solar PV and onshore and offshore wind), a financial model was built in excel for a 100 MW power plant considering a project lifetime of 20 years.

3.1.4. Estimation of green hydrogen export potential and cost

The estimation of the GH2 and green NH2 and their costs followed the following process:



LCOH can be computed for three possible electrolyser cases: stand-alone, connected to a dedicated RE plant via the national grid and direct connected to the grid.

Case 1: Stand-alone hydrogen production plant:

Under this case, a hydrogen electrolyser is directly connected to off-grid solar or/and wind farms. Thus, the electrolyser is independent of the transmission and distribution grid; instead, it draws electricity directly from its own RE sources. Under this case, we investigate four scenarios: solar PV, onshore wind, offshore wind, and a combination wind and solar PV.

Case 2: Connected to a dedicated RE source through the grid:

This case also requires the electrolyser to consume 100% renewable electricity, but this time from a RE power plant supplying the electrolyser via the power grid, implying wheeling charges. The same scenarios as in case 1 were also explored.

Case 3: Grid connected hydrogen production plant:

This scenario was analysed to make use of curtailed electricity where the electrolyser is grid connected, but only operated in times of high RE generation to mitigate curtailment.

The computation of LCOH was done for Case 2 and case 3 using a 100 MW PEM electrolyser technology for each RE type described in the previous section. The LCOH is the average cost per kg (in discounted real dollar) of building and operating a GH2 production asset over the project lifetime. LCOH covered all relevant project related costs, including investment costs, fixed and variable operating cost, fuel/electricity cost and well as the financing costs.

LCOH was simulated at different capacity factors (CF) and those simulations that yielded low LCOH in comparison with LCOH in selected countries (mainly potential importing countries) were considered for export potential analysis. The annual GH2 export potential was then estimated dividing the total annual energy generation at the potential CF by the energy required to produce 1 kg H2. Finally, the estimated GH2 was converted into NH3 and the corresponding LCOA was calculated.

3.1.5. Limitations

- Data availability and reliability: there is a wide range in available data on GH2 production, conversion and reconversion, and the simulation results depend on the considered values. This study used average values where possible and applicable.
- Assignment timeframe: the time and resources allocated to the assignment was not enough to collect and process all necessary data, given the extent of the mission which required the estimation of the LCOE for different RE technologies, estimation of the LCOH and GH2 potential as well as the shipment cost.
- RE potential to be dedicated to GH2 production: there was no information on how much land would be made available for RE project development. The potential for GH2 was based on own assumptions.
- Hydrogen shipment: apart from ammonia, all the other two shipping options are still at earlier stage with very little or no showcases currently available. All the calculations with regard to hydrogen shipping costs are therefore based on existing studies and industry data.

3.2 Results

This   section presents the estimated LCOE for solar PV and wind technologies, LCOH, estimates of GH2 export potential as well as green NH3 export potential and its production cost (LCOA).

3.2.1. Levelized cost of electricity

Since electricity represents a considerable share of the total LCOH (30% to 60% of the LCOH[1]), we have put more emphasis on the LCOE for both solar and wind technologies under different conditions, especially the capacity factor at each geographical location. In addition to technical conditions, two financing options for each technology were simulated:

- Local conditions: 70% debt, 30% equity, 10-year debt term, cost of debt: 8%, cost of equity: 13%, Weighted cost of capital (WACC): 9%, inflation: 3% p.a., Tax treatment in line with Viet Nam tax code according to Circular 78/2014 / TT-BCT
- Concessional financing: 80% debt, 20% equity, 18-year debt term, cost of debt: 3%, cost of equity: 9% (WACC: 4.0%), inflation: 3% p.a., Tax treatment in line with Viet Nam tax code according to Circular 78/2014 / TT-BCT

1 Lazard, 2021. Lazard's Levelized cost of hydrogen Analysis

- The simulation of the above assumptions led to the following results:
- Solar PV: the LCOE for solar PV varies between 92 US$/MWh and 50 US$/MWh for project financed under local conditions and between 61 US$/MWh and 36$/MWh for project funded by concessional financing.
- Onshore wind: under local financing conditions, the simulation results showed that the LCOE ranges between 103 US$/MWh (areas with low wind) and 48 US$/MWh (areas with high wind) while concessional financing would lead to an LCOE ranging between 74 US$/MWh and 34 US$/MWh.
- Offshore wind: the highest LCOEs were recorded for offshore wind where the financing under local conditions led to an LCOE varying between 197 US$/MWh and 105 US$/MWh whereas concessional financing would slightly improve the LCOE and bring it to between 139 US$/MWh and 75 US$/MWh.

Figure 9 to Figure 11 present the simulation results at different technical and financial conditions.

3.2.2. Levelized cost of green hydrogen

The LCOH simulations results exhibit a wide range of LCOH, as presented in the table below.

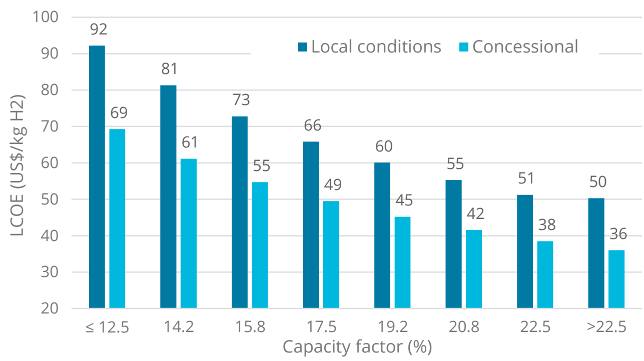


Figure 9: LCOE for solar PV power generation

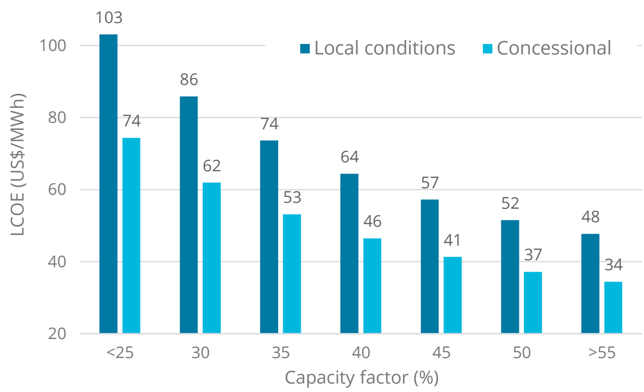


Figure 10: LCOE for onshore wind power generation

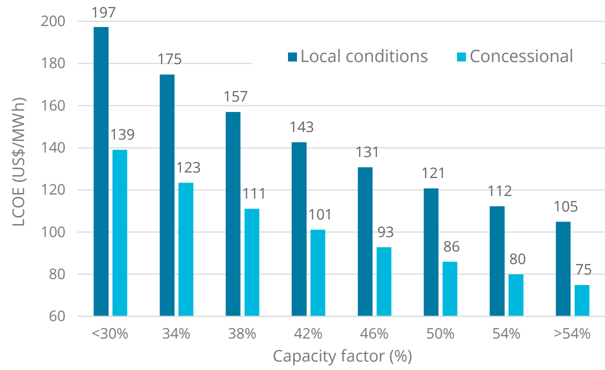


Figure 11: LCOE for offshore wind power generation

Table 3: LCOH in 2030 for different technologies and financing conditions

TECHNOLOGY	SCENARIO	MIN	MEDIAN	MAX
Solar PV	Local conditions	3.76	4.86	6.88
	Concessional	2.84	3.63	5.14
Onshore wind	Local conditions	2.79	3.63	5.44
	Concessional	2.09	2.65	3.97
Offshore wind	Local conditions	4.73	6.08	8.43
	Concessional	3.45	4.43	6.02

Note: for details on the financing cost assumptions, see Annex 1.

For table 2 above, the min, median, and max cases are calculated based on a range of different capacity factors for each technology. For solar PV, the assumed range of capacity factors extends from 12.5% to 22.9%; for onshore wind power, the range is 25% to 50%; and for offshore wind, the assumed range extends from 30% to 55%. For each technology, the minimum case is the case with the lowest, realistically achievable LCOH in Viet Nam, based on the two financing cases presented.

Due to the high costs of electrolysers, the LCOH depends to a significant degree on the capacity utilisation factor (CUF) of the electrolyser. Simply put, electrolyser costs can be amortised more quickly when the electrolysers operate at higher capacity factors. An electrolyser operating purely on solar power, for instance, would be limited to a capacity utilisation factor (CUF) of between 15%-25%, depending on the specific location. If the electrolyser were operating purely on onshore wind power, the maximum CUF would range between 30% and 45%; for offshore wind, between 35% and 55%, depending on the wind regime. For geothermal power, the utilisation factors could be as high as 90%, occasionally slightly more.

In order to overcome this limitation and to improve the economics of GH2 in relation to grey (or fossil-based) hydrogen production, a further option that is gaining traction is to hybridise the installations and generate GH2 using a combination of different RE sources, including solar, wind, biomass, geothermal, or hydropower. Together, a hybrid combination of technologies can produce higher capacity factors, and therefore enable a lower LCOE.

Among the countries currently positioned to become major exporters of GH2, the majority have either excellent solar or wind resources, and many plan to use a combination of both wind and solar in hybrid facilities. This is partly due to the lower per-kWh costs of solar and wind power, as well as the shorter lead times to construct new projects. Building new hydropower or geothermal projects, by contrast, is not only costlier per-kWh, it also takes significantly longer (e.g., 6-10 years vs. 1-2 years for solar and wind).

Since the focus of the study was to estimate GH2 export potential at competitive prices, the estimations focused on the scenarios that would yield lower costs of hydrogen (i.e., solar PV and onshore wind financed with the help of concessional finance).

Figure 12 and Figure 13 present LCOH according to the geographic location of power generating plant for solar and onshore wind respectively.

Green hydrogen and green ammonia export potential

The potential for GH2 export potential depends on how much land that can be made available to accommodate GH2 dedicated power plants and their geographic locations. Since this information was not available, the

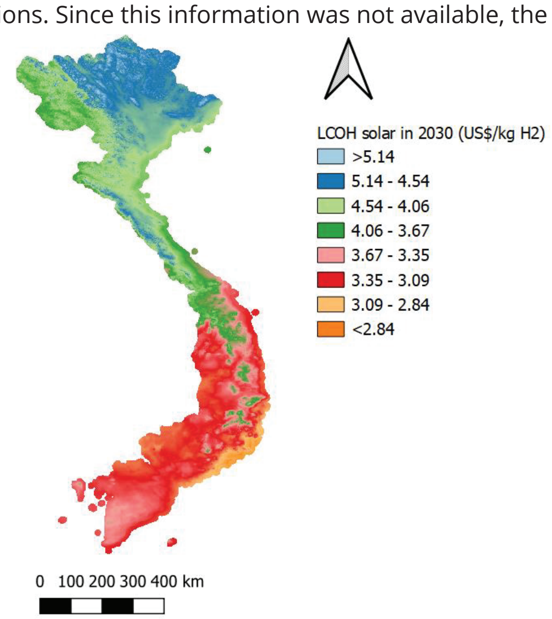


Figure 12: LCOH for GH2 from solar PV

Source: based on GSA 2.0

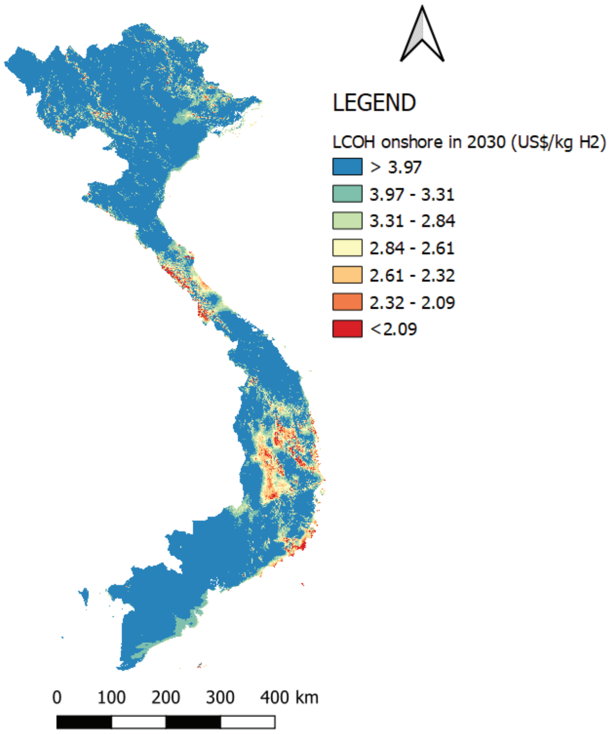


Figure 13: LCOH for GH2 from onshore wind

Source: based on GWA 3.1

study assumed that 5% of the country's land would be assigned to GH2 projects (3% for solar PV and 2% for onshore wind). To estimate the GH2 potential an average power density of 80 MW/km2 was used for solar PV (GIZ Viet Nam, 2018), while 2.3 MW/km2 (Nguyen, 2006) was applied for onshore wind.

The GH2 potential was estimated based on the following equation:

Where GH2pot. is the estimated GH2 potential in ton, 8760 the total number of hours in a year, CFi is the plant capacity factor in %, Pi the installed capacity in MW, and ηelec. the unit electricity consumption for GH2 production (kWh/kg). The unit electricity consumption (ηelec.) is given by the product of H2 higher heating value

$$GH2_{pot.} = \sum_{i=1}^{n} \frac{8760.\,CF_i.\,P_i}{\eta_{elec.}}$$

(HHV) with the system efficiency. The study used 70% as the system efficiency (IRENA, 2020) and 39.4 kWh/kg as hydrogen HVV.

The two tables below present the estimated GH2 potential at different plant capacity factor values.

Table 4: Estimated GH2 potential from solar PV

Capacity factor	Area (km2)	3% of the area (km2)	Capacity (MW)	Annual energy (MWh)	Equiv. GH2 (ton)	LCOH in 2030 (US$/kg)	LCOH in 2050 (US$/kg)
Below 12.5%	329	9.9	790	864,678	15,441	Above 5.14	Above 1.85
12.5 - 14.2%	25530	766	61,273	76,218,302	1,361,041	5.14 - 4.54	1.85 – 1.63
14.2 - 15.8%	82765	2483	198,635	274,926,734	4,909,406	4.54 - 4.06	1.63 – 1.46
15.8 - 17.5%	59101	1773	141,843	217,445,968	3,882,964	4.06 - 3.67	1.46 – 1.32
17.5 - 19.2%	24554	737	58,929	99,114,276	1,769,898	3.67 - 3.35	1.32 – 1.21
19.2 - 20.8%	78744	2362	188,987	344,348,620	6,149,082	3.35 - 3.09	1.21 – 1.11
20.8 - 22.5%	51726	1552	124,143	244,685,815	4,369,390	3.09 - 2.84	1.11 – 1.03
Above 22.5%	5189	156	12,454	27,274,395	487,043	Below 2.84	Below 1.03
	327,939	**9,838**	**787,054**	**1,284,878,789**	**22,944,264**	**Average: 3.45**	**Average: 1.24**

Table 5: Estimated GH2 potential from onshore wind

Capacity factor	Area (km2)	% of the area (km2)	Capacity (MW)	Annual energy (MWh)	Equiv. GH2 (ton)	LCOH in 2030 (US$/kg)	LCOH in 2050 (US$/kg)
Below 25%	252,572	5,051	11,618	25,444,113	454,359	Above 3.97	Above 1.42
25 - 30%	29,935	599	1,377	3,618,725	64,620	3.97 - 3.31	1.42 – 1.19
30 - 35%	17,953	359	826	2,532,046	45,215	3.31 - 2.84	1.19 – 1.02
35 - 40%	12,044	241	554	1,941,277	34,666	2.84 - 2.61	1.02 – 0.93
40 - 45%	8,175	164	376	1,482,404	26,471	2.61 - 2.32	0.93 – 0.83
45 - 50%	4,139	83	190	833,954	14,892	2.32 - 2.09	0.83 – 0.75
Above 50%	3,121	62	144	691,725	12,352	Below 2.09	Below 0.75
	327,939	**6,559**	**15,085**	**36,544,244**	**652,576**	**Average: 3.60**	**Average: 1.30**

As shown in the above tables, the estimated annual GH2 potential from solar PV is 22,944 kilotons at an average production cost (LCOH) of 3.45 US$/kgH2 in 2030 and 1.24 US$/kgH2 in 2050. As for GH2 from onshore wind, its annual potential is estimated to be 652 kilotons with at an LCOH of 3.60 US$/kgH2 in 2030 and 1.3 US$/kgH2 in 2050.

Concerning green ammonia, its annual potential was calculated by dividing the estimated GH2 potential by its weight fraction in ammonia of 17.65%. This resulted into 129,996 kilotons of ammonia from solar PV and 3,697 kilotons of ammonia from onshore wind.

The LCOA were calculated as part of shipping cost.

Chapter 4

Hydrogen shipping cost

This chapter describes the applied methodology to estimate hydrogen-shipping cost from Viet Nam to potential importing countries, mainly Europe/Germany.

4.1 Methodology

Hydrogen shipping analysis consisted of estimating the levelized cost of hydrogen shipping from centralized production facilities to the import terminal in German, Japan, and Republic of Korea. Transporting hydrogen by ships requires converting it into LH2, ammonia or LOHCs.

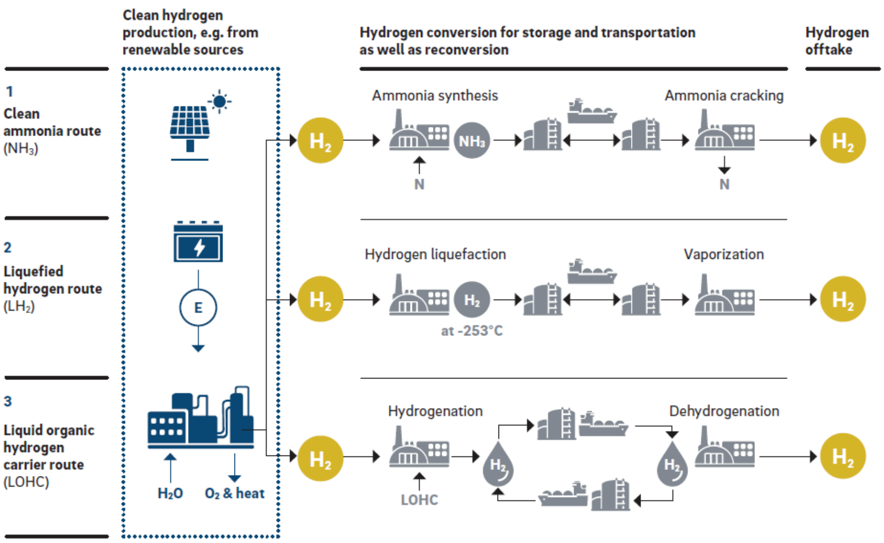
4.1.1. Hydrogen shipping cost elements

Our assessment of the export cost includes the following cost elements:

- Cost for converting pure hydrogen into LH2, NH3 and LOHCs
- Cost of storing LH2, NH3 or LOHCs in ports before their shipment
- Transportation cost from export terminal to the terminals in importing countries
- Boil-off gas (BOG) cost
- Cost of storing LH2, NH3 or LOHCs in import terminals before their reconversion
- Cost of reconverting NH3 and LOHCs to pure hydrogen

Figure 14: Hydrogen shipping equipment and infrastructure

Source: Hydrogen transportation (Roland Berger)



The below figure illustrates hydrogen shipping value chain. As shown in the above figure, hydrogen shipping analysis covered the following equipment and infrastructure:

1. **Liquefaction/conversion:** a facility that liquefies hydrogen, convert H2 into NH3 (Haber-Bosch process), or convert toluene to cyclohexane (LOHC).
2. **Storage at export terminal:** to store LH2, NH3 or LCOH before their shipment
3. **Shipping**: transportation of LH2, NH3 or LOHC from the export terminal to import terminals via tanker ship.
4. **Storage at import terminal:** to store the delivered LH2, NH3 or LOHC at the import terminal state before their gasification/reconversion.
5. **Gasification/reconversion:** a facility that gasifies the LH2, crack the NH3, or dehydrogenate the cyclohexane to toluene and hydrogen.

The estimation of the shipping cost was conducted using a 100 MW PEM electrolyser (same as in the case of LCOH calculation) with the following characteristics:

- Capacity factor: 45%
- LCOH: 4.61 US$/kgH2 in 2022, 2.76 US$/kgH2 in 2030, 1.66 US$/kgH2 in 2040 and 1 US$/kgH2 in 2050
- System efficiency: 70% in 2022,

The data used for estimating the shipping cost was obtained from three main sources:

- Gas Infrastructure Europe (GIE): Database containing cost estimates for technologies required for the import of liquid RE carriers. The database is based on publicly available information and project experiences (DNV GL, 2020);
- The Future of Hydrogen – IEA G20 Hydrogen report: Assumptions (IEA, 2020);
- Different research articles from international recognised scientific journals and information from IEA and IRENA websites.

The study assumed the case of an electrolyser installed at harbour, meaning that no pipeline was analysed. For generation facilities not located at harbours, a pipeline should be included in the analysis.

The table below presents the techno-economic assumptions for hydrogen shipping.

Table 6: Techno-economic assumptions for hydrogen shipping

Cost element	Parameter	LH2	Ammonia	LOHC
Conversion	Lifetime (years)	20	20	20
	CAPEX ($/kW)	1 500	889	97
	OPEX (%CAPEX/a)	2.5	1.5	3
	Electricity use (kWh/kg H2)	10*	4.7	1.5
	Toluene CAPEX ($/kg tol)	-	-	400
Export Terminal	Lifetime (years)	20	20	20
	CAPEX ($/ton)	3 190	1 995	812
	OPEX (%CAPEX/a)	2	2.5	2.5
	Electricity use (kW/kg H2)	0.61	0.005	0.01
	Boil-off (%/day)	0.1	-	0.1
Ship	Lifetime (years)	20	20	200
	CAPEX ($/t)	3 745	1 600	691
	OPEX (%CAPEX/a)	4	4	2.5
	Speed (km/h)	37	37	37
	Berthing time (h)	48	48	48
	Fuel use (MJ/ton.km)	0.07	0.07	0.07
	Boil off (%/day)	0.2	-	-
Import Terminal	Lifetime (years)	20	20	20
	CAPEX ($/tpa)	3 190	1 710	568
	OPEX (%CAPEX/a)	2	2.5	2.5
	Electricity use (kW/kg H2)	-	0.02	0.01
	Boil-off (%/day)	0.1	-	-
Reconversion	Lifetime (years)	20	20	20
	CAPEX ($/kW)	300	259	261
	OPEX (%CAPEX/a)	3	3	3
	Electricity use (kW/kg H2)	0.1	4,7	13

*6.1 kWh/kg H2 used from 2030 onwards

To calculate shipping costs in 2030, 2040 and 2050, cost reductions were applied to the initial CAPEX numbers based on projections of Wijayanta et al. (2019).

4.2 Results

This section summarises the calculation results for shipping hydrogen from Viet Nam (Port of Saigon) to Europe (Port of Rotterdam – The Netherlands), Japan and South Korea.

4.2.1. Hydrogen shipment to Europe

Based on the data and assumptions presented in the methodological section, ammonia is the most economical option to export GH2 from Viet Nam to Europe as shown in the figure below.

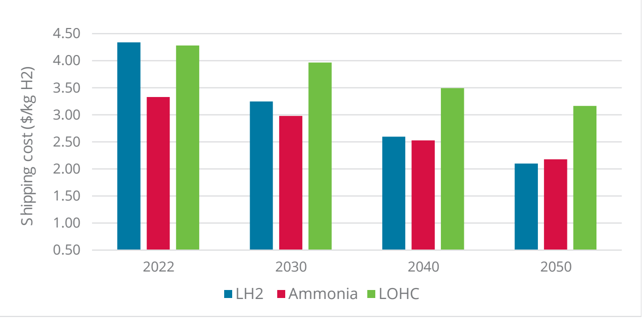


Figure 15: Estimates of hydrogen shipping cost to Europe by 2050

As can be seen from the figure below, which presents different cost elements of the shipping cost, LOHC is the most expensive option under this case. This is justified by the high dehydrogenation energy needs (about 15 kWh/kg H2) combined with the high price of electricity in The Netherlands of 0.134 US$/kWh (GlobalPetrolPrices, 2022a) .

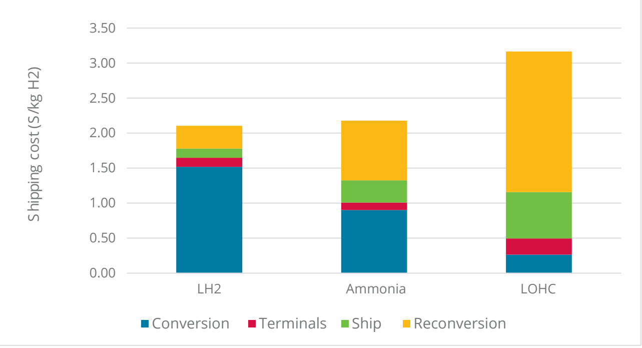


Figure 16: Cost elements for hydrogen shipping to Europe in 2050

4.2.2. Hydrogen shipment to Japan

The simulation of the shipping cost revealed that, by 2030, ammonia would be the best way to export hydrogen to Japan. After 2030 LH2 would be the most economical way of shipping hydrogen to Japan as noticeable in the below figure.

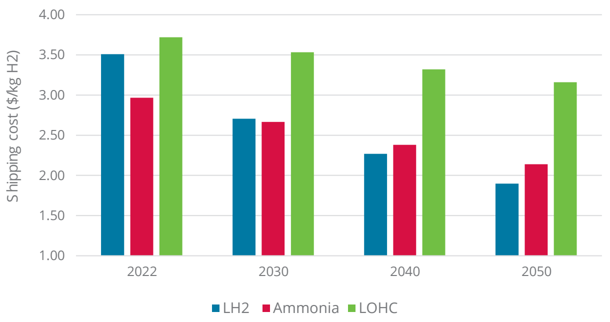


Figure 17: Estimates of hydrogen shipping cost to Japan by 2050

Similar to shipping hydrogen to Europe, LOHC is the most expensive shipping option due to the high electricity prices for LOHC dehydrogenation, which amounts 0.182 US$/kWh for businesses (GlobalPetrolPrices, 2022b).

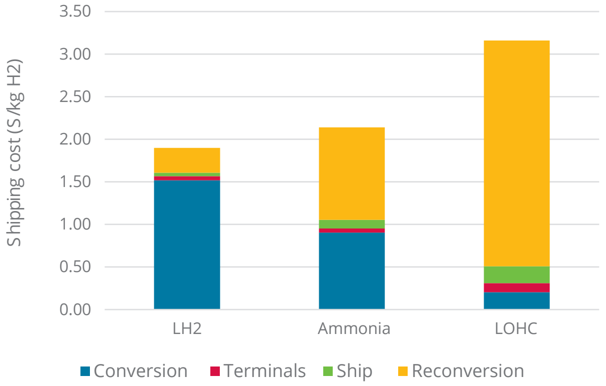


Figure 18: Cost elements for hydrogen shipping to Japan in 2050

4.2.3. Hydrogen shipment to South Korea

Unlike the shipment to Europe and Japan where ammonia and LH2 are seen promising, the study found that Ammonia and LOHC would be the cheapest option to export GH2 from Viet Nam to South Korea as it can be seen in the figure below.

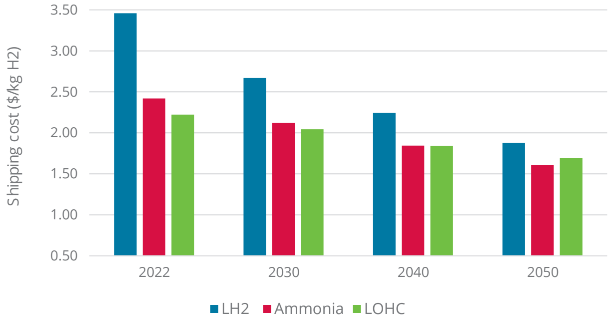


Figure 19: Estimates of hydrogen shipping cost to South Korea by 2050

The low cost of shipping hydrogen using ammonia and LOHC is explained by the low electricity price in South Korea of 0.075 US$/kWh for businesses (GlobalPetrolPrices, 2022c) compared to other two countries. The figure below shows the shares of different cost elements for hydrogen shipping to South Korea in 2050.

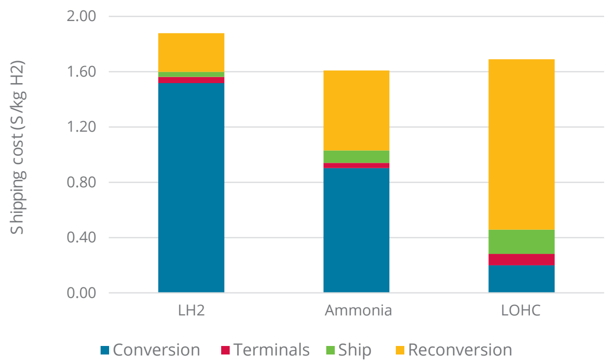


Figure 20: Cost elements for hydrogen shipping to South Korea in 2050

Another important factor that influences the shipping cost is geographic proximity. The table below provides an overview of the main distances between the primary competitors outlined above to three of the main ports in the countries examined.

Table 7: Shipping distances port-to-port

Country	Distance to the EU (Port of Rotterdam)	Distance to South Korea (Port of Daesan)	Distance to Japan (Port of Tokyo)
Morocco (Casablanca)	1.682nm	11.287nm	11.648nm
South Africa (Cape Town)	7.323nm	10.047nm	10.430nm
Chile (Chacabuco)	10.044nm	15.971nm	16.342nm
Australia (Perth)	11.511nm	5.063nm	5.298nm
Viet Nam (Saigon)	10.082nm	2.727nm	3.088nm

Source: (Ports, 2022)

In addition to its greater proximity to Europe, Morocco has also already signed agreements to cooperate on green hydrogen production with EU Member States such as Portugal, specifically for the export of green hydrogen (Kasraoui, 2022). The distance from Morocco to other key ports in the EU are comparatively short, including to the Port of Cadiz (256 nautical miles, or "nm"), Marseille (999 nm), Rotterdam (1.682 nm), Bremerhaven (1.927 nm), and Hamburg (1.959 nm). Compared to the distances involved in shipping from Viet Nam (Port of Saigon) to the EU (Rotterdam) of 10.082 nm, Viet Nam is approximately 5-7 times further from the key EU ports than other major potential competitors such as Iceland or Morocco. This puts countries like Morocco in an advantageous position with regard to shipping costs for shipping green hydrogen to the EU.

Chapter 5

Green hydrogen export potential of Viet Nam

5.1 Potential green hydrogen exporting countries (competitors)

Investments toward the production of green hydrogen are growing rapidly worldwide. A growing number of jurisdictions are starting to adopt plans to make sure that new natural gas infrastructure, for instance, is “hydrogen-ready” while dozens of hydrogen production facilities are emerging in Europe, the Middle East, India, the U.S., and Canada. Within the framework of the EU’s recently launched Clean Hydrogen Alliance, a total of 600 projects are expected to come online across the EU by 2025.[1] Thus far, the majority of these hydrogen production facilities have been launched as part of pilot projects to test the feasibility and costs of green hydrogen production and include projects at various stages of planning and development. However, the majority of the projects currently under development are aimed first and foremost at meeting domestic demand (e.g., in the EU) and not at international exports.

The main markets that are currently emerging as near-term exporters of green hydrogen considered in this study Chile, Morocco, South Africa, and Australia

When considering potential competitor countries in terms of green hydrogen production, there are five main variables to consider:

1. Renewable energy resource quality
2. Proximity to target market
3. Land availability
4. Cost of capital
5. Political stability/Political will

This analysis will consider each of these five variables in turn with reference to the four main competitors identified above.

1 EC (2021). https://ec.europa.eu/info/news/hydrogen-europes-industry-rolling-out-hydrogen-projects-massive-scale-2021-nov-30_en

Table 8: Key variables for green hydrogen competitiveness

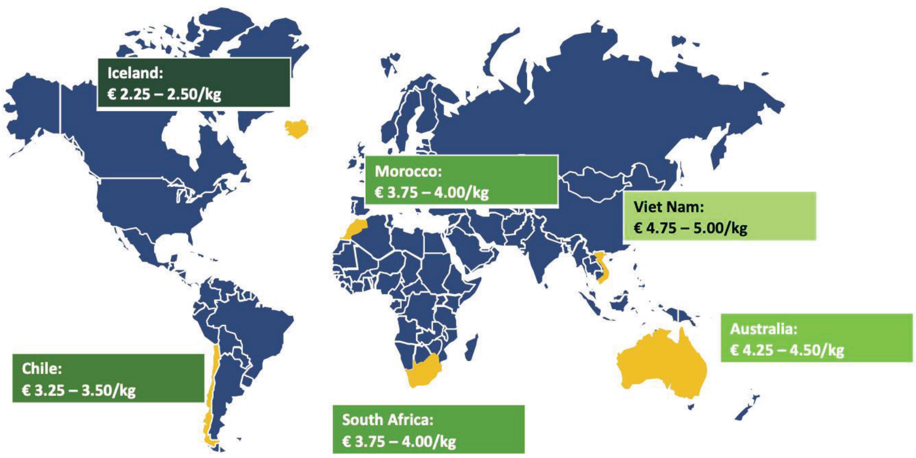
Key Variable	Viet Nam’s relative position
Renewable energy resource quality	Viet Nam has good overall renewable energy resource quality. However, on an international level, GIS and RE resource maps indicate that Viet Nam’s relative position is weaker in solar than other potential competitors such as Australia, Morocco, and Chile. With regard to wind power, Viet Nam’s resources are among the best in Southeast Asia at between 6-10m/s at 100m hub heights. However, the best resource potential is offshore, which entails a higher production cost due to significantly higher CAPEX and OPEX (https://globalwindatlas.info/ | https://globalsolaratlas.info/map)
Proximity to target market	Viet Nam is located roughly 2.700 nautical miles from ports in South Korea, and just over 3.000 nautical miles from major ports in Japan. This is in contrast to over 10.000 nautical miles from the port of Rotterdam, Europe’s largest. Due to the significant additional costs of shipping, it will be difficult for Viet Nam to compete directly on exports to the EU in the near-term against other neighbouring exporting countries such as Morocco, which is located roughly 1.700 nautical miles from Rotterdam.
Land availability	Viet Nam has a total land surface of 331.690km2. This is in contrast to Morocco (446.550km2), Australia (7.692.000km2) and Chile (756.950km2). In addition, Viet Nam has a significantly higher population density at 311 inhabitants/km2 vs. a population density of 83/km2 for Morocco, 3/km2 for Australia.
Cost of capital	The cost of debt provided for renewable energy projects in Viet Nam ranges from between 6.5% and 10%, depending on whether the loan is provided by a national bank or a local commercial bank. Debt tenors are typically limited to a maximum of 14-15 years from national banks and around 10 years for commercial banks. It can be expected that similar conditions will be available for projects dedicated to green hydrogen production. By contrast, lending for major renewable energy projects in countries like Australia and Chile benefit from a cost of debt as low as 2-3%, and debt tenors of up to 18 years. In order to be competitive globally in terms of green hydrogen production, it is likely that Viet Nam will need to rely on concessional financing from major international lenders, or consortia of lenders, in order to bring the cost of capital down, and in turn, the cost of green hydrogen production.

Political stability / Political will	Overall Viet Nam benefits from a high degree of political stability. It has a credit rating of BB from the major credit rating agencies and is considered investable. In addition, it ranked relatively well on the World Bank's ease of doing business report in 2020, at 70 out of 190, but behind other competitors such as Australia (14th), Chile (59th), and Morocco (53rd). In addition, Viet Nam has articulated a clear political will to accelerate the energy transition and to develop ambitious policies to support the emergence of a clean energy economy. This provides Viet Nam with a strong position in terms of mobilizing investment for green hydrogen production.

Compared to Viet Nam, the four major competitors considered here currently have certain competitive advantages in terms of green hydrogen production (see the figure below). These competitive advantages are reflected in the current estimated cost of green hydrogen production. (Note that the country that currently has the lowest green hydrogen production costs is Iceland, which has a competitive edge that is expected to persist until roughly 2030; as such, Iceland is included to provide an additional benchmark.)

Figure 21: International Green Hydrogen Production Costs (2022)

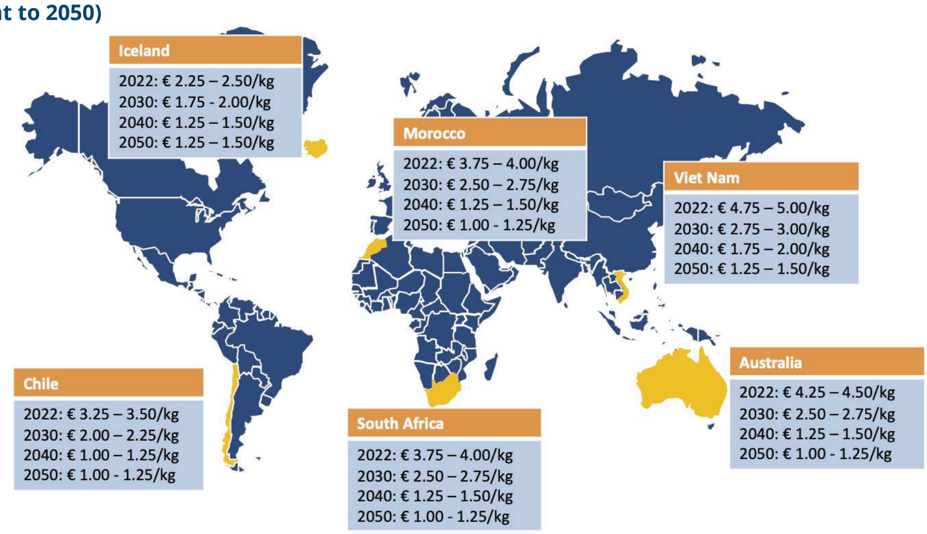
Source: PwC (2022)[1]



However, this merely provides a snapshot of the costs of hydrogen production today. **Forecasting these values forward for the coming years, the relative competitive position of each country changes, and Viet Nam's relative position improves substantially** (see the below figure).

Figure 22: International GH production cost range among potential exporting countries (Present to 2050)

Source: PwC (2022)



1 https://www.pwc.com/gx/en/industries/energy-utilities-resources/future-energy/green-hydrogen-cost.html

As the above figure shows, Viet Nam is expected to continue having a slightly higher production cost than other markets with higher resource quality, more abundant land, a lower cost of capital, or all three. However, this slightly higher production cost does not necessarily mean that Viet Nam will be unable to compete: much hydrogen production built for exports is likely to be developed in the context of bilateral partnerships, with preferential financing conditions and long-term supply contracts. For instance, countries within the EU as well as Japan and South Korea face constraints with regard to how much GH2 they can produce domestically and will likely need to be reliant on imports. Under such an approach, Viet Nam's production costs are likely to remain sufficiently competitive to be able to secure bilateral agreements for GH2 supply.

The broader question for Viet Nam is which export markets it should focus on first. Given the significant impact of shipping costs, it is more likely that Viet Nam will be able to export green hydrogen at a competitive price in the Asia Pacific region than to Europe in the near-term. The next section looks at the current status among potential green hydrogen importing countries.

5.2 Overview of potential green hydrogen-importing countries

The main export markets that are emerging for the sale of green hydrogen are largely concentrated among industrialised countries with ambitious climate goals. This analysis considers four major jurisdictions: the EU, including a separate sub-section in Germany, Japan, as well as South Korea.

5.2.1. EU's Hydrogen Strategy

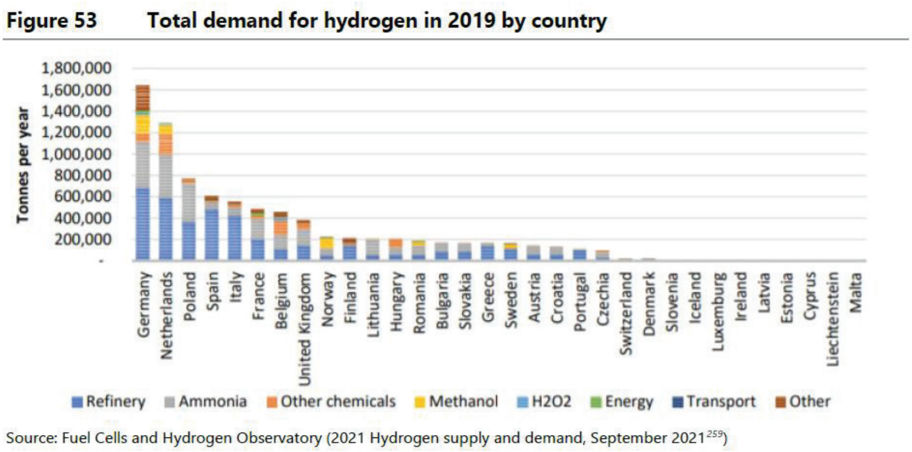
In 2020, the EU released its "Hydrogen strategy for a climate-neutral Europe" in support of the EU's vision of achieving its European Green Deal and the energy transition to net zero emissions. The EU Strategy outlines the plan for scaling up a European green hydrogen supply and demand, prioritizing investments, and regulations, promoting research and innovation, and international cooperation. The EU Strategy is broken down to three phases:

- Phase I – (2020-2024) – install at least 6 GW of green hydrogen electrolyzers and achieve 1 million metric tons/year of green hydrogen production.
- Phase II – (2024-2030) – green hydrogen becomes highly integrated in the European energy system. Strategic objective of installing at least 40 GW of green hydrogen electrolyzers and producing up to 10 million metric tons/year of green hydrogen.
- Phase III – (2030-2050) green hydrogen reaches technological maturity, is deployed at large scale, and reaches sectors that are considered hard to decarbonize. [1]

The figure below shows the total EU demand for hydrogen and related synthetic products such as ammonia by country and fuel type (as of 2019).

Figure 23: 2019 EU Hydrogen Demand by Country

Source: Entec (2022) [2]



1 European Commission (2020) P.5-7 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301

2 https://op.europa.eu/en/publication-detail/-/publication/7ab70e32-a5a0-11ec-83e1-01aa75ed71a1/language-en

Measures to Encourage Hydrogen Demand

- Strategic Forum for Important Projects of Common European Interest (IPCEI) – the Strategic Forum for IPCEI built a common European vision strategic value chains for technologies such as hydrogen and facilitated cooperation to engage in new joint investments. Through the Forum, which concluded in 2020, helped identify a range of large investment projects along the strategic hydrogen value chain which could be designated as 'IPCEI projects' and allow them to receive member state subsidies.[1]
- Clean Hydrogen Partnership – The EU established the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), which was succeeded in late 2021 by the Clean Hydrogen Joint Undertaking (or "Clean Hydrogen Partnership"). This public-private partnership between the European Commission, the hydrogen industry and academia support research and innovation on hydrogen technologies in Europe.[2]
- European Clean Hydrogen Alliance – Launched in 2020, this is collaboration between government, industry, and civil society groups to guide the investment in hydrogen technologies with a pipeline of concrete projects and promote the production and consumption of clean hydrogen. [3]

EU's Hydrogen Demand Targets and Estimates

While hydrogen may have only made up 2% of final energy production in 2015, the industry is expected to grow significantly in the EU and reach between 8-24% of final energy consumption by 2050. [4] Under ambitious scenarios, some forecasts see EU hydrogen demand growing to as high as 2 250 TWh by 2050 (roughly 69 million metric tonnes), with less ambitious forecasts projecting total demand of roughly 780 TWh (roughly 24 million metric tonnes).[5] Although much of this hydrogen is currently grey hydrogen, produced from fossil fuels like natural gas and coal, national plans expect that a growing share of this hydrogen demand will need to be met with green hydrogen in order to remain in compliance with the Paris Agreement.

The figure below provides an overview of the projected development of the green hydrogen industry in Europe through 2050.

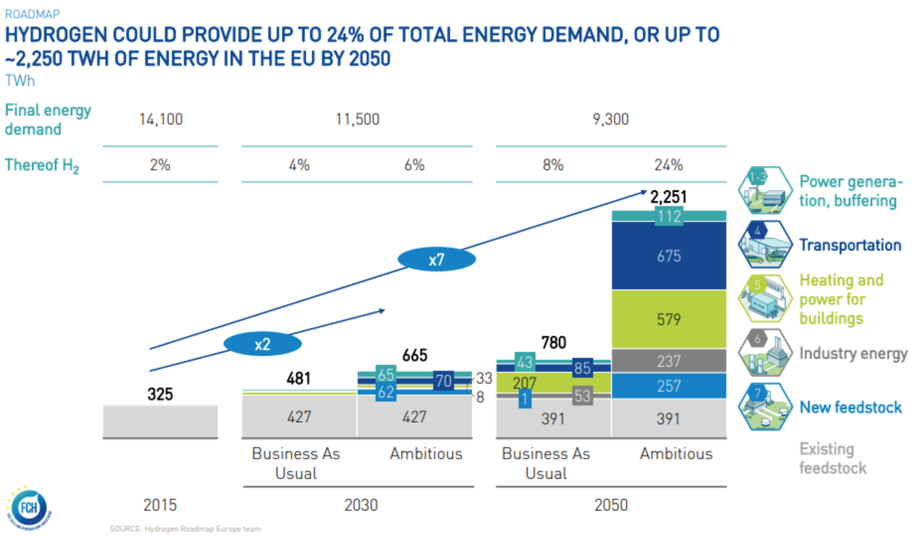


Figure 24: Forecast of European Union Hydrogen and Final Energy Demand through 2050

Source: Source: FCH JU (2019)

1 Ibid., 8-9.
2 Clean Hydrogen Partnership (2022) https://www.clean-hydrogen.europa.eu/about-us_en
3 European Commission (2020) P.3 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301

4 FCH JU
5 FCH (2019). Hydrogen Roadmap Europe, Fuel Cells and Hydrogen, https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

Domestic Hydrogen Production

The EU strategy specifies that the bloc will build up its productive capacity for green hydrogen over the next 20 years in order to meet some of its projected demand. In 2019, the bloc produced an estimated 10.8 million metric tons/year of primarily grey hydrogen for the petrochemical and other industries. [1]

- 2030 – 5 million metric tons/year green hydrogen (from 40 GW of electrolyzers) [2]
- 2040 – (not specified in EU 2020 Strategy)
- 2050 – up to 23.6 million metric tons/year to 68.2 million metric tons/year (780-2,251 TWh) or 8-24% of final energy demand based on the Hydrogen Roadmap estimate range (not specified in EU 2020 Strategy)[3]

Hydrogen Imports

The EU strategy emphasizes the need to foster international cooperation regarding hydrogen technologies and identifies a medium-term target for imports from its potential hydrogen partners.

- 2030 – 5 million metric tons/year green hydrogen (from 40 GW of electrolyzers "in Europe's neighborhood')[4][5]
- 2040 – (not specified in EU 2020 Strategy)
- 2050 – (not specified in EU 2020 Strategy)

Import Standards

RED II sets the standard for green hydrogen use across all EU sectors. To qualify, hydrogen sources must:

- Come from renewable energy sources (excluding biomass) (Art. 27),
- Mass balancing[6] of the produced volumes along the value chain (Art. 30),
- Meet additionality requirements (supply must be derived from new renewable energy projects), and
- Provide information on received state aid.[7]

Although the EU could, in principle, meet its needs in GH2 with domestic production (see the figure below), many EU Member States are likely to remain reliant on imports to meet a portion of the GH2 needs due to a range of factors including cost, political constraints, land availability, and the need to simultaneously decarbonise the power as well as the heating sectors.

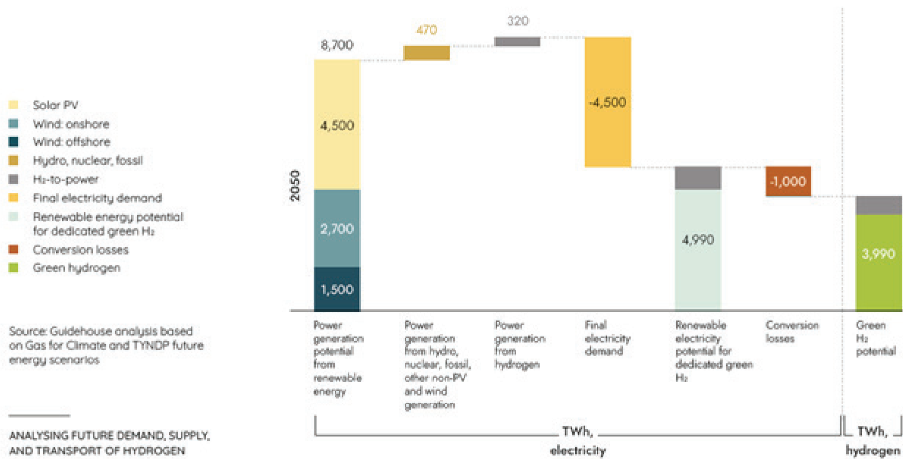


Figure 25: Overview of technical potential for green hydrogen production in the EU27+UK

Source: Wang et al. (2021). European Hydrogen Backbone, Guidehouse

1 Entec (2022) P.155 https://op.europa.eu/en/publication-detail/-/publication/7ab70e32-a5a0-11ec-83e1-01aa75ed71a1/language-en
2 ENTEC (2022) p.9 https://op.europa.eu/en/publication-detail/-/publication/7ab70e32-a5a0-11ec-83e1-01aa75ed71a1/language-en
3 FCH JU (2019) P.12 https://www.fch.europa.eu/sites/default/files/20190206_Hydrogen%20Roadmap%20Europe_Keynote_Final.pdf
4 The EU is interested in trade with neighboring countries in the Eastern Neighborhood (i.e., Ukraine) and Southern Neighborhood countries. (European Commission (2020) p.19)
5 European Commission (2020) P. 2 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301
6 "The mass balancing approach links the certificate with the respective physical delivery of the energy carrier. Sustainability certificates are traded via mass balancing, so that a physical delivery of an energy carrier goes hand in hand with the certificate." (DENA (2022) p.23)
7 DENA (2022) P.13 https://www.dena.de/newsroom/publikationsdetailansicht/pub/report-global-harmonisation-of-hydrogen-certification/

5.2.2. Germany's Hydrogen Strategy

Germany in particular has already announced that it plans to rely on imports to meet a substantial portion of its green hydrogen needs, with estimates ranging from between 55% and 95% of its demand by 2050.

Thus, most countries looking to transition to green hydrogen in the coming decades are likely to pursue a two-tiered approach: first, encourage domestic green hydrogen production to meet a portion of domestic needs, and second, develop or retrofit infrastructure in order to enable imports of green hydrogen from abroad.

National Hydrogen Strategy

In 2020, Germany adopted its National Hydrogen Strategy, which is envisioned as a coherent framework to support Germany's decarbonization, create new value chains for the German economy and foster international energy policy cooperation.[1] The Strategy contains an action plan with 38 concrete measures to be implemented by 2023 (initial ramp-up phase) to accelerate the development of the hydrogen market.[2]

Measures to Encourage Hydrogen Demand

Government Financing

- Package for the Future – Pandemic-related funding which includes €9 billion for accelerating the market rollout of hydrogen technology in Germany. This includes €2 billion towards fostering international partnerships.[3]
- NIP funding – €2.1 billion funding cumulative through 2026 for National Innovation Program on Hydrogen and Fuel Cell Technology (NIP) since 2006.[4]
- ECF funding – €51 million for 2020-2023 under the Energy and Climate Fund (ECF) for research on green hydrogen and energy applications of hydrogen technology.[5]
- Commercializing green technologies – €600 million in 2020-2023 to foster the commercialization of sustainable technologies, including hydrogen solutions.[6]
- €1 billion in 2020-2023 funding towards technology & facilities that use hydrogen to decarbonize their manufacturing processes.[7]
- €860 million over 17 years as part of the coal exit to establish a research center for sustainable and infrastructure-compatible hydrogen economy (HC-H2).[8]
- IPCEI projects – Germany will allocate €8 billion towards 62 EU recognized IPCEI projects in the industrial and transportation sectors.[9]
- *Hydrogen Promotion in the Energy Sector*
- EEG levy exemption – Under the 2021 update to the Renewable Energies Law (EEG), renewable energy that is used to produce green hydrogen is exempt from the EEG levy.[10]

Developing International Supply Chains

- "Hydrogen Potential Atlas" – the Federal Ministry of Research has been funding a "Hydrogen Potential Atlas" since 2020 that is focused primarily on the H2 production potential of African countries.[11]
- HySupply – The Federal Ministry of Research is also funding a feasibility study for a long-term strategic hydrogen partnership between German and Australian government and industry partners though which Germany would export hydrogen technologies and import green hydrogen produced in Australia.[12]

Industrial Decarbonization

- Action Concept Steel - more than 2 GW of green hydrogen production capacity and about 1,700 km of hydrogen pipelines are planned for decarbonizing steel production within this framework.[13]
- Carbon Contracts for Difference (CfD) – the Federal Government will provide funding in support of decarbonizing the steel and chemical industries equal to the difference between the cost of avoiding emissions and the EU's emission trading system (ETS) carbon price (budget of €3 billion until 2024). [14]

1 BMWK (2020) P.5 https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.html
2 Ibid., p.16-27.
3 Ibid., 5.
4 Ibid., 5.
5 Ibid., 5.
6 Ibid., 5.
7 Ibid., 5.
8 CSIS (2021a) https://www.csis.org/analysis/germanys-hydrogen-industrial-strategy
9 Ibid.
10 CSIS (2021a) https://www.csis.org/analysis/germanys-hydrogen-industrial-strategy
11 BMBF (2021) https://www.bmbf.de/bmbf/de/home/_documents/potenzialatlas-wasserstoff-afr-ergieversorger-der-welt-werden.html#:~:text=Potenzialatlas%20Wasserstoff%3A%20Afrika%20k%C3%B6nnte%20Energieversorger%20der%20Welt%20werden%2020.05.2021,Partnerschaft%20zwischen%20Deutschland%20und%20Westafrika
12 Acatech (2022)
13 CSIS (2021a) https://www.csis.org/analysis/germanys-hydrogen-industrial-strategy
14 CSIS (2021a) https://www.csis.org/analysis/germanys-hydrogen-industrial-strategy

Hydrogen Demand Targets and Estimates

55 TWh of hydrogen (about 1.7 mt) are used in Germany each year and are used in industrial applications amongst the chemicals and petrochemicals sectors.[15] The German government expects hydrogen to see greater market penetration led by increased consumption in the industrial sector (0.3 million metric tonnes/year or 10 TWh alone by 2030) and FCEVs and potentially other sectors such as heating in the long term.[16]

- 2030 – 2.7 million metric tonnes/year – 3.3 million metric tonnes/year or 32-39 GW (equivalent of 90 to 110 TWh) [17]

- 2040 – estimated by third parties to be between 3.6 million metric tonnes/year and 11.6 million metric tonnes/year for hydrogen and related products (119 and 382 TWh) (not specified in Germany's 2020 Strategy)[18]

2050 – estimated between 7.1 million metric tonnes/year and 22.4 million metric tonnes/year for hydrogen and related products by third parties, though may be as high as 45 million metric tonnes/year (234 – 740 TWh) (not specified in Germany's 2020 Strategy).[1920]

Domestic Hydrogen Production

- 2030 – 0.4 million metric tonnes/year or 5 GW (14 TWh) ,[2122]

- 2040 – 0.8 million metric tonnes/year or 10 GW (28 TWh) ,[2324]

- 2050 – up to 1.9 million metric tonnes/year (63 TWh) estimated by third parties (not specified in Germany's 2020 Strategy) [25]

15 BMWK (2020) P.9 https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.html
16 BMWK (2020) P.9 https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.html
17 Ibid., p.5
18 Fraunhofer (2021) p.20-21 https://www.wasserstoffrat.de/fileadmin/wasserstoffrat/media/Dokumente/Metastudie_Wasserstoff-Abschlussbericht.pdf
19 Fraunhofer (2021) p.20-21 https://www.wasserstoffrat.de/fileadmin/wasserstoffrat/media/Dokumente/Metastudie_Wasserstoff-Abschlussbericht.pdf
20 Bundesregierung (2022) https://www.bundesregierung.de/breg-de/themen/klimaschutz/faq-wasserstoff-1732248
21 The Physics Factbook (2005) https://hypertextbook.com/facts/2005/MichelleFung.shtml
22 BMWK (2020) P.5 https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.html
23 The Physics Factbook (2005) https://hypertextbook.com/facts/2005/MichelleFung.shtml
24 2020 DE strategy p.5
25 Fraunhofer (2021) p.20-21, 33-34, 81 https://www.wasserstoffrat.de/fileadmin/wasserstoffrat/media/Dokumente/Metastudie_Wasserstoff-Abschlussbericht.pdf

Hydrogen Imports

In order to meet the projected green hydrogen demand in Germany, the government estimates that it would need to install more than three times the renewable energy capacity of Australia (35.7 TW in 2020).[2627], Germany instead is expected to rely heavily on imports of hydrogen and related products.

- 2030 – 2.3 million metric tonnes/year to 2.9 million metric tonnes/year or 27-34 GW (equivalent of 76 to 95 TWh)[28]. Third party estimates range from 43% to 70% for hydrogen and 90 to 100% for synthesis product imports.[29]

- 2040 – 0.67million metric tonnes/year to 9.49 million metric tonnes/year (22.2 to 313.3 TWh) based on third party estimates, which is from 55% to 78% for hydrogen and 93% to 100% for synthesis product imports as a percentage of total demand (not specified in Germany's 2020 Strategy)[30]

- 2050 – 45 million metric tonnes/year[31]. Third party estimates range up to 17.24 million metric tonnes/year (568.8 TWh), or 53% to 80% for hydrogen and 79% to 100% for synthesis product imports as a percentage of total demand.[32]

26 BMBF (2022) https://www.bmbf.de/bmbf/shareddocs/kurzmeldungen/de/woher-soll-der-gruene-wasserstoff-kommen.html;jsessionid=725C8EB1E6810005E627A034DAD7E9E9.live722
27 Statista (2021) https://www.statista.com/statistics/1248614/australia-renewable-energy-capacity/#:~:text=In%202020%2C%20Australia's%20total%20renewable,tripled%20within%20the%20last%20decade
28 CSIS https://www.csis.org/analysis/germanys-hydrogen-industrial-strategy
29 Fraunhofer (2021) p.20-21, 33-34, 81 https://www.wasserstoffrat.de/fileadmin/wasserstoffrat/media/Dokumente/Metastudie_Wasserstoff-Abschlussbericht.pdf
30 Fraunhofer (2021) p.20,-21 33-34, 81 https://www.wasserstoffrat.de/fileadmin/wasserstoffrat/media/Dokumente/Metastudie_Wasserstoff-Abschlussbericht.pdf
31 Bundesregierung (2022) https://www.bundesregierung.de/breg-de/themen/klimaschutz/faq-wasserstoff-1732248
32 Fraunhofer (2021) p.33-34, 81 https://www.wasserstoffrat.de/fileadmin/wasserstoffrat/media/Dokumente/Metastudie_Wasserstoff-Abschlussbericht.pdf

5.2.3. Japan's Hydrogen Strategy

In 2017, Japan was the first country in the world to issue a national hydrogen strategy. Japan's "Basic Hydrogen Strategy" has 10 primary goals that range from promoting technological innovation in hydrogen technologies to further integrating the use of hydrogen across multiple sectors.[33][34]

Japan has also supported its strategy by issuing a "Strategic Roadmap for Hydrogen and Fuel Cells" in 2014 with updates in 2016 and 2019 that provide targets for technological deployment, the breakdown of costs, and the measures needed to achieve these deployment goals.[35] Additionally, the Japanese government issued a "Green Growth Strategy" in 2020 with an update in 2021 which provide timelines and targets for hydrogen infrastructure deployment, end-use fuel cell products like FCEVs and home fuel cells, and hydrogen volumes used in industries.[36]

Measures to Encourage Hydrogen Demand

Government Financing

- Japan's national R&D agency, the New Energy, and Industrial Technology Development, allocated $2.7 billion to establish a large-scale hydrogen supply chain and an additional $700 million to generate green hydrogen.[37]
- 2020 annual investments totaled $670 million across the hydrogen and fuel cell industry.[38]

Facilitating Industrial Decarbonization

- COURSE50 project – Under this initiative, Japan aims to cut total CO2 emissions in its steel mills by 30% by integrating hydrogen into the production process.[39]

Energy Sector Hydrogen Utilization

- Pilot projects – Since 2018, Japan has been testing hydrogen as a fuel source for gas turbines and successfully demonstrated its use in the world's first hydrogen-only cogeneration system.[40]

Promoting hydrogen-based mobility

- FCEV and HSR deployment – Japan currently have 5,500 FCEV passenger vehicles and busses and has 137 HRSs in operation.[41] It plans to scale up to 800,000 passenger FCEVs, 1,200 FCEV buses, 10,000 FCEV forklifts and 1,000 HRSs by 2030.[42]
- Hydrogen trains – The East Japan Railway Company is partnering with Hitachi and Toyota and is currently testing a hydrogen train.[43]
- Hydrogen ships – the Japanese government aims to introduce the first hydrogen vessel by 2028 [44]

Hydrogen Demand Targets and Estimates

Japan currently consumes 2 million metric tons/year of hydrogen, and it aims to increase the relative share of hydrogen and ammonia to 1% of primary energy and electricity demand by 2030.[45][46]

- 2030 – up to 3 million metric tons/year[47]
- 2040 – up to 9.6 million metric tons/year (200 pj to 1,150 pj per year) based on third party estimates (no set target)[48][49][50]
- 2050 – approximately 20million metric tons/year[51]

33 These elements are: (1) achieving low-cost hydrogen use, (2) developing international hydrogen supply chains, (3) facilitating renewable energy expansion in Japan, (4) H2 use in power generation, (5) expanding hydrogen use in mobility, (6) further utilizing hydrogen in industrial processes, (7) promoting fuel cell technology, (8) achieving further technological innovations, (9) expanding its international presence through international frameworks and cooperation, and (10) promoting public education and cooperation with local governments.
34 METI (2017) p.20-37 https://www.meti.go.jp/english/press/2017/pdf/1226_003b.pdf
35 METI (2019) https://www.meti.go.jp/english/press/2019/0312_002.html
36 CSIS (2021b) https://www.csis.org/analysis/japans-hydrogen-industrial-strategy#:~:text=Japan%20is%20focused%20on%20expanding,the%20current%20level%20by%202030
37 CSIS (2021b) https://www.csis.org/analysis/japans-hydrogen-industrial-strategy#:~:text=Japan%20is%20focused%20on%20expanding,the%20current%20level%20by%202030
38 IRENA (2022) p.41https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen
39 METI (2019) P.35 https://www.meti.go.jp/english/press/2019/0312_002.html
40 Ibid., 19.
41 IEA (2021) p. 76 https://iea.blob.core.windows.net/assets/3a2ed84c-9ea0-458c-9421-d166a9510bc0/GlobalHydrogenReview2021.pdf
42 Ibid.
43 Ibid., 77
44 Ibid.,
45 Ibid., 76.
46 CSIS (2021b) https://www.csis.org/analysis/japans-hydrogen-industrial-strategy#:~:text=Japan%20is%20focused%20on%20expanding,the%20current%20level%20by%202030
47 2021 Japan Green Growth Strategy Update https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/02_hydrogen.pdf
48 1 mt of hydrogen is equal to 0.00012 Pj to 0.00014 Pj, which is based on the assumption that there is 120-140 Mj of hydrogen per kg. The Physics Factbook (2005) https://hypertextbook.com/facts/2005/MichelleFung.shtml
49 ACIL Allen (2018) P.C-5 https://arena.gov.au/assets/2018/08/opportunities-for-australia-from-hydrogen-exports.pdf
50 The Physics Factbook (2005) https://hypertextbook.com/facts/2005/MichelleFung.shtml
51 https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/02_hydrogen.pdf

Domestic Hydrogen Production

- 2030 – up to 3million metric tons/year
- 2040 – 210,000 mt/year to 1.4 million metric tons/year (34 pj to 173 pj) based on third party estimates assuming 85% imports (no set government domestic target)
- 2050 – 3 million metric tons/year (based on 85% import assumption) ,

Hydrogen Imports

A key component of Japan's hydrogen strategy is to establish a large-scale hydrogen supply chain to accommodate imports from energy exporting countries. Japan's demand for imported hydrogen may represent more than 85% of its total hydrogen demand. The following import estimates are shown below:

- 2030 – up to 300,000 mt/year (government target - hydrogen type not specified). Third party estimates range from 744,000 mt/year to 3.28 million metric tons/year.
- 2040 – 1.19 million metric tons/year to 8.16 million metric tons/year (166 pj to 977 pj) based on third party estimates assuming 85% imports (no set government domestic target) ,
- 2050 – 17 million metric tons/year (based on 85% import assumption) ,

Import Standards

Japan has neither a national certification scheme, nor a definition for clean hydrogen, nor are there any further known developments on these matters. The Aichi Prefecture is the only region in Japan with a certification scheme which was established in 2018. In Aichi, the scheme defines renewable hydrogen as hydrogen from water electrolysis using renewable electricity sources or from steam-reforming using biomass (see Table 9 on certification requirements).

5.2.4. South Korea's Hydrogen Strategy

Korean Hydrogen Economy Roadmap

In 2019, the Republic of Korea ("South Korea") released its national "Hydrogen Economy Revitalization Roadmap," which sets out the government's plans for growing the South Korean hydrogen economy. The Roadmap sets growth targets for FCEVs, fuel cells, hydrogen supply and consumption, and hydrogen distribution and storage.

The Roadmap and subsequent policies specify the following targets:

- Consumption growth: from 220,000 mt/year in 2020 to 5.26 million metric tons/year in 2040
- Fuel cell vehicles and fueling stations – In 2021, South Korea had over 14,400 passenger FCEVs and at least 52 operational HRSs. Targets:
    - 2022 – 80,000 passenger FCEVs and 310 HRSs ,
    - 2025 – 200,000 passenger FCEVs and 450 HRSs (Korean New Deal)
    - 2040 - 6.2 million passenger FCEVs and at least 1,200 HRSs. This includes 2.9 million cars, 80,000 taxis, 40,000 buses, and 30,000 trucks by 2040.
    - 2050 - more than 2,000 HRSs (no 2050 FCEV target)
- Power generation – 13.8-21.5% of power generation from hydrogen and ammonia by 2050

Measures to Encourage Hydrogen Demand

Government Policies

- Hydrogen Law – In 2020, the Korean National Assembly passed the Hydrogen Economy Promotion and Hydrogen Safety Management Law ("Hydrogen Law"). The Hydrogen Law codifies elements of the hydrogen industrial strategy and provides support to hydrogen-focused companies with subsidies, loans, and tax exemptions for R&D. The Hydrogen Law was revised in late 2021 with amendments defining clean hydrogen and introducing a Clean Hydrogen Energy Portfolio Standard (CHPS) and Clean Hydrogen Certification System.
- Renewable Portfolio Standard – since 2012, large power producers have been required produce a minimum amount of their electricity from clean energy technologies, including fuel cell power generation.

Government Financing

- Korean New Deal – As part of the national development strategy to support the Korean economy's recovery from the COVID pandemic, the Korean government committed 13.1 trillion won (nearly $11 billion) by 2025 to expand the zero-emission vehicle supply (including FCEVs).
- Total hydrogen-related spending – Total fiscal year spending in 2021 on hydrogen technologies was $701.9 million, which represented a 40 percent increase from 2020 spending.
- Funding for the FCEV industry – the South Korean government has committed $2.34 billion to grow the hydrogen vehicle industry

Subsidies

The South Korean government is providing the following subsidies:

- FCEV purchase subsidies – In 2019 the national and local governments provided subsidies for an FCEV purchase ranging from $27,300 to $30,300.
- HRS subsidies – Currently about half the cost of installing fuel stations is subsidized by the government. A hydrogen fuel subsidy is also planned for vehicles through a future amendment to the Passenger Transport Service Act and the Trucking Transport Business Act.
- Natural gas feedstock subsidy – The government subsidizes the purchase of natural gas used to produce hydrogen for buildings and at utility scale with a 6.5% discount.

Hydrogen Demand Targets and Estimates

The government aims to boost grow their overall consumption from 200,000 mt/year to 27.9 million metric tons/year based on the following year targets

- 2030 – 3.9 million metric tons/year, with a target of 56% green hydrogen
- 2040 – 5.26 million metric tons/year, 70% blue or green hydrogen
- 2050 – 27.9 million metric tons/year, over 90% green hydrogen with blue hydrogen making up an estimated 2million metric tons/year

Other targets:

- Fuel mixing with fossil generation – "The government is targeting a fuel mix of 30% hydrogen at all its gas-fired power plants by 2035 and a mix of 20% ammonia at more than half of its coal-fired power plants in 2030. The government does not specify if the hydrogen and ammonia must be green or blue, or if grey is allowed.
- FCEV and HRS targets – (See section "Korean Hydrogen Economy Roadmap")
- Electricity – South Korea aims to boost their power generation from hydrogen from 314MW in 2018 to 1.55GW in 2022 and to 17.1GW by 2040.

Domestic Hydrogen Production

South Korea produces 220,000 mt/year exclusively from grey hydrogen. The country currently does not produce any green hydrogen. The annual domestic production targets are as follows:

- 2030 – 1.94million metric tons/year.
- 2040 – 1.58-5.26 million metric tons/year (minimum of 30% of the 5.26 million metric tons/year are targeted to be from domestic production).
- 2050 – 5million metric tons/year (3 million mt/year of green hydrogen and 2 million mt/year of blue hydrogen)

Hydrogen Imports

The South Korean government anticipates that it will rely heavily on imported hydrogen to meet its future hydrogen consumption. To that end, the country has planned 40 import bases by 2050 and expects the following annual import volumes:

- 2030 –1.96 million mt/year green hydrogen Third-party estimates range from 317,000 mt/year to 1.3million metric tons/year.
- 2040 – Up to 3.68million metric tons/year (up to 70% of 2040 target) of unspecified hydrogen. No target specifically for green hydrogen. Third-party estimates range from 1.36 mm to 4.59 million metric tons/year (200 pj to 550 pj), or 85% of imports.
- 2050 –22.9 million mt/year of green hydrogen from overseas

Import Standards

In its 2021 revision of the Hydrogen Law, the South Korean government established a mandatory purchase standard, the CHPS, which is scheduled to take effect in mid-2022 and set the foundation for a clean hydrogen certification system. The Korean government defines clean hydrogen as either green hydrogen (produced with renewable energy) or blue hydrogen (hydrogen that is produced from non-renewable energy sources with carbon capture and storage (CCS). Development of the clean hydrogen certification system is underway and is expected to be completed in 2023 (see Table 9 on certification schemes below).

Table 9: Overview of certification schemes for imported hydrogen and/or ammonia

MARKET	EU	GERMANY	SOUTH KOREA	JAPAN - AICHI PREFECTURE
Requirements	a. Hydrogen must be sourced from 100% RE b. Proof of guaranteed of origin (GO) cancellation must be provided in accordance with electricity volumes consumed c. Information on received state aid	a. 100% RE b. Data on received state aid	Unspecified. Will need to be either green or blue hydrogen to be deemed "clean hydrogen" under the CHPS. Official certification standards are expected to be complete by 2023	a. Renewable electricity or grid electricity accompanied by renewable electricity certificates. b. Renewable electricity installations that will be used for hydrogen production should be new or unused. c. Existing renewable facilities can be included in the short-term.
Certification Schemes	ISCC PLUS, CertifHy, dena Biogasregister, TÜV Süd CMS 70	dena Biogasregister, TÜV Süd CMS 70	Clean hydrogen certification system (under development)	Certification Scheme
Sustainability Tracking Method	• Mass balancing: RED II • Book & Claim: CertifHy • Both: dena Biogasregister, TÜV Süd CMS 70	Both Book & Claim and Mass Balancing for both dena Biogasregister and TÜV Süd CMS 70	N/A	Mass balancing
Status	In progress	Implemented, but not currently applicable to hydrogen	In progress, expected in 2023	Implemented, but applies only to Japan's Aichi Prefecture
Additional Explanation	RED II has been implemented, but national implementation is pending. All certifications will need to seek recognition by EU under RED II regulation.	Applies to biomethane and biogas but could be expanded to green hydrogen		There are no known developments towards creating a national hydrogen certification scheme

A central part of the regulations in the EU with regard to the import of green hydrogen is the question of additionality (see Text Box below).

Understanding Additionality Requirements

It is important to note, however, that additionality requirements apply: in order to be eligible to export to the EU, green hydrogen production must be derived from new facilities in order to prevent that clean electricity from existing facilities is merely diverted from supplying homes and businesses to the production of hydrogen, without catalysing additional investment in clean energy supply.

While such additionality standards are not yet universally applied, and exemptions exist depending on the country, they are likely to make it difficult, if not impossible, to rely on existing hydropower or geothermal assets to produce green hydrogen that is eligible for export.

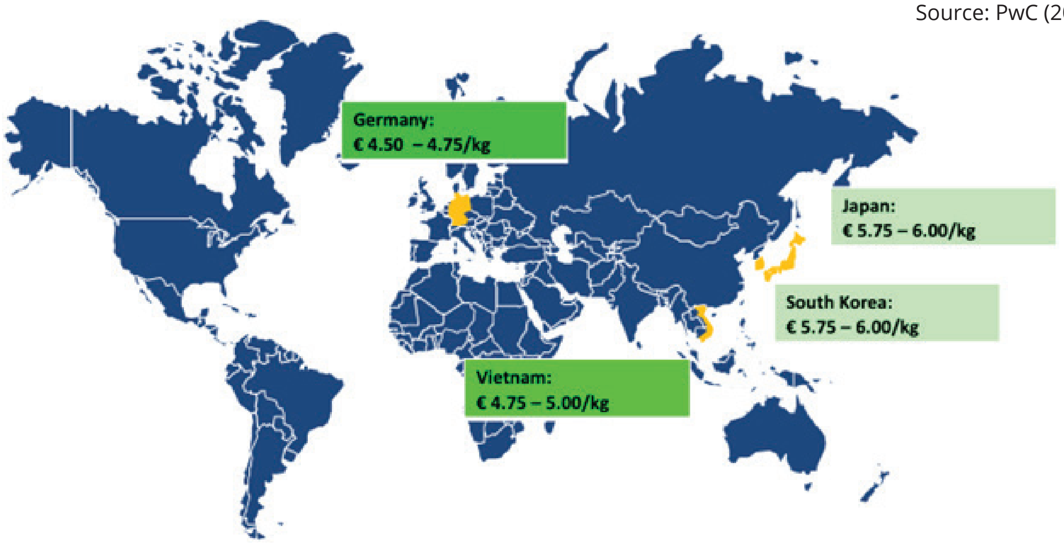
For more information on additionality requirements, see: Agora Energiewende (2021). Making Renewable Hydrogen Cost-Competitive, https://static.agora-energiewende.de/fileadmin/Projekte/2020/2020_11_EU_H2-Instruments/A-EW_223_H2-Instruments_WEB.pdf

5.3 LCOH in importing countries and GH2 delivery cost from importing countries

In order to be able to export green hydrogen to other markets, the cost of production in each of those markets is of central importance. The current cost of producing green hydrogen within the EU, Japan, and South Korea ranges from EUR 4.50 – 6.00/kg, with both Japan and South Korea having a higher production cost than Germany.

Figure 26: Green Hydrogen Production Cost Range in Potential GH2-Importing Countries (2022)

Source: PwC (2022)



Based on the above figure, the current cost of producing green hydrogen in Germany (EUR 4.50 – 4.75/kg) is roughly equivalent to the cost of producing it in Viet Nam (EUR 4.75 – 5.00/kg). Based on current costs, the more attractive export markets are South Korea and Japan, both of which have higher green hydrogen production costs, and greater geographic proximity to Viet Nam.

However, in order to obtain a more complete picture, it is necessary to consider both the hydrogen production costs as well as the respective shipping costs from different competitors to the key importing markets. **The total green hydrogen delivery cost** combines both the production and the transportation costs. Thus, to compare how Viet Nam is positioned competitively against other potential GH2 exporting countries, **it is necessary to compare the total combine GH2 production costs in different competitor markets as well as the respective distance from those markets to the GH2 importing countries.**

The GH2 exporting capabilities of Viet Nam was conducted by comparing H2 production cost in potential importing countries (Europe, South Korea, and Japan) with H2 delivery cost (production plus transportation cost) from Viet Nam to these importing countries as well as the H2 delivery costs from potential competitors (including specifically Australia, Chile, Morocco, and South Africa). Information on LCOH was extracted from a study on Cost-development of renewable hydrogen elaborated by PwC (2021). To estimate the transportation cost from potential GH2 exporting to potential importing countries, the unit shipment cost (in US$/kgH2/1000 km) from Viet Nam to respective importing countries was first calculated (see Table 3 below) and then used as unit shipment cost from potential exporting countries to respective importing countries.

Table 10: Distances from Viet Nam to Key Import Markets including Unit Shipping Costs

Destination	Distance (km)	2030		2050	
		Total shipping cost (US$/kg)	Unit shipping cost (US$/kg/1000 km)	Total shipping cost (US$/kg)	Unit shipping cost (US$/kg/1000 km)
Europe	18670	2.98	0.16	2.18	0.12
Japan	5719	2.67	0.47	2.14	0.37
South Korea	5050	2.12	0.42	1.61	0.32

Table 11: Green hydrogen exporting capabilities of Viet Nam to Europe

Cost type (US$/kgH2)	2030			2050		
	Av. LCOH (US$/kg H2)	Shipping (US$/kg H2)	Total Delivery cost (US$/kg H2)	Av. LCOH (US$/kg H2)	Shipping (US$/kg H2)	Total Delivery cost (US$/kg H2)
Europe/ Germany	3.44	0.00	3.44	2.33	0.00	2.33
Morocco (Casablanca)	2.92	0.50	3.42	1.33	0.36	1.69
South Africa (Cape Town)	2.92	2.17	5.09	1.33	1.58	2.91
Chile (Chacabuco)	2.39	2.98	5.37	1.33	2.17	3.50
Australia (Perth)	2.92	3.41	6.33	1.33	2.49	3.82
Viet Nam (Saigon)	3.18	2.98	6.16	1.59	2.18	3.77

*Converted from EUR to US$ (1 € = 1.06 US$ based on https://www.oanda.com/currency-converter/en/ of 28.04.2022); Note: port-to-port distances are derived from http://ports.com/sea-route/

Table 12: Green hydrogen exporting capabilities of Viet Nam to South Korea

Cost type (US$/kgH2)	2030			2050		
	Av. LCOH (US$/kg H2)	Shipping (US$/kg H2)	Total Delivery cost (US$/kg H2)	Av. LCOH (US$/kg H2)	Shipping (US$/kg H2)	Total Delivery cost (US$/kg H2)
South Korea	4.24	0.00	4.24	2.92	0.00	2.92
Morocco (Casablanca)	2.92	8.78	11.70	1.33	6.69	8.02
South Africa (Cape Town)	2.92	7.81	10.73	1.33	5.95	7.28
Chile (Chacabuco)	2.39	12.42	14.81	1.33	9.46	10.79
Australia (Perth)	2.92	3.94	6.86	1.33	3.00	4.33
Viet Nam (Saigon)	3.18	2.12	5.30	1.59	1.62	3.21

*Converted from EUR to US$ (1 € = 1.06 US$ based on https://www.oanda.com/currency-converter/en/ of 28.04.2022)

Table 13: Green hydrogen exporting capabilities of Viet Nam to Japan

Cost type (US$/ kgH2)	2030			2050		
	Av. LCOH (US$/ kg H2)	Shipping (US$/ kg H2)	Total Delivery cost (US$/kg H2)	Av. LCOH (US$/ kg H2)	Shipping (US$/ kg H2)	Total Delivery cost (US$/kg H2)
Japan	4.24	0.00	4.24	4.24	0.00	4.24
Morocco (Casablanca)	2.92	10.05	11.7	1.33	8.07	9.40
South Africa (Cape Town)	2.92	9.00	10.73	1.33	7.22	8.55
Chile (Chacabuco)	2.39	14.10	14.81	1.33	11.32	12.65
Australia (Perth)	2.92	4.57	6.86	1.33	3.67	5.00
Viet Nam (Saigon)	3.18	2.67	5.3	1.59	2.14	3.73

*Converted from EUR to US$ (1 € = 1.06 US$ based on https://www.oanda.com/currency-converter/en/ of 28.04.2022)

The hydrogen supply cost is an essential input to decide whether it is worthwhile to import or export hydrogen. The hydrogen supply combines both the production and the transportation costs.

The table below compares the delivery costs of green hydrogen (in the form of green ammonia) from Viet Nam to the three analysed destinations.

Table 14: Green hydrogen delivery costs to South Korea, Japan, and Europe

COST TYPE (US$/KGH2)	2030			2050		
	SOUTH KOREA	Japan	Europe	South Korea	Japan	Europe
LCOH	2.76	2.76	2.76	1.00	1.00	1.00
Shipping cost	2.12	2.67	2.98	1.61	2.14	2.18
Total	4.88	5.43	5.74	2.61	3.14	3.18

Based on the competitive position of Viet Nam against other potential competitors, including shipping cost factors, **the destinations where Viet Nam is most likely to be able to supply green hydrogen cost-competitively are in the Asia-Pacific region, in particular, South Korea and Japan**. For most other regions in the world, other competitors located closer to the importing market are likely to retain a competitive edge.

When shipping costs are added (see Section 4), the more attractive near-term opportunities exist in exploring exports of GH2 to markets in the Asia Pacific region such as Japan and South Korea.

5.4 Viet Nam's GH2 export advantages and disadvantages

As the market for green hydrogen gains momentum in the coming years, a number of export opportunities are likely to emerge. With a clear and focused policy framework, Viet Nam can position itself to become more active in the production and export of green hydrogen to other parts of the world. In this regard, Viet Nam has several key advantages:

Number	Advantages
1.	Stable and forward-looking energy policy framework
2.	Large and diverse renewable energy industry
3.	Proximity to major importers in the Asia-Pacific region
4.	Strong renewable energy resource potential
5.	Low political risk

In addition, Viet Nam's latest draft PDP signals a growing interest in boosting production, storage, and export capacity for green hydrogen. However, with regard to export opportunities, Viet Nam faces a number of important challenges:

Number	Challenges
1.	**Limited land availability** when compared to other major potential exporting countries, such as Australia, Chile, and Morocco;
2.	**Slightly lower resource quality** than some of the other potential competitors, in particular with regard to solar.
3.	**Greater geographic distance to the EU** (and hence, higher GH2 shipping cost)
4.	**Higher cost of capital** than many other potential exporting countries such as Australia, or Chile.

In this regard, Viet Nam has both important advantages but also faces some significant challenges in scaling up export-oriented green hydrogen production. Policymakers will need to take these challenges and advantages into consideration when developing their policy frameworks.

Chapter 6

Conclusions and recommendations

Green hydrogen is poised to play an increasingly important role in the energy transition worldwide, in particular to facilitate the decarbonisation of "hard-to-decarbonise" sectors, such as steel production, shipping, and the production of chemical feedstocks. While hydrogen is already in use in a number of industries around the world, it has yet to realise its full potential to support the global energy transition. As of early 2022, less than 1% of the hydrogen used around the world today is derived from water electrolysis; the vast majority is still produced using fossil fuels. In addition, the majority is currently used in oil refineries and in the production of fertilizers. Concerted policy, investments, and planning are necessary to overcome the remaining barriers to green hydrogen and further reduce costs.

The cost reductions expected in green hydrogen production will be critical to helping drive demand. Looking ahead to 2030, 2040, and 2050, significant cost reductions are anticipated, brining green hydrogen costs down from a range of EUR 3 - 6/kg in much of the world today to EUR 1,00 - 1,50/kg by 2050. In combination with these projected cost declines, it is expected that global green hydrogen production costs will converge in much of the world in the coming decades. This should favour countries like Viet Nam that are developing clear policies and strategies to support the growth of the sector.

However, given the substantial impact of shipping costs, it is likely in the next decade that the international trade in green hydrogen will occur primarily on a regional basis, with regional trading hubs between markets that are close to one another geographically. Pipelines remain the cheapest and safest method for shipping green hydrogen, which means that countries with existing pipeline networks will have an early advantage and will be able to procure green hydrogen more cheaply than by ship. The high shipping costs also mean that many countries will try to produce some share of their green hydrogen needs themselves, which may weaken import needs. All of these factors have important implications for the development of trade in green hydrogen in the years ahead.

A further factor that needs to be overcome in countries like Viet Nam that wish to export green hydrogen is the cost of capital. As highlighted above, the cost of capital in Viet Nam is notably higher than the cost of capital in other competitor markets like Australia. Other countries with excellent solar resources such as in the Middle East also benefit from abundant oil and gas production and can cross-subsidize green hydrogen production either directly, or by providing low-interest loans, or sovereign backing for green hydrogen production. Given the important role that the cost of capital plays in determining the levelized cost of hydrogen production, strategies will be needed in Viet Nam to help reduce the cost of capital used to finance green hydrogen production.

In order to participate and compete in this growing market, there are a number of policy measures that Viet Nam can implement. The policy recommendations are broken into three major areas:

6.1 Policies for Encouraging Green Hydrogen Production

- **Establish clear long-term targets for the production of green hydrogen in Viet Nam**. Such targets should be incorporated directly into Viet Nam's Power Development Plan (PDP) and be adjusted as the market develops.

- **Introduce favourable taxation and fiscal rules for green hydrogen production**. Since much of the investment for large-scale hydrogen production is likely to come from international investors, tax rules play an important role in determining the success of a particular country in mobilizing investment.

- **Offer government-backed loans for green hydrogen production**. Given the scale of the investments required, and the higher overall cost of capital in Viet Nam, the government should consider offering government backing to loans used to financed green hydrogen production.

- **Ensure all new natural gas infrastructure, including pipelines, are hydrogen-ready**. Although the future growth of natural gas infrastructure in Viet Nam remains unclear, Viet Nam can send a strong signal to the market by requiring all new investments in natural gas infrastructure to be "hydrogen-ready".

- **Explore the introduction of feed-in tariffs for green hydrogen production fed into the natural gas network**. Such "green gas feed-in tariffs" could help mainstream green hydrogen use in Viet Nam by introducing it into the natural gas system.

- **Develop monitoring and certification protocols to ensure compliance with international norms and standards**. One of the central aspects to a successful program of green hydrogen production is a robust monitoring and certification regime. In order to export to major markets like the EU and Japan, it will be important to ensure a high degree of trust in the certification process for green hydrogen production. Viet Nam can support this certification process by aligning itself with international norms.

- **Establish a designated industrial cluster for hydrogen production and research**. Since the majority of current hydrogen use is located in oil refineries, and oil refineries are typically located near major ports, ports could become central nodes in such green hydrogen research clusters.

6.2 Policies for Encouraging Green Hydrogen Demand

In addition to green hydrogen support policies, it is important to develop specific policies aimed at creating greater domestic demand for green hydrogen, in order to help accelerate Viet Nam's own energy transition. This includes a set of policies specifically to encourage hydrogen adoption in the natural gas pipeline network, shipping, aviation, and industry:

- Provide fiscal incentives for industries to shift their hydrogen or ammonia consumption to green hydrogen. Many users of ammonia or hydrogen are unlikely to make the shift to green hydrogen without such incentives, as green hydrogen is currently more expensive than grey hydrogen.

- Introduce requirements for key domestic users of hydrogen (e.g., refineries) to meet a minimum share of their hydrogen needs with certified, domestically produced green hydrogen (similar to a Renewable Electricity Standard or "Renewable Portfolio Standard")

- Introduce policies to encourage green hydrogen use in key sectors such as shipping. The shipping industry is one major potential customer for green hydrogen. However, many ships currently run on highly polluting Bunker C or diesel fuel, which is often cheaper. Transitioning the shipping industry to clean fuels like green hydrogen will require more targeted policies, including regulatory requirements to reduce their carbon emissions.

- Adopt carbon pricing. Carbon pricing increases the costs of fossil fuel-based energy carriers, thereby improving the competitive position of alternatives like green hydrogen. A clear carbon price, gradually increasing over time, can help provide a signal to the industry and help drive demand for greener alternatives.

- Introduce standards for the injection of green hydrogen into natural gas infrastructure. Viet Nam should adopt standards to provide clarity over the injection of green hydrogen or its derivatives into the natural gas system.

- Invest in retrofitting gas distribution infrastructure to be "hydrogen-ready".

- Fund research projects to explore new applications for green hydrogen use. Such funding could be allocated to the industrial research clusters mentioned above and help foster the skills and knowledge required.

- Fund the establishment of an annual monitoring report to track the cost development and near-term market competitiveness of new applications for green hydrogen in order to encourage greater investment, innovation, and market demand.

6.3 Policies for Reducing the Cost of Capital

- Establish export-oriented partnerships with importing regions (e.g., the EU, Germany) to bring lower-cost, long-term financing to support the development of green hydrogen production infrastructure in Viet Nam

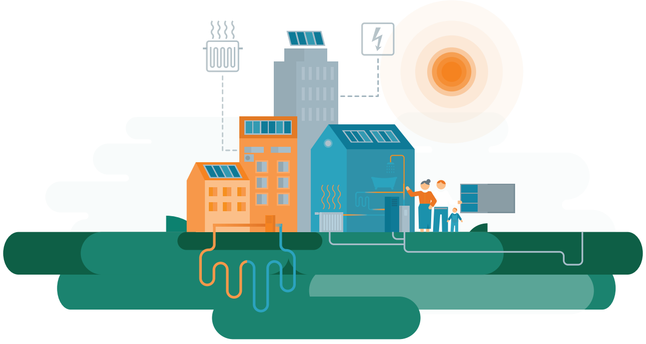
- Explore the creation of a green hydrogen export initiative to encourage multi-lateral lenders to support the build-out of green hydro production.

- Explore providing sovereign backing, or direct government investment, for strategic green hydrogen investments

- Explore introducing guaranteed offtake agreements or establishing a government-backed "buyer-of-last-resort" for green hydrogen to reduce market risk.

As the market for green hydrogen gains momentum in the years ahead, Viet Nam is well-positioned to participate in green hydrogen production. With targeted policies and clear targets, Viet Nam can ensure that the industry is ready to meet the growing global demand for green hydrogen.

Based on current economics and the important role played by shipping costs, the more viable opportunities for Viet Nam to export green hydrogen are likely to be concentrated in the Asia Pacific region, including in particular to Japan and South Korea. By focusing first on meeting growing demand in Asia, Viet Nam can actively support the emergence of regional trade in green hydrogen, which could eventually flourish into a truly global trade by the 2040s as the green hydrogen industry enters its more mature growth phase.



Annex 1: Input Parameters for Financing Costs

	Technical Parameters	Commercial Financing	Concessional Financing
Solar PV Cost Calculation	20-year operating life, 1-year construction time, 100MW project, Annual production degradation of 0.6%, Installed cost: USD $640/kW, Fixed O&M: USD $10/kW/year, Variable O&M USD $0/MWh, Lease costs: USD $3.000/year	70% debt, 30% equity, 14-year debt term, cost of debt: 7%, cost of equity: 12% (WACC: 8.1%), Inflation: 3% p.a., Tax treatment in line with Viet Nam tax code according to Circular 78/2014 / TT-BCT	80% debt, 20% equity, 18-year debt term, cost of debt: 3%, cost of equity: 8% (WACC: 3.8%), Inflation: 3% p.a., Tax treatment in line with Viet Nam tax code according to Circular 78/2014 / TT-BCT
Onshore Wind Power Cost Calculation	20-year operating life, 2-year construction time, 100MW project, Annual production degradation of 1.6%, Installed cost: USD $1.350/kW, Fixed O&M: USD $30/kW/year, Variable O&M USD $0/MWh, Lease costs: USD $10.000/year	70% debt, 30% equity, 10-year debt term, cost of debt: 8%, cost of equity: 13% (WACC: 9%), Inflation: 3% p.a., Tax treatment in line with Viet Nam tax code according to Circular 78/2014 / TT-BCT	80% debt, 20% equity, 18-year debt term, cost of debt: 3%, cost of equity: 9% (WACC: 4.0%), Inflation: 3% p.a., Tax treatment in line with Viet Nam tax code according to Circular 78/2014 / TT-BCT
Offshore Wind Power Cost Calculation	20-year operating life, 3-year construction time, 100MW project, Annual production degradation of 1.6%, Installed cost: USD $2.750/kW, Fixed O&M: USD $60/kW/year, Variable O&M USD $4.5/MWh, Lease costs: USD $6.500,	70% debt, 30% equity, 10-year debt term, cost of debt: 9%, cost of equity: 13% (WACC: 9.7%), Inflation: 3% p.a., Tax treatment in line with Viet Nam tax code according to Circular 78/2014 / TT-BCT	80% debt, 20% equity, 18-year debt term, cost of debt: 3.5%, cost of equity: 10% (WACC: 4.6%), Inflation: 3% p.a., Tax treatment in line with Viet Nam tax code according to Circular 78/2014 / TT-BCT

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