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Renewable Hydrogen Import Routes into the EU

Hydrogen

ENERGY TRANSITION

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Abdurahman Alsulaiman, OIES-Aramco Fellow, OIES

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Abstract

Hydrogen's production versatility, coupled with its potential as an energy vector, positions it as a potentially important fuel for the future. It can be sourced in many different ways, and has the ability to meet many applications, both in existing and future technology, and this means that hydrogen is in the forefront of the minds of investors and policymakers. Moreover, hydrogen is not subject to the same geographical limitations as, say, fossil fuels or pure battery-electric systems.

When looking at the latest announcements concerning hydrogen, the EU has set an ambitious target for hydrogen demand by 2030, specifically to import 10 MT of renewable hydrogen a year by that date. This target could kick-start the international trade of renewable hydrogen, and already more than fifty countries have announced, or are preparing, hydrogen strategies. Between them, these strategies add up to more than 45 Mt of hydrogen capacity by 2030, although at the time of publishing, only 2 Mt of this capacity is at FID or at a more advanced stage, for operation by or before 2030. This contrast between announcements and capacity currently considered likely to come into operation creates many challenges and opportunities for countries who are considering the export or import of hydrogen. The EU's latest hydrogen announcement places it in a strong position to shape the future decarbonized hydrogen market, as it could galvanize exporting countries to initiate production.

The EU has indicated the possible regions it is considering for future supply of renewable hydrogen, regions which include more than seventy countries. Within this total, this paper identifies fourteen promising countries for future hydrogen imports to the EU, of which six are expected to be among the first to deliver hydrogen, in the form of shipped ammonia, to EU shores. This paper also recognizes that discussion on future imports and exports of hydrogen requires focus on infrastructure, joint scenario building, technology cooperation, standardization, investments and finance frameworks, market development and trading platforms, education and training, and the creation of coordination hubs.

Introduction

There is widespread discussion around hydrogen production and use, spanning various platforms and eliciting both bullish and bearish views on the molecule's future role in end-use sectors. The focus is not limited to decarbonizing existing uses of hydrogen, as the discourse also extends to exploring its potential in sectors where it currently has little or no presence. A particularly significant topic of discussion is the future of low-carbon hydrogen as an internationally-traded energy commodity, akin to LNG or crude oil.

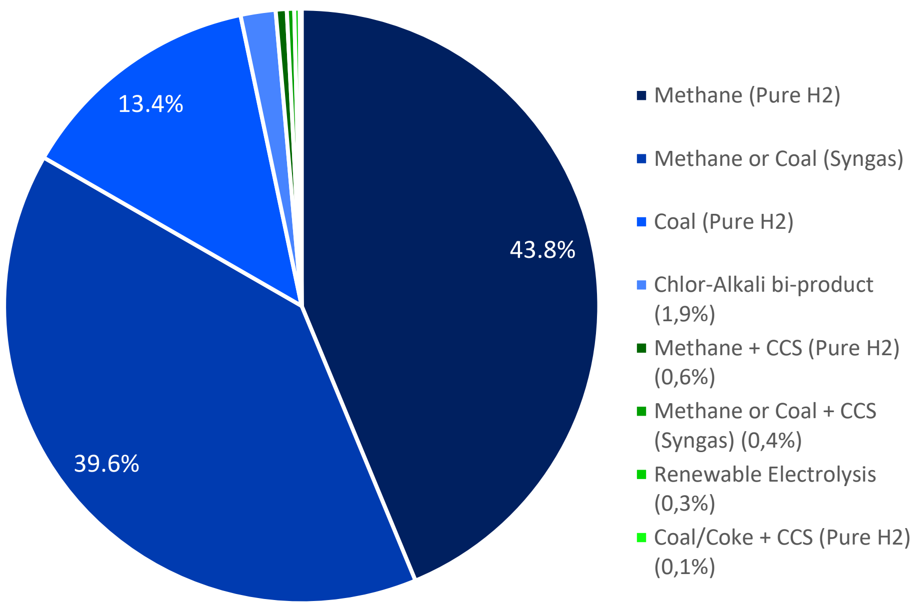
Prior to 2022, export and import announcements regarding hydrogen did not align with projected supply and demand trends. Given the significant investments required to establish a functional value chain between its endpoints, a stronger signal was necessary to catalyze investment in the export-import domain. This paper argues that in 2022, the European Union's (EU) revision of its hydrogen demand target played a crucial role in providing this signal by nearly quadrupling the original target and stating that half of this demand should be met by imports (European Commission, 12/2021), (European Commission, 2/2022). This is the largest import target for decarbonized and renewable hydrogen by 2030 globally. It is likely, for example, that this import target may have stimulated new or existing announcements from export-oriented countries such as Saudi Arabia and the UAE, which have suggested or announced plans to export hydrogen within the next seven years (Nakano, J., 1/2022), (Benny, J., & Rahman, F., 1/2022).

This paper seeks to examine the current hydrogen market, explore its potential, evaluate the EU's latest policy within the decarbonized hydrogen sphere, assess its potential impact on prospective trade partner countries, and identify potential hydrogen import routes to the EU. This paper also aims to highlight the recommendations for unlocking the value chain of EU hydrogen trade by identifying areas of focus which need to be addressed for trade to be successful.

1. Existing hydrogen production and the state of hydrogen trade

According to recent estimates, the current global production of hydrogen stands at approximately 100 million metric tonnes (Mt) (IEA, 9/2022), (IEAGHG, 7/2022), (IEAGHG, 6/2022). This production constitutes a 60/40 split between pure hydrogen and hydrogen that is mixed with other gases (syngas). Notably, 99 per cent of the hydrogen produced in 2020 was derived from sources with unabated CO2 emissions, where the primary feedstock sources were natural gas and coal (see Figure 1).

Figure 1: Hydrogen production split by feedstock in 2020 (per cent)

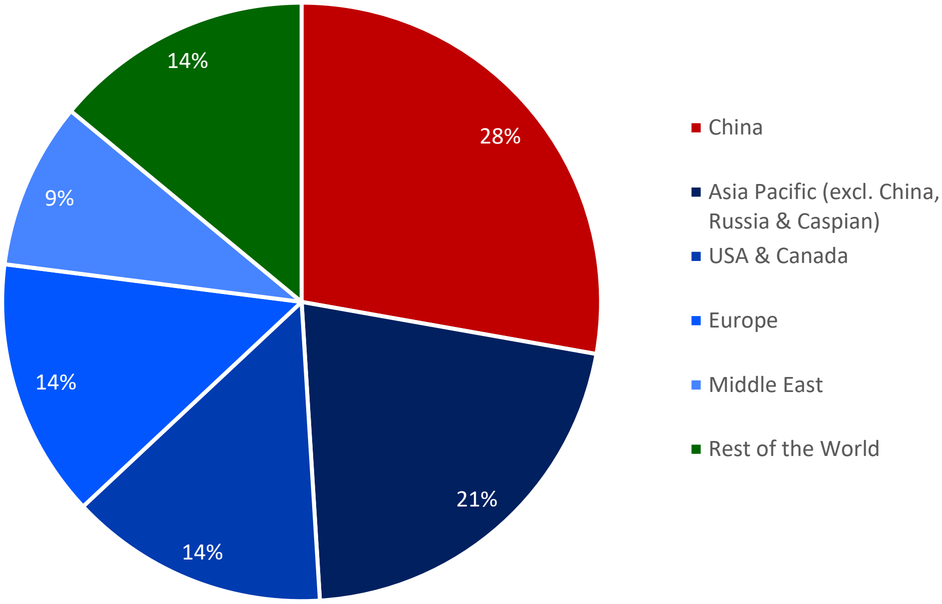


Source: IEAGHG, 6/2022

Figure 1 provides an overview of the various feedstocks employed in the global production of hydrogen and the percentage they contribute to the total production. Methane, for dedicated hydrogen production, constitutes the most significant proportion, accounting for 44 per cent of total global production. The next most significant contributor to production is methane or coal, used for hydrogen extracted from syngas, which comprise 40 per cent of total production. Coal, when used for dedicated hydrogen production, accounts for 13 per cent of the total production, whereas hydrogen from chlor-alkali bi-products contributes to 1.9 per cent of the total. Methane with carbon capture and storage (CCS), for dedicated hydrogen production accounts for 0.6 per cent, and methane or coal with CCS for hydrogen production extracted from syngas, contributes to 0.4 per cent. Lastly, renewable electrolysis and coal/coke with CCS, for dedicated Hydrogen production, each account for 0.3 per cent and 0.1 per cent, respectively.

Geographically, a significant proportion of hydrogen is currently produced in Asia, which accounts for almost half of global production. Meanwhile, Europe and North America combined accounted for roughly one-third of global production in 2020. Figure 2 provides further details on the geographical distribution of global hydrogen production.

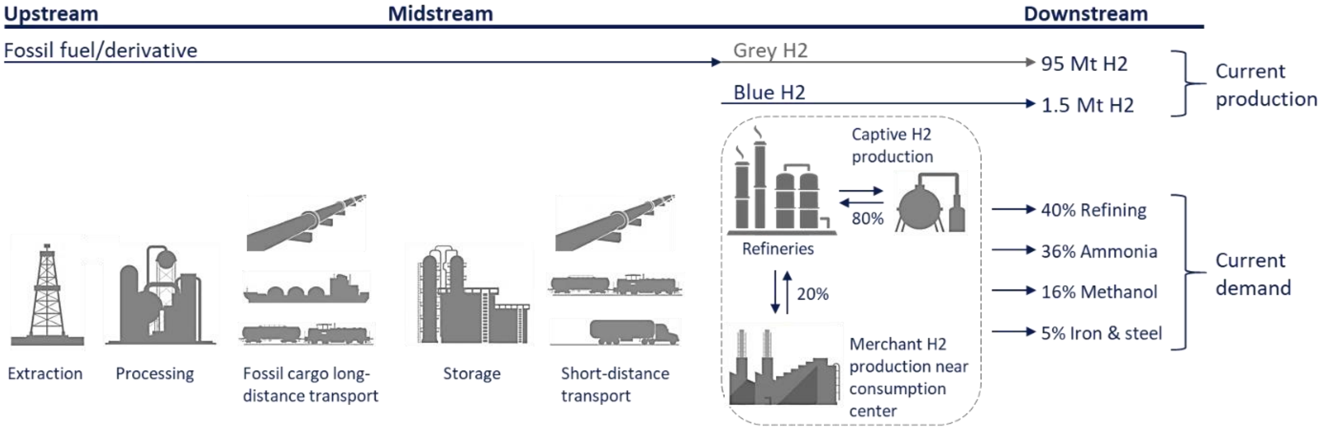
Figure 2: Hydrogen production by region (per cent)



Source: IEA, 9/2022, IEAGHG, 7/2022

The geographical concentration of hydrogen production is largely linked to the need to meet local demand within each region. Currently, approximately 80 per cent of hydrogen is produced through captive or by-product processes, while the remaining 20 per cent is produced for merchant purposes. However, it is not uncommon for merchant production to be located close to consumption sites, with pipelines connecting to major consumers and cylinder deliveries made to smaller batch consumers. Figure 3 illustrates a typical configuration of the value chain for hydrogen production, reflecting how most of today's hydrogen value chain is structured (Kumar, S., 12/2022), (Connelly, E., Elgowainy, A., & Ruth, M., 10/2019).

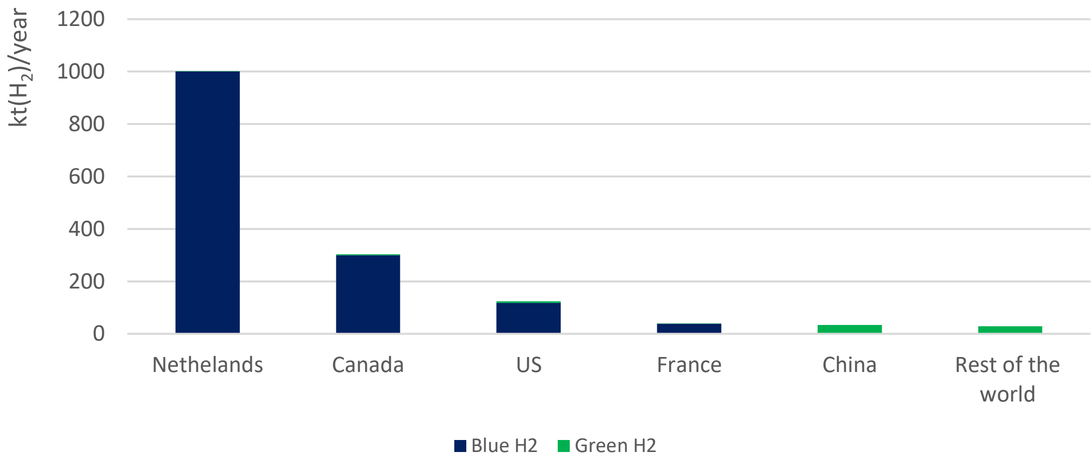
Figure 3: General overview on today's hydrogen value-chain[1]



Source: Author's analysis of the 2022 IEA Hydrogen Review and H2 analysis by Kumar, S

Based on the data presented in Figure 1, it is evident that most of the current production of hydrogen is unabated. It is worth noting that current estimates for decarbonized hydrogen production, including experimental and demonstration projects, and corresponding to over 200 different projects from around the world, indicate a global output of only 1.5 Mt. Of this total, more than 1 Mt of production is situated within the EU, which could at first glance be seen as a reflection of the region's commitment to sustainable energy practices. Figure 4 provides a breakdown of the current capacity for low-carbon hydrogen production by country. It is important to note that the figures are subject to change as more data become available. [2,3]

Figure 4: Decarbonized hydrogen capacity per country[4]



Source: Author's analysis of the 2022 IEA Hydrogen Database

Within the EU, the Shell Pernis refinery in the Netherlands stands out as a significant contributor to the EU's low-carbon hydrogen production, accounting for nearly 95 per cent of the EU's current low-carbon hydrogen capacity through a carbon capture and utilization process. The refinery processes crude oil and produces hydrogen as one of its many aggregate products, which is then used within the refinery for various processes.

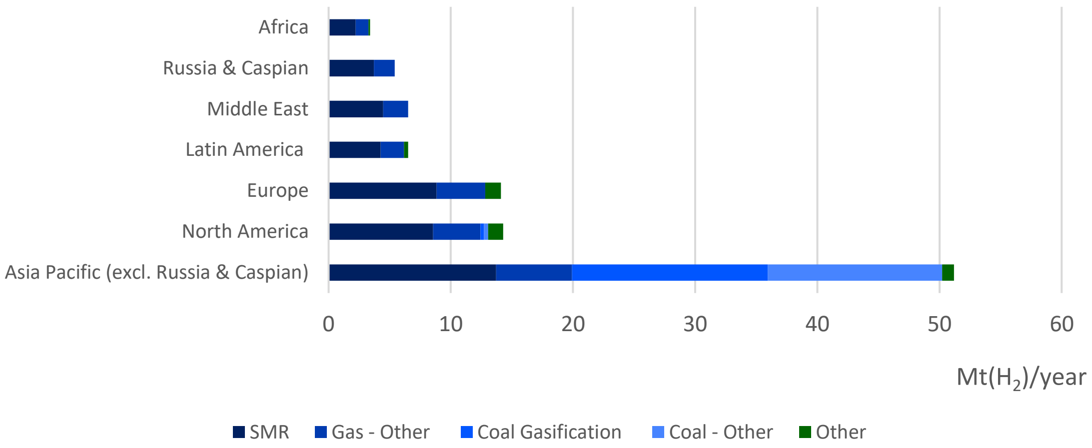
[1] Data drawn from the 2022 IEA Hydrogen Review and H_2 analysis by Kumar, S.
[2] There is currently no standardized definition for the types of H_2. However, Blue H_2 commonly refers to H_2 from fossil resources with CCUS while Green H_2 refers to production from renewable electricity.
[3] Refer to Appendix A1 for the full list of countries and specific capacities.
[4] Data drawn from the 2022 IEA Hydrogen Database.

The refinery is taking steps to reduce its carbon footprint, planning a retrofit in 2025 to allow for carbon capture and storage (CCS), which involves capturing CO2 emissions from industrial processes and storing them underground. This is a significant step towards reducing the refinery's carbon emissions, as currently the captured CO2 is vented to local agricultural greenhouses near the refinery. (Shell, 2020).

As noted earlier and illustrated in Figure 3, current hydrogen production is largely located in close proximity to areas of consumption, which is due to a lack of competitively priced hydrogen for export and the significant costs associated with storage and transport of hydrogen and hydrogen-related products. This limited trade of hydrogen over long distances is further compounded by the nature of hydrogen production, which is typically achieved through the storage of the prerequisite feedstock such as natural gas or coal rather than storing hydrogen itself[5].

Furthermore, different regions have varying preferences for feedstock used in hydrogen production to meet their respective end-use demands. This is shown in Figure 5, which shows the distribution of hydrogen consumption by feedstock production technology across the different regions. (IEAGHG, 7/2022).

Figure 5: Hydrogen demand by production type and region



Source: IEAGHG, 7/2022

Asia Pacific (excluding Russia and the Caspian) is the largest contributor to global hydrogen demand, requiring almost 52 Mt in 2020. To meet this demand, coal-based hydrogen production technologies are the most commonly utilized, accounting for around 60% of the hydrogen used in the region.

Within other parts of the world, steam methane reforming (SMR) is the leading technology, with North America and Europe being its two largest users.

Finally, when looking at the sources for current hydrogen demand, refineries account for approximately 40 per cent of the total demand, with the primary use being in treating crude oil with processes such as hydrogenation, hydrotreating, hydrocracking, catalytic reforming, and isomerization. Meanwhile, the industrial sector accounts for nearly 57 per cent of hydrogen demand, split between the production of ammonia (36 per cent), methanol (16 per cent), and direct reduced iron (5 per cent) (IEA, 9/2022). It is worth noting that the remaining demand for hydrogen is generated by other sectors, including transport and niche industry segments.

2. Potential Hydrogen market

The potential to expand hydrogen's utilization in other sectors, including transport, buildings, and power generation, is significant as the world seeks to decarbonize. To achieve this goal, various CO2-abated

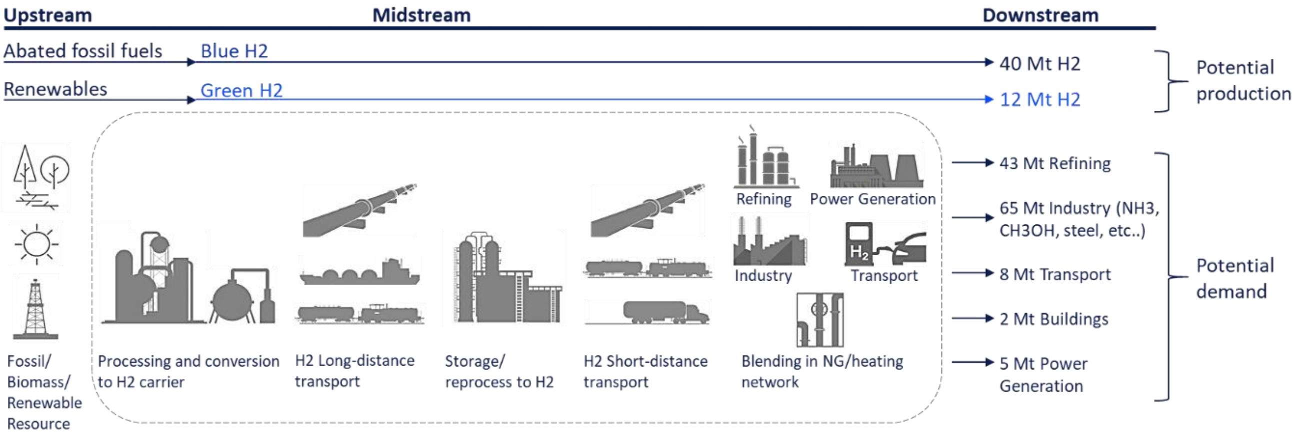
[5] Refer to the OIES "Global trade of hydrogen: what is the best way to transfer hydrogen over long distances?" and "Hydrogen storage for a net-zero carbon future" for an in-depth analysis on hydrogen transport and storage

hydrogen technologies can be employed, which can be produced using diverse methods. One approach involves utilizing conventional energy resources and applying carbon capture, utilization, and storage (CCUS) technologies to mitigate the CO2 emissions associated with hydrogen production. Another approach involves the use of biomass or renewable electricity to produce renewable hydrogen, which holds the promise of significantly reducing greenhouse gas emissions.

Apart from expanding the utilization of hydrogen, there is also potential to produce and transport it in multiple forms. These may include ammonia, methanol, liquid organic hydrogen carriers, as well as compressed or liquefied hydrogen. Such forms of hydrogen can be transported through dedicated pipelines, blended pipelines, or even shipped, which could dramatically extend the scope of hydrogen production and consumption[6].

A graphical representation of the potential hydrogen value chain is depicted in Figure 6, similar to the framework of Figure 3.

Figure 6: Possible configuration for the hydrogen value chain[7]



Source: Author's analysis of the 2022 IEA Hydrogen Database and 2022 IEA Hydrogen Review reports

National Policy announcements – top-down approach

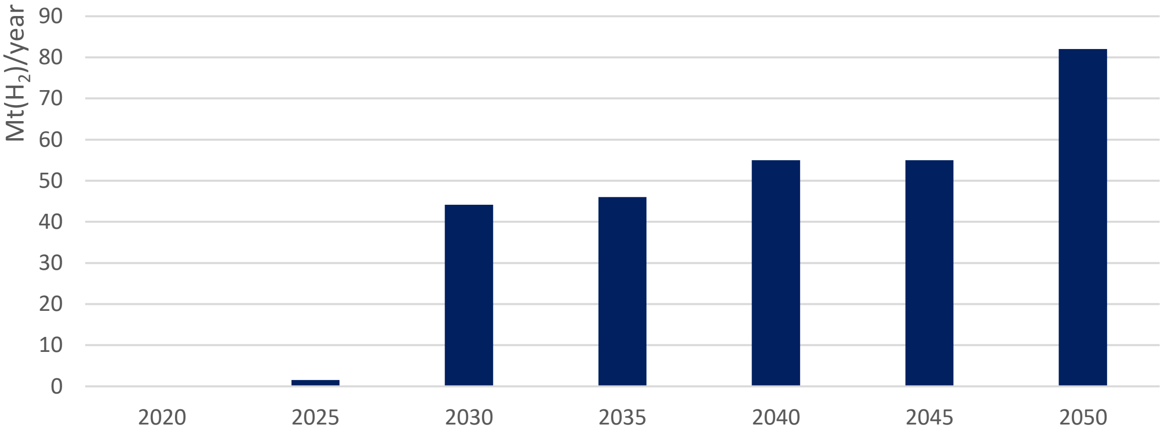
As of Q1 2023, over fifty countries, including the EU-27, have published, or are in the process of publishing, decarbonized hydrogen strategies. Analysis of these documents has revealed that roughly 75 per cent of national announcements and aspirations have quantifiable targets set for a specific year. These targets and aspirations amount to over 40 Mt of decarbonized hydrogen that is intended to be produced and used by 2030, with this amount approximately doubling by 2050. The evolution of these targets and aspirations can be seen in Figure 7, which was created based on the analysis conducted.

It is worth noting that the hydrogen production and demand targets in Figure 7 are not uniform, as some national strategies prioritize exporting hydrogen, while others aim to meet domestic demand through imports. For instance, Chile's strategy is to supply hydrogen for export, while the EU's approach is to import hydrogen to meet domestic demand. To better understand these targets, representative criteria were used to distinguish between import and export intentions, which revealed that export-centric economies have announced a production/demand volume of around 35 Mt, while import-centric economies have announced more than 25 Mt. However, when considering a 2030 timeline, these numbers are scaled down to almost 17 Mt and 23 Mt, respectively, with the high demand from import-centric countries largely due to the EU's target of 20 Mt by 2030. It is important to note that these production/demand numbers are not explicit volumes for future hydrogen export and import, but rather represent the announcements made by countries expressing their intentions for export and import.

[6] Refer to the OIES "Global trade of hydrogen: what is the best way to transfer hydrogen over long distances?" and "Hydrogen storage for a net-zero carbon future" for an in-depth analysis on hydrogen transport and storage

[7] Data drawn for production and demand are drawn from the 2022 IEA Hydrogen Database and 2022 IEA Hydrogen Review report.

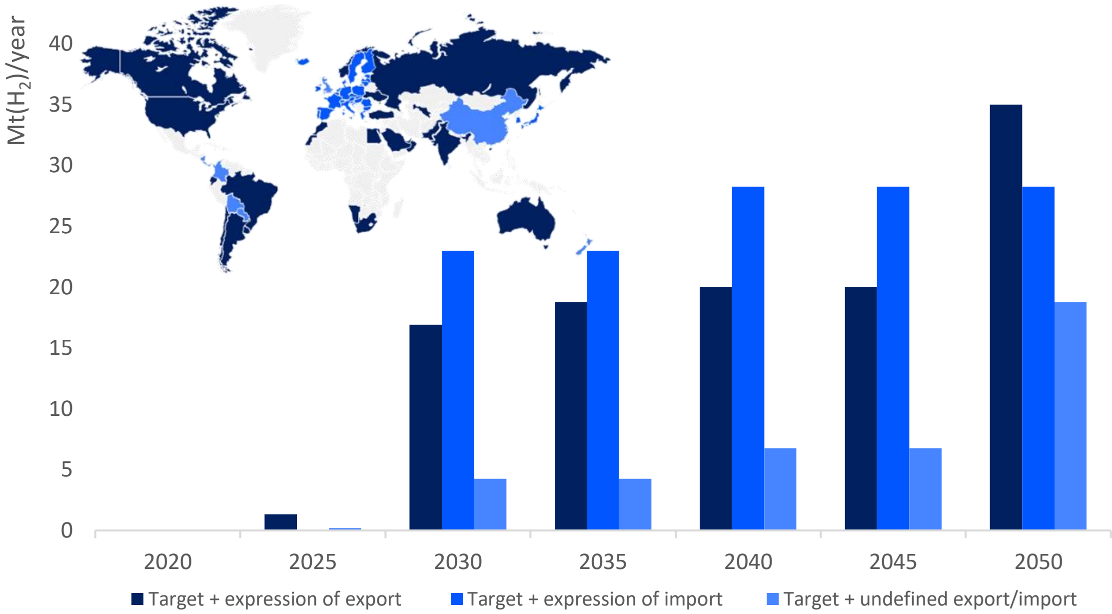
Figure 7: Quantifiable decarbonized hydrogen amounts from the various national documents[8]



Source: Author's analysis of the identified sources related to national policies available at the time of the report's publication

To clarify further, it should be noted that the EU has announced that a share of its hydrogen demand will be met with local production, and thus the demand numbers from import-centric countries do not accurately represent their exact import needs. Additionally, most of the quantifiable national announcements are set in the 2030-2040 range, with a sharp increase in both supply and demand observed in the 2025-2030 period. Geographical indication is provided in Figure 8, which gives further information on the evolution of targets announced between 2020 and 2050 of the identified export-centric and import-centric economies.[9]

Figure 8: Announced hydrogen targets based on underlying intention and respective geographical split[10]



Source: Author's analysis of the identified sources related to national policies available at the time of the report's publication

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[8] Based on analysis of identified sources related to national policies available at the time of the report's publication.

[9] Refer to Appendix A2 for the list of identified countries.

[10] The map is for illustrative purposes and does not imply the expression of any opinion on the part of the Author or the Oxford Institute for Energy Studies.

The analysis of national policies provides a valuable insight into the evolving direction that countries are taking by striking paths for either export-centric or import-centric approaches. However, it is important to note that the assessment of both export- and import-focused policies has limitations, as it is the case that most export and import capacity does not have a specified supplier/consumer country in any particular region. Nevertheless, it is possible that recent export-centric announcements have been made in response to the EU's ambitious hydrogen import target of 10 Mt by 2030, which is currently the largest hydrogen import target announced to date. The shift towards an import-centric model for the EU reflects a growing recognition of the crucial role for clean energy carriers, such as hydrogen, from decarbonized or renewable energy sources, and the need for international cooperation to address climate change through energy trade.

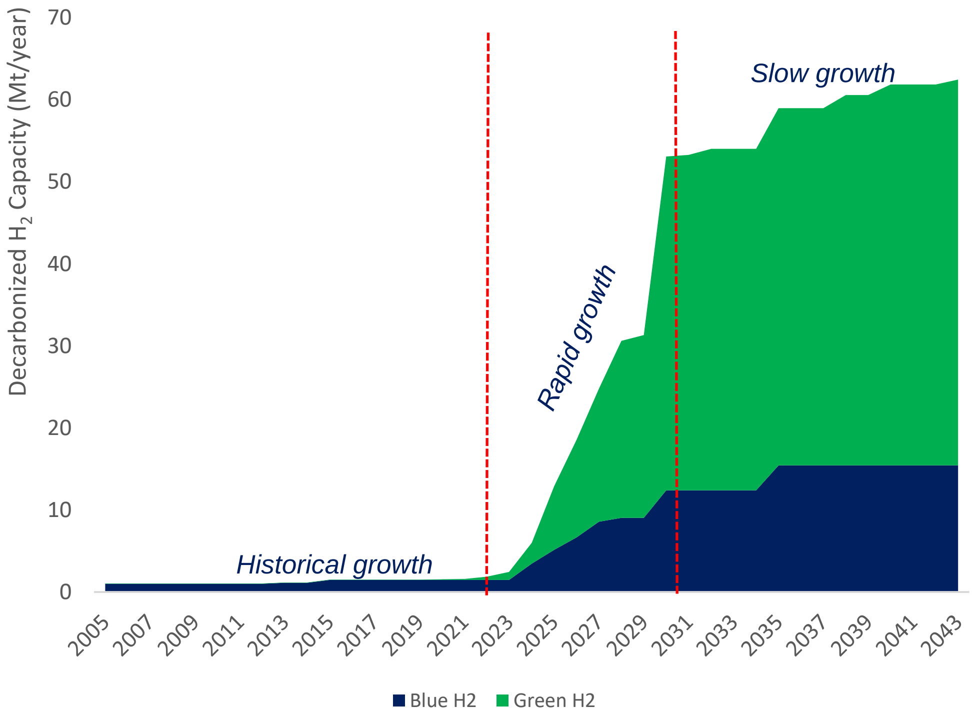
With the lack of specificity in future export plans within the announced national hydrogen production plans and aspirations, this presents a significant opportunity for net importers such as the EU, Japan, and South Korea to influence the type and shape of future hydrogen trade. As net-importer requirements are likely to steer upstream investments in net-export countries, this creates conditions for a buyers' market, especially considering the large number of countries interested in exporting hydrogen.

While the latest national policies provide an ambitious estimate for the magnitude of future hydrogen production and consumption, they are less representative when it comes to quantifying the expected hydrogen capacity to come online in the next seven years. Thus, a bottom-up approach would be better suited to clarify the current capacity due to be operational by the end of the decade. Nonetheless, these policies serve as a good point of reference for expected long-term decarbonized hydrogen supply and demand. It is important to continue monitoring how countries adapt their policies to meet their energy needs while also meeting their climate targets as the demand for hydrogen continues to grow.

Project announcements – bottom-up approach[11]

With a bottom-up approach that considers time-bound, decarbonized hydrogen project announcements and commitments, we can create a timeline that reaches to 2043. This is depicted in Figure 9, which shows the cumulative growth from 2005 to 2043 incorporating all project announcements.

Figure 9: Historical and potential growth trajectory based on a bottom-up approach



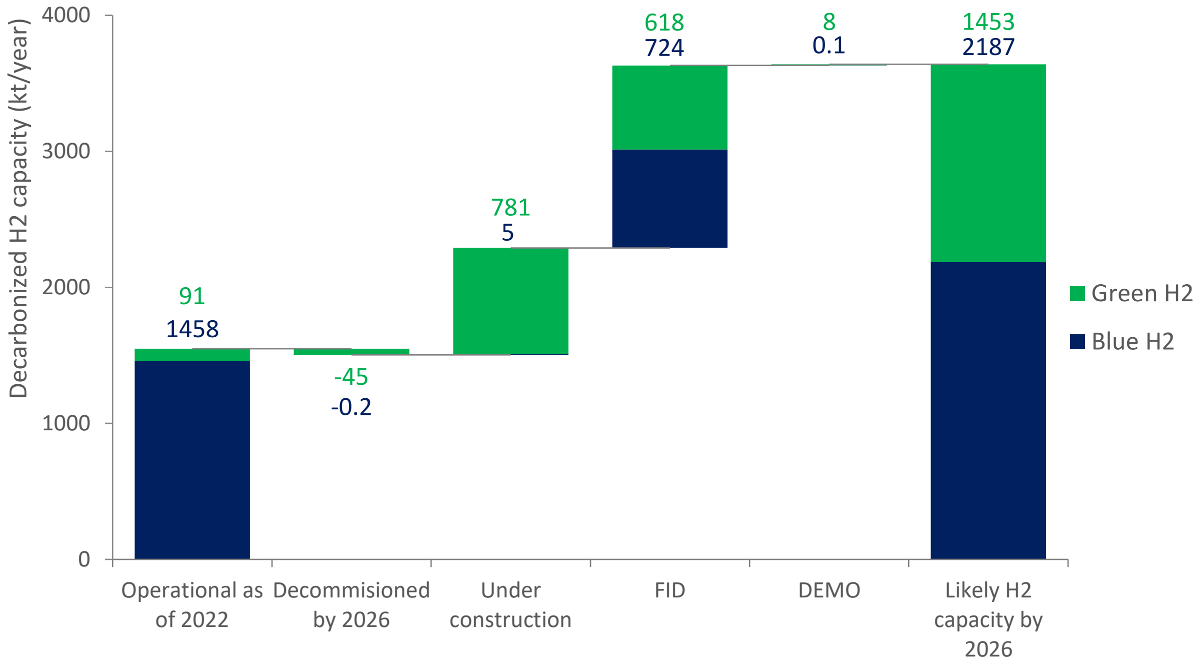
Source: Author's analysis of the 2022 IEA Hydrogen Database

[11] Data drawn for the analysis of this section was taken from the 2022 IEA Hydrogen Database

Based on Figure 9, three distinct growth segments can be identified: historical growth, rapid growth, and slow growth. Historical growth is characterized by almost indistinguishable annual growth rates for both blue hydrogen at around 81 kt/y and green hydrogen (8 kt/y). Rapid growth is observed for the next seven years, with additional rates of around 1800 kt/y for blue hydrogen and 5800 kt/y for green hydrogen. Slow growth is then shown for the period from 2030 - 2043, with additions for blue hydrogen at almost 1200 kt/year and 3600 kt/y for green hydrogen.

The behaviour seen in Figure 9 confirms the pattern seen in the top-down analysis, where a focus is evident for projects coming online in the 2025-2030 period. However, the numbers seen for the aforementioned period, could be argued as being inflated. From 2029-2030 alone, more than 18000 kt is supposed to come online, which raises questions about the availability of offtake for such capacities. While the high numbers may not be entirely realistic, they do reflect the strong interest and growing investments in decarbonized hydrogen projects around the 2030 target. However, an analysis of the project announcements highlights the lack of two key components: firstly, a lack of offtake agreements and, secondly, the fact that most of these announcements and aspirations do not have secured funding. This gives a better idea for why such high numbers are observed. If we only consider projects with secured investments, the timeline reduces to 2026, and the equivalent hydrogen capacity for that timeline reduces from almost 19000 kt/y to around 3600 kt/y. Figure 10 highlights the capacities for the different stages of projects with secured funding or which are at a Final Investment Decision (FID) stage.

Figure 10: Likely decarbonized hydrogen project capacities by 2026



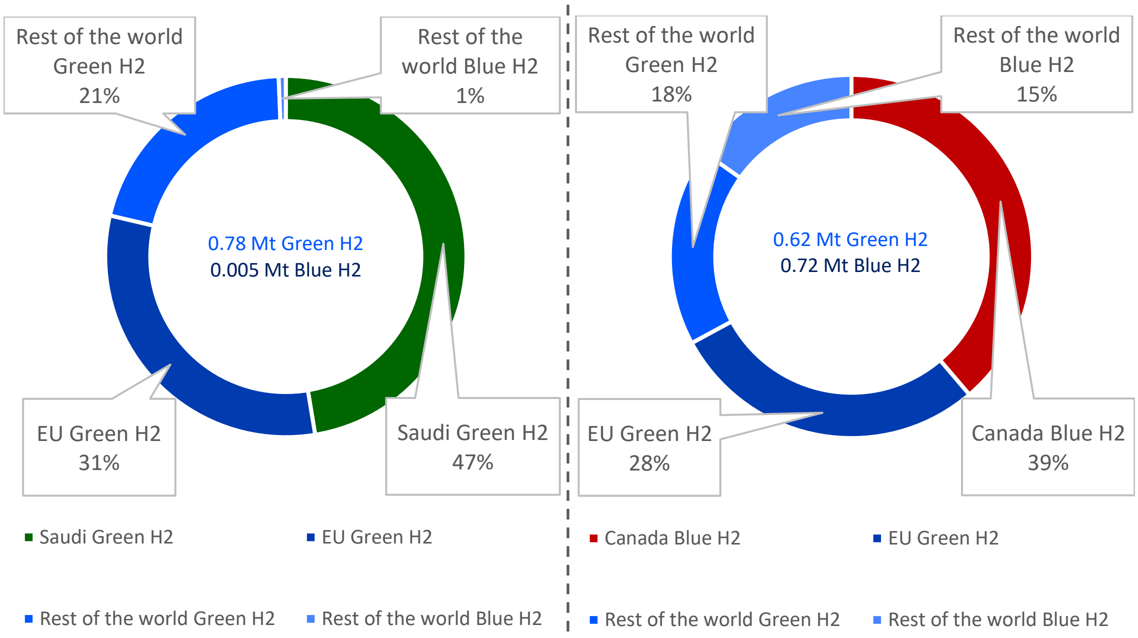
Source: Author's analysis of the 2022 IEA Hydrogen Database

Comparing the more realistic case of projects expected to go online in the next three years (Figure 10) with projects announced to come online in the same period (Figure 9), we can highlight three key points. Firstly, as mentioned earlier, only around 20 per cent of the capacity announced is currently at FID or at a more advanced stage, with the remaining projects at various earlier stages of development. Secondly, the large growth rate of electricity-based hydrogen production seen in Figure 9 does not translate to expected projects due to come online. Thirdly, when looking at announced projects alone, one might observe that electricity-based hydrogen would outgrow CCUS fossil-based production, but this is not the case as CCUS fossil-based production is still expected to be the primary method for producing decarbonized hydrogen by 2026.

Interestingly, when we consider projects under construction and projects at FID, we can observe that the majority of these likely projects are concentrated within the EU, Canada, and Saudi Arabia. At least one project in NEOM, Saudi Arabia, has stated that its hydrogen capacities are intended for export.

Figure 11 provides further details on the shares and types of hydrogen by location for projects under construction or at FID.

Figure 11: Shares and types of hydrogen by location for projects under construction (left) or at FID (right) stage due by 2026



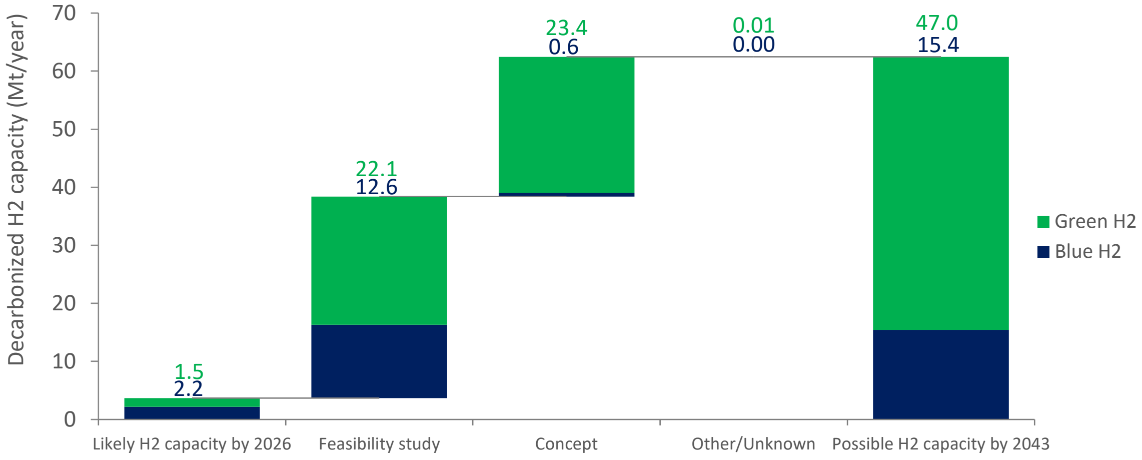
Source: Author's analysis of the 2022 IEA Hydrogen Database

As mentioned earlier, there is a noticeable divide between the leading feedstock technologies for hydrogen production. While renewable-based hydrogen is the technology of choice when considering the full range of announcements and aspirations, this is not reflected in the likely projects expected to come online in the next three years. In fact, CCS-enabled hydrogen will continue to be the dominant method for producing decarbonized hydrogen during this period. However, this may shift in the post-2026 timeframe as more renewable-based projects are expected to be developed and come online.

If we attempt to categorize the different project capacities beyond 2026, we find that many hydrogen projects are still in the feasibility study stage, with most studies being focused on green hydrogen projects. Figure 12 highlights the different categories (feasibility study, concept, other/unknown) for hydrogen projects beyond 2026. Moreover, when it comes to projects intended for the EU market, it is highly probable that recent EU acts will encourage the development of renewable energy projects in tandem with electrolyzer installations in export-oriented countries, with the aim of achieving economic benefits within those countries (European Commission, 2/2023). These acts will be discussed further in the next section.

The hydrogen market is at an early stage, and its future as a traded commodity for decarbonized energy is yet to be fully realized. However, there are strong signals of growth in the mid to long term as more governments announce and start to implement their hydrogen strategies. As the market matures, it will be interesting to see how the use of CCUS fossil-based hydrogen for existing industries such as refineries correlates with the use of renewable-based hydrogen for new and emerging industries such as transport. While the EU's target for hydrogen import is currently the largest and most prominent, it is likely that countries in other regions such as Asia will start to develop or revise their hydrogen strategies as the market becomes more competitive and mature. Therefore, the future of hydrogen as a decarbonized, energy-traded commodity holds great promise, but its full potential is yet to be realized.

Figure 12: Current upper limit of current decarbonized hydrogen project capacities



Source: Author's analysis of the 2022 IEA Hydrogen Database

EU policy within the decarbonized hydrogen sphere and its potential impact on possible trade partner countries

Prior to 2022, the EU had set a hydrogen target through its Renewable Energy Directive, which aimed for demand of 5.6 Mt of renewable hydrogen by 2030. However, in 2022, the EU launched REPowerEU, with the aim of diversifying away from Russian energy imports. This document includes an upgraded hydrogen target of 20 Mt by 2030, which is to be met solely through the use of renewable hydrogen. Additionally, REPowerEU determines that half of the upgraded target should be met by renewable hydrogen imports. (European Commission, 5/2022).

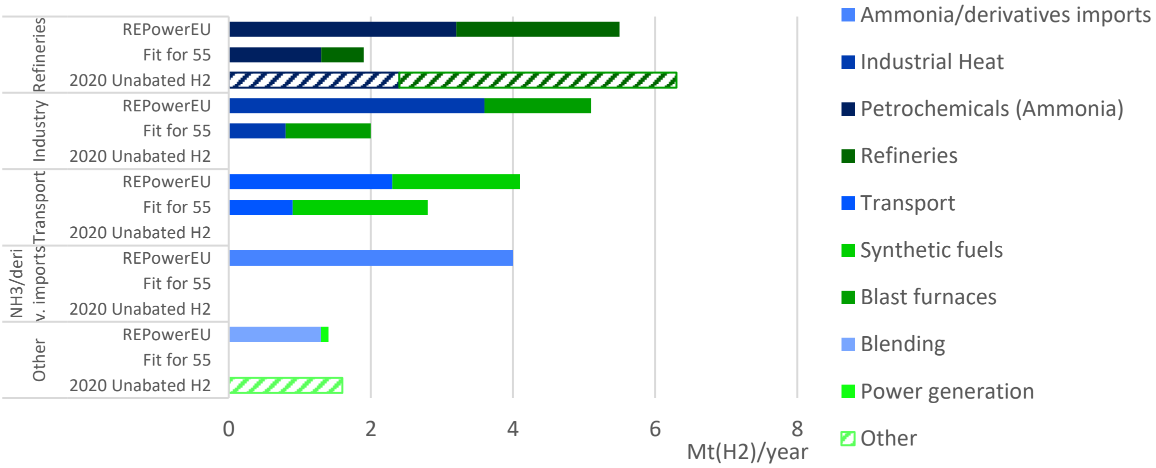
With regards to financing such a target, the EU plans to support and finance future hydrogen projects through EU-wide schemes such as Carbon Contracts for Difference (CCfD), [12] which could be financed by revenues from the EU Emissions Trading System (ETS).

As to the end-use of the upgraded hydrogen target, the main areas for renewable hydrogen use in the EU until 2030 will revolve around the refining, industrial, and transport segments, with the aim of increasing and scaling up the use of renewable hydrogen, ammonia, and derivatives in the coming seven years. Comparing the EU's modeled demand scenarios between REPowerEU, Fit for 55 (the previous EU modeled demand that included the previous hydrogen target), and historical demand, we can observe a significant increase in the anticipated use of renewable hydrogen within the refining sector and industrial heat, as well as the introduction of hydrogen as a direct import in the form of ammonia/derivatives as well as the use of hydrogen blending. However, it is important to note that anticipated renewable hydrogen use in refineries will still be less than unabated hydrogen demand seen in refineries in 2020. Figure 13 illustrates these figures.

When reviewing EU policy with the aim of clarifying the position that the EU is taking for its future hydrogen imports, it becomes clear that the EU is actively engaging with third-party countries to secure future renewable hydrogen imports, with the stated goal of decarbonizing these countries' energy systems and ensuring future hydrogen imports to the EU. Additionally, the EU plans to implement certification processes with future exporting countries to ensure that future hydrogen imports are produced to the same standards as the renewable hydrogen produced in the EU (EU external energy engagement in a changing world, 5/2022).

[12] CCfDs set an effective guaranteed price for CO_2. In theory, the price would be set at a level that covers the incremental capital and operating cost of a new or disruptive technology.

Figure 13: EU modeled renewable hydrogen demand by 2030[13, 14]



Source: EC staff working document, 5/2022

The latest two EU delegated acts for Renewable Fuels of Non-Biological Origin (RFNBOs) provide a possible example of the principles behind these certifications. The acts outline the conditions for renewable hydrogen and renewable hydrogen-based fuels and establish the principle of "additionality". This principle stipulates that renewable energy must be specifically constructed for electrolyzer operation up to 36 months before production. Additionally, the acts offer a methodology for calculating life-cycle greenhouse gas emissions for RFNBOs, which considers emissions across the entire lifecycle, including upstream emissions, processing, and transport. The acts also clarify how to calculate greenhouse gas emissions of renewable hydrogen, or its derivatives, produced alongside fossil-based fuels.

The EU considers three ways for renewable electricity to be used to produce renewable hydrogen. The first method involves a direct connection to a renewable energy plant that must be constructed solely for electrolyzer operation to avoid using existing renewable energy capacity for hydrogen production. The second method involves purchasing grid electricity in a bidding zone[15] with a renewable energy share of over 90 per cent, and the maximum number of operating hours for the electrolyzer operation is determined by multiplying the renewable energy share in the electricity mix by the number of hours in a year. The third method involves a Power Purchase Agreement (PPA) between the renewable energy operator and the hydrogen producer, which must meet the principles of temporal and geographical correlation to be considered renewable. The principle of additionality is also required unless the grid emission intensity is lower than 64.8 g CO2, per kWh. Additionally, renewable electricity consumption that avoids the shutdown of a renewable energy plant for a redispatch measure can also count as fully renewable for RFNBO production, ensuring the best possible use of available renewable energy capacity.

The rules will be gradually phased in, and both domestic and third-country producers will need to comply with the EU framework's requirements for producing renewable hydrogen. A voluntary certification scheme will also be put in place to ensure compliance with the framework (European Commission, 2/2023).

From the perspective of countries considering the production of hydrogen for export, the delegated acts provide clarity on the type of hydrogen that the EU is seeking for its future use. However, it is important to note that more hydrogen projects in third-party countries may be constructed for economic diversification purposes rather than for the decarbonization of the local energy system.

[13] Data drawn from the European Commission "Implementing the Repower EU Action Plan" and EU JRC "The role of hydrogen in energy decarbonisation scenarios" technical documents.

[14] The EU defines ammonia production in the refineries segment while the IEA defines it as part of industry.

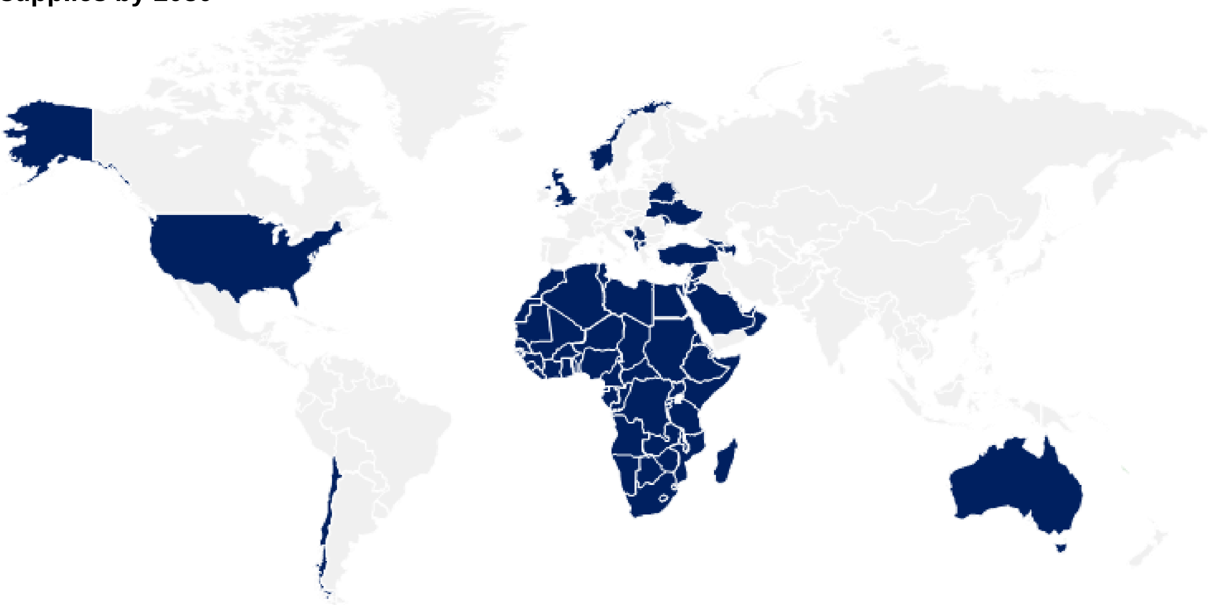
[15] A bidding zone is a region in which the same electricity price is applied.

Finally, within the scope of identified EU policy, the EU has identified potential renewable hydrogen suppliers within the EU Neighbourhood, Southern Neighbourhood, Sub-Saharan Africa, the Middle East, the Arabian Gulf, Chile, the US, and Australia. By 2030, the EU aims to establish at least three major hydrogen corridors from North Africa, the North Sea, and Ukraine. The EU is also considering the use of pressurized hydrogen pipelines from nearby export-oriented countries and shipping ammonia from distant export-oriented countries (EU external energy engagement in a changing world, 5/2022), (European Commission, 5/2022), (EU- JRC, 12/2022).

3. Potential hydrogen import routes to the EU

As discussed in the previous section, the EU has identified potential hydrogen supply regions in its technical documents (European Commission, 5/2022), (EU- JRC, 12/2022). These regions include over seventy countries, as depicted in Figure 14. Therefore, to provide more clarity, this section will identify those countries that are more likely to supply hydrogen to the EU based on the available information at the time of writing.

Figure 14: Countries within the regions indicated by the EU for potential future Hydrogen supplies by 2030[16]



Source: Author's analysis of the EU technical documents

With the aim of narrowing down the list, we will focus only on the countries that have announced or are preparing a hydrogen strategy as of Q1 2023. This reduces the list of potential supplier countries to fourteen: Australia, Chile, Egypt, Morocco, Namibia, Norway, Oman, Saudi Arabia, South Africa, Turkey, Ukraine, the UAE, the UK, and the US. Further information on the status of hydrogen announcements within these countries can be found in Table 1.

[16] The map is for illustrative purposes and does not imply the expression of any opinion on the part of the Author or the Oxford Institute for Energy Studies.

Table 1: Analysis on the status of announced/anticipated strategies of potential EU hydrogen suppliers by 2030

Country	Quantified Hydrogen target	Announced Hydrogen[17]	Hydrogen Project Capacity (kt)[18]	Likely Renewable Hydrogen (kt)[19]	Clear Expression for Export[10]
Australia	-	-	7500	12	×
Chile	×	5 GW	3040	0.3	×
Egypt	-	-	1570	0	-
Morocco	-	-	50	0.3	×
Namibia	×	-	5	0.7	-
Norway	-	-	660	15	-
Oman	×	1 Mt	1200	0	×
Saudi Arabia	×	2.9 Mt	370	370	×
South Africa	×	5 GW	640	0.6	-
Turkey	-	-	0.04	0.04	-
Ukraine[20]	-	-	10	0	-
UAE	-	-	250	1.2	×
UK	×	10 GW	4020	10	-
USA	×	10 Mt[21]	5030	100	-

Source: Author's analysis of the identified sources related to national policies available at the time of the report's publication.

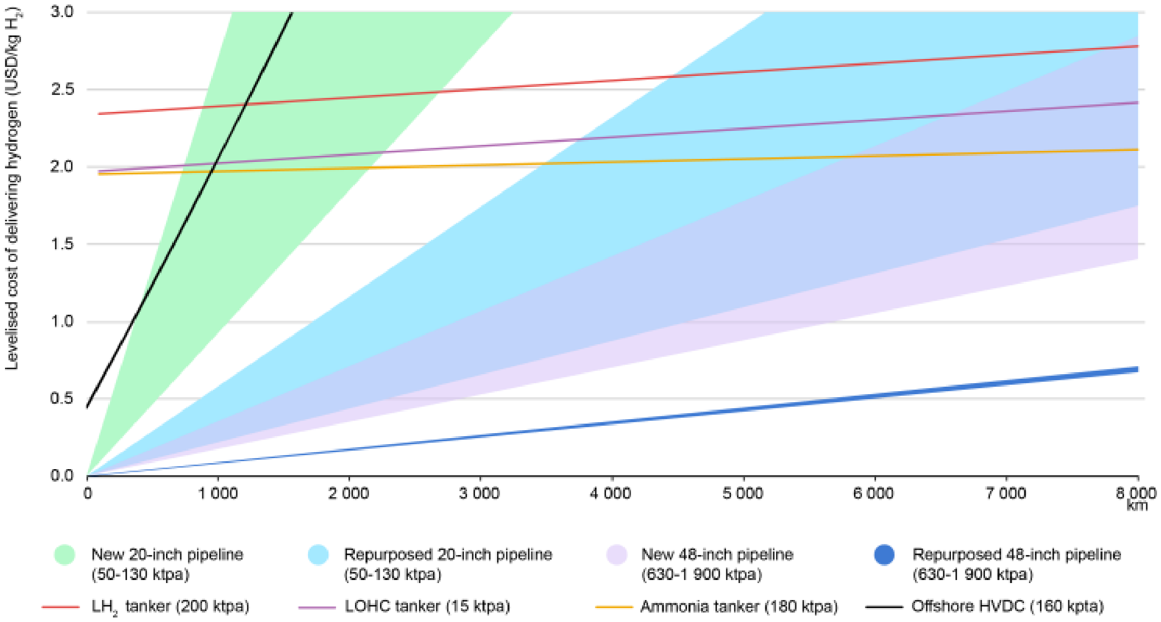
In summary, while there are fourteen potential supplier countries for renewable hydrogen, which currently account for only 0.5 Mt of decarbonized hydrogen capacity currently being built or at FID, only six of these fourteen countries have indicated clear export intentions by 2030, which makes them prominent candidates for likely hydrogen supplies to the EU. These countries are Australia, Chile, Morocco, Oman, Saudi Arabia, and the UAE. However, it is worth noting that this analysis does not take into account existing competencies related to pipelines or ammonia, which may influence the actual supply sources of hydrogen to the EU.

As previously mentioned, the EU's policy regarding future import supplies of hydrogen suggests that it will either come through pressurized hydrogen pipelines or through shipping hydrogen in the form of ammonia/derivatives.

When comparing the two hydrogen delivery methods, with a focus on the levelized costs of delivery, pipelines would be the more economical solution for short to medium distances, as demonstrated in Figure 15, which highlights the significant economic opportunity of utilizing pipelines over shipping.

[17] Based on identified sources related to national documents. All the listed countries could potentially export hydrogen .
[18] Based on data from 2022 IEA Hydrogen Database.
[19] When considering projects currently at FID or under-construction.
[20] Ukraine will likely be a hydrogen exporter to the EU as soon as the situation allows.
[21] Upper limit assessment potential.

Figure 15: Levelized costs of delivering hydrogen by pipeline and by ship as liquid hydrogen, LOHC and ammonia carriers, and electricity transmission, 2030



Source: IEA 2022 Hydrogen report

It is nevertheless the case that pipeline projects, especially those that cross different national boundaries, although relatively short in construction time, are characterized by long lead-times. The exact duration can vary depending on various factors, such as the length and complexity of the pipeline, environmental and social impact assessments, land acquisition and permitting processes, and technical challenges.

The closest examples could be taken from natural gas pipelines. The Trans-Adriatic pipeline, for instance, was first announced in 2003 and began construction in 2016, with first gas deliveries in 2020 (TAP, n.d.). Another example is the Nord Stream 2 pipeline between Russia and Germany, which was first announced in 2011 and completed construction in 2021 (Reuters, 10/2021). While pipeline construction can take between two to five years, this timeframe is relatively short compared to the other requirements that need to be addressed before construction starts. Moreover, building transnational hydrogen pipelines may require additional time and effort due to the lack of existing competencies and the associated regulatory, environmental, and technical challenges.

Given the long lead-time and the various factors that need to be addressed before the construction of transnational pipelines, it is speculated that hydrogen pipelines are unlikely to start being used in the EU before 2030. Therefore the shipping of ammonia is likely to be the earliest method of choice for hydrogen deliveries, until dedicated pipelines become more established.

Additionally, it is worth noting that the current and foreseeable demand for hydrogen in the EU will continue to come primarily from the refining and industrial sectors, at least for the next seven years. As a result, it is likely that import supplies in the form of shipped ammonia will be directed towards the northwestern region of the EU, where most of these industrial complexes are situated (EHB, 4/2022).[22] This provides a useful reference point for evaluating the competitiveness of the six potential suppliers, particularly with regards to the landed costs of hydrogen (LCOH) into the EU via the shipping of green ammonia. Table 2 presents an overview of these costs.

[22] The Port of Rotterdam has been selected as the geological point of reference for hydrogen supplies delivery.

Table 2: Approximate estimated 2030 LCOH to the Port of Rotterdam[23,24]

Country	Export port	Route	Estimated LCOH by 2030 (USD/kgH2)	Proportion of shipping cost to total LCOH)
Australia (West)	Perth	Via Suez Canal	2.49	24%
Australia (East)	Gladstone	Via Suez Canal	2.69	30%
Chile (Panama/South)	Valparaiso	Via Panama Canal	2.06	23%
Morocco	Casablanca	-	2.19	6%
Oman	Mina Al-Fahel	Via Suez Canal	2.28	17%
Saudi Arabia (West/East)	Jeddah	Via Suez Canal	2.32	14%
UAE	Sharjah	Via Suez Canal	2.39	16%

Source: Author's analysis of the different studies identified for hydrogen production in the specified geography and through the use of the HySupply Shipping Analysis Tool.

The table presented above is a valuable resource for evaluating potential suppliers of green ammonia and their estimated LCOH. However, it is crucial to acknowledge that this is just one aspect of a complex decision-making process. Other factors such as political stability, regulatory environment, and technology capabilities need to be considered when assessing potential suppliers. Moreover, it is important to note that the figures included for hydrogen production and used for the LCOH calculations were based on estimates of future wind and solar project costs, which may not be accurate..

Additionally, it is important to note that the estimated LCOH presented in the table may vary depending on various factors such as currency fluctuations, changes in shipping costs, and fluctuations in renewable energy prices.

In summary, while the table provides a useful comparison of potential green ammonia suppliers, it is important to consider other factors beyond the estimated LCOH when making decisions on potential suppliers. A comprehensive approach that considers all aspects of the decision-making process will undoubtedly lead to better outcomes and increased sustainability for the EU's hydrogen strategy.

Lastly, when we look at the existing competencies of the six aforementioned countries, we can note that while all six countries have an export trade in ammonia, there is a vast difference in scale between Saudi Arabia and the others. As of 2020, Saudi Arabia was by far the biggest exporter of ammonia in the world, responsible for around 33 per cent of the exported value, while the remaining five countries were each responsible for less than 2 per cent of the exported value. (OEC, 2023) This could create a competitive advantage for the Gulf State in its aim of exporting renewable ammonia in the future. However, it is important to note that the EU will aim to diversify the sources of its imports and it is not

[23] Considering only the approximated LCOH for hydrogen production and transport of ammonia without taking into account storage beyond import/export ports and conversion between ammonia and hydrogen.

[24] Refer to appendix A3 for production and transport assumptions.

expected that a single source of imports will provide all the future renewable hydrogen imports of the EU.

4. Recommendations to unlocking the EU hydrogen trade investments and value chain

This section examines the key themes and topics that need to be addressed for the EU to be able to align with potential third country partners for potential renewable hydrogen supplies. Eight areas have been identified which have significance for any type of external EU engagement. These are: infrastructure, joint scenarios, technology cooperation, standards, investments and finance, market development and trading platforms, education and training, and finally, the creation of coordination hubs.

While it is recognized that each of these merits further lengthy analysis, this paper will attempt to summarize the essence behind each topic.

Infrastructure

The infrastructure required to support the production and trade of renewable hydrogen is crucial for the success of any collaboration between the EU and potential third country partners. This includes investments in production facilities, transport, and storage.

The EU and its potential partners must commit to supporting appropriate infrastructure for the production and trade of hydrogen and hydrogen-related products. This requires understanding the expertise of the third country partner and investing in infrastructure that is appropriate to its needs, such as ammonia or methanol production. It is also important to ensure that means of transport and storage are in place to support this potential production. This can include pipelines, shipping, and storage facilities. Building and maintaining infrastructure is a long-term commitment that requires significant investment and cooperation between the EU and its partners.

Joint scenarios

Joint scenario building is an essential tool for enabling large investments in renewable hydrogen production for export in partner countries. This requires a clear vision of the opportunities available for collaboration between the EU and its partners.

Joint scenarios provide information on planned or anticipated future supply or demand volumes of hydrogen. This information is based on a methodology that both the EU and third country partners agree upon. Joint scenario building can also support EU-based investments, such as import facilities, storage facilities, ammonia cracking facilities, and regasification terminals. A clear understanding of the opportunities available for collaboration between the EU and its partners is essential for enabling large investments in renewable hydrogen production for export.

Technology cooperation

The EU is a global leader in renewable hydrogen technology, and technological cooperation with potential partners is essential for the success of any collaboration.

Technology cooperation can take many forms, including local manufacturing, technology transfer, and joint research and development. By sharing expertise and resources, the EU and its partners can accelerate the development and deployment of renewable hydrogen technologies. This can include everything from production processes to storage and transport. Technology cooperation is essential for ensuring that the EU and its partners remain at the forefront of renewable hydrogen technology development.

Standards

To ensure that renewable hydrogen can be produced, transported, and used safely and efficiently, it is essential to establish harmonized standards between the EU and potential third country partners. This will require close collaboration between regulators, industry, and standards bodies to develop common standards and regulations that promote the safe and sustainable production, transport, storage, and use of renewable hydrogen.

There are several aspects of standards that need to be addressed when it comes to renewable hydrogen. One important feature is safety standards, which must be established to ensure that renewable hydrogen is produced, transported, and used safely. This includes standards for the design, construction, and operation of renewable hydrogen production, transport, and storage facilities, as well as safety standards for the handling and use of renewable hydrogen in various applications.

Another aspect of standards that needs to be considered is the development of technical standards for renewable hydrogen quality, purity, and measurement. This is important for ensuring the interoperability of hydrogen infrastructure across different regions and for facilitating international trade in renewable hydrogen. The establishment of common technical standards will also help to ensure that renewable hydrogen meets the required quality and purity standards for different applications.

In addition to safety and technical standards, there is a need to establish environmental and sustainability standards for renewable hydrogen production and use. This includes standards for carbon footprint, water usage, land use, and biodiversity, among others. These standards will help to ensure that renewable hydrogen is produced and used in an environmentally sustainable manner, with minimal impact on the environment and local communities.

Investments and finance

Investments and finance are crucial components for the development of renewable hydrogen projects. While renewable hydrogen production costs are declining, initial investments remain high. Therefore, adequate funding mechanisms and access to capital markets must be established to support renewable hydrogen projects.

The EU and its third-country partners need to develop financing mechanisms and instruments to fund renewable hydrogen projects. This includes establishing partnerships between public and private entities to leverage funding sources. Additionally, governments must ensure regulatory frameworks for long-term investment security. Furthermore, innovative financing models should be explored to mobilize public investments towards renewable hydrogen projects.

The establishment of financial mechanisms and investments in renewable hydrogen projects are crucial for achieving the EU's decarbonization goals. By leveraging public and private funds, the EU and its third-country partners can develop innovative financing models to support the transition towards renewable hydrogen production.

Market development and trading platforms

Market development and trading platforms are essential for the commercialization of renewable hydrogen products. The establishment of a market with robust demand is critical to support the production of renewable hydrogen at scale. Moreover, effective trading platforms can help to create a transparent and efficient market for renewable hydrogen.

The EU and its third-country partners must collaborate to develop and promote a renewable hydrogen market. This includes creating demand for renewable hydrogen products by establishing policies that incentivize renewable hydrogen adoption. For example, subsidies or mandates can be used to promote renewable hydrogen as a feedstock for industry or as a fuel for transportation. Additionally, the development of standardized quality assurance and certification schemes will promote confidence in renewable hydrogen products.

Moreover, trading platforms must be developed to facilitate the buying and selling of renewable hydrogen products. The EU can leverage its experience in developing successful carbon trading platforms to develop similar mechanisms for renewable hydrogen.

Education and Training

Education and training are vital components for the development and deployment of renewable hydrogen technologies. The growth of the renewable hydrogen industry will require skilled labour and workforce development.

The EU and its third-country partners must therefore prioritize workforce development and education in renewable hydrogen technologies. This includes investing in research and development to improve understanding and knowledge of renewable hydrogen technologies. Additionally, education and training programs should be established to develop skilled labour in renewable hydrogen industries. These programs should include both traditional academic programs and vocational training courses.

Furthermore, public-private partnerships should be established to promote knowledge transfer and technology sharing. This includes the establishment of research and development centres, technology transfer offices, and academic exchanges. Additionally, collaborations between academic institutions and industry should be encouraged to ensure that education and training programs meet industry demands.

Coordination hubs

In order for the EU to align with potential third-country partners on renewable hydrogen supplies, the creation of coordination hubs is a key element.

Coordination hubs can provide a central point for information exchange, project development, and joint decision-making between the EU and its partner countries. These hubs can serve as a platform for sharing best practices, technical expertise, and knowledge related to hydrogen production, transport, and storage. In addition, they can facilitate the identification of investment opportunities, the development of business models, and the promotion of financing options. Coordination hubs can also help align policies, regulations, and standards across different jurisdictions, thereby promoting the growth of the hydrogen market and reducing trade barriers.

Establishing coordination hubs requires a concerted effort from both the EU and its partner countries. The first step is to identify potential hub locations based on various criteria, such as geographical proximity, existing infrastructure, and regulatory frameworks. Once the locations are identified, the EU and its partner countries can work together to establish the necessary infrastructure, communication channels, and governance structures for the coordination hubs. This can include physical facilities, such as offices and meeting rooms, as well as digital platforms and tools for remote collaboration.

It is also important to ensure that the coordination hubs are inclusive and accessible to all stakeholders, including industry players, policymakers, researchers, and civil society organizations. This can be achieved through transparent and participatory processes for decision-making, as well as open and accessible communication channels for information exchange. Moreover, the coordination hubs should be flexible and adaptable to changing circumstances and evolving needs, allowing for continuous improvement and innovation.

Conclusion

In conclusion, the next seven years hold great promise for the growth of decarbonized hydrogen and related fuels and products. While the current hydrogen market is mainly dominated by captive unabated production, many countries around the world are setting ambitious goals and targets for decarbonized hydrogen production. However, it is important that these announcements translate into projects that have secured funding and offtake. Currently, only 2 Mt of decarbonized hydrogen projects are under construction or at FID, mainly within the EU, Saudi Arabia, and Canada.

The EU has positioned itself well in terms of potential hydrogen imports, setting the largest announced import target of 10 Mt by 2030. This provides export-oriented countries with the ability to scale up their decarbonization strategies and diversify their economies in order to meet this future demand. The EU's definition of renewable hydrogen and its early adopter advantage is likely to provide clarity for export-oriented countries and drive them to invest in projects that align with the EU definition.

Finally, while the EU has identified potential regions for future renewable hydrogen supplies, these regions remain undefined, encompassing over seventy countries. However, as of March 2023, Australia, Chile, Morocco, Oman, Saudi Arabia, and the UAE have stood out amongst fourteen countries that have declared hydrogen ambitions or targets and are within the regions identified by EU policy as potential future suppliers of renewable hydrogen. This paper argues that these countries are the most likely immediate candidates to supply future hydrogen imports, particularly for shipped ammonia, which is the likely method of hydrogen delivery into the EU by 2030. In addition, to facilitate sustainable hydrogen supplies from export-oriented countries to the EU, there is a need for engagement in discourse related to infrastructure, joint scenarios, technology cooperation, standards, investments and finance, market development and trading platforms, education and training, and the creation of coordination hubs.

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Appendices

Appendix A1 - Current low-carbon hydrogen capacity

Table 3: Current operating low carbon hydrogen capacity per country

Country	Blue Hydrogen (kt)	Green Hydrogen (kt)
Netherlands	1000,000	0,410
Canada	300,000	3,487
US	117,726	5,707
France	38,982	0,568
China	0,000	34,252
Germany	0,000	9,901
Spain	0,000	4,112
Japan	0,000	1,773
Austria	0,000	1,679
Italy	1,169	0,373
Finland	0,000	1,525
UK	0,000	0,991
Iceland	0,000	0,936
Sweden	0,000	0,915
India	0,000	0,900
Denmark	0,000	0,796
Norway	0,000	0,626
South Africa	0,000	0,593
Australia	0,000	0,475
Estonia	0,000	0,409
Belgium	0,000	0,377
Poland	0,000	0,364
Switzerland	0,000	0,352
New Zealand	0,000	0,195
UAE	0,000	0,187
Thailand	0,000	0,156
Argentina	0,000	0,140
Slovenia	0,000	0,104
Malaysia	0,000	0,047
Iran	0,000	0,035
Turkey	0,000	0,032
Greece	0,000	0,022
Lebanon	0,000	0,019
Chile	0,000	0,009
Singapore	0,000	0,002
Costa Rica	0,000	0,001

Appendix A2 – Decarbonized hydrogen country announcements

Table 4: Identified decarbonized hydrogen country announcements

Jurisdiction	Key Documents	Type	Release Date
Argentina	2030 National Low-Emission Hydrogen Strategy	National Strategy	Jun-22
Australia	Australia's National Hydrogen Strategy	National Strategy	Nov-19
Austria	Hydrogen Strategy for Austria	National Strategy	Jun-22
Belgium	Federal Hydrogen Vision and Strategy	National Strategy	Oct-21
Brazil	Hydrogen strategy in preparation		
Canada	Hydrogen Strategy for Canada	National Strategy	Dec-20
Chile	National Green Hydrogen Strategy	National Strategy	Nov-20
China	China Fuel Cell Subsidy Policy / Medium and Long-Term Planning for the Development of Hydrogen Energy Industry (2021-2035)	Policy Statement / Planning Document	Septembe r 2020 / March 2022
Colombia	National Roadmap for Colombia	National Roadmap (draft)	Aug-21
Croatia	Croatia Hydrogen Strategy	National Strategy	Mar-22
Czech Republic	National Hydrogen Strategy of the Czech Republic	National Strategy	Jul-21
Denmark	The Government's Strategy for Power-to-X	National Strategy	Dec-21
European Union	REPowerEU	Supranational Strategy	Mar-22
Egypt	Hydrogen strategy in preparation		
Finland	National Hydrogen Roadmap for Finland	National Roadmap	Nov-20
France	National Strategy for the Development of Decarbonised and Renewable Hydrogen in France	National Strategy	Sep-20
Germany	The National Hydrogen Strategy	National Strategy	Jun-20
Greece	National Strategy for the Promotion of Technologies – Applications of Hydrogen and Renewable Gases	National Strategy	Nov-22
Hungary	National Hydrogen Strategy	National Strategy	May-21
India	Green Hydrogen Policy	Policy	Feb-22
Italy	National Hydrogen Strategy Preliminary Guidelines	Preliminary Guidelines	Nov-20

Japan	Basic Hydrogen Strategy / The Strategic Roadmap for Hydrogen and Fuel Cells	National Strategy / National Roadmap	December 2017 / March 2019
Luxembourg	Luxembourg Hydrogen Strategy	National Strategy	Sep-21
Morocco	National Hydrogen Development Strategy	National Strategy	Aug-21
Namibia	Green Hydrogen Strategy	National Strategy	Nov-22
Netherlands	Government Strategy on Hydrogen	National Strategy	Apr-20
New Zealand	A Vision for Hydrogen in New Zealand	Vision	Sep-19
Norway	The Norwegian Government's Hydrogen Strategy	National Strategy	Jun-20
Oman	Net Zero Emissions in 2050 and Green Hydrogen Strategy	Policy Announcemen t	Oct-22
Paraguay	Towards the Green Hydrogen Roadmap in Paraguay	National Roadmap	Jun-21
Poland	Draft Polish Hydrogen Strategy until 2030 with an Outlook until 2040	Draft National Strategy	Jan-21
Portugal	Portugal National Hydrogen Strategy	National Strategy	Jul-20
Republic of Korea (South Korea)	Hydrogen Economy Roadmap of Korea	National Roadmap	Jan-19
Russia	Roadmap for Development of Hydrogen Energy for 2020-2024 / Concept for the Development of Hydrogen Energy in Russia	National Roadmap / Policy Statement	October 2020 / August 2021
Saudi Arabia	Hydrogen strategy in preparation		
Singapore	Singapore's National Hydrogen Study	National Strategy	Oct-22
Slovakia	National Hydrogen Strategy	National Strategy	Jun-21
South Africa	Hydrogen Society Roadmap for South Africa 2021	National Roadmap	Feb-22
Spain	Hydrogen Roadmap – A Commitment to Renewable Energy	National Roadmap	Oct-20
Sweden	Proposal for a national strategy for fossil-free Hydrogen, electric fuels and ammonia – Swedish Energy Agency	National Strategy	Nov-21
Turkey	Hydrogen strategy in preparation		
Switzerland	Theses on the future importance of Hydrogen in Swiss energy supply	Discussion Paper	Sep-22
Ukraine	Draft Roadmap for Production and Use of Hydrogen in Ukraine	Draft Roadmap	Mar-21
United Arab Emirates	Hydrogen Leadership Roadmap	National Roadmap	Nov-21

United Kingdom	UK Hydrogen Strategy	National Hydrogen Strategy	Aug-21
United States	DOE National Clean Hydrogen Strategy and Roadmap	Strategy and Roadmap	Sep-22
Uruguay	Green Hydrogen Roadmap in Uruguay	Draft National Roadmap	Jun-22

Appendix A3 – Production and transport assumptions

Production assumptions

Table 5: Further information on hydrogen production assumptions

Country	LCOH by 2030 for production from renewables	Assumption
Australia	1.89	Based on 2023 BNEF data over a different set of technologies
Chile	1.59	Based on 2023 BNEF data
Morocco	2.06	Based on data from MASEN, CEA, and IRENA with a renewable energy cost of EUR 30/MWh and an electrolyzer capital cost of EUR 500/kW
Oman	1.9	Based on a study by the Oman Power and Water Procurement Company, with an assumed renewable energy cost of USD 20/MWh and an electrolyzer capital cost of USD 400/kW
Saudi Arabia	2.0	Based on a study by Aramco, with an assumed renewable energy cost of USD 30/MWh and an electrolyzer capital cost of USD 500/kW
UAE	2.0	Based on a study by Masdar, with an assumed renewable energy cost of USD 20/MWh and an electrolyzer capital cost of USD 400/kW

Transport assumptions

For transport of ammonia, the main variables were taken from the HySupply Shipping Analysis Tool, with routes that were not included within the tool approximated using the sea-distances online tool.