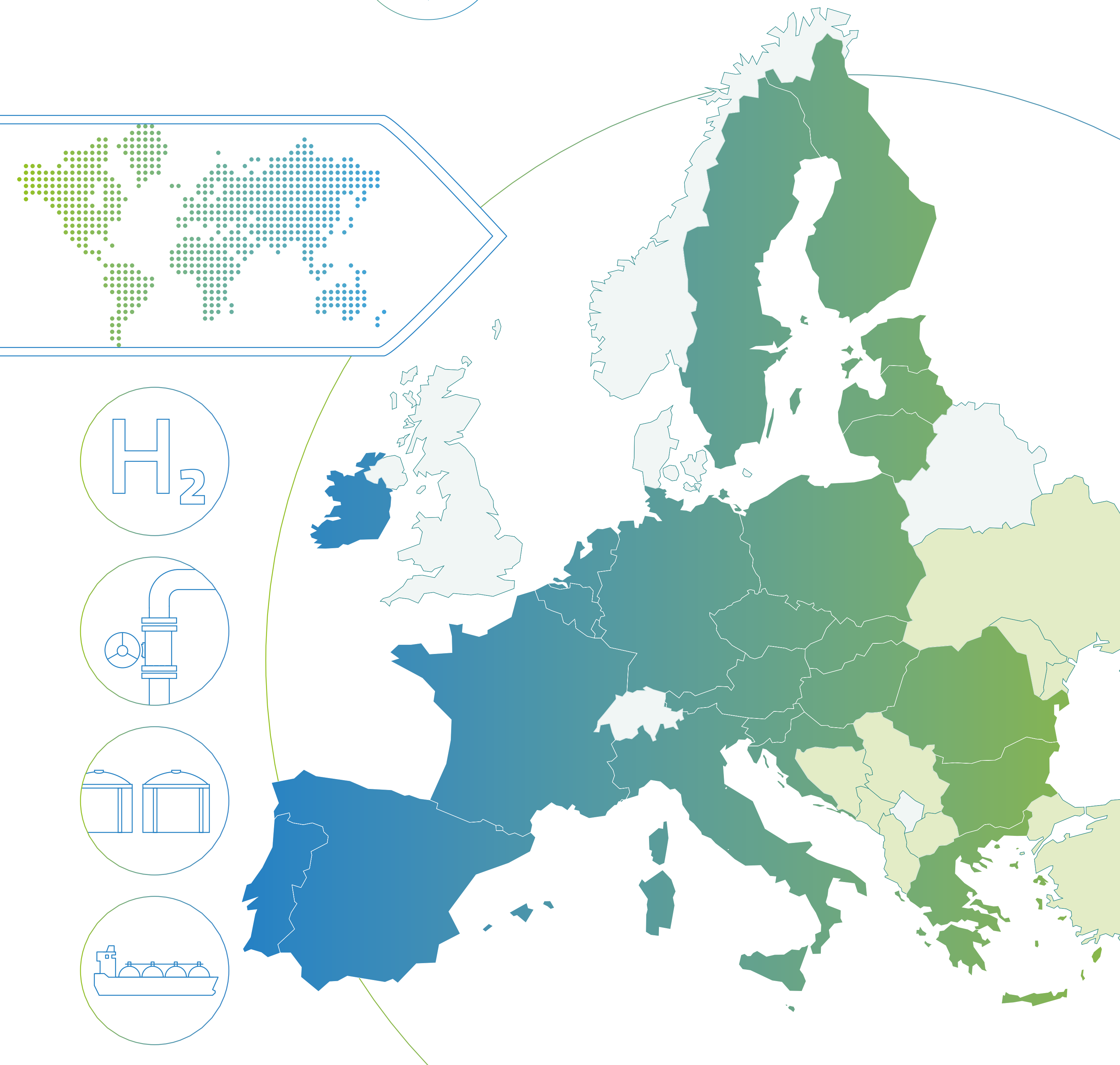
LEARNBOOK: HYDROGEN IMPORTS TO THE EU MARKET

Clean Hydrogen Alliance
Transmission and Distribution Roundtable

European Clean Hydrogen Alliance



November 2023

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Disclaimer:

This document reflects the work of the Transmission and Distribution roundtable of the set up in the context of the European Clean Hydrogen Alliance. The input identified does not necessarily represent the position of the European Commission nor the position of individual members of the Alliance.

1 INTRODUCTION

The European Clean Hydrogen Alliance (ECH2A) was launched in July 2020, as one of the key initiatives of the EU Hydrogen Strategy for a climate-neutral Europe. It aims to support the European hydrogen production and deployment ambitions and to ensure the emergence of an EU hydrogen economy by 2030.

The principal role of the Alliance is to build up a pipeline of concrete and viable investment projects along the complete hydrogen value chain. The expectation is to create a clean hydrogen market that contributes to economic growth, generates jobs, and reduces greenhouse gas emissions.

HYDROGEN OUTLOOK – STRATEGIES, ROADMAPS, PROJECTS

Roughly 50 countries covering all corners of the globe have hydrogen strategies or roadmaps, and this number is still growing. Recently, several countries with large hydrogen production export potential in the Middle East, Africa and Latin America have joined this list [1], adding further impetus to the sector's growth. All these countries see a new sector in the hydrogen exportation - providing sustainable jobs, growth and prosperity for their countries.

Concrete import/export projects between continents are already under development. Australia and Brunei have delivered their first shipments of hydrogen to Japan with pilot projects. The Inflation Reduction Act (IRA) in the USA includes powerful fiscal incentives to boost investment in clean hydrogen, possibly even for exports.

Based on the strategies of the respective countries and trade project plans, a new global commodity market could emerge, with net-importing countries (e.g. Japan, Korea, Germany, Netherlands, Belgium) and net-exporting countries (Australia, MENA countries, Chile, Namibia, South Africa, US, Canada and more)

By 2050, the volume of hydrogen traded globally might be comparable to the current natural gas trade.[2]

AIM OF THE LEARNBOOK

This Learnbook from the Transmission and Distribution of Clean Hydrogen roundtable of the Alliance shares the experience of actors working on the import of clean hydrogen into the EU, and its subsequent transportation within the Union. In sharing information on the successes and challenges of developments to date, the document aims to contribute to the wider discussion on the buildout of the sector and serve as a useful reference point for policymakers and decision-makers going forward.

The document outlines the benefits, options, and environmental implications of importing H_2 to the EU and provides a list of barriers and recommendations supported by the members of the roundtable. This is the second Learnbook produced by the roundtable, following the first edition in the series released in 2023. This most recent edition builds on the experience gained from the first Learnbook, includes the latest project information, and updates the recommendations to reflect the current landscape

1 Including Saudi Arabia, UAE, Oman, Morocco, Egypt, Namibia, India, Chile, Uruguay, Brazil, and Argentina.

2 International Renewable Energy Agency – IRENA, Global hydrogen trade to meet the 1.5 °C climate goal: Part I – Trade outlook for 2050 and way forward, International Renewable Energy Agency, (2022), (p. 39)

2 EXECUTIVE SUMMARY

EUROPEAN AMBITIONS

The European Hydrogen Strategy ("A hydrogen strategy for a climate-neutral Europe") published by the European Commission in 2020 recognised the important role of hydrogen in decarbonising industrial processes and other hard-to-abate sectors of the economy. Within the framework of the European Green Deal, Europe has set the target to become climate-neutral by 2050.

In 2022 the European Commission published its REPowerEU plan, which aims to rapidly reduce dependence on Russian fossil fuels and accelerate the green transition. Hydrogen plays a key role in this plan. The REPowerEU plan sets the political ambition of having 20 million tons of renewable hydrogen per year in the EU by 2030 – 10 million tons via domestic production and up to 10 million tons via imports. In parallel - with the goal of reducing EU emissions by at least 55 % by 2030 - the "Fit for 55 Package", has introduced multiple pieces of legislation with binding demand side targets for RFNBOs (renewable H_2 and H_2 derivatives) by 2030.

GOAL OF THE LEARNBOOK

In the context of REPowerEU and the European Green Deal, the Learnbook explains why the EU needs H_2 imports from outside (and within the EU) and the main benefits and challenges associated with them. It also discusses the different import options and technologies for importing H_2 to the EU, highlights the main announced import infrastructure projects and comments on how they connect to EU H_2 supply corridors.

ANALYSING HYDROGEN IMPORTS AND GOING FORWARD

H_2 and H_2 carriers can be imported in large volumes via pipeline or ship. Europe has a wealth of gas transport assets, and there are many instances where existing infrastructure (gas pipelines, ports installations, shipping, etc.) can be repurposed to allow cost-effective high-volume imports. While H_2 pipeline imports are envisaged primarily for imports from the EU's neighbouring regions and between Member States, imports via maritime routes enable access to exporters from anywhere in the world, including intra-EU imports, further facilitating diversification and improving Europe's security of energy supply.

When assessing import options, it is important to consider how these imports of H_2 and H_2 carriers will be integrated into the EU market. Some volumes will be injected into the emerging European H_2 network system so that the imported H_2 is readily transported to the demand centres. In other cases, the H_2 carriers (e.g. ammonia, methanol, etc.) will have their end use as well (e.g. bunkering, industrial sites, etc.).

To meet the H_2 targets and demand mentioned above, the EU needs H_2 imports. These imports are required to supplement domestic production in the EU to achieve the EU's energy and climate targets, as Europe cannot rely solely on domestic H_2 production to meet its growing H_2 demand.

Hence, infrastructure and support mechanisms must be implemented along with a clear, stable and enabling EU regulatory framework. The lack of consistency across global rules and certification schemes, insufficient financing support for production and import infrastructure, and inadequate capacity for authorisation and permitting prevent the development of the critical mass of projects within the desired timeframe.

This Learnbook provides specific reflections into the most pressing challenges of H_2 imports at this time and how these challenges can be overcome. In short, the EU should focus on the following points:

- Develop **international strategic partnerships** and cooperation between the EU and 3rd countries, which have the potential to export renewable H_2.
- Support the growth of **large-scale production projects in 3rd countries**. The Union needs to implement a sound support mechanism with the **international pillar of the EU Hydrogen Bank**.
- Evaluate **infrastructure needs** at **national** and **trans-European** levels. This would be followed by constructing suitable H_2 trade infrastructure (H_2 terminals, import pipelines, etc.) while taking advantage of the option to repurpose existing infrastructure.
- Address the lack of **certification, standards** and guarantees of origin for H_2 Imports. We need **common rules** for measuring carbon intensity.
- Develop long-term **H_2 adoption roadmaps**. These shall be based on the evolution of **demand clusters** that outline the gradual integration of H_2 imports into the energy mix.
- Increase **EU** (and national) **funding for H_2 import infrastructure in the EU** (e. g. CEF-E and CEF-T funding)
- Improve and speed up **licensing and permitting** for H_2 import projects
- **Stimulate** industry **demand** for Renewable H_2 and bridge the cost gap with the fossil benchmark.
- Enable a clear, stable and supportive **regulatory framework**, including market and commercial rules, safety standards, quality assurance and environmental regulations. Proper implementation and **consistency between national regulatory frameworks and the EU level** should be ensured.
- Understand and mitigate the **climate and wider environmental concerns** related to H_2 emissions and transport of H_2 carriers
- Define the future **low-carbon H_2 Delegated Act** to provide regulatory clarity.[3]
- Continue allocating **funding to R&D and Innovation initiatives** and **public-private partnerships** that contribute to improving and lowering the costs of imported technologies and help address and better understand the climate and environmental impacts of hydrogen. Enable and promote the development of **regulatory sandboxes**.

3 In the Transmission and Distribution Roundtable and in the European Clean Hydrogen Alliance exist diverging views on the topic of low carbon hydrogen, please see the disclaimer: *"Joining the ECH2A, NGOs agree to engage and contribute to the deployment of renewable hydrogen in terms of supply, demand and distribution as we promote the rapid phase-out of the use and production of all fossil fuels in order to reach the objectives of the Paris Agreement. Thus, we do not consider fossil fuel-based hydrogen as a short or long-term solution. We see our role in contributing to targeting the use of renewable hydrogen specifically to those sectors and industrial processes which are hard to decarbonise (steel, cement and basic chemicals, aviation, shipping and heavy good vehicles)."*

RECOMMENDATIONS

Section 6 includes more details on these recommendations, as well as specific recommendations to address concrete barriers linked to maritime and pipeline imports.

- Build International Partnerships
- Infrastructure Development (national/EU)
- Implement Regulatory Framework
- Promote Production in 3rd countries
- Increase EU (and national) Funding
- Address Environmental Risks
- Global Certification & Standards
- Accelerate Licensing & Permitting
- Define Low-carbon H_2 Delegated Act
- Import/Export Roadmaps and Clusters
- Stimulate Market Demand
- Continue driving R&D&I, PPP and Sandboxes

3 WHY DOES THE EU NEED H_2 IMPORTS?

3.1 EU IMPORTS TARGETS AND HOW TO ACHIEVE THEM

The **EU Hydrogen Strategy** ("A hydrogen strategy for a climate-neutral Europe") published by the European Commission in 2020 recognised the important role of hydrogen in decarbonising industrial processes and other hard-to-abate sectors of the economy. To upscale production - key to enabling hydrogen to play that role - the strategy set the target of having 40 GW of installed electrolyser capacity in Europe by 2030, producing up to 10 Mt of renewable hydrogen domestically. This announcement was complemented by statements of some Member States who expressed their intentions to scale up H_2 production (including low-carbon hydrogen production using natural gas with CCS or nuclear energy).

After the Russian invasion of Ukraine, the European Commission launched the **REPowerEU Plan**, which set the goal of reducing the EU's dependence on Russian fossil fuels by accelerating the clean transition. Moreover, the Commission continues to work with neighbours and partners in the Western Balkans, and in the Energy Community, which share the EU's fossil fuel dependencies and exposure to price hikes, while also having committed to the same long-term climate and decarbonisation goals.

Through the "Hydrogen accelerator" in the REPowerEU plan the EU aims to increase the domestic production and import of renewable H_2 in the EU. In this sense, the plan included two targets to be achieved by 2030: a renewable H_2 production of 10 Mt/y within the EU and the import of 10 Mt/year of renewable H_2.

The achievement of the 10Mt H_2 import target by 2030 might appear ambitious due to the nascent nature of the H_2 sector in the EU. However, it is a much-needed target to reach our EU energy and climate goals.

Even if domestic H_2 production should be prioritised, the **REPowerEU plan recognises that the EU cannot rely solely on domestic H_2 production to meet its growing H_2 demand**. Consequently, some EU Member States will need to import H_2 from others regions that have the potential to produce renewable H_2 in large amounts at a competitive cost due to economies of scale (e.g. regions with abundant sun or wind).

Importing hydrogen into the EU involves flexible approaches. H_2 imports can come from third countries or be generated within the EU using imported renewable and non-fossil electricity. To facilitate this, imports need to be supported, and the EU needs to invest not only in the required infrastructure, including pipelines and terminals but also in innovative solutions on the demand side.

Hydrogen imports will use renewable and low-carbon supply. For low-carbon hydrogen, the industry is waiting for a Delegated Act on Low-Carbon Hydrogen to have a clear definition. This aspect is also important in the context of the upcoming CCUS strategy to be announced by the European Commission in the first quarter 2024.

H_2 imports aren't limited to its pure form, such as compressed or liquid H_2. Hydrogen carriers offer an alternative. These carriers can be converted back into gaseous hydrogen, serving the EU market. Alternatively, they can be directly used based on consumers' needs. For example, green ammonia is valuable for fertilisers, green methanol powers transport, synthetic methane replaces fossil methane, and H_2-loaded LOHC serves bunkering purposes.

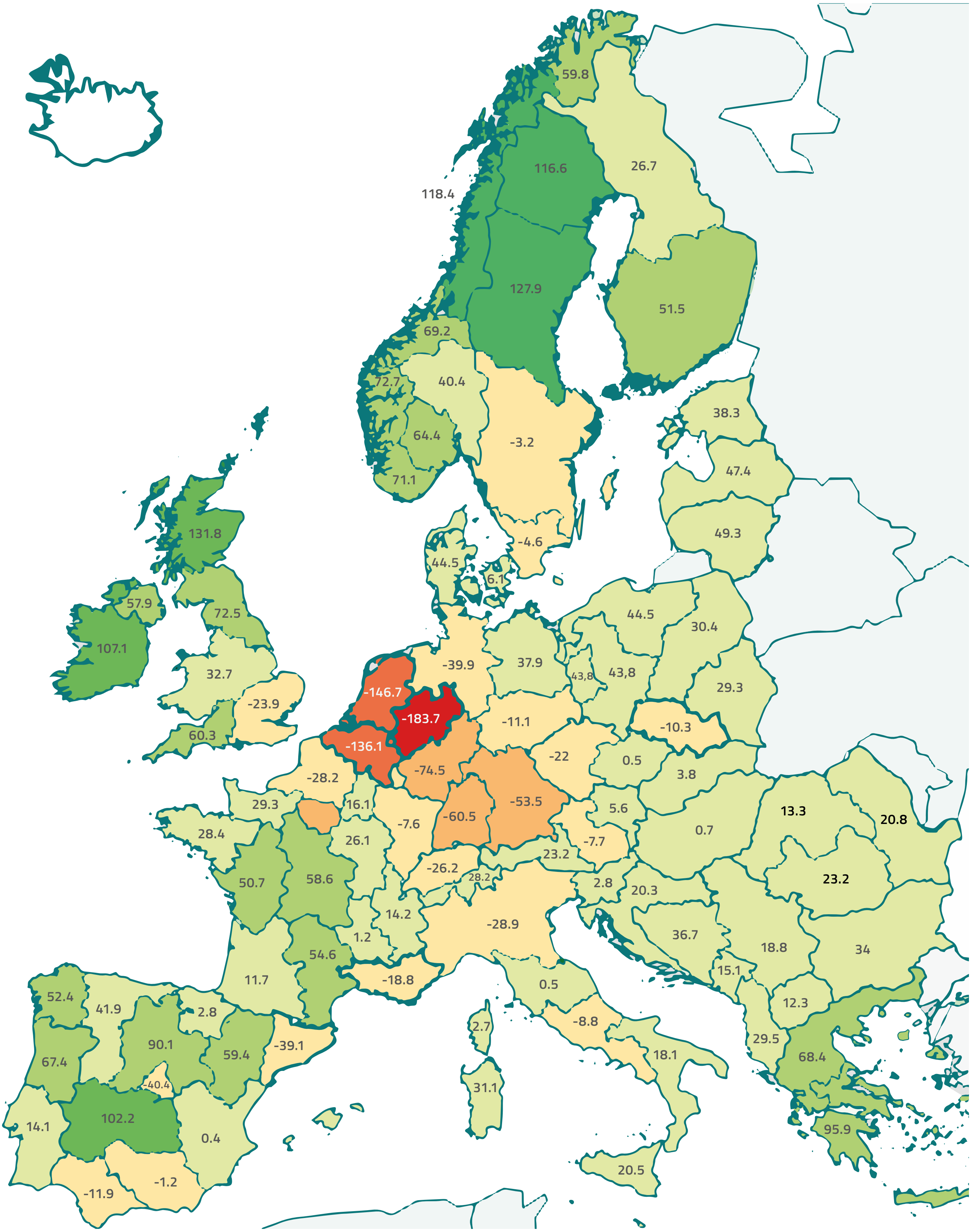


Figure 1: Saldo of total generation potential minus total demand inclusive H_2 in TWh,
Source: Wuppertal Institute, 2023, (Hydrogen Import Coalition Final Report)

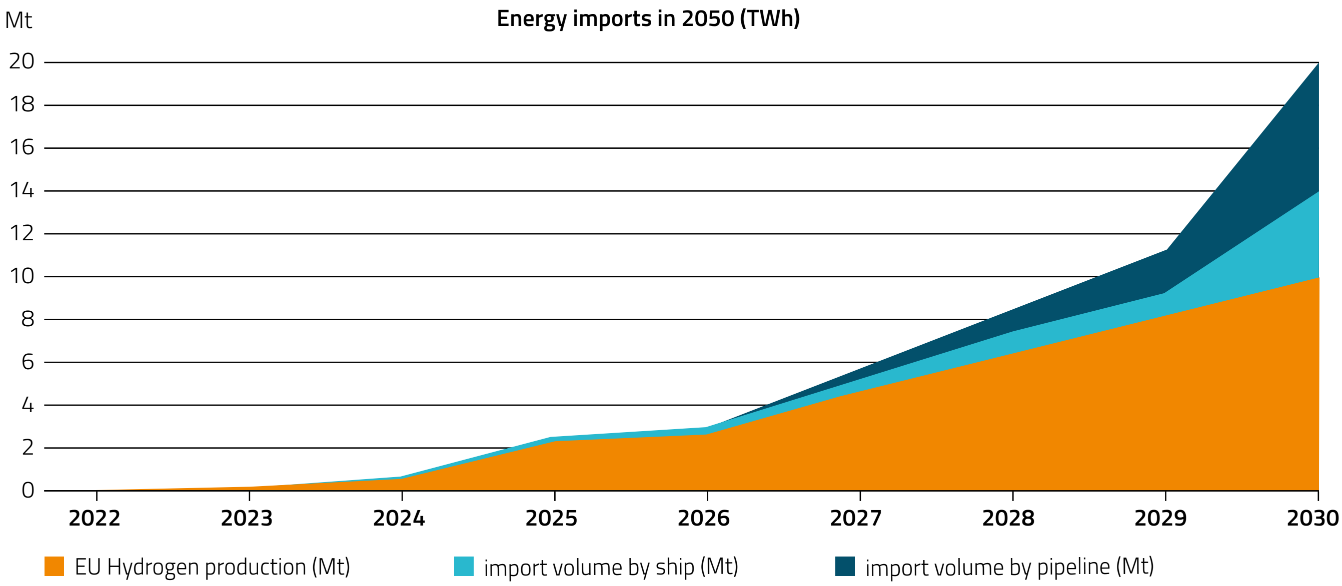


Figure 2: Anticipated EU H_2 domestic production and imports volumes by delivery type (ship or pipeline) from 2022 to 2030,
Source: European Commission, 2023

3.2 BENEFITS AND CHALLENGES ASSOCIATED WITH H_2 IMPORTS

For the EU there are several **advantages in importing renewable and low-carbon hydrogen** from non-EU countries:

— **Diversification and Security of supply - Reducing the EU's reliance on Russian fossil fuels:** Importing H_2 from multiple non-EU countries can help to diversify the EU's energy supply, reducing its reliance on a single source and/or a single route. This increases the EU's energy security, which is especially important in light of the current geopolitical situation where the risks of relying on Russian fossil fuels have been evident. Additionally, EU members without sufficient renewable and non-fossil energy production can diversify their hydrogen imports to avoid relying on only one or a few EU countries.

— **Decarbonisation of the EU's economy:** Importing H_2 can help the EU to decarbonise its industrial feedstock and energy needs. Renewable and low-carbon H_2, including its derivatives, can replace fossil fuels in various applications, where electrification alone cannot fully achieve decarbonisation - such as in the industrial, power generation or transport sector.

— **Lowering the energy transition cost:** Long-distance and international cross-border H_2 trade will play a key role in matching the lowest-cost global supply of hydrogen with EU demand in the most cost-effective manner. This will accelerate the transition to net-zero and reduce total system costs across the hydrogen value chain by as much as US $6 trillion[4]. **By optimising global hydrogen trade flows, we can accelerate the energy transition and reduce investment costs** across the supply chain.

— **Liquidity and a more competitive European H_2 market:** Importing H_2 allows the EU to supplement its domestic production and access more and potentially more cost-competitive hydrogen. This makes H_2 supplies more accessible and potentially more affordable for the EU economy and, by increasing the offer of energy from diversified sources, reduces the EU's vulnerability to energy price shocks. A diversified portfolio of H_2 exporting countries allows for arbitration between the different sources, ensuring a liquid and competitive supply of H_2 and guaranteeing a high level of security of supply. The growing demand for renewable H_2 in the EU will drive the search for the most commercially viable (lowest price) sources of supply, including imports. The renewable import pathway will become competitive in the longer term thanks to significant cost reduction potential, but financial support is required in the short term in order to support the industrial scale-up.

— **Creating jobs and boosting EU's economic growth:** importing H_2 requires investments in technologies and infrastructures which bring additional economic activity, growth, employment and new skills development to the EU's job market.

4 As shown in the new Hydrogen Council report (2022), co-authored by McKinsey & Company (link)

— **Promote technological leadership:** By fostering H_2 imports, the EU accelerates the innovation and development of H_2 technologies, which give the EU a competitive advantage in the global technology race against other regions (e.g. China).

— **Increased international cooperation:** International partnerships and H_2 trade with third countries bring economic cooperation and local added value, allowing for higher common prosperity and geopolitical stability.

— **Welfare for exporting countries:** Exporting countries could develop their own economy along a more sustainable path, attracting investments, employment and prosperity to these countries.

— **Lower H_2 system costs:** Imports provide an additional source of hydrogen, which can help to partially back up the fluctuating local production of renewable hydrogen production (especially in the first decade as the portfolio effect will be limited) to meet constant demand (e.g. from industry). As a result, imports contribute to reducing the costs of balancing the overall hydrogen grids, benefiting all hydrogen users and producers. Ambitious expansion of the H_2 infrastructure reduces also EU's overall energy system cost, considering both feedstock and energy supply and related infrastructures.

— **Achievement of RED III objectives:** imports of renewable hydrogen, or its derivatives will provide additional volumes to meet the RED III objectives on renewable hydrogen utilisation in the industrial and transport sectors.

The maximisation of the benefits associated with future H_2 imports into the EU requires addressing and dealing with several challenges of imports:

— **Ensuring a fair complementary role between EU's domestic H_2 production and H_2 imports:** H_2 produced domestically in the EU, at competitive costs, will be complemented with H_2 imports from third countries, ultimately making H_2 supplies more accessible and affordable across the EU economy. Still, there will be uncertainty on how global H_2 supply and demand and the international hydrogen price will develop. The future EU framework for imports should ensure a fair complementary role to domestic production, maximising the benefits for the EU.

Moreover, it should be kept in mind that EU Member States can import H_2 volumes not only from 3rd countries but also from other parts of the EU, either by pipe or by ship. Enabling the development of **intra-EU H_2 supplies** from EU regions with abundant renewable energy produced according to EU rules provides higher security of supply and energy independence whilst bringing techno-economic benefits to the exporting regions. In this sense, the EU should also support the development of intra-EU renewable H_2 sources of supply, as well as the necessary hydrogen intra-EU import infrastructure (H_2 terminals and pipelines).

— **Need for assessing Infrastructure:** the importation of significant amounts of H_2 requires import infrastructure to be in place (H_2 terminals, import pipelines, etc.). The evaluation of infrastructure needs, at national and trans-European levels, would be followed by constructing suitable H_2 trade infrastructure (H_2 terminals, import pipelines, etc.) while taking advantage of the complementary option to repurpose existing infrastructure. The need for and the level of import infrastructure will need to be carefully assessed to minimise costs, avoid stranded assets and maximise benefits.

— **Need for Financing and Funding:** Significant financing and funding would be needed to deploy the required production, transportation and import H_2 projects. Simplified procedures to apply and receive funds would shorten the timeline and ramp up import capacity faster.

— **Need for Certification:** To enable H_2 (intra EU and international) import, there is a need for European harmonised and internationally accepted certification rules for renewable and low-carbon hydrogen. A robust science-based standard should require full lifecycle accounting, including all climate warming emissions over multiple time horizons, as well as robust accounting standards for electricity. In the interim period, and in the absence of these certification standards, the imports should be in line with EU domestic regulations. The EU is on the way to set clear and harmonised rules, standards and certification schemes to recognise renewable hydrogen. The recent relevant delegated acts[5] put forward by the European Commission refer to renewable H_2 produced from additional renewable energy. The EU would need to establish adequate and coherent certification schemes for H_2 renewable imports from 3rd Countries, as well as implement other relevant regulations affecting H_2 imports, such as the low carbon Gas Package and CBAM (Carbon Border Adjustment Mechanism).

5 – Commission Delegated Regulation (EU) 2023/1184 of 23 May 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council with regard to the definition of renewable fuels of non-biological origin (RFNBOs) and the methodology for calculating the greenhouse gas emissions savings from RFNBOs (link)
– Commission Delegated Regulation (EU) 2023/1185 of 23 May 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council with regard to the minimum threshold for greenhouse gas emissions savings of recycled carbon fuels (link)

— **Attention to** Environmental Aspects such as **H_2 Emissions:** Whilst section 3.4 develops further the environmental aspects linked to H_2 imports, attention must be paid to address and minimise emissions throughout the value chain. This is particularly relevant as we develop hydrogen import routes and the necessary infrastructure. Life-cycle assessments (LCAs) should include the climate impacts of hydrogen emissions for hydrogen and ammonia technologies. At this point, there are still many uncertainties which make it difficult to have empirically verified values, preventing the accurate quantification of the real environmental impact linked to hydrogen emissions. Empirical data collection should be encouraged for existing and upcoming infrastructure, as well as the development of needed instrumentation and methodological research. It is critical to start filling the data gap in order to ensure the accurate quantification of the real environmental impact linked to hydrogen emissions. In the meantime, the potential impact of H_2 emissions should not be ignored even though the accurate values are unknown. The use of a range of emission rates or median rates based on current scientific literature, together with other best practices such as the use of both a near- and long-term time horizon (such as 20- and 100-years) in the analysis, would be a first essential step in the right direction.

— **Mitigate Impact on Origin countries:** producing renewable H_2 for the EU market should not hinder or delay the domestic decarbonisation efforts in 3rd countries by displacing renewable energy. In addition, any potential adverse environmental impacts, including on water quality and quantity, should be mitigated.

— **Allow H_2 Blending as a fallback option in appropriate cases:** Importing hydrogen blended into an existing gas pipeline[6] could be a transitional option. The challenges of hydrogen blending vary on a case-by-case basis and depend on the percentage of hydrogen intended to be in the gas pipeline. Different aspects must be carefully assessed for each project, such as material/equipment compatibility, climate and environmental benefits, leakage and releases of the mixed gas, as well as technical interoperability of cross-border flows. H_2 blending will be subject to national rules and the rules to be set up by the upcoming Hydrogen and Decarbonised Gas Market Package.

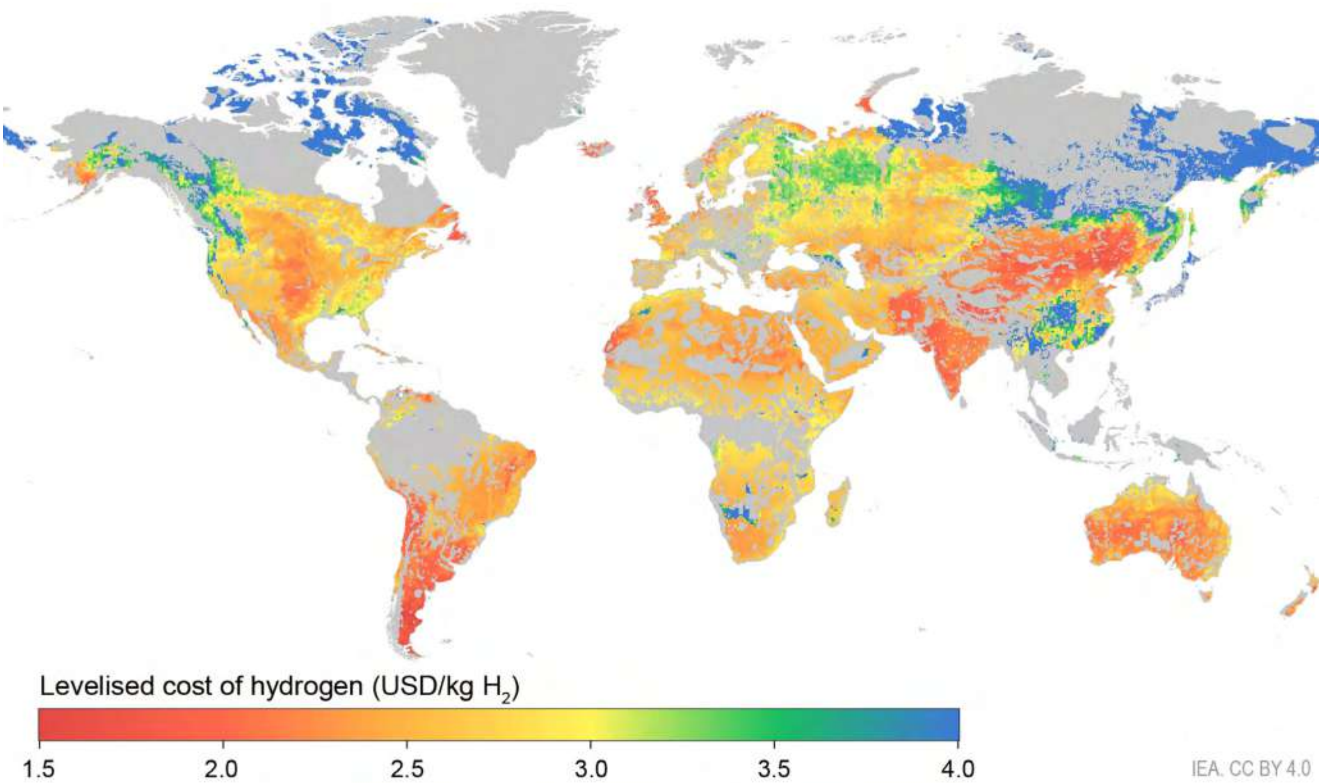


Figure 3: Hydrogen production costs and share of solar PV from hybrid PV and onshore wind systems, 2030.
Source: IEA, "Global Hydrogen Review 2023", 2023

6 For an example, please see one potential planned project in the Southern Gas Corridor in table 6 of this Learnbook

3.3 H_2 IMPORT OPTIONS

At this point in time, there is no "silver-bullet" technological means of transportation to import H_2 into the EU. **The best option for importing hydrogen can vary on a case-by-case basis.** It will depend on a number of factors, among them the cost of the different options, the capacity of existing infrastructure, the distance the hydrogen needs to be transported, purity required, end-use, approach to energy security, etc.).

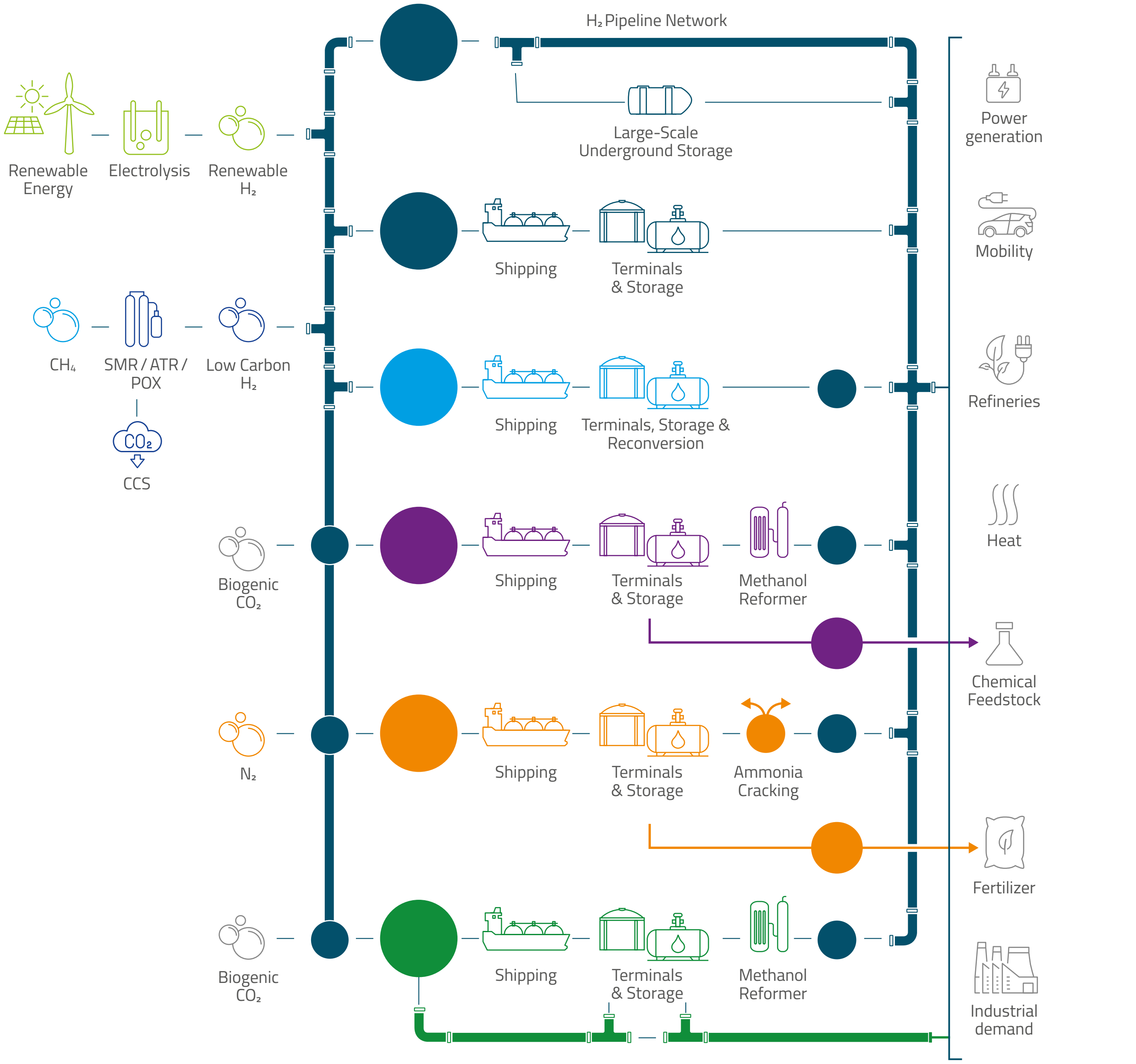


Figure 4: Possible gaseous H_2 Export/Import Pathways. Source: Gas for Climate Hydrogen derivatives such as methanol and ammonia will also be used as feedstock or fuels, targeting other economic markets different from the gaseous hydrogen, which will predominantly be injected into the regulated hydrogen grid. Please note that Figure 4 presents a non-exhaustive list of hydrogen carriers and that others are being developed. For instance, the non-organic liquid H2 carriers (NOLHC) with similar handling as LOHC but with different hydrogenation/dehydrogenation process.

THERE ARE TWO MAJOR WAYS TO IMPORT H_2 INTO THE EU MARKET:

- **Pipelines:** H_2 and/or H_2 carriers can be transported through pipelines. In the case of compressed gaseous H_2, **this option does not differ significantly from transporting natural gas by pipeline**. H_2 pipelines are an import option that is already being used in some countries. The i**mport pipelines can either be newly built, or existing gas pipelines can be repurposed into H_2 pipelines**. The cost of building and operating import H_2 pipelines makes it **a preferred option for short-medium distances**. The import capacity of pipelines may not be sufficient to meet the EU's future demand for H_2.

- **Shipping: H_2 and/or liquid H_2 carriers can also be transported by ship.** Maritime routes are the **preferred import option when transporting them over long distances** and they provide upstream flexibility since they are not necessarily bound to one origin. The liquid H_2 or liquid H_2 carriers arriving by ship to Europe will be unloaded into hydrogen import terminals. Different H_2 carriers (e.g. NH_3, LH_2) will require different import terminal infrastructure. These terminals can be (new) dedicated terminals or (a part of) existing terminals (e.g. LNG terminals) which have been repurposed into H_2/H_2 carrier-specific import terminals.

The case of compressed H_2 being transported by ship is also possible, with existing projects already looking to this technology option for short maritime distances.

Import terminals – for methane (LNG), ammonia and methanol to be used as fuel or feedstock – have already been available in many EU ports for decades. Today, a number of import terminals for H_2 and H_2 carriers (which will make gaseous hydrogen available for the EU H_2 market) are currently in planning or under construction. Figure 4 lists possible H_2 pathways to import/export gaseous H_2. Hydrogen derivatives such as methanol and ammonia can be used as feedstock or fuels, targeting other economic markets different from the gaseous hydrogen, which will predominantly be injected into the regulated hydrogen grid.

Besides the two H_2 transportation channels described above, H_2 and H_2 carriers can also be transported by land transportation, such as trucks, trains or barges (rivers). These are the least developed options for H_2 imports, but they are becoming more feasible as the cost of hydrogen production decreases.

3.4 ENVIRONMENTAL ASPECTS LINKED TO H_2 IMPORTS

The **ultimate goal** of renewable H_2 production and deployment **is to help reach climate neutrality**. This can be achieved by progressively switching to renewable H_2 in those sectors where currently its fossil fuel-based forms are being used and expanding its deployment scope to other hard-to-abate sectors. These include such sectors as steel production and maritime transport, which can make an important contribution to this overarching objective.

In this sense, these environmental aspects linked to H_2 imports have a significant impact.

- **Production method:** H_2 produced from electrolysis supplied by renewable energy sources, such as solar and wind power, is considered to be a sustainable source of energy and does not entail emissions of direct GHGs. However, it can still indirectly warm the climate in case of leaks (see below). According to EU rules, the renewable energy used to produce H_2 has to be additional to what is used to decarbonise the electricity grid directly.

  In the case of fossil-based H_2, produced directly from fossil fuels such as natural gas, the resulting GHG emissions can be, to a certain extent, abated with CCUS-related technologies, but not completely reduced since there will always be a percentage of harmful emissions (e.g. upstream methane leakage, uncaptured/leaked CO_2, various air pollutants such as NOx, particular matter, and VOCs)

- **Mode of transportation:** The mode of transportation used to import H_2 consumes energy, and consequently, it has an environmental impact. This impact can be mitigated over time using ships fuelled with clean ammonia or hydrogen. Transporting H_2 or its derivatives and carriers by ship is more energy-intensive than transporting H_2 by pipeline. The pipeline systems also need inline compression that may not be powered by clean energy sources. Unless the transportation mode is powered by clean energy, more energy used to transport H_2 means more emissions.

— **End-use application:** Hydrogen (including H_2 imports) shall target end-use applications where other decarbonisation options (e.g. electrification) are not more energy-efficient, climate-beneficial, and economical.[7] In contrast to fuel cell applications, it shall be noted that hydrogen combustion is not completely pollutant-free as it forms NOx emissions when released into the air, which shall be minimised.

— **H_2 leaks/emissions:** H_2 is an indirect greenhouse gas. This means it warms the climate by increasing amounts of short-lived greenhouse gases, namely methane, tropospheric ozone, and stratospheric water vapour, through chemical atmospheric reactions. H_2 can be leaked from infrastructure and equipment because of its small molecular size. It might also be vented and purged in routine operations. Recent studies[8] suggest that high hydrogen emissions can severely undermine hydrogen's intended climate benefit, especially in the short term, if not properly addressed. Therefore, more research is required to address and minimise emissions throughout the value chain.

Concerning processes, infrastructure operators have long-standing experience handling gas and there is a clear safety framework.

— **Water consumption:** The production of H_2 requires a significant amount of water. For example, hydrogen production from water electrolysis or steam methane reforming (SMR) can use about 10 litres of water per kilogram of H_2 produced. The gross water demand between these two methods is similar[9], but electrolysis requires water at a much higher purity. It is also important to consider the geographical location of where such water demand is created. For example, a country/region with abundant wind and solar may be short of fresh water, in which case desalinisation of seawater or other alternative technologies (e.g. purification of wastewater) might be necessary to avoid further strain on local water resources.

— **Minerals and raw materials:** Similar to other renewable energy technologies, some hydrogen infrastructure/equipment, such as electrolysers and fuel cells, require the use of minerals/raw materials – these materials should be extracted in a clean or equitable way. Therefore, it is important to have the proper ESG standards in place.

7 Several members of the Roundtable express the opinion that no applications of hydrogen shall be ruled out and a technology-neutral level playing field shall be created. Regulations shall allow market players to find the best fitting overall solution.

8 – Ocko and Hamburg, "Climate Consequences of Hydrogen Emissions", 2022, (link)
– Hauglustaine et al., "Climate Benefit of a Future Hydrogen Economy", 2022, (link)

9 – Hydrogen Council, "Hydrogen Decarbonisation Pathway: A Life -Cycle Assessment" (exhibit 2), (2021), (link)
– Ramirez et al., "Distilling Green Hydrogen's Water Consumption", (2023), (link)
– Saulnie et al., "Water for the Hydrogen Economy", (2020), (link)

4 MARITIME ROUTES

4.1 SHIPPING H_2 AND H_2 CARRIERS

International trade in hydrogen is today at a very nascent stage, not least when compared to the need for hydrogen trade in the IEA's Net Zero Emissions by 2050 Scenario (NZE Scenario). In this more than 20% of merchant demand for H_2 and hydrogen-based fuels is met through international trade by 2030.

Trade of H_2 by ship is limited today to a few pilot projects. However, there are exceptions for H_2 carriers such as ammonia and methanol, which are globally traded as feedstocks for the chemical industry. In the case of ammonia, it is currently transported as feedstock in gas (LPG) carriers. However, the use of ammonia as H_2 carrier involves higher volumes which brings new safety and sustainability challenges to be properly managed.

Around 10 % of global ammonia demand was met through international trade by 2021, and for methanol, the international trade share was 20 %. Thus, existing trade for ammonia and methanol is linked to use in the chemical industry as feedstock but not as a fuel or H_2 carrier. According to IRENA[10], it corresponds to 18-20 million tonnes annually and roughly corresponds to 40 Liquid Petroleum Gas (LPG) carriers used to transport ammonia, a small share of the global LPG fleet.

For long distances, transporting H_2 or H_2 carriers[11] by tanker can be more cost-effective than alternative pipeline transport options. **In addition to the ships, this solution would require dedicated infrastructure at ports**, including access to deep-water infrastructure and facilities to convert H_2 into H_2 carriers, in some cases at the exporting port, and, in some instances, facilities for reconversion back to H_2 at the importing port.

4.2 ROLE OF H_2 TERMINALS AND PORTS

Hydrogen terminals and ports will be critical in importing H_2 and H_2 carriers to the EU via maritime routes. Hydrogen terminals will usually be located in ports. These terminals will be equipped with the necessary infrastructure to receive, store and transform liquid H_2 or H_2 carriers into gaseous H_2 for injection into the H_2 grid (or into the gas grid, blending it with gas). They will typically be large, specialised facilities capable of handling significant volumes. From the H_2 terminals, H_2 or H_2 carriers can be distributed locally to third parties locally via other channels such as trains, trucks, barges, etc.

Ports are expected to play a key role in facilitating the hydrogen supply to the wider port community or even the hinterland in their role as energy hub.

With European ports being natural gateways for H_2 and H_2 carrier flows, accelerated investment in hydrogen-related infrastructure in port areas is needed to provide renewable and low-carbon H_2 to the EU H_2 market. Driven by the unfolding of the "Fit for 55" Package and the REPowerEU plan, and if supported by further demand stimulation incentives at national and European level, the expected accelerated emergence of a European green H_2 market will result in fundamental economic changes and infrastructure developments over the next decade and beyond, with a significant impact on maritime and inland port areas.

Approximately 150 terminals and ports can handle ammonia around the globe. Although the expected transformations will be port-specific, **a thorough understanding of the implications**, requirements, and opportunities of the accelerated emergence of a H_2 market **for port areas will enhance a successful transition**, beneficial to all port-related stakeholders.

Although the existing ammonia infrastructure could already be used for hydrogen-based fuel trade, the current global ammonia trade is around 20 Mt[12] , equivalent to around 3.5 Mt H_2. This is well below the announced 12 Mt H_2 by 2030 for ammonia-based projects (Figure 7). Meeting this demand would require tripling the existing ammonia trade infrastructure within this decade. While some capacity could be integrated into existing plants, potentially

10 IRENA, "Innovation Outlook – Renewable Ammonia", (2022), (link)

11 The international trade of large amounts of liquid hydrogen is still technologically challenging and economically costly.

12 IRENA, "Innovation Outlook – Renewable Ammonia", (2022), (link)

replacing fossil-based ammonia trading or increasing annual plant utilisation with the required adjustments, **realising the full potential of announced trade projects would require significant infrastructure expansion**.

Other H_2 carriers, like LOHCs, could use the existing non-cryogenic liquid fuel infrastructure at ports and thus, transform assets without leaving stranded investments. Synthetic methane could be shipped to LNG terminals.

REPURPOSING OF LNG TERMINALS

Worldwide, and according to GIIGNL[13], there are more than 100 natural gas liquefaction plants in more than 40 ports and more than 160 natural gas regasification plants in nearly 150 ports. **The possibility of repurposing**, totally or partially, LNG terminals into H_2 terminals (e.g. ammonia terminals) **is an option to be considered. They could be utilised for H_2 and H_2 carrier imports.** The cost of converting an LNG import terminal to meet new requirements (e.g. ammonia) includes engineering, equipment, materials, and civil works to dismantle and remove items and install new materials and equipment. It is commonly **assumed that repurposing an existing LNG terminal into an ammonia terminal would have a lower cost than building a new ammonia terminal**.

A recent assessment[14] shows that converting an existing LNG import terminal to an ammonia-ready terminal is feasible but the **cost and investment profiles will depend on a number of factors** such as the individual characteristics of each terminal, its location, the final use, etc. Other sources[15] have estimated that investments in repurposing an LNG terminal to become "ammonia ready" are roughly 20% of the LNG Terminal's CAPEX.

In July 2023, the European Union approved EUR 40 million support for a land-based LNG terminal in Brunsbüttel (Germany), to replace the current floating one, on the condition that the terminal be converted to import renewable energy carriers by 2043 at the latest.

Moreover, constructing new hydrogen-ready LNG terminals is also another aspect to be considered.

THE ROLE OF PORTS

The port areas can act as direct users, provider of infrastructure and transit platforms for H_2 and H_2 carriers:

- **Direct Users:** Like other commercial players, climate and energy policies will incentivise key port stakeholders (i.e., port authorities, terminal operators, etc.) to set decarbonisation targets and implement decarbonisation solutions for the assets and operations under their responsibility. In particular, **H_2/H_2 carrier fuels could play a role in shifting away from the use of fossil fuels in the following activities:** Maritime and inland shipping, onshore power supply (e.g. cold ironing, provided by H_2 and fuel cells), cargo handling and terminal equipment, industrial activities located in port areas (e.g., refineries, ammonia plants, other chemicals, etc.) and refuelling of heavy-duty trucks (for loading/unloading activities) in port areas.
- **Provider of Infrastructure:** The unfolding of the H_2 economy will **require the construction of specific infrastructure** to transmit, store, convert and supply end-users, which is expected to have a fundamental impact on spatial planning and services within many European ports. In particular, **ports may offer a suitable location for developing the following H_2 and H_2 carrier infrastructure**: New sea or land-based bunkering, import terminals, landing of offshore produced power, green hydrogen production, tank storage, conversion infrastructure, and multimodal H_2 refuelling stations. The ports could also repurpose existing infrastructure in some cases instead of building new H_2 and H_2 carrier infrastructure.
- **Transit Platform:** European ports, primarily those located along the TEN-T and/or TEN-E core and comprehensive networks, **can be instrumental in the transportation and supply of H_2 and H_2 carriers**. In particular, since ports are often connected to nearby industrial clusters, residential areas, and energy logistics nodes, **they could serve as a natural transit hub for transporting H_2 and H_2 carriers to multiple end-users along the coastal area and into the hinterland**. Ports can provide a suitable location for transporting H_2 and H_2 carriers by pipeline, truck trailers, trains and inland ships (barges).

13 GIIGNL, "The LNG Industry – Annual Report 2023", (2023), (link)

14 Fraunhofer ISI, "Conversion of LNG Terminals for Liquid Hydrogen", (2022), (link)

15 Gas for Climate, "Facilitating hydrogen imports from non-EU countries", (2022), (link)
Black and Veatch "Converting LNG Import Terminals to Ammonia Import Terminals", (2020), (link)

4.3 H_2 CARRIERS

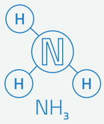
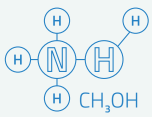
Gaseous H_2 is typically compressed and transported through pipelines. H_2 can be liquified or transported into H_2 carriers such as LOHCs, ammonia, methanol, or synthetic methane and shipped to import destinations.

H_2 can be inserted and/or extracted from its carriers, resulting in efficiency losses and cost increases. After the transformation process, and once H_2 is in gaseous form, it can be injected into the European H_2 network to be transported towards its demand locations. H_2 carriers can also be directly utilised, e.g., ammonia as a fertiliser, methanol as a chemical feedstock, or methane covering a wide range of applications in industrial and transportation sectors.

There are different H_2 carriers which can be used to import hydrogen. They present different advantages and disadvantages.

The choice of hydrogen carrier will depend on several factors, including the carrier's cost, the distance the hydrogen needs to be transported, and the safety requirements.

The table 1 below presents some of the advantages and challenges of the different H_2 carriers:

Hydrogen Carrier	Advantages	Challenges
Ammonia  Liquid ammonia is stored at ambient temperature under high pressure or at –34 °C under atmospheric pressure. NH_3 is currently the second most highly produced chemical globally, with a global manufacturing capacity of ~230 Mt annually. Around 20 Mt per year of ammonia are traded globally. The main utilisation today is to produce fertilisers. Ammonia is produced through SMR (grey ammonia) and is responsible for ~5 % of global emissions.	▪ H_2 carrier with the highest number of export-oriented projects globally announced. ▪ It has an excellent H_2 density (18.6 MJ/kg). ▪ Easy to transport around the world in large quantities as it happens today. ▪ Attractive supply chain costs via the use of world-scale carriers. ▪ There are already existing infrastructure and many concrete plans to expand their capacity. ▪ Can be used not only as H_2 carrier but also as a feedstock to decarbonise fertilisers and chemicals. ▪ This carrier offers competitive costs if reconversion to gaseous H_2 is not needed. ▪ It is carbon-free.	▪ Toxic and flammable. ▪ Requires special handling and safety precautions, but the industry has wide experience in handling it safely. ▪ To be used as H_2 carrier, ammonia needs to be cracked back into H_2. This technology exists, but the number of commercial large-scale crackers is not numerous. IEA classifies NH_3 cracking with TRL 4. ▪ It produces NO_x emissions when combusting NH_3 (e.g. transport and power applications).
Methanol  As a liquid at room temperature, methanol is easy to store and transport. The transformation back to H_2 encompasses CO_2 emissions	▪ Energy density slightly higher than ammonia (20.1 MJ/kg). ▪ Safer than hydrogen. ▪ Already being shipped today in large quantities and long distances. ▪ Transported at ambient conditions. ▪ It is widely available, commercially available fuel, and easy to obtain. ▪ Not only can be used as H_2 carrier but also as a feedstock for chemicals, and soon as a new green fuel in shipping.	▪ It is toxic, flammable and corrosive, but the industry has wide experience in handling it safely. ▪ It contains carbon and, to be climate neutral, the CO_2 source for producing methanol should preferably be biogenic, direct air capture, or industrial process. ▪ It requires large quantities of affordable CO_2 upstream, and it competes with bio-based feedstock for end products (e.g. olefins).

>>>

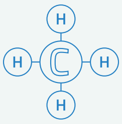
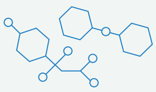
Hydrogen Carrier	Advantages	Challenges
Methane  CH_4 CH_4 can be produced by combining captured CO_2 with H_2 using the well-established Sabatier methanation process. It would be then transformed back to H_2 or, in some cases, used as methane with carbon capture	▪ Makes up a large part of our energy supply worldwide today. ▪ Compatible with existing infrastructure (ships, terminals, pipelines, etc.). ▪ Different origins: e-methane, biomethane, fossil methane. ▪ H_2 gas is obtained from methane via different ways: SMR, ATR, and Pyrolysis.	▪ The CO_2, or black carbon in the case of pyrolysis, released in the process has to be handled adequately (e.g. captured for storage, closed system with a return loop, etc.).
LOHC  $C_{14}H_{26}/C_{14}H_{14}$ Liquid Organic Hydrogen Carriers (LOHCs) are organic compounds that can absorb and release H_2 through chemical reactions. According to IEA, LOHC has a TRL classification of 6–7.	▪ By chemically bonding H_2 to a stable organic liquid carrier, this eliminates the need for compression and makes it safer and more cost-efficient to transport at ambient conditions. ▪ Existing oil infrastructure (ships, terminals, pipelines, etc.) can easily transport LOHC. ▪ Allows for an easy hinterland transport of H_2 (beyond the receiving terminal). ▪ Different options available. ▪ The energy need for reconversion can be significantly reduced with free or cheap heat supply (integration with industrials at import terminals).	▪ Some LOHC carriers can be toxic and/or health-hazardous. ▪ Innovation and tests needed to continue improving efficiency. ▪ The preparation phase (hydrogenation) and reconversion phase (de-hydrogenation) are commercially available only at the pilot scale. Industry scale planned for 2025. ▪ Low hydrogen content by mass (but it allows handling big volumes and weights).
Liquid Hydrogen (LH_2)  LH_2 LH_2 is stored at cryogenic temperatures (−253 °C) and commonly stored in a pressurised environment with low pressure (1–6 bar).	▪ Highest energy density by mass (142 MJ/kg) . ▪ H_2 is transported in high-purity form (lowest H_2 impurity). ▪ There is no need for conversion/reconversion in other chemicals. ▪ Energy consumption for transformation into gaseous H_2 is low. The cryogenic power of the gasification process could be (partially) recovered.	▪ Costly and energy-intensive process. High-energy preparation phase (liquefaction). ▪ Given LH_2's temperature of −253 °C, its overseas transportation presents a major technology challenge. Transport is viable for LH_2 vessels but is still in the pre-commercial phase, with limited capacity. ▪ The transport of large quantities of liquid H_2 overseas needs more effort on R&D in the short and medium term. ▪ Ships for transporting LH_2 are not yet commercially available. ▪ Highly flammable, but this is more a disadvantage of the carrier rather than a barrier for the development of the technology. ▪ LH_2 is subjected to boil-off loss. If the ship doesn't use hydrogen to propel its engine, then the boil-off will have to be vented into the atmosphere, generating hydrogen emissions.
Compressed H_2  Compressed H_2 can be transported in gas cylinders or gas tubes with pressures between 200 and 500 bar. It is suited for short-distance transportation in the absence of pipeline infrastructure	▪ The absence of any conversion step in its packing and unpacking processes could favour it enough to overcome the disadvantages in case of short-distance.	▪ It has the lowest H_2 density among the carriers listed, penalising the long-distance shipping and storage steps. ▪ Highly flammable, but this is more a disadvantage of the carrier rather than a barrier to the development of the technology.

Table 1: Advantages and challenges for commonly known H_2 carriers. Source: own elaboration, based on RT members input and other sources

Table 1 shows a **non-exhaustive list of H_2 carriers**. ere are also other H_2 carriers such as non-organic liquid H_2 carriers (NOLHC) with similar handling as LOHC but with different hydrogenation/dehydrogenation process. While this Learnbook acknowledges their existence, the level of knowledge on this technology (and potential related projects) is still limited for the Learnbook's authors at the moment of writing this chapter. In the case of metal hydrides, which are solids and can absorb hydrogen, they are more energy-efficient to transport than LH_2, but they have a lower energy density by mass.

The development of new hydrogen carriers is ongoing, and they may be developed further to offer even better performance than the carriers currently available.

4.4 MARITIME ROUTES (NON-EU IMPORT, INTRA-EU SHIPPING)

The choice of maritime route will depend on a number of factors, including the cost of the route, the distance the H_2 needs to be transported, and the availability of H_2 production facilities.

It is important to note that **the development of maritime routes for hydrogen imports is still in its early stages**. There are a number of challenges that need to be addressed, such as the cost of infrastructure and the safety of transporting hydrogen. However, the **potential benefits of importing hydrogen by sea are significant**, and it is **likely that maritime routes will play an important role in the future of the EU hydrogen market**.

Some of the maritime routes that could be used to import hydrogen into the EU market could be (non-exhaustive list): North-America, Latin-America, Middle-East, North Africa or South-Western-Africa. Table 2 on page 20 shows a list of countries which have announced H_2 exports projects.

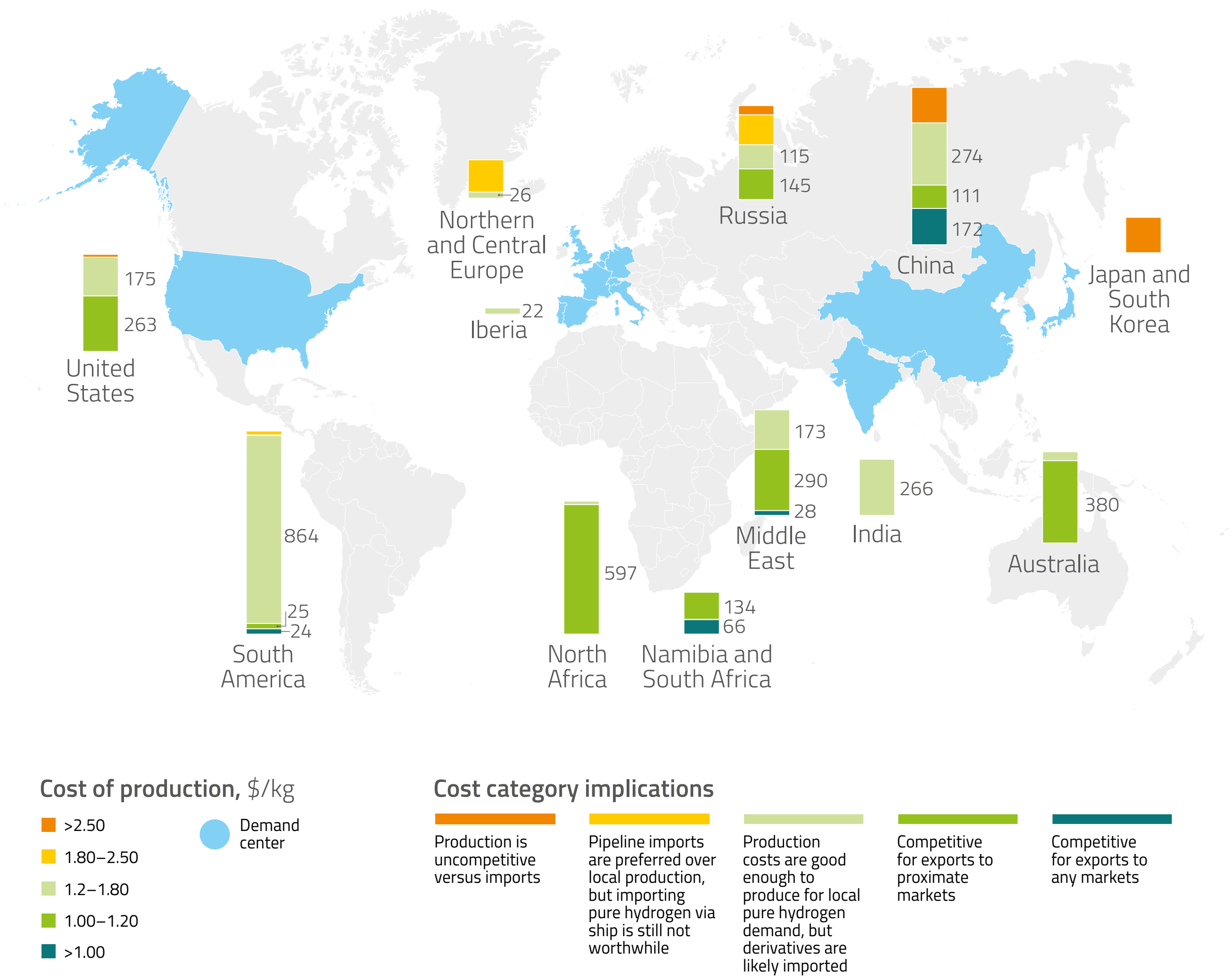


Figure 5: Hydrogen production potential, 2050, millions of tons per annum. Source: Hydrogen Council, "Global Hydrogen Flows" (Oct 2022)

EU DOMESTIC PRODUCTION VERSUS IMPORTS – THE CASE OF NORTH-WEST EUROPE

The cost of transporting hydrogen from the exporting to the importing region can be substantial, so assessing the total supply cost – for the full value chain – is essential. Depending on the carrier and the transport distance, transport costs can shift the competitiveness in favour of domestic production. For example, at USD 2.1/kg H_2, levelised production costs in Latin America are cheaper than domestic production from offshore wind in north-west Europe. However, adding the maritime transport costs of H_2 (including the transformation of H_2 into a H_2 carrier at the exporting country and its transformation back into hydrogen in north-west Europe), it makes domestic EU production a cheaper option, although constraints on renewable resources or alternative uses for renewable electricity could limit domestic production.

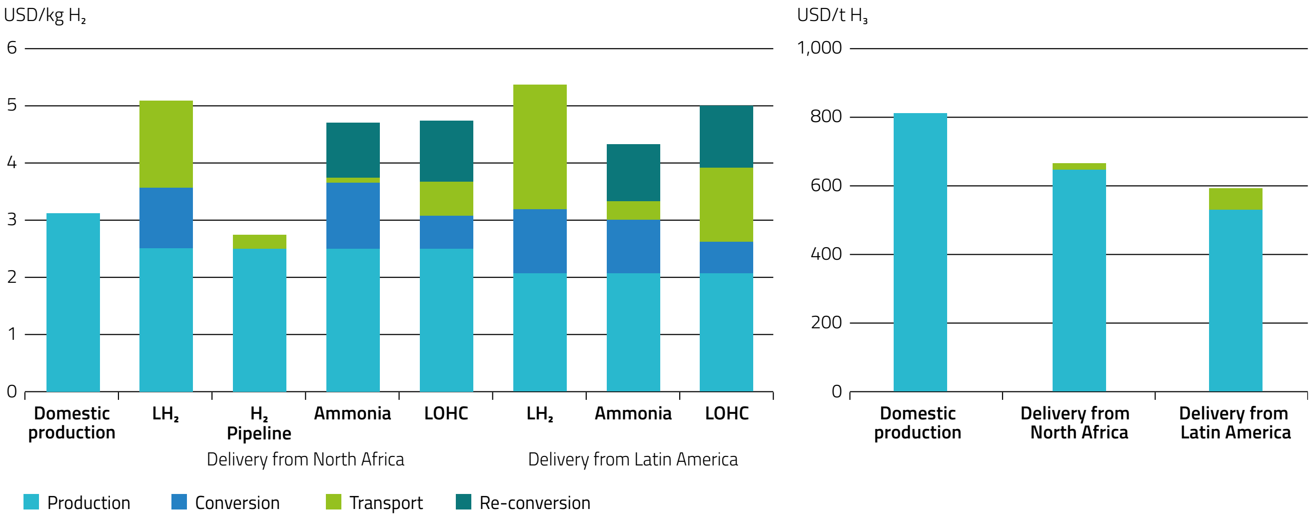


Figure 6: Supply costs for hydrogen and ammonia in North-West Europe compared to imports. Source: IEA, "Global Hydrogen Review 2023", 2023

POTENTIAL HYDROGEN SUPPLIERS

Several non-EU countries around the world have announced a hydrogen strategy so far. An analysis of the status of announced/anticipated strategies of potential EU hydrogen suppliers by 2030 are listed in table 2.

Country	Announced Export H_2 volumes/capacities	Clear Expression for Export	Country	Announced Export H_2 volumes/capacities	Clear Expression for Export
Algeria	1 Mt*	Yes	Oman	1 Mt	Yes
Australia	**	Yes	Saudi Arabia	2.9 Mt	Yes
Argentina		Yes	South Africa	5 GW	–
Canada	**	Yes	Turkey	**	–
Chile	5 GW	Yes	Ukraine	**	–
Egypt	**	–	UAE	**	Yes
Morocco	**	Yes	UK	10 GW	–
Namibia	**	Yes	USA	10 Mt	Yes
Norway	**	Yes			

*Hydrogeninsight, (2023), (link) ** Non-quantified target

Table 2: Analysis on the status of announced/anticipated strategies of potential EU hydrogen suppliers by 2030. Source: OEIS and own assessment.

While there are seventeen potential supplier countries for renewable hydrogen, only twelve of them have indicated clear export intentions by 2030, which makes them prominent candidates for likely H_2 supplies to the EU (see Table 2 for more details). However, it is worth noting that this analysis does not consider existing competencies related to pipelines or ammonia, which may influence the actual supply sources of H_2 to the EU.

INTRA-EUROPEAN SHIPPING ROUTES – POTENTIAL SUPPLIERS

Apart from the international shipping routes connecting third countries with the EU, the potential intra-European trade flows via maritime routes should not be forgotten since there is also potential export production within the European region. More concretely, by 2030 and beyond, we could see the emergence of intra-European H_2 flows by ship from different countries such as:

- **Iberia:** The Iberian Peninsula has a large solar and wind power capacity, and it could export renewable H_2 to other EU countries by pipeline and ship.
- **Norway:** Norway could become a large exporter of H_2 to other EU countries by pipeline and ship.
- **Iceland:** Iceland is another potential exporter of hydrogen to the EU. Iceland has significant geothermal resources, which could be used to produce hydrogen.

4.5 MAIN PROJECTS – MARITIME ROUTES

The shipment of hydrogen in the form of liquefied hydrogen and LOHC has been demonstrated in the first projects, while experience in shipping ammonia exists in the fertiliser industry for decades. In 2020, the first international trade of 102 t H_2 occurred from Brunei to Japan, using methylcyclohexane as a LOHC. For liquefied hydrogen, the first cargo of 75 t H_2 was delivered in 2022 from Australia to Japan as part of the Hydrogen Energy Supply Chain (HESC) project, with plans to scale up the trade volumes to 225 kt per year in the 2030s. Kawasaki Heavy Industry is preparing a feasibility study for another project that plans to ship 36.5 kt H_2 per year from the port of Townsville, Australia, to Japan.

In 2020, for the first time, ammonia was shipped from Saudi Arabia to Japan for use as a fuel. More ammonia shipments[16] from Saudi Arabia and the United Arab Emirates occurred in 2022 and 2023 or are planned for later this year, targeting multiple destinations such as Japan, China, Korea, Bulgaria, India, Germany, etc.

There are already several publicly announced projects aiming at hydrogen exports located in different parts of the world. Some of these projects are located in Europe, allowing for intra-European hydrogen flows.

IEA estimates that, based on announced export-oriented projects, **16 Mt of hydrogen equivalent (Mt H_2-eq) could be exported worldwide by 2030**, and this number could rise to **25 Mt H_2-eq by 2040**. Export-oriented projects represent more than 40 % of the low-emission hydrogen production of 38 Mt from all announced projects in 2030, indicating that the potential export market is a strong driver in the development of projects.

Despite this large amount of announced export/trade projects, progress in pre-existing projects has been slow. According to the IEA Global Hydrogen Review 2023, only five H_2 projects are at advanced stages of development, i.e. having at least reached a final investment decision (FID):

1. NEOM project in Saudi Arabia
2. Green Hydrogen and Chemicals SPC project in Oman
3. CF Industries' plant in Donaldsonville in the United States.
4. Canada Net-zero Hydrogen Energy Complex
5. OCI Bluean Ammonia Site in Texas, USA

The three first projects aim to use ammonia as the carrier for a combined export volume of less than 0.3 Mt H_2-eq by 2030. Three-quarters of the export-oriented projects planned for 2030 or sooner are still at the early stages of development and only less than one-quarter is undergoing a feasibility study.

Moreover, less than one-third of the volume that could be traded by 2030 has already identified a potential off-taker – although only a few have reached FID (final investment decision) or signed a binding off-take agreement. This is the case of the NEOM Green Hydrogen Project in Saudi Arabia: a 30-year off-take agreement has been secured with Air Products for the low-emissions ammonia produced from 2026 onwards[17]. The realisation of the announced trade projects will depend not only on the deployment of the production facility and the necessary infrastructure but also on securing one or more off-takers for the long run. These two aspects should be pursued in parallel to ensure that projects are realised on time and are economically sustainable.

16 Please see the International Energy Agency's Global Hydrogen Review 2023 (link), page 100, for more details.

17 See corresponding press release with NEOM information (link).

According to the latest information, the majority of announced projects – accounting for 80 % of potential production – prioritise ammonia for the transport of hydrogen, in many cases aiming for a final use that does not require reconversion back to H_2. This includes use as feedstock in the fertiliser industry or as a fuel for co-firing in power generation (e. g. Japan). Reconversion back to hydrogen requires energy and adds significant cost, potentially altering the economic competitiveness of the supply chain. Moreover, many projects are at an early stage of development, and for several of them, the carrier has not yet been chosen.

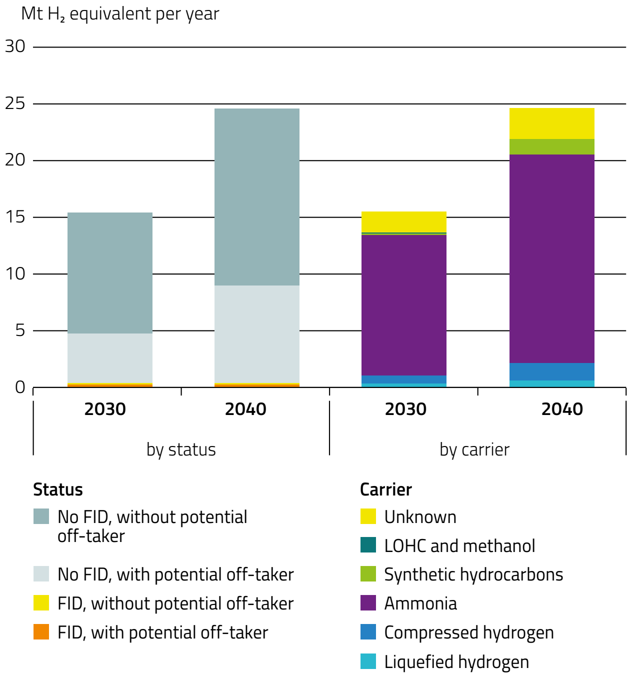


Figure 7: Hydrogen trade by status and by carrier based on announced projects, 2030-2040. Source: IEA, "Global Hydrogen Review 2023", 2023

Country	Location	H_2 carrier	Production Capacity	Start-up Date
Australia	various locations	NH_3	39 Mt/y NH_3 + 3.3 GW wind + 4.25 GW solar	2024–2038
		CH_2	0.776 Mt/y	> 2026
		LH_2	0.53 Mt/y	2026–2028
		MeOH	0.2 Mt/y	2027
		LOHC	–	–
		Undefined	–	–
Brazil	Port of Açu	NH_3	10 MW	2025
Canada	Nujio'qonik	NH_3	1 Mt/y	2026
Chile	Magallanes, Mejillones	NH_3	1,5 Mt	2028 -2030
Egypt	Ain Sokhna	NH_3	> 3 Mt	> 2030
Iceland	Bakki ind. park	NH_3	0,1 Mt	2025
Mauritania	Nouadhibou port	NH_3	10 GW	2030
Malaysia	various locations	NH_3	2.2 Mt	> 2025
		LOHC	0.06 Mt	2023–2027
Namibia	Khaeb National Park	NH_3	3 Mt	2026–2030
New Zealand	Tiwai Point	NH_3	0.5 Mt	–
Morocco	–	NH_3	–	–
Norway	Gulen, Narvik	NH_3	0.3 Mt/y	2026–2028
Oman	Duqm	NH_3	12 Mt	2026–2028
Paraguay	Villeta	NH_3	0.05 Mt/y	2024
Saudi Arabia	NEOM	NH_3	1.2 Mt/y	2026
South Africa	Boegoebaai Port, Ngqura	NH_3	> 0.8 Mt/y	> 2026
USA	Corpus Christi	NH_3	10 Mt	2030

Table 3: Non-EU H2 Export Projects using the maritime route (non-comprehensive list of projects). Source: IEA, "Hydrogen Production and Infrastructure Projects Database", 2023

Country	Location	Project Name (promoter)	H_2 carrier	Production Capacity	Start-up Date
France	Bordeaux	Green P(Hy)sics	H_2 and H_2 Derivatives	–	2024
Finland	Naantali	Green NorthH2 Energy (Flexens Oy Ab)	NH_3 and H_2 Derivatives	–	–
	Kokkola	Karysta (Hy2Gen)	H_2 and H_2 Derivatives	–	–
Ireland	Money Point	Green Atlantic (ESB)	NH_3	–	–
Portugal	Sines	H2Sines	LH_2	0.036 Mt/y	2028
	Sines	Madoqua	NH_3	–	2027
Spain	Algeciras & Huelva	Andalusian Green Hydrogen Valley (Cepsa, Yara, Gasunie)	NH_3	0.75 Mt/y	2027
	Multiple locations	Conversion of existing LNG Terminals into H_2 Export terminals (Enagás)	–	–	–

Table 4: EU Export Projects. Sources: IEA, "Hydrogen Production and Infrastructure Projects Database", 2023; Joint H_2 Infra Map (www.h2inframap.eu), 2023; Project Promoters

It is important to note that these are just a few of the many hydrogen projects that are currently being developed around the world. The production capacity of these projects is also subject to change, as they are still in the early stages of development.

As regards the projects announced globally by 2030, around 60 % of them have not yet identified a destination country, and of the projects that have done so, about two-thirds have identified a potential off-taker. According to Figure 9, based on the currently announced projects, Europe could receive 5 Mt H_2-eq by 2030, with one-fifth of it having been produced and traded inside the region itself. This could double to around 10 Mt H_2-eq by 2040, with two-thirds of these imports in the form of ammonia. Australia accounts for half of the announced export projects by 2030, while around one-third of the announced exports globally are earmarked for Europe. Still, around 60 % of export projects have not yet identified a destination country.

Regarding import infrastructure projects into the EU, the Hydrogen Infrastructure Map (www.h2inframap.eu) already identifies several of them. Additional projects, which are not displayed in the Hydrogen Infrastructure Map, have been provided by European Clean Hydrogen Alliance Members. There are other import projects under development, but no public information about them.

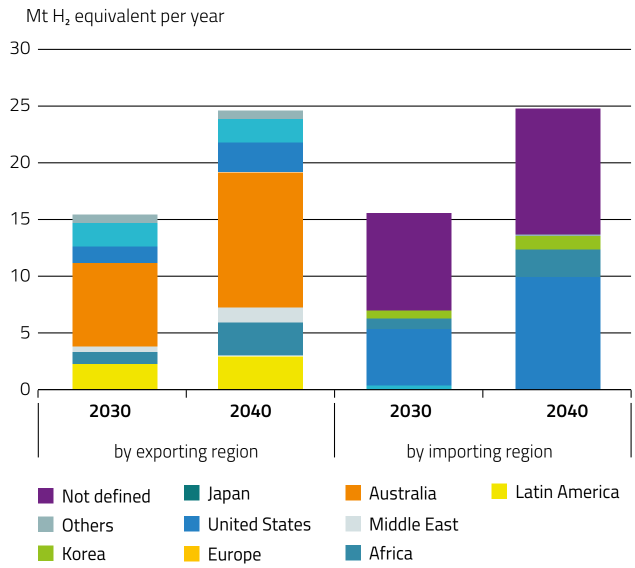


Figure 8: Hydrogen trade by exporting and importing region based on announced projects (2030–2040).
Source: IEA, Global Hydrogen Review, 2023

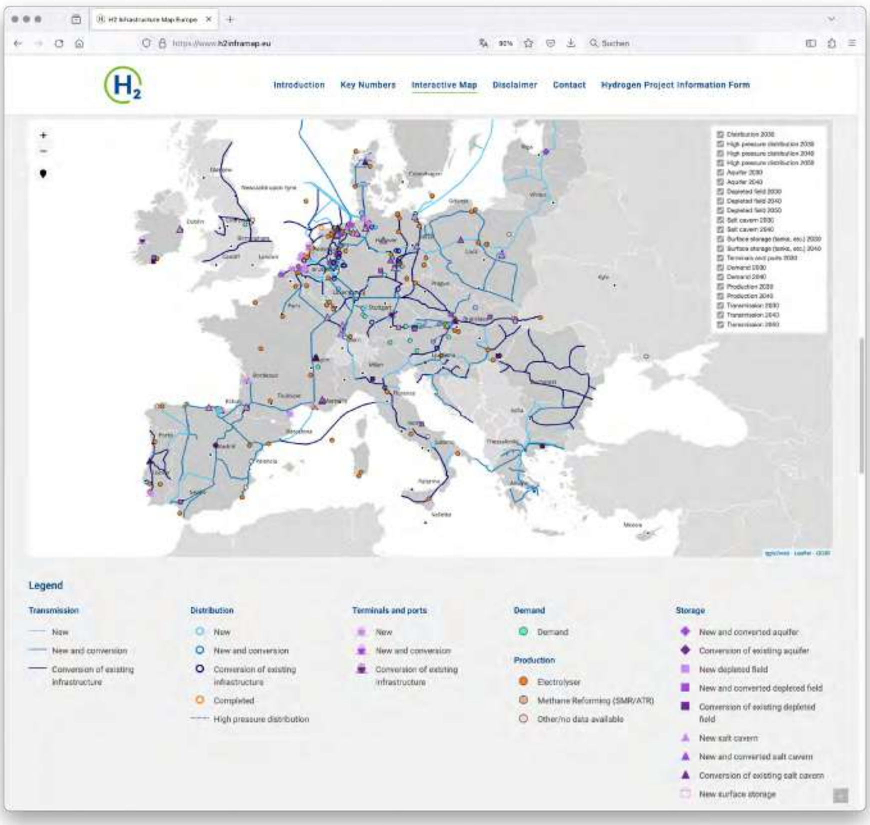
Country, Location	Project Name (Project promoter)	H_2 carrier	Production Capacity	Start-up Date
Belgium, Antwerp (PoAB)	Antwerp NH_3 Import Terminal (Fluxys-Advario)	NH_3	16.2 GWh/d	2027/2028
	Amplifhy Antwerp (VTTI)	NH_3	45 GWh/d	2026
Belgium, Zeebrugge (PoAB)	NH3 import terminal (Fluxys Belgium)	NH_3	48 GWh/d	2029
France, Dunkerque	–	NH_3	–	–
France, Port-la-Nouvelle	Mediterranean Hydrogen Gateway	NH_3 & MeOH	100 Kt H_2	2027
Germany, Brunsbüttel	German LNG Terminal (RWE, Gasunie, KfW)	NH_3	23.5 GWh/d	–
	Ammonia Brunsbüttel	NH_3	0.3 Mt/y	2026
Germany, Wilhelmshaven	Green Wilhelmshaven (Uniper)	NH_3	31.2 GWh/d	2028
	Wilhelmshaven Green H_2 (BP)	NH_3	54.8 GWh/d	2028
	Green Gas Terminal (TES)	CH_4	0.5 Mt/y	2027
Germany, Stade	Hanseatic Energy Hub (Partners Group, BG, Dow, Enagás)	NH_3 ready	–	2027
Germany, Hamburg	Hamburg Blue Hub	H_2 derivatives	–	2026
	Bunker terminal (Mabanaft, Hapag-Lloyd, Air Products)	NH_3	–	2026
	H2 Imports to Hamburg (Shell)	LH_2	–	2026
	TransHyDE (Hydrogenious)	LOHC	0.8 GWh/d	2023
Poland, Gulf of Gdansk	FSRU adaptation (GAZ-SYSTEM)	NH_3	–	–
The Netherlands, Amsterdam	H2A (Consortium multiple organisations)	LH2, LOHC and others	1 Mt H_2	–
The Netherlands, Rotterdam	H2SinesRDAM (Port of Rotterdam)	LH_2	0.036 Mt	2028
	Amplifhy Rotterdam (VTTI, Essent, E.ON)	NH_3	45 GWh/d	2026
	OCI Terminal expansion (OCI)	NH_3	1.2–1.8 Mt/y	2023–2025
	ACE Terminal (Gasunie, HES, Vopak)	NH_3	47.7 GWh/d	2027
	Koole Terminal (Hyphen)	NH_3	–	2028
	IPCEI Northern Green Crane* (Hydrogenious LOHC Technologies)	LOHC	0.8 GWh/d	2026
	Helios (Gunvor Petroleum Rotterdam)	NH_3	–	2026
The Netherlands, Vlissingen	"Greenpoint Valley" NW-Europe (Vesta, Uniper)	NH_3	0.96 Mt/y	2026

Table 5: Import Terminals. Sources: IEA, Hydrogen Production and Infrastructure Projects Database, 2023; Joint H_2 Infra Map (www.h2inframap.eu), 2023. *Access to southern Germany via inland waterways

In addition to the H_2 import terminals, several large-scale ammonia cracking projects have been announced. Facilities are being considered in Wilhelmshaven, Rostock and Brunsbüttel (Germany), in the port of Antwerp (Belgium), in the ports of Liverpool and Immigham (United Kingdom), as well as two facilities in the port of Rotterdam (Netherlands), which could crack ammonia to supply around 1.5 Mt H_2 by 2030. In total, up to 4.4 Mt[18] of H_2 imports could be realised by 2030 via already planned terminals and repurposed infrastructure dedicated to hydrogen carriers.

18 Gas for Climate, "Facilitating hydrogen imports from non-EU countries", (2022), (link).

Figure 9: Terminals and Ports 2030: Map of planned hydrogen import terminals in Europe and neighbourhood region based on projects submitted to the H_2 Infrastructure Map platform. The H_2 Infrastructure Map is regularly updated – not all current projects may be shown in the map. Source: H_2 Infrastructure Map, 2023



www.h2inframap.eu

4.6 SHIPPING INFRASTRUCTURE – TANKERS

Currently, around 40 tankers exclusively transport ammonia globally, and there up to 200 gas (LPG) tankers capable of carrying ammonia. Meeting the potential tripling of ammonia trade in this decade would require a significant increase in gas tankers.

There are currently no commercially available tankers for shipping liquefied hydrogen. The Suiso Frontier, with a capacity of 1,250 m^3 (~75 t LH_2), was the only demonstration project, with an LH_2 shipment from Australia to Japan in 2022. Several companies are developing liquefied hydrogen tankers, expected to be operational by 2030, with a H_2 cargo capacity of up to 160,000 m^3 (~9,600 t LH_2).

For LOHC, in general, the existing worldwide shipping infrastructure for liquid bulks (e.g. ships, terminals, tanks, bunkers, jetties) could be used. Nevertheless, the usage depends on the LOHC technology and further regulatory details.

Compressed hydrogen shipping is being considered[19] alongside liquefied hydrogen as an option for shipping hydrogen, particularly at smaller scales.

4.7 CONNECTION TO EU H_2 SUPPLY CORRIDORS

The H_2 supply corridors are a key building bloc of the EU's importation strategy into the bloc. These corridors will connect H_2 import facilities with H_2 demand centres in the EU.

The H_2 terminals receiving H_2 and H_2 carriers from different exporting countries will inject the gaseous H_2 into the EU's hydrogen grid. The H_2 supply corridors will be able to transport large amounts of H_2, either received via maritime or pipeline routes, across borders within the EU, moving the imported H_2 to those consumption centres where hydrogen is valued the most.

19 There is a project in Norway looking into compressed H2-shipment as the most cost-effective solution (link)

5 PIPELINE ROUTES

5.1 GEOGRAPHICAL COVERAGE

In contrast to the liquid carrier options considered in this analysis, the **value chain for pipeline transport of gaseous hydrogen is relatively simple**. The energy-intensive steps of liquefying H_2 or converting it to a carrier at the export location and then reversing the process to liberate H_2 at the import location are completely avoided, and other requirements for storage and transportation are also greatly reduced. Gaseous H_2 must be compressed for pipeline transport, but at relatively modest associated energy requirements.

H_2 dedicated pipelines extend globally by more than 5,000 km, with more than 90 % located in Europe and the United States. **Hydrogen import by pipelines is a promising way to transport hydrogen from large-scale production facilities to demand centres**. Pipelines are **a well-established and reliable method of transporting gas**, and they can be used to transport H_2 over short and medium distances cost-effectively.

Whenever hydrogen transport by pipeline reaches economies of scale (~0.1 Mt/y for a 20-inch pipeline and 2 Mt/y for a 48-inch pipeline operating at 75 % of their design capacity and 50–80 bar), **it will become the cheapest option for H_2 transport in the short and medium distances**, particularly in the case of repurposed pipelines where available. Pipelines with larger diameters are cost-efficient for longer distances compared to those with smaller diameters.

The REPowerEU Plan identified three main corridors to import H_2 from neighbouring regions of the EU and facilitate the achievement of 10 Mt imported by 2030:

- North-Sea corridor
- Mediterranean corridor
- Eastern Europe corridor, with Ukraine

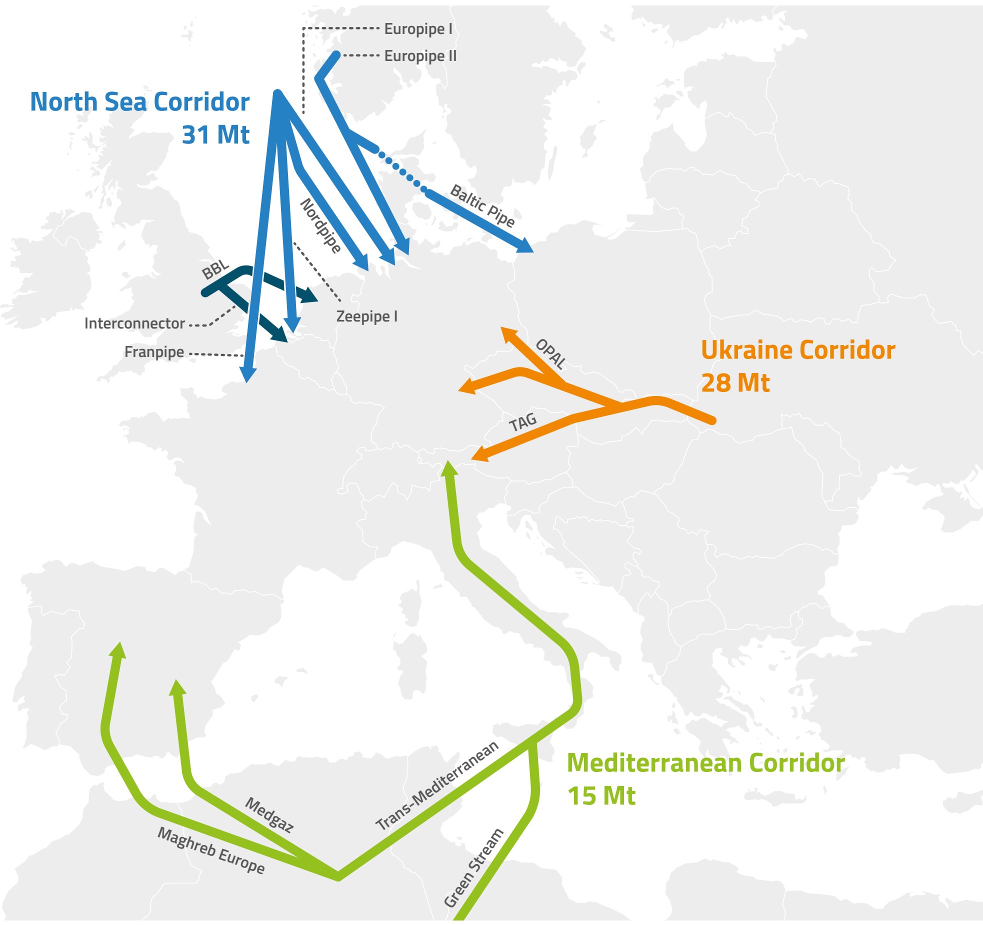


Figure 10: Natural gas import pipelines with their potential H_2 import capacities. Source: Gas for Climate, 2022.
Please refer to table 6 for a current list of hydrogen import projects at the point of publication of this Learnbook.

5.2 TRANSPORTING HYDROGEN VIA PIPELINES: REPURPOSING

When planning hydrogen imports from third countries via pipelines, the first step is to decide whether to build new H_2 pipelines or to repurpose existing gas pipelines into hydrogen pipelines. A third option, a temporal one that might help the growth of the market, is to inject H_2 into existing gas pipelines (blending) and to use existing gas import routes to bring H_2 mixed with natural gas to ramp up the decarbonisation of the gas and industrial sector.

There are **several reasons why it is better to reuse existing gas pipelines to import hydrogen** from the EU's neighbouring regions:

— **Less Cost:** Repurposing a gas pipeline is typically about half the cost of building a new hydrogen pipeline. This is because the existing pipeline infrastructure can be reused to a large extent, and there is no need to find and acquire new suitable land.[20]

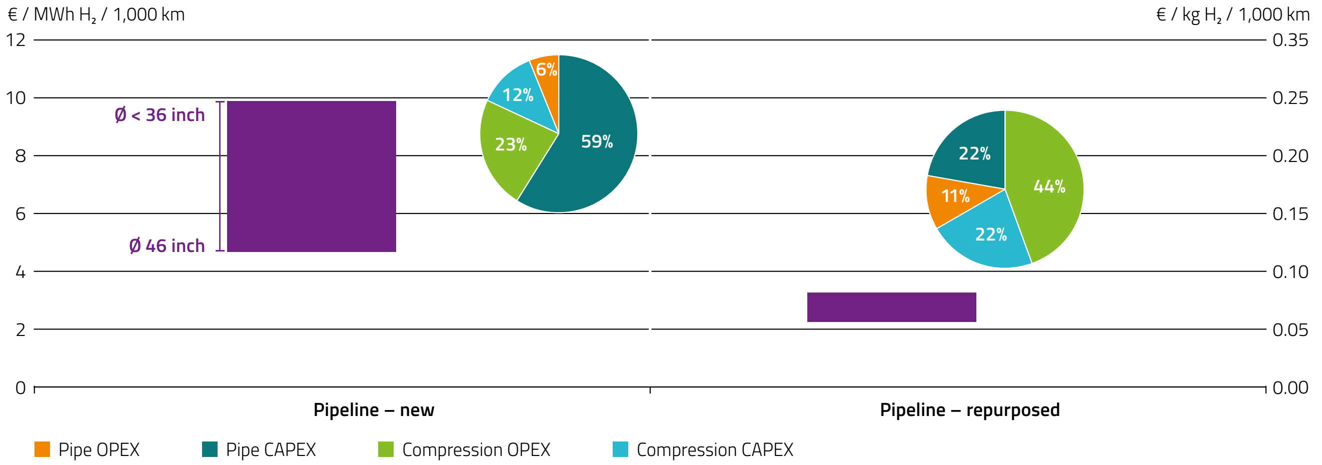


Figure 11: Cost comparison of new and repurposed hydrogen pipelines. Source: German Federal Ministry for Economic Affairs and Climate Action, Ministry of Energy Saudi Arabia (2022), Hydrogen cooperation potential between Saudi Arabia and Germany.

— **More Speed:** It takes much longer to build new pipelines than to repurpose existing gas pipelines. This is because the existing pipeline infrastructure is already in place, and the permitting process required is usually much quicker than the one for new hydrogen pipelines.

— **Less Environmental impact:** Building new pipelines has a significantly higher environmental impact than reutilising the existing gas pipelines. When repurposing gas pipelines, due attention is to be paid to address the risk of embrittlement and hydrogen leakages from the pipelines.

Moreover, there are other aspects to be considered:

— **Availability of existing gas pipelines:** According to recent studies[21] it is possible to repurpose the vast majority of existing gas grids into hydrogen. However, only those existing pipelines that, at a certain point in time, are not needed anymore to supply gas to end users will be available for repurposing. When a gas pipeline is planned to supply gas (or biomethane) to end-users for the long term, this line will not be available for repurposing.

— **Regulatory environment:** The regulatory environment for hydrogen pipelines can vary from country to country and is still under discussion. This can make it more difficult or expensive to build new pipelines in some countries.

20 For more insight into Repurposing besides the shown graphic, please see this ACER study as well.

21 DNV, Carbon Limits, "Re-Stream: Study on the reuse of oil and gas infrastructure for hydrogen and CCS in Europe", 2022, (link)

5.3 MAIN PROJECTS – PIPELINE ROUTES

Hydrogen pipelines for H_2 import can be either offshore or onshore. Offshore pipelines could be developed in places such as the North Sea or the Mediterranean.

Regarding offshore H_2 pipelines, there are none in operation today. Despite this limited experience and related uncertainties, several offshore pipeline projects have been announced. In June 2023, Gasunie launched a tender for a feasibility study for an offshore hydrogen pipeline in the North Sea, including the design of the offshore platform (compression/electrolysis) and the pipeline routing. In January 2023, Norway and Germany commissioned a joint feasibility study to assess large-scale hydrogen transport from Norway to Germany, and CO_2 transport from Germany to Norway for offshore storage. The feasibility study is being carried out by Gassco (Norway's gas operator) and DENA (the German energy agency), and in September 2023 the two countries set up a joint task force to follow up on the results.

Other offshore pipelines are being considered, albeit still at a conceptual stage, between Spain and France (H_2Med – Bar-Mar); Algeria/Tunisia and Italy (SouthH_2 Corridor); Finland, Sweden, Denmark and Germany (Baltic Sea Hydrogen Collector); Denmark and Germany (H_2 Interconnector Bornholm Lubmin). Offshore pipelines in the North Sea are being considered more generally, such as the AquaDuctus project (Germany), and as highlighted by the Ostend Declaration of Energy Ministers signed in April 2023 by Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway and the UK.

A main onshore pipeline is also planned between Finland, Estonia, Latvia, Lithuania, Poland and Germany (Nordic-Baltic Hydrogen Corridor project) – for an overview of Hydrogen Supply Corridors, please see our previous Learnbook.

If offshore wind is going to be used for H_2 production, the offshore production of H_2 and its delivery to the coast by pipeline can, in some cases, become an alternative to transporting electricity for onshore H_2 production.

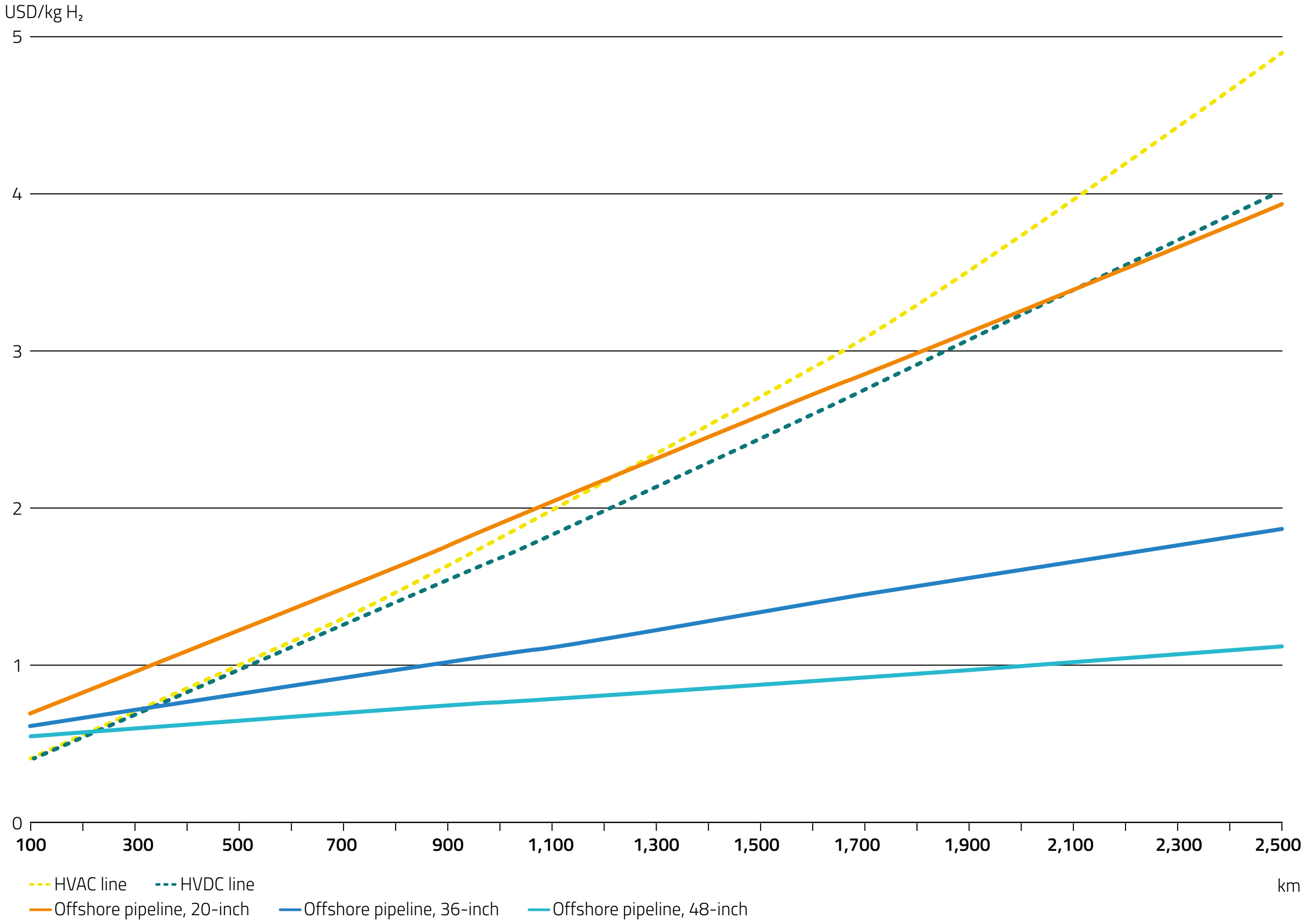


Figure 12: Cost of Offshore hydrogen and power transmission. Source: IEA

Table 6 (non-extensive list) aims to compile the publicly announced import H_2 pipelines or routes into the EU which are currently planned or under study.

Origin – EU Entry Country	Name	Capacity	Start-up Date
Algeria – Italy	SunsHyne	106 TWh (2030) 363 TWh (2040)	2030
Algeria – Italy	South H2 Corridor	Import capacity up to 448 GWh/day Export capacity up to 200 GWh/day	2030
Azerbaijan – EU	Southern Gas Corridor	(H_2 blend)	2030s*
Caspian – EU	Green Energy Corridor	–	2030s
Morocco – Spain	H2Med (extension)	–	~2040
Norway – Germany	H_2 pipeline (RWE, Equinor)	2GW (2030), 10 GW (2030)	2030
Qatar – Saudi Arabia – Egypt – Greece	Gulf to Europe Pipeline	2,5 Mt/y	2030s
UK (Scotland) – Germany	Hydrogen Backbone Link	35 TWh/y (2030), 94 TWh/y (2050)	Mid 2030
Ukraine – Slovakia/Hungary/Slovakia	East H_2 Corridor	12 TWh/y (2030), 100 TWh/y (2050)	2030

* The Agreement "Strategic Partnership in the field of Green Energy Development and Transmission between the Governments of the Republic of Azerbaijan, Georgia, Hungary and Romania" (link) signed on 17 December 2022, envisages the export of Green energy to Europe. Currently, the Feasibility Study of the project is expected to be ready in 2024 or early 2025, and one of the green energy transfer components is green hydrogen – potentially via the Southern Gas corridor. The European Commission's long-awaited "Enlargement Package" also foresees some bold actions on climate, energy and infrastructure in the Western Balkans, including Albania.

Table 6: Main H_2 import pipeline projects into the EU. Source: Own analysis based on IEA and project promoters' data

5.4 CONNECTION TO EU H_2 SUPPLY CORRIDORS

The targeted European hydrogen infrastructure will be organised in three priority supply corridors according to the REPowerEU plan, namely the Mediterranean, the North Sea region and, as soon as conditions allow, Ukraine. These corridors align with the supply corridors published by the European Hydrogen Backbone initiative and would be a first, tangible step towards a pan-European hydrogen infrastructure connected to neighbouring regions.

The future hydrogen terminals and H_2 import routes will facilitate the arrival of hydrogen until the EU's external borders. From there, the European hydrogen network and, consequently, the EU H_2 supply corridors, will distribute hydrogen across borders and move it internally within the EU towards the consumption centres where hydrogen will be most valued.

This perspective around the future H_2 imports to the EU is complementary and coherent with the existence of H_2 Supply corridors as described in the European Clean Hydrogen Alliance Learnbook on H_2 Supply Corridors.

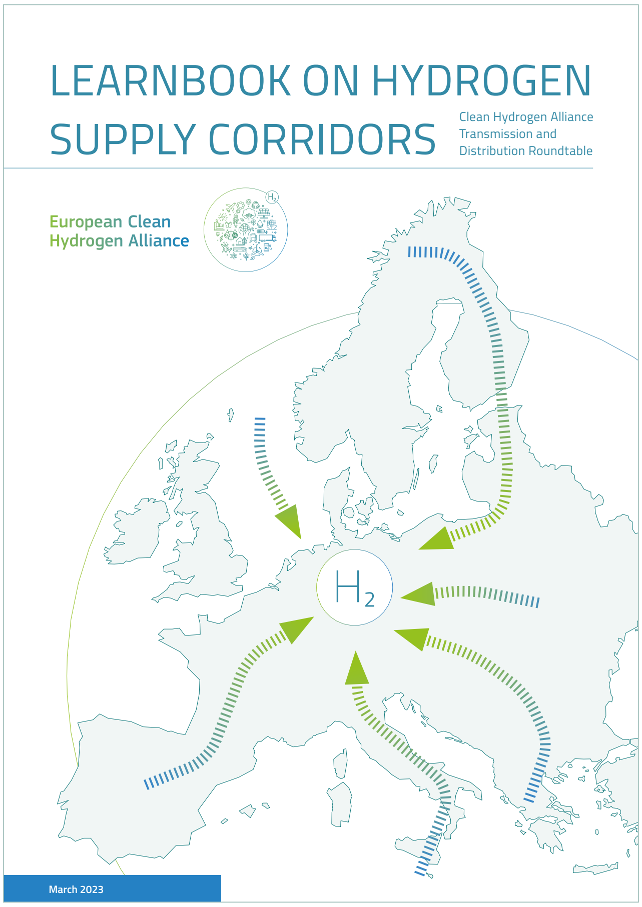


Figure 13: Frontcover of ECH₂A Learnbook on H_2 Supply Corridors, (2023). Source: European Clean Hydrogen Alliance

6 BARRIERS AND RECOMMENDATIONS

This Learnbook underlines the need and necessity of H_2 imports, without being prescriptive on the route and/or the type of H_2 carrier. This document provides neutral and commonly supported information on behalf of the ECH_2A Roundtable on Transmission and Distribution of Clean Hydrogen, to contribute to the discussions on this subject and be a useful reference for policymakers and decision-makers.

Many active members within the ECH_2A Roundtable on Transmission and Distribution of Clean Hydrogen are project promoters. They are involved in projects linked to H_2 imports. Based on their experience, this Learnbook collects a list of main barriers and recommendations supported by the Roundtable members. By addressing the challenges and opportunities associated with the import of H_2, the EU can create a secure and sustainable hydrogen supply for the future.

H_2 IMPORTS – GENERAL ASPECTS

INTERNATIONAL COOPERATION

— **Develop Strategic Partnerships and Cooperation between the EU and Exporting Countries:** Under the REPowerEU Plan, the Global European Hydrogen Facility and the Green Hydrogen Partnerships will be established and promoted. The Global European Hydrogen Facility should create investment certainty and business opportunities for renewable and low-carbon hydrogen production, as well as a reliable supply and transparency for European hydrogen usage. This facility should be coherent with intra-EU measures and market functioning. The Green Hydrogen Partnerships promote the import of renewable hydrogen and should incentivise decarbonisation and the development of renewable energy production for domestic use in partner countries, while encompassing policy dialogue, including sustainability standards. On top of this, the EU aims to develop at least 100 hydrogen valleys worldwide by 2030 and the joint purchasing of hydrogen. These intentions make clear that the EU is looking to lead in developing international hydrogen supply chains. This ambition should be realised in more numerous, deeper and more comprehensive international partnerships and cooperation with exporting countries around the globe.

MARKET DEMAND

— **Stimulate Industry Demand for Renewable and Low-carbon H_2**: Securing demand is fundamental for realising the project pipeline. International trade is a driver for renewable and low-carbon hydrogen growth and a source of uncertainty. Many national governments are signalling long-term import targets, including 10 Mt by the European Union by 2030. However, bringing projects to an FID situation requires a certain degree of security of demand and contracts with off-takers.

— A clear policy framework needs to set the right conditions to **bridge the cost gap with the fossil benchmark**: This can be achieved by setting clear binding targets for different end-users (e.g.: RED II), by creating a level playing field at the international level (Carbon Border Adjustment Mechanism, ETS CO2 prices…) and/or by providing financial support. CAPEX and OPEX support (e.g. CCfDs) is vital for the kick-off phase.

GLOBAL H_2 MARKET

— **Address the Lack of Certification and Standards:** The lack of global standards and certification for H_2 imports is a major barrier to their deployment. Most leading H_2 economies stress its importance. The type of certification, the degree of implementation, and the level of ambition differ substantially between countries. Thresholds for certification differ in each region of the world, creating fragmentation and becoming a barrier to developing a global market. There is a need to push the implementation of internationally recognisable certification standards for hydrogen. However, the harmonisation of these approaches on the international level remains a challenge, mostly due to the differences in ambition and focus among countries, with countries targeting renewable H_2 directly only or providing substantially higher support for renewable hydrogen, while others, having wider ambition and a clear focus on low-carbon H_2 produced from natural gas. A clear certification system could make both the renewable and low-carbon hydrogen markets grow in parallel, and the different approaches taken by different countries would not be an issue.

For the successful implementation of a global hydrogen economy, a harmonised approach is crucial to give potential exporters a system to rely on for their investment decisions. Having harmonised certifications helps minimise compliance costs for developers and increase market opportunities.

Ultimately, for hydrogen to maintain its integrity as a climate solution, it is essential that standards ensure that hydrogen systems deliver substantial climate benefits compared to fossil fuels, in alignment with the EU's climate neutrality goal. This will require robust full lifecycle accounting, including all climate-warming emissions.

In the interim period, in the absence of these global rules, and to future-proof the global H_2 trade, the EU imports should align with EU domestic regulations and meet the EU's sustainability framework under RED III. For this purpose, effective verification and control mechanisms should be implemented.

The EU is on the way to setting clear and harmonised rules, standards, and certifications to recognise renewable hydrogen. The recent relevant delegated acts[22] adopted by the European Commission refer to renewable H_2 produced from additional renewable energy. The EU would need to establish robust certification schemes for H_2 imports from within the EU and from third countries, as well as implement other relevant regulations affecting H_2 imports, such as the Gas Package (for low carbon hydrogen definition) and CBAM (Carbon Border Adjustment Mechanism).

— **Guarantees of Origin** are also needed to clarify renewable hydrogen certification among exporting and importing countries and to enable the trading of the renewable value associated with renewable H_2 imports. According to the EU Renewable Energy Directive, Member states shall refuse GOs from non-EU member states, unless the EU has agreed with that third country on mutual recognition and only where there is direct import or export of energy. Until this administrative request is not addressed, it might represent a possible challenge for the import of renewable H_2 or other renewable H_2 carriers.

— **Develop Common Rules for Measuring Carbon Intensity:** Quantifying and measuring[23] the carbon intensity of H_2 production will be necessary to develop international trade. While there is currently no internationally agreed standard on the accounting methodology, substantial progress has been made by the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE).

In October 2022, the IPHE's Hydrogen Production Analysis Task Force (H_2PA TF) released a proposal for a methodology to determine the GHG emissions from different hydrogen production pathways, which will serve as the basis for a common global standard currently under development developed by the ISO.

CBAM is also supposed to provide guidance on this matter but will only make it in the future because currently, only H_2 and NH_3 imports have to report their carbon intensity. Under CBAM, there are some rules on how this has to be done; these rules are not permanent and will evolve over time.

INFRASTRUCTURE

— **Develop Infrastructure for Maritime and Pipeline imports:** The trade infrastructure may be located at strategic entry points, such as ports, including storage tanks, jetties, further facilities and expanded and updated shipping fleets. New infrastructure development can have long lead times, high capital costs and, in some cases, require technological advances.

— **Capitalise on Existing Infrastructure to import H_2 and H_2 Derivatives:** Repurposing existing infrastructure can reduce costs and lead times, whilst these efforts are expected to consider risks such as H_2 emissions, embrittlement, and safety. For example, Australia and Singapore announced an AUD 30 million partnership to accelerate the deployment of low-emission fuels at maritime and existing port operations.

22 Commission Delegated Regulation (EU) 2023/1184 of 23 May 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council with regard to the definition of renewable fuels of non-biological origin (RFNBOs) and the methodology for calculating the greenhouse gas emissions savings from RFNBOs (link)

Commission Delegated Regulation (EU) 2023/1185 of 23 May 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council with regard to the minimum threshold for greenhouse gas emissions savings of recycled carbon fuels (link)

23 For more analysis on the topic, see the IEA's report "Towards hydrogen definitions based on their emissions intensity", 2023, (link)

PLANNING

- **Evaluate Infrastructure needs and Plan Accordingly:** Evaluate the costs of transporting renewable hydrogen to consumers and identify cost-effective options. If pipelines are needed, evaluate when it is possible to repurpose existing natural gas pipelines and infrastructure [24]. Storage will be needed to address supply and demand imbalances, and the costs and technology options will need to be considered. Co-locating industries with similar energy needs together into "industrial clusters" can help reduce transport costs by using shared infrastructure. Aggregating hydrogen industries also have the added benefit of creating the skilled workforce needed to accelerate.

- Develop long-term **hydrogen adoption roadmaps** that outline the gradual integration of H_2 imports into the energy mix, with clear milestones and targets.

PERMITTING

- **Improve and Speed up Project Licensing and Permitting:** Governments should work to make licensing and permitting processes as efficient as possible and to improve co-ordination among different authorities involved in the process, to minimise their significant impact on project lead times, particularly for certain infrastructure developments, such as new pipelines, underground storage and import/export terminals. The challenge for governments in this regard is to develop permitting and siting processes that ensure infrastructure projects do not harm local communities and ecosystems, while not inhibiting such projects from being built at the scale and speed necessary. The most recent reports of the IEA, i.e. the Global Hydrogen Review 2023, show clearly that the EU is falling behind in the implementation of the clean hydrogen objectives with less than 5 % of planned projects in the phase of Final Investment Decision (FID) or under construction.

REGULATORY FRAMEWORK

- **Establishment of a clear, stable and supportive regulatory framework** to ensure investor certainty and create a well-functioning international market for hydrogen and all possible H_2 carriers, with easy and appropriate regulations at the European level and considering third countries, as well as transition periods that might help the kick-off of the market

- Common definition of the required **safety standards, quality assurance, and environmental regulations**.

- Fast **implementation and harmonisation between national regulatory frameworks and the European level** are needed to avoid wrong signals to the market and the major importers.

- Ensuring a **level playing field between the renewable H_2 production from electrolysis and other methods** in terms of regulation, public funding and permitting.

- Approve the future **low-carbon H_2 Delegated Act**, to provide regulatory certainty for the hydrogen market players.

FUNDING

- Support the growth of **large-scale production projects in 3rd countries**, helping to kickstart and ramp up the renewable H_2 import value chain.

- Implement a sound support mechanism with the **international pillar of the EU Hydrogen Bank** to promote H_2 production in third countries to be exported to the EU.

- Increase **EU funding for H_2 import infrastructure in the EU** (e.g. CEF-E and CEF-T funding).

- Fund and support i**mport projects that can ramp up and kick-start the market whilst** showcasing the viability and benefits of H_2 imports in real-world applications. Pilot projects to explore new technological options would be also needed.

ENVIRONMENT

- Understand and address properly the **climate and wider environmental concerns** related to H_2 emissions and transport of H_2 carriers (e.g. ammonia). This includes accounting for potential H_2 emissions in life cycle assessment analyses, including fugitive emissions and operational releases, and incorporating multiple time horizons for global warming potentials (20 years in addition to 100 years) given that the warming effects from short-lived pollutants, such as hydrogen and methane, are not sufficiently characterised by a single time horizon.

INNOVATION

- Continue allocating **funding to R&D and innovation initiatives** that contribute to improving and lowering the costs of import technologies, as well as help address and better understand the climate and environmental impacts related to H_2 (as noted above).

- Enable and promote the development of **regulatory sandboxes**.

- **Public-private partnerships** can facilitate funding, research, and knowledge sharing to advance pipeline technology and infrastructure

24 For instance, Chile's National Hydrogen Strategy highlights plans to review existing natural gas infrastructure and regulations to integrate low-carbon hydrogen.

MARITIME SPECIFIC

Apart from what is already above, there are a number of specific identified barriers and challenges linked to maritime H_2 imports from non-EU countries. These include:

- **Safety and environmental protection:** Regarding NH_3, although well-established practices for safe handling have existed in the chemical industry for decades, the regulatory framework associated with operations at the import terminal needs to be deepened in light of much larger volumes to be handled, including the specificities of NH_3.

  This is particularly relevant since NH_3 undergoes natural transformations in the environment, resulting in nitrous oxide (N_2O) and nitric oxide (NOx) production . While N_2O is a potent GHG that depletes stratospheric ozone (the protective ozone), NOx is a precursor of tropospheric ozone (a potent GHG) and air-polluting particulate matter . Consequently, ammonia emissions across its value chain, including leakage, spills, and engine slip, also have the potential to contribute to climate warming and air-quality deterioration.

  In general, ammonia production, transport and storage and related technology are already well-developed and referenced in the industry globally. Operators, companies and regulators know the processes and have built up relevant experience for several decades.

- **Hinterland Destinations:** Address regulatory challenges linked to transporting hydrogen and hydrogen carriers from the landing ports to the hinterland destinations by different transport modes (barge, train, pipelines).

- Identification of strategic **H_2 import routes** to be developed in the short-medium term and the definition of **import hubs** capable of transforming H_2 carriers back to H_2.

PIPELINE SPECIFIC

Apart from what was mentioned before, amongst other things, this aspect should also be taken into account:

- **Network Codes for imports:** The EU framework detailing the EU rules applicable to H_2 imports arriving to the EU H_2 grids from third countries should be in place in a timely manner. These rules would cover interoperability (including hydrogen quality), capacity allocation, balancing, etc.

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ABBREVIATIONS AND ACRONYMS

ATR – auto-thermal reforming

CAPEX – capital expenditure

CBAM – cross-border adjustment mechanism (link)

CCfD – carbon contracts for difference

CCS – carbon capture and storage of CO_2

CCUS – carbon capture utilisation and storage of CO_2

CEF-E – connecting Europe facility for energy

CEF-T – connecting Europe facility for transport

CO_2 – carbon dioxide

ECH2A – European Clean Hydrogen Alliance

ETS – emissions trading scheme

H_2 – hydrogen

FID – final investment decision

GIIGNL – International Group of LNG Importers

IEA – International Energy Agency

IPCEI – Important Project of Common European Interest

IPHE – International Partnership for hydrogen and fuel cells

IRENA – International Renewable Energy Agency

LCOH – levelised cost of hydrogen

LH_2 – liquefied hydrogen

LNG – liquefied natural gas

LOHC – liquid organic hydrogen carrier

LPG – liquefied petroleum gases

MeOH – methanol

MoU – Memorandum of understanding

NH_3 – ammonia

NO_x – nitrogen oxides

NZE – net-zero emissions

OPEX – operational expenditure

POX – Partial oxidation

REPowerEU – European Commission communication to quickly reduce dependence on Russian fossil fuels and fast forward the green transition (link)

PPP – Private Public Partnerships

REDIII – EU's renewable energy directive approved in 2023

RFNBO – renewable fuel of non-biological origin

R&D – Research and Development

SAF – sustainable aviation fuel

SMR – steam methane reforming

TEN-E – Trans-european energy networks regulation

TEN-T – Trans-european transport networks regulation

TRL – technology readiness level

UNITS

AUD – Australian dollar

°C – degree Celsius

bar – metric unit of pressure

bcm – billion cubic meters

CO_2 -eq – carbon dioxide equivalent

EUR – euro currency

GWh – gigawatt hours

GW – gigawatt

H_2-eq – hydrogen equivalent

J – joule

m^3 – cubic meter

MJ – mega joules

Mt – million tonnes

MWh – megawatt hours

t – tonne

TWh – terawatt hours

USD – USA Dollar

y – year

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to achieve the EU climate goals