European Hydrogen Backbone

IMPLEMENTATION ROADMAP — CROSS BORDER PROJECTS AND COSTS UPDATE

NOVEMBER 2023

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Executive summary

Motivation

Building out an integrated pan-European hydrogen network before 2030 is of critical importance to Europe's goals for the energy transition, including energy affordability, security, and independence. Early hydrogen infrastructure enables a competitive European energy transition on multiple fronts, facilitating large-scale deployment of renewable energy and hydrogen production, allowing for hydrogen production in regions where costs are low, and enabling imports from third-party countries. Cross-border infrastructure has been and remains a crucial component of the energy value chain—connecting supply with demand and storage and sending important signals to mitigate perceived financial risk for market participants, project developers, and downstream end users. To fulfill Europe's hydrogen objectives, hydrogen infrastructure will be paramount.

Existing progress and momentum

The buildout of the European Hydrogen Backbone (EHB) network is well underway. Transmission System Operators (TSOs) are planning to make substantial investments and can point to tangible progress on corridor projects. All five envisioned corridors[1] have projects currently in progress, with a clear majority of EHB member TSOs working on implementation and producing real progress in their countries.

This report highlights a set of 40 concrete projects managed by the EHB's TSO members, representing 31.500 kilometres of hydrogen pipelines with expected commissioning prior to 2030. TSOs are actively seeking sufficient contractual commitments from future network users to underpin their investment decisions in hydrogen networks. With the EHB moving from a vision towards reality, the first financial investment decision (FID) in a project which is part of the backbone has already been taken. Furthermore, together, the TSOs are using their existing expertise with gas networks and working to ensure that the EHB is not just a vision but a tangible reality that will support and accelerate the European energy transition.

Updating costs from EHB's flagship 2020 publication

The world has undergone substantial changes since the initial publication of EHB cost estimates in 2020. Globally impactful factors like COVID, the Russian invasion of Ukraine, rising inflation, and policy responses to climate change have all influenced implementation costs. This report presents an updated, bottom-up accounting of unitary costs for capital expenditures (CAPEX) and developmental expenditures (DEVEX) of pipelines and compressors, based on new primary data collected from the TSOs' real-world projects.

Costs are nominally higher as compared with the 2020 update but are shown to be largely in line with economy-wide inflation (of course, the broader impacts of inflation are felt across nearly all sectors, including other energy vectors). The cost data in this report reflects Europe-wide average numbers. However, it is important to consider that energy infrastructure costs tend to be highly project-specific, with geographic, demographic, and other factors playing an important role in project economics.

1 EHB (2022). Five hydrogen supply corridors for Europe in 2030. Source: EHB-Supply-corridors-presentation-ExecSum.pdf

Framing the financial challenge

Conceptually and once operational, the EHB network is likely to encounter two distinct financial phases that are linked to the development of the European hydrogen economy. The first of these phases represents the market ramp-up, involving limited hydrogen demand and low booking of capacity on the hydrogen network. However, as the hydrogen economy develops and demand rises, the market will transition to the later, mature market phase.

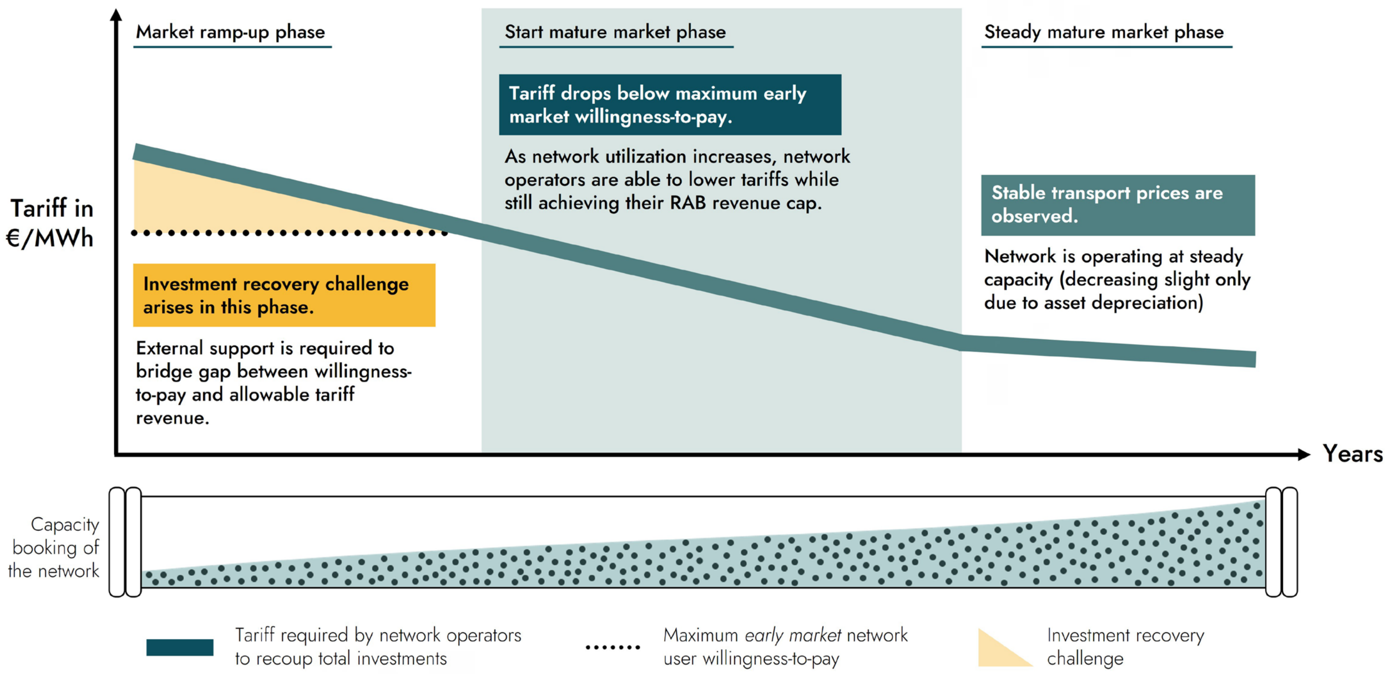
Defined here, the *investment recovery challenge (IRC)* arises from the potential financial disparity between the regulated revenue cap and the revenue that can be earned from network users on account of real network capacity bookings during the initial market ramp-up phase. A simplified way to interpret the origin and timing of this challenge is presented conceptually in Figure 1. Please note that some pipelines will be financially feasible from the start of operation and not only during the mature market phase, in particular in case of high share of repurposing. Therefore, this graph is not a reflection of the real dynamics of the entire EHB network but rather a simplification of a single pipeline, used to illustrate the structure of the IRC framing.

Underpinning this potential challenge is the possibility that demand might take time to develop, as market design enablers will take some time to be fully developed and implemented. (These include, for example, RED III obligations, European Union [EU] and national policy enablers, and subsidies for renewable and low carbon hydrogen production to enable hydrogen to become increasingly cost competitive with fossil fuels.) The impact of demand development over time can be observed via the teal line in Figure 1. The hydrogen demand, and equally the use of the booked capacity, increases until a steady booked capacity is observed in the mature market phase. This increase in booked capacity allows TSOs to lower tariffs until the market transition to the mature phase.

The extent of the potential financial challenge of course depends on the amount of public financial support for infrastructure, the share of existing infrastructure that can be repurposed, as well as the location of supply and demand centers (which are very much country specific).

Figure 1

The IRC and level of tariff required to realise regulated return.



The *upfront financing gap (UFG)* is a consequence of the IRC and represents the difference between the total required upfront investment *prior to project operation*[2] and the *ability of a TSO to finance the project*. Policymakers could mitigate the challenges associated with a potential UFG by developing mechanisms to manage market risk while in parallel allocating public funding or guarantees to mitigate the IRC where relevant. These mechanisms should be designed in a way that network development is sufficiently derisked and able to attract market-rate investment to finance its buildout.

Conclusions and looking forward

EHB member TSOs are moving ahead with real, tangible progress on building out a Europe-wide hydrogen network. Investment in the EHB is a necessary step forward for achieving lowest-cost societal decarbonisation in Europe. Hydrogen makes use of plentiful European and neighboring resources, serves a multitude of sectors—including those typically viewed as hard to decarbonize—and provides connectivity and resilience across the continent. Furthermore, building out infrastructure enables the creation of a liquid, pan-European, hydrogen market. Simply put, the hydrogen infrastructure network is of critical importance for achieving energy transition goals.

Here, we the research team have provided important cost updates to help inform policymakers on the competitive advantages offered by the EHB and maintain the progress that is already underway. Additionally, we have laid out a conceptual framework for the potential financial challenges that could become most prominent for network development. Future EHB efforts will quantify the potential amount of required EU-wide support, present recommended solutions to mitigate the defined financial challenges, and provide additional suggestions for addressing other aspects of the hydrogen value chain. Regardless of the specific path forward, we expect that the road ahead is likely to require collaboration amongst energy network operators, end-user industries, governments, and regulators. The EHB—and the energy transition as a whole—requires proactive planning, collective action, and a dedication to the overarching goal.

2 Investment required prior to operation is composed of CAPEX and DEVEX.

1. The role of EHB within the European energy transition

1.1 Hydrogen's key role for European climate policy

In 2020, the EU envisioned a hydrogen strategy to create a continent-wide hydrogen ecosystem in line with the European Green Deal. In July 2021, the European Commission set out a target of 5.6 million tonnes (Mt) of renewable hydrogen in Europe by 2030 in its Fit For 55 legislative package[3]. Russia's invasion of Ukraine in February 2022 strengthened the already clear need for a rapid energy transition. In the face of these events, the European Commission published REPowerEU[4], setting a target of 20 Mt of renewable hydrogen (10 Mt domestically produced and 10 Mt imported).

Before the European Commission released the REPowerEU plan, the EHB initiative conducted a bottom-up assessment of demand by sector and country. In this analysis, the EHB identified 14.7 MT of demand[5], representing tangible and achievable projections based on national targets, market developments, and announced projects (prior to the release of REPowerEU).

The sizeable hydrogen demand in 2030 laid out in both the REPowerEU plan and the EHB's bottom-up analysis underscores the key role hydrogen is envisioned to play in the future European energy system, both as an energy carrier and as an energy feedstock in industrial and other processes. Hydrogen is likely to be a crucial component of the energy transition across end-use sectors, as an important tool for hard-to decarbonise sectors such as heavy industry (e.g., iron and steel manufacturing), freight and transportation sectors that historically depended upon fossil fuels, and as a means of storing renewable energy for use on a dispatchable basis.

3 European Commission (2022). Commission launches consultations on the regulatory framework for renewable hydrogen. Source: https://commission.europa.eu/news/commission-launches-consultations-regulatory-framework-renewable-hydrogen-2022-05-23_en
4 European Commission (2022). REPowerEU: Joint European Action for more affordable, secure, and sustainable energy. Source: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511.
5 EHB (2022). Five hydrogen supply corridors for Europe in 2030. Source: https://ehb.eu/files/downloads/EHBSupply-corridor-presentation-Full-version.pdf

1.2 The EHB initiative: a collaborative effort to build out the clean hydrogen infrastructure network

The EHB initiative is a group of TSOs spanning the European continent and collaborating to lead hydrogen infrastructure development. The original group of 11 EHB partners published their first paper in July 2020, outlining a vision for dedicated hydrogen pipeline infrastructure—to a large extent based on repurposed existing natural gas pipelines—including maps showing hydrogen infrastructure covering their home regions. Since then, the EHB initiative has grown to 33 European network operators with infrastructure covering 24 EU member states plus Norway, the United Kingdom, Switzerland, and Ukraine (Figure 2).

Figure 2

The 33 members of the EHB, as of 2023.

Since the EHB's initial report in 2020, subsequent publications served to enhance the vision as more partners entered the initiative, adding detail to recommended actions and building additional momentum for the deployment of large-scale hydrogen infrastructure. In view of national and European climate ambitions, first-mover market actors have called for accelerated hydrogen infrastructure planning and development to support lower-cost implementation of their energy transition strategies. In addition to contributing to REPowerEU climate targets, the ability to strengthen European resilience and energy security in response to global energy market disruptions, while preserving the overall EU competitiveness, underscores the urgency of large-scale hydrogen infrastructure planning.

From the EHB's formation in 2020 through today, EHB partners have collaborated to develop a common hydrogen infrastructure strategy. By combining and validating the viewpoints and ambitions of a growing number of members, this strategy continues to evolve. Since the beginning, we have periodically updated our expectations of infrastructure size and cost to reflect the dynamic external environment of recent years.

Since our previous publication describing hydrogen corridors in June 2022, many ambitions have turned into reality as all members have been engaged in real project development, allowing first-hand access to key financial indicators that allow us to report more accurately on the investment needs of the EHB.

1.3 The clear benefits of an integrated pan-European hydrogen network

While both electricity transmission and hydrogen transmission will be required in a mature energy system, a previous EHB report[6] demonstrated that a pipeline transmission system offers a more cost-effective energy transfer solution to serve hydrogen demand as compared with high voltage direct current or high voltage alternating current options, with a particularly strong competitive advantage at high volumes. Therefore, the rollout of hydrogen infrastructure is key to scale up Europe's renewable energy supply efficiently and fully—including domestic renewable hydrogen production—and enable a significant increase in the amount of low-carbon energy transferred between countries and imports from outside EU.

The EHB has long advocated for European hydrogen corridors and their role in contributing to an affordable and secure energy supply in Europe. The corridor concept provides an economical means to bridge the substantial variation of hydrogen producers and end users throughout regions of Europe, owing to demographic, geographical, economic, and climatic factors.[7] Some European regions—the Nordics, Baltics, North Sea, and southern Europe—are characterised by a net oversupply of low-cost hydrogen resources. These regions benefit from vast renewable energy potential, high-capacity factors, and substantial land availability. Other regions—such as central Europe—will require hydrogen imports from neighbouring European or other countries to meet their hydrogen demand.

Offering an economical connection between regions of hydrogen supply and the hydrogen consumers in central Europe via cross-border pipeline corridors will become increasingly important as adoption of hydrogen increases in the transport, industry, and power sectors. Such a scenario could lead to demand outpacing supply in regions with lower renewable energy potential. Importantly, this mirrors the EU sentiment, aligning with goals of the Projects of Common Interest (PCIs).[8]

6 Note that this comparison is made against transmitting renewable energy as electric current to the place of local hydrogen demand and then converting into hydrogen (locally). EHB (2021). Analysing future demand, supply, and transport of hydrogen.p.81. Source: https://ehb.eu/files/downloads/EHB-Analysing-the-future-demand-supply-and-transport-of-hydrogen-June-2021-v3.pdf

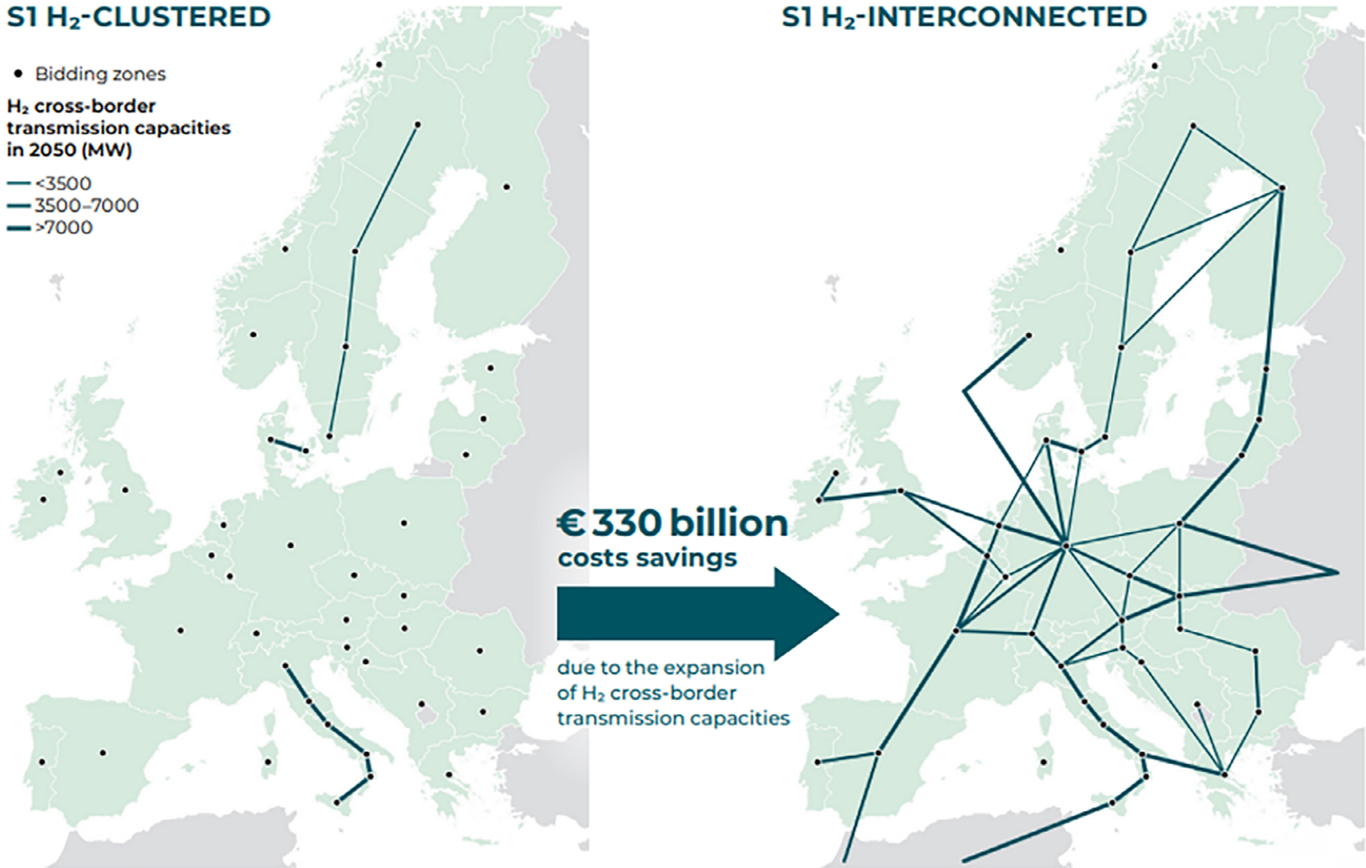
7 EHB (2022). Five hydrogen supply corridors for Europe in 2030. Source: https://ehb.eu/files/downloads/EHB-Supply-corridor-presentation-Full-version.pdf

8 Projects of Common Interest (PCIs) are intended to help the EU achieve its energy policy and climate objectives: affordable, secure, and sustainable energy for all citizens and long-term decarbonization. Source: https://energy.ec.europa.eu/topics/infrastructure/projects-common-interest/key-cross-border-infrastructure-projects_en

A recent study by the Gas for Climate consortium—using a methodology based on optimising a single European energy system—estimated the cost savings resulting from a pan-European hydrogen network over the 2030 to 2050[9] timeframe to be as high as €330 billion as compared with a more isolated cluster approach (see Figure 3).[10] Here, it becomes clear that an integrated pan-European hydrogen network contributes to an affordable energy supply, supporting the most competitive integration of large-scale variable renewable energies and strengthening Europe's security of supply.[9]

Figure 3

A comparison of the clustered vs. interconnected hydrogen network approach in the S1 scenario.[11]



9 Gas For Climate (2023). Assessing the benefits of a pan-European hydrogen transmission network. Source: https://gasforclimate2050.eu/wp-content/uploads/2023/03/2023_Assessing_the_benefits_of_a_pan-European_hydrogen_transmission_network.pdf

10 Based on supply and demand data from the 2022 Ten Year Network Development Plan (TYNDP), factoring an adjustment for the phase-out of Russian supply and consideration of REPowerEU targets, the study shows that total cost savings could reach €330 billion. These cost savings are mainly attributed to the ability to source hydrogen from the most economical regions, while additional savings can be attributed to lower investment requirements for electricity generation, storage, and transmission capacities.

11 The S1 scenario is the TYNDP Global Ambition scenario.

2. Current EHB progress to date

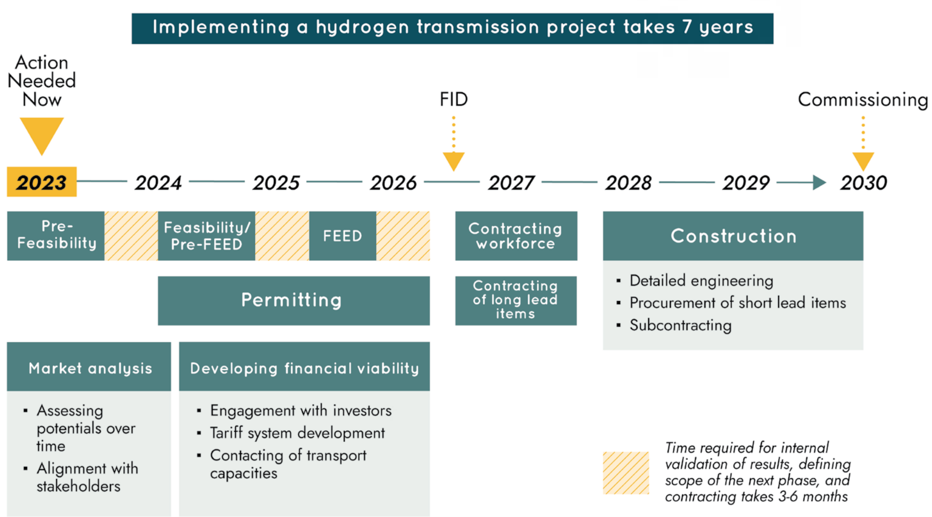
EHB members are central actors enabling hydrogen's role in decarbonising the European energy system. Amidst large-scale economic, geopolitical, and regulatory changes, these TSOs are moving forward with project development and working to turn the EHB vision[12] into a tangible reality.

2.1 Typical hydrogen infrastructure project timelines

Figure 4 shows a representative implementation timeline for the types of transmission projects comprising the EHB. This timeline shows that urgency and speed is essential for realising Europe's decarbonisation goals for 2030. Project-specific timelines likely vary depending on the jurisdiction, size, and complexity of a project, as well as established corporate and national procedures. On average, implementing a hydrogen transmission project implementation takes 7 years from initiation to commissioning.

Figure 4

A representative timeline for transmission project implementation.



The most important milestone of any project is the Final Investment Decision (FID). The building blocks of the timeline prior to FID are intended to address the technical and financial complexities of a project. In addition to technical studies and permitting, market and financial analyses are important. The main objective is to ensure that the project will generate a sufficient return to cover the investment. The costs incurred before FID are referred to as DEVEX and are assumed to be a couple percentage of the total CAPEX of a project. The EHB's members are currently working proactively with policymakers and industry to ensure FIDs can be taken at a speed in line with Europe's decarbonisation ambitions.

12 Note, on a national level, continual discussions are being held on the development of national grids. These discussions could lead to a deviation from the current EHB vision.

2.2 Overall network development and project timelines

Projects initiated by the EHB members have been planned in close cooperation with industry stakeholders and regulators and are anticipated to receive strong support at the national and international level. Most of these projects are already in the early phase of development and are expected to be operational between 2029 and 2031 (see Figure 5).

The projects currently in the front-end engineering design (FEED) phase are expected to be operational within a couple of years. If FID is taken, these projects will establish the first 4.000 km of the European hydrogen transmission network. In total, 40 projects are expected to be commissioned in by the start of the next decade.

Figure 5

Anticipated kilometers of commissioned hydrogen pipelines, per year.

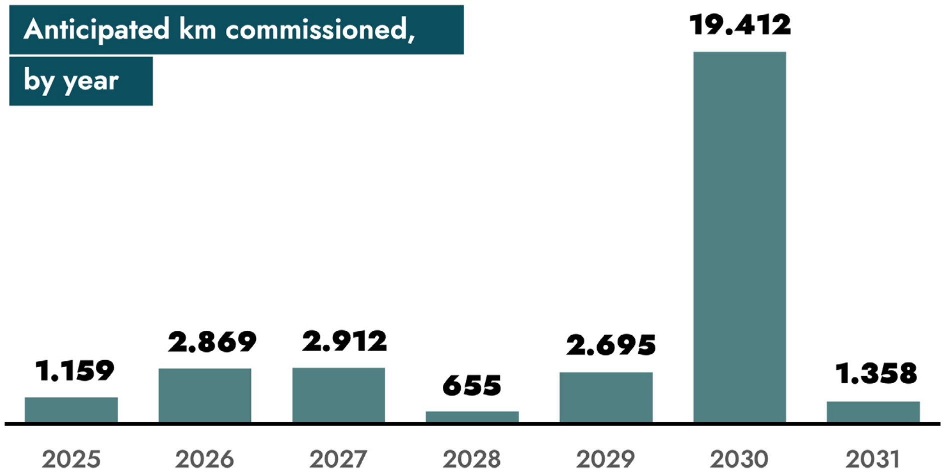
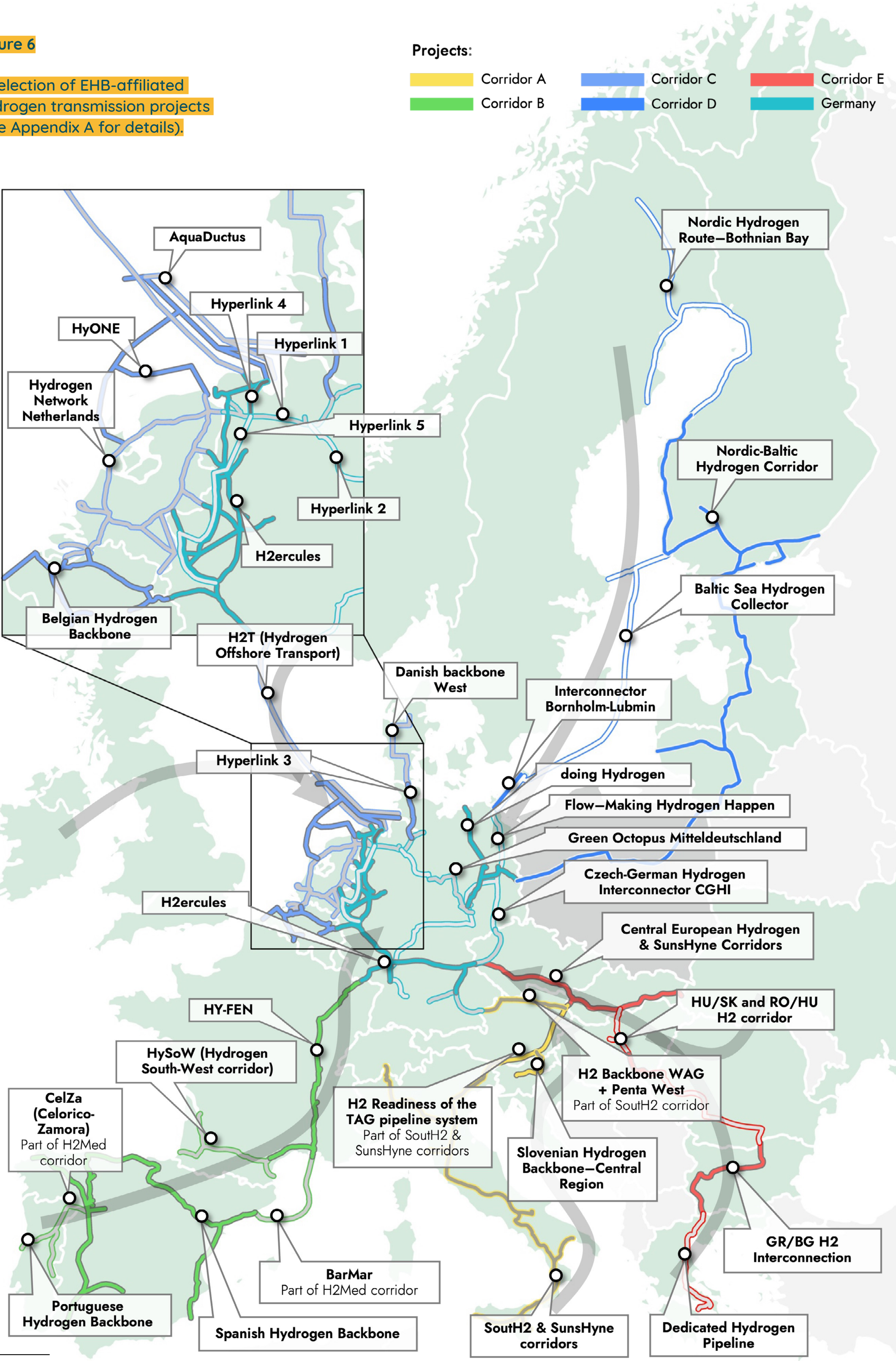


Figure 6

A selection of EHB-affiliated hydrogen transmission projects (see Appendix A for details).



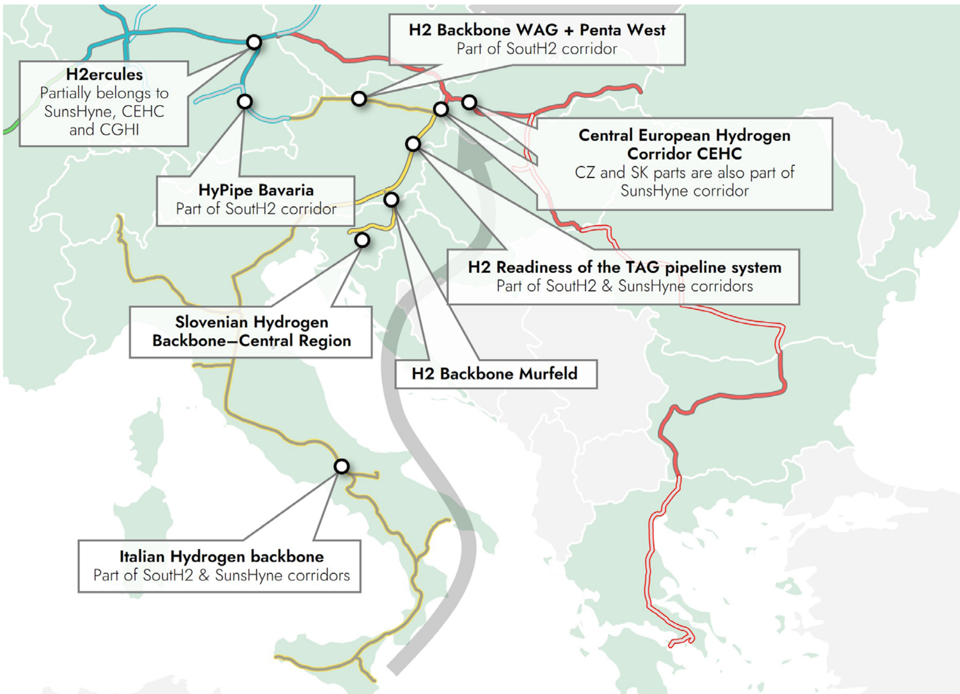
2.3 Corridor-specific development

The next sections provide in-depth information about projects planned for commissioning by EHB partners in the coming years.[13] The projects are arranged and color-coded by corridor. The transmission network in Germany is included separately because that would otherwise have been discussed in multiple corridors. For more detail about the projects included in the sections below see the Appendix A: Selected Projects to Create EHB by Early 2030s.

3.3.1 Corridor A — North Africa and Southern Europe

Figure 7

Corridor A development (selected projects).



Corridor A is intended to deliver low-carbon hydrogen from North Africa and Southern Italy towards Central Europe. Overarching initiatives such as the *SunsHyne Corridor* and the *SoutH2 Corridor* combine multiple national projects into bigger alliances that enhance political support and enable them to benefit from a streamlined permitting process as well as pursue a value-for-money framework through mechanisms such as the Projects of Common European Interest (PCI). The very broad support and exchange of stakeholders along the entire value chain—from production to consumers—is a success factor for the development of the favourable production areas in North Africa. Focusing on the development within specific countries, green hydrogen from North Africa will first be injected to the *Italian Hydrogen Backbone*, consisting of approximately 2.300 km of pipeline (of which 75% is repurposed). After serving domestic demand in Italy, hydrogen will be moved into additional central European countries. Within Austria—in addition to serving domestic demand—hydrogen will be transported

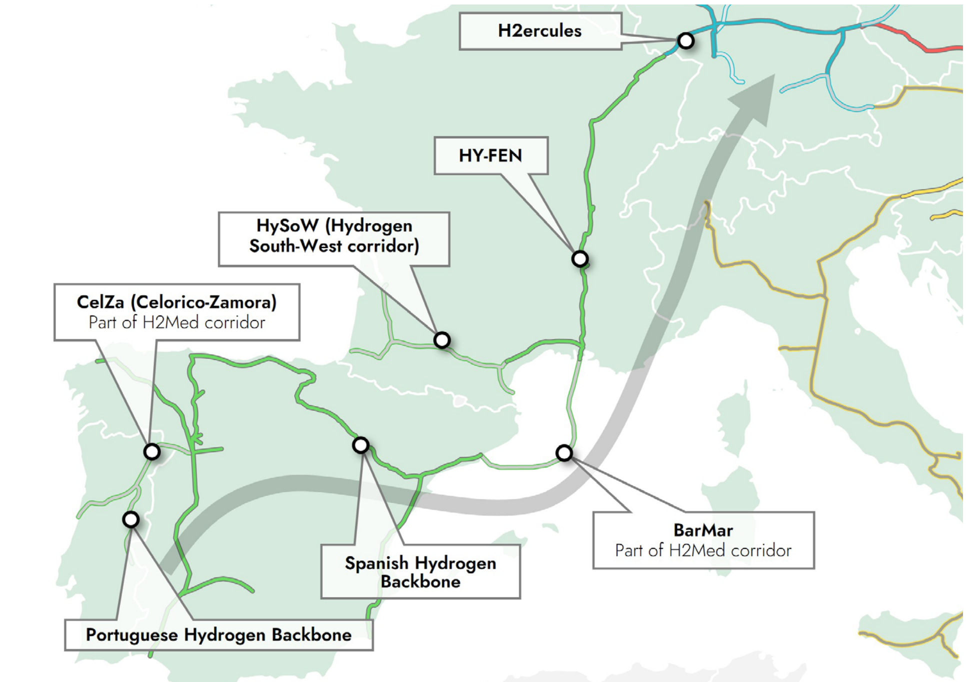
13 These maps do not provide a complete overview of projects in each region. There are additional projects in development that are not shown.

via one repurposed *TAG pipeline, WAG,* and *Penta West pipeline* towards Germany and connected to storage facilities along the route. HyPipe Bavaria in Germany finally forms the link between Austria and the German Hydrogen Backbone. The route from Austria via Slovakia and Czech Republic to Germany is fully made up by repurposed pipelines and will serve demand centres along the corridor. Additionally, a connection to the Slovenian Hydrogen Backbone will not only supply national demand but also enable further connection to Croatia. Furthermore, the SunsHyne corridor will be used to serve hydrogen demand in Slovakia and Czechia. When needed, the connection to Hungary can also serve demand in southern Europe.

3.3.2 Corridor B — Southwest Europe and North Africa

Figure 8

Corridor B development (selected projects).

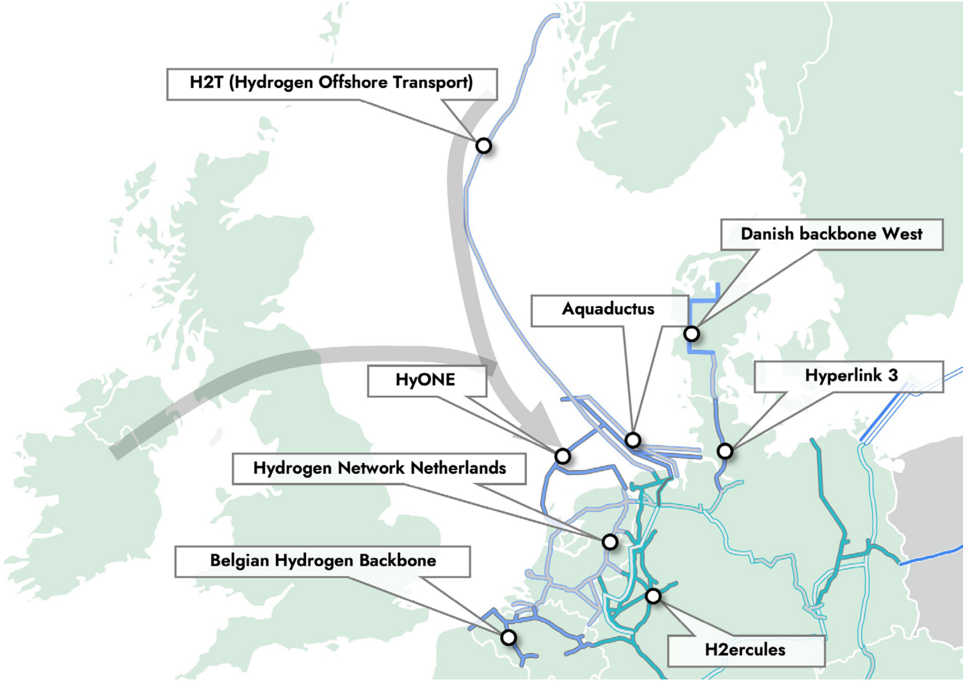


The Southwest Europe & North Africa Corridor aims to transport hydrogen to demand centres in Germany and beyond, through the H2ercules project. Within Corridor B, *H2Med* is the overarching project connecting hydrogen networks in Portugal, Spain, France, and Germany. It consists of the *CelZa* project in Portugal that connects hydrogen producers such as the *Green H2 Valley* to the *Spanish Hydrogen Backbone*. The Spanish Hydrogen Backbone collects multiple supply sources from around Spain and allows connection to North African project developments, making it one of the most promising hydrogen production locations in Europe. To transport planned supply volumes to the main demand centres of Europe, the connection into France is essential. The *BarMar* project circumvents geographic challenges of the Pyrenees by traversing the Mediterranean Sea as an offshore pipeline from Barcelona to Marseille. From Marseille onwards, the hydrogen network branches into two directions, through France with *HySoW* towards the Atlantic coast and as connection to Western European countries via *HyFen*.

3.3.3 Corridor C — North Sea

Figure 9

Corridor C development (selected projects).

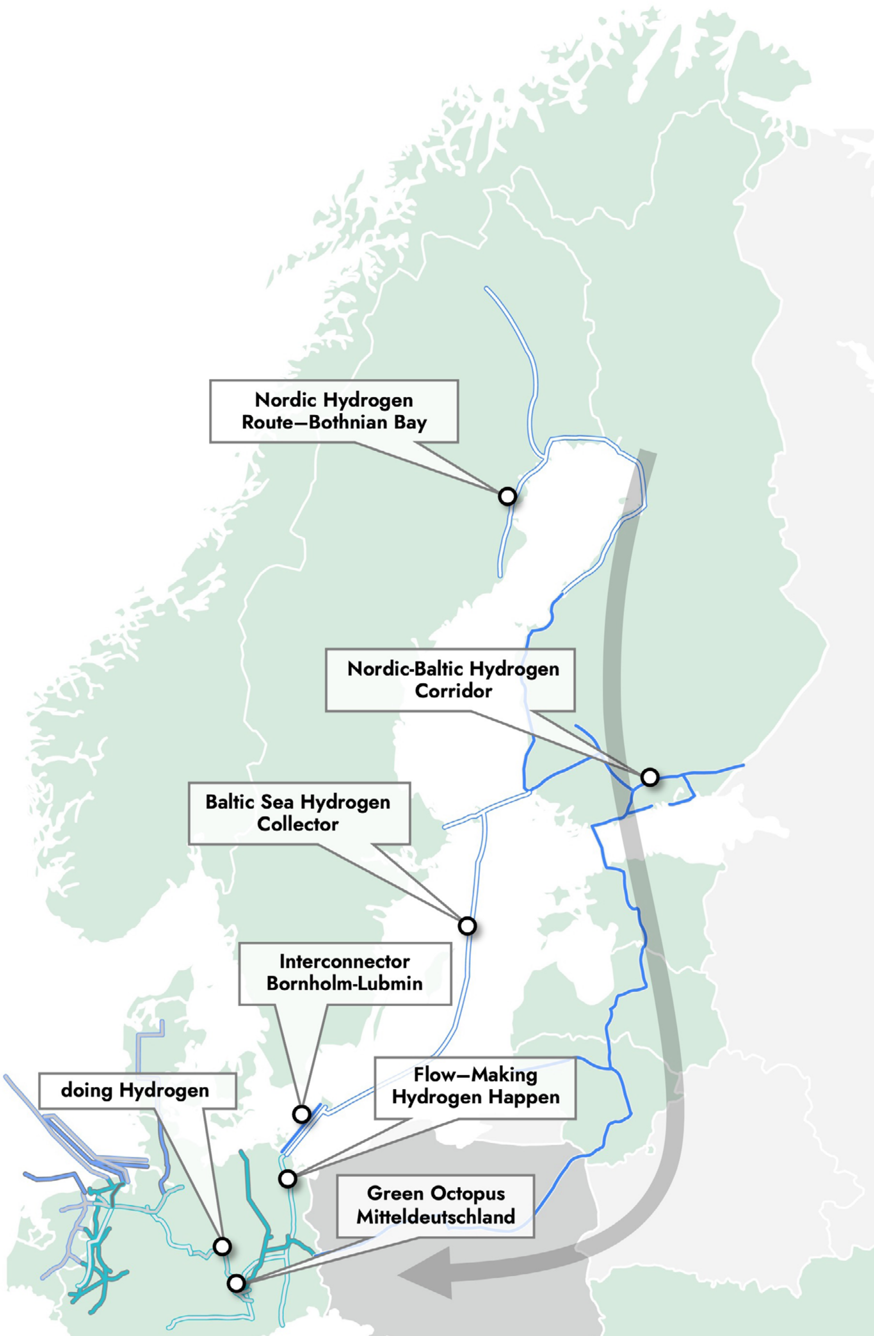


The North Sea Corridor aims to expedite the delivery of hydrogen to demand centres in the western part of Germany. A primary energy feedstock for hydrogen in this corridor is provided by the vast offshore wind potential in the region. With this aim, *H2T* envisions to develop a pipeline from Norway in close collaboration with the German and Norwegian government. Nearby, the *Danish-German Hydrogen Network* intends to transport hydrogen via a 561 km onshore pipeline through Denmark into the north of Germany. Additional offshore wind energy from the North Sea is brought to the German coastline with hydrogen initiatives such as *HyOne* and *AquaDuctus* in which hydrogen will be produced offshore and will be transported via pipelines to the mainland. Entities in Corridor C also envision supplying hydrogen in this corridor by importing hydrogen derivatives via ports such as Rotterdam and Antwerp. Additionally, to transport hydrogen across the mainland and into Europe, projects such as the *Belgium Hydrogen Backbone* and the *Hydrogen Network Netherlands* are progressing rapidly—the *Belgium Hydrogen Backbone* is in the FEED phase, while the *Hydrogen Network Netherlands* has already taken FID. The construction of the Hydrogen Network Netherlands has started on 27th of October.

3.3.4 Corridor D — Nordic and Baltic Regions

Figure 10

Corridor D development (selected projects).

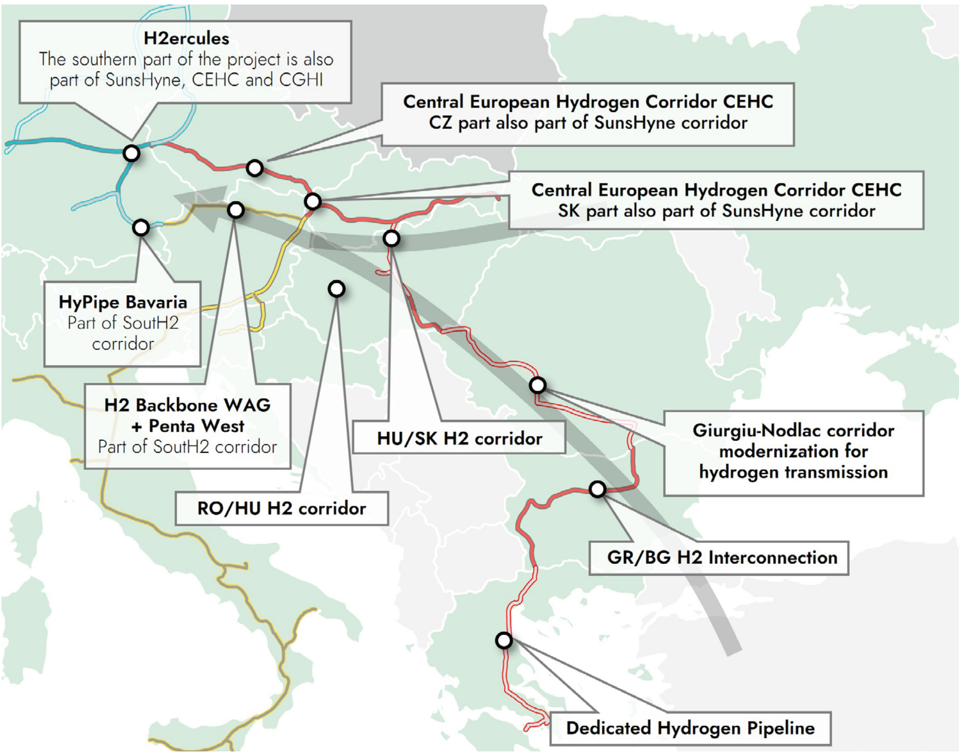


The Nordic and Baltic regions have significant renewable energy resources based on low-cost renewable energy. The availability of land and water for hydrogen production makes the region lucrative for hydrogen projects and new P2X (Power-to-X, the process of turning hydrogen into something else) industries. Therefore, three major projects are planned to connect with demand regions. The *Nordic Hydrogen Route-Bothnian Bay* connects the northern parts of Finland and Sweden with their abundant renewable energy resources (onshore and offshore wind) to demand centers in these regions. It is also connected to the onshore *Nordic-Baltic Hydrogen Corridor* project, which connects the future Baltic hydrogen market with Germany. The offshore *Baltic Sea Hydrogen Collector* offshore project, which connects Finland, Sweden, and Germany, as well as the energy islands in the region, will link the vast offshore wind resources to be used for hydrogen production with demand in Western and Central Europe. The offshore project might also be connected to the *Bornholm-Lubmin* interconnector in Denmark.

3.3.5 Corridor E — East and Southeastern Europe

Figure 11

Corridor E development (selected projects).

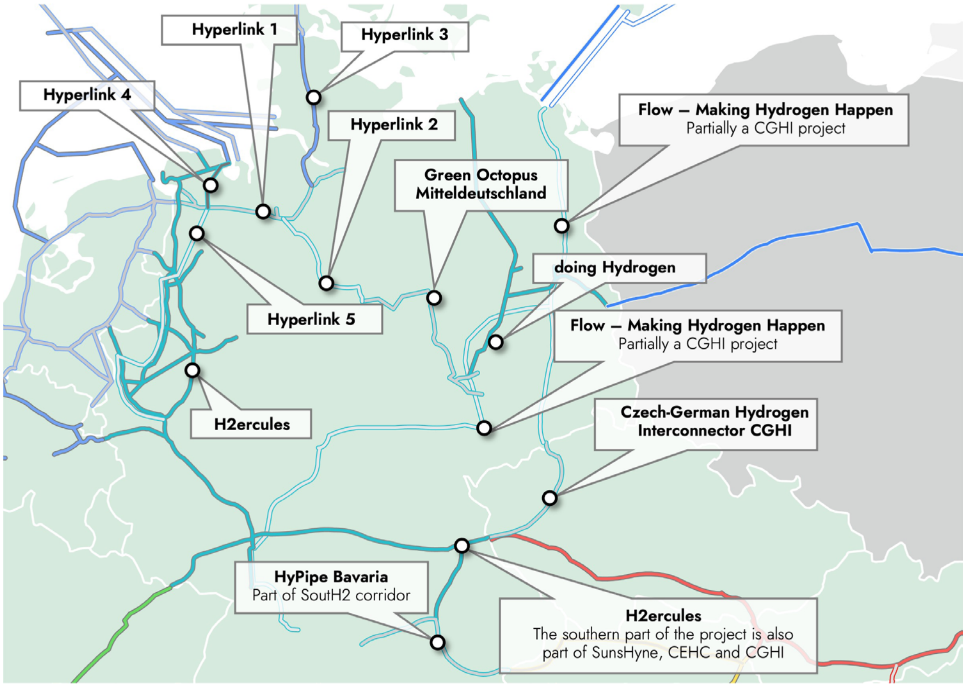


Corridor E—the East and Southeastern corridor—enables the transport of hydrogen from Greece or from Ukraine through Bulgaria, Romania, Hungary, Slovakia, and Austria to Central Europe. Projects already under development include the *RO/HU H2 corridor*, the *HU/SK H2 corridor*, and the *Central European Hydrogen Corridor (CEHC) or the H2EU +Store initiative*. Each of these projects is currently in the pre-feasibility phase and are all aiming to be operational in 2030. A significant part of these projects also directly interfaces with other neighboring initiatives, such as the *SunShyne Corridor* and the *SoutH2 Corridor*, where they enable transport of hydrogen from East and Southeastern Europe as well as from Northern Africa through Corridor A. To enable flows in all these directions, there is a need for technical flexibility of the transmission system, especially in Slovakia and Austria.

3.3.6 Transmission Network in Germany

Figure 12

Development of the network in Germany (selected projects).



Germany is part of all EHB corridors and is therefore discussed separately here. Germany is expected to import large amounts of hydrogen to meet the largest national hydrogen demand. Development of the network in Germany (selected projects). shows the key projects of some German TSOs as part of the planned *Hydrogen Core Network,*[14] which will enable the connection of domestic hydrogen production and neighboring countries for hydrogen imports to the demand centers. The German TSOs are closely cooperating on several projects in Germany, the Netherlands, Belgium, France, Norway, Austria, Denmark, and the Czech Republic.

The German TSOs work closely with FNB Gas e.V.[15] and the Federal Ministry of Economics and Climate Action (BMWK) to coordinate the development of *the Hydrogen Core Network*. As of July 2023, the total length of the network is expected to be about 11.200 km. The goal of the planning is to connect the key supply and demand facilities to enable an open and competitive hydrogen market. Joint planning will also enable the development of comprehensive support mechanisms to minimise and derisk investments.[16] Note that the final network is still under discussion and therefore might be updated after the publication of this report. The latest version can be found on the website of FNB Gas e.V.[17]. Development of the network in Germany (selected projects). shows only selected projects and therefore does not fully correspond to the network developed under the FNB Gas e.V. initiative.

14 FNB Gas (2023). Hydrogen core network. Source: https://fnb-gas.de/en/hydrogen-core-network/
15 The association of the supra-regional gas transmission companies.
16 Hydrogen Insights (2023). How should Germany fund its 11,200km national hydrogen network? This is Berlin's latest thinking. Source: https://www.hydrogeninsight.com/policy/how-should-germany-fund-its-11-200km-national-hydrogen-network-this-is-berlins-latest-thinking/2-1-1497289
17 https://fnb-gas.de/en/

3. Update of pipeline infrastructure costs

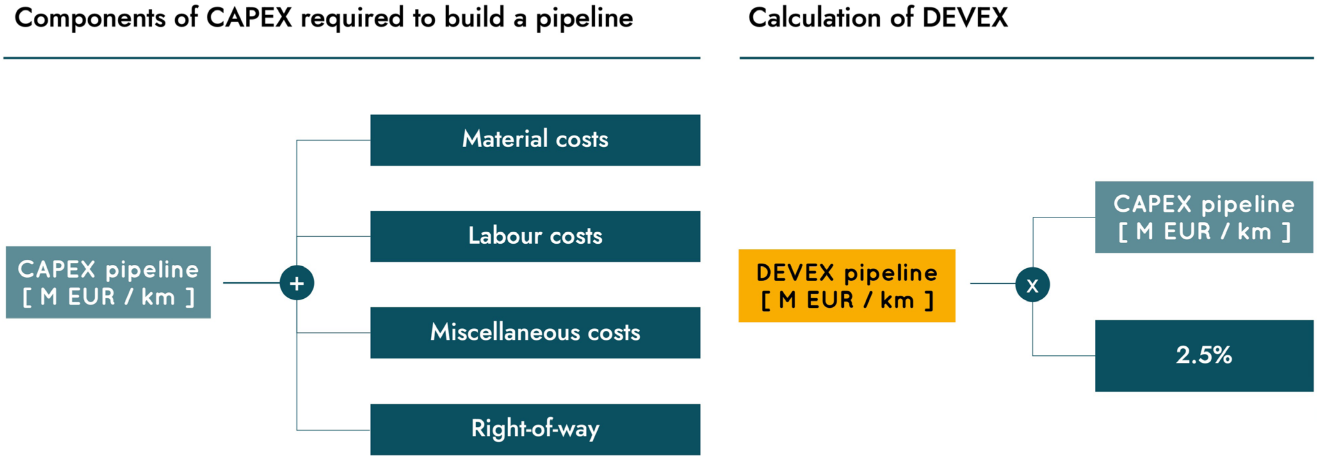
In 2020, the EHB published first-of-its-kind cost data for hydrogen pipeline infrastructure, outlining the costs associated with pipelines of different sizes, onshore versus offshore, and new versus repurposed. This data has been circulated around the world, being utilised by commercial actors, research institutions, planners, policymakers, and others. Given recent developments to the global economic picture—whether COVID, geopolitical, or climate-related—the EHB has undertaken an effort to provide updated cost information to keep project development, planning, and policy efforts as current and accurate as possible. In this section, we provide a discussion of CAPEX relating to pipeline and compressor costs.

3.1 Cost inputs and results

The 2023 cost update included a survey of TSOs to estimate the costs associated with each of the components necessary to build out pipeline infrastructure. Broadly speaking, these components include material costs, labour costs, costs to acquire rights-of-way, and miscellaneous additional costs. DEVEX were calculated as a percentage of the total CAPEX costs. A simple schematic of the CAPEX calculation methodology can be seen in Components included in the calculation of CAPEX and DEVEX..

Figure 13

Components included in the calculation of CAPEX and DEVEX.

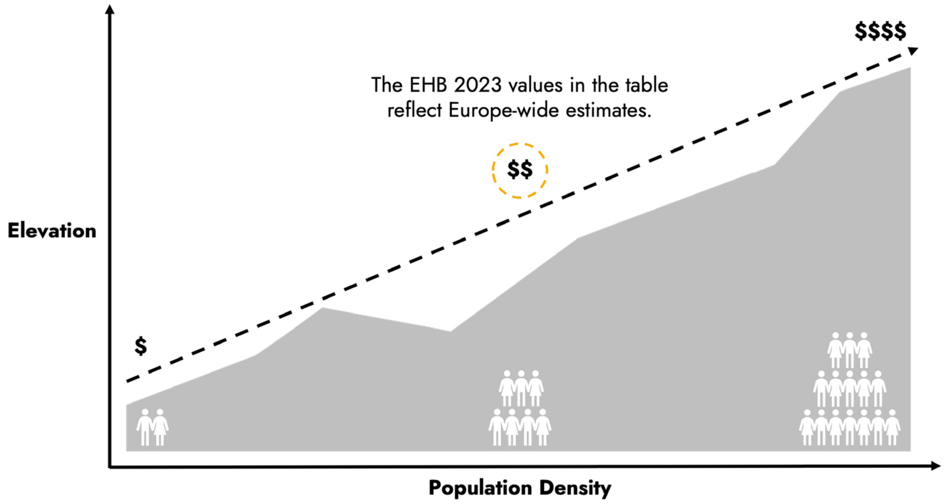


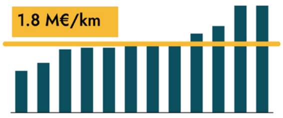
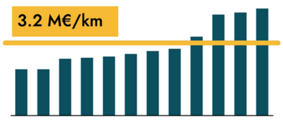
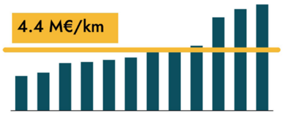
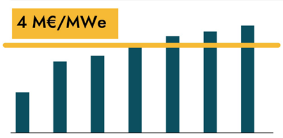
EHB member TSOs—the stakeholders most familiar with real-world hydrogen infrastructure implementation—provided primary data to inform this cost update. The collected data originates from a variety of sources, including vendor quotes, pre-feasibility studies, real project data, and internal budgeting departments. Additionally, we used an external model,[18] historical project database,[19] and commercial studies[20,21] to corroborate and validate TSO data. To account for varying data quality and specificity, we categorised collected data by level of rigor—assigning different weights to the various source types and creating weighted average cost values for pipelines of different sizes. In this process, TSO primary data was given a stronger weighting than external models and studies. Within collected TSO data, real project cost data was valued with a higher weighting than costs from pre-feasibility studies and the assumptions from internal budgeting departments.

Figure 14 provides comparison of the new and previous EHB cost assumptions for new-build onshore pipelines and compressors. The graph above the table displays how the costs of a pipeline can be influenced by external factors (e.g. population density and elevation). The EHB 2023 values in the table are reflected of Europe-wide estimates. Although the data distribution has been anonymised for confidentiality purposes, the visualisation does reflect the true nature of the collected data. The yellow line represents the current assumption of EHB network costs.

Figure 14

Visualisation of data received from EHB members for new pipeline and new compressors costs.



Visualization data distribution	CAPEX of category	2019 EHB values	2023 EHB values	Standard deviation
 1.8 M€/km	20″ new onshore pipes	1.5 M € / km	1.8 M € / km	0.4 M € / km
 3.2 M€/km	36″ new onshore pipes	2.2 M € / km	3.2 M € / km	0.9 M € / km
 4.4 M€/km	48″ new onshore pipes	2.8 M € / km	4.4 M € / km	1.6 M € / km
 4 M€/MWe	New compressor	3.4 M € / MWe	4 M € / MWe	1.2 M € / MWe

▬ = 2023 EHB values, based on weighted average

18 Khan, M.A., Young, C. and Layzell, D.B. (2021). The Techno-Economics of Hydrogen Pipelines. Transition Accelerator Technical Briefs Vol. 1, Issue 2, Pg. 1-40. ISSN 2564-1379.
19 Energy Information Administration (2023). U.S. natural gas pipeline projects. Source: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.eia.gov%2Fnaturalgas%2Fpipelines%2FEIA-NaturalGasPipelineProjects.xlsx&wdOrigin=BROWSELINK
20 DNV (2023). Specification of a European Offshore Hydrogen Backbone. Source: https://www.gascade.de/fileadmin/downloads/DNVStudy_Specification_of_a_European_Offshore_Hydrogen_Backbone.
21 Strategy& (2021). HyWay 27: hydrogen transmission using the existing natural gas grid?

Not visualized in Visualisation of data received from EHB members for new pipeline and new compressors costs. (but compiled using the same method), TSO data shows that repurposed 20″ pipelines represent 30% of the cost of new pipeline deployment. For all other sizes, repurposing costs are approximately 20% of the cost of new pipeline construction. (Note that this 20% repurposing cost assumption is in line with previous EHB values). For offshore pipelines, we retain the previous EHB assumption, indicating that these kinds of pipelines cost approximately 1.7x more than similarly sized onshore pipes. Detailed cost results by size and type of pipeline can be seen in EHB CAPEX Assumptions.

Table 1

EHB CAPEX Assumptions

Parameter		**CAPEX costs** (M€/km for pipelines and M€/MWe for compressors)
New pipelines	20″ onshore pipes	1.80
	36″ onshore pipes	3.20
	48″ onshore pipes	4.40
	36″ offshore pipes	5.44
	48″ offshore pipe	7.48
Repurposed pipelines	20″ onshore pipes	0.54
	36″ onshore pipes	0.64
	48″ onshore pipes	0.88
	36″ offshore pipes	1.09
	48″ offshore pipe	1.50
Compressor station		4.0

It is important to note that although this report presents the latest cost estimates for hydrogen infrastructure within Europe, the numbers are based on three broad financial assumptions:

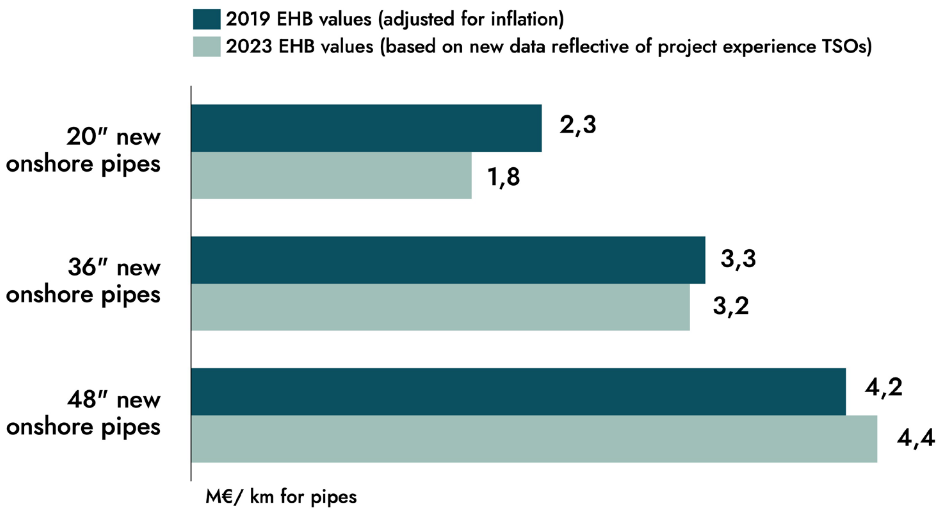
1. **EHB cost data reflects a Europe-wide estimate.** Europe-wide estimates are reasonable to use in EHB calculations due to the diversity of pipelines in the pan-European grid. However, these assumptions might not apply to individual projects, given the diverse terrain or required infrastructure in differently populated regions. Regions with greater population density or mountainous geography might encounter costs toward the higher end of these ranges, while more sparsely populated or with flatter or less complex terrain will likely be able to take advantage of lower values.
2. **Limited empirical data exists regarding large-scale hydrogen transmission pipelines in Europe.** While gas transmission pipeline data can be extrapolated, uncertainties regarding operating pressure, pipeline materials, etc., contribute to uncertainty for hydrogen-specific costs. As described previously, TSO data is consolidated across all responses and compared with existing studies to reduce any potential bias. However, the data still relies on estimates underlied by a limited amount of empirical data.
3. **Material and labour costs account for 70%-80% of transmission pipeline and compressor expenses.** Consequently, future cost developments are strongly tied to the development of steel prices, energy prices, inflation, and workforce dynamics. Overall, it is the EHB's aim to estimate and monitor the true cost of a pan-European hydrogen network, enabling this research to provide value for real pipeline network planners and implementers.

3.2 The impact of inflation

While prices in this update are nominally higher than the costs cited in 2020, Figure 15 shows that the bulk of the cost increase—as compared with previous EHB publications—can be attributed to inflation. To corroborate this assertion, the figure portrays the previous EHB assumptions adjusted for sector-specific inflation,[23] leading to CAPEX numbers that are approximately equal to the new EHB values.

Figure 15

Comparison of 2019 EHB assumptions (adjusted for inflation compared) to EHB 2023 assumptions (based on new data reflective of project experience of TSOs) show costs increase are largely due to inflation



A comparison of Eurostat data[24] on producer price indices by sector shows that the gas pipeline and electricity transmission sectors (and their associated raw materials) have seen an equivalent rise in prices on account of recent inflation.

Considering this cost increase, the primary aim of policy makers should be to enable sufficient investment in infrastructure across all energy carries. Both electricity and hydrogen infrastructure have an important role to play in decarbonising the European energy system. However, with regard to hydrogen, several studies conclude that it is more cost-efficient to install electrolysers close to renewable power generation and then use pipelines to transport hydrogen to the point of consumption than it is to install electrolysers close to hydrogen demand and consequently power electrolysers through the electricity grid.[25,26,27] Given our observation that the inflation has impacted both hydrogen pipelines and electricity transmission infrastructure, we believe this conclusion still holds true.

23 Inflation numbers are based on producer prices in industry – specifically for manufactures of tubes, pipes, hollow profiles and related fittings, of steel. Eurostat (2023). Producer prices in industry. Source: ttps://ec.europa.eu/eurostat/databrowser/view/STS_INPP_A__custom_6529451/default/table?lang=en
24 All producer price indices are based on Eurostat data, indicating—since 2019—a 47% increase in prices for manufacture of tube pipes, hollow profiles and related fittings of steel; a 48% increase for copper production; a 52% increase for aluminium production; and a 125% increase in electric power generation, transmission and distribution: ec.europa.eu/eurostat/databrowser/view/STS_INPP_A__custom_8023762/default/table?lang=en
25 International Energy Agency (2023). Energy Technology Perspective 2023. Page 320. Source: https://iea.blob.core.windows.net/assets/a86b480e-2b03-4e25-bae1-da1395e0b620/EnergyTechnologyPerspectives2023.pdf.
26 Gas For Climate (2023). Assessing the benefits of a pan-European hydrogen transmission network. Page 6. Source: https://gasforclimate2050.eu/wp-content/uploads/2023/03/2023_Assessing_the_benefits_of_a_pan-European_hydrogen_transmission_network.pdf.
27 EHB (2021). Analysing future demand, supply, and transport of hydrogen. Page 81. Source: https://ehb.eu/files/downloads/EHB-Analysing-the-future-demand-supply-and-transport-of-hydrogen-June-2021-v3.pdf

4. Conceptual framing of the financial challenge

Upfront CAPEX and DEVEX costs are just a part of the broader financial picture of hydrogen network development. Conceptually, the EHB network is likely to encounter two distinct financial phases during its operation that are strongly linked to the development of the European hydrogen economy (*Figure 16*). The first of these phases represents the market ramp-up, involving limited hydrogen demand and low hydrogen capacity booking on the network. The capacity booking of the network could consist of both long-term and short-term bookings. However, as the hydrogen economy develops and demand rises, the market will transition to the later mature market phase.

The EHB network is projected to be financially viable in the long term, given the updated unit costs explained in section 4.1 of this report and bottom-up demand development as laid out by the EHB in previous publications.[28] Given the signals of wider institutional support towards hydrogen in Europe, the financial challenges during operation discussed in the upcoming section relate primarily to the first, developmental phase of network operation. The main cause of this potential financial challenge is that demand might take time to develop, as market design enablers will take some time to be fully developed and implemented.

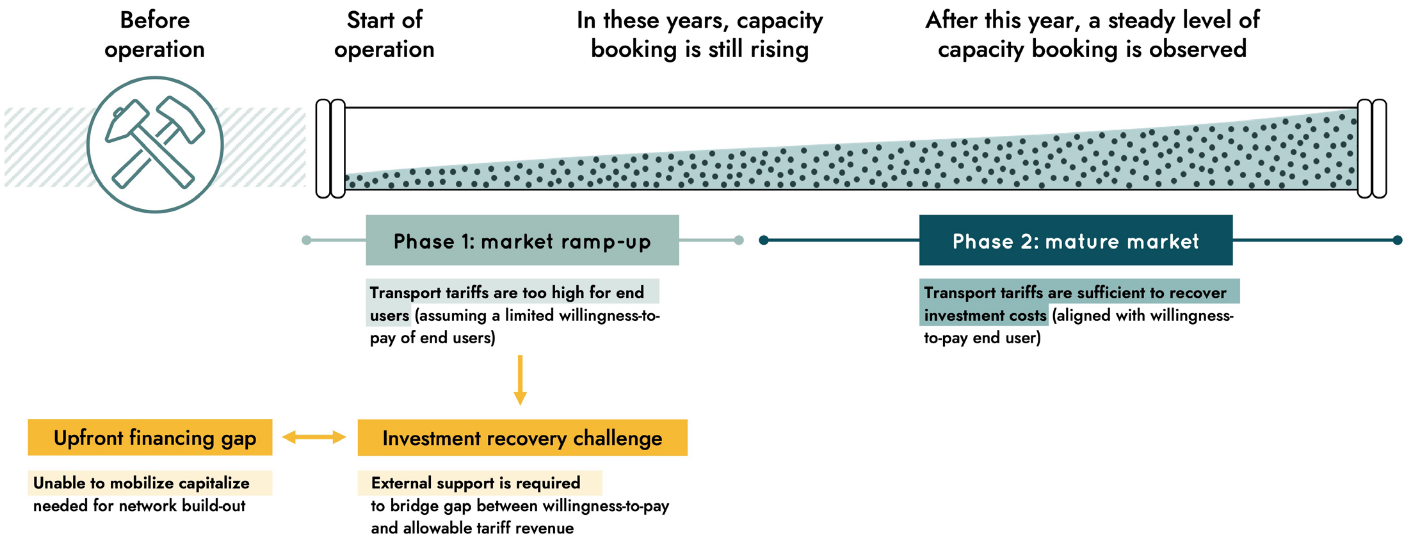
During the ramp-up phase, the EHB might therefore encounter an *investment recovery challenge (IRC),* meaning that the network might not generate the full revenue allowed by regulators under a largely similar application of existing—natural gas infrastructure-based—regulations. Operational revenue streams are necessary to refinance the costs associated with building and operating the network; therefore, the challenge is caused by low earned tariff revenue resulting from a low level of capacity bookings or uncertain network user willingness-to-pay in the initial phase. Additionally, the duration of market ramp-up might exceed the timeframe for network operators to recoup missed revenue under existing cost recovery rules.

28 EHB (2022). Five hydrogen supply corridors for Europe in 2030. Source: https://ehb.eu/files/downloads/EHB-Supply-corridor-presentation-Full-version.pdf

Figure 16

Structure of the EHB's main financial challenges

Fundamentally, the IRC can be perceived as a source of investment risk for TSOs and other EHB investors during network buildout. This perceived risk leads to a *upfront financing gap (UFG)*, which emerges if network operators are not able to mobilise sufficient market capital to develop the EHB. This section explains the fundamentals of the IRC and UFG, the impact these challenges might have on EHB buildout, and potential measures to mitigate their risks.



4.1 Investment recovery challenge — conceptual framework

As introduced earlier, the first potential financial challenge—occurring during the market ramp-up phase—is the IRC. For simplicity, we assume that the EHB network will be regulated under a typical Regulated Asset Base (RAB) model, mirroring to a large extent the current gas infrastructure regulatory framework. The RAB represents the total value of owned infrastructure and is used (alongside considerations of operating expenses and allowed maximum return on capital) by regulators to set a revenue cap each year, defining the TSOs' regulated returns based on depreciated asset value over time.

Additionally, we can estimate the revenue generated by a pipeline as the amount of booked capacity times a tariff equal to the assumed network user willingness-to-pay for hydrogen conveyance. The IRC arises from the financial disparity between the regulated revenue cap and the real revenue that can be earned from network users on account of actual network usage.

A simple way to interpret the IRC is presented conceptually in Figure 17. Note that this graph is not a reflection of the real dynamics of the entire EHB network but rather a simplification of a single pipeline, used to illustrate the structure of the IRC framing.

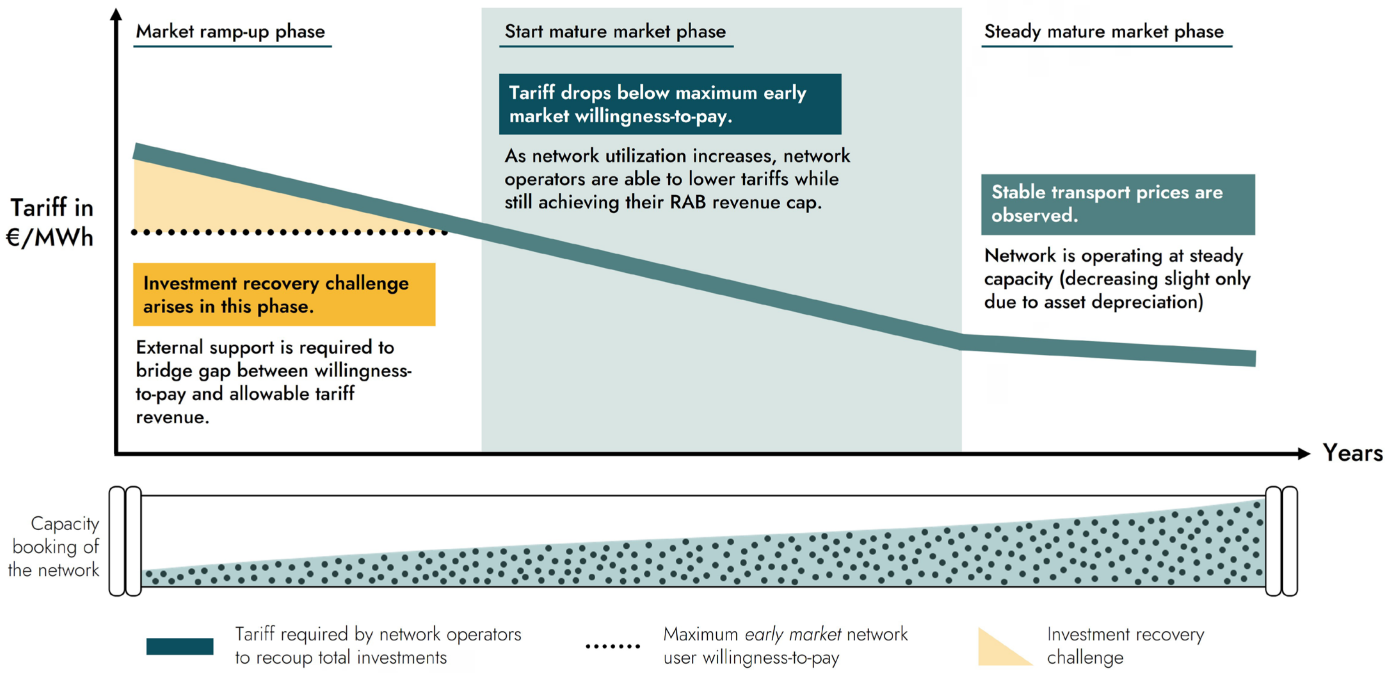


Figure 17

Level of tariff required to realise regulated return across different financial phases (utilising a single simplified pipeline model).

Represented by the yellow area on the left side of the graphic, the challenge arises during the early years of operation. Even considering the optimistic long-term financial picture, it is important to mitigate the potential effects of high early tariffs hindering hydrogen market development. Building a smaller pipeline to match the initial low hydrogen capacity booking level—while initially requiring less investment—is neither an efficient nor a competitive solution: it would fail to accommodate the expected future hydrogen flows, leading either to additional costs required to build new lines outside of the initial large-scale buildout or insufficient transport capacity and a bottleneck for Europe's decarbonisation efforts.

Conceptual IRC Example: In this simple illustrative example, assume that the regulator has set the RAB revenue cap at 100€, that the expected booked capacity is 4 MWh/y in the first year, and that the pipe can transport 20 MWh/y at maximum capacity.

The TSO is allowed to set the tariff at 25€/MWh = *100€ (RAB) / 4 MWh/y (booked capacity)*. This tariff is visualised by the yellow line at the start of market ramp-up phase. If network users are willing to pay a tariff of 25€/MWh, no IRC exists. However, due to low initial capacity booking level (and subsequently low denominator in the IRC equation), the TSOs need to ask for the calculated 25€/MWh tariff to earn back their network costs. However, such a tariff (*in this example*) is likely to be unacceptably high for first movers. Consequently, if network users are only willing to pay 10€/MWh (visualised by the blue line in Figure 17), there is a 15€/MWh = 25€/MWh – 10€/MWh difference between the tariffs required to realise the regulated return and the willingness-to-pay of (initial) network users. This scenario results in an IRC of 60€ = 15€/MWh x 4 MWh.

By contrast, in a mature market where hydrogen capacity booking level matches the maximum capacity of the pipes, the required tariff would be: 5€/MWh = *100€ (RAB) / 20 MWh/y (capacity booking level)*. This 5€/MWh is likely lower than the maximum early market end-user willingness-to-pay. After the market has matured, this would mean that tariffs are acceptable to network users while also allowing TSOs to recover their investments.

4.2 Upfront financing gap — conceptual framework

One consequence of an IRC—should one arise—is investor concern about the bankability of the EHB, which manifests as investment risk, preventing them from providing the necessary capital available to TSOs. While some TSOs will be able to fully fund the buildout of their portions of the EHB network, many TSOs must attract additional external capital to do so. In this report, we refer to the capacity to do so as the financing ability per TSO.

Therefore, in many cases, the UFG arises as a consequence of the projected IRC and represents the difference between the total required upfront investment *prior to project operation*[29] and the *ability of a TSO to finance the project* (Figure 18). There are cases where TSOs have sufficient capital available but are not able to invest this capital, as the IRC poses too big of a risk.

Figure 18

Definition of the UFG.

The UFG poses a particular problem for the upfront capital that is reserved for DEVEX. If TSOs do not have sufficient capital to conduct developmental activities, the timeline to build a project is directly delayed *(this is the first step in realising a project, as section 3.1 shows)*. Therefore, the UFG—which impacts the DEVEX—should be a primary concern of European policymakers aiming to achieve ambitious decarbonisation goals.

Policymakers could mitigate the challenges associated with the UFG by facilitating funding or guarantees in an amount appropriate to counter the IRC. In this way, network development could be sufficiently derisked and able to attract market-rate investment to finance its buildout.

29 Investment required prior to operation is composed of CAPEX and DEVEX.

5. What to expect from the EHB in 2024

We view investment in the EHB as a necessary step forward for achieving lowest-cost societal decarbonisation in Europe. For a new venture—especially at this scale—the path forward is likely to at times be complicated, uncertain, and involve numerous different stakeholders. Despite these challenges, the EHB effort remains a vital and strategic investment in the future of the European energy system. Hydrogen makes use of plentiful European and neighbouring resources, serves a multitude of sectors—including those typically viewed as hard to decarbonise—and provides connectivity and resilience across the continent. Simply put, the hydrogen infrastructure network is of critical importance for achieving energy transition goals while preserving the competitiveness of the EU.

In this paper, we have conceptually framed certain financial challenges that could potentially arise in the emerging hydrogen market. Future EHB efforts will explore the size of the financial commitment required for the EHB network development and compare it with the existing funding mechanisms already available for hydrogen infrastructure development. In conjunction, we aim to examine the current and future role of the EU and member states in funding the EHB.

Beyond the financial challenges, there are a variety of considerations related to the hydrogen value chain and project delivery process that could help to enable the timely and efficient implementation of the EHB. Each of these ecosystem factors contributes to the success of the emerging hydrogen market, and in turn provides some measure of risk mitigation for financiers by streamlining the process and encouraging hydrogen market development. Future EHB efforts will also recap the current understanding of these supplemental and ecosystem considerations, with recommendations for an efficient path forward to implementation.

6. Appendix

6.1 Appendix A: selected projects to create EHB by early 2030s

Overview of selected projects planned for commissioning by early 2030s.

6.1.1 Corridor A — North Africa and Southern Europe

Italian Hydrogen Backbone (part of SoutH2 and SunsHyne Corridors)
Project partners: Snam
Development phase: Pre-feasibility phase / feasibility phase

The project includes the development of a hydrogen backbone from Sicily to the export points with Austria and Switzerland, enabling the transport of hydrogen produced in Northern Africa and Southern Italy to the main national and European consumption areas. The project supports creation of an interconnected EU hydrogen market, ensuring diversification and security of supply and positioning Italy as a hydrogen hub.

The Italian Hydrogen Backbone will be approximately 2,300 km long with around 75% share of repurposed pipelines and up to 500 MW of compressor stations. The project would be a major European renewable hydrogen import artery, serving Italian demand clusters and enabling exports towards Central and Western European countries via Austria and Switzerland. Snam is currently analysing the possibility of converting depleted gas storage fields into hydrogen storage sites that could complement the backbone to mitigate the volatility of the increasing RES production and provide flexibility to the power system.

SoutH2 Corridor
Project partners: Snam, TAG, Gas Connect Austria and bayernets
Development phase: Pre-feasibility phase / feasibility phase
Website: https://www.south2corridor.net/

The SoutH2 Corridor project is a 3300 km hydrogen pipeline connecting North Africa, Italy, Austria, and Germany. Led by TSOs that each submitted Project of Common Interest submissions to the European Commission, it aims to supply competitive renewable hydrogen to European demand clusters. It utilises >70% repurposed infrastructure, with new pipeline segments where necessary. The corridor has trilateral political endorsement, as well as strong support from companies involved in production (ca. 2.5 Mt/y) and offtake of hydrogen along the whole corridor. The SoutH2 Corridor plays a vital role in enabling the transportation of both imported and domestically produced hydrogen.

SunsHyne Corridor

Project partners: Snam, TAG, Eustream, NET4GAS, OGE
Development phase: Pre-feasibility phase
Website: https://www.sunshynecorridor.eu/

The SunsHyne Corridor is a strategic infrastructure initiative promoted by a group of five leading TSOs – Snam, TAG, Eustream, NET4GAS, OGE – whose ambition is to enable hydrogen flows from North Africa to Germany supplying and crossing Italy, Austria, Slovakia, and the Czech Republic. The corridor has a total length of 3.400 km, a share of 85 % repurposed pipelines, and aims to offer a capacity of minimum 126 GWh/d in 2030. Each TSO has applied for the status of Project of Common Interest. Due to its strategic location, the SunsHynde Corridor will not only enable the development of a common hydrogen market in Italy, Slovakia, the Czech Republic, and Germany but also in wider Central and Eastern Europe, supporting competition and security of supply.

H2 Readiness of the TAG Pipeline System (part of SoutH2 and SunsHyne corridors)

Project partners: TAG
Development phase: Feasibility phase

The project connects the hydrogen pipeline at the Italian-Austrian border (Arnoldstein) with those at the Austrian-Slovakian border (Baumgarten). It consists of repurposing one of the three existing natural gas pipelines of the TAG system to 100% hydrogen, with all associated facilities between Arnoldstein and Baumgarten. There, it will be connected to the H2-WAG pipeline within Austria to supply central Austria and southern Germany and will be connected to EUSTREAM's hydrogen pipeline.

The bidirectional design of TAG's 380 km hydrogen pipeline meets the local needs of customers in Austria and enables Italy, Germany, Slovakia, Czech Republic, and all of central and eastern Europe to develop a common hydrogen market, promoting competition and security of supply. The system is optimised to transport hydrogen from the Snam system at 168 GWh/day capacity from low-cost production areas in North Africa.

H2 Backbone WAG + Penta West (part of SoutH2 corridor)

Project partners: Gas Connect Austria
Development phase: Feasibility / Pre-FEED phase
Website: https://h2backbone-wag-pw.at/en/home-english/

With the realisation of the project bidirectional cross-border hydrogen transport possibilities between Slovakia and Austria as well as between Austria and Germany to the extent of 150 GWh/day (55 TWh/a) are established. The project connects part for South-North as part of the SoutH2 Corridor initiative and East-West as part of the H2EU+Store initiative. The project would enable hydrogen from the south via the TAG-hydrogen pipeline systems in the Baumgarten node. This setup allows for obtaining hydrogen from different sources in the future such as North Africa, Ukraine, Germany, Romania, and Croatia. The development of this project is a precondition to address the hydrogen import need of Austria and deliver the hydrogen to the large demand centers along the route, in particular the wider area around Vienna and Linz. Additionally, the project allows for the connection to storage facilities in Austria, which helps to create security of supply with hydrogen.

Central European Hydrogen Corridor, Czech part

Project promoter: NET4GAS
Development phase: Pre-feasibility phase
Website: https://www.sunshynecorridor.eu/, www.cehc.eu

The Central European Hydrogen Corridor, Czech part (gas pipeline DN 1.400, 403 km), between the Czech/Slovak border and Czech/German border enables transport of pure hydrogen of 144 GWh/d starting by the end of 2029 and aims to create a part of a hydrogen "highway" in Central Europe for transporting hydrogen from two major hydrogen supply areas outside the EU (mainly Ukraine and North Africa) as well as the supply areas along the corridor to expected high demand clusters along the corridor, especially in Germany.

The supply corridor from North Africa will go to Germany through Italy, Austria, Slovakia, and Czechia and is developed as SunsHyne. The project is promoted by the following gas TSOs: Snam (IT), TAG (AT), EUSTREAM (SK), NET4GAS (CZ), and Open Grid Europe (DE).

The supply corridor from Ukraine will go to Germany through Slovakia and Czechia and is developed as project CEHC. The east-west corridor is promoted by four gas TSOs: Gas TSO of Ukraine, EUSTREAM (SK), NET4GAS (CZ), and Open Grid Europe (DE).

H2 Backbone Murfeld

Project partners: Gas Connect Austria
Development phase: Pre-feasibility phase
Website: https://h2backbone-murfeld.at/en/home-english/

With the realisation of the project bidirectional cross-border hydrogen transport possibilities between Slovenia and Austria to the extent of 33 GWh/day (12 TWh/a) are established. The project enables the transportation of hydrogen from the South, e.g., from Croatia via Slovenia or Italy to Austria. Hence, it contributes to the diversification of the future hydrogen supply supporting consumption areas in Austria, such as Styria, the wider area of Vienna and Linz and surrounding industrial regions in neighbouring countries.

Slovenian Hydrogen Backbone – Central Region

Project partners: Plinovodi d.o.o.
Development phase: Pre-feasibility phase

Project is the first phase of development of the Slovenian Hydrogen Backbone. The repurposed part of the project will connect the Slovenian capital Ljubljana with Austria and will lead to the first hydrogen interconnection point in Slovenia with Austria. The project will also enable the establishment of a new interconnection point with Croatia. The repurposed part of the project consists of 165 km of existing pipelines. Bidirectional capacity of the new hydrogen interconnection point with Austria is aligned with GCA and is equal to 33 GWh/day (12 TWh/a). The first phase of the project is expected to be completed by 2029.

In Germany, Corridor A connects to the H2ercules project via the SunsHyne Corridor and the SoutH2 Corridor.

6.1.2 Corridor B — Southwest Europe and North Africa

CelZa (part of H2Med corridor)[30]
Project partners: REN and Enagás
Development phase: Pre-feasibility

The CelZa (Celorico-Zamora) is part of the H2Med corridor and is about 242 km long with a bidirectional capacity of 81 GWh/d (HHV), links and supplements the development of the BarMar interconnection project, enabling the emergence of a supply corridor. With the CelZa as an enabler, REN considers a first component of the Portuguese Hydrogen Backbone with new pipelines between Figueira da Foz and Cantanhede and the repurposed portion between Cantanhede — Celorico da Beira — Monforte, allowing the connection of Green H2 Valley at Figueira da Foz and other producers along the corridor.

Portuguese Hydrogen Backbone
Project promoters: REN
Development phase: Pre-feasibility

The Portuguese Hydrogen Backbone is linked to the CelZa project and includes a new Figueira da Foz—Cantanhede hydrogen pipeline, about 50 km long, and three repurposed pipelines: Cantanhede-Mangualde (68 km of a trunkline and 8 km branch line), Mangualde-Celorico da Beira (48 km of a trunkline), and Celorico da Beira-Monforte (213 km of a trunkline plus 4 km branch line).

This project creates a condition for the production and integration of green hydrogen, both in Portugal's central inland region and in the Figueira da Foz region, which benefits from its proximity to industrial infrastructures and offshore wind production as part of the objectives pursued by the government.

Spanish Hydrogen Backbone
Project partners: Enagás
Development phase: Feasibility / Pre-FEED phase

By 2030, the proposed hydrogen network will connect the industrial clusters along the Mediterranean coast and in the north of Spain, where two underground storage projects could also link to the network. The network will also comprise pipeline axis along the Via de la Plata and Ebro Valley to harness the potential for hydrogen production from the rich renewable resources of these areas. Later, the development of the network will guarantee cohesion between the different demand regions and integrate the multiple supply points that will be distributed across the country.

Spain's long-term ambition is to be one of the main hydrogen suppliers in Europe, building on its significant solar PV, wind, and hybrid potential to produce green hydrogen. The national backbone will enable this setup by connecting with France through a new marine pipeline route from Barcelona to Marseille by 2030 and later by converting the existing connections via Irún and Larrau to hydrogen. A new connection between Portugal and Zamora (2030) is also planned.

30 H2Med partners: GRTgaz, Teréga, REN and Enagás

HySoW (Hydrogen South-West corridor of France)
Project partners: Teréga
Development phase: Pre-feasibility

The project has a capacity of 0.40 Mt/y and consists of 460 km of new and 180 km of repurposed natural gas pipelines for hydrogen transport:

- Connection of the saline cavern storage facility near Lacq to the Iberian-Franco-German H2Med corridor
- Connection to the renewable energy and hydrogen production hub in Port-la-Nouvelle
- Connections to key demand centres and additional production sites in the ports of Bordeaux and Bayonne

HySoW has received explicit support from more than 37 national and international stakeholders, including public authorities (e.g., French Ministry for the Energy Transition, Région Occitanie, Région Nouvelle Aquitaine), hydrogen producers (e.g., H2V, DH2 Energy), and off-takers (e.g., Lafarge, Aerospace Valley, or BASF). Teréga is also actively cooperating with GRTgaz, Enagas, and REN on delivering the H2Med corridor.

BarMar (part of H2Med corridor)
Project partners: GRTgaz, Teréga, Enagás, OGE
Development phase: Pre-feasibility / Feasibility

As part of H2Med corridor, the BarMar project will transport up to 2 Mt/y of green hydrogen between the Iberian Peninsula and France (between Barcelona and Marseille), which is 10% of the hydrogen consumption anticipated by REPowerEU. The hydrogen will be mainly produced in the Iberian Peninsula (by RES) and then transported through the H2Med corridor to supply the industrial and mobility sectors. By 2040, some imports from North Africa are expected, which will increase the flows through this corridor. The project will allow to scale future European hydrogen markets by providing affordable and low-cost hydrogen by 2030. It will also allow for development of national backbones and storage projects along the corridor. This project is politically supported by the announcement of high officials of the European Commission, Portugal, Spain, France, and Germany.

HY-FEN
Project partners: GRTgaz
Development phase: Pre-feasibility phase

The HY-FEN project aims to develop a French hydrogen transmission network via pipeline, connecting the Iberian Peninsula (via H2Med) to Germany (H2ercules) and national storage sites by 2030. Security of supply and flexibility will be enhanced through access to UGS projects (such as GeoH2 and HySoW) and future salt cavern projects in Etrez and Tersanne/Hauterives in the Rhône Valley. HY-FEN will further enhance the Hynframed, MosaHYc, HySoW, and RHYn projects by providing access to competitive hydrogen from various sources, particularly imports. Overall, stakeholders of the mentioned projects will gain access to hydrogen volumes produced/stored outside their immediate periphery, thereby broadening the market for large hydrogen volumes. In Germany, Corridor B connects to the H2ercules project to continue supply from HY-FEN (see Section).

6.1.3 Corridor C — North Sea

Hydrogen Network Netherlands
Project partners: Gasunie
Development phase: FID taken

The objective of the Dutch hydrogen network project is to create an open access non-discriminatory national and cross-border network and for connection with large-scale hydrogen storage in northeast Netherlands. This network will be composed of 70%-80% repurposed natural gas pipelines, with the addition of new pipes in areas where connections are not yet available. Once complete, the hydrogen network will connect onshore and offshore hydrogen sources with consumers in the Netherlands, Germany, and Belgium. As such, the hydrogen network will form a vital part of the EHB and help kickstart the shift towards carbon-neutral energy in Europe.

Capacities of the total hydrogen network and the different cross-border connections will be gradually increased. The industrial clusters are planned to be connected from 2025-2026. The entire backbone will be operational from 2030 and will have a capacity between 10 GW and 15 GW.

Danish-German Hydrogen Network (Danish backbone West and Hyperlink 3)
Project partners: Gasunie, Energinet
Development phase: Feasibility / Pre-FEED phase

The 561 km project includes construction of a dedicated hydrogen pipeline between Denmark (Danish backbone West) and Germany (Hyperlink 3 project) to transport up to 10 GW of hydrogen from Denmark to end customers in Germany. The German part of the project will include repurposing of the existing natural gas infrastructure to hydrogen transportation (114 km) and construction of new hydrogen pipelines (84 km). The project Hyperlink 3 is an integral part of the Hyperlink system, developed by Gasunie as well as the future German National Hydrogen Network. It will provide a possibility to transport hydrogen from the interconnection point Ellund, domestic production sides in Schleswig-Holstein and northern Lower Saxony and hydrogen receiving terminal in Brunsbüttel, to the German final consumers as well as provide access to the underground hydrogen storage in Harsefeld, project SaltHy, developed by Storengy.

HyONE (Hydrogen Offshore Network)
Project partners: Gasunie
Development phase: Feasibility / Pre-FEED phase

HyONE focuses on offshore hydrogen transport to link the European onshore hydrogen network with offshore wind farms in the Dutch and German economic zones in the North Sea as well as offshore connections to Norway and Denmark. HyONE enables a large-scale rollout of offshore electrolysis and the ramp-up of the national and cross-border North-West European hydrogen market. It links offshore hydrogen production sites connected to Hydrogen Network Netherlands and demand centres in Western Europe and provides interconnectors to Germany, Belgium, Denmark, and potentially to the UK. HyONE is part of the CH2-4EU project, designed to enable the transport of renewable and low-carbon hydrogen along the HI West hydrogen corridor. Planned capacities are 30 GW for the network and 6 GW for the interconnector between the Netherlands and Germany.

H2T (Hydrogen Offshore Transport)
Project partners: Gassco on behalf of the H2T group[31]
Development phase: Feasibility / Pre-FEED phase

Norway wants to actively contribute to the rapid development of the hydrogen market in Germany and the EU. To realise the fastest possible import of about 4 Mt/y of hydrogen and ensure the rapid availability thereof, the country also jointly plan to use blue hydrogen for a transition period. Germany and Norway want to work together closely to ensure a reliable energy supply for Europe that is based on an increasing share of renewable energy. Both countries aim to be completely climate-neutral by mid-century, Germany by 2045 at the latest, Norway by 2050.

AquaDuctus
Project partners: GASCADE, Fluxys
Development phase: Feasibility / Pre-FEED phase

AquaDuctus will be an offshore hydrogen pipeline and connect the first large-scale offshore hydrogen wind farm site SEN-1 (up to 1 GW generation capacity) located 150 km northwest of the island of Heligoland. The 48" offshore pipeline will transport green hydrogen to Wilhelmshaven, Germany. Through an additional onshore pipeline, a direct link to Hyperlink will secure downstream connection to hydrogen users. AquaDuctus will be capable of picking up additional hydrogen quantities, e.g., from further hydrogen wind farm sites, re-powering existing wind farms, and providing the interconnection of adjacent offshore hydrogen pipelines (e.g., from DK, NL, UK or NOR) aiming for export of local hydrogen production to the European market. Hence, AquaDuctus (total length of approximately 250 km) will already be designed to transport up to approximately 20 GW of hydrogen capacity.

Belgium Hydrogen Backbone
Project partners: Fluxys
Development phase: FEED phase

Fluxys has the ambition to link hydrogen import facilities and local hydrogen production in Belgium with industrial clusters through an interconnected hydrogen backbone. This project aims to kickstart the development of the hydrogen economy in northwest Europe. The import of hydrogen in maritime ports and interconnections with adjacent countries such as Germany, the Netherlands, and France are foreseen to ensure security of supply and flexibility. Repurposing existing infrastructure is put forward to reduce the system cost of the hydrogen value chain. The first phase of infrastructure is planned for implementation in 2026.

In Germany, Corridor C connects to the H2ercules (see Chapter) to continue supply from AquaDuctus, H2T, Hydrogen Network Netherlands, and Belgium Hydrogen Backbone.

31 The H2T group is a potential hydrogen producer and infrastructure owner.

6.1.4 Corridor D — Nordic and Baltic regions

Nordic-Baltic Hydrogen Corridor
Project partners: Amber Grid, Conexus Baltic Grid, Elering, Gasgrid Finland, Ontras, Gaz System Poland
Development phase: Pre-feasibility phase

The aim of the Nordic Baltic Hydrogen Corridor project is to enable transport of 7-11 Mt of green hydrogen produced in the Nordic and Baltic Sea region to Central Europe and demand centers along the corridor covering up to 100% of REPowerEU domestic hydrogen supply targets. The corridor project aims to integrate the Nordic, Baltic, Polish, and German hydrogen markets with connecting hydrogen infrastructure and to trigger further infrastructure developments to connect additional hydrogen suppliers and consumers in these countries. The project is aiming to foster market processes between producers, consumers, and trading companies that might enter the hydrogen markets in Finland, Estonia, Latvia, Lithuania, Poland, Germany, and beyond.

The Nordic Hydrogen Route — Bothnian Bay
Project partners: Gasgrid Finland, Nordion Energi
Development phase: Pre-feasibility phase

The Nordic Hydrogen Route is an initiative between Gasgrid Finland and Nordion Energi to accelerate the creation of a hydrogen economy by building up cross-border hydrogen infrastructure in the Bothnian Bay region and an open hydrogen market by 2030. The aim of the Nordic Hydrogen Route is to drive decarbonization and support regional green industrialisation, economic development, and European energy independence. The region has abundant RES energy sources and is one of the key regions of Europe for green hydrogen production. In the Nordic Hydrogen Route project, the companies seek to develop a network of pipelines that would effectively transport energy from producers to consumers to ensure they have access to an open, reliable, and safe hydrogen market.

Baltic Sea Hydrogen Collector
Project partners: Nordion Energi, OX2, Gasgrid Finland and Copenhagen Infrastructure Partners
Development phase: Pre-feasibility phase

The Baltic Sea Hydrogen Collector will be a newly built, large-scale, cross-border, offshore, bidirectional transmission system of 1,250 km in the Baltic Sea, promoted by Gasgrid Finland Oy and Nordion Energi AB, and supported by co-investors OX2 AB (OX2) and Copenhagen Infrastructure Partners (CIP).

As one of the core systems envisioned as part of the EHB, the Baltic Sea Hydrogen Collector is an offshore pipeline project with the potential capacity of 296 TWh/y that will connect mainland Finland and Sweden with Finnish Åland island and Germany by 2030. The offshore project might also be connected to other energy islands in the region such as Gotland and Bornholm in Sweden and Denmark. The aim of the Baltic Sea Hydrogen Collector is to unlock the significant offshore wind potential in the Bothnia Bay and Baltic Sea region, creating a booming hydrogen market and connecting both supply and demand.

Interconnector Bornholm-Lubmin
Project partners: GASCADE, Energinet
Development phase: Pre-feasibility phase

The envisioned 140 km cross-border pipeline from Bornholm to Lubmin, located in the priority corridor of BEMIP Hydrogen, will connect the large-scale hydrogen production and compressor station on Bornholm with large demand centres in Germany and central Europe through GASCADE's repurposed onshore hydrogen pipeline network. The project intends to construct the first hydrogen pipeline in the Baltic Sea while supporting the emergence of an EU-wide network for hydrogen transport, giving access to multiple network users on a transparent and non-discriminatory basis. The pipeline will enable the planning of several projects developing large-scale hydrogen production on Bornholm from gigawatt-scale offshore wind in the area already by 2027. The 42" pipeline is expected to transport upwards of 4 GWel by 2028-2030 while enabling additional capacity of up to 10 GW, meaning the pipeline can furthermore enable and enhance an accelerated development of additional offshore wind in the region.

6.1.5 Corridor E — East and Southeast Europe

Central European Hydrogen Corridor CEHC[32]
Project partners: TSO of UA, EUSTREAM, NET4GAS, OGE
Development phase: Pre-feasibility
Website: www.cehc.eu

The Central European Hydrogen Corridor (CEHC) enables competitive hydrogen transport from renewable sources in Ukraine through Slovakia and the Czech Republic to Germany and further in the EU. The project aims to be operational by 2030, with later target transport capacity of up to 1.5 Mt/y (144 GWh/d). The overall length of the corridor is about 1,225 km made up of more than 90% of repurposed pipelines. The project is currently in the pre-feasibility phase, focusing on assessment of the technical feasibility and the investment required to prepare the existing natural gas infrastructure to transport hydrogen.

HU/SK Hydrogen Corridor Project
Project partners: Eustream, FGSZ
Development phase: Pre-feasibility

The project is critical for the development of EHB Corridor E, connecting southeastern Europe to the backbone. Initially, by 2030, hydrogen transported through Corridor A (Italy — Austria — Germany) can be channeled through Slovakia into Hungary for an early access to the backbone. The project also provides access for large hydrogen customers in the Transdanubian hydrogen valley to the backbone, such as refinery and fertilizer industry. The southeastern region will be a net exporter by 2040, and most of the hydrogen can be transported through this corridor to the central parts of Europe.

32 Note that Czech and partially SK parts of CEHC are also part of SunHyne Corridor, see Corridor A.

RO/HU Hydrogen Corridor Project
Project partners: Transgaz, FGSZ
Development phase: Pre-feasibility

The project is critical for the development of EHB Corridor E, connecting southeastern Europe to the backbone. The southeastern region could be a net exporter by 2040, and the majority of the hydrogen can be transported through this corridor to the central parts of Europe. The area near Algyo has the best potential for solar PV-based renewable electricity production in Hungary, which makes it an ideal development zone for electrolyser projects. The Hungarian natural gas storage operator considers development of hydrogen storage in the vicinity of the pipeline utilising depleted gas fields and three natural gas storages.

The description of the hydrogen Backbone WAG + Penta West project, which enables hydrogen transportation from Slovakia – Austria - Germany can be found in the project description in Corridor A. It is also part of the SoutH2 Corridor.

In Germany, Corridor E connects to the H2ercules via CEHC and CGHI projects and also to the HyPipe Bavaria project via H2 Backbone WAG + Penta West.

GR/BG H2 Interconnection
Project partners: DESFA, Bulgartransgaz
Development phase: Feasibility

The GR/BG H2 Interconnection corridor aims to connect the future hydrogen networks between Bulgaria and Greece at the first hydrogen interconnection point in the Kulata/Sidirokastro region on the Bulgarian-Greek border. The new hydrogen interconnection is indispensable, as it will enable hydrogen transport from southeastern Europe to the north and continue the efficient interoperability between the two countries. The project on Bulgarian territory includes potential exit points for hydrogen deliveries from Bulgaria to Romania through the future hydrogen network of Bulgartransgaz. The entire corridor is currently being developed and is expected to be operational in 2030.

Dedicated Hydrogen Pipeline
Project partners: DESFA
Development phase: Pre-feasibility

The Dedicated Hydrogen Pipeline project consists of a new, approximately 540 km long hydrogen pipeline with two compressor stations in Patima and Nea Messimvria, and a possible branch comprising an additional 250 km. The aim of the project is to transport pure hydrogen mainly from the production regions in southern and eastern Greece to the interconnector with Bulgaria for further export and to the Kavala region, where a future storage facility will be located. The project will enable the transport and supply of hydrogen for local consumption in industrial areas with hydrogen demand near Athens and Thessaloniki. This new 36"pipeline will run in parallel to the existing natural gas pipeline. The project is expected to be operational in 2029.

6.1.6 Transmission Network in Germany

Flow - Making Hydrogen Happen
Project partners: Ontras, GASCADE
Development phase: FEED phase

GASCADE, ONTRAS Gastransport GmbH, and terranets bw GmbH have developed the project "Flow – making hydrogen happen" to connect the Baltic Sea with Czech Republic and Poland and southern Germany. The flow foresees the repurposing of existing infrastructure to supply clean hydrogen from local sources in and around the Baltic area. Clean hydrogen produced onshore and offshore in the Lubmin region and Baltic Sea will be transported south. Hydrogen will flow to the Czech-German border and further to the Net4Gas network. This cooperation is formed under the title of the Czech-German Hydrogen Interconnector (CGHI), which will ensure an integrated cross-border hydrogen network from the Baltic Region to central European countries.

H2ercules
Project partners: OGE
Development phase: Pre-feasibility and feasibility phases

The H2ercules network aims to create a super-sized hydrogen infrastructure for Germany and is a substantial part of the German Hydrogen Core[33] network, which is planned to be realised by 2032. The H2ercules pipeline network by OGE consists of about 2,000 km of pipelines. For the most part, this will mean converting pipelines from the existing natural gas network to hydrogen. On key routes, where pipelines with sufficient capacity for conversion are not available in the short term, H2ercules relies on new construction to support the faster ramp-up of the European hydrogen economy. The H2ercules network will establish connection to five European countries - Norway, the Netherlands, Belgium, France, and Czech Republic - via pipeline and a terminal for the import of hydrogen derivatives by ship. The H2ercules pipeline network will also enable the connection of domestic green hydrogen production and thus connect new sources to the existing pipeline network.

33 FNB Gas (2023). Hydrogen core network. Source: https://fnb-gas.de/en/hydrogen-core-network/

Czech-German Hydrogen Interconnector CGHI
Project partners: GASCADE, NET4GAS, OGE
Development phase: Pre-feasibility phase
Website: https://www.cghi.eu/

The Czech-German Hydrogen Interconnector (CGHI) will provide a hydrogen transportation route between potential hydrogen supply areas in the Nordic-Baltic region, via the 150 km 100% repurposed pipeline over Czech Republic to large hydrogen demand clusters in southern Germany. Additionally, this corridor will supply hydrogen customers in the Czech Republic along this corridor, mainly to the expected hydrogen cluster in Northern Bohemia.

With an initial technical capacity of 144 GWh/d, the project aims to transport hydrogen as of 2030. The total length of the corridor is 1,068 km and consists of 90%-100% repurposed pipelines.

doing Hydrogen
Project partners: ONTRAS Gastransport GmbH
Development phase: feasibility phase/pre-FEED
Website: https://www.doinghydrogen.com/

Doing hydrogen is a 550 km hydrogen transmission system that connects projects in Mecklenburg-Western Pomerania, Brandenburg, Berlin, Saxony, and Saxony-Anhalt to form a high-performance hub: production, transport, storage, and consumption all under one roof. The operation of doing hydrogen will start in 2026. In the medium-term Alongside Green Octopus Mitteldeutschland, doing hydrogen is one of the ONTRAS projects that has been selected by the German Federal Ministry of Economics and Technology as Important Projects of Common European Interest (IPCEI) in 2021.

Green Octopus Mitteldeutschland
Project partners: ONTRAS Gastransport GmbH
Development phase: feasibility/pre-FEED
Website: https://www.ontras.com/en/go

The Central German Chemical Triangle needs green hydrogen. The same is true for the industries in Saxony-Anhalt and the steel region in Salzgitter/Lower Saxony. Green Octopus Mitteldeutschland (GO!) is the future transport route for this hydrogen: GO! connects the regions and integrates the future hydrogen storage facility in Bad Lauchstädt. From 2026, GO! will ensure the secure transport of hydrogen with a network of pipelines covering around 305 km. GO! will also make use of other hydrogen pipelines to integrate these regions into the growing EHB. A connected cavern storage facility with a working gas volume of 50 million cubic meters supports the hydrogen infrastructure and ensures a balance between supply and demand. Along with doing hydrogen, GO! is one of the ONTRAS projects that has been selected by the German Federal Ministry of Economics and Technology as IPCEI in 2021.

Hyperlink 1 & 2 & 3

Project partners: Gasunie
Development phase: feasibility phase/pre-FEED
Website: https://www.hyperlink-gasunie.de/en

A hydrogen pipeline system of the Hyperlink 1 and 2 projects will connect the Dutch and German hydrogen networks. As a central part of the hydrogen network planned by Gasunie, the pipeline will run from the border at Oude Statenzijl and Bunder Tief through Germany to the Hamburg region. It also connects a storage facility near Nüttermoor and the Bremen region with Leversen. The first consumers and producers within the area covered by Hyperlink 1 will be able to be connected in 2026-2027. The Hyperlink 2 project is expected to be completed and operational by 2029 to supply a steel plant in Salzgitter. The project has an IPCEI status. In Heidenau, Hyperlink 3 joins up with the other Hyperlink sections to enable the transmission of hydrogen to customers in other parts of Germany too.

Hyperlink 4 & 5

Project partners: Hyperlink 4 – Gasunie; Hyperlink 5 – Gasunie and Thyssengas
Development phase: feasibility phase/pre-FEED
Website: https://www.hyperlink-gasunie.de/en

The Hyperlink 4 project will enable the transfer of imported hydrogen from the Wilhelmshaven terminal and Norway to northwestern Europe. The Wilhelmshaven terminal will be directly connected to the hydrogen network. The Hyperlink 4 project will enable direct supply to the major industrial clusters and urban centres of Hamburg, Bremen, and Hanover via the Hyperlink 1 and 2 pipelines and to the Ruhr region via Hyperlink 5. The Hyperlink 4 and 5 projects are candidates for PCI status and are expected to be in operation by 2030.