European Hydrogen Backbone

A EUROPEAN HYDROGEN INFRASTRUCTURE VISION COVERING 28 COUNTRIES

APRIL 2022

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Executive summary

Since its founding in 2020, the European Hydrogen Backbone (EHB) initiative has contributed to the development of a European hydrogen market through the publications of its flagship EHB maps, with a vision of a pan-European hydrogen transport infrastructure. These network maps demonstrate how this vision is both technically feasible and economically affordable. The role of hydrogen in enabling climate neutrality is widely acknowledged, as is the need for hydrogen pipeline transport in the future European energy system. Recently, the essential role for hydrogen pipeline infrastructure in fostering market competition, security of supply, and security of demand was recognised in the European Commission's hydrogen and decarbonised gas package, published in December 2021.[1]

Following the invasion of Ukraine by Russia, the impetus for a rapid clean energy transition has never been stronger. This position was firmly established in the European Commission's REPowerEU proposal, a plan to phase out Europe's dependence on fossil fuels from Russia well before 2030 and to increase the resilience of the EU-wide energy system. Amongst other measures, REPowerEU introduces an ambition to reach an additional 15 million tonnes (Mt) of renewable hydrogen on top of the 5.6 Mt foreseen under Fit for 55, going beyond the targets of the EU's hydrogen strategy.[2] Achieving these targets will require a rapid acceleration of the development of an integrated gas and hydrogen infrastructure, hydrogen storage facilities, and port infrastructure.

In light of the EC's REPowerEU proposal and in response to accelerated hydrogen market developments, this report presents an updated, extended, and accelerated EHB vision, now involving 31 energy infrastructure companies from 28 countries. The updated hydrogen infrastructure network maps as presented in this report build on the EHB initiative's prior body of work. The accelerated vision shows that by 2030, five pan-European hydrogen supply and import corridors could emerge, connecting industrial clusters, ports, and hydrogen valleys to regions of abundant hydrogen supply — and supporting the EC's ambition to promote the development of a 20.6 Mt renewable and low-carbon hydrogen market in Europe.[3] The hydrogen infrastructure can then grow to become a pan-European network, with a length of almost 53,000 km by 2040, largely based on repurposed existing natural gas infrastructure.[4] Moreover, the maps show possible additional routes that could emerge, including potential offshore interconnectors and pipelines in regions outside the area where the EHB members are active. A 'live' version of the maps presented in this report can also be found in digital format on the EHB initiative's website, which will be launched shortly after this report in April 2022.[5]

The European Hydrogen Backbone for 2040 as proposed in this report requires an estimated total investment of €80-143 billion. This investment cost estimate, which is relatively limited in the overall context of the European energy transition, includes subsea pipelines and interconnectors linking countries to offshore energy hubs and potential export regions. Transporting hydrogen over 1,000 km along the proposed onshore backbone would on average cost €0.11-0.21 per kg of hydrogen, making the EHB the most cost-effective option for large-scale, long-distance hydrogen transport. In case hydrogen is transported exclusively via subsea pipelines, the cost would be €0.17-0.32 per kg of hydrogen per 1,000 km transported.

1 European Commission (2021) – Proposal for a recast Directive / Regulation on gas markets and hydrogen (COM(2021) 803 final) / (COM(2021) 804 final). Source: https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/hydrogen-and-decarbonised-gas-market-package_en

2 European Commission (2022) – REPowerEU: Joint European Action for more affordable, secure, and sustainable energy (COM(2022) 109 final). Source: https://energy.ec.europa.eu/repowereu-joint-european-action-more-affordable-secure-and-sustainable-energy_en

3 According to REPowerEU, the additional 15 Mt (compared to 5.6 Mt foreseen in Fit for 55) would be made of 10 Mt of imported hydrogen from diverse sources and an additional 5 Mt of hydrogen produced in Europe.

4 The share of repurposed natural gas pipelines in 2040 would be over 60%.

5 https://www.ehb.eu/maps

European climate protection, energy system resilience, and security of supply are interlinked more than ever before. The European Hydrogen Backbone creates an opportunity to accelerate decarbonisation of the energy sector by efficiently integrating substantial volumes of additional renewable and low-carbon energy and by connecting regions with abundant supply potential with centres of demand. Moreover, the EHB has the potential to revitalise Europe's industrial economy whilst ensuring energy system resilience, increased energy independence, and security of supply across Europe. Such a vision can be achieved in a cost-effective manner, but it requires close collaboration between EU Member States and neighbouring countries and a stable, supportive, and adaptive regulatory framework.

To achieve the EC's ambitious Fit for 55 and REPowerEU goals, and to foster an accelerated development of the European Hydrogen Backbone, this paper presents the following levers to facilitate implementation of infrastructure projects.

The EHB recommends introducing in the REPowerEU plan the establishment of import corridors, including all infrastructure requirements, as a political objective.

- Establish a more integrated energy system planning of hydrogen, natural gas, and electricity infrastructure at EU and Member State level.
- Promote efficient measures to facilitate the swift development of a dedicated hydrogen infrastructure by fostering repurposing of existing natural gas infrastructure.
- Simplify and shorten planning and permitting procedures for renewable energy and hydrogen projects.
- Unlock financing to fast-track hydrogen infrastructure deployment by leveraging funding mechanisms such as the Connecting Europe Facility (CEF), Important Projects of Common European Interest (IPCEI) and Horizon Europe funds.
- Encourage international cooperation and create intra and extra-European energy and hydrogen partnerships.

The EHB initiative is looking forward to discussing its vision with stakeholders including policy makers, companies, and initiatives along the hydrogen value chain.

In Figure 1 the accelerated and updated 2030 EHB network, which supports the EC's REPowerEU ambition, is shown.

Figure 1 – 2030

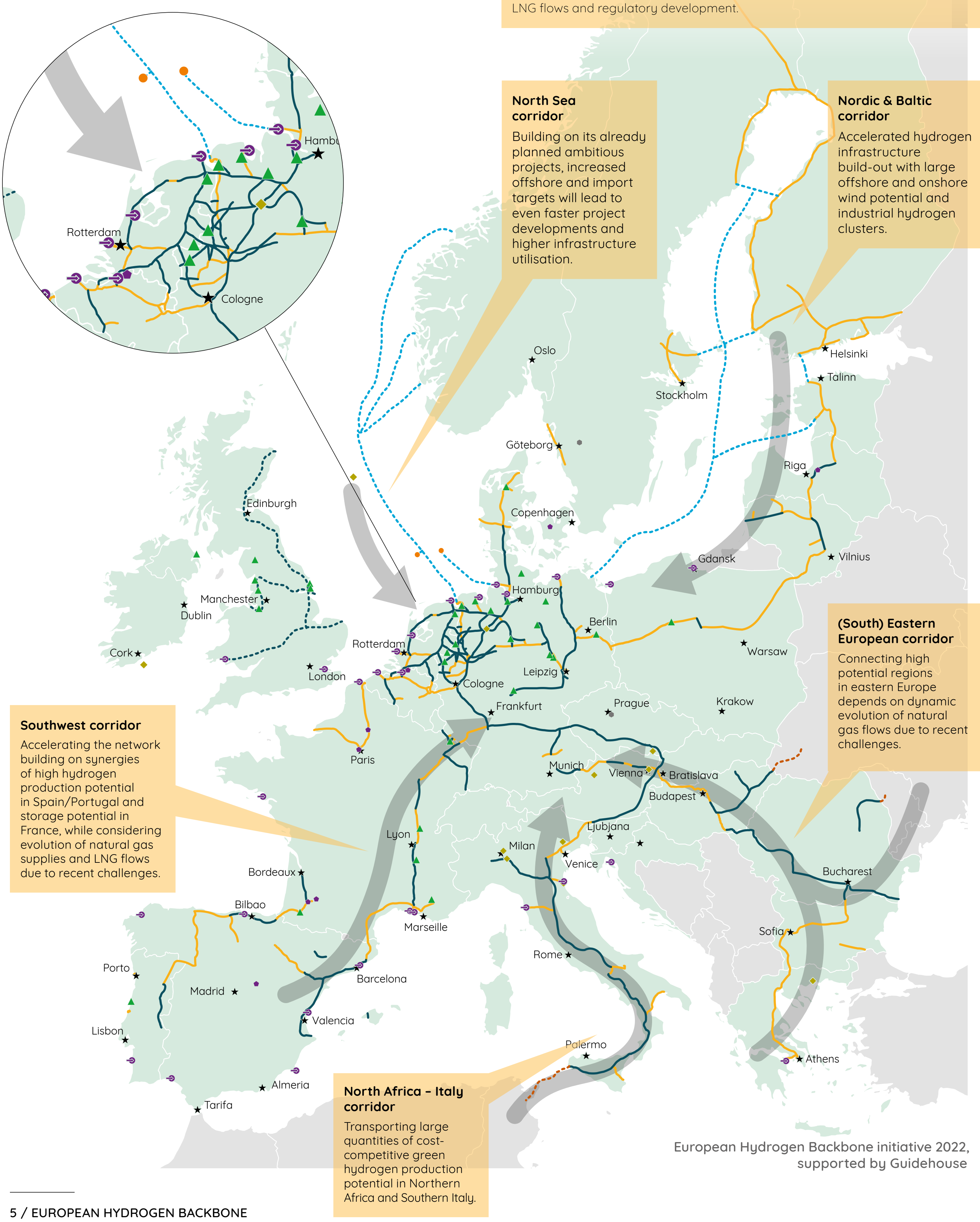
Accelerated and updated 2030 EHB network supports the EC's REPowerEU ambition to create a domestic and import market for hydrogen and increase European energy system resilience

Pipelines
- Repurposed
- New
- Subsea
- Import / Export
- UK 2030 pielines depends on pending selection of hydrogen clusters

Storages
- Salt cavern
- Aquifer
- Depleted field
- Rock cavern

Other
- City, for orientation purposes
- Energy hub / Offshore (wind) hydrogen production
- Existing or planned gas-import-terminal

General remarks
Across all corridors, market conditions are continuously evolving. Map subject to updates resulting from new announcements, considering natural gas supplies, LNG flows and regulatory development.



North Sea corridor
Building on its already planned ambitious projects, increased offshore and import targets will lead to even faster project developments and higher infrastructure utilisation.

Nordic & Baltic corridor
Accelerated hydrogen infrastructure build-out with large offshore and onshore wind potential and industrial hydrogen clusters.

(South) Eastern European corridor
Connecting high potential regions in eastern Europe depends on dynamic evolution of natural gas flows due to recent challenges.

Southwest corridor
Accelerating the network building on synergies of high hydrogen production potential in Spain/Portugal and storage potential in France, while considering evolution of natural gas supplies and LNG flows due to recent challenges.

North Africa – Italy corridor
Transporting large quantities of cost-competitive green hydrogen production potential in Northern Africa and Southern Italy.

European Hydrogen Backbone initiative 2022, supported by Guidehouse

1. Introduction

The European Hydrogen Backbone (EHB) initiative is a group of European energy infrastructure operators which initially published a vision paper for a dedicated hydrogen pipeline infrastructure, to a large extent based on repurposed natural gas pipelines in July 2020, with maps covering nine EU Member States plus Switzerland, home to the eleven Transmission System Operators (TSOs) participating at that time. Since then, the EHB initiative has grown to 31 European network operators with infrastructure covering 25 EU Member States plus Norway, the United Kingdom, and Switzerland. This report contains a geographically extended vision for a dedicated hydrogen infrastructure stretching across these 28 European countries.

Following the release of the initial vision network, market participants across the hydrogen value chain have engaged and signalled interest in the EHB initiative's work. Market feedback frequently concerned the as yet long time periods required to realise the envisaged vision network. In view of accelerated national and European climate ambitions, first-mover market actors have called for the need to accelerate hydrogen infrastructure planning and development to support feasibility, security, and affordability of their energy transition strategies.

In addition, the invasion of Ukraine by Russia in February 2022 has made a strong and clear case for a rapid clean energy transition. In the face of these events, the European Commission published REPowerEU,[6] a plan to phase out Russian fossil fuel imports well before 2030 and to increase the resilience of the European energy system. The plan aims to diversify gas supplies and speed up the roll-out of renewable gases and hydrogen in Europe, setting a goal to reach an additional 15 million tonnes (Mt) of renewable hydrogen — 5 Mt domestically produced, and 10 Mt imported — on top of the 5.6 Mt foreseen under Fit for 55, going beyond the targets of the EU's hydrogen strategy.

In response to accelerated market developments and a Europe-wide strategic need to increase energy system security through hydrogen, this EHB report presents an updated vision of the growing initiative, with hydrogen infrastructure maps for 2030 and 2040:

- The geographical expansion of the EHB maps is reflective of the EU's accelerating climate ambitions and the heightened interest in a pan-European hydrogen network, as indicated in the European Commission's Fit for 55 and hydrogen and decarbonised gas packages, respectively.[7]
- The updated pan-European hydrogen network map for 2030 is aligned to the EC's ambition to develop a 20.6 Mt renewable and low-carbon hydrogen market in Europe, as presented in the REPowerEU proposal.
- The vision maps indicate possible future locations of underground hydrogen storage.[8] These storage locations are indicative and do not yet consider the concurrent need for methane and hydrogen storage nor the fact that new underground storage sites could be developed. The amount of storage that would be required in the future depends on several factors and is not further analysed in this paper.
- The maps and results presented in this report can also be found in digital format on the EHB initiative's website, launched jointly with this report.[9]

The suggested pathway for the creation of a dedicated hydrogen backbone infrastructure is informed by studies commissioned by the Gas for Climate consortium in 2019 and 2020, and by the EHB initiative in 2021, which showed a large future role for hydrogen in a decarbonised European energy system and a gradually declining role for natural gas, partially replaced by biomethane. The network vision presented in this report builds on the body of work undertaken by the EHB initiative in previous years, national hydrogen strategies and planning processes as well as an evaluation of announced projects on hydrogen supply and demand across Europe and neighbouring countries that are potentially able to export hydrogen.

6 European Commission (2022) – REPowerEU: Joint European Action for more affordable, secure, and sustainable energy (COM(2022) 109 final). Source: https://energy.ec.europa.eu/repowereu-joint-european-action-more-affordable-secure-and-sustainable-energy_en
7 European Commission (2021) – Proposal for a recast Directive / Regulation on gas markets and hydrogen (COM(2021) 803 final) / (COM(2021) 804 final). Source: https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/hydrogen-and-decarbonised-gas-market-package_en
8 Gas Infrastructure Europe (2021) – Picturing the value of gas storage to the European hydrogen system. Source: https://www.gie.eu/gie-presents-new-study-picturing-the-value-of-underground-gas-storage-to-the-european-hydrogen-system/
9 https://www.ehb.eu/maps

The European Hydrogen Backbone vision starts from the current status quo yet assumes a high ambition level for future climate change policies. Nonetheless, it is important to note that the eventual infrastructure solution will be highly dependent on future supply and demand dynamics of the integrated energy system, including natural gas, hydrogen, electricity, and heat. The real development of hydrogen supply and demand and the increasing integration of the energy system may lead to alternative or additional routes compared to the ones described in this paper, and the timeline of some of the 2030 and 2040 proposed routes may be shifted forward or backward in time. The timelines for the scale up of hydrogen can vary from country to country, reflecting national energy policy discussions and the status of hydrogen investment projects as well as the rate of renewable energy developments. Across Europe, the speed with which dedicated hydrogen transport infrastructure can be created depends on market conditions for natural gas and hydrogen, political support to stimulate hydrogen production and demand, and regulatory frameworks for hydrogen transport.

The aforementioned energy market, policy, and regulatory drivers are subject to even more volatility as a result of the ongoing war in Ukraine. Although this report considers and welcomes the need to accelerate hydrogen developments in view of geopolitical events, it also acknowledges that the corresponding level of disruption to energy and gas markets and infrastructure are and will continue to be multi-faceted, unpredictable, and variable over time. The role of LNG, biomethane, alternative pipeline gas, and hydrogen volumes, including all connected infrastructure, are closely interlinked and their uncertainty — especially in the short and medium-term — implies that infrastructure planning must be done in a manner that is responsive and resilient to different potential future scenarios. For this reason, the network maps and infrastructure proposals in this publication are accompanied, where possible, by call-out boxes indicating key uncertainties, identified by the TSOs, that have the potential to affect the infrastructure proposals as shown.

The next chapter presents updated 2030 and 2040 EHB maps, including a description of their developments and impact. The final chapter describes acceleration levers that can help to promote rapid roll-out of the EHB and support the EC's goals as described in their REPowerEU plan.

The EHB initiative has grown to 31 European network operators with infrastructure covering 25 EU Member States plus Norway, the United Kingdom, and Switzerland.

2. Gradual creation of a dedicated hydrogen infrastructure to increase the resilience of the European energy system

2.1. Acceleration of hydrogen infrastructure to enable the emergence of pan-European supply and import corridors by 2030

The European Commission's REPowerEU plan aims to reach an additional 15 Mt of hydrogen on top of the 5.6 Mt foreseen under Fit for 55.[10] The total expected volume of 20.6 Mt by 2030 will likely consist of a range of supply sources including, amongst other options: co-located (demand-side) electrolysis; centralised hydrogen production from captive renewable energy sources; large-scale blue hydrogen production; pipeline imports; and ship imports of hydrogen derivatives such as ammonia and methanol. Depending on their use case, these volumes will require varying degrees of transport infrastructure to connect supply regions to demand.

Previous EHB analysis has shown that a hydrogen pipeline can transport some 65 TWh of hydrogen per year.[11] **For perspective, this means that transporting half of the REPowerEU target of 10 Mt, or 330 TWh, would require approximately five large-scale pipeline corridors.** Based on an initial analysis of supply potentials, demand centres, and TSOs assessments of the ability to repurpose existing natural gas and build new hydrogen pipelines,[12] up to five supply corridors could emerge by 2030. These cross-border corridors, shown in the accelerated EHB network map in Figure 2, can integrate large volumes of renewable and low-carbon hydrogen using solar resources in southern and eastern European countries, and wind resources around the North, Baltic, and Mediterranean Seas. In regions where solar PV and wind resource potential are both abundant, hybrid PV and wind configurations are also an option to provide cost-competitive hydrogen production by drawing on strong renewable potential. The 2030 hydrogen infrastructure map, as presented in figure 2, would consist of a total length of ~28,000 km[13].

Connecting these abundant supply regions to hydrogen consumers in the centre of Europe through cross-border pipeline corridors will become increasingly important as adoption of hydrogen in the transport, industry, and power sectors accelerates and leads to demand outgrowing supply in regions with modest renewable energy production potential. The developments also pave the way for hydrogen pipeline imports from North Africa through Spain or Italy, from Ukraine through Poland, Slovakia or Hungary, or ship imports of hydrogen derivatives via planned new or repurposed import terminals.

10 20.6 Mt of hydrogen corresponds with 680 TWh (lower heating value).

11 13 GW 5000 full load hours is consistent with assumptions used in previous EHB work, however these can vary depending on operational parameters such as operating pressure, steel grade, etc. Detailed techno-economic assumptions used in prior EHB work are documented in the Appendix of this report.

12 EHB (2021) – Analysing future demand, supply, and transport of hydrogen. Source: https://gasforclimate2050.eu/wp-content/uploads/2021/06/EHB_Analysing-the-future-demand-supply-and-transport-of-hydrogen_June-2021_v3.pdf.

13 The kilometres represent all stretches that are visualised in the map, except the dotted import lines from third countries

Figure 2 – 2030

Accelerated and updated 2030 EHB network supports the EC's REPowerEU ambition to accelerate the creation of a domestic and import market for hydrogen and to increase European energy system resilience

Pipelines
- Repurposed
- New
- Subsea
- Import / Export
- UK 2030 pielines depends on pending selection of hydrogen clusters

Storages
- Salt cavern
- Aquifer
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- Rock cavern

Other
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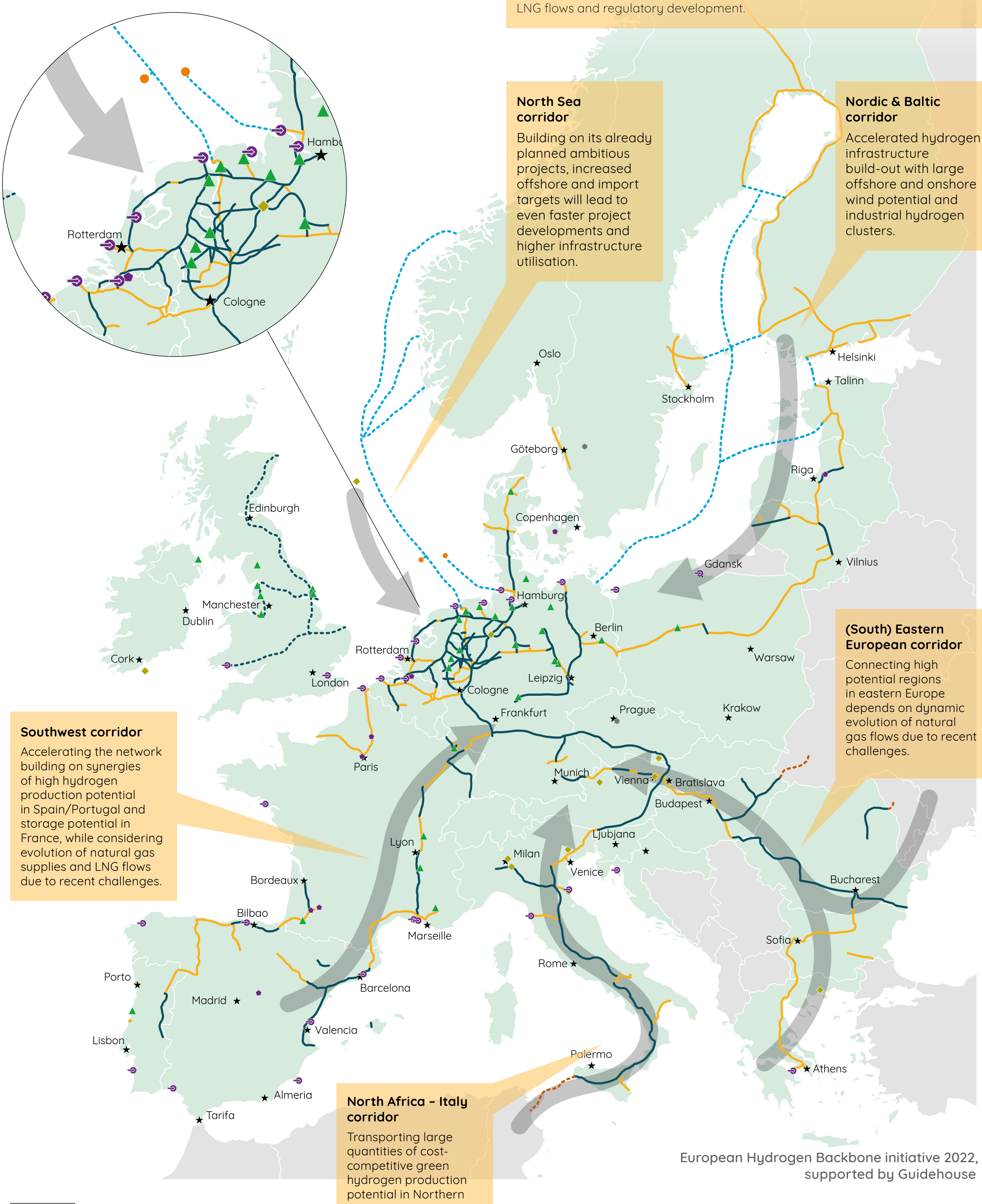

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Building on its already planned ambitious projects, increased offshore and import targets will lead to even faster project developments and higher infrastructure utilisation.

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As shown in Figure 2, up to five pan-European supply and import corridors can be envisioned to support the European Commission's REPowerEU ambitions. The increased ambition for diversification towards offshore renewables away from fossil fuels, will lead to more renewable hydrogen being transported through each of these five corridors. Owing to rapid developments regarding import projects, more hydrogen imports can be accommodated leading to higher infrastructure utilisation.

In southern Europe, a corridor is likely to emerge connecting supply from Tunisia and Algeria through Italy to central Europe. Drawing also on an extensive and in some areas parallel natural gas network, this corridor will likely be able to leverage repurposed existing natural gas pipelines in Italy, Austria, Slovakia, and Czech Republic to import and transport green hydrogen from North Africa to central Europe. This corridor could provide cost-competitive Tunisian and Algerian and Italy solar and wind based green hydrogen to decarbonise existing industries along the transit route as well as the Southern German clusters in Bavaria, the Rhin-Main area, and Rhinland.

Another corridor could develop to export and transport green hydrogen produced in the Iberian Peninsula. New interconnections between Portugal and Spain, and the Iberian Peninsula and France through the East Pyrenees, could allow all three countries to benefit from the complementary nature of low-cost, high-volume Spanish and Portuguese hydrogen production and underground storage sites, in France and in the Iberian Peninsula, to help provide stable supply for off-takers in the region.[14] This corridor, which would stretch all the way to Germany, can play an important role in decarbonising regional industrial and transport ecosystems in Portugal, Spain and France,[15] and deliver hydrogen at low cost to demand centres in Germany. In the longer term this corridor can also provide access to hydrogen imports from Morocco.

An interconnected corridor is likely to emerge around the North Sea, building on ongoing and planned offshore wind, large-scale integrated hydrogen projects, and ship imports of hydrogen derivatives such as ammonia, methanol, and liquid hydrogen to meet demand around the industrial clusters and Ports of Rotterdam, Zeebrugge, Antwerp, Wilhelmshaven, Brunsbüttel and le Havre.[16]

In the Netherlands, the national backbone can be ready by 2027, connecting all industrial clusters, storage facilities and neighbouring network operators (Germany and Belgium), and by 2030 will function as a ring network. In Germany, hydrogen clusters in the North-West, in the Ruhr area and in the East, the Central German Chemical Triangle, are expected to develop and will be interconnected and linked to hydrogen networks in other North-West European countries.[17]

Significant green hydrogen supply potential based on onshore and offshore wind drive the development of **additional supply corridors that can connect Nordic and Baltic hydrogen supply to the rest of Europe,** building on regional networks around industrial clusters in the regions of Jutland, Göteborg, the Bothnian Bay and industrial clusters in Baltic states and Poland. This supply route can serve numerous new green steel, e-fuel projects in the Nordics, and decarbonise existing industry along the onshore route through Finland, the Baltic states and Poland. Great offshore wind potential can also drive the development of new offshore pipeline connecting Nordic supply with Central European demand. As this corridor will consist mostly of newly built pipelines, development of this route by 2030 is especially dependent on the funding, speed and efficiency of the permitting and planning processes as well as the local market needs.

14 This corridor will for example be able to connect the salt caverns around Lyon and Marseille with the hydrogen stretches around the east coast of Spain. For example, Lacq Hydrogen Project which exploits the synergies of production of renewable hydrogen in Spain and storage in Terega's UGS in France.

15 7 hydrogen clusters were identified in France resulting from a Public Consultation by gas TSOs Terega and GRTgaz. National and European H_2 network interconnections will make it possible to cover possible local production deficits in certain regions. https://www.terega.fr/acteur-de-lhydrogene/consultation-des-acteurs-du-marche-de-l-hydrogene-bas-carbone-et-renouvelable

16 Planned projects include for example Aquaventus, the North Sea Wind Power Hub, the Norwegian energy hub or Danish offshore energy islands, other terminal locations are under investigation such as Stade and Rostock.

17 Based on announced and planned projects, such as the H2ercules project, some updates to the network in 2030 in this corridor are expected.

In East and South-East Europe, a fifth and final corridor could connect hydrogen off-takers in Central Europe to regions with abundant renewable energy in countries such as Romania, Greece, and Ukraine. The vast land availability and high capacity factors for solar and wind, the availability of low-carbon hydrogen from nuclear energy, and the option to repurpose large transit gas pipelines make this region an attractive candidate for large-scale hydrogen production. Nevertheless, the uncertainty concerning the evolution of future natural gas flows in this area impacts the development of this corridor.

By 2030, hydrogen is likely to be imported through both pipelines and import terminals. The split between pipeline and ship imports will depend on import terminal strategies unfolding as well as the pace of hydrogen production scale-up in pipeline export regions such as Algeria, Tunisia. Where the more economically favourable pipeline imports are not available, hydrogen derivatives could be imported via ship to be directly used as methanol or ammonia or to be reconverted to hydrogen for pipeline transmission in the onshore network. Different regions will opt for different approaches and solutions when it comes to hydrogen import and export, based on their geopolitical situation. The updated and accelerated 2030 EHB vision shows that European TSOs are ready to deliver on the infrastructure that is necessary to meet the REPowerEU targets.

2.2. Mature infrastructure stretching towards all directions by 2040

Between 2030 and 2040, the European Hydrogen Backbone will continue to grow, covering more regions and developing new interconnections across Member States. Driven by the ambitious policy environment set in the Green Deal, Fit for 55, and REPowerEU proposals, an increased urgency to meet climate targets, and a rapidly increasing number of projects and initiatives supported by public authorities and industry, the supply corridors will naturally extend into areas where cost-effective pipeline transport of hydrogen is needed to meet market demands.

As large supply corridors come together, a core European Hydrogen Backbone can be envisaged by 2040. This means that a pan-European hydrogen infrastructure can be created connecting 28 European countries, as shown in Figure 3. By 2040, the proposed backbone can have a total length of almost 53,000 kilometres[18], consisting of approximately 60% repurposed existing infrastructure and 40% of new hydrogen pipelines. Assuming that the backbone is equipped with a fit for purpose and technically robust compression system, the proposed network could be able to adequately meet the foreseen 1,640 TWh of annual hydrogen demand in Europe by 2040.[19]

Whereas initially the hydrogen backbone mainly serves industrial hydrogen demand, between 2030 and 2040 hydrogen will increasingly become a significant energy carrier in other sectors, including heavy transport, e-fuel production, the building sector, and long-duration energy storage and dispatchable power generation, thereby complementing the electricity grid to integrate large volumes of renewables in the energy system. Hydrogen imports via connections from export regions such as Namibia, Chile, Australia and the Middle East, and hydrogen import terminals are expected to replace existing natural gas imports and will make up a material portion of future hydrogen volumes.

18 The kilometres represent all stretches that are visualised in the map with the billion euros in the main text, except the dotted import lines from third countries

19 EHB initiative (2021) – Analysing the future demand, supply, and transport of hydrogen. Source: https://gasforclimate2050.eu/wp-content/uploads/2021/06/EHB_Analysing-the-future-demand-supply-and-transport-of-hydrogen_June-2021_v3.pdf.

By connecting hydrogen producers with off-takers, this physical **European hydrogen network could enable the creation of a liquid pan-European hydrogen market,** thereby accelerating deployment of renewables, fostering market competition, and revitalising Europe's decarbonised industrial sector. By 2040, many European countries will be closing in on their respective climate targets. Complementing rapid deployment of renewables and electrification with storable, climate-neutral energy carriers such as hydrogen will be key to ensure the overall affordability and system adequacy of a future climate-neutral energy system. By connecting hydrogen producers and consumers to large-scale underground hydrogen storage sites[20], the proposed backbone could help to integrate renewable energy during periods of oversupply and offer much-needed 'green' security of supply and European energy sovereignty during periods of reduced renewable energy production.

The direct link between hydrogen flows and corresponding network capacities is beyond the scope of this paper. However, an initial study, commissioned by the EC to serve as technical support to the development of the hydrogen and decarbonised gas package proposal published in December 2021, makes use of future EHB transmission and interconnection capacities to estimate the benefits and costs of a pan-European hydrogen network[21]. The participating organisations of the EHB initiative are currently also working on integrated modelling studies, at both Member State and at European level.

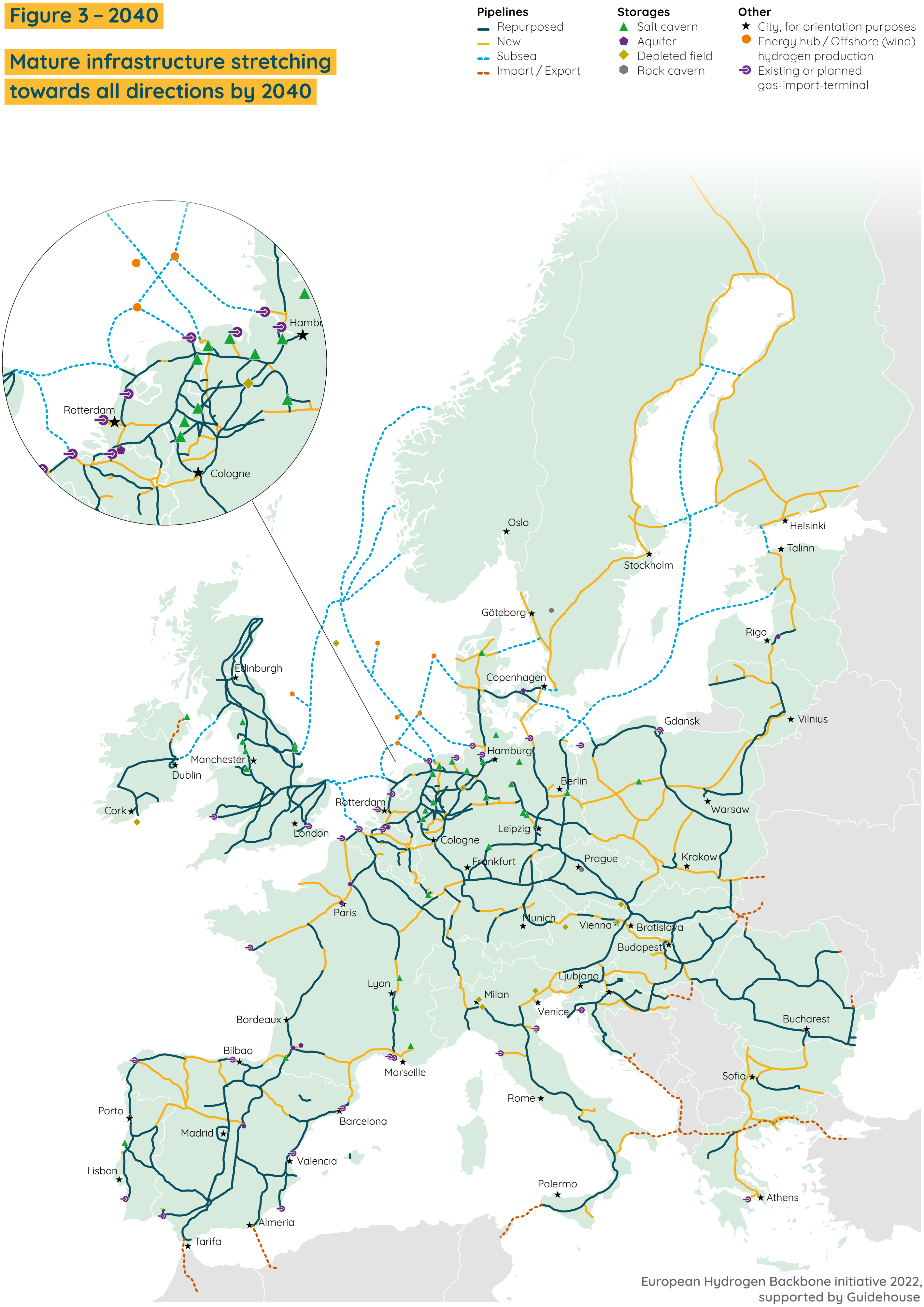
Finally, it is important to note that while most accelerated climate scenarios expect hydrogen demand growth between 2030-2040 to be significant, even more growth in volume is expected to occur during the 2040s. As such, the 2040 backbone displayed in Figure 3 should be considered as a critical milestone, but not a final product. The **backbone as proposed for 2040** represents a foundational network, **"a mature hydrogen highway"**, upon which further developments can be built. Depending on the evolution of the hydrogen market, including the pace and location of development, additional reinforcements and extensions to the backbone can be made to accommodate these ambitions.

20 As a first-order result, GIE (2021) estimates that repurposing all existing European natural gas sites to hydrogen would lead to up to working gas capacity of 265 TWh hydrogen storage, of which 50 TWh in salt caverns and 215 TWh in gas fields and aquifers. The role of underground hydrogen storage is expected to vary from country to country and is subject to national energy market dynamics. Source: https://www.gie.eu/gie-presents-new-study-picturing-the-value-of-underground-gas-storage-to-the-european-hydrogen-system/.

21 METIS study on costs and benefits of a pan-European hydrogen infrastructure (2021). Source: https://op.europa.eu/en/publication-detail/-/publication/c50a12fc-5eeb-11ec-9c6c-01aa75ed71a1/language-en.

Figure 3 – 2040

Mature infrastructure stretching towards all directions by 2040



European Hydrogen Backbone initiative 2022, supported by Guidehouse

3. Accelerating implementation of the EHB

To achieve the EC's ambitious Fit for 55 and REPowerEU goals, and to foster an accelerated development of the European Hydrogen Backbone as shown, this paper presents the following levers to facilitate implementation of infrastructure projects.

The EHB recommends introducing in the REPowerEU plan the establishment of import corridors, including all infrastructure requirements, as a political objective.

Establish a more integrated energy system planning of hydrogen, natural gas, and electricity infrastructure at Member State level. Lead times for large-scale transmission, storage, and port infrastructure implementation – including development, engineering studies, and construction – can take up to 10 years. Integrated infrastructure planning must start today in order to send the right market signals, seize the upcoming investment windows, and have concrete infrastructure projects in place by 2030 and 2035.

Promote efficient measures to facilitate the swift development of a dedicated hydrogen infrastructure by fostering repurposing of existing natural gas infrastructure Regulatory provisions should incentivise rapid roll-out of hydrogen infrastructure – pipeline, storage, and port – including investment in assets that can be repurposed before 2030.

Simplify and shorten planning and permitting procedures for renewable energy and hydrogen projects. Red tape is a major hurdle to the deployment of renewables and hydrogen projects across Europe. Governments and the EU can support project deployment by introducing frameworks for rapid mapping, assessment, and allocation of suitable land for infrastructure projects; and by defining maximum processing times for environmental, permitting, and planning applications.

Unlock financing to fast-track hydrogen infrastructure deployment. Flexible economic models to incentivise investment in hydrogen infrastructure during the volatile market ramp-up years should be explored. On a national level, countries can subsidise upfront capital investments to mitigate utilisation risk during the early years when volumes are scaling up. The EU can also incentivise private project financing and make funding mechanisms such as the Connecting Europe Facility (CEF), Important Projects of Common European Interest (IPCEI) and Horizon Europe funds, available to project developers and promoters.

Encourage international cooperation and create intra and extra-EU energy and hydrogen partnerships. In order to maintain the quality of hydrogen, the EU must create EU-wide accepted standards, regulations and certifications for the production and consumption of hydrogen. It must also enforce these standards on the imports of hydrogen. Member States can explore symbiotic energy and hydrogen partnerships with future exporting countries, either through EU programmes such as Strategic Partnerships for the Implementation of the Paris Agreement (SPIPA), or bilaterally, such as Germany has done with multiple countries from Morocco to the UAE in order to stimulate trade, energy imports, and technology exports.

Appendix. Cost of an expanded European Hydrogen Backbone

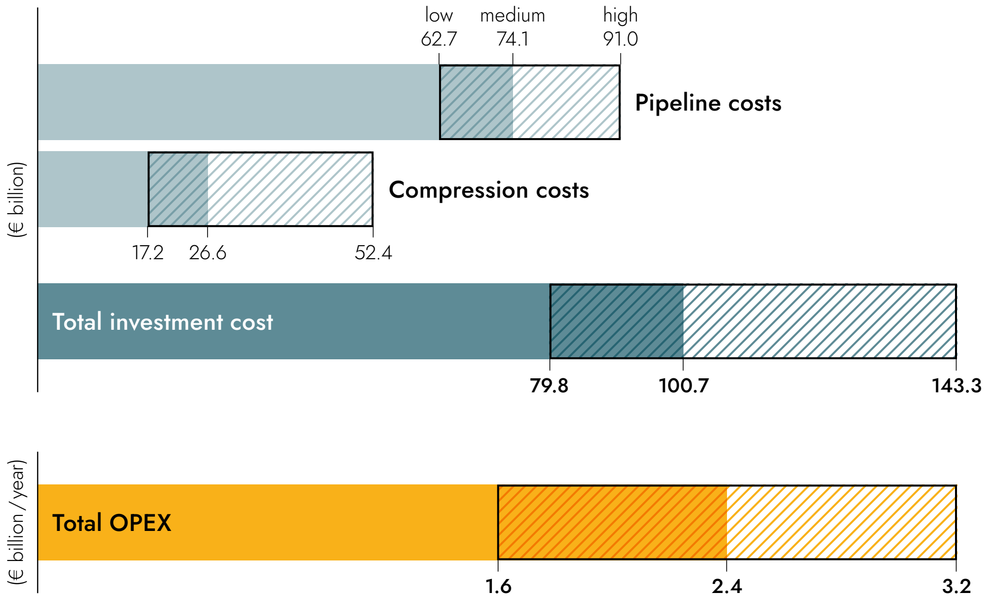
Investment and operating costs

Based on the cost figures shown in Table 1, the total investment costs of the envisaged 2040 European Hydrogen Backbone are expected to range from €80 to €143 billion[22] covering the full capital cost of building new hydrogen pipelines and repurposing pipelines for the European hydrogen backbone. Annual operating costs are estimated to be between €1.6 and €3.2 billion when assuming a load factor of 5,000 hours per year[23]. An overview of these costs is given in Figure 4.

FIGURE 4

Estimated investment and operating costs of the European Hydrogen Backbone (2040)

Range depending on input assumptions as described in Appendix A



The main reason for the relatively large bandwidth is the uncertainty and variability concerning compression system design and costs. In particular, compression system capital costs depend heavily on the underlying concept design; including whether the project is greenfield or brownfield, the design operating pressure range, n+1 rule implementation,[24] and compressor technology choice (centrifugal or reciprocating).

22 The euro amounts represent all stretches that are visualised in the map, except the dotted import lines from third countries

23 This study considers the backbone from an infrastructure investment perspective and does not take a strong stance on the exact level of network utilisation. A load factor of 5000 hours per year is deemed reasonable, cognizant of the fact this value will change depending on future market developments – and impact resulting costs accordingly.

24 For pipeline transport, the n+1 redundancy rule applies to ensure system availability in the event of component failure.

Levelised transport cost

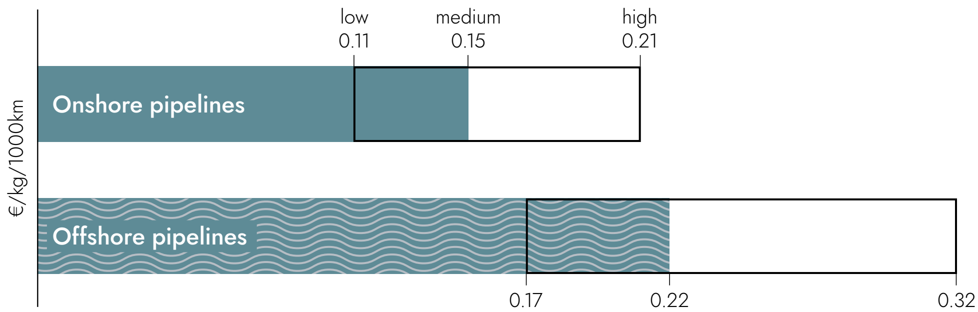
Transporting hydrogen over 1,000 km along an average stretch of the onshore hydrogen backbone, as presented in this report, would cost €0.11 – €0.21 per kg of hydrogen transported (€3.3 - €6.3 per MWh), with €0.15 per kg (€4.5 per MWh) for the scenario with medium cost estimates. This cost estimate would be €0.17 - €0.32 per kg of hydrogen (€4.5 - €8.7 per MWh) per 1,000 km in case the hydrogen is transported entirely via dedicated subsea offshore pipelines. These figures confirm that the EHB is an attractive and cost-effective option for long-distance transport of hydrogen, considering an estimated future production cost of €1.0-€2.0 per kg of hydrogen (€30 - €60 per MWh).

These cost estimates represent a weighted average across a wide range of pipeline sizes and types – ranging from repurposed 20-inch pipelines to new 48-inch ones – and also reflect their respective distance and capacity-weighted shares within the context of the overall European Hydrogen Backbone[25].

This means that even though smaller pipelines have a higher cost of transport per unit distance, their modest share in terms of length and capacity leads to a marginal impact on overall transport costs when considering the pan-European picture. The cost ranges reflect uncertainties in the estimate of the cost of the European Hydrogen Backbone as a whole. Depending on circumstances, the costs for individual stretches can be lower or higher than the range indicated.

FIGURE 5

Comparison of levelised transport costs for onshore and offshore pipelines for an average stretch of the backbone in €/kg/1000km



Unit cost assumptions

Representative unit capital cost figures for small, medium, large and offshore hydrogen pipelines are summarised in Table 1. These figures use 20-inch (~500 mm), 36-inch (~900 mm), and 48-inch (~1200 mm) as models to represent small, medium, and large pipelines respectively. The offshore pipelines are assumed to have the same dimensions as onshore pipelines and costs are estimated by applying a 1.7x multiplication factor to onshore pipelines of the same diameter.[26] Only using three different pipeline sizes is a simplification of reality, given that the actual backbone is made up of a continuous range of pipeline sizes. Additional underlying cost assumptions such as compressor costs, depreciation periods, and operating and maintenance costs are also shown in Table 1 and are consistent with those used in previous EHB reports.

25 The levelised cost of hydrogen transport per kg per 1,000 km is calculated by multiplying the estimated levelised costs for each pipeline diameter by their respective capacity-distance-weighted shares, i.e., the relative amount of hydrogen transported by that pipeline size across the entire backbone.

26 Offshore pipeline CAPEX and compressor needs (expressed in MWe/km) are estimated in a simplified manner by applying a 1.7x multiplication factor to onshore pipelines of the same diameter. This figure is based on typical offshore-onshore cost ratios seen in existing offshore natural gas pipelines.

These cost estimates are based on gas TSOs' preliminary R&D efforts regarding hydrogen infrastructure. The ranges are determined through comparison with experience investing in and operating existing natural gas networks and based on initial experience in pilot projects. Although some dedicated hydrogen components have been tested in pilot projects, no large-scale hydrogen infrastructure exists to date to provide real historical benchmark figures. Equal to the previous results in 2020 and 2021, these cost estimates are based on running an average single stretch of hydrogen pipeline. They do not incorporate a scenario-based simulation of a full-scale network as is commonly done for network development planning.

TABLE 1

Cost input ranges used for estimating total investment, operating, and maintenance costs for hydrogen infrastructure

Cost parameter		Low	Medium	High	Unit
Pipeline Capex, new	Small	1.4	1.5	1.8	M€/km
	Medium	2.0	2.2	2.7	
	Large	2.5	2.8	3.4	
	Offshore Medium	3.4	3.7	4.6	
	Offshore Large	4.3	4.8	5.8	
Pipeline Capex, repurposed[27]	Small	0.2	0.3	0.5	
	Medium	0.2	0.4	0.5	
	Large	0.3	0.5	0.6	
	Offshore Medium	0.3	0.4	0.5	
	Offshore Large	0.4	0.5	0.6	
Compressor station Capex		2.2	3.4	6.7	M€/MW_e
Electricity price		40	60	80	€/MWh
Pipeline operating & maintenance costs		0.8	0.9	1.0	€/year as % of Capex
Compressor operating & maintenance costs		1.7	1.7	1.7	
Weighted average cost of capital		5.0			%
Depreciation period pipelines		40			Years
Depreciation period compressors		25			

27 Offshore pipeline CAPEX for repurposed pipelines is assumed to be 10% of the CAPEX of the new pipelines. This is a based on Guidehouse desk research and is percentage wise a bit less than for onshore pipelines.

The updated cost estimates are the result of a series of hydraulic simulations conducted by gas TSOs. The modelled scenarios cover a range of point-to-point pipeline transport cases with varying input parameters – selected by TSOs – including pipeline diameter and design capacity. Note that these analyses, while thoroughly conducted, are not exhaustive and merely serve as high-level approximations of what would happen in a real network. Hence, given the simplifying assumptions made in the analyses, these results should not be considered as representative of a fully optimised, actual meshed pipeline grid. Below, Key results are summarised in Table 2 below.

TABLE 2

Overview of unit capital costs and estimated costs of pipeline transport for different pipeline types in the medium scenario

Pipeline specifications		GW[28]	Pipeline Capex	Compression Capex	LCOH	Unit
Small	New	1.2	1.5	0.09	0.16	€/kg/200 km
	Repurposed	1.2	0.3	0.09	0.05	
Medium	New	4.7	2.2	0.32	0.35	€/kg/1000 km
	Repurposed	3.6	0.4	0.14	0.12	
Large	New	13	2.8	0.62	0.19	
	Repurposed	13	0.5	0.62	0.09	
Offshore Medium	New	4.7	3.7	0.54	0.60	
	Repurposed	3.6	0.4	0.23	0.15	
Offshore Large	New	13	4.8	1.06	0.32	
	Repurposed	13	0.5	1.06	0.14	

28 The pipeline capacities are kept constant in comparison with the previous EHB report from April 2021 and are based on 75% capacity. Furthermore, the operating pressure for large pipelines was assumed to be 80 bar, and 50 bar for medium and small pipelines.