Five hydrogen supply corridors for Europe in 2030

EUROPEAN HYDROGEN BACKBONE

MAY 2022

Guidehouse

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Who we are & EHB Mission

Who we are

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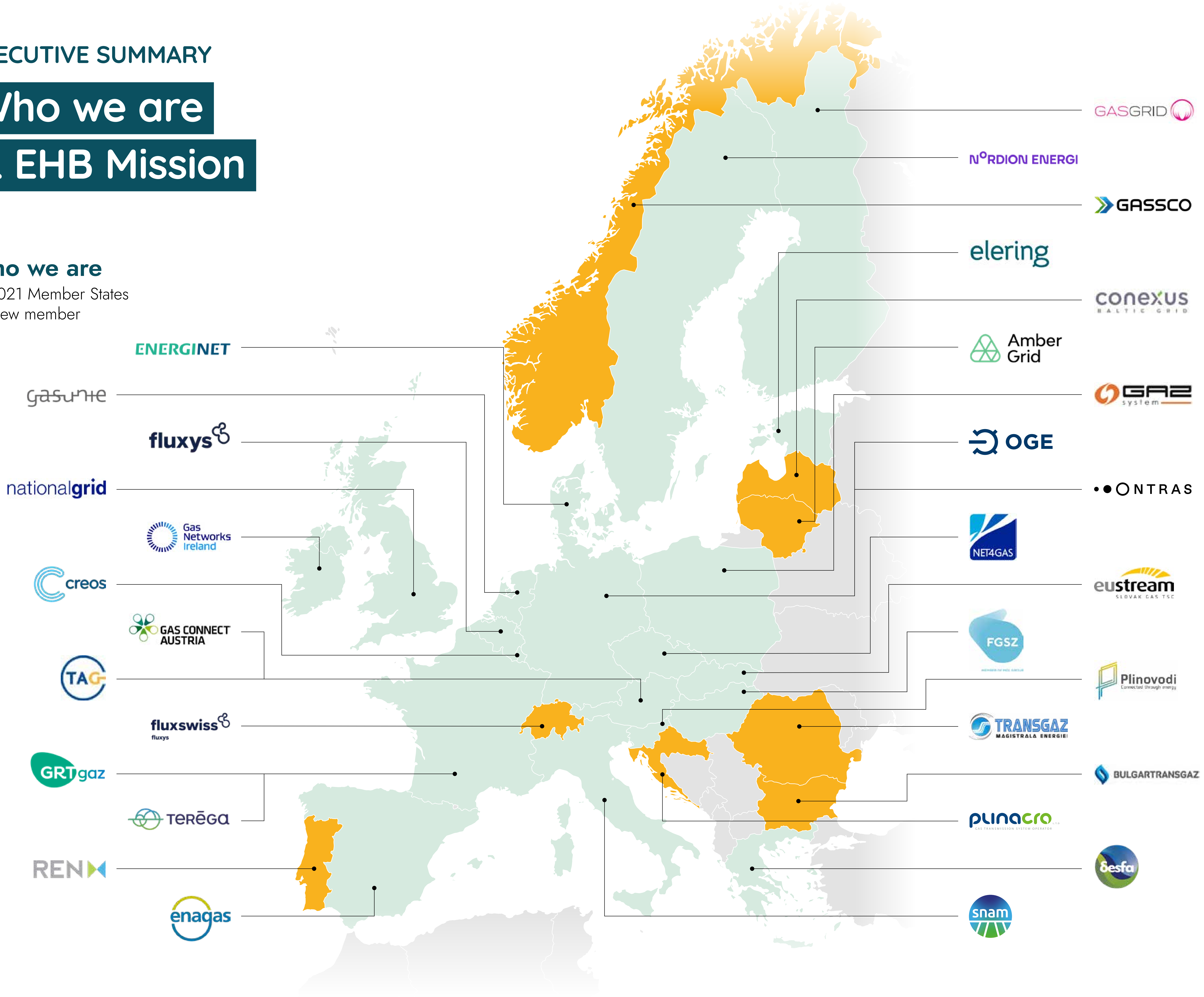


EHB Mission

- **Accelerate** decarbonisation of the **European energy system**
- **Define** the critical role of **hydrogen infrastructure**
- **Support development** of a competitive and liquid **European hydrogen market**
- **Foster cross-border collaboration** between Europe and its neighbors

Europe's accelerated 2030 climate targets define an aggressive role for hydrogen

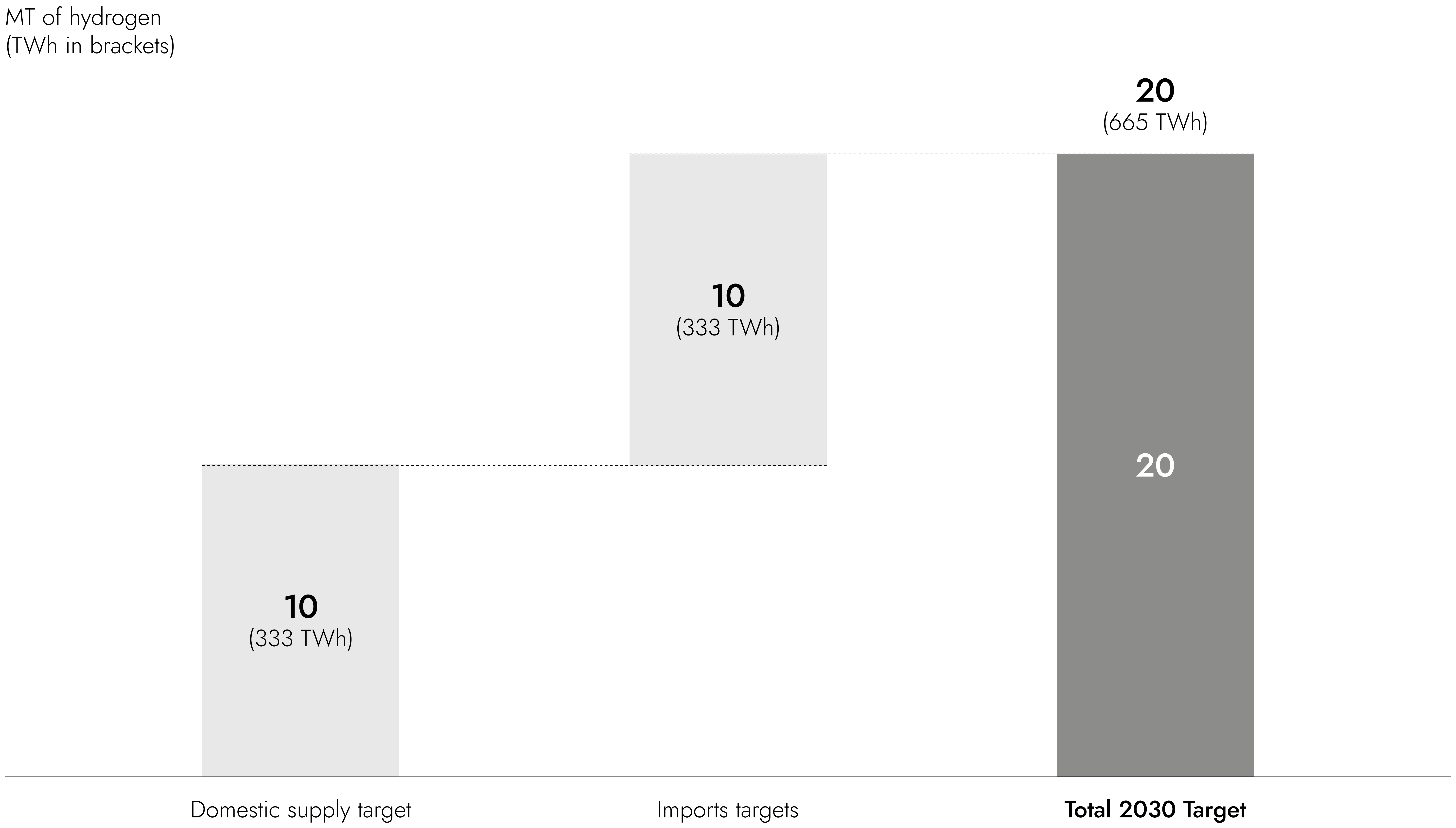
Europe has defined a **bolder and more ambitious hydrogen target of 20 MT** by 2030 in response to the **RePowerEU plan** to phase out Russian fossil fuel imports well before 2030

This includes a **10 MT target of domestic EU hydrogen supply**, as well as a **10 MT target of hydrogen imports** from outside the EU.[1]

These targets are strengthened by accelerated **national climate ambitions** as well as the accelerated development of the **European hydrogen market**.

Note: This study's underlying analysis was largely completed prior to the publication of the detailed RePowerEU plan and its 2030 hydrogen targets. As such, this study's supply and demand estimates were not intended to align with the 20 MT target by 2030.

2030 Hydrogen Targets



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[1] The RePowerEU target of 10 MT of imports includes 6 MT of renewable hydrogen and 4 MT of imported ammonia / derivatives.

The EHB initiative has identified sufficient hydrogen supply to exceed the 2030 domestic targets

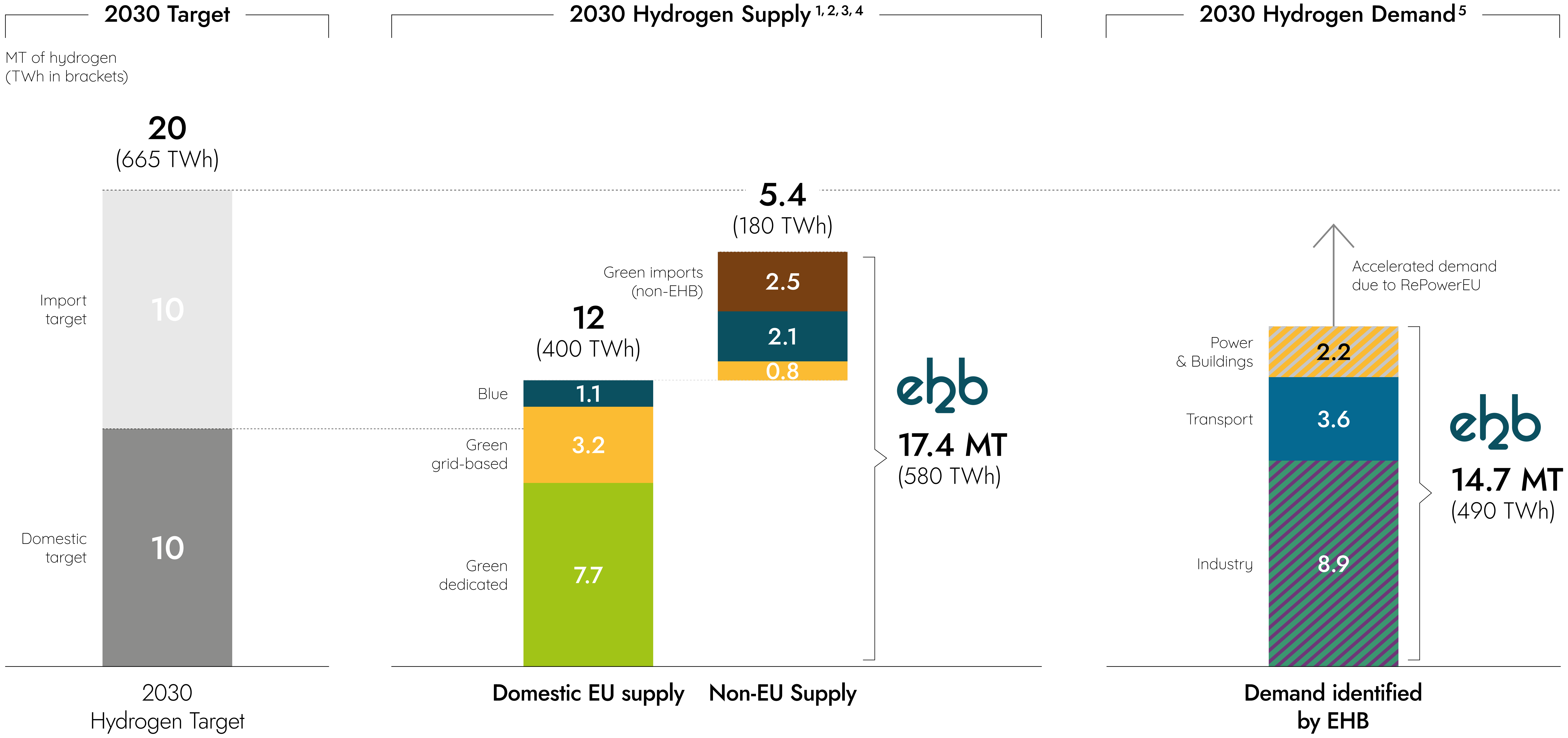
EHB **identified 12 MT of domestic supply, exceeding the RePowerEU domestic target by 20%** and supporting European energy independence and security of supply.

EHB also identified **5.4 MT of supply** from non-EU neighboring countries, for a **total of 17.4 MT of supply.**

EHB also identified **14.7 MT of demand** based on a bottom-up assessment of demand by sector and country.

We expect this demand estimate to **increase and accelerate further** in response to the RePowerEU plan.

These supply and demand estimates represent **tangible and achievable projections** based on national targets, market developments and announced projects, primarily **prior to the release of the RePowerEU plan**.



+20%
higher than RePowerEU

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1 EHB did not analyse ship imports of hydrogen or derivatives like ammonia and methanol. To meet the 20 MT target, an additional 2.6 MT of hydrogen or derivative imports would be needed.

2 The 5.4 MT of non-EU supply includes 2.5 MT (~80 TWh) of green hydrogen imports from non-EHB countries (Morocco, Algeria, Tunisia and Ukraine), along with 2.1 MT of blue hydrogen and 0.8 MT of grid-based hydrogen from EHB, non-EU countries (the UK and Norway). Blue hydrogen potential, and its economic viability, is subject to the evolution of gas markets, regulations and the uncertainty of natural gas prices.

3 Estimates of national green hydrogen supply for European countries are based on projections of renewable energy scaling up above and beyond supply levels needed to meet electricity demand.

4 Other imports may include pipeline or ship imports from other regions not analysed in this study.

5 Demand includes all EU countries and the UK and Norway. Demand estimates do not include domestic EU consumption of ammonia for shipping or other derivates. For comparison, RePowerEU considered 4 MT of demand for ammonia and other derivatives.

Regional differences in supply and demand show the importance of connecting regions across Europe

Across different regions in Europe, there are **significant differences in the hydrogen supply-demand balance**.

Some regions are characterised by a **net supply of low-cost, hydrogen resources**. These regions benefit from vast renewable energy potential, high capacity factors and substantial land availability.

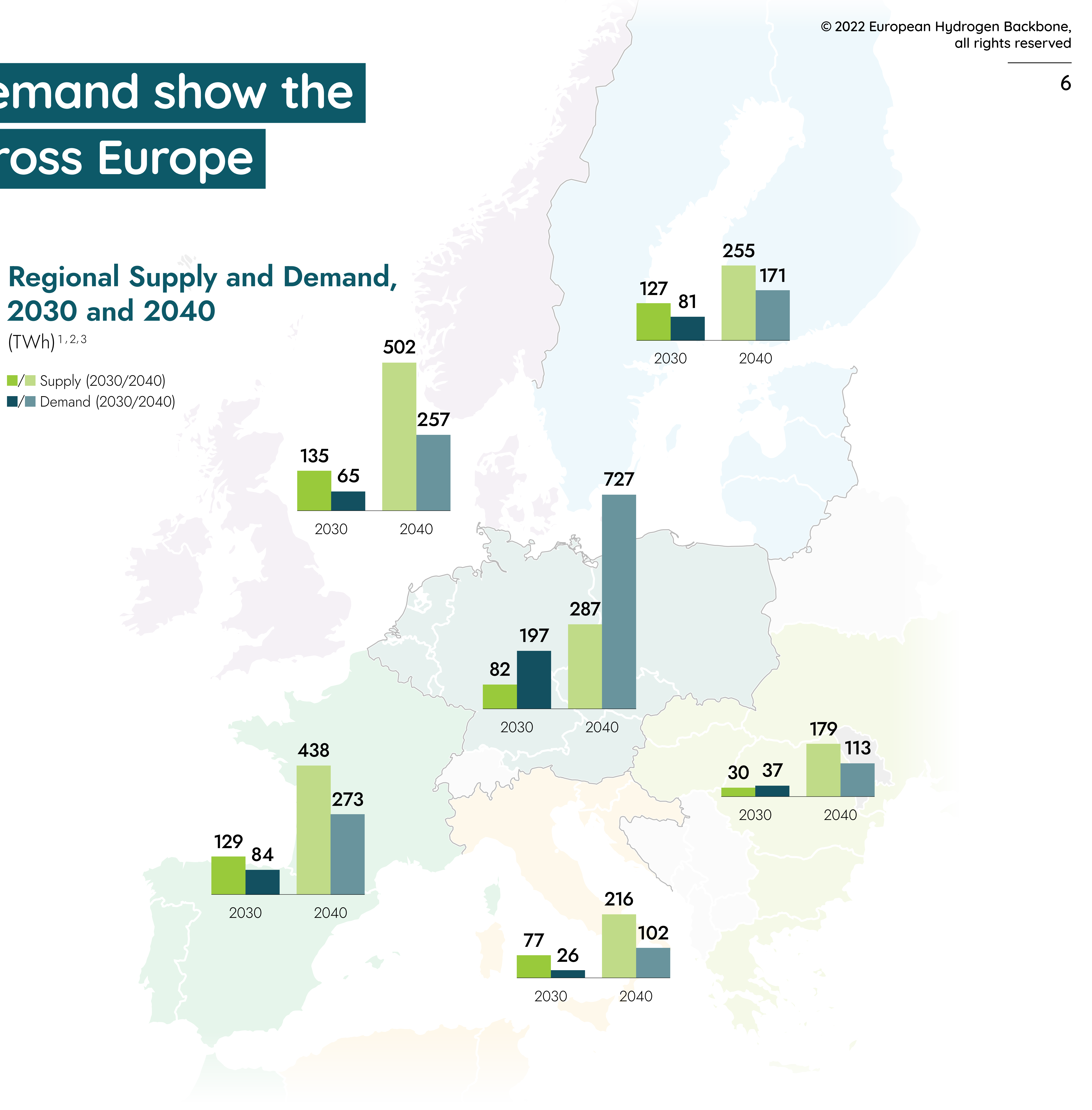
Other regions will require hydrogen imports from other European or neighboring regions to meet their hydrogen demand.

Hydrogen pipeline infrastructure can bridge these regional supply-demand differences across Europe in a cost-effective manner.

The EHB vision delivers the infrastructure needed to connect hydrogen supply and demand across Europe.

Regional Supply and Demand, 2030 and 2040

(TWh)[1, 2, 3]



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1 Aggregated demand and supply are based on the 2030 figures determined in this study. Supply figures include imports from North Africa and Ukraine. Note: Demand and supply figures may increase further in response to more ambitious national policies and measures following the RePowerEU plan.

2 This analysis estimates ~490 TWh of demand and ~580 TWh of supply in 2030 and does not attempt to determine how hydrogen supply and demand will balance out across Europe, nor which hydrogen supply sources – or from which regions – will be used to meet demand.

3 Demand and supply figures may not align with figures presented in the rest of the report based on aggregation of countries into regions and due to rounding.

Five supply corridors are key to the EHB vision and can deliver access to abundant and low-cost hydrogen supply by 2030

To deliver the 2030 hydrogen demand targets set by the RePowerEU plan, **five large-scale pipeline corridors are envisaged**.

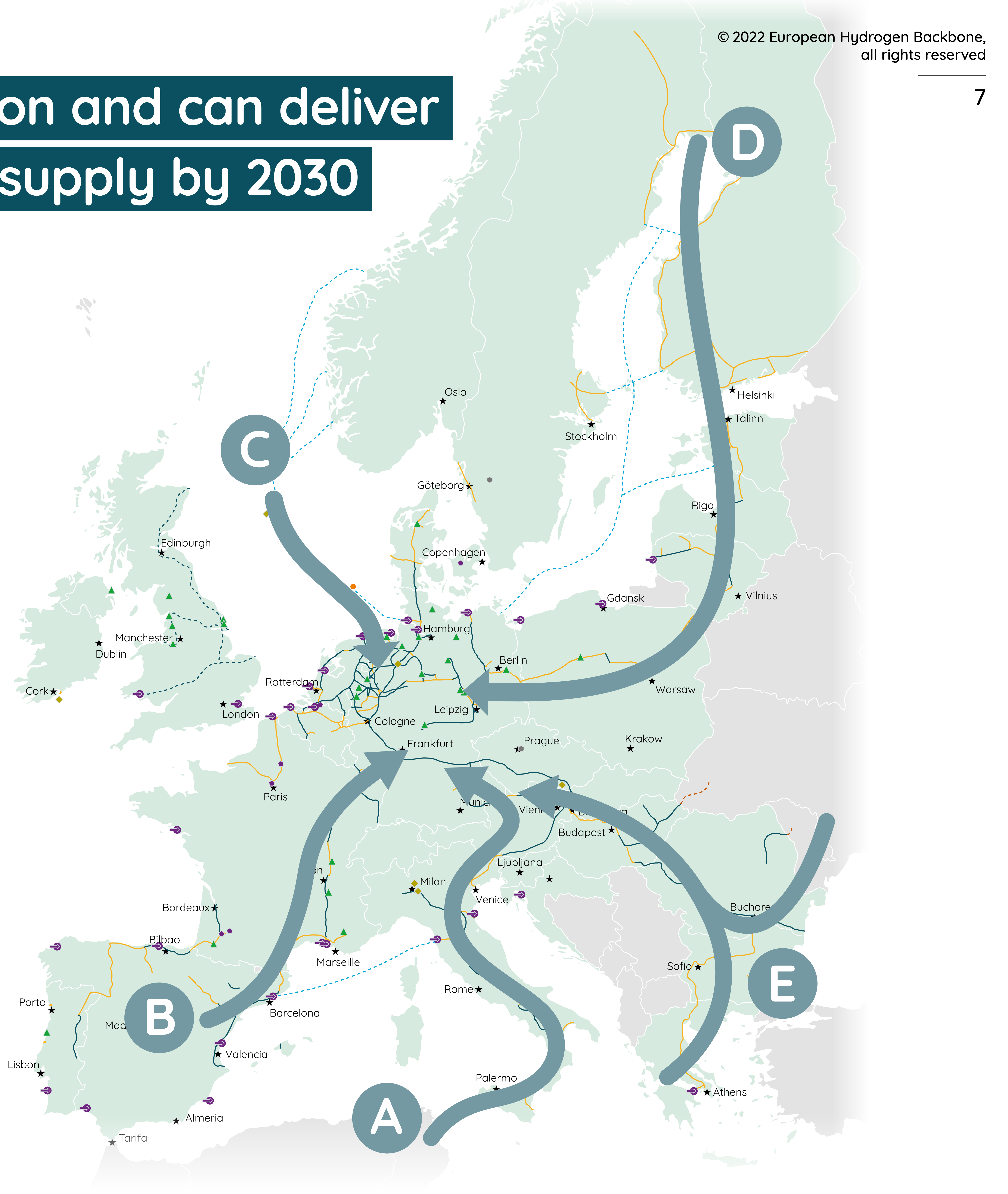
The corridors will **initially connect local supply and demand** in different parts of Europe, before expanding and **connecting Europe with neighboring regions** with export potential.

Certainty about the deployment of this infrastructure will **enable market actors to develop** supply and demand more rapidly

The five hydrogen supply corridors are:

- Corridor A: **North Africa & Southern Europe**
- Corridor B: **Southwest Europe & North Africa**
- Corridor C: **North Sea**
- Corridor D: **Nordic and Baltic regions**
- Corridor E: **East and South-East Europe**

These five corridors **span across both domestic and import supply markets**, consistent with the **three import corridors** identified by the RePowerEU plan, including a corridor via the **Mediterranean** (Corridors A and B), via the **North Sea** (Corridor C) and via **Ukraine** (Corridor E)



These five corridors represent the collective vision of the 31 gas infrastructure companies part of the EHB initiative

Corridor A
North Africa & Southern Europe

- eustream SLOVAK GAS TSC
- fluxswiss fluxys
- GAS CONNECT AUSTRIA
- GRTgaz
- NET4GAS
- OGE
- ONTRAS
- Plinovodi
- snam
- TAG

Corridor B
Southwest Europe & North Africa

- creos
- enagas
- fluxys
- GRTgaz
- OGE
- ONTRAS
- REN
- Terēga

Corridor C
North Sea

- creos
- ENERGINET
- fluxys
- Gas Networks Ireland
- GASSCO
- gasunie
- GRTgaz
- nationalgrid
- OGE
- ONTRAS

Corridor D
Nordic and Baltic regions

- Amber Grid
- conexus BALTIC GRID
- ENERGINET
- elering
- GASGRID
- GAZ-system
- NET4GAS
- NORDION ENERGI
- OGE
- ONTRAS

Corridor E
East and South-East Europe

- BULGARTRANSGAZ
- desfa
- eustream SLOVAK GAS TSC
- FGSZ
- GAS CONNECT AUSTRIA
- GAZ-system
- NET4GAS
- OGE
- ONTRAS
- PLINACRO
- Plinovodi
- TAG
- TRANSGAZ MAGISTRALA ENERGIEI

Note: Since all corridors terminate in Germany, OGE and ONTRAS are presented in each corridor grouping.

Each corridor has a unique regional role in enabling the scale up of low-cost hydrogen supply and the decarbonisation of energy demand

Corridor A
North Africa & Southern Europe

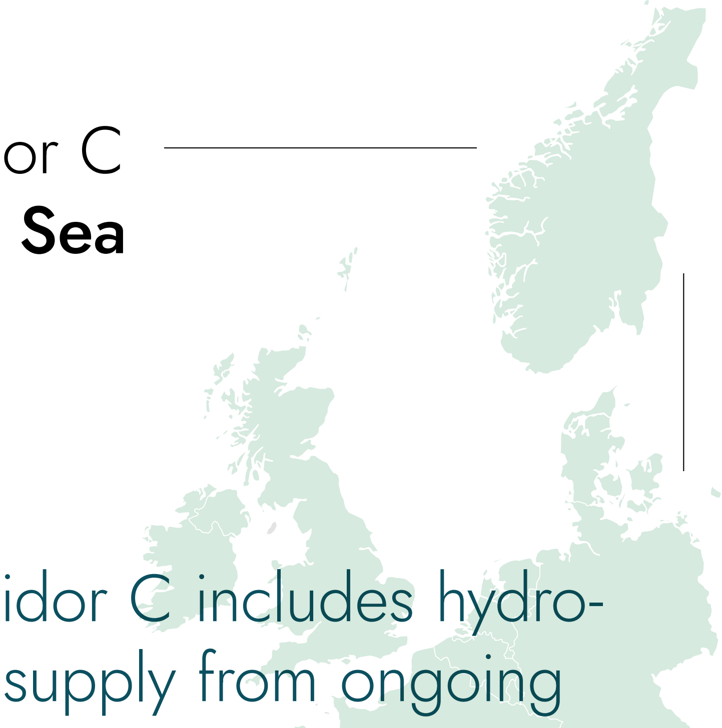
Corridor A would transport **large quantities of cost-competitive green hydrogen potential from Tunisia and Algeria** through Italy to central Europe leveraging existing gas infrastructure.

Corridor A would decarbonise **existing industries along the route in Italy and Central Europe as well as in Germany**.

Corridor B
Southwest Europe & North Africa

Corridor B would transport **green hydrogen supply from the Iberian peninsula and North Africa**, and gain **access to underground storage sites in France** to deliver stable hydrogen supply.

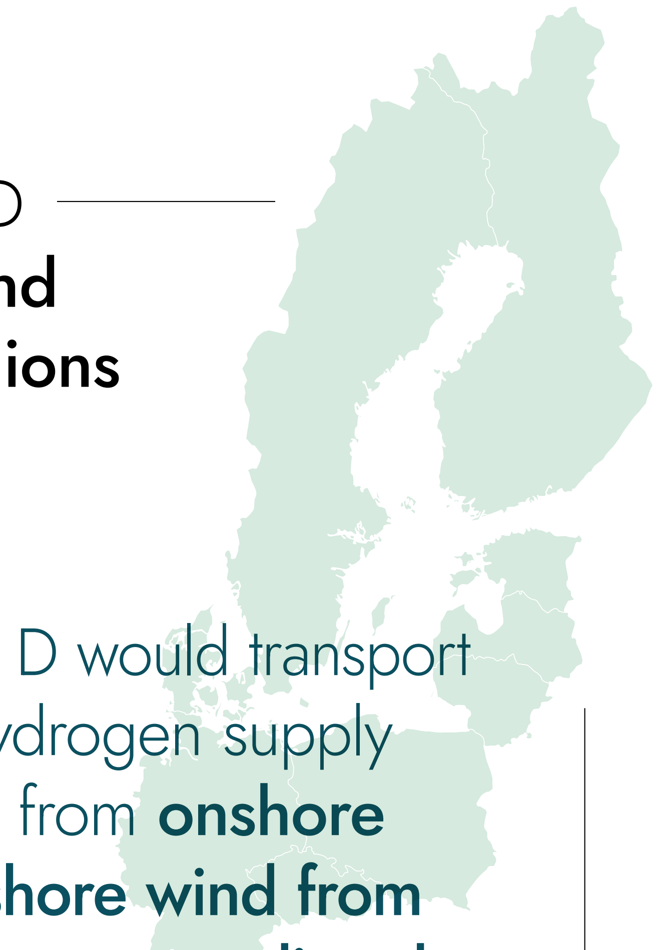
Corridor B would decarbonise **regional industry and transport clusters in Portugal, Spain, France and Germany**.



Corridor C
North Sea

Corridor C includes hydrogen supply from ongoing and planned **offshore wind, blue hydrogen and large-scale integrated hydrogen projects in the North Sea**.

Corridor C would meet **demand from industrial clusters and ports in the UK, the Netherlands, Belgium and Germany**.



Corridor D
Nordic and Baltic regions

Corridor D would transport green hydrogen supply potential from **onshore and offshore wind from countries surrounding the Baltic Sea**.

Corridor D would be built around **regional networks around industrial clusters**, serving numerous new **green steel, e-fuel, fertilizer and green chemicals projects in the Nordics** as well as decarbonizing existing industry in the Nordics, Baltics, Poland and Germany along the corridor route.

Corridor E
East and South-East Europe

Corridor E would connect **high supply potential regions such as Romania, Greece, and Ukraine**[1] — leveraging vast land availability and high-capacity factors for solar and wind.

Corridor E would deliver hydrogen to **off-takers in Central Europe and Germany**.

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[1] While Ukraine is expected to be a hydrogen exporting region, there is significant uncertainty related to Russia's invasion of Ukraine and its impact on Ukraine's gas infrastructure and economic development.

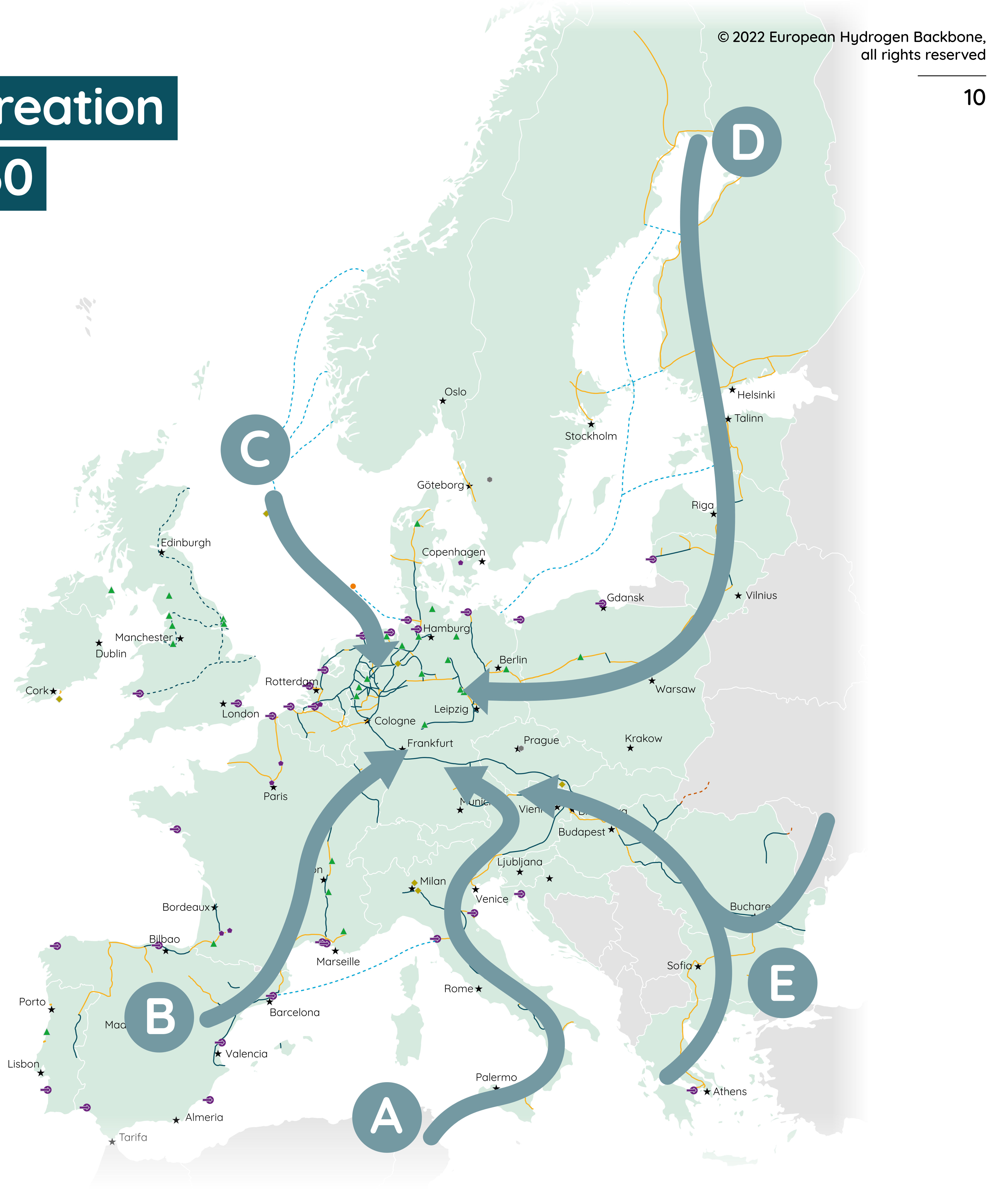
These five supply corridors will enable the creation of a pan-European hydrogen market by 2030

- **Connect** substantial hydrogen supply and demand across European regions and **leverage** underground storage to deliver stable supply
- **Access** vast volumes of cost-competitive domestic hydrogen supply and hydrogen imports from neighboring regions
- **Foster** the creation of a liquid, pan-European, hydrogen trading market

- **Accelerate** the deployment and integration of renewable energy resources
- **Support** scale-up of green, innovative European industries

- **Increase** the resiliency of Europe's energy system
- **Contribute** to European energy independence and diversity of supply.

- **Deliver** substantial and cost-effective emission reductions



To ensure the development of each corridor by 2030, there is a need for clear and concrete actions

Fostering development of new and repurposed hydrogen infrastructure, for example, by unbundling rules facilitating the efficient use of TSO expertise and services and by allowing the adoption of different vertical unbundling models in the EU, as is the case with natural gas

Unlock financing to fast-track hydrogen infrastructure deployment by applying regional regulatory flexibility and other pragmatic financing solutions (including incentivizing the adoption of hydrogen by demand sectors)

Simplify and shorten planning and permitting procedures for the full value chain of renewable energies and hydrogen infrastructure projects.

Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure supporting the accelerated deployment and integration of renewable energy resources

Intensify energy partnerships with exporting, non-EHB countries (e.g., with Morocco, Algeria, Tunisia, Ukraine) providing financing support to reduce the cost of capital in export countries and identifying a common certification system for hydrogen exchanges

→ However, speed will be of essence!

The EHB initiative stands ready to deliver the hydrogen infrastructure needed to achieve Europe's 2030 hydrogen targets

We have identified a large share of the **demand and supply** needed to meet the **RePowerEU targets**.

We analysed and studied **five large-scale, hydrogen supply corridors** that will be critical in transporting the required amounts of hydrogen.

These five supply corridors have the potential to provide Europe with **access to abundant and low-cost hydrogen supply** by 2030.

To ensure the **development of these supply corridors** on time, we have identified **five key concrete actions**

Ultimately, to realise the hydrogen pipeline infrastructure required by 2030, **action is needed now**.

→ The EHB initiative and its members are ready to deliver

Our recommendation: Establish hydrogen supply corridors as enabler for hydrogen market creation

Answering to RePowerEU

This reports shows how all **31 members** are able to **accelerate the hydrogen infrastructure development** to enable the 20 MT of renewable hydrogen by 2030

EHB recommends introducing the **establishment of hydrogen supply & import corridors as front-running infrastructure,** including all infrastructure requirements, **as a political objective**.

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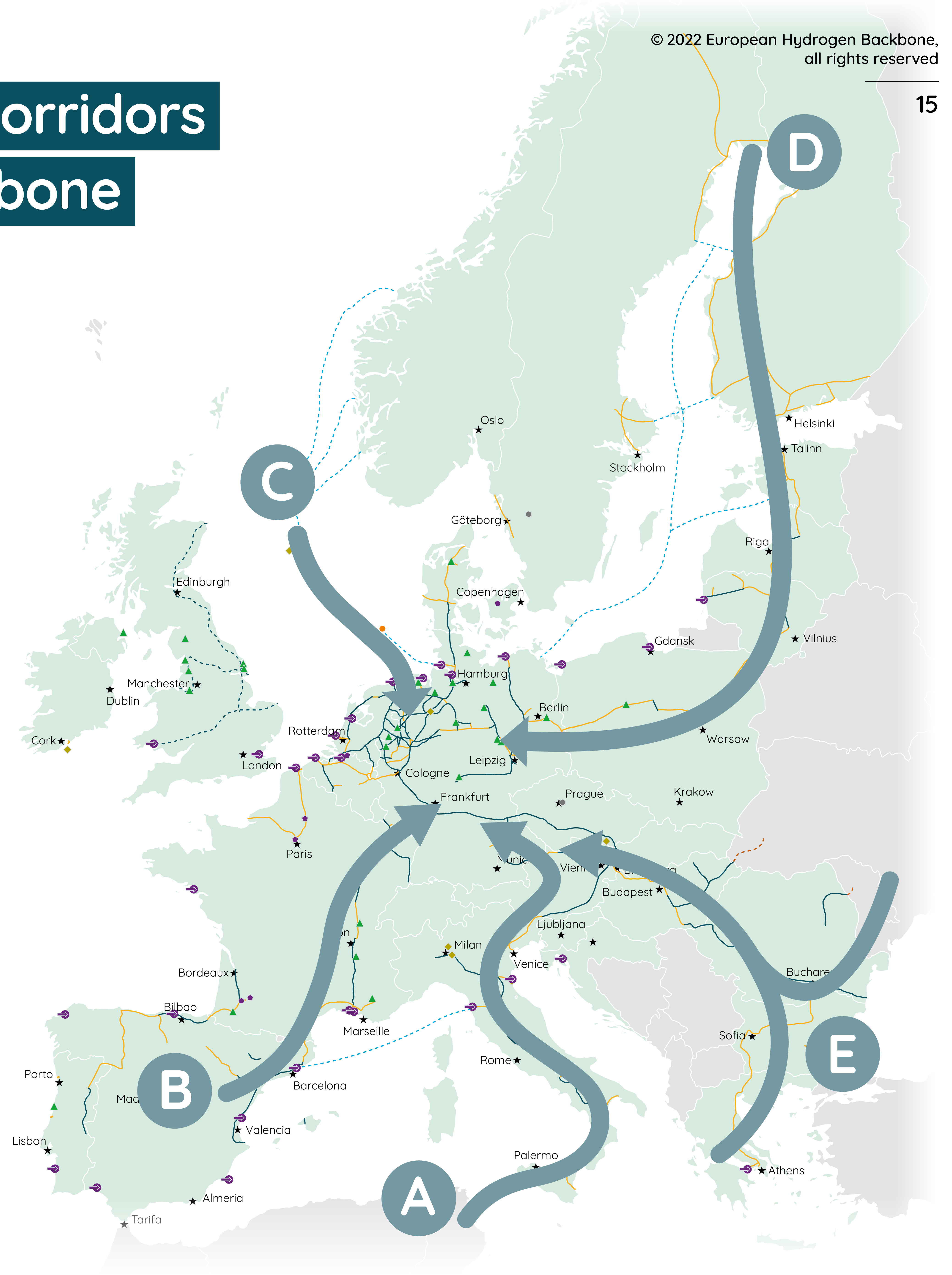
This report analyses each of the five hydrogen corridors and their roles in enabling a pan-European backbone

Sections	Questions answered
1 **Hydrogen Demand & Supply**	– How will **hydrogen demand and supply** evolve over time in this corridor? – Which **countries and sectors** will drive the development of hydrogen demand in this corridor? – How will the **hydrogen supply mix** change over time?
2 **Costs & Cost Competitiveness**	– How **competitive** will hydrogen from this corridor be with fossil alternatives? – What **cost-levers** can lower hydrogen cost?
3 **National Strategies & Regulations**	– What is the state of **national hydrogen strategies and regulation** in the countries of this corridor?
4 **Actions Needed**	– What **near-term regulatory and planning actions** are required to support the development of this corridor?



This study builds on previous EHB reports and findings, and incorporates new corridor-specific analysis

Key study inputs

Inputs are defined primarily over the 2030-2050 timeframe, building on the most recently published EHB reports and maps:

- **Hydrogen demand forecasts** by country, sector and year.
- **Realisable hydrogen supply potential** by country and year;
- **Existing gas pipeline infrastructure** (onshore and offshore) and **storage facilities**;
- **Hydrogen infrastructure development plans** by country; and
- **Costs assumptions** associated with green and blue hydrogen supply and pipeline repurposing.

Major study uncertainties

- **Uncertainty** on near- and long-term European **natural gas prices and supply mix**.
- **Uncertainty** related to Russia's invasion of Ukraine and its impact on Ukraine's gas infrastructure, economic recovery and development of a hydrogen market.
- **Uncertainty** regarding the **development of hydrogen pipeline infrastructure across Europe**, which is subject to developments in European and national energy policy, regulations and funding.
- **Uncertainty regarding future hydrogen demand and supply**, which may accelerate and increase further as a result of additional regulatory measures adopted in response to the RePowerEU plan.

Out of scope

- **This study does not incorporate detailed infrastructure planning** associated with the repurposing of existing natural gas pipelines, storage facilities, or gas import / export terminals.
- **This study does not account for ship imports** of hydrogen or hydrogen-derivatives like ammonia and methanol into Europe.

→ **Methodology Section:** Refer to the **Section 3: Methodology** for a description of the general supply and demand approach, key inputs, data sources, calculations, etc.

Since some corridors transit through the same countries, key metrics – like corridor length, supply and demand – overlap

In this study, **when a corridor transit through a given country**, even if only partially, **it becomes part of the analysis of the corridor**, including its hydrogen demand, supply and transport infrastructure.

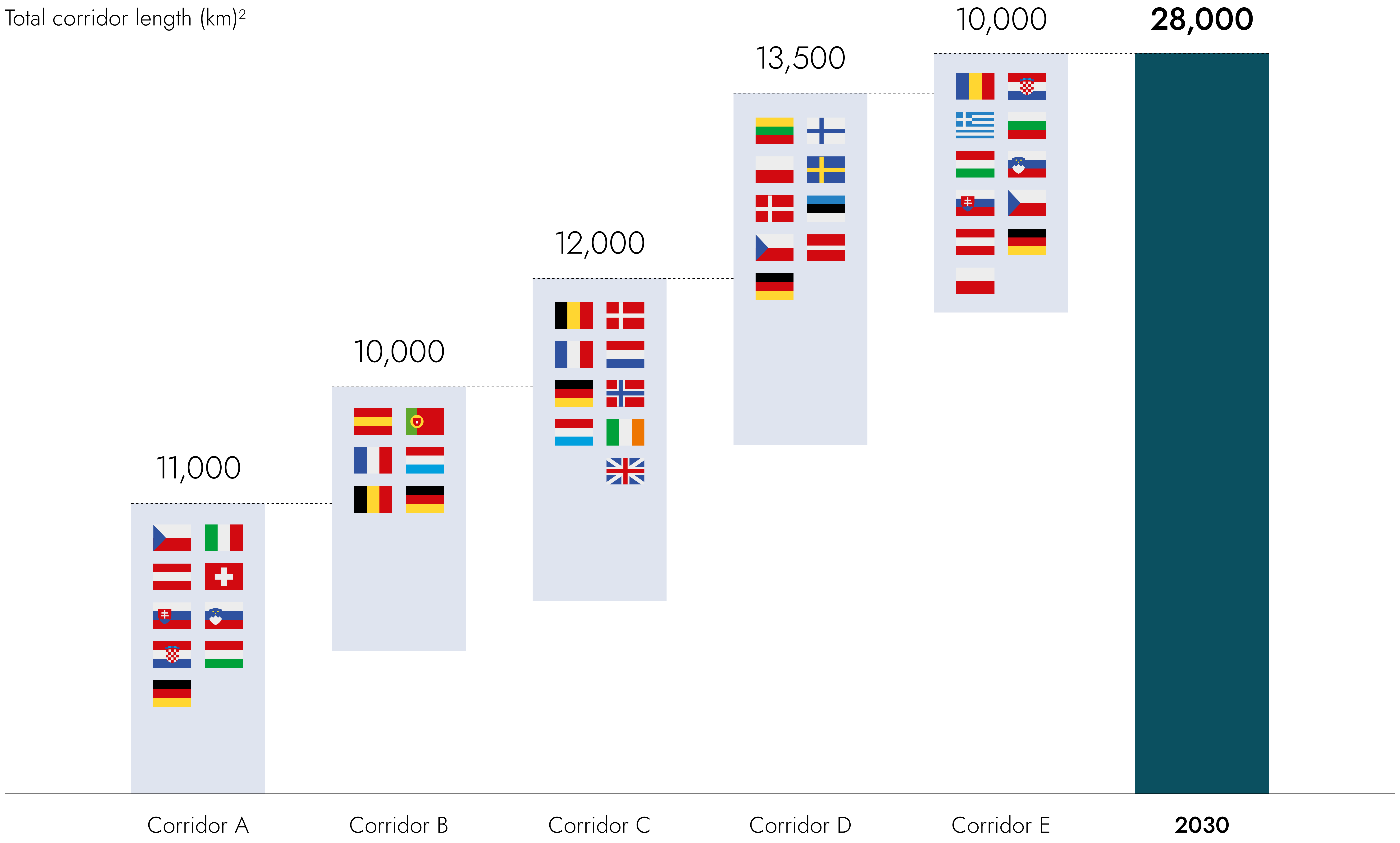
All five corridors of this study either: **(1) transit through some of the same countries, or (2) terminate in the same country**[1].

For example:

- **Corridor B** (Southwest Europe and North Africa) and **Corridor C** (North Sea) both transit through sections of **the Netherlands, Belgium and Germany**.
- **Corridor D** (Nordic and Baltic regions) and **Corridor E** (East and South-East Europe) both transit through section of **Germany, Czechia and Poland**.

This means that **all corridors partially overlap with other corridors. As a result, key metrics – like corridor length, supply and demand – overlap and are not mutually exclusive**.

This is illustrated on the right for corridor lengths.



Note: Since all corridors partially overlap, summing all individual corridor lengths – without adjusting for overlaps – adds up to ~56,000km, which is two times the combined length of 28,000 km in 2030².

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1 Since the largest demand clusters in Europe are concentrated in and around Germany, all five corridors terminate – and thus, overlap – in Germany

2 The basis for these determining corridor lengths is the most recent publication of the EHB maps (April 2022).

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North Africa
& Southern Europe

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2. Hydrogen Demand & Supply
3. Supply Costs & Cost-Competitiveness
4. National Strategies & Regulation
5. Actions Needed

CORRIDOR A / FACTSHEET

North Africa & Southern Europe

Corridor emerges in Southern Europe providing access to low-cost hydrogen supply from North Africa to demand clusters along the corridor

- Italy
- Switzerland
- Slovenia
- Hungary
- Croatia
- Czechia
- Austria
- Slovakia
- Germany

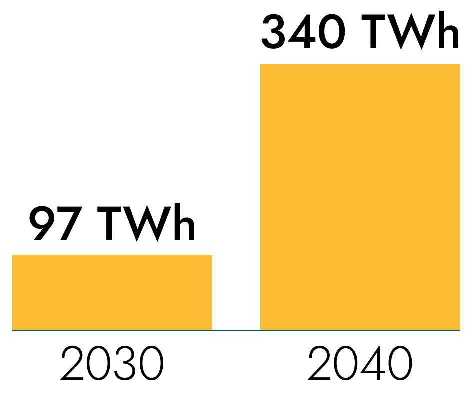
Drivers & Opportunities

Major driver of development is the need to meet **hydrogen demand from industry, transport and power** in Italy, Central Europe and Germany. Key opportunities include the high **repurposing potential of gas pipelines from Italy to Central Europe**, and **pipeline interconnections with Algeria and Tunisia**.

Hydrogen Supply & Decarbonization Potential

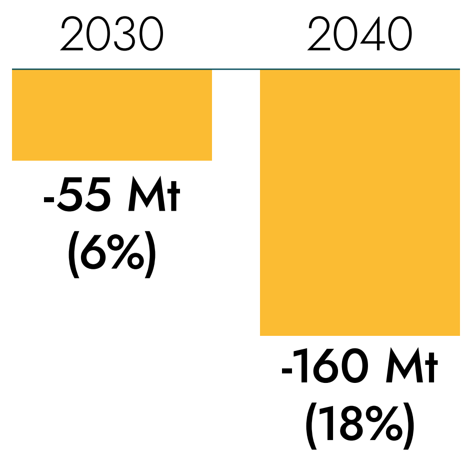
H_2 supply potential[1]

(TWh/year)



Emissions Reductions

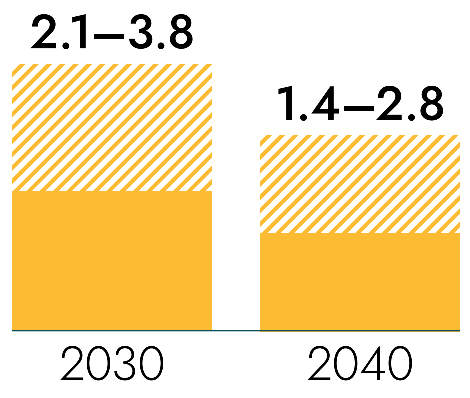
($MtCO_2$/year vs. 2019; % reduction)



Supply Costs & Cost-Competitiveness

Cost of H_2 production[1]

(€/kg of H_2)

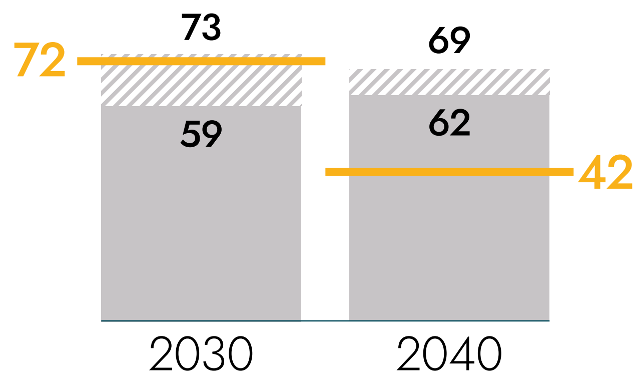


Cost competitiveness[2]

— Hydrogen delivered price

vs.

▨ natural gas price high/low, (€/MWh)



Actions Needed

- Fostering development of new and repurposed hydrogen infrastructure
- Unlock financing to fast-track hydrogen infrastructure deployment
- Simplify and shorten planning and permitting procedures
- Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure
- Intensify energy partnerships with exporting, non-EHB countries like Tunisia and Algeria

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[1] Figures reported reflect outputs for all countries included in the corridor. Even if a country is only partially in the corridor, results for the full country are included (e.g., supply potential and costs, demand, transmission network length).

[2] Savings are based on the corridor's case study of hydrogen delivered in 2030 and 2040. The cost of natural gas includes CO_2 prices. Refer to Subsection 3 (Supply Costs & Cost-Competitiveness)

CORRIDOR A

North Africa & Southern Europe

Agenda

1. **Corridor Summary**
2. Hydrogen Demand & Supply
3. Supply Costs & Cost-Competitiveness
4. National Strategies & Regulation
5. Actions Needed

Corridor offers access to low-cost hydrogen supply from North Africa to demand centers in Italy, Central Europe and Germany

Drivers & Opportunities

- **The major driver** behind the development of this corridor is the adoption of hydrogen associated with the **decarbonisation of industry, transport and power** in Italy, Central Europe and Germany. The speed of hydrogen adoption in these regions may be even faster than anticipated driven by increasing CO_2 prices in the EU and the RePowerEU ambitions to replace natural gas consumption.
- In the near term, the corridor offers **access to abundant low-cost, renewable production from Italy and Tunisia**. In the longer term, this corridor may also provide access to hydrogen imports from Algeria (via Tunisia) and additional supply from Central and South-Central Europe.
- A major opportunity of the corridor is the **ability to repurpose a large share of existing gas pipeline infrastructure** across Italy, Austria, Slovakia, and Czechia. Another key opportunity is the **potential repurposing of the Trans-Mediterranean pipeline** connecting Tunisia to Italy via Sicily, giving the corridor access to the abundant solar and wind resources of Northern Africa.
- Recently, RePowerEU identified the development of a new subsea pipeline connecting Spain and Italy, expected to be available for hydrogen transport by 2030.
- The corridor would be stood up by 2030, covering **11,000 km** of large-scale hydrogen pipelines across all countries of the corridor, of which approximately **60% will be repurposed pipelines**.

Hydrogen Demand & Supply

- **Total hydrogen demand** in the corridor reaches **~140 TWh by 2030**, increasing substantially to **~550 TWh by 2040**. Up to 2030, most hydrogen demand is driven by the industrial sector in Germany and Italy, along with some use of hydrogen in power generation. From 2040 to 2050, hydrogen demand expands into the transport sector and continues to ramp up in industry and power generation.
- Hydrogen adoption across all countries of the corridors enables an emissions reduction of ~220 $MtCO_2$/yr. by 2050, equivalent to a **25% emissions reduction**.
- The corridor enables access to **hydrogen supply potential of ~100 TWh by 2030, increasing to roughly 340 TWh by 2040**. Major sources of supply include hydrogen imports from North Africa and green hydrogen from Italy.

CORRIDOR SUMMARY

To successfully stand up this corridor by 2030, actions are needed to support infrastructure planning, financing and development

Costs & Cost-Competitiveness

- **By 2030**, the corridor provides access to hydrogen ranging in production costs from **2.1 to 3.8 €/kg**. **By 2040**, as supply options increase, technology costs decrease, and increased imports from North Africa become available, hydrogen production costs decrease to **1.4 to 2.8 €/kg**.
- Already by 2030, this corridor's lowest-cost supply options are imports from North Africa.
- Based on a case-study of hydrogen supply and transport from Tunisia to Germany, **the cost of delivered hydrogen** – inclusive of transport and storage costs – **can be lowered to achieve cost levels comparable to production costs by 2040**. Lowering delivery costs can be achieved through various cost levers including optimised operation of the system and cost of capital reductions.

National Strategies & Regulation

- **Most countries have developed** – or are in the process of developing – **national strategies**. Moving forward, the **development of hydrogen regulation** in all countries will be key in enabling investment in infrastructure.
- In select countries, **substantial funding has been allocated** to support the development of the hydrogen market including funding for gas network infrastructure.

Actions Needed

To support the buildout of this corridor by 2030, clear and concrete actions related to infrastructure planning, financing and development have been identified:

- Fostering development of **new and repurposed hydrogen infrastructure**.
- Unlock financing to **fast-track hydrogen infrastructure deployment** by applying regional regulatory flexibility and other pragmatic financing solutions.
- Simplify and shorten **planning and permitting procedures** for the full value chain of renewable energies and hydrogen infrastructure projects.
- Establish **integrated energy system planning** of hydrogen, natural gas, and electricity infrastructure.
- **Intensify energy partnerships** with exporting, non-EHB countries like Tunisia and Algeria.

North Africa & Southern Europe

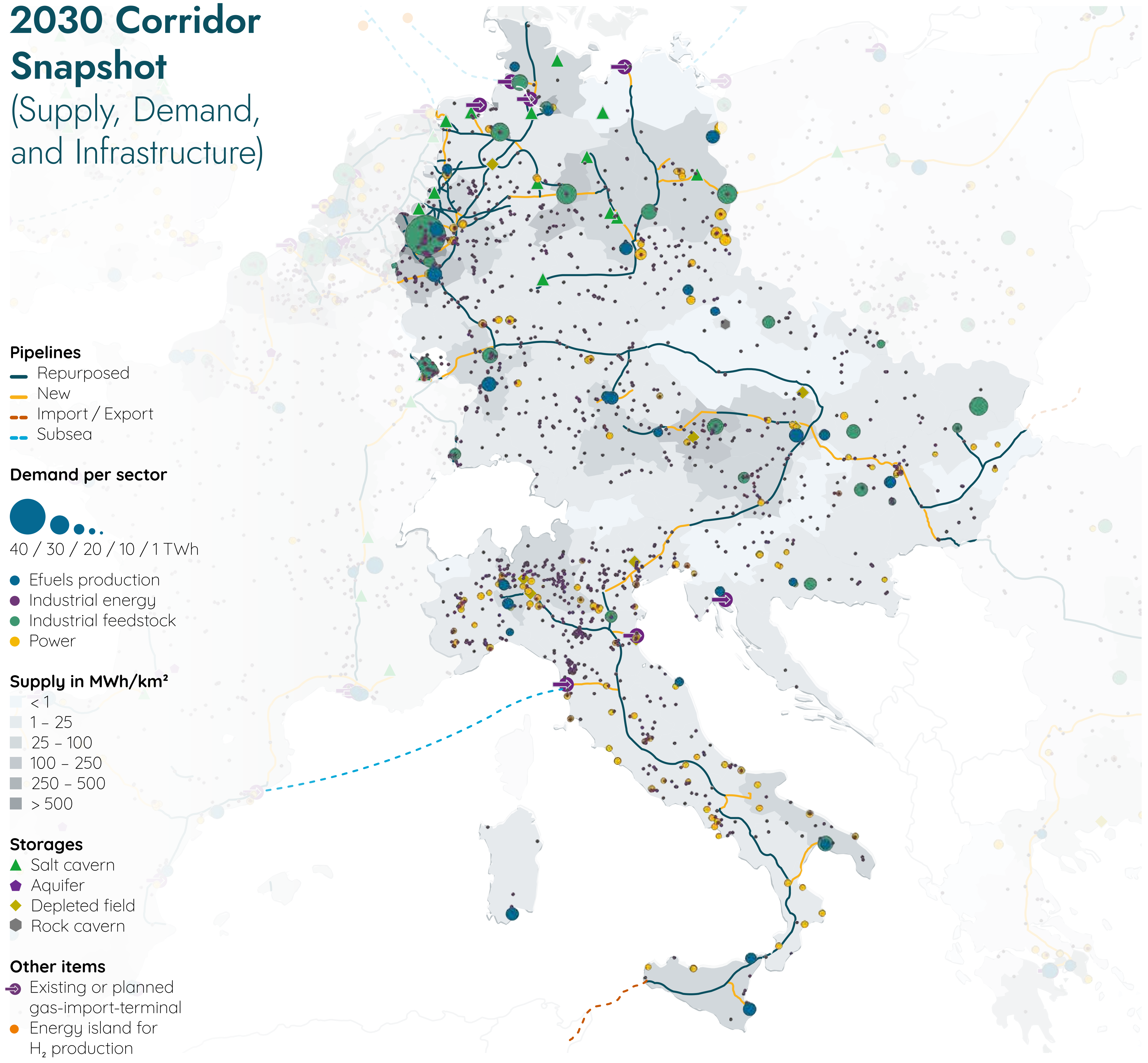
Agenda

1. Corridor Summary
2. **Hydrogen Demand & Supply**
3. Supply Costs & Cost-Competitiveness
4. National Strategies & Regulation
5. Actions Needed

This section explores the development of demand, supply and transport infrastructure in the corridor from 2030 to 2050

2030 Corridor Snapshot

(Supply, Demand, and Infrastructure)



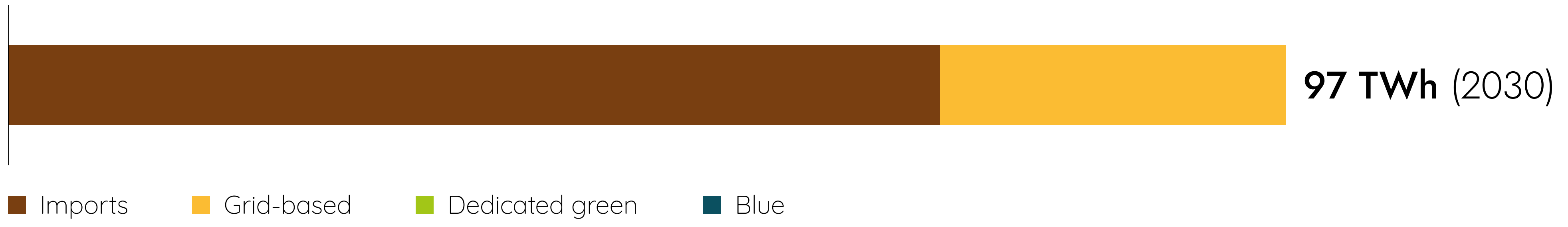
Hydrogen demand

By 2030, the corridor connects **all major industrial clusters** from Italy to Germany. **From 2030 to 2040**, the corridor expands to **all demand centers along its route**, increasing demand from 140 to ~550 TWh.

Hydrogen supply

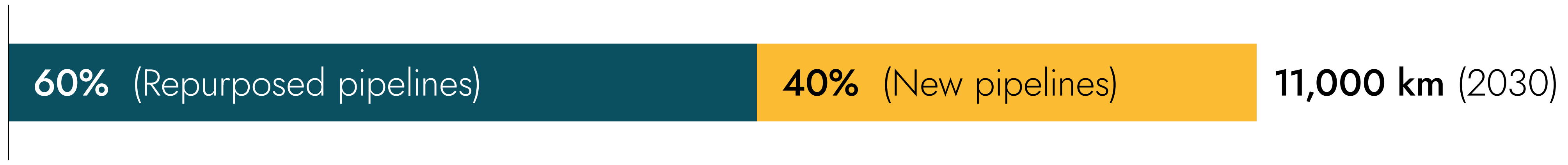
By 2030, the corridor enables access to low-cost supply from **Italy and Tunisia**. **By 2040**, the corridor gains access to **supply from Algeria (via Tunisia), Central and South-Central Europe**

In 2030, hydrogen supply is ~100 TWh, of which more than 70% is imports. Hydrogen supply increases significantly by 2040, reaching 340 TWh.

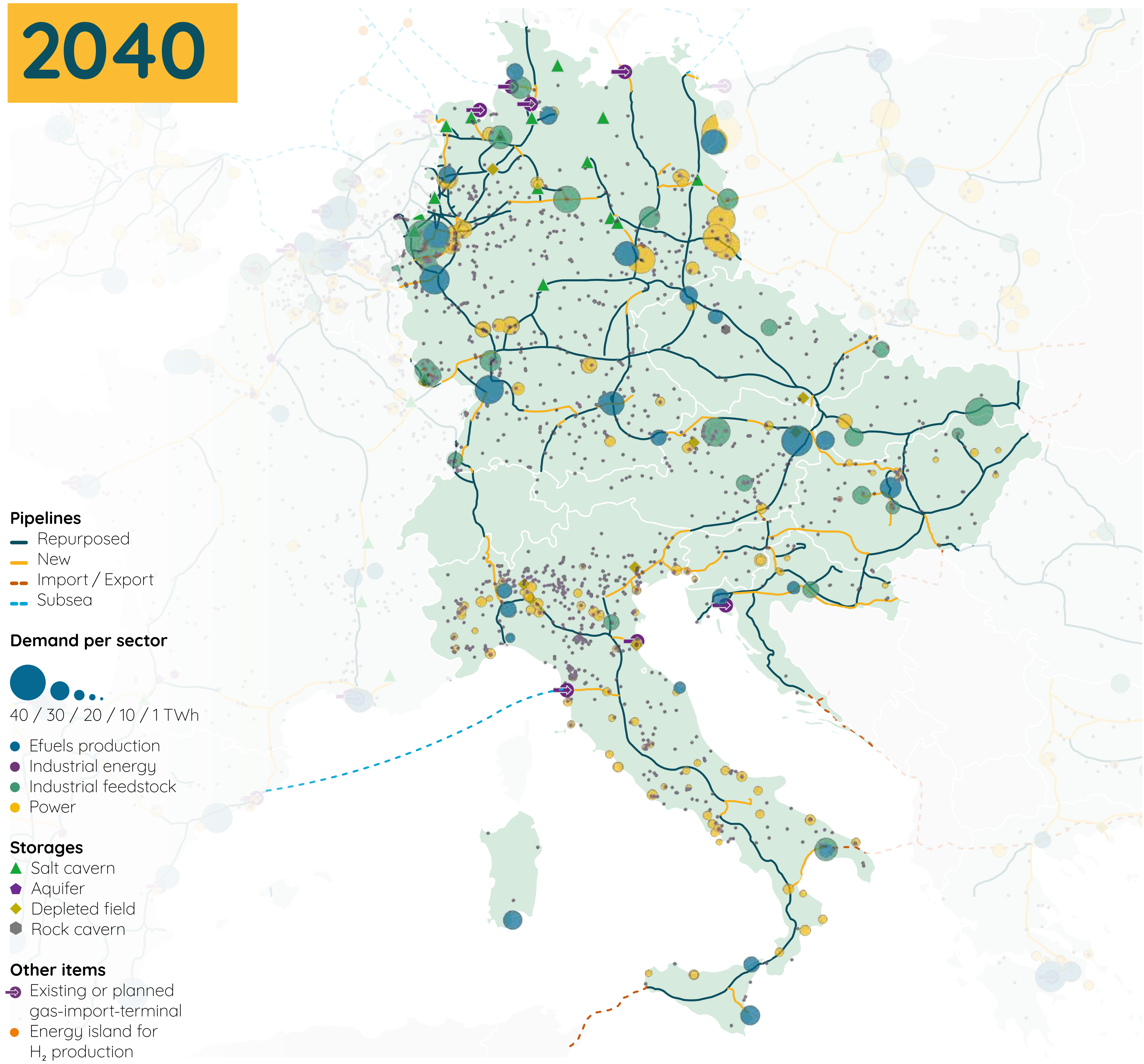


Hydrogen Infrastructure

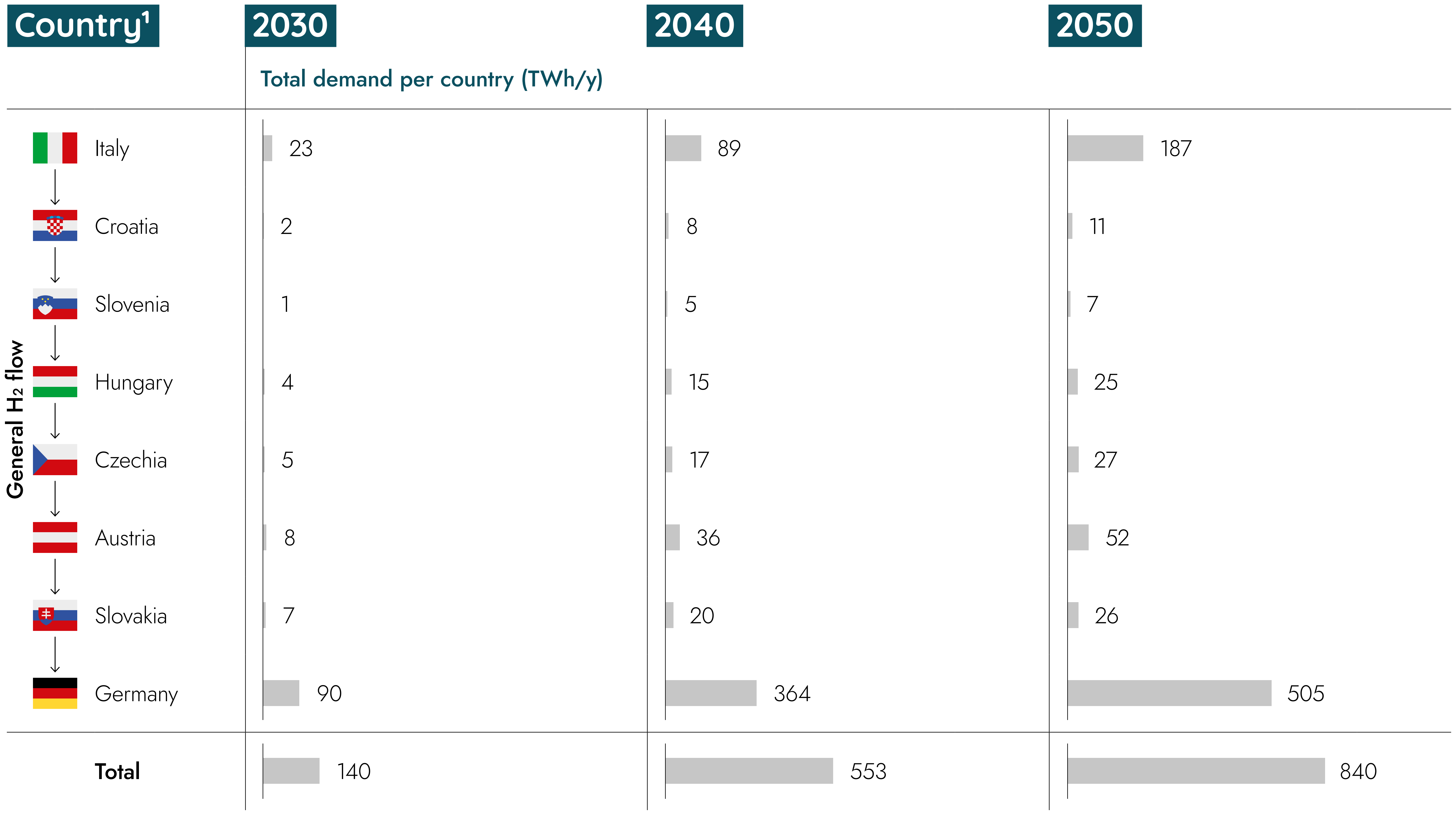
By 2030, the buildout of pipeline infrastructure across all countries of the corridor reaches **11,000 km** of large-scale pipelines. Corridor benefits from a **very large share of repurposed infrastructure**.



Corridor connects major hydrogen clusters across Italy and Central Europe by 2030, expanding to all demand centers by 2040



Hydrogen demand increases rapidly from 2030 to 2040, largely driven by Germany and Italy. Demand continues increasing to 2050



Total demand per country (TWh/y)

Country[1]	2030	2040	2050
Italy	23	89	187
Croatia	2	8	11
Slovenia	1	5	7
Hungary	4	15	25
Czechia	5	17	27
Austria	8	36	52
Slovakia	7	20	26
Germany	90	364	505
Total	140	553	840

Hydrogen demand – across all countries of the corridor – increases significantly from 2030 to 2050. Demand reaches 140 TWh by 2030, increasing to 840 TWh by 2050.

Hydrogen demand may accelerate and increase further as a result of additional regulatory measures adopted in response to the RePowerEU plan.

- **Up to 2030, most hydrogen demand is driven by the industrial sector in Germany and Italy**, along with some use of hydrogen in transport and power generation.
- **From 2040 to 2050**, hydrogen demand expands into the transport sector and continues to ramp up in industry and power generation.

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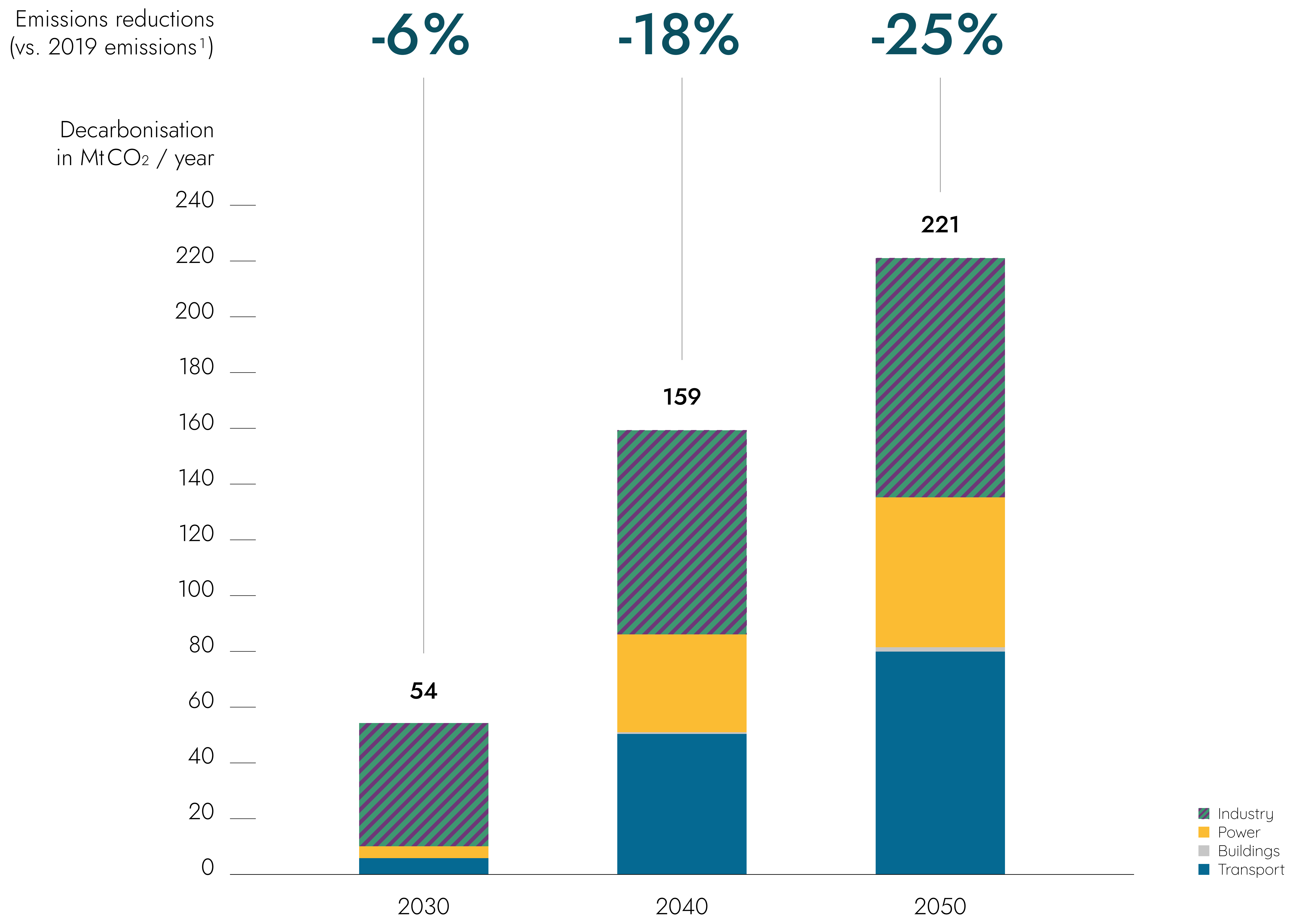
[1] Switzerland is not included in the demand figures because as a non-EU member, Switzerland is not included in the datasets used to estimate hydrogen demand in 2030, 2040 and 2050.

Note: Does not include grey hydrogen demand. Numbers represent total demand by country, even if only parts of the country are included in the corridor.

Hydrogen adoption enables a reduction in emissions of 25% by 2050 across all countries of the corridor



Hydrogen adoption across all demand sectors enables an **emission reduction of ~220 $MtCO_2$/yr. by 2050**, equivalent to a **25% reduction**[2].

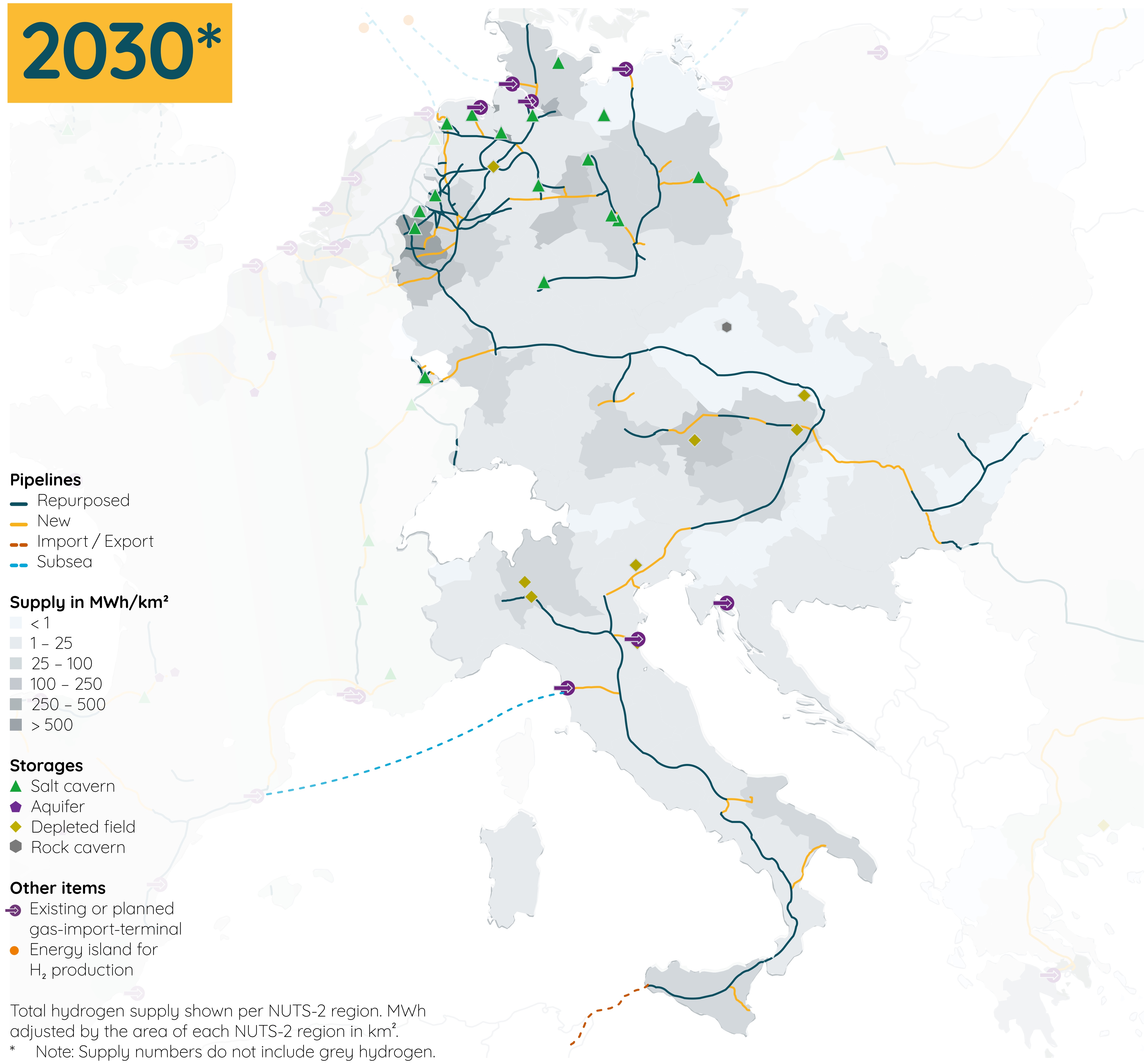
- **Up to 2030**, the decarbonisation of industry — largely the steel sector and refining — contributes 75% of the total emissions reductions.
- **By 2040**, emissions reductions from power generation and transport (road, shipping and aviation) increase substantially and combined account for 50% of emissions reductions.
- **By 2050**, most incremental emissions reductions are associated with hydrogen adoption in the power and transport sectors.

---

[1] CO_2-Emissions from countries and sectors included in corridor (0.89 bn t CO_2 / year), Source: EEA

[2] Emissions reductions are calculated compared to the baseline fossil fuel used in each sectors. For example, emissions reductions associated with the adoption of hydrogen by the primary steel sector are relative to the use of coal. Similarly, emissions reductions , for e-fuels production are relative to the use of fossil fuels in domestic transport, shipping and other uses.

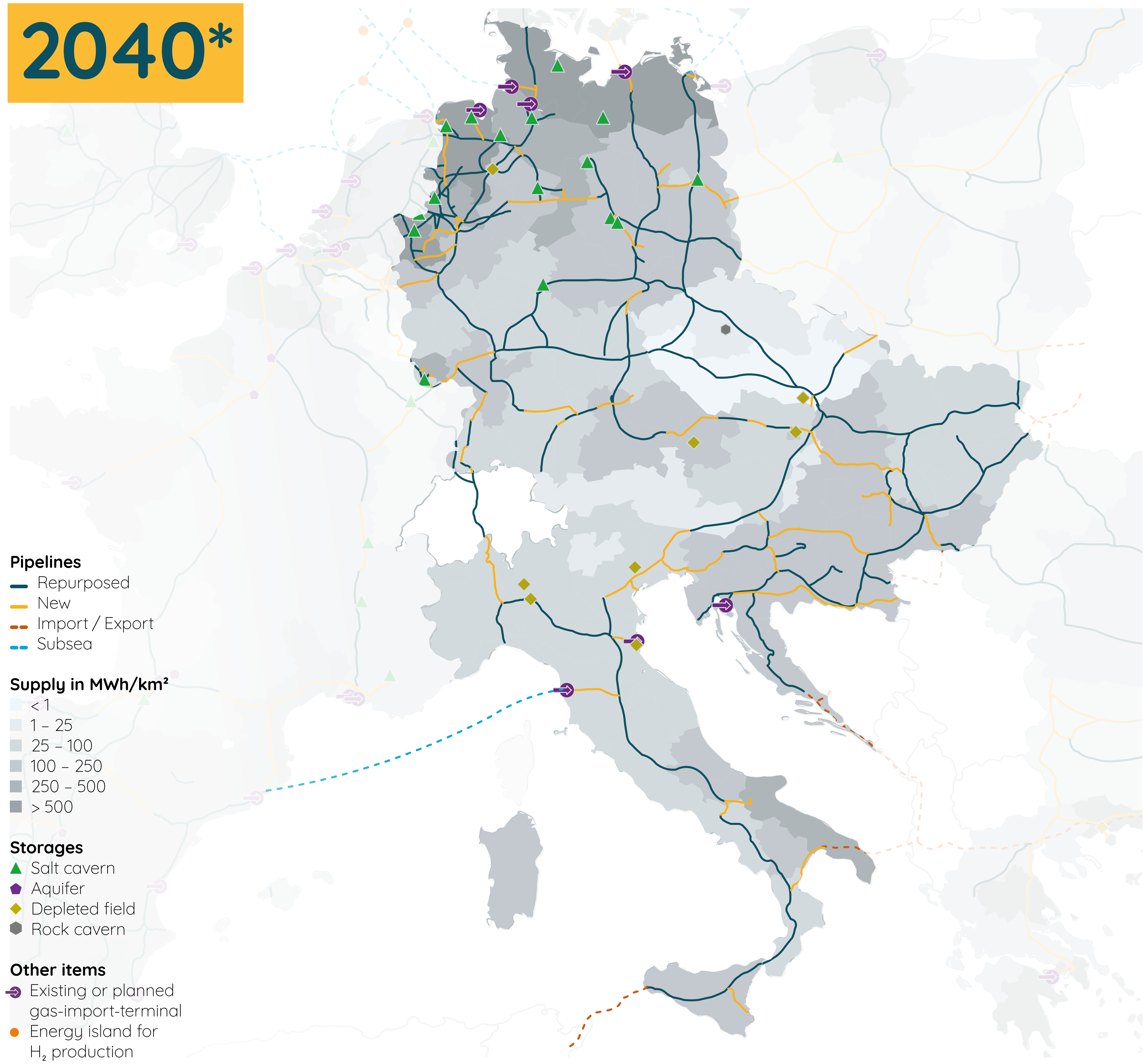
Corridor enables access to supply from Italy and Tunisia by 2030, expanding to supply from Central and South-Central Europe by 2040



2030*

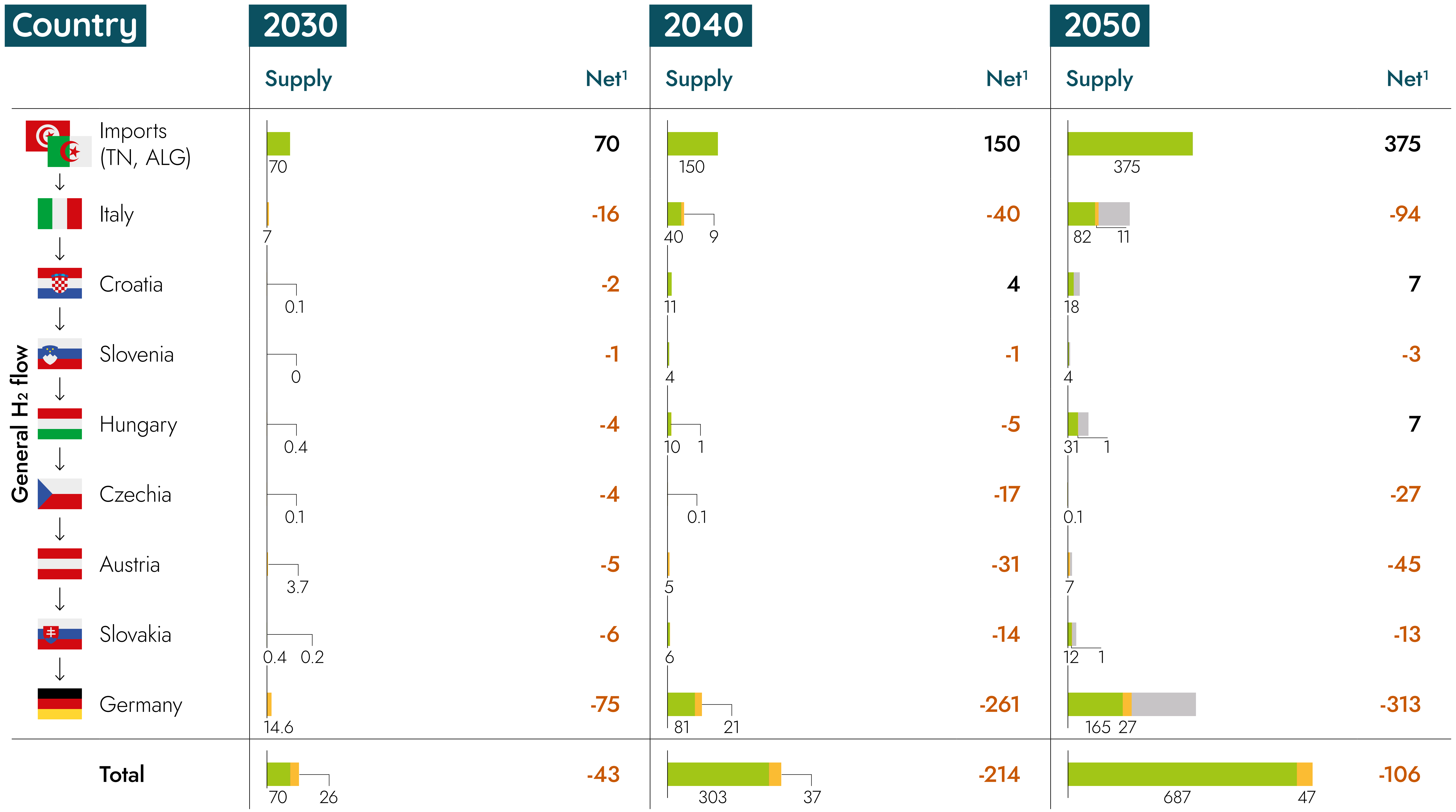
Total hydrogen supply shown per NUTS-2 region. MWh adjusted by the area of each NUTS-2 region in km².

* Note: Supply numbers do not include grey hydrogen.



2040*

Hydrogen supply increases significantly from 2030 to 2040, largely driven by green hydrogen supply from North Africa and Italy



Hydrogen supply includes a mix of supply options including **grid-based green hydrogen[2] and dedicated green hydrogen**.

- **By 2030, hydrogen supply reaches ~100 TWh**, largely from grid-based hydrogen.
- **By 2040, hydrogen supply increases substantially to ~340 TWh**, of which 90% is from dedicated green hydrogen. The remaining share is grid-based hydrogen.
- **By 2050, hydrogen supply increases further to ~730 TWh**. Dedicated green supply continues to account for the largest share at roughly 95%.

Hydrogen supply may accelerate and increase further as a result of additional regulatory measures adopted in response to the RePowerEU plan.

Note: Hydrogen supply volumes do not include hydrogen imports by ship.

---

[1] *Net* represents excess supply after subtracting demand;

[2] Grid-based is estimated using national 2030 electrolyser targets which, by 2030, are assumed to be largely grid-connected rather than dedicated. Grid-based increases over 2030-2050 with increasing RES adoption;

[3] Switzerland is not included in the demand figures because as a non-EU member, Switzerland is not included in the datasets used to estimate hydrogen demand in 2030, 2040 and 2050.

Tunisia and Algeria may become a potential sources of hydrogen imports to Europe as early as 2030

State of Gas Infrastructure

- North Africa connects to Italy via Tunisia with **one interconnector**: the **Enrico Mattei – Transmed pipeline** via Sicily (525km, 30 bcm/year)
- **Two existing Algerian LNG export terminals**: Arzew/Bethouia (20.8 mln tonne per year) and Skikda (7.7mln tonnes per year)
- Hydrogen export potential via this corridor focuses primarily on **hydrogen supply from Tunisia and Algeria via the Transmed pipeline**.

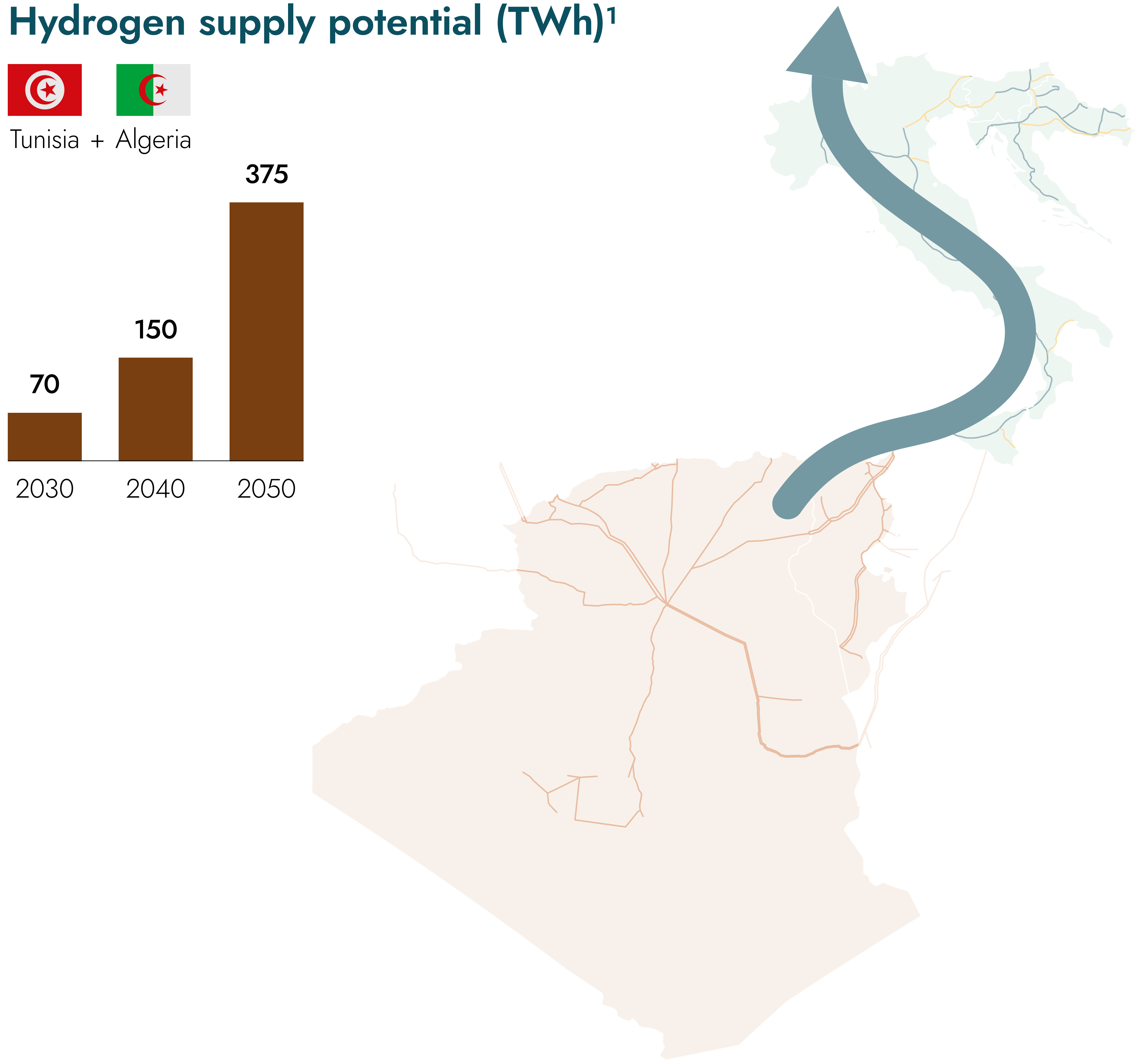
Market Attractiveness

- **Abundant renewable energy potential** particularly solar PV and onshore wind
- **Partnerships**: Germany has established partnerships with both Tunisia and Algeria exploring the potential of green hydrogen exports
- **Market developments**:
  - **Tunisia** is taking part in the HyDeal project, which could see 1.4Mt/year produced in the country and an investment of over 20bn €.
  - Availability of **Algerian** hydrogen exports to Europe highly depends on repurposing natural gas pipelines between Algeria and Tunisia.

Market Barriers

- **Limited renewable energy infrastructure, low renewables penetration** in own energy system and strong **reliance on hydrocarbons** today
- **Inadequate financing mechanisms** on a state and local level for renewable projects
- **Future growth in domestic hydrogen** demand may impose limit on exports.

Hydrogen supply potential (TWh)[1]



Note: The high potential import from Algeria and Tunisia depends on development of both demand and infrastructure

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1 Supply figures estimated based on hydrogen supply potential combined for Tunisia and Algeria. Export potential is dependent on development of demand and infrastructure.

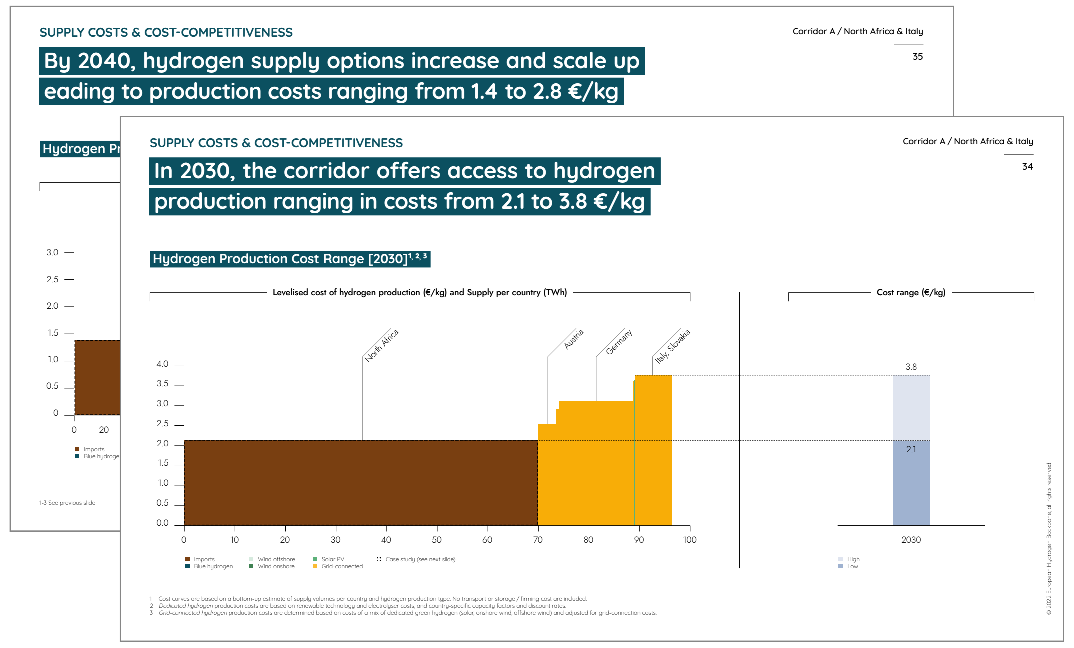
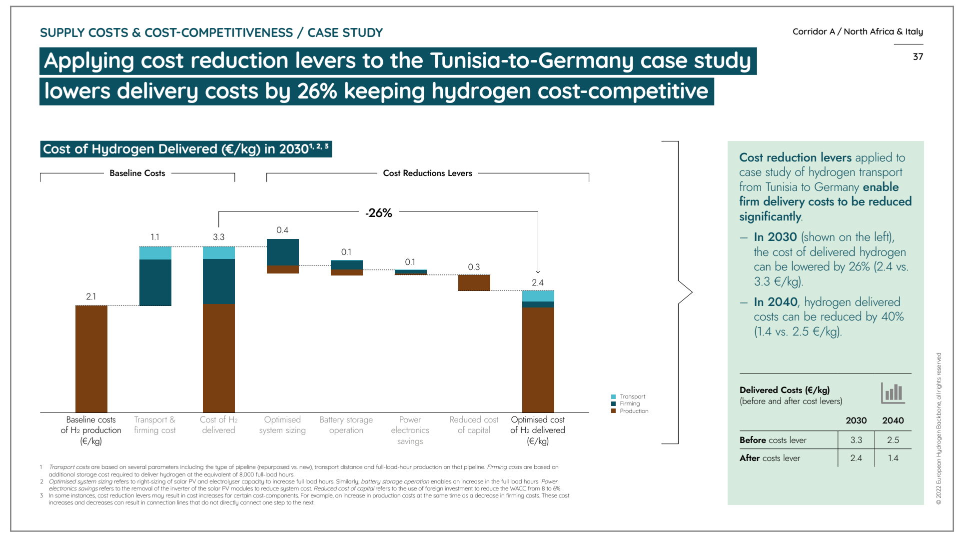
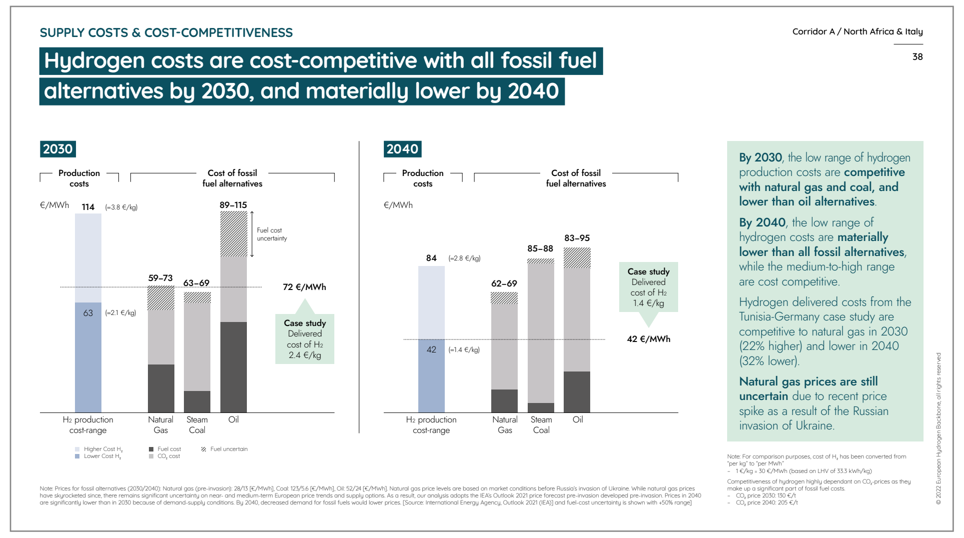
CORRIDOR A

North Africa & Southern Europe

Agenda

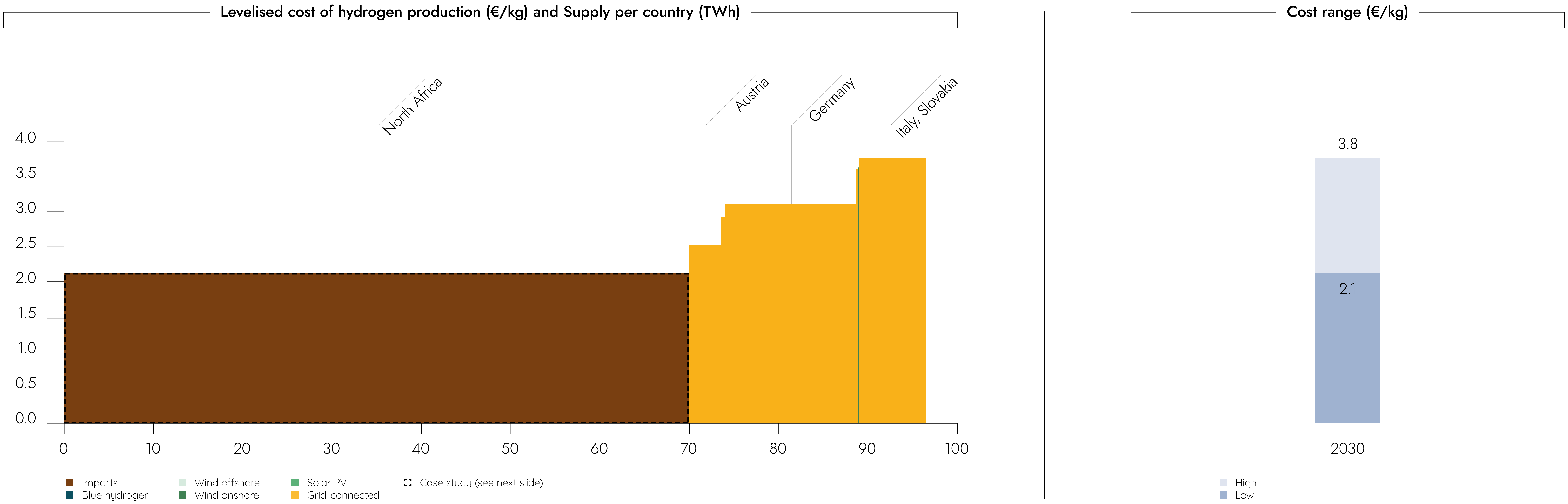
1. Corridor Summary
2. Hydrogen Demand & Supply
3. **Supply Costs & Cost-Competitiveness**
4. National Strategies & Regulation
5. Actions Needed

This section explores the costs of hydrogen production and delivery for this corridor and their competitiveness with fossil fuels

	Hydrogen production cost	**Hydrogen delivered costs**	**Comparison with fossil alternatives**
Key Questions Answered	What **is the range of production costs** achieved by the corridor **in 2030 and 2040**?	Based on a **case-study of hydrogen supply** from Tunisia to Germany: – What are the **full costs of firm hydrogen delivery** after accounting for **transport** and **storage** costs? – What **cost levers** are available to lower the cost of hydrogen delivery?	How **competitive** is hydrogen supply from this corridor compared to fossil fuel alternatives?
Content Material	 SUPPLY COSTS & COST-COMPETITIVENESS Corridor A / North Africa & Italy 35 By 2040, hydrogen supply options increase and scale up eading to production costs ranging from 1.4 to 2.8 €/kg SUPPLY COSTS & COST-COMPETITIVENESS Corridor A / North Africa & Italy 34 In 2030, the corridor offers access to hydrogen production ranging in costs from 2.1 to 3.8 €/kg Hydrogen Production Cost Range [2030][1, 2, 3]	 SUPPLY COSTS & COST-COMPETITIVENESS / CASE STUDY Corridor A / North Africa & Italy 37 Applying cost reduction levers to the Tunisia-to-Germany case study lowers delivery costs by 26% keeping hydrogen cost-competitive Cost of Hydrogen Delivered (€/kg) in 2030[1, 2, 3]	 SUPPLY COSTS & COST-COMPETITIVENESS Corridor A / North Africa & Italy 38 Hydrogen costs are cost-competitive with all fossil fuel alternatives by 2030, and materially lower by 2040
Key Findings & Results	– **By 2030**, the corridor provides access to hydrogen production costs of **2.1 to 3.8 € / kg**. – **By 2040**, hydrogen production costs decrease to the range of **1.4 to 2.8 € / kg**.	– Several **cost reduction levers** can be applied to **lower the costs of hydrogen delivery**. – For the Tunisia-to-Germany case study, **these levers achieve delivery costs that are low and cost-competitive**.	– **Hydrogen costs are competitive with fossil fuel alternatives by 2030**, and lower by 2040. – Fossil fuel costs are subject to **significant uncertainty**.

In 2030, the corridor offers access to hydrogen production ranging in costs from 2.1 to 3.8 €/kg

Hydrogen Production Cost Range [2030][1, 2, 3]



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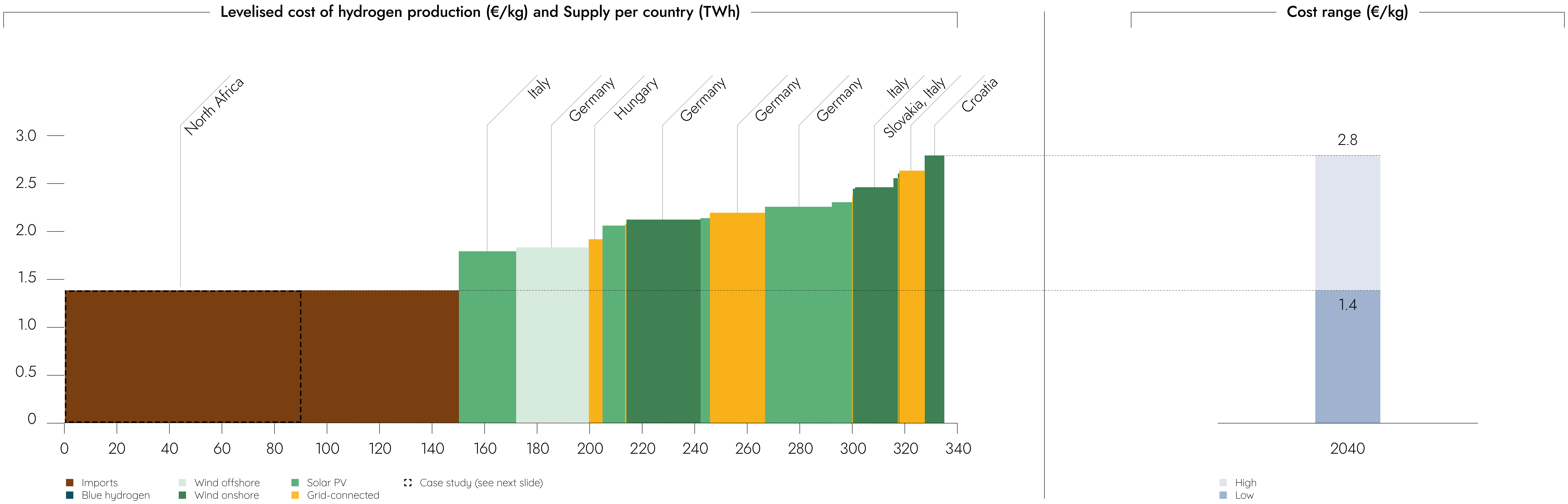
1 Cost curves are based on a bottom-up estimate of supply volumes per country and hydrogen production type. No transport or storage / firming cost are included.
2 *Dedicated hydrogen* production costs are based on renewable technology and electrolyser costs, and country-specific capacity factors and discount rates.
3 *Grid-connected hydrogen* production costs are determined based on costs of a mix of dedicated green hydrogen (solar, onshore wind, offshore wind) and adjusted for grid-connection costs.

By 2040, hydrogen supply options increase and scale up leading to production costs ranging from 1.4 to 2.8 €/kg

Hydrogen Production Cost Range [2040][1, 2, 3]



1-3 See previous slide

Hydrogen delivered costs, including transport and storage costs, can be kept low by applying cost reduction levers

1 This analysis assesses a **case study** of hydrogen supply from Tunisia to industrial offtakers in southern Germany **to explore how the costs of firm hydrogen delivery can be lowered**.

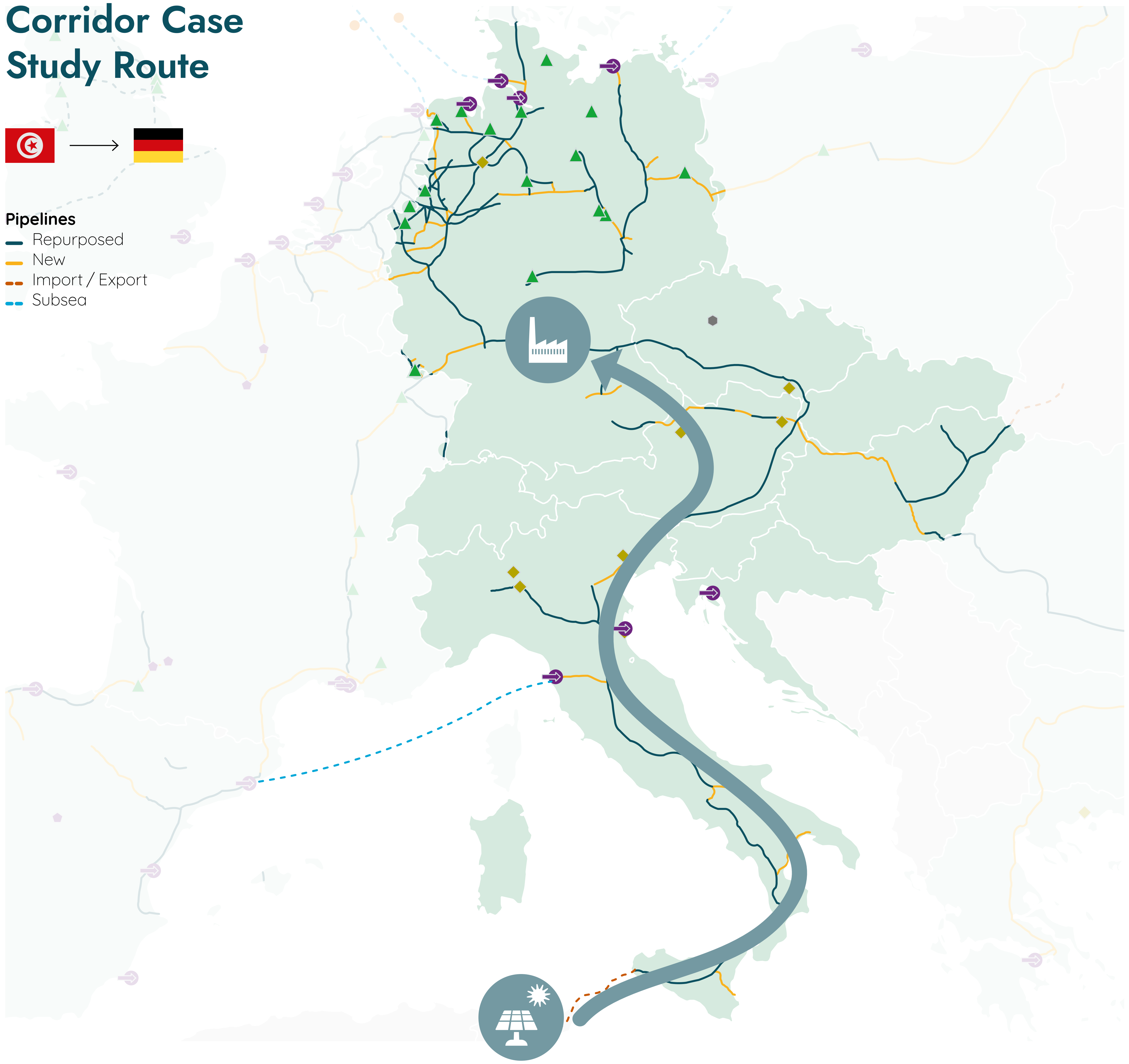
2 To assess the full cost of firm delivery to Germany, **transport and storage costs are added to the cost of hydrogen production from Tunisia**.

Production Costs + Transport Costs + Storage Costs = Delivered Costs

3 **Several cost reduction levers can be applied to lower firm delivery costs**, including optimised system operation, battery storage use, cost of capital reductions, among others.

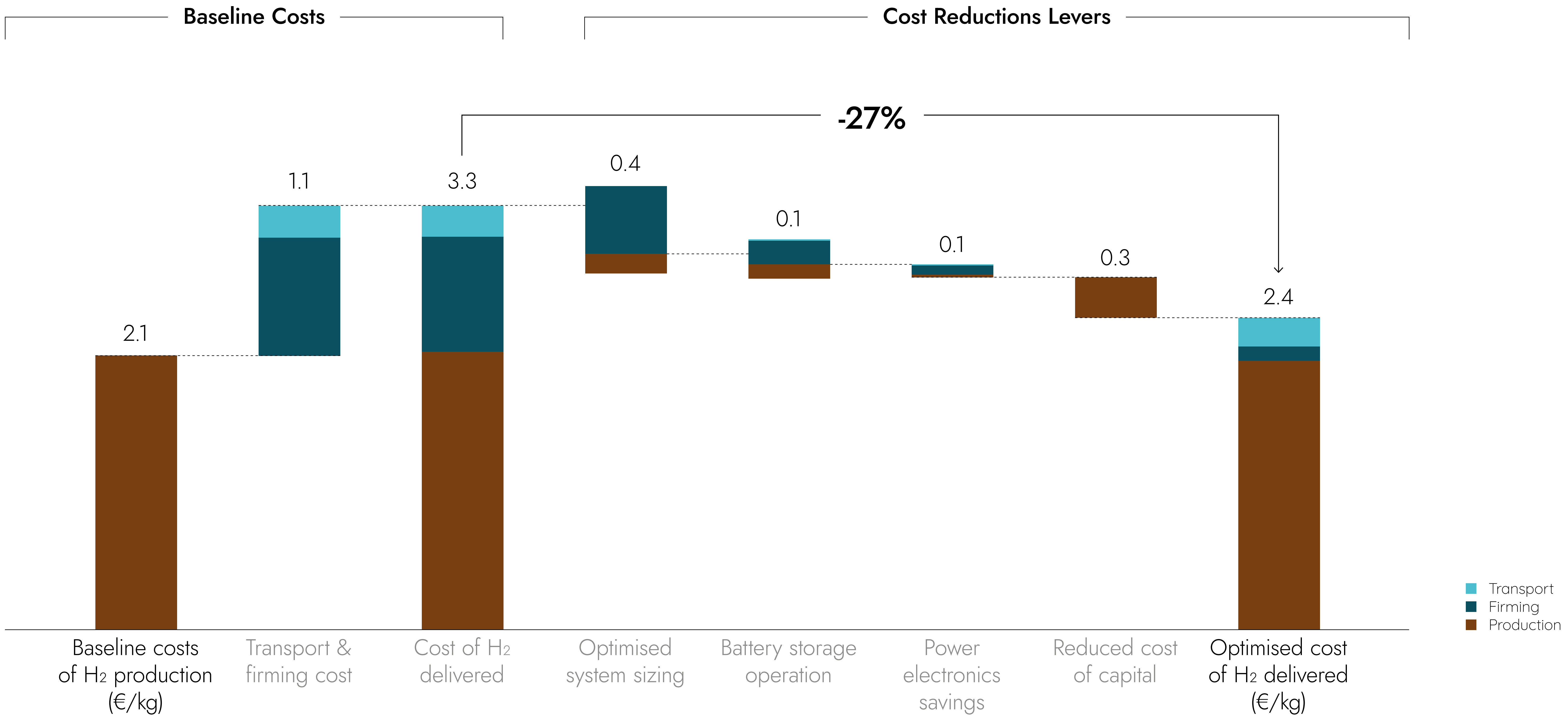
4 **These cost reduction levers achieve sufficient cost savings to keep firm hydrogen delivery costs low and cost-competitive.**

Corridor Case Study Route



Applying cost reduction levers to the Tunisia-to-Germany case study lowers delivery costs by 26% keeping hydrogen cost-competitive

Cost of Hydrogen Delivered (€/kg) in 2030[1, 2, 3]



Cost reduction levers applied to case study of hydrogen transport from Tunisia to Germany **enable firm delivery costs to be reduced significantly**.

- **In 2030** (shown on the left), the cost of delivered hydrogen can be lowered by 27% (2.4 vs. 3.3 €/kg).
- **In 2040**, hydrogen delivered costs can be reduced by 44% (1.4 vs. 2.5 €/kg).

Delivered Costs (€/kg)
(before and after cost levers)

	2030	2040
Before costs lever	3.3	2.5
After costs lever	2.4	1.4

---

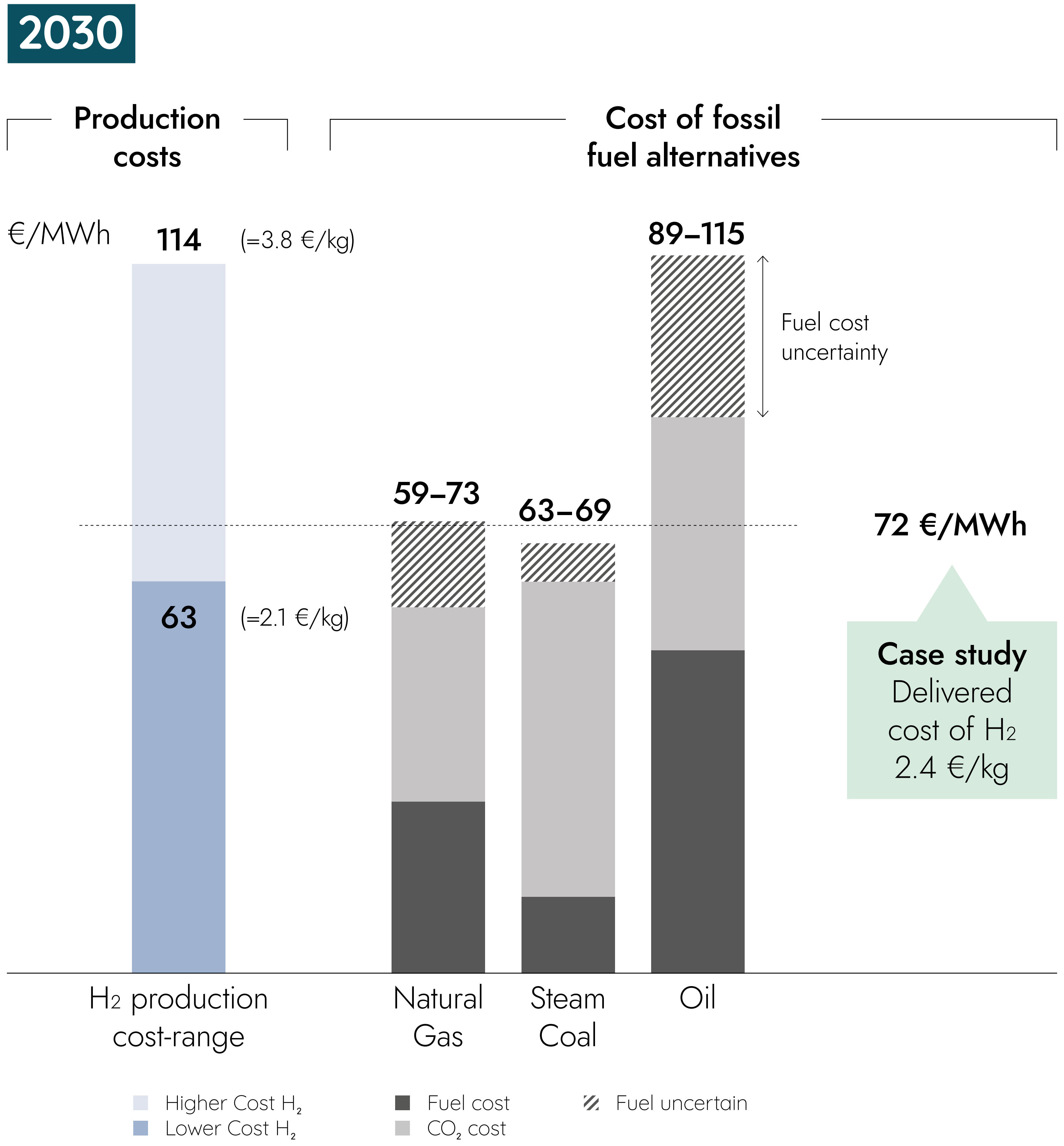
1 *Transport costs* are based on several parameters including the type of pipeline (repurposed vs. new), transport distance and full-load-hour production on that pipeline. *Firming costs* are based on additional storage cost required to deliver hydrogen at the equivalent of 8,000 full-load hours.

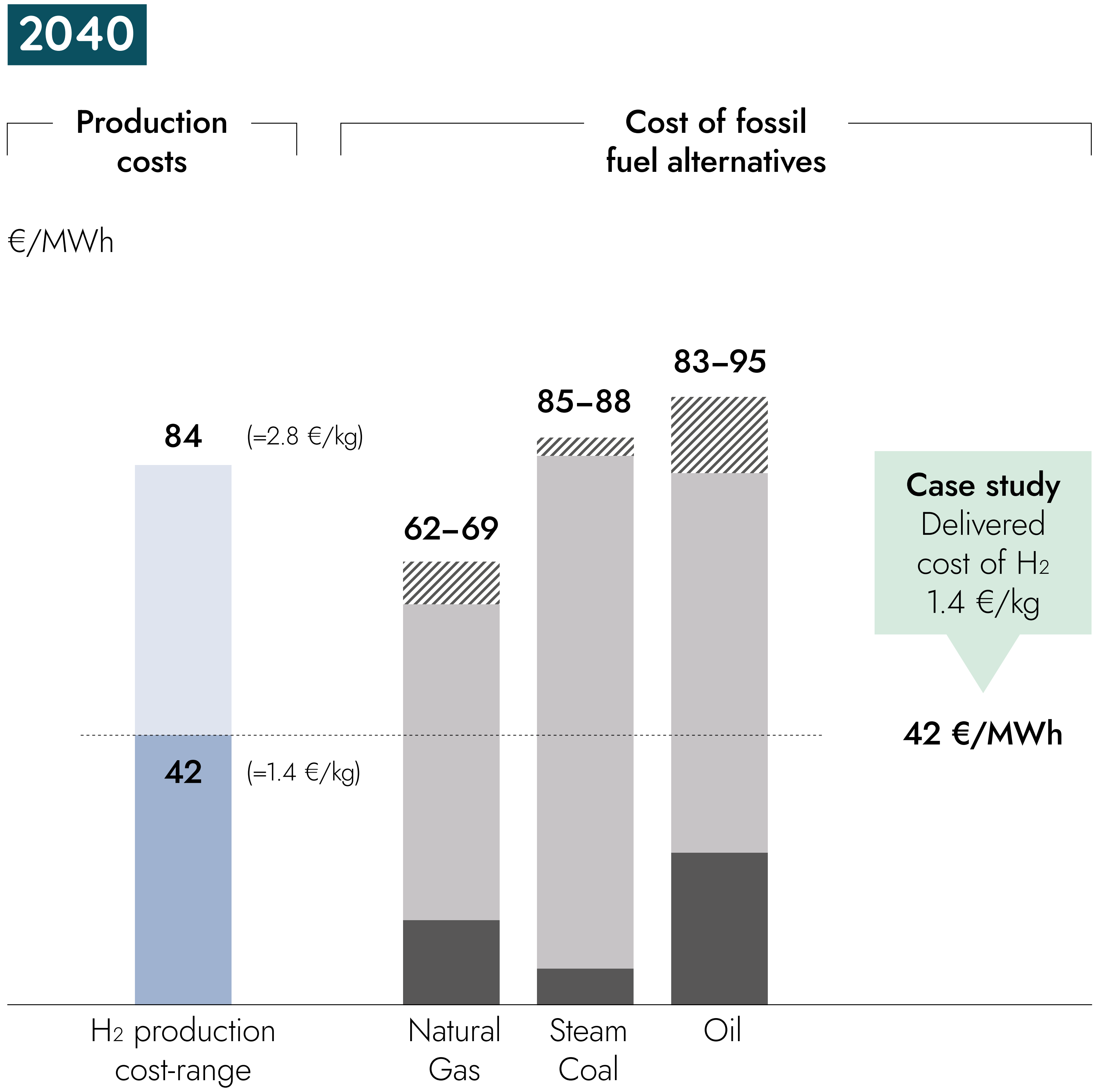
2 *Optimised system sizing* refers to right-sizing of solar PV and electrolyser capacity to increase full load hours. Similarly, *battery storage operation* enables an increase in the full load hours. *Power electronics savings* refers to the removal of the inverter of the solar PV modules to reduce system cost. *Reduced cost of capital* refers to the use of foreign investment to reduce the WACC from 8 to 6%.

3 In some instances, cost reduction levers may result in cost increases for certain cost-components. For example, an increase in production costs at the same time as a decrease in firming costs. These cost increases and decreases can result in connection lines that do not directly connect one step to the next.

SUPPLY COSTS & COST-COMPETITIVENESS

Hydrogen costs are cost-competitive with all fossil fuel alternatives by 2030, and materially lower by 2040





By 2030, the low range of hydrogen production costs are **competitive with natural gas and coal, and lower than oil alternatives**.

By 2040, the low range of hydrogen costs are **materially lower than all fossil alternatives**, while the medium-to-high range are cost competitive.

Hydrogen delivered costs from the Tunisia-Germany case study are competitive to natural gas in 2030 (22% higher) and lower in 2040 (32% lower).

Natural gas prices are still uncertain due to recent price spike as a result of the Russian invasion of Ukraine.

Note: For comparison purposes, cost of H_2 has been converted from "per kg" to "per MWh"

- 1 €/kg = 30 €/MWh (based on LHV of 33.3 kWh/kg)

Competitiveness of hydrogen highly dependant on CO_2-prices as they make up a significant part of fossil fuel costs.

- CO_2 price 2030: 130 €/t
- CO_2 price 2040: 205 €/t

Note: Prices for fossil alternatives (2030/2040): Natural gas (pre-invasion): 28/13 [€/MWh], Coal: 123/5.6 [€/MWh], Oil: 52/24 [€/MWh]. Natural gas price levels are based on market conditions before Russia's invasion of Ukraine. While natural gas prices have skyrocketed since, there remains significant uncertainty on near- and medium-term European price trends and supply options. As a result, our analysis adopts the IEA's Outlook 2021 price forecast pre-invasion developed pre-invasion. Prices in 2040 are significantly lower than in 2030 because of demand-supply conditions. By 2040, decreased demand for fossil fuels would lower prices. [Source: International Energy Agency, Outlook 2021 (IEA)] and fuel-cost uncertainty is shown with +50% range]

CORRIDOR A

North Africa & Southern Europe

Agenda

Most countries have developed, or are developing, national strategies. Moving forward, the development of regulation is key to enable infrastructure investment.

Pre-RePowerEU targets²

	National Hydrogen strategy (NHS)	Network regulation & policy	Funding¹ (bn €)	Highlights
Italy	– NHS preliminary. **2% H_2 share** at final energy 2030 (20% in 2050) in transport, industry, refineries, blen. – **5 GW** electrolyser installed until 2030 – **Hydrogen valleys** / industrial clusters	– Public consultation process in relation to pilot projects to optimise the innovative uses of existing natural gas transmission and distribution networks	 5.0	– Focus on transport sector and hydrogen valleys for demand (industry) and production – Funding mainly to increase production of H_2 – 99% of infrastructure is ready to transport H_2
Switzerland	– The parliament currently developing national strategy – Explicitly mentioned import strategy for H_2	– N/A		– Hydrogen strategy is being developed – Energy plan: Industry & heavy duty transport
Slovenia	– In NECP is set indicative target to have 10 % of renewable methane or hydrogen in the network (2030)	– TSO is obliged to prepare the plan for acceptance of H_2		– Foreseen demand sectors: Transport (2030), followed by industry & buildings (NECP)
Croatia	– Foresees demand in industry, buildings, transport and power, with a supply potential of 1.3 GW electrolysers	– N/A		– First production site by 2025
Hungary	– Production of 36k tons/a (incl. low carbon H_2) – **240 MW** of electrolyser capacity – Use to decarbonize industry and transport	– Min. 2% volume blending to natural gas grid	 0.1	– **H_2 infrastructure in focus**. Funding for storage is available and blending to natural gas grid is envisioned
Czech Republic	– Focus **Transport**, then **energy** & **chemical** industry – Green H_2 production – **Import and transit country** for H_2	– N/A		– **H_2-Readiness** of gas transmission system is urged, due to potential focal role in **H_2 transport** (south to north and east to west)
Austria	– NHS is still in discussion; known elements are: 1 – 2 GW electrolyser capacity (2030), use in industry	– H_2 mixtures of up to 10 % within Austria and 4-5 % on entry/exit points are allowed	 0.5	– Production of green H_2 is subsidised – Preferred use to decarbonise industry – Focus: Transport sector and underground H_2 storage
Slovakia	– H_2 used in the chemicals, petrochemicals, steel and heating industries as well as in transport	– N/A		– Use H_2 in industries/areas impossible or not cost-effective to directly use electricity
Germany	– National production & import focus due to supply gap – In place **since 2020, currently reviewed towards increasing its ambition** – **10 GW (2030)** electrolyser in coalition plans	– H_2 network potentially opt-in regulated and vertically unbundled – First rules and standards for high pressure pipelines are formulated	 9	– Strong focus on **international cooperation** to ensure sufficient supply – National funding

■ General funding
■ Supply
■ Network
■ Demand

Note: Sequencing of countries follows the general corridor direction but does not represent the hydrogen flows.

1 Cumulative public funding amount by the respective state until 2030

2 Strategies and funding is under evaluation of meeting latest targets

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North Africa & Southern Europe

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4. National Strategies & Regulation
5. **Actions Needed**

ACTIONS NEEDED

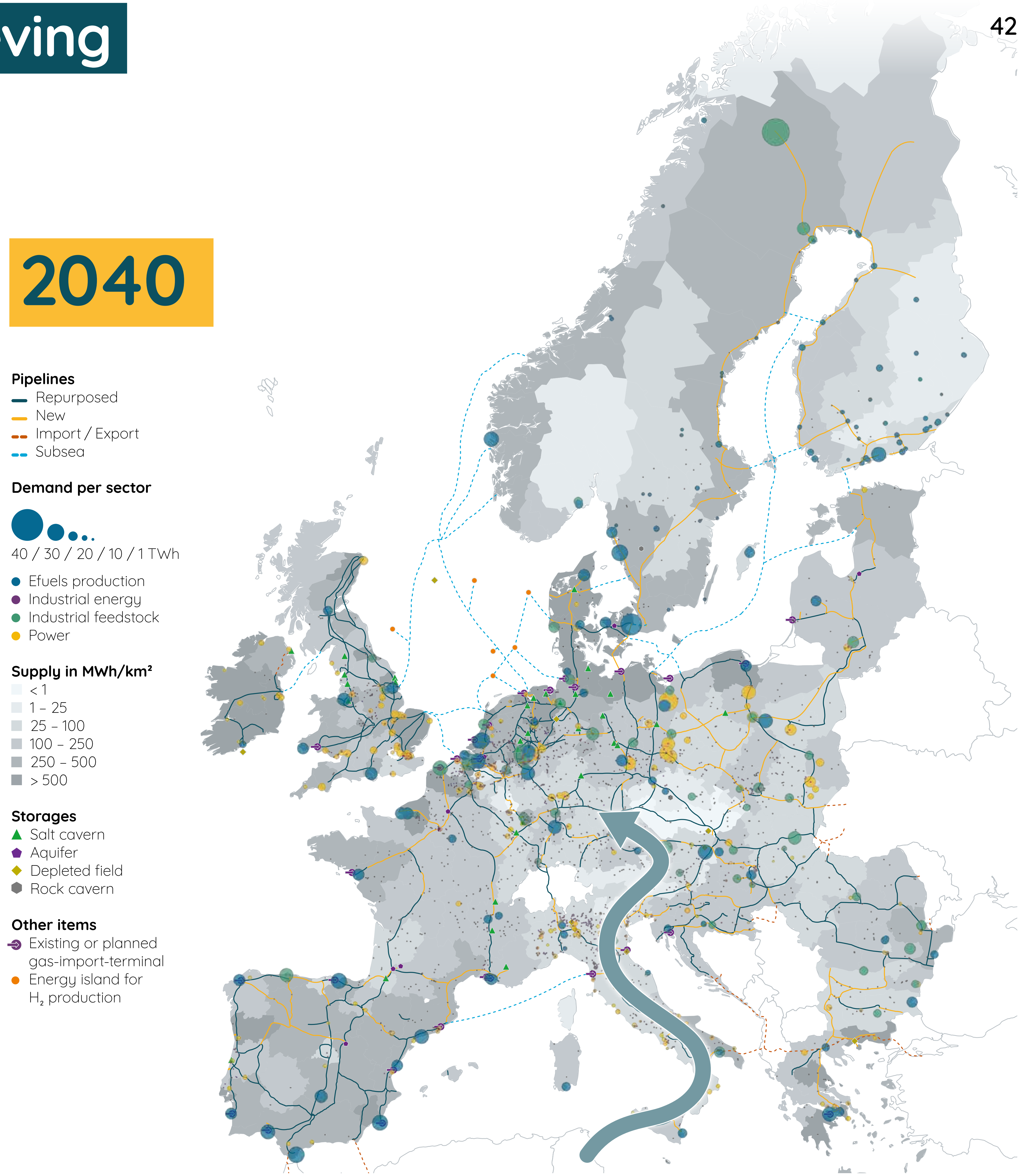
This corridor plays a fundamental role in achieving a European backbone by 2040

The need for this corridor

- The development of **this corridor ensures access to abundant, low-cost hydrogen supply from Italy and Tunisia** by 2030, and by 2040 additional supply from Algeria (via Tunisia) and from Central and South-Central Europe.
- The **decarbonisation of the largest hydrogen demand centers along this corridor** – in **Italy, Central Europe and Germany** – is dependent on the buildout of this corridor by 2030, and its expansion towards 2040.

Actions required

- The buildout of this corridor by 2030 **requires national governments to take clear and concrete actions across**.
- This includes actions associated with **infrastructure development and planning, the development of cross-national initiatives** and **securing access to early funding and long-term, low-cost financing**.



ACTIONS NEEDED

To ensure the development of this corridor by 2030, there is a need for clear and concrete actions

Fostering development of new and repurposed hydrogen infrastructure, for example, by unbundling rules facilitating the efficient use of TSO expertise and services and by allowing the adoption of different vertical unbundling models in the EU, as is the case with natural gas

+

Unlock financing to fast-track hydrogen infrastructure deployment by applying regional regulatory flexibility and other pragmatic financing solutions (including incentivizing the adoption of hydrogen by demand sectors)

+

Simplify and shorten planning and permitting procedures for renewable energy and hydrogen infrastructure projects.

+

Intensify energy partnerships with exporting, non-EHB countries like Algeria and Tunisia, and providing financing support to reduce their cost of capital

+

Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure supporting the accelerated deployment and integration of renewable energy resources

→ **However, speed will be of essence!**

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Southwest Europe & North Africa

Corridor emerges in Southwest Europe providing access to low-cost hydrogen supply from the Iberian peninsula, and potentially Morocco.

- Portugal
- Spain
- France
- Belgium
- Luxembourg
- Germany

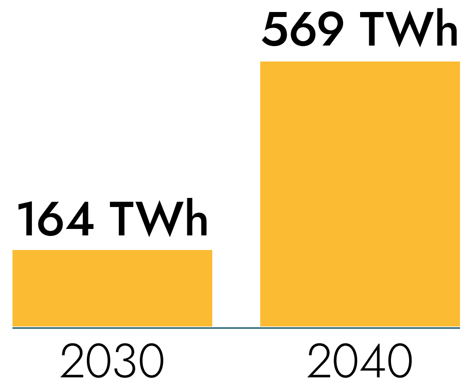
Drivers & Opportunities

Major driver of development is the need to meet **hydrogen demand from industry, transport and power** in the Iberian peninsula, France and Germany. Key opportunities include the development of a **new Spain-France interconnector** and **underground storage in France**, and access to **imports from Morocco.**

Hydrogen Supply & Decarbonization Potential

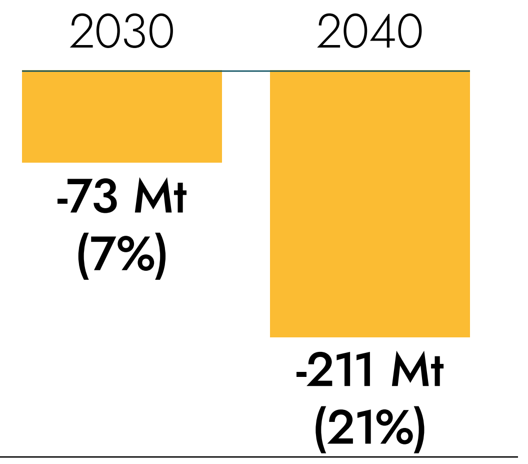
H_2 supply potential[1]

(TWh/year)



Emissions Reductions

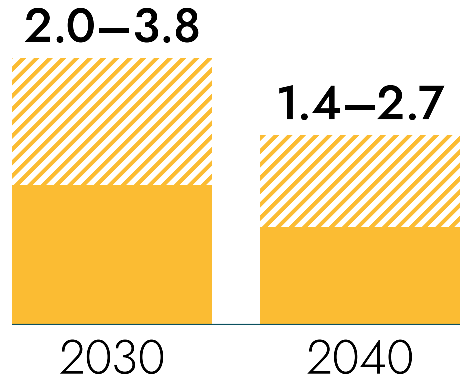
($MtCO_2$/year vs. 2019; % reduction)



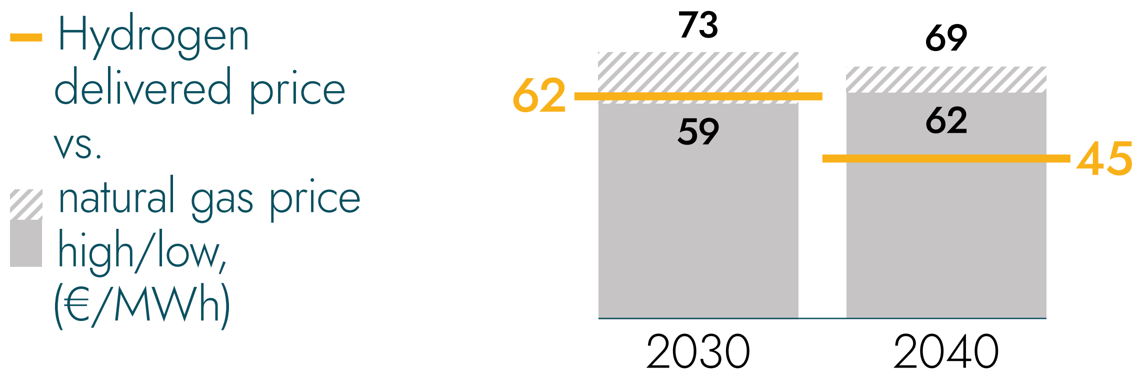
Supply Costs & Cost-Competitiveness

Cost of H_2 production[1]

(€/kg of H_2)



Cost competitiveness[2]



Actions Needed

- Fostering development of new and repurposed hydrogen infrastructure
- Unlock financing to fast-track hydrogen infrastructure deployment
- Simplify and shorten planning and permitting procedures
- Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure
- Intensify energy partnerships with exporting, non-EHB countries like Morocco and Algeria

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[1] Figures reported reflect outputs for all countries included in the corridor. Even if a country is only partially in the corridor, results for the full country are included (e.g., supply potential and costs, demand, transmission network length).

[2] Savings are based on the corridor's case study of hydrogen delivered in 2030 and 2040. The cost of natural gas includes CO_2 prices. Refer to Subsection 3 (Supply Costs & Cost-Competitiveness)

CORRIDOR B

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Corridor offers access to low-cost hydrogen supply from the Iberian peninsula to demand centers in France and Germany

Drivers & Opportunities

- **The major driver** behind the development of this corridor is the adoption of hydrogen associated with the **early decarbonisation of the industry, transport and power** in the Iberian Peninsula, France and Germany. The speed of hydrogen adoption in these regions will accelerate driven by increasing CO_2 prices in the EU and the RePowerEU ambitions to replace natural gas consumption.
- The corridor offers **access to low-cost, renewable production from the Iberian peninsula**, currently the source of Europe's lowest renewable auction prices. In the longer term, this corridor may also provide **access to hydrogen imports from Morocco and potentially Algeria.**
- A major opportunity of the corridor is the **potential development of a new interconnection between Spain and France through** the East Pyrenees. The development of this interconnection would allow both countries to benefit from the complementary nature of **low-cost, high-volume Spanish and Portuguese hydrogen production and French underground storage sites** to help provide stable supply for off-takers in the region. This development of this new interconnection would in turn require **infrastructure reinforcements** along the corridor.
- A key longer-term opportunity is the **potential repurposing of the currently-underutilised, Maghreb-Europe subsea interconnector** to enable low-cost hydrogen supply from Morocco and Algeria.
- Recently, RePowerEU identified the development of a new subsea pipeline connecting Spain and Italy, expected to be available for hydrogen transport by 2030.
- The corridor would be stood up by 2030, covering **10,000 km** of large-scale hydrogen pipelines across all countries of the corridor, of which approximately **60% will be repurposed pipelines.**

Hydrogen Demand & Supply

- Total hydrogen demand in the corridor reaches **200 TWh by 2030**, increasing substantially to **~720 TWh by 2040**. Up to 2030, the major demand sector is industry, with hydrogen being used as feedstock and for energy needs. From 2040 onwards, most hydrogen demand is for e-fuels production and the power sector.
- Hydrogen adoption across all countries of the corridors enables an emissions reduction of c.300 $MtCO_2$/yr. by 2050, equivalent to a **29% emissions reduction.**
- The corridor enables access to **hydrogen supply potential of ~160 TWh by 2030, increasing to ~570 TWh by 2040**. Major sources of supply include green hydrogen from the Iberian Peninsula and France by 2030, with a potential role for Moroccan imports by 2040.

Key needs for action identified to successfully stand up the hydrogen supply corridor until 2030

Costs & Cost-Competitiveness	– By 2030, the corridor provides access to hydrogen production costs ranging from a production cost of **2.0 to 3.8 €/kg**. By 2040, as supply options increase and technology costs decrease, hydrogen production costs decrease to **1.4 to 2.7 €/kg**. – In the long term, this corridor's lowest-cost supply options are imports from Morocco and solar PV hydrogen from Spain and Portugal.	– Based on a case-study of hydrogen supply and transport from Spain to Germany, **the cost of delivered hydrogen** – inclusive of transport and firming costs – **can be lowered to achieve cost levels comparable to production costs**. Lowering delivery costs can be achieved through various cost levers including optimised operation of the system and cost of capital reductions.
National Strategies & Regulation	– **National hydrogen strategies** have been developed by all countries in the corridor, providing clear direction and supply targets.	– In select countries, **substantial funding has been allocated** to support the development of the hydrogen market including funding for gas network infrastructure.
Actions Needed	Low-cost H_2 supply/demand, but for realization and build-out of this corridor until 2030, key needs for action has been identified: – Fostering development of **new and repurposed hydrogen infrastructure**. – Unlock financing to **fast-track hydrogen infrastructure deployment** by applying regional regulatory flexibility and other pragmatic financing solutions.	– Simplify and shorten **planning and permitting procedures** for the full value chain of renewable energies and hydrogen infrastructure projects. – Establish **integrated energy system planning** of hydrogen, natural gas, and electricity infrastructure. – **Intensify energy partnerships** with exporting, non-EHB countries like Morocco and Algeria.

Source: Guidehouse analysis

Southwest Europe & North Africa

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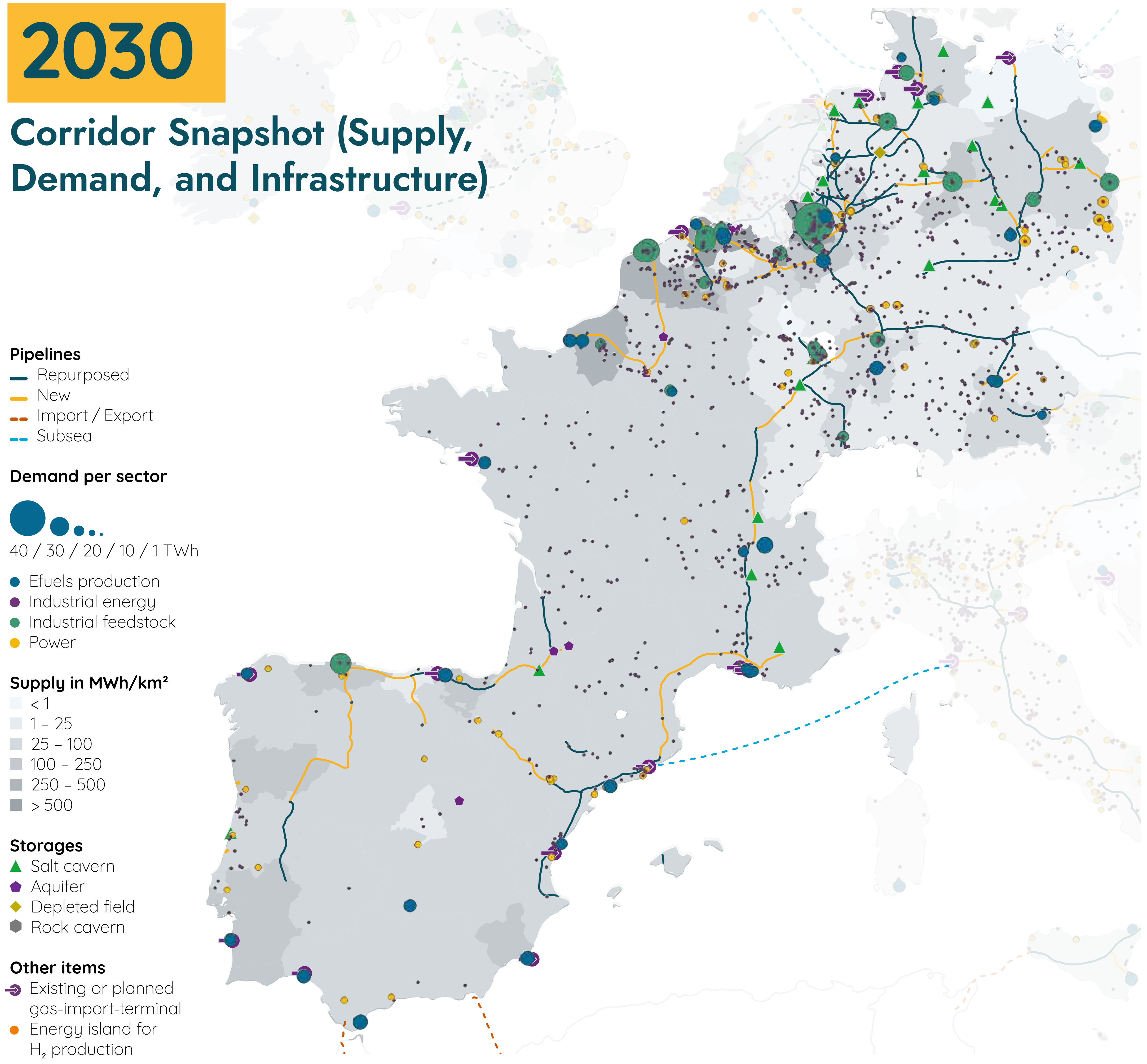
This section explores the development of hydrogen demand, supply and transport infrastructure across the corridor

2030

Corridor Snapshot (Supply, Demand, and Infrastructure)



Hydrogen Demand

By 2030, the corridor connects **all major industrial clusters** from Spain to Germany. **From 2030 to 2040,** the corridor expands to **all demand centers along its route**, increasing demand from 200 to ~720 TWh.

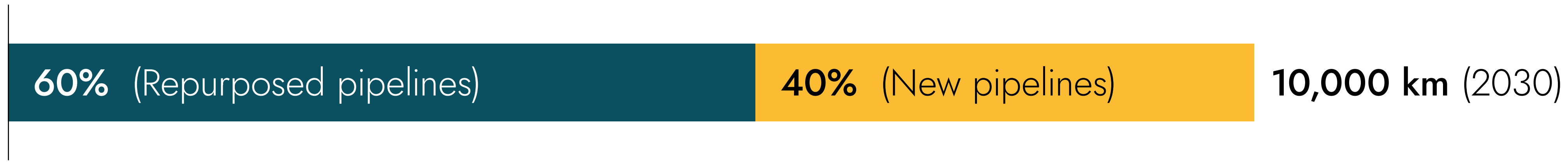
Hydrogen supply

By 2030, the corridor enables access to low-cost supply from **parts of the Iberian peninsula**. **By 2040**, the corridor gains access to **supply from most of the peninsula and low-cost imports from Morocco**.

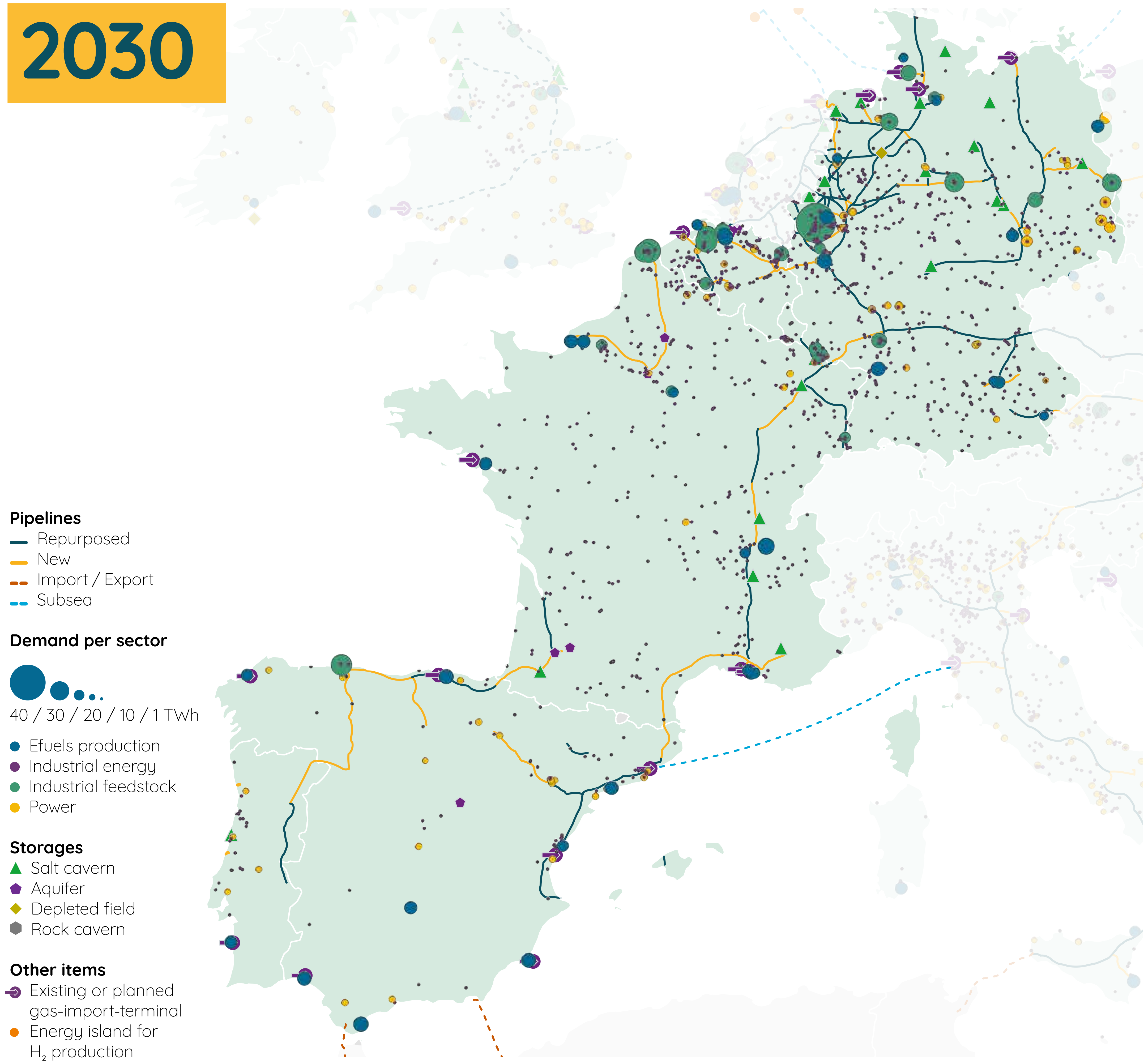
In 2030, hydrogen supply is ~160 TWh, of which 65% of supply is from dedicated green hydrogen. Hydrogen supply increases significantly by 2040, reaching 570 TWh.

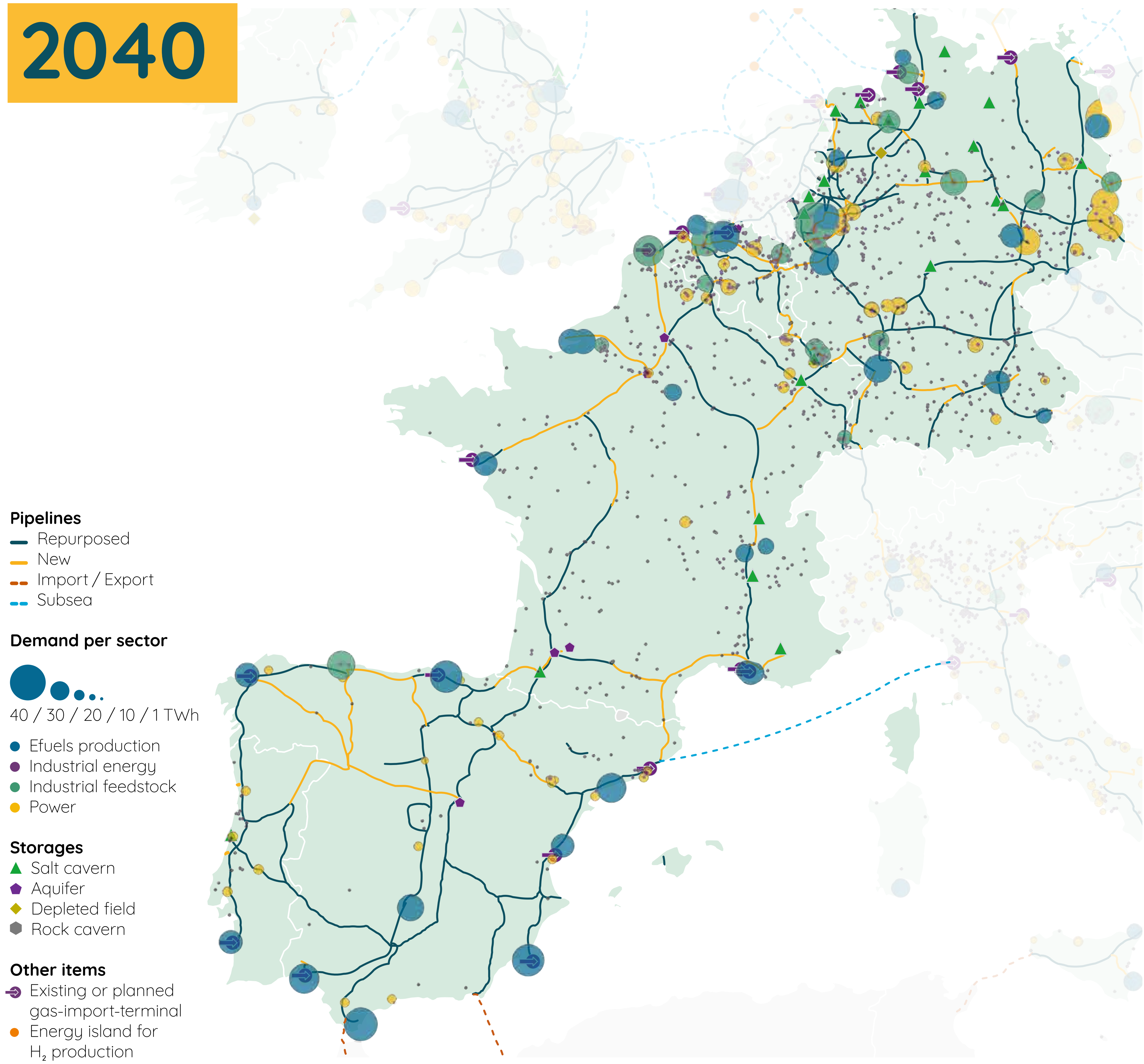
Hydrogen Infrastructure

By 2030, the buildout of pipeline infrastructure across all countries of the corridor reaches **10,000 km** of large-scale pipelines. Corridor benefits from a **large share of repurposed infrastructure**.

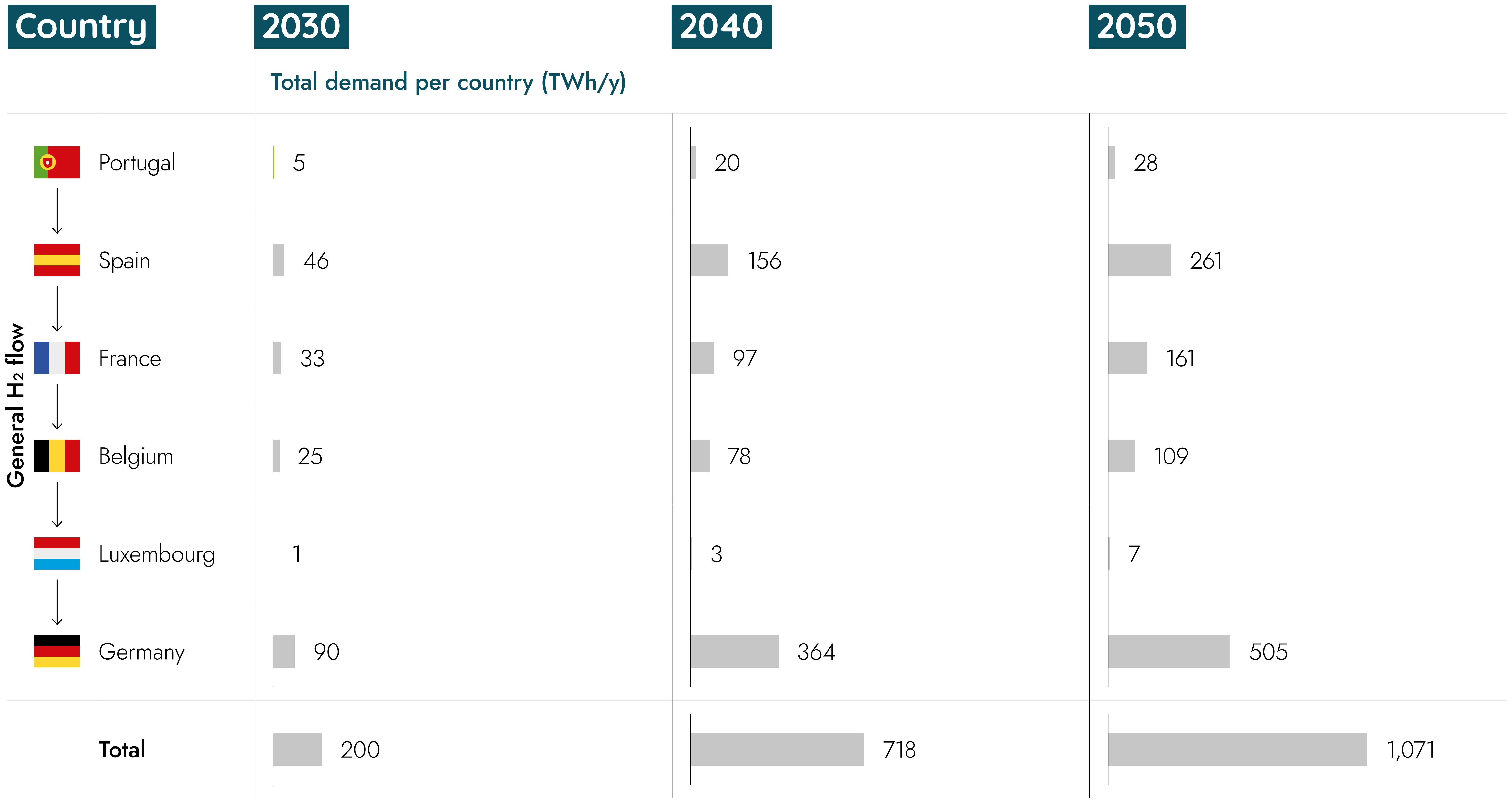


Corridor connects substantial hydrogen demand by 2030, expanding to all major demand centers by 2040





Hydrogen demand increases rapidly from 2030 to 2040, with most demand from Germany and Spain



Total demand per country (TWh/y)

Country	2030	2040	2050
Portugal	5	20	28
Spain	46	156	261
France	33	97	161
Belgium	25	78	109
Luxembourg	1	3	7
Germany	90	364	505
Total	200	718	1,071

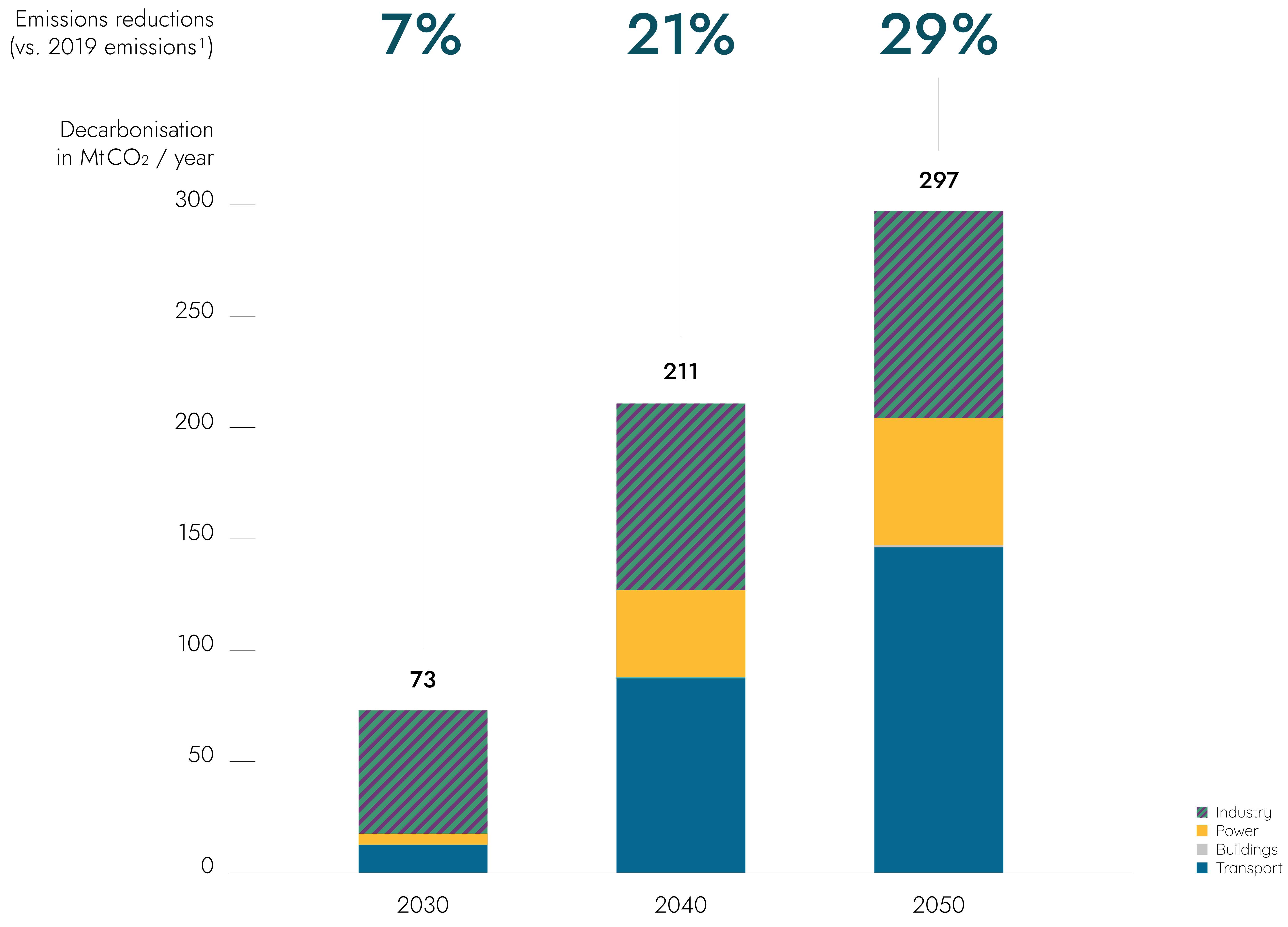
Note: Does not include grey hydrogen demand. Numbers represent total demand by country, even if only parts of the country are included in the corridor.

Hydrogen demand — across all countries of the corridor — increases significantly from 2030 to 2050. Demand reaches 200 TWh by 2030, increasing to roughly 1,100 TWh by 2050.

Hydrogen demand may accelerate and increase further than forecasted as a result of additional regulatory measures adopted in response to the RePowerEU plan.

- **Up to 2030, most hydrogen demand is driven by the industrial sector in Spain, France and Germany** with hydrogen being used as feedstock and for energy needs.
- **From 2040 to 2050, most new hydrogen demand is for e-fuels production and for power generation.**

Hydrogen adoption in all countries of the corridor enables an emissions reduction of 29% by 2050



Hydrogen adoption across all demand sectors enables an **emissions reduction of ~300 MtCO_2/yr. by 2050**, equivalent to a **29% reduction**[2].

- **Up to 2030**, the industrial sector contributes 75% of the total emissions reductions, largely driven by the decarbonisation of the steel sector.
- **By 2040**, emissions reductions from transport (road, shipping and aviation) increase substantially and combined with industry, account for 80% of emissions reductions. The power sector account for the remaining 20% of reductions.
- **By 2050**, the transport sector alone accounts for over 50% of emissions reductions.

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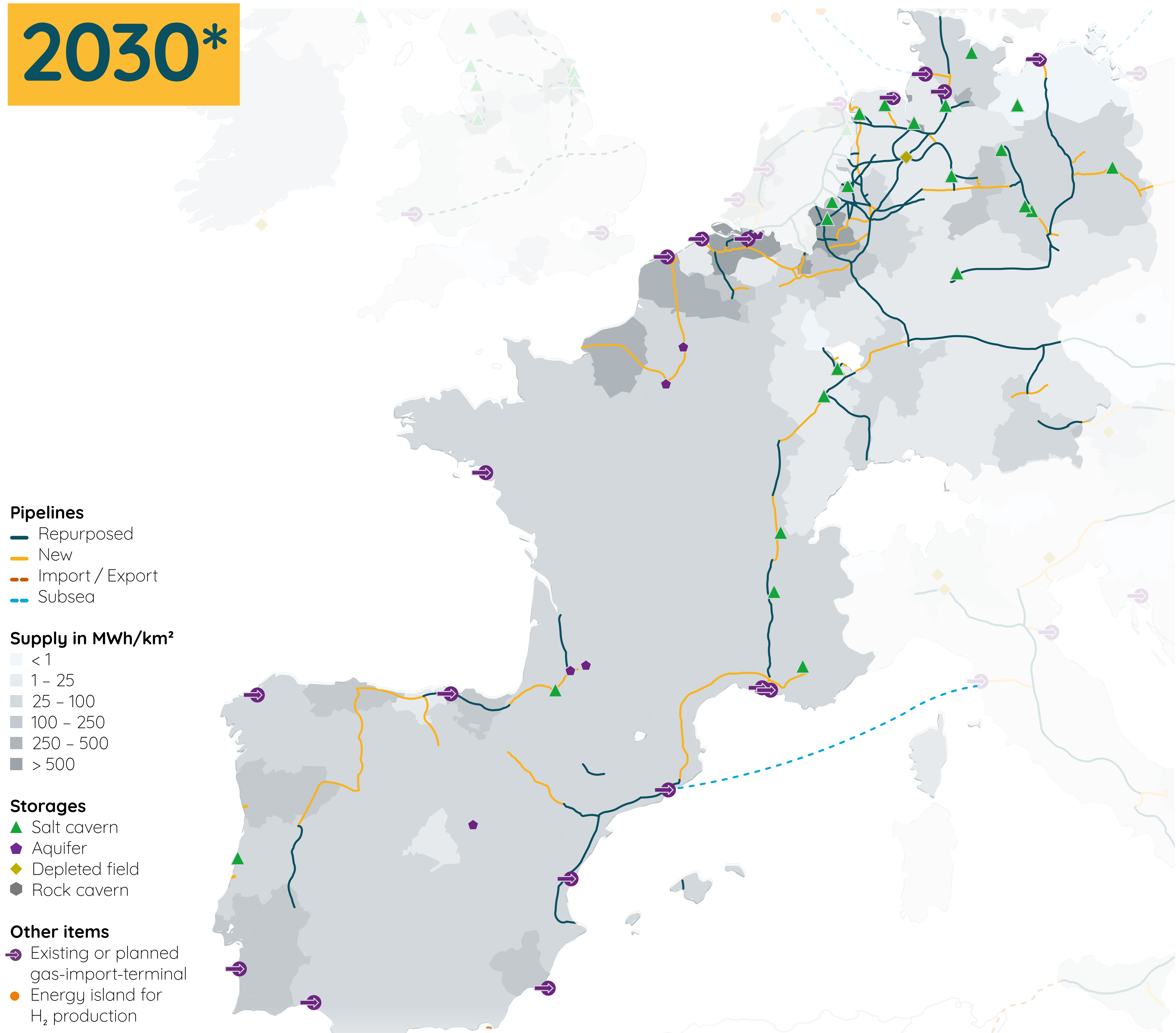
[1] CO_2-Emissions from countries and sectors included in corridor (1.02 bn t CO_2 / year), Source: EEA

[2] Emissions reductions are calculated compared to the baseline fossil fuel used in each sectors. For example, emissions reductions associated with the adoption of hydrogen by the primary steel sector are relative to the use of coal. Similarly, emissions reductions , for e-fuels production are relative to the use of fossil fuels in shipping, aviation and other uses.

Corridor enables access to supply from parts of the Iberian peninsula by 2030, and potentially from North Africa, by 2040

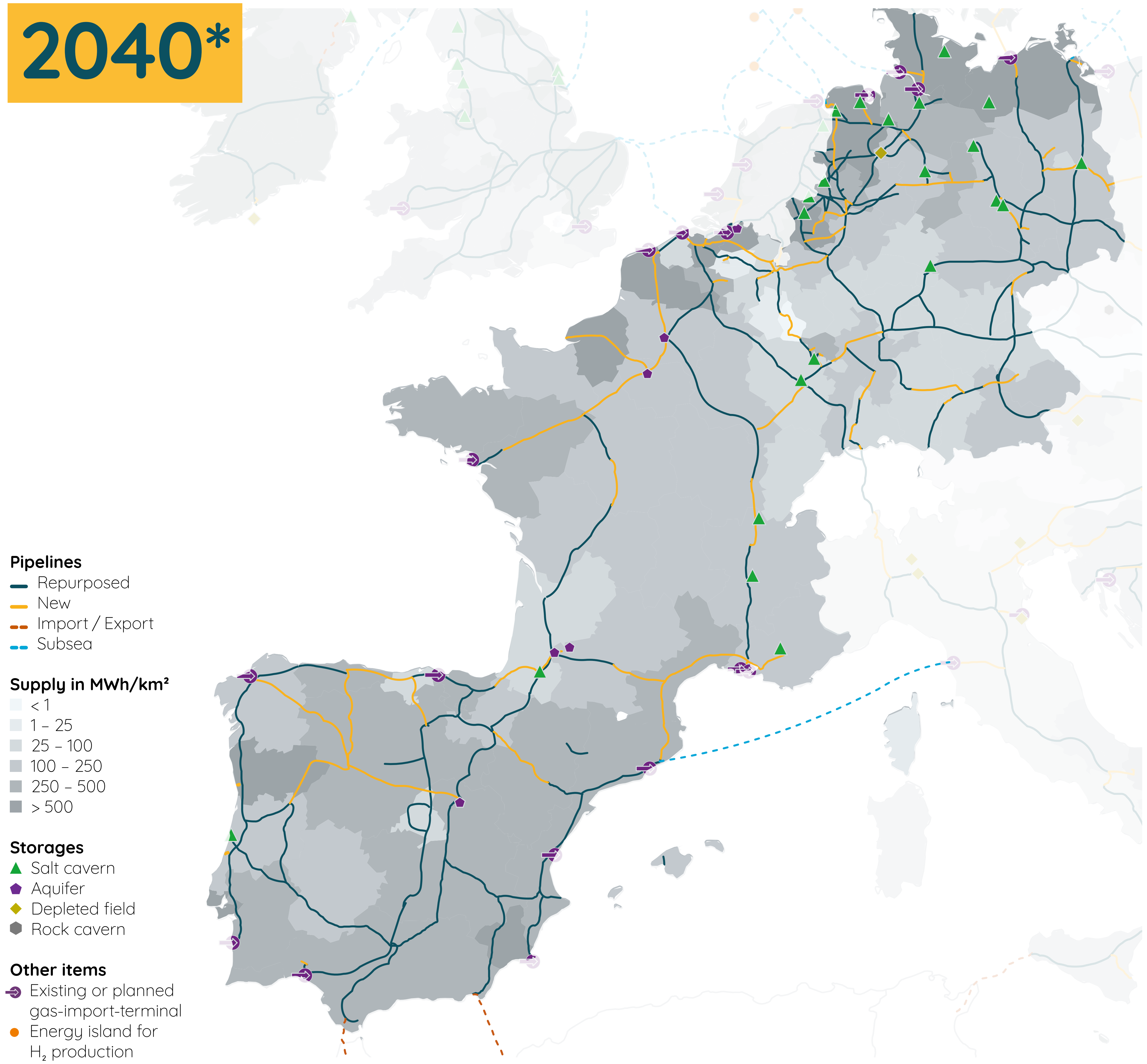
2030*



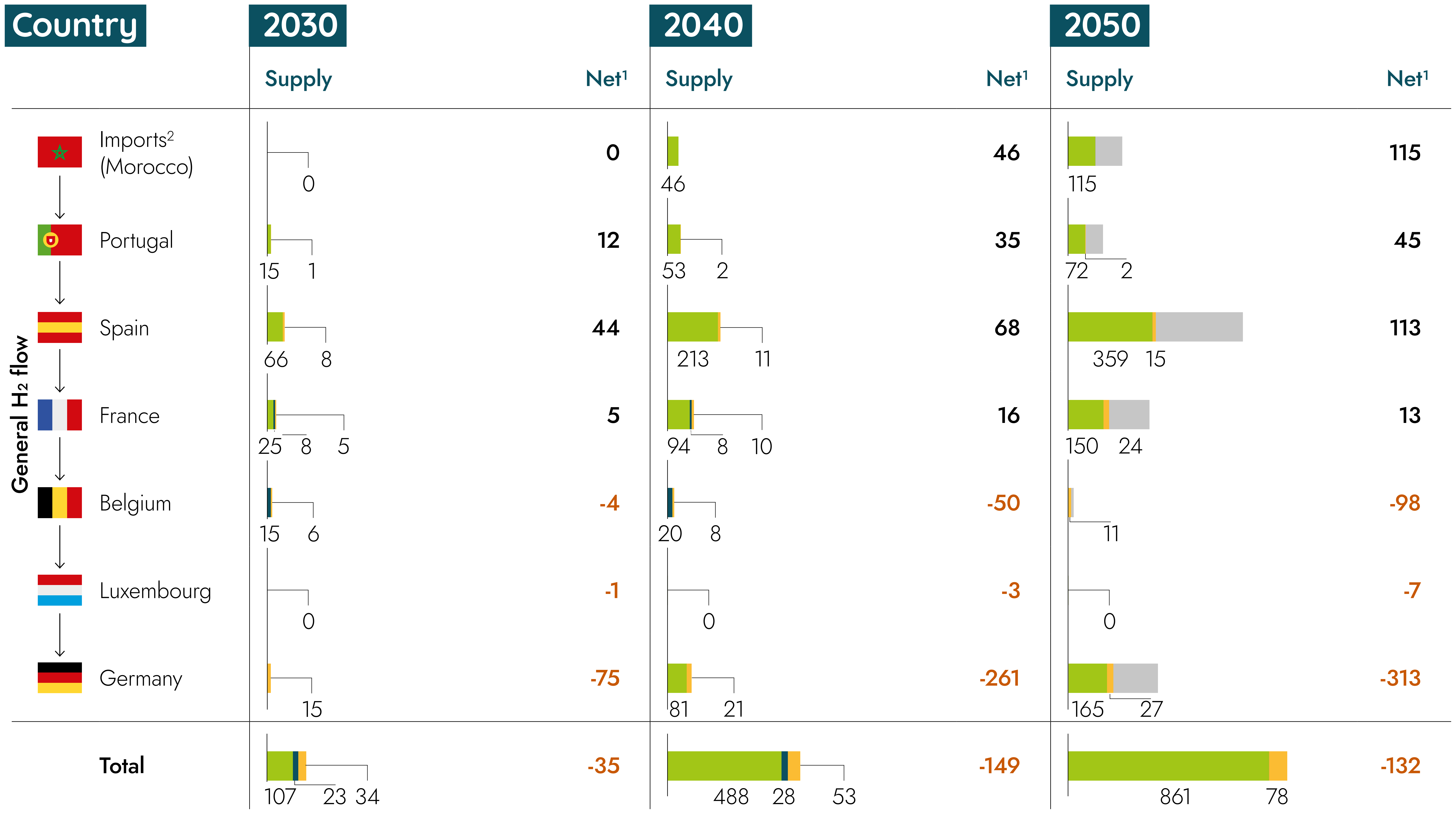
Total hydrogen supply shown per NUTS-2 region. MWh adjusted by the area of each NUTS-2 region in km².

* Note: Supply numbers do not include grey hydrogen.

2040*



Hydrogen supply increases significantly from 2030 to 2040, largely driven by green hydrogen supply from Spain



Hydrogen supply includes a mix of supply options including **grid-based green hydrogen[3], dedicated green hydrogen, and blue hydrogen[4].**

By 2030, hydrogen supply reaches ~160 TWh, largely from dedicated green hydrogen and grid-based hydrogen.

By 2040, hydrogen supply increases substantially to ~570 TWh, of which roughly 85% is from dedicated green hydrogen. The remaining 15% is from grid-based and blue hydrogen supply. Grid-based supply increases slightly from 2030 due to the increasing decarbonization of the electricity grid mix.

By 2050, hydrogen supply increases further to ~1,000 TWh. Dedicated green supply continues to account for the largest share at roughly 90%. Blue hydrogen supply is not included in 2050 due to assumed target of zero emissions and de-fossilisation of Europe by 2050.

🟩 Dedicated green
■ Blue
🟨 Grid-based
⬜ 2050 technical potential

---

1 *Net* represents excess supply after subtracting demand

2 No imports are reported for Morocco in 2030 as the interconnection with Morocco would likely not be available until after 2030.

3 Blue hydrogen supply volumes will be subject to the evolution of gas markets and the development of low carbon hydrogen regulation in different country. As a result, some countries may have additional blue hydrogen supply which could be used to satisfy local demand.

4 Grid-based green hydrogen is estimated based on the oversupply of electricity (demand less supply) in each country of the corridor from 2030 to 2050.

Note: Hydrogen supply volumes do not include hydrogen imports by ship.

Morocco may become a potential source of hydrogen imports to Europe by 2040, and potentially Algeria

State of Gas Infrastructure

- North Africa connects to Spain through Morocco via the **Maghred-Europe offshore pipeline,** currently used for natural gas exports to Europe. Morocco's national hydrogen roadmap identified the potential to **repurpose the Maghreb-Europe pipeline** for hydrogen export[1].
- Morocco is in currently in preparatory stages ahead of **upgrades to its existing port infrastructure for LNG imports.**
- Hydrogen export potential via this corridor focuses primarily on **hydrogen supply from Morocco,** however, there is also potential for hydrogen exports from Algeria to contribute to this corridor.

Market Attractiveness

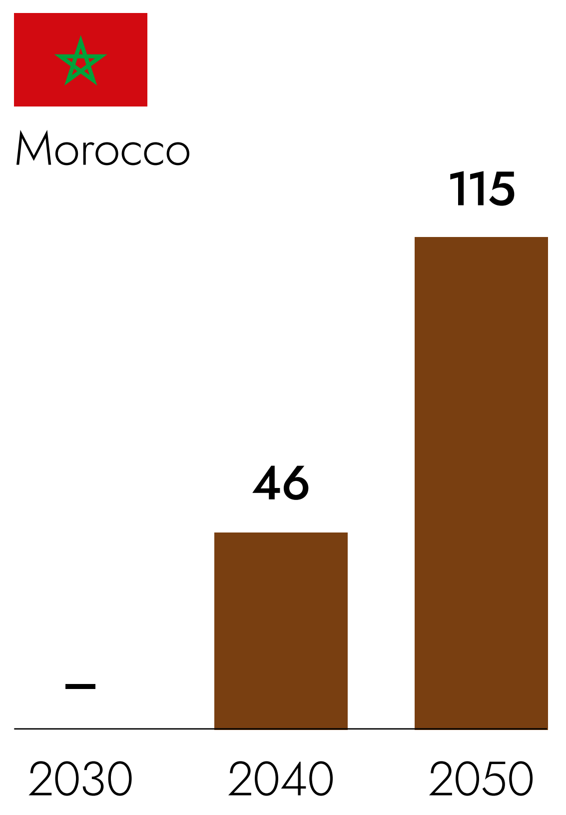
- **Abundant renewable energy potential, particularly solar PV**
- **Partnerships:** Hydrogen cooperation agreement with Germany (June 2020) to develop the hydrogen sector in Morocco[2].
- **Market developments:**
  - HEVO Ammonia: 183k t/yr. of green ammonia by 2026 (Vitol, Fusion Fuel)[3]
  - Cluster Maroc Hydrogen: Organization aiming to mediate between the different market actors to create a hydrogen cluster in Morocco.

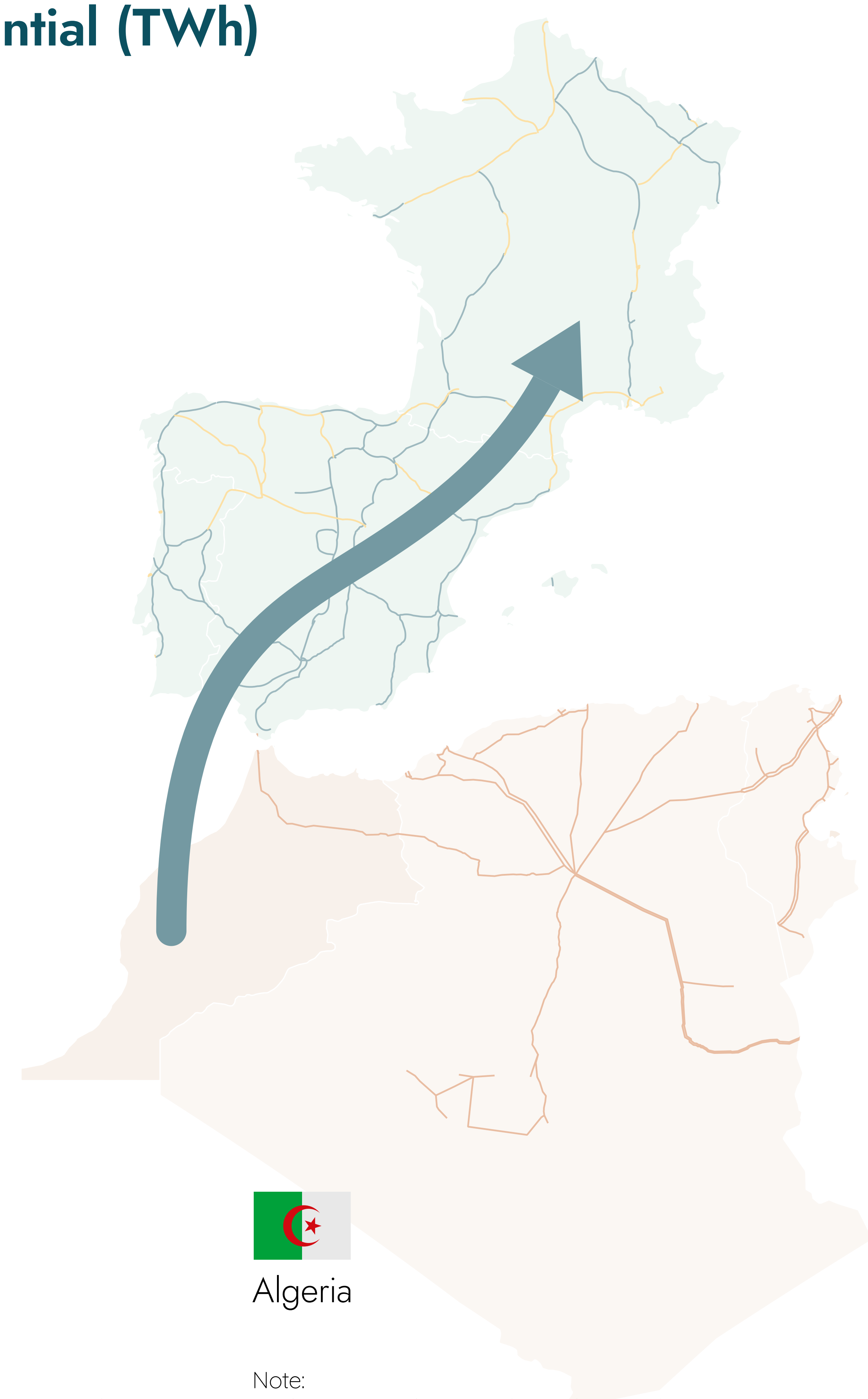
Market Barriers

- **Limited transparency** and **slow decision-making and procedures** when dealing with Government entities
- **Recent political disputes** with neighboring countries (Algeria) and international partners (Germany)

Hydrogen supply potential (TWh)

Morocco only





Note:
Supply potential based on Reference scenario from National Green Hydrogen Roadmap for Morocco'

Note:
Hydrogen supply from Algeria has not been incorporate into the supply figures of this corridor. Rather, it is reported under Corridor A.

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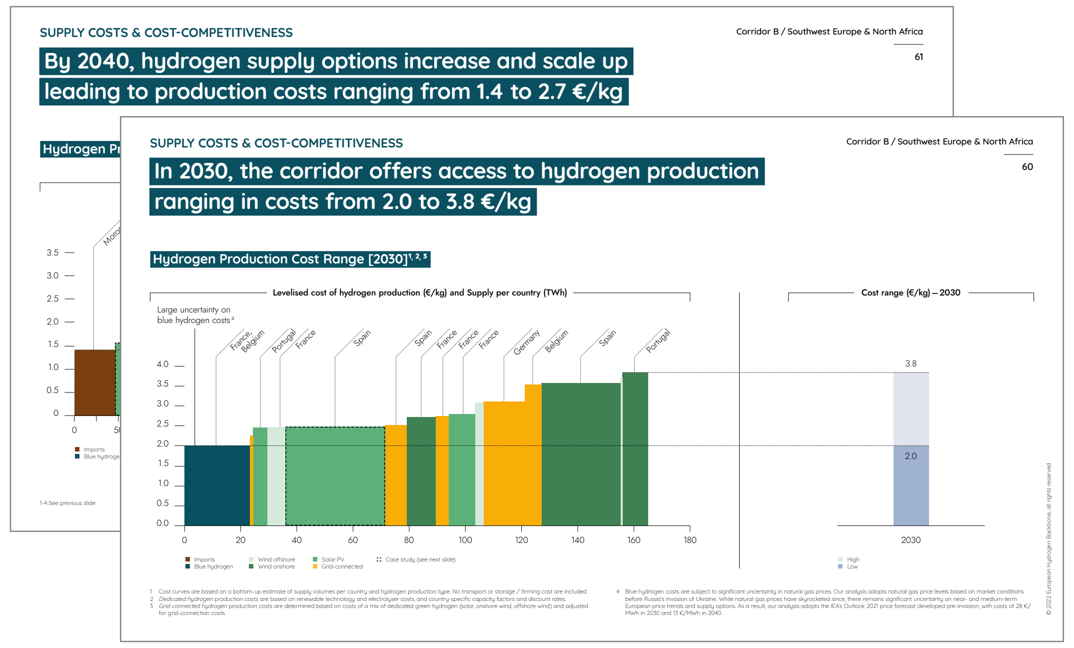
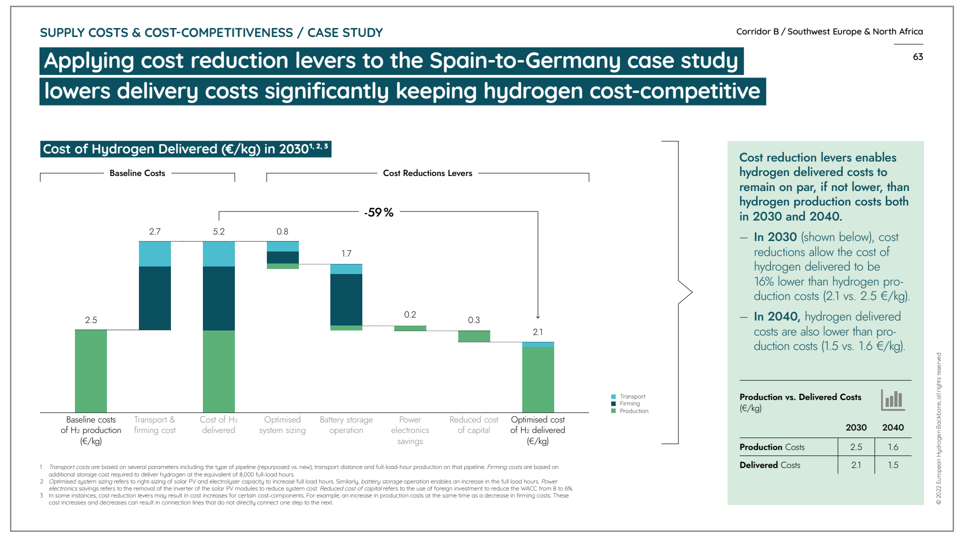
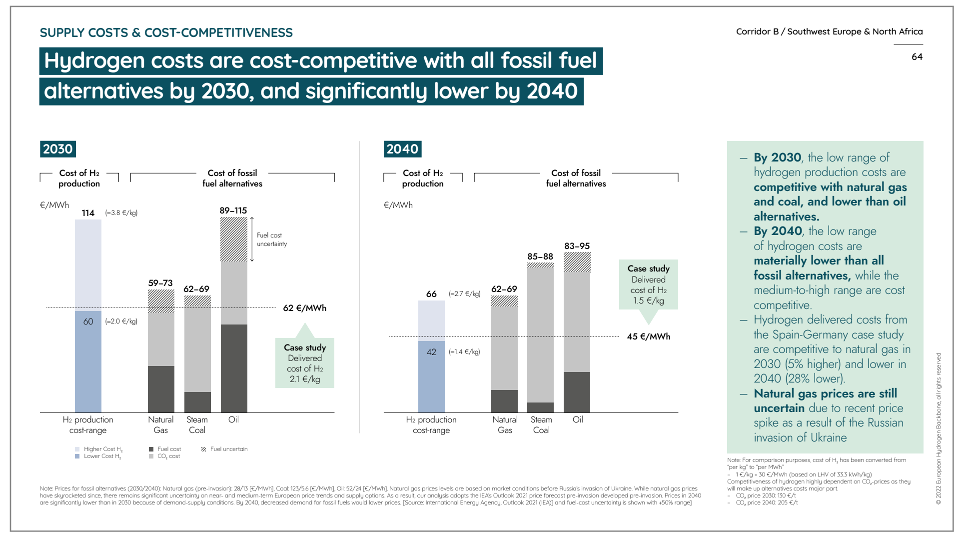
1 MEM – Green Hydrogen Roadmap (2021)
2 HEVO Ammonia (https://energy-utilities.com/fusion-fuel-and-ccc-to-develop-850m-morocco-green-news113290.html; and stakeholder interviews)
3 Due to political tension as a result of the Western Sahara sovereignty, Morocco halted the agreement in 2021, however, it is currently looking to restore ties as of 2022.

Southwest Europe & North Africa

Agenda

1. Corridor Summary
2. Hydrogen Demand & Supply
3. **Supply Costs & Cost-Competitiveness**
4. National Strategies & Regulation
5. Actions Needed

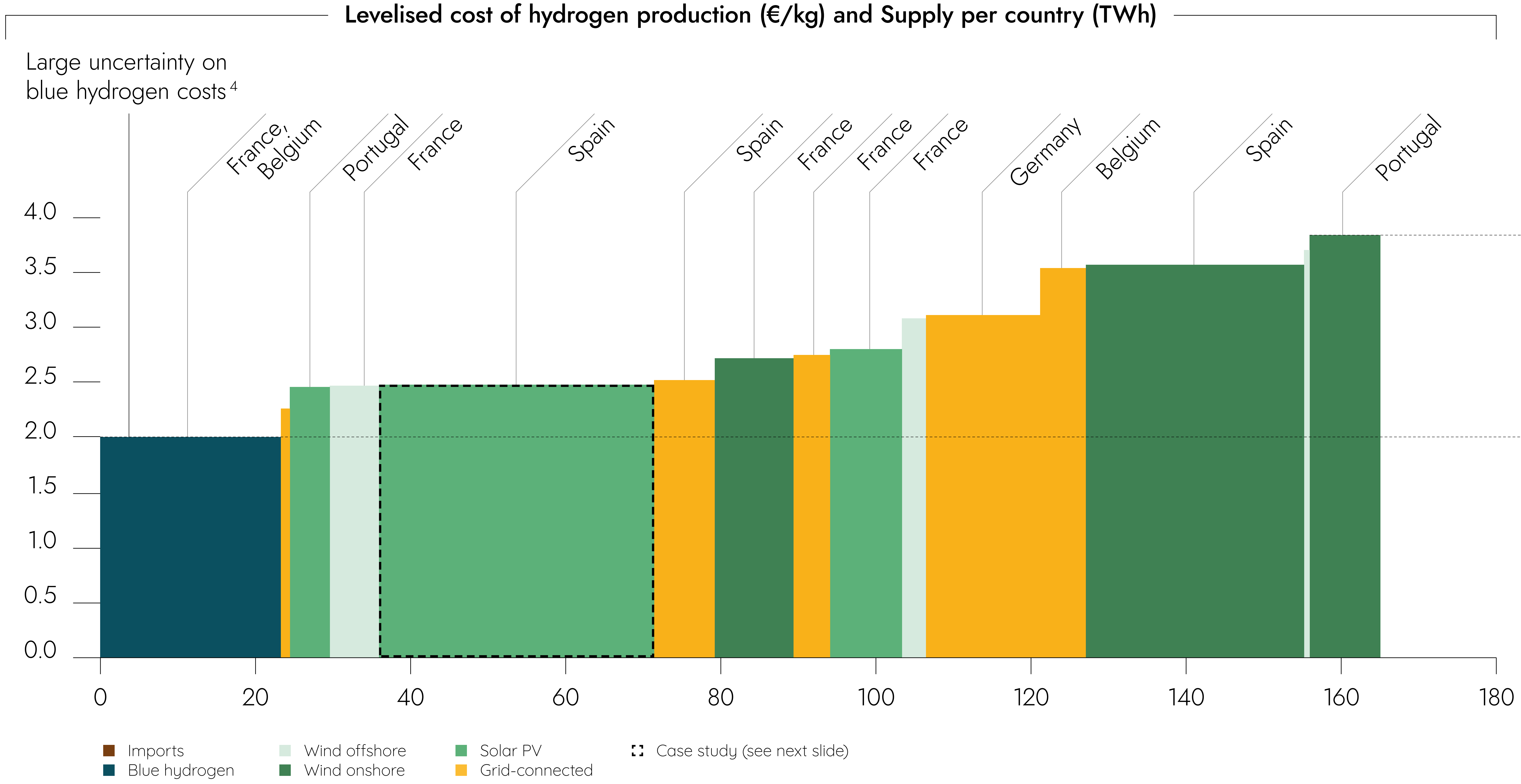
This section explores corridor’s hydrogen production and delivery costs and their cost-competitiveness with fossil-fuel alternatives

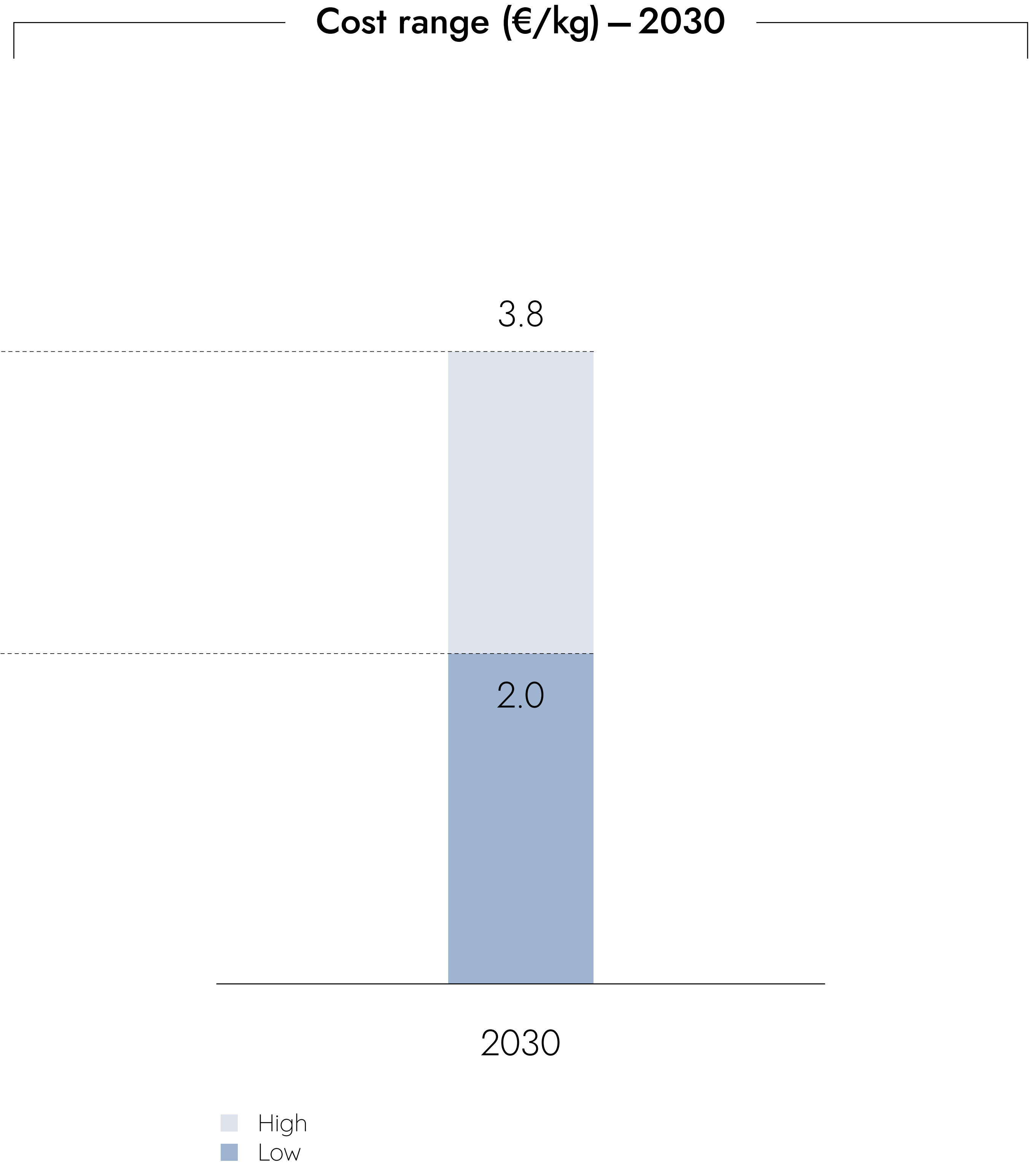
	Hydrogen production cost	Hydrogen delivered costs	Comparison with fossil alternatives
Key Questions Answered	What **hydrogen production costs** does the corridor provide access to **by 2030 and by 2040**?	What are the **full costs of delivered hydrogen** accounting for **transport** and **storage** costs? What **cost levers** are available to lower the cost of delivery costs?	How **cost-competitive** are hydrogen costs compare to fossil fuel alternatives?
Content Material	 SUPPLY COSTS & COST-COMPETITIVENESS Corridor B / Southwest Europe & North Africa 61 By 2040, hydrogen supply options increase and scale up leading to production costs ranging from 1.4 to 2.7 €/kg SUPPLY COSTS & COST-COMPETITIVENESS Corridor B / Southwest Europe & North Africa 60 In 2030, the corridor offers access to hydrogen production ranging in costs from 2.0 to 3.8 €/kg Hydrogen Production Cost Range (2030)	 SUPPLY COSTS & COST-COMPETITIVENESS / CASE STUDY Corridor B / Southwest Europe & North Africa 63 Applying cost reduction levers to the Spain-to-Germany case study lowers delivery costs significantly keeping hydrogen cost-competitive	 SUPPLY COSTS & COST-COMPETITIVENESS Corridor B / Southwest Europe & North Africa 64 Hydrogen costs are cost-competitive with all fossil fuel alternatives by 2030, and significantly lower by 2040
Key Findings & Results	— Corridor provides access to hydrogen production costs of **2.0–3.8 €/kg by 2030** — The scale-up of hydrogen supply leads to reductions to **1.4–2.7 €/kg in 2040**	— Several **cost reduction levers** can be applied to **lower the costs of hydrogen delivery**. — For the Spain-to-Germany case study, **these levers achieve delivery costs that are low and cost-competitive**.	— **Hydrogen costs are competitive with fossil fuel alternatives by 2030**, and lower by 2040. — Fossil fuel costs are subject to **significant uncertainty**.

SUPPLY COSTS & COST-COMPETITIVENESS

In 2030, the corridor offers access to hydrogen production ranging in costs from 2.0 to 3.8 €/kg

Hydrogen Production Cost Range [2030][1, 2, 3]





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[1] Cost curves are based on a bottom-up estimate of supply volumes per country and hydrogen production type. No transport or storage / firming cost are included.

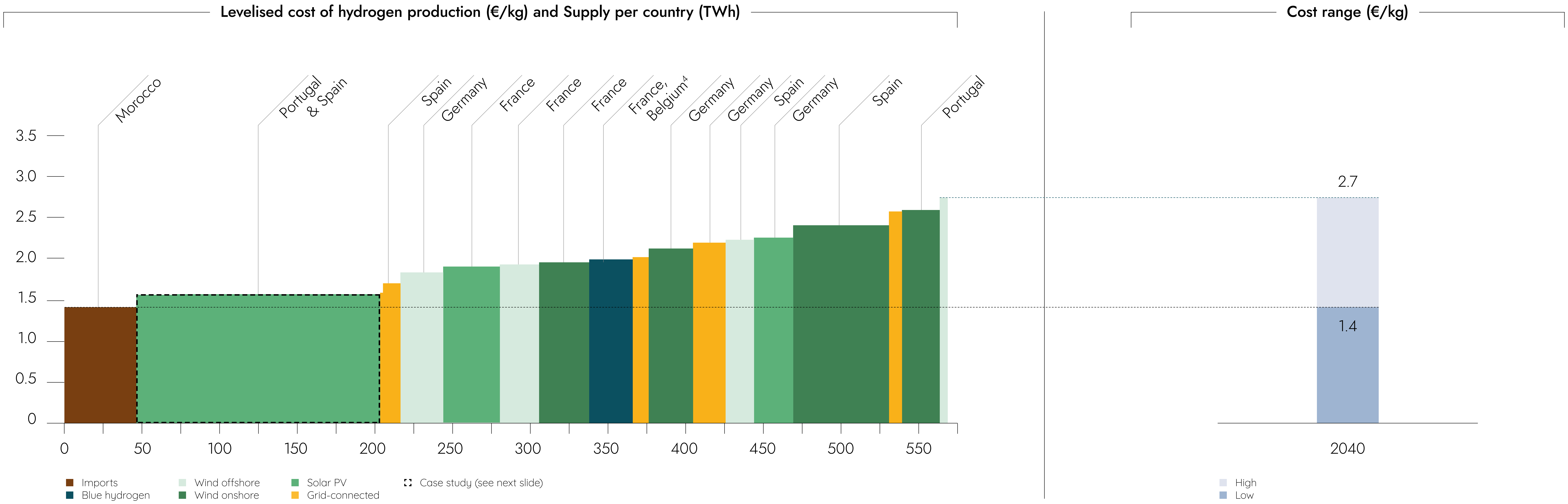
[2] *Dedicated hydrogen* production costs are based on renewable technology and electrolyser costs, and country-specific capacity factors and discount rates.

[3] *Grid-connected hydrogen* production costs are determined based on costs of a mix of dedicated green hydrogen (solar, onshore wind, offshore wind) and adjusted for grid-connection costs.

[4] Blue hydrogen costs are subject to significant uncertainty in natural gas prices. Our analysis adopts natural gas price levels based on market conditions before Russia's invasion of Ukraine. While natural gas prices have skyrocketed since, there remains significant uncertainty on near- and medium-term European price trends and supply options. As a result, our analysis adopts the IEA's Outlook 2021 price forecast developed pre-invasion, with costs of 28 €/MWh in 2030 and 13 €/MWh in 2040.

By 2040, hydrogen supply options increase and scale up leading to production costs ranging from 1.4 to 2.7 €/kg

Hydrogen Production Cost Range [2040][1, 2, 3]



1-4 See previous slide

Corridor offers access to low-cost hydrogen supply from the Iberian peninsula to demand centers in France and Germany

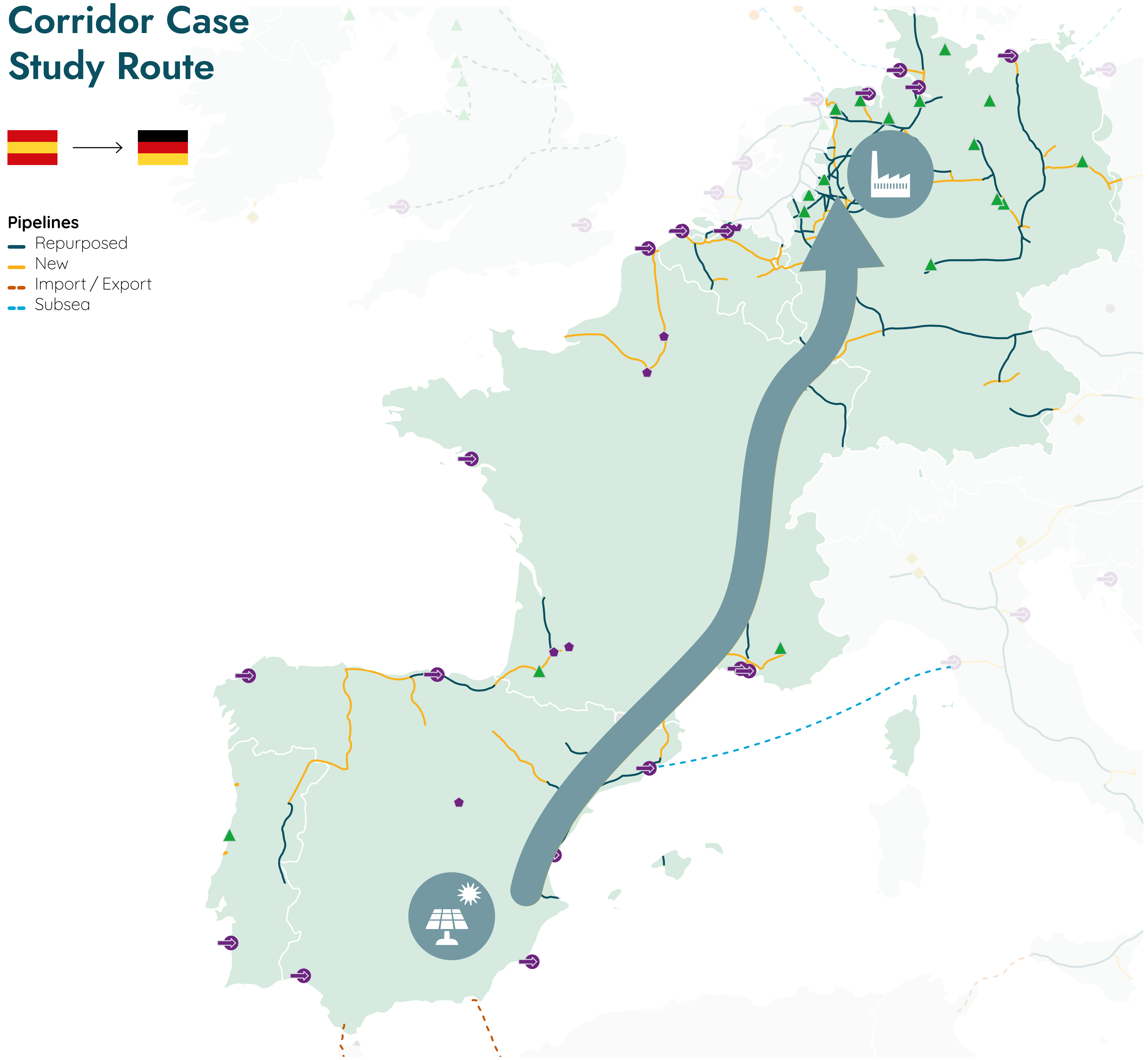
1 Our analysis assesses a **case study of hydrogen supply** from southern Spain to industrial offtakers in Germany **to explore how hydrogen delivered costs can be lowered.**

2 To assess the full cost of hydrogen delivery to Germany, **transport and storage costs are added to the cost of hydrogen production** from Spain.

Production Costs + Transport Costs + Storage Costs = Delivered Costs

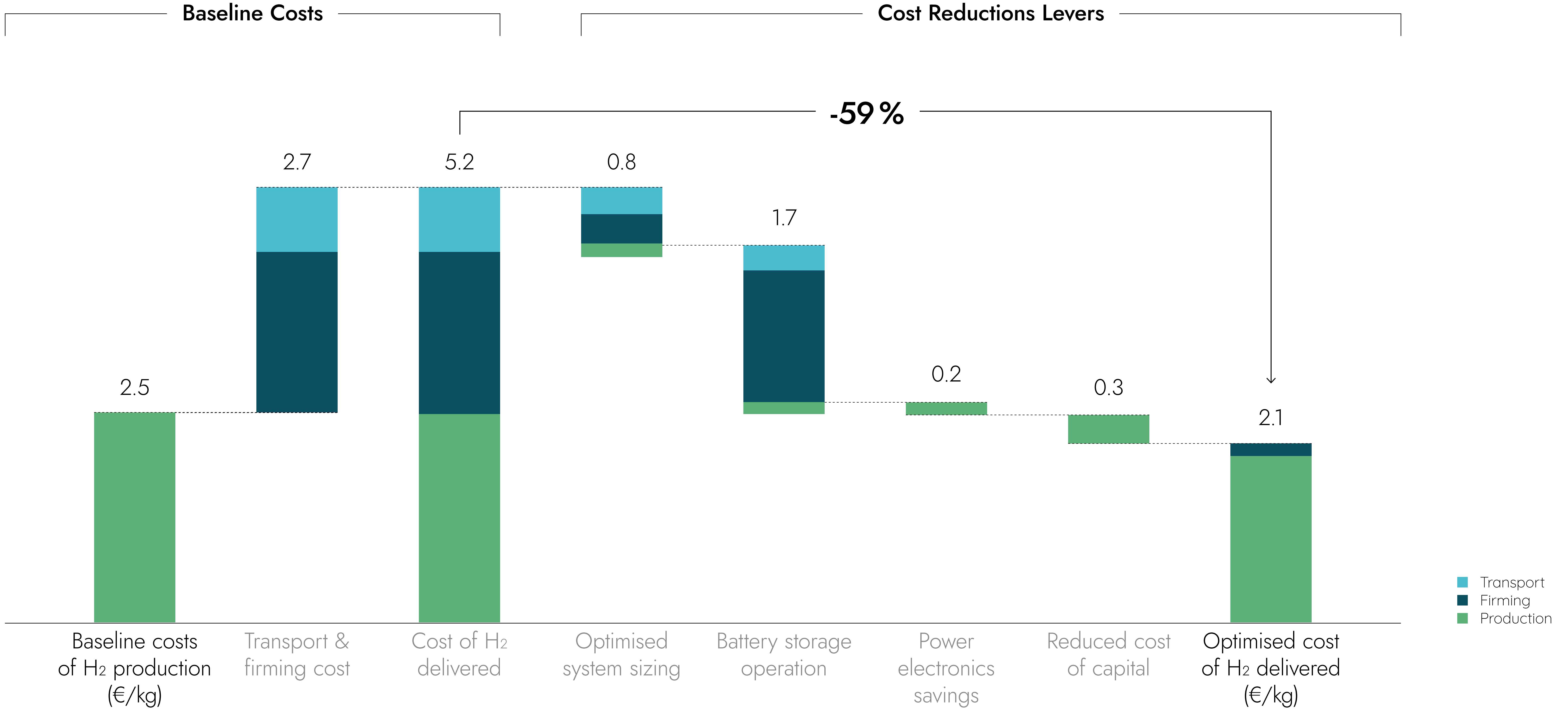
3 Several **cost reduction levers are applied to lower firm delivery costs**, including optimised system operation, battery storage use, cost of capital reductions, among others.

4 **These cost reduction levers achieve sufficient cost savings to keep firm hydrogen delivery costs low and cost-competitive.**



Applying cost reduction levers to the Spain-to-Germany case study lowers delivery costs significantly keeping hydrogen cost-competitive

Cost of Hydrogen Delivered (€/kg) in 2030[1, 2, 3]



Cost reduction levers applied to case study of hydrogen transport from Spain to Germany **enable firm delivery costs to be reduced significantly.**

- **In 2030** (shown on the left), the cost of delivered hydrogen can be lowered by 59% (2.1 vs. 5.2 €/kg).
- **In 2040,** hydrogen delivered costs can be reduced by 63% (1.5 vs. 4.0 €/kg).

Delivered Costs
(€/kg)
(before and after cost levers)

	2030	2040
Before costs levers	5.2	4.0
After costs levers	2.1	1.5

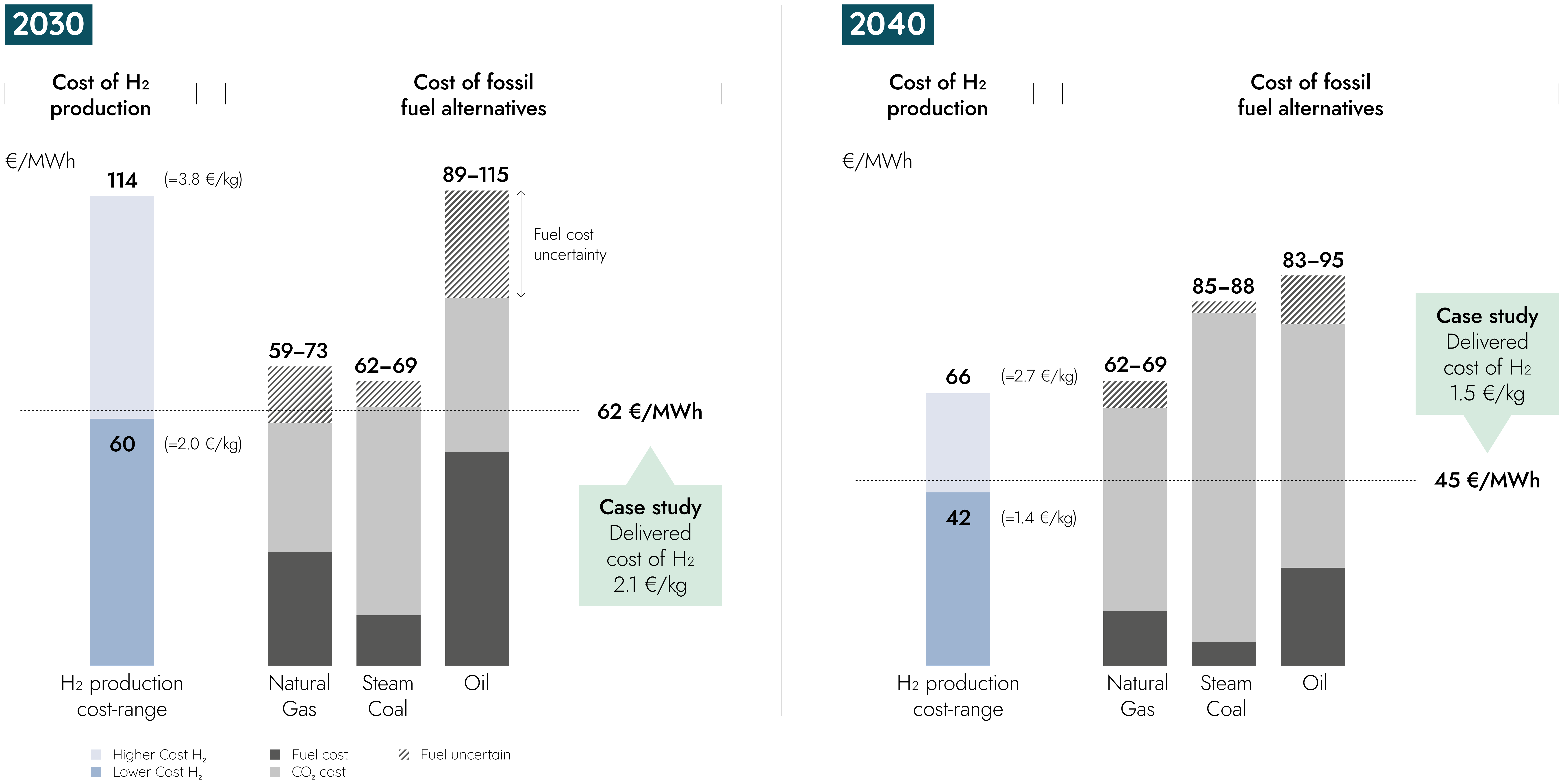
---

[1] *Transport costs* are based on several parameters including the type of pipeline (repurposed vs. new), transport distance and full-load-hour production on that pipeline. *Firming costs* are based on additional storage cost required to deliver hydrogen at the equivalent of 8,000 full-load hours.

[2] *Optimised system sizing* refers to right-sizing of solar PV and electrolyser capacity to increase full load hours. Similarly, *battery storage* operation enables an increase in the full load hours. *Power electronics* savings refers to the removal of the inverter of the solar PV modules to reduce system cost. *Reduced cost of capital* refers to the use of foreign investment to reduce the WACC from 8 to 6%.

[3] In some instances, cost reduction levers may result in cost increases for certain cost-components. For example, an increase in production costs at the same time as a decrease in firming costs. These cost increases and decreases can result in connection lines that do not directly connect one step to the next.

Hydrogen costs are cost-competitive with all fossil fuel alternatives by 2030, and significantly lower by 2040



- **By 2030**, the low range of hydrogen production costs are **competitive with natural gas and coal, and lower than oil alternatives.**
- **By 2040**, the low range of hydrogen costs are **materially lower than all fossil alternatives,** while the medium-to-high range are cost competitive.
- Hydrogen delivered costs from the Spain-Germany case study are competitive to natural gas in 2030 (5% higher) and lower in 2040 (28% lower).
- **Natural gas prices are still uncertain** due to recent price spike as a result of the Russian invasion of Ukraine

Note: For comparison purposes, cost of H_2 has been converted from "per kg" to "per MWh"

- 1 €/kg ≈ 30 €/MWh (based on LHV of 33.3 kWh/kg)

Competitiveness of hydrogen highly dependent on CO_2-prices as they will make up alternatives costs major part.

- CO_2 price 2030: 130 €/t
- CO_2 price 2040: 205 €/t

Note: Prices for fossil alternatives (2030/2040): Natural gas (pre-invasion): 28/13 [€/MWh], Coal: 123/5.6 [€/MWh], Oil: 52/24 [€/MWh]. Natural gas prices levels are based on market conditions before Russia's invasion of Ukraine. While natural gas prices have skyrocketed since, there remains significant uncertainty on near- and medium-term European price trends and supply options. As a result, our analysis adopts the IEA's Outlook 2021 price forecast pre-invasion developed pre-invasion. Prices in 2040 are significantly lower than in 2030 because of demand-supply conditions. By 2040, decreased demand for fossil fuels would lower prices. [Source: International Energy Agency, Outlook 2021 (IEA)] and fuel-cost uncertainty is shown with +50% range]

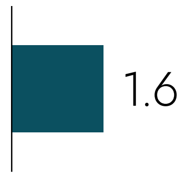
CORRIDOR B

Southwest Europe & North Africa

Agenda

All countries have developed national strategies and targets. Moving forward, the development of regulation is key to enable infrastructure investment.

Pre-RePowerEU targets[2]

	National Hydrogen strategy	Network regulation & policy	Funding[1] (bn €)	Highlights
Portugal	– 5% share of hydrogen at final energy consumption, **2 GW electrolyser** 2030 – 10 – 15% H_2 injection to gas grid by 2030	– Expected to come with EU regulations	 1.1	– Mixed focus on national consumption and export to central Europe – Production for export with 1 GW in Sines planned
Spain	– **Replacing 25% of industrial grey hydrogen** – Installation of **4 GW** electrolyser capacity – Setting up H_2 refuelling stations across Spain	– Expected to come with EU regulations	 1.6	– Decarbonisation of grey hydrogen use by industry – H_2 in heavy transport (fuelling stations)
France	– Implementation of local hydrogen hubs pre 2030 – Focus on **demand** (e.g. heavy transport) and **generation** (6.5 GW electrolyser in 2030) – No strategy on H_2 infrastructure yet	– Hydrogen injections to gas grid are possible, below threshold of technical restrictions	 7.2	– Strong investments in transport sector (heavy duty) and hydrogen production for industry – Need to accelerate strategy and policy around exports and imports
Belgium	– Focus: Industry, (freight) transport, electricity storage – **150 MW for electrolysis** production by 2026 – **Import and transit** of H_2 and its derivatives via existing network and additional infrastructure	– 2026: 100-160 new km pipelines – Open access H_2 backbone by 2030 connecting ports, industrial clusters, and neighboring countries	 0.1	– The NHS sees Belgium as an import hub of renewable molecules for Europe – Strong focus on national and cross-country hydrogen network infrastructure
Luxembourg	– Focus on **renewable hydrogen** – Prioritized use in industry, sector coupling & transport – **Dedicated H_2 network explicitly mentioned**	– Goal to regulate transmission, storage & distribution infrastructure in line with ambitions of the EU		– Strong need for imports, hence cross border H_2 infrastructure & national networks to meet industry & transport demand
Germany	– National production & import focus due to supply gap – In place **since 2020, currently reviewed towards increasing its ambition** – **10 GW (2030)** electrolyser in coalition plans	– H_2 network potentially opt-in regulated and vertically unbundled – First rules and standards for high pressure pipelines are formulated	 9	– Strong focus on international cooperation to ensure sufficient supply – National funding

■ General funding ■ Network
■ Supply ■ Demand

Note: Sequencing of countries follows the general corridor direction but does not represent the hydrogen flows.

[1] Cumulative public funding amount by the respective state until 2030

[2] Strategies and funding is under evaluation of meeting latest targets

Southwest Europe & North Africa

Agenda

ACTIONS NEEDED

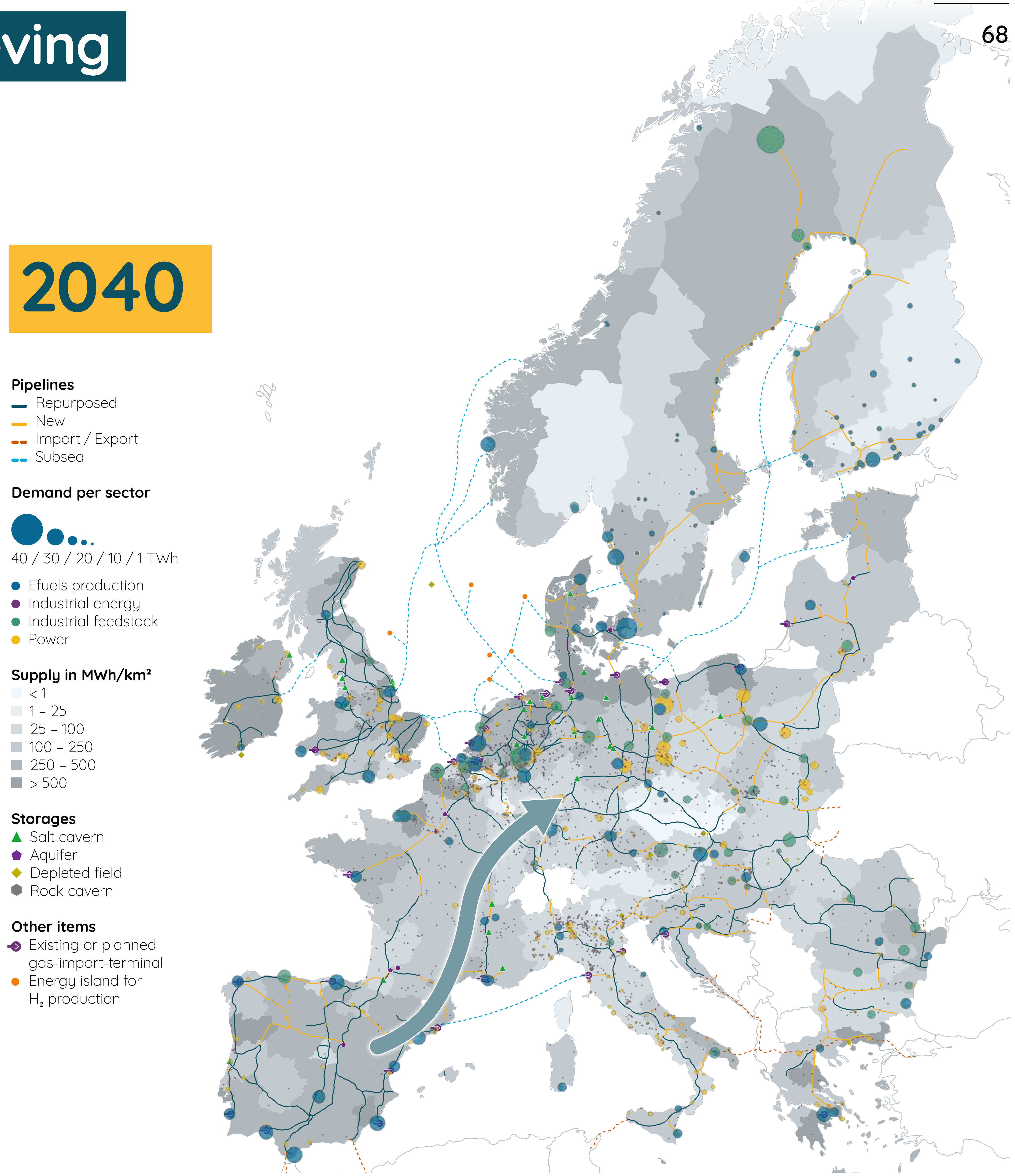
This corridor plays a fundamental role in achieving a European backbone by 2040

The need for this corridor

- The development of **this corridor ensures access to abundant, low-cost hydrogen supply from Spain and Portugal** by 2030, and by 2040 additional supply from Morocco and potentially Algeria.
- The **decarbonisation of the largest hydrogen demand centers along this corridor** – in **Spain, France, and Germany** – is dependent on the buildout of this corridor by 2030, and its expansion towards 2040.

Actions required

- The buildout of this corridor by 2030 **requires national governments to take clear and concrete actions across.**
- This includes actions associated with **infrastructure development and planning, the development of cross-national initiatives** and **securing access to early funding and long-term, low-cost financing.**



To ensure the development of this corridor by 2030, there is a need for clear and concrete actions

Fostering development of new and repurposed hydrogen infrastructure, for example, by unbundling rules facilitating the efficient use of TSO expertise and services and by allowing the adoption of different vertical unbundling models in the EU, as is the case with natural gas

+

Unlock financing to fast-track hydrogen infrastructure deployment by applying regional regulatory flexibility and other pragmatic financing solutions (including incentivizing the adoption of hydrogen by demand sectors)

+

Simplify and shorten planning and permitting procedures for renewable energy and hydrogen infrastructure projects.

+

Intensify energy partnerships with exporting, non-EHB countries like Morocco, and other countries in North Africa, and providing financing support to reduce their cost of capital

+

Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure supporting the accelerated deployment and integration of renewable energy resources

→ **However, speed will be of essence!**

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CORRIDOR C

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2. Hydrogen Demand & Supply
3. Supply Costs & Cost-Competitiveness
4. National Strategies & Regulation
5. Actions Needed

CORRIDOR C / FACTSHEET

North Sea

- 🇳🇴 Norway
- 🇮🇪 Ireland
- 🇳🇱 Netherlands
- 🇩🇰 Denmark
- 🇬🇧 United Kingdom
- 🇱🇺 Luxembourg
- 🇧🇪 Belgium
- 🇫🇷 France
- 🇩🇪 Germany

Corridor emerges in the North Sea providing access to low-cost, blue and green hydrogen supply to demand clusters in northwestern Europe

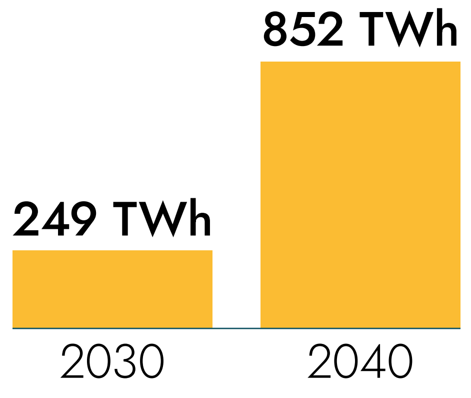
Drivers & Opportunities

Major driver of development is the need to meet **demand from large industrial & transport clusters** in the UK, Netherlands, Belgium, France and Germany. Key opportunities include the **repurposing potential of onshore/offshore infrastructure, integration of North Sea wind resources** and the portfolio of **planned import terminals**

Hydrogen Supply & Decarbonization Potential

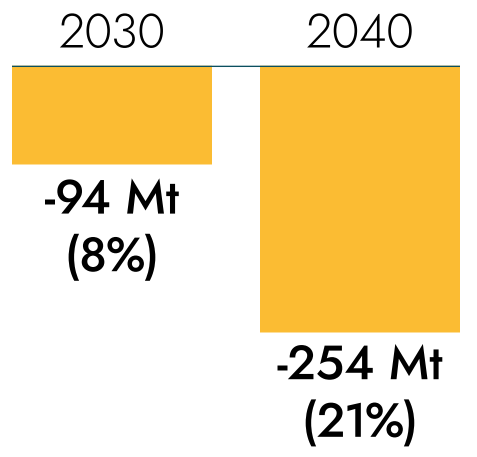
H_2 supply potential[1]

(TWh/year)



Emissions Reductions

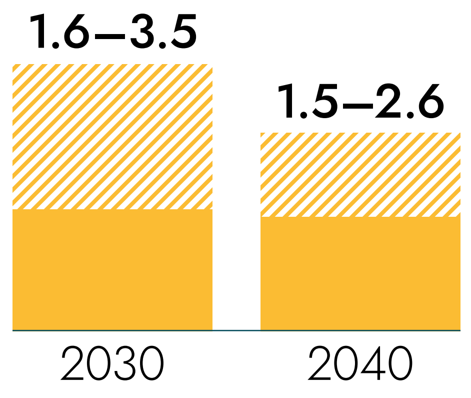
($MtCO_2$/year vs. 2019; % reduction)



Supply Costs & Cost-Competitiveness

Cost of H_2 production[1]

(€/kg of H_2)

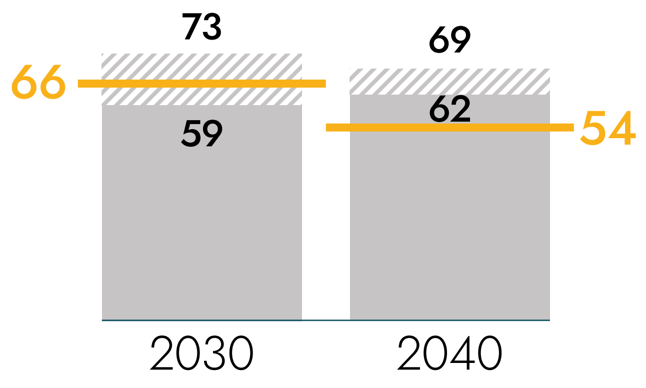


Cost competitiveness[2]

— Hydrogen delivered price

vs.

▨ natural gas price high/low, (€/MWh)



Actions Needed

- Fostering development of new and repurposed hydrogen infrastructure
- Unlock financing to fast-track hydrogen infrastructure deployment
- Simplify and shorten planning and permitting procedures
- Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure

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[1] Figures reported reflect outputs for all countries included in the corridor. Even if a country is only partially in the corridor, results for the full country are included (e.g., supply potential and costs, demand, transmission network length).

[2] Savings are based on the corridor's case study of hydrogen delivered in 2030 and 2040. The cost of natural gas includes CO_2 prices. Refer to Subsection 3 (Supply Costs & Cost-Competitiveness)

CORRIDOR C

North Sea

Agenda

CORRIDOR SUMMARY

Corridor offers access to low-cost, North Sea blue & green hydrogen supply to demand clusters in the UK and northwestern Europe

Drivers & Opportunities

- **The major driver** behind the development of this corridor is hydrogen adoption associated with the **decarbonisation of industry**, transport and power in the UK and northwestern Europe. The speed of hydrogen adoption in these regions may be even faster than anticipated driven by increasing CO_2 prices in the EU and the RePowerEU ambitions to replace natural gas consumption.
- In the near term, the corridor offers **access to abundant, low-cost blue hydrogen supply from the North Sea**. In the longer term, this corridor also provide access to significant green hydrogen potential leveraging **strong onshore and offshore wind resources in the North Sea**, offering an opportunity to integrate even higher capacities of offshore wind.
- A **major opportunity** for this corridor relates to the **large portfolio of ongoing and planned hydrogen infrastructure projects** in the region — including large-scale offshore wind developments, large-scale integrated hydrogen projects, and a growing list of planned **import terminals for hydrogen and hydrogen-derivatives** — in the Netherlands, Belgium, Germany and France.
- This corridor emerges as a **highly-integrated supply corridor** that can leverage **extensive offshore gas infrastructure in the North Sea**, planned **national and regional hydrogen backbones** in the Netherlands (by 2027), and in Belgium and Germany by 2030 — connecting all major demand clusters in north-western Europe — as well as **potential hydrogen storage** at salt cavern locations northwest Europe.
- The corridor would be stood up by 2030, covering **12,000 km** of large-scale hydrogen pipelines across all countries of the corridor, of which approximately **70% will be repurposed pipelines**. The corridor's high repurposing potential of existing infrastructure offers an opportunity to keep the cost of hydrogen transport relatively low.

Hydrogen Demand & Supply

- **Total hydrogen demand** in the corridor reaches **~260 TWh by 2030**, increasing substantially to **~900 TWh by 2040**. Up to 2030, most hydrogen demand is driven by large industrial clusters in the UK and northwestern Europe. Hydrogen use in the transport sector also contributes a significant share of hydrogen demand. From 2040 to 2050, hydrogen demand increases substantially in the transport and power sectors and continues to ramp up in industry.
- Hydrogen adoption across all countries of the corridors enables an emissions reduction of ~360 $MtCO_2$/yr. by 2050, **equivalent to a 29% emissions reduction.**
- The corridor enables access to **hydrogen supply potential of ~250 TWh by 2030, increasing to roughly 850 TWh by 2040.** Major sources of supply include North Sea blue hydrogen potential in 2030, expanding to green hydrogen from onshore and offshore wind resources in the North Sea.

To successfully stand up this corridor by 2030, actions are needed to support infrastructure planning, financing and development

Costs & Cost-Competitiveness

- By 2030, the corridor provides access to hydrogen ranging in production cost from **1.6 to 3.5 €/kg**. By 2040, as supply options increase and technology costs decrease, hydrogen production costs decrease to **1.5 to 2.6 €/kg**.
- In the long term, this corridor's lowest-cost hydrogen supply options are onshore and offshore wind resources from the North Sea.
- Based on a case-study of green hydrogen supply and transport from the North Sea to North Rhine Westphalia (Germany), **the cost of delivered hydrogen** – inclusive of transport and firming costs – **can be lowered to achieve cost levels comparable to production costs** both in 2030 and 2040. Lowering delivery costs can be achieved through various cost levers including optimized operation of the system and cost of capital reductions.

National Strategies & Regulation

- **Most countries have developed** – or are in the process of developing – **national strategies**. Further, in most high-demand countries, hydrogen regulation is also already in place, if not currently under development. The **development of hydrogen regulation** in all other countries will accelerate investment in infrastructure.
- In select countries, **substantial funding has been allocated** to support the development of the hydrogen market including funding for gas network infrastructure.

Actions Needed

To support the buildout of this corridor by 2030, clear and concrete actions related to infrastructure planning, financing and development have been identified:

- Fostering development of **new and repurposed hydrogen infrastructure**.
- Unlock financing to **fast-track hydrogen infrastructure deployment** by applying regional regulatory flexibility and other pragmatic financing solutions.
- Simplify and shorten **planning and permitting procedures** for the full value chain of renewable energies and hydrogen infrastructure projects.
- Establish **integrated energy system planning** of hydrogen, natural gas, and electricity infrastructure.

CORRIDOR C

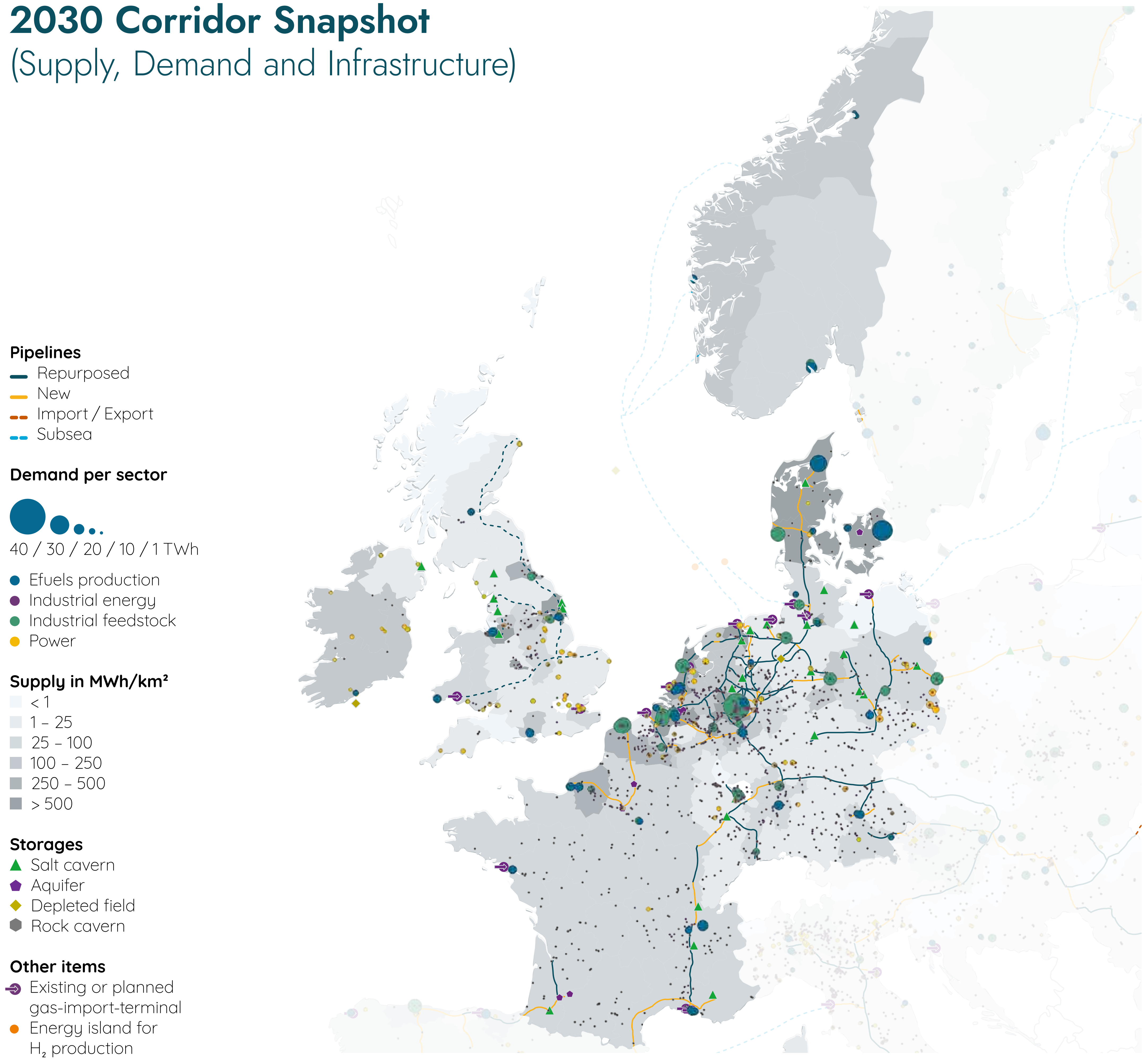
North Sea

Agenda

This section explores the development of demand, supply and transport infrastructure in the corridor from 2030 to 2050

2030 Corridor Snapshot

(Supply, Demand and Infrastructure)



Hydrogen demand

By 2030, the corridor connects **all major industrial clusters** in the UK and northwest Europe. **From 2030 to 2040**, the corridor expands to **all demand centers along its route**, increasing demand from 260 to ~900 TWh.

Hydrogen supply[1]

By 2030, the corridor enables access to low-cost, blue hydrogen supply from the **North Sea. By 2040**, the corridor diversifies its supply with green hydrogen from offshore wind resources in the North Sea.

In 2030, hydrogen supply is ~250 TWh, of which over 40% is blue hydrogen. Hydrogen supply increases significantly by 2040, reaching 850 TWh.

Hydrogen Infrastructure

By 2030, the buildout of pipeline infrastructure across all countries of the corridor reaches 12,000 km of large-scale pipelines. Corridor benefits from a very large share of repurposed infrastructure.

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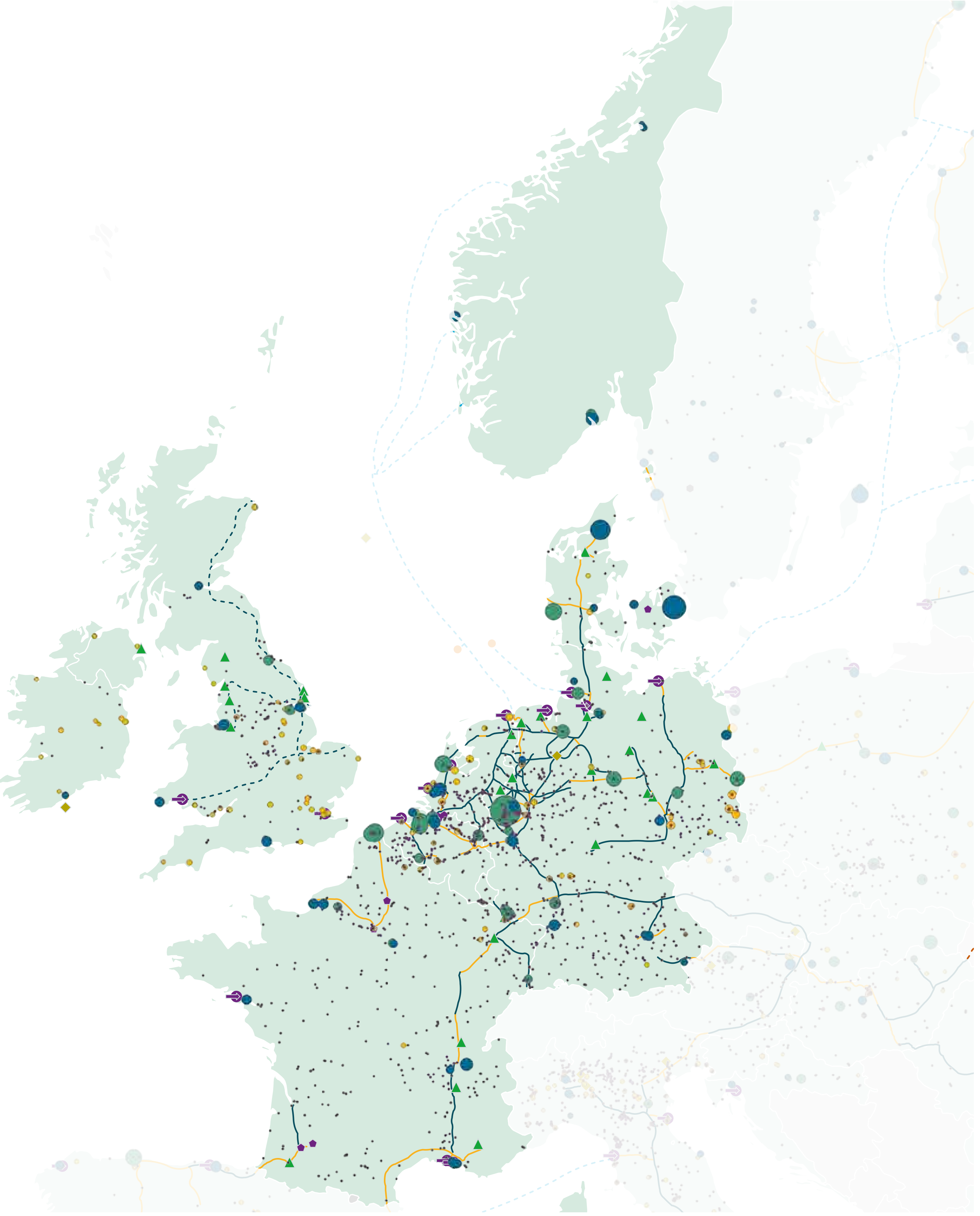
[1] Ship imports of hydrogen and hydrogen-derivatives are not included.

Corridor connects major industrial clusters in the UK and northwest Europe by 2030, expanding to all demand centers by 2040

2030



Pipelines
- — Repurposed
- — New
- -- Import / Export
- -- Subsea

Demand per sector

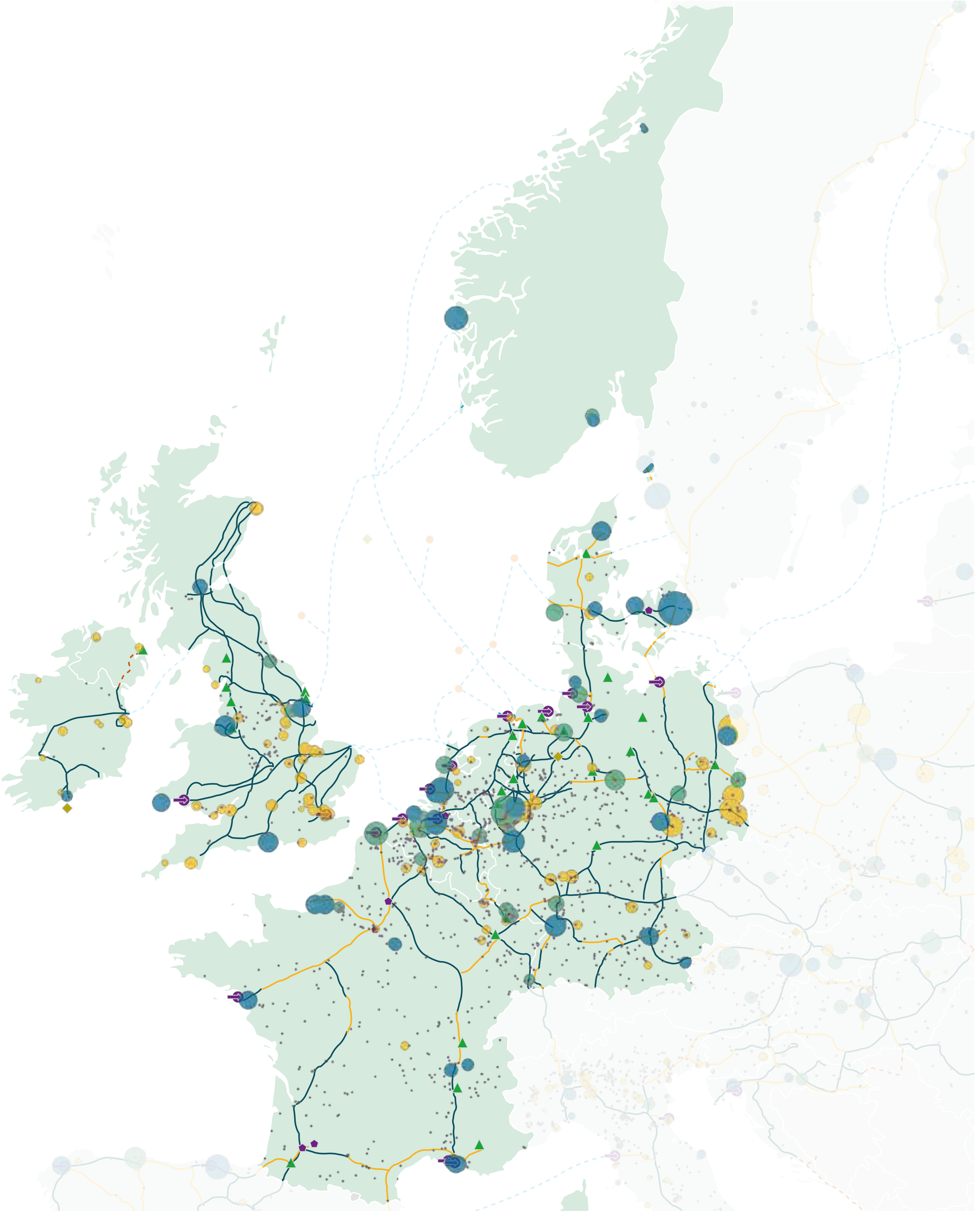
● ● • • 40 / 30 / 20 / 10 / 1 TWh

- ● Efuels production
- ● Industrial energy
- ● Industrial feedstock
- ● Power

Storages
- ▲ Salt cavern
- ⬟ Aquifer
- ◆ Depleted field
- ⬢ Rock cavern

Other items
- ⊖ Existing or planned gas-import-terminal
- ● Energy island for H_2 production

2040



Pipelines
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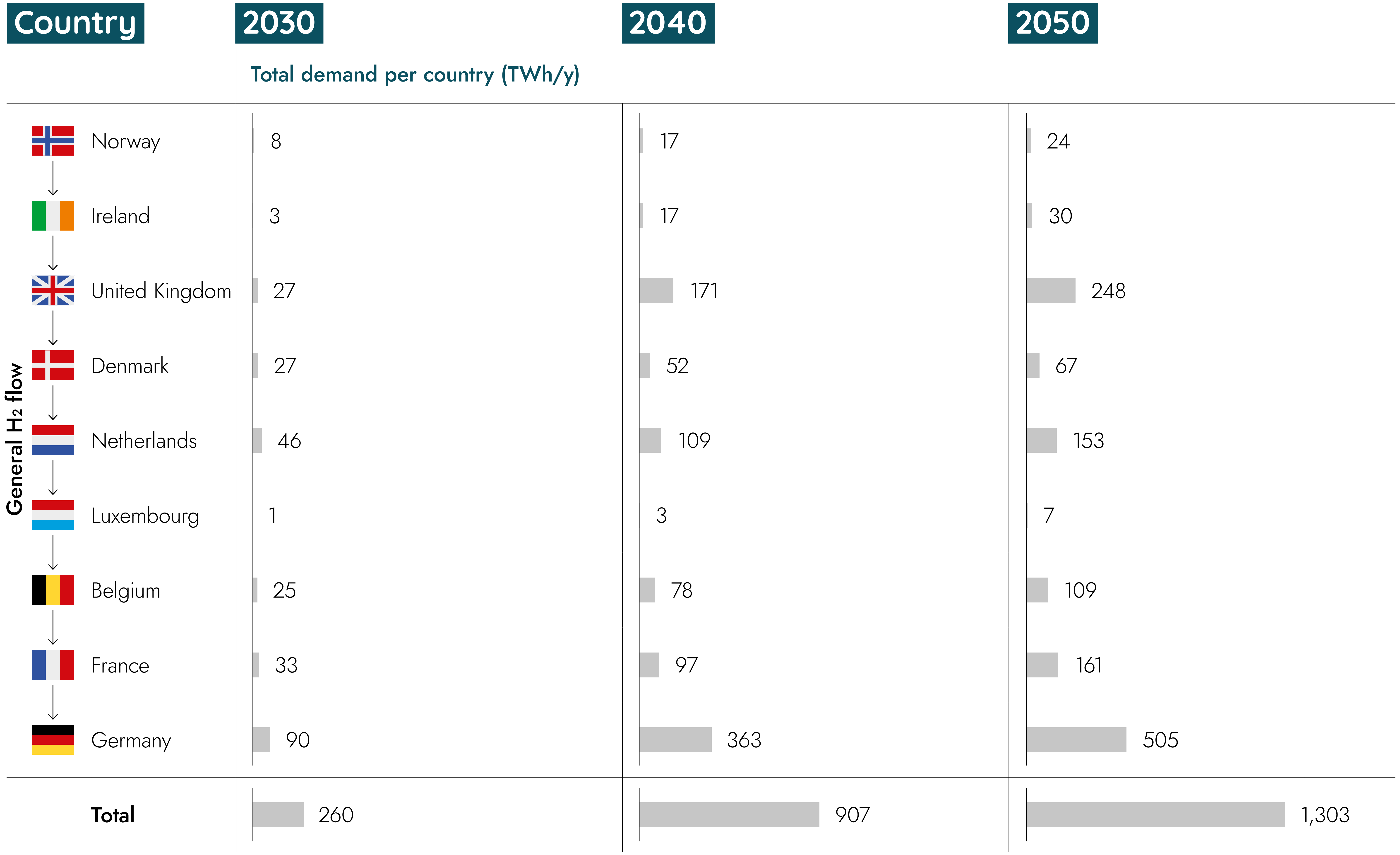
Hydrogen demand increases rapidly from 2030 to 2040, largely driven by the UK, Belgium, the Netherlands, France and Germany



Total demand per country (TWh/y)

Country	2030	2040	2050
Norway	8	17	24
Ireland	3	17	30
United Kingdom	27	171	248
Denmark	27	52	67
Netherlands	46	109	153
Luxembourg	1	3	7
Belgium	25	78	109
France	33	97	161
Germany	90	363	505
Total	260	907	1,303

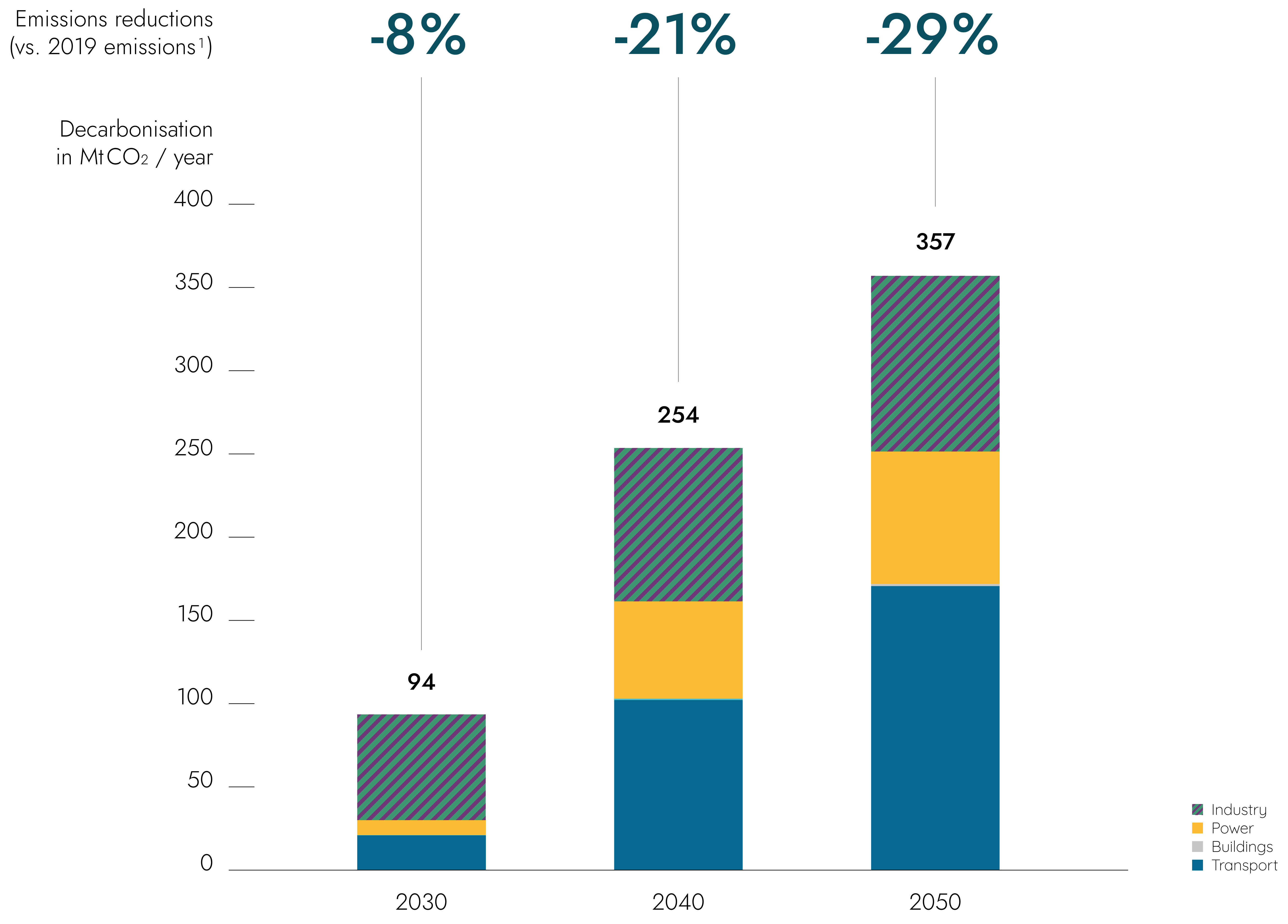
Note: Does not include grey hydrogen demand. Numbers represent total demand by country, even if only parts of the country are included in the corridor.

Hydrogen demand – across all countries of the corridor – increases significantly from 2030 to 2050. Demand reaches 260 TWh by 2030, increasing to roughly ~900 TWh by 2050.

Hydrogen demand may accelerate and increase further than forecasted as a result of additional regulatory measures adopted in response to the RePowerEU plan.

- **Up to 2030, most hydrogen demand is driven by large industrial clusters** in the UK, Belgium, the Netherlands, France and Germany. Hydrogen use in power generation also accounts for a significant share of demand.
- **From 2040 to 2050**, hydrogen demand expands into the transport sector and continues to ramp up in industry and power generation.

Hydrogen adoption enables a reduction in emissions of 29% by 2050 across all countries of the corridor



Hydrogen adoption across all demand sectors enables an **emissions reduction of ~360 MtCO_2/yr. by 2050**, equivalent to a 29% reduction[2].

- **Up to 2030**, the industrial sector contributes just under 70% of the total emissions reductions, largely driven by the decarbonisation of the steel sector. Notably, roughly 20% of emissions reductions are from the transport sector.
- **By 2040**, emissions reductions from transport (road, shipping and aviation) increase substantially and combined with industry, account for 80% of emissions reductions. The power sector account for the remaining 20% of reductions.
- **By 2050**, the transport sector alone accounts for over 50% of emissions reductions.

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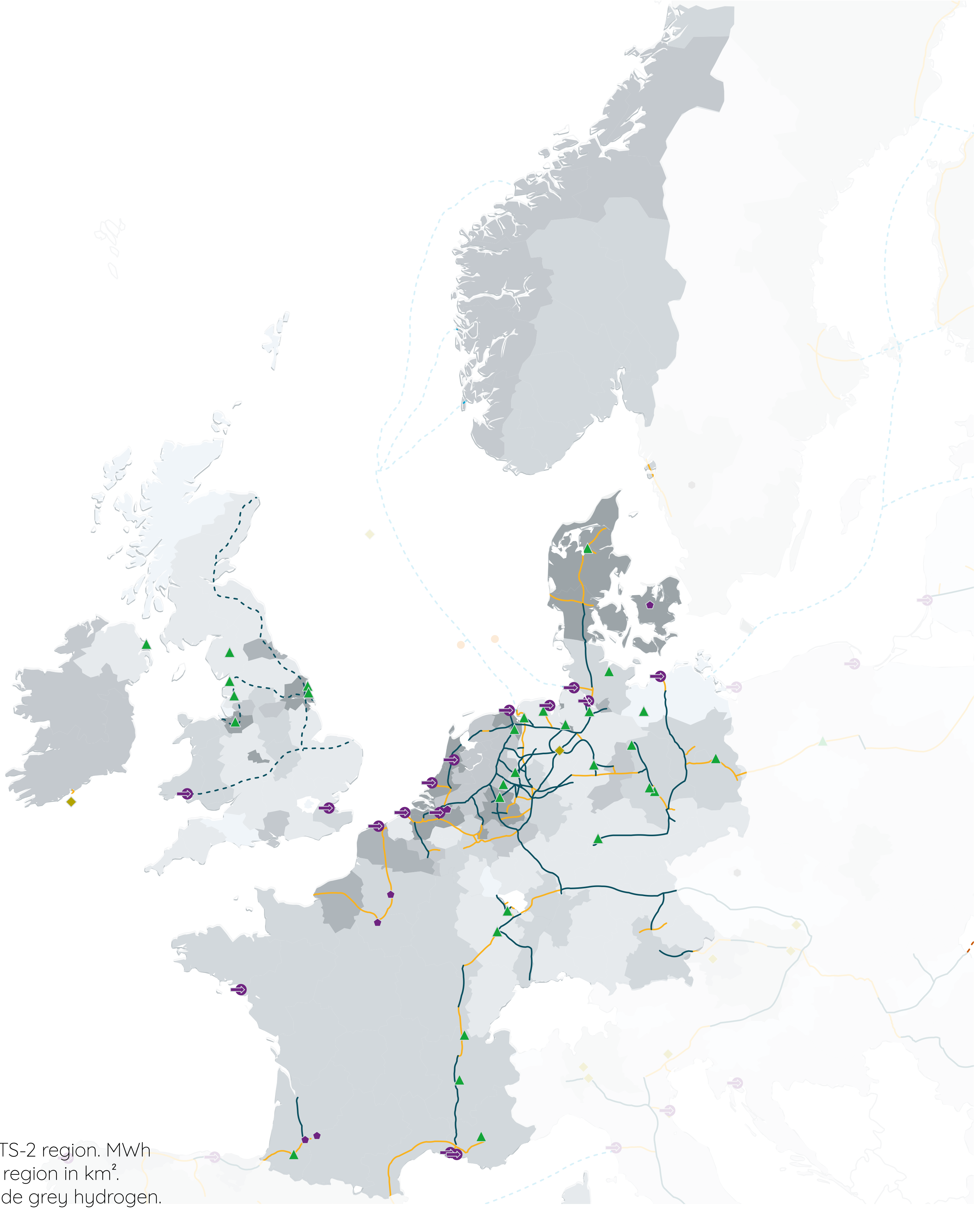
[1] CO_2-Emissions from countries and sectors included in corridor (1.24 bn t CO_2 / year). Source: EEA

[2] Emissions reductions are calculated compared to the baseline fossil fuel used in each sectors. For example, emissions reductions associated with the adoption of hydrogen by the primary steel sector are relative to the use of coal. Similarly, emissions reductions , for e-fuels production are relative to the use of fossil fuels in domestic transport, shipping and other uses.

Corridor enables access to North Sea blue hydrogen by 2030, expanding to hydrogen supply from abundant offshore wind by 2040

2030*



Pipelines
- Repurposed
- New
- Import / Export
- Subsea

Supply in MWh/km²
- < 1
- 1 – 25
- 25 – 100
- 100 – 250
- 250 – 500
- > 500

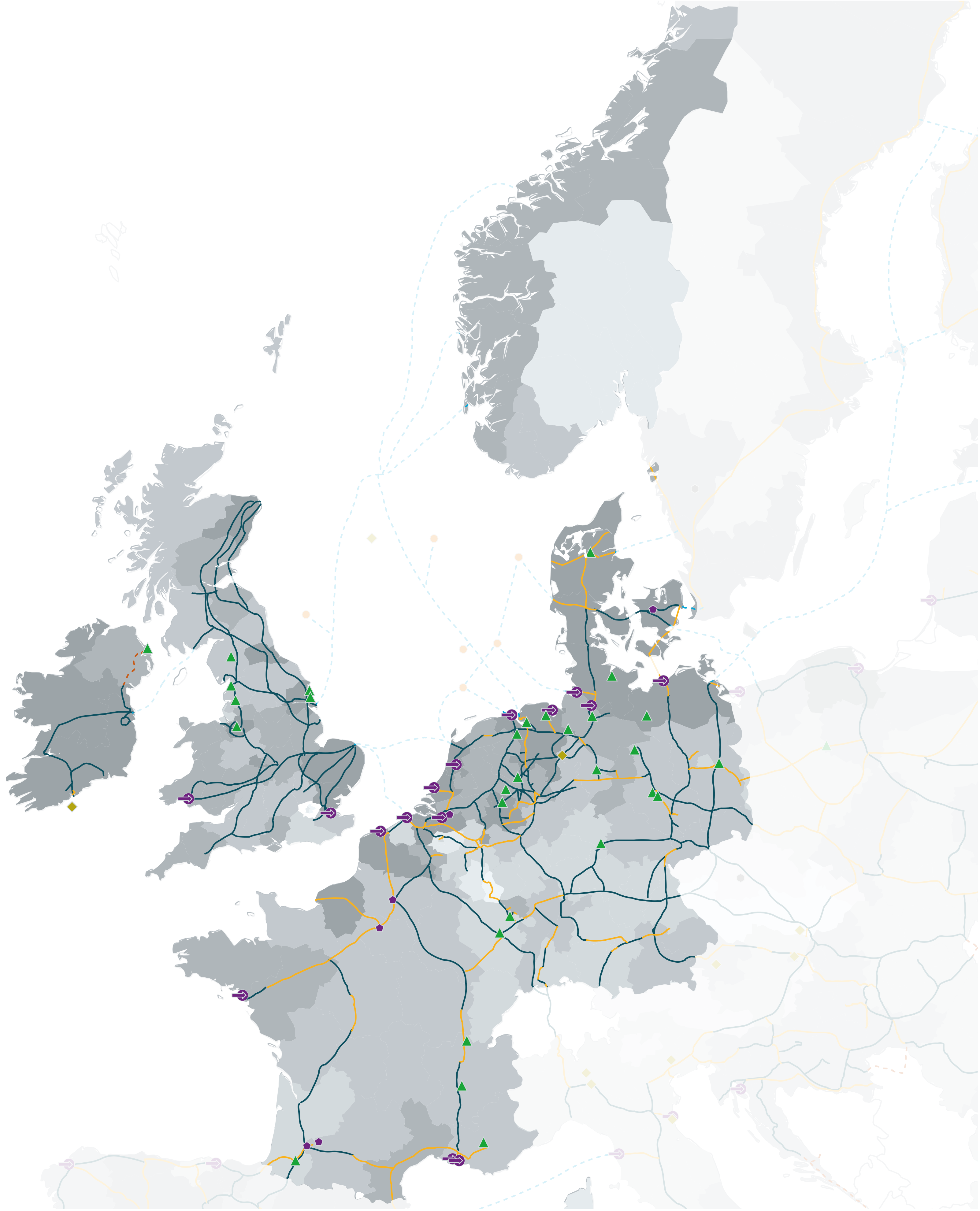
Storages
- ▲ Salt cavern
- ⬟ Aquifer
- ◆ Depleted field
- ⬢ Rock cavern

Other items
- Existing or planned gas-import-terminal
- ● Energy island for H_2 production

Total hydrogen supply shown per NUTS-2 region. MWh adjusted by the area of each NUTS-2 region in km².

* Note: Supply numbers do not include grey hydrogen.

2040*



Pipelines
- Repurposed
- New
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Supply in MWh/km²
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Other items
- Existing or planned gas-import-terminal
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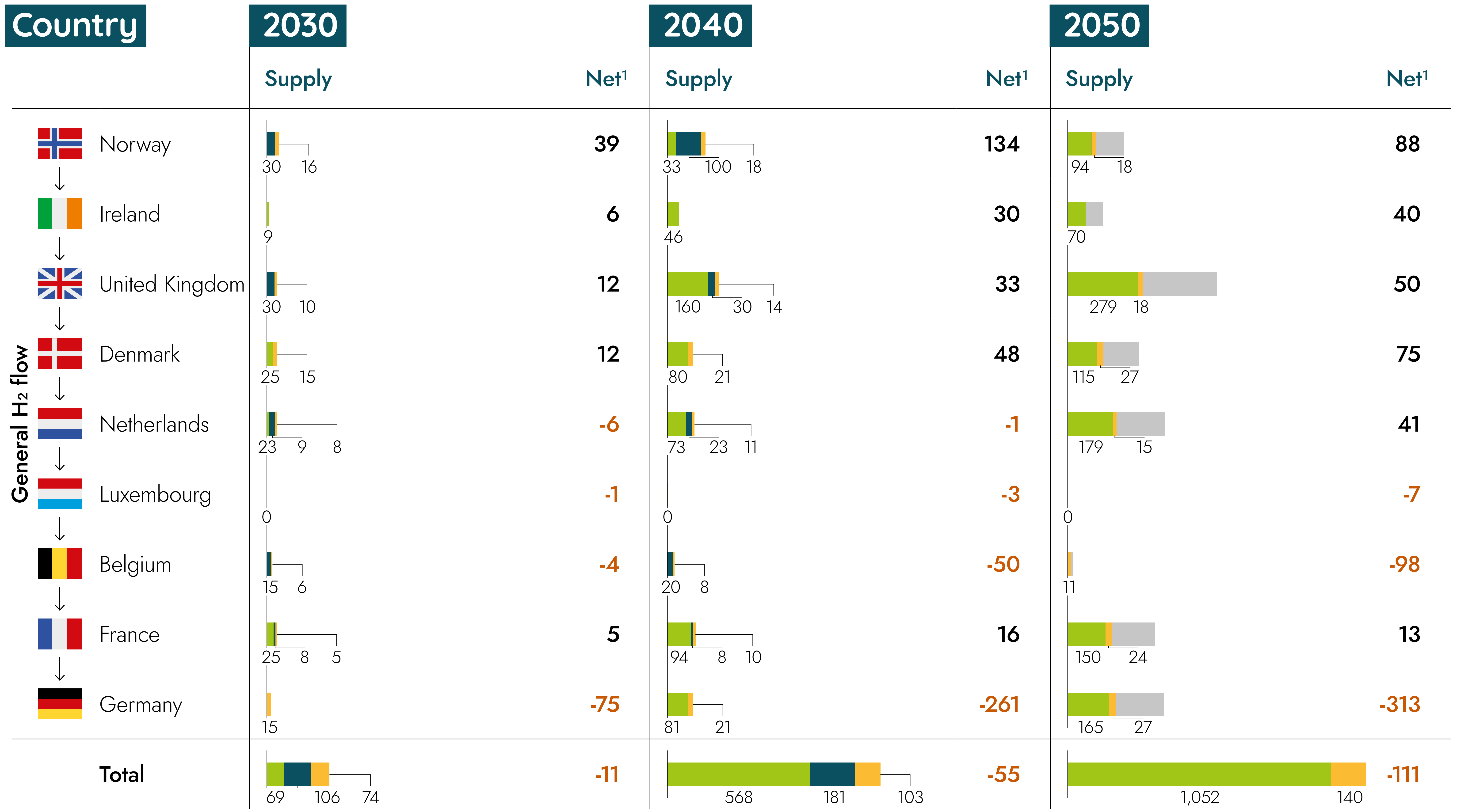
Hydrogen supply increases significantly from 2030 to 2040, driven by a scale up in supply across multiple countries in the corridor



Hydrogen supply includes a mix of supply options including **grid-based green hydrogen², dedicated green hydrogen, and blue hydrogen³.**

- **By 2030, hydrogen supply reaches ~250 TWh,** roughly 40% blue hydrogen and 30% each for dedicated green and grid-based hydrogen.
- **By 2040, hydrogen supply increases substantially to ~850 TWh,** of which 70% is from dedicated green hydrogen. Blue hydrogen accounts for just under 20%, while grid-based hydrogen for the remaining 10%.
- **By 2050, hydrogen supply increases further to ~1,190 TWh.** Dedicated green supply account for the largest share at 90%, while grid-based hydrogen account for the remaining 10%. Blue hydrogen supply is not included in 2050 due to assumed target of zero emissions and de-fossilisation of Europe by 2050.

Hydrogen supply may accelerate and increase further as a result of additional regulatory measures adopted in response to the RePowerEU plan.

Note: Hydrogen supply volumes do not include hydrogen imports by ship.

---

1 *Net* represents excess supply after subtracting demand;

2 Grid-based is estimated using national 2030 electrolyser targets which, by 2030, are assumed to be largely grid-connected rather than dedicated. Grid-based increases over 2030-2050 with increasing RES;

3 Blue hydrogen supply volumes will be subject to the evolution of gas markets and the development of low carbon hydrogen regulation in different country. As a result, some countries may have additional blue hydrogen supply which could be used to satisfy local demand.

🟩 Dedicated green
■ Blue
🟨 Grid-based
▨ 2050 technical potential

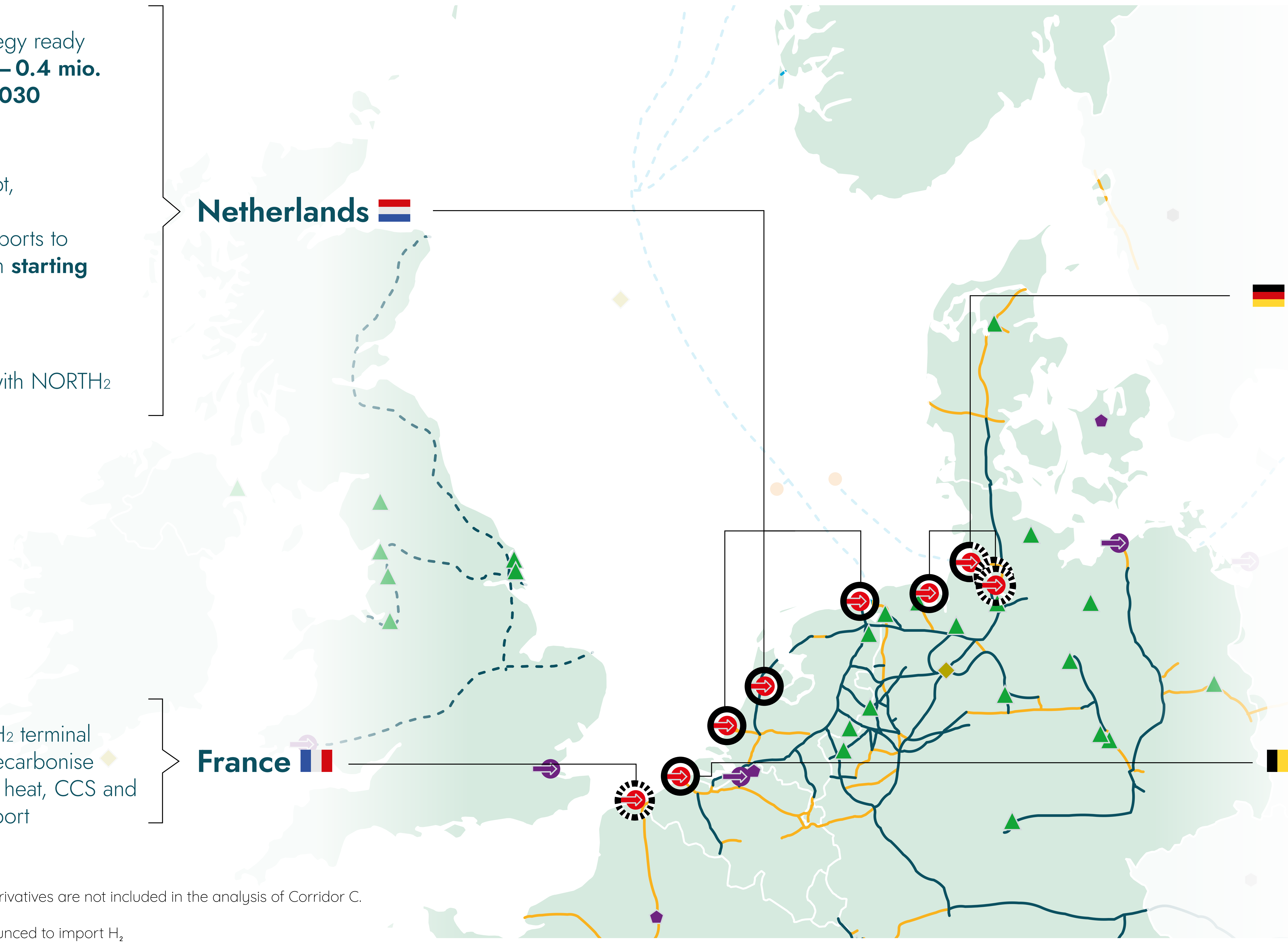
The scale up in supply is supported by the development of several hydrogen import terminals in the North Sea

Rotterdam
- In feasibility study, strategy ready
- Planning to import **0.3 – 0.4 mio. tons** of hydrogen **by 2030**

Amsterdam
- During proof of concept, strategy ready
- Planning to scale up imports to **1 mio. ton** of hydrogen **starting 2030**

Eemshaven / Groningen
- Planning to import H_2 with NORTHH_2 Project

Dunkerque
- Ambitions to establish H_2 terminal
- Onsite H_2-strategy to decarbonise harbour with integrated heat, CCS and hydrogen use for transport



Netherlands 🇳🇱

Germany 🇩🇪

France 🇫🇷

Belgium 🇧🇪

Hamburg
- Ambitions to establish H_2 terminal
- Onsite H_2-project H_2Global

Stade
- LNG-terminal underway
- Comes ready with fuel switch option to H_2

Wilhelmshaven
- Working on feasibility study, strategy ready
- LNG-terminal underway
- Planning to import and produce with 410 MW electrolyser onsite **0.3 mio. tons by 2030**

Brunsbuettel
- LNG-terminal underway
- Comes ready with fuel switch option to H_2

Zeebrugge
- Large scale LNG-terminal present, ambitions to accommodate H_2
- Planning to import 0.5 mio tons of hydrogen by 2030

Note: Ship imports of hydrogen or hydrogen-derivatives are not included in the analysis of Corridor C.
Infrastructure shown for 2030.
Strategy ready indicates that the terminal announced to import H_2

○ Strategy ready ◌ Strategy in progress ◌ Strategy ambitions

CORRIDOR C

North Sea

Agenda

1. Corridor Summary
2. Hydrogen Demand & Supply
3. **Supply Costs & Cost-Competitiveness**
4. National Strategies & Regulation
5. Actions Needed

This section explores the costs of hydrogen production and delivery for this corridor and their competitiveness

Hydrogen production cost

Hydrogen delivered costs

Comparison with fossil alternatives

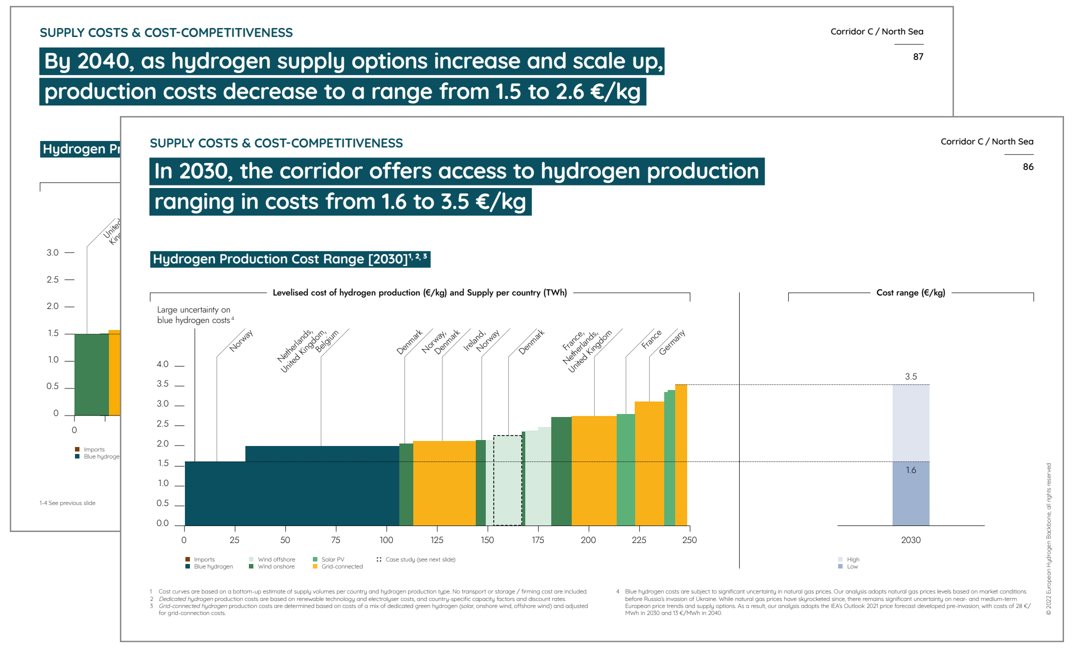
Key Questions Answered

What **is the range of production costs** achieved by the corridor **in 2030 and 2040**?

Based on a **case-study of hydrogen supply** from the North Sea to Germany:
- What are the **full costs of firm hydrogen delivery** after accounting for **transport** and **storage** costs?
- What **cost levers** are available to lower the cost of hydrogen delivery?

How **competitive** is hydrogen supply from this corridor compared to fossil fuel alternatives?

Content Material



SUPPLY COSTS & COST-COMPETITIVENESS

Corridor C / North Sea

87

By 2040, as hydrogen supply options increase and scale up, production costs decrease to a range from 1.5 to 2.6 €/kg

1-4 See previous slide

SUPPLY COSTS & COST-COMPETITIVENESS

Corridor C / North Sea

86

In 2030, the corridor offers access to hydrogen production ranging in costs from 1.6 to 3.5 €/kg

Hydrogen Production Cost Range [2030][1, 2, 3]

1 Cost curves are based on a bottom-up estimate of supply volumes per country and hydrogen production type. No transport or storage / firming cost are included.
2 *Dedicated hydrogen* production costs are based on renewable technology and electrolyser costs, and country-specific capacity factors and discount rates.
3 *Grid-connected hydrogen* production costs are determined based on costs of a mix of dedicated green hydrogen (solar, onshore wind, offshore wind) and adjusted for grid-connection costs.
4 Blue hydrogen costs are subject to significant uncertainty in natural gas prices. Our analysis adopts natural gas prices levels based on market conditions before Russia's invasion of Ukraine. While natural gas prices have skyrocketed since, there remains significant uncertainty on near- and medium-term European price trends and supply options. As a result, our analysis adopts the IEA's Outlook 2021 price forecast developed pre-invasion, with costs of 28 €/MWh in 2030 and 13 €/MWh in 2040.

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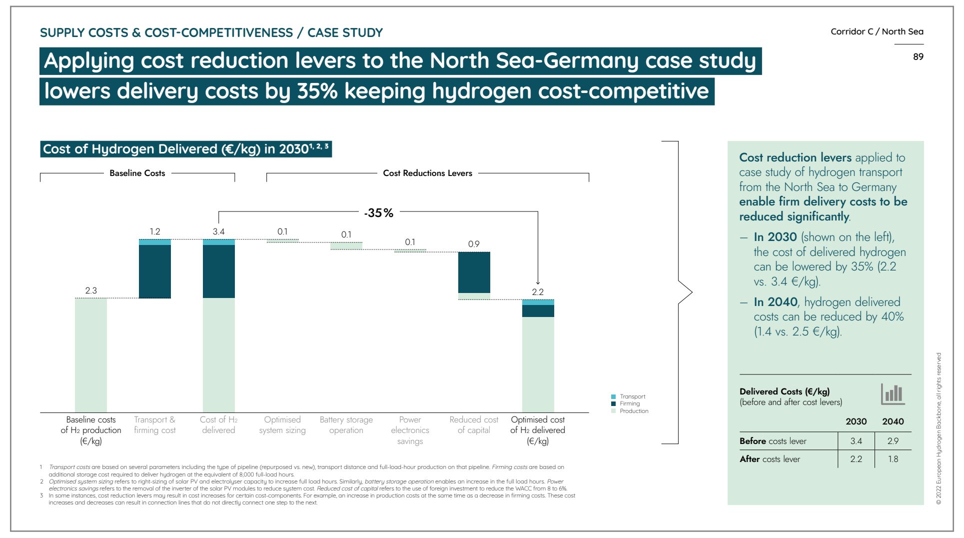

SUPPLY COSTS & COST-COMPETITIVENESS / CASE STUDY

Corridor C / North Sea

89

Applying cost reduction levers to the North Sea-Germany case study lowers delivery costs by 35% keeping hydrogen cost-competitive

Cost of Hydrogen Delivered (€/kg) in 2030[1, 2, 3]

Cost reduction levers applied to case study of hydrogen transport from the North Sea to Germany **enable firm delivery costs to be reduced significantly**.
- **In 2030** (shown on the left), the cost of delivered hydrogen can be lowered by 35% (2.2 vs. 3.4 €/kg).
- **In 2040**, hydrogen delivered costs can be reduced by 40% (1.4 vs. 2.5 €/kg).

Delivered Costs (€/kg) (before and after cost levers)

	2030	2040
Before costs lever	3.4	2.9
After costs lever	2.2	1.8

1 *Transport costs* are based on several parameters including the type of pipeline (repurposed vs. new), transport distance and full-load-hour production on that pipeline. *Firming costs* are based on additional storage cost required to deliver hydrogen at the equivalent of 8,000 full-load hours.
2 *Optimised system sizing* refers to right-sizing of solar PV and electrolyser capacity to increase full load hours. Similarly, *battery storage operation* enables an increase in the full load hours. *Power electronics savings* refers to the removal of the inverter of the solar PV modules to reduce system cost. *Reduced cost of capital* refers to the use of foreign investment to reduce the WACC from 8 to 6%.
3 In some instances, cost reduction levers may result in cost increases for certain cost-components. For example, an increase in production costs at the same time as a decrease in firming costs. These cost increases and decreases can result in connection lines that do not directly connect one step to the next.

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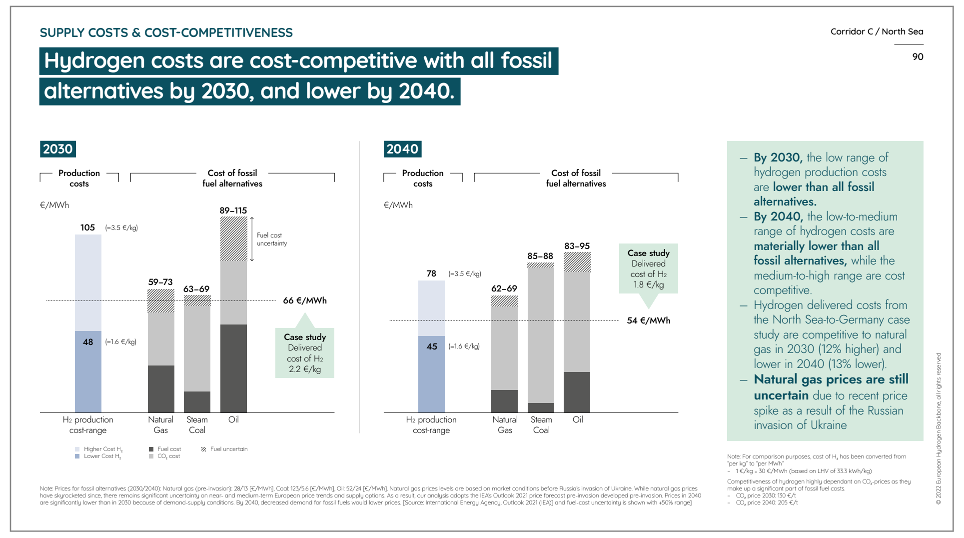

SUPPLY COSTS & COST-COMPETITIVENESS

Corridor C / North Sea

90

Hydrogen costs are cost-competitive with all fossil alternatives by 2030, and lower by 2040.

- **By 2030,** the low range of hydrogen production costs are **lower than all fossil alternatives.**
- **By 2040,** the low-to-medium range of hydrogen costs are **materially lower than all fossil alternatives,** while the medium-to-high range are cost competitive.
- Hydrogen delivered costs from the North Sea-to-Germany case study are competitive to natural gas in 2030 (12% higher) and lower in 2040 (13% lower).
- **Natural gas prices are still uncertain** due to recent price spike as a result of the Russian invasion of Ukraine

Note: Prices for fossil alternatives (2030/2040): Natural gas (pre-invasion): 28/13 [€/MWh], Coal: 123/5.6 [€/MWh], Oil: 52/24 [€/MWh]. Natural gas prices levels are based on market conditions before Russia's invasion of Ukraine. While natural gas prices have skyrocketed since, there remains significant uncertainty on near- and medium-term European price trends and supply options. As a result, our analysis adopts the IEA's Outlook 2021 price forecast pre-invasion developed pre-invasion. Prices in 2040 are significantly lower than in 2030 because of demand-supply conditions. By 2040, decreased demand for fossil fuels would lower prices. [Source: International Energy Agency, Outlook 2021 (IEA)] and fuel-cost uncertainty is shown with +50% range]

Note: For comparison purposes, cost of H_2 has been converted from "per kg" to "per MWh"
- 1 €/kg = 30 €/MWh (based on LHV of 33.3 kWh/kg)

Competitiveness of hydrogen highly dependant on CO_2-prices as they make up a significant part of fossil fuel costs.
- CO_2 price 2030: 130 €/t
- CO_2 price 2040: 205 €/t

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Key Findings & Results

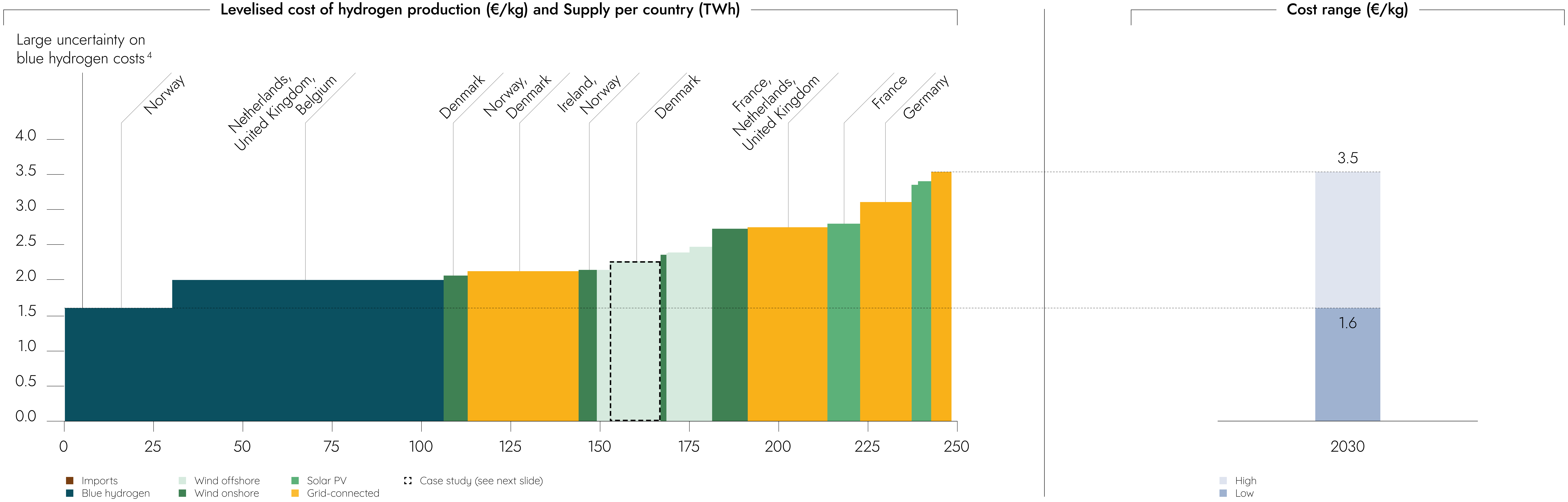
- **By 2030**, the corridor provides access to hydrogen production costs of **1.6 to 3.5 €/kg.**
- **By 2040**, hydrogen production costs decrease to the range of **1.5 to 2.6 €/kg.**

- Several **cost reduction levers** can be applied to **lower the costs of hydrogen delivery**.
- For the North Sea-to-Germany case study, **these levers achieve delivery costs that are low and cost-competitive**.

- **Hydrogen costs are competitive with fossil fuel alternatives by 2030**, and lower by 2040.
- Fossil fuel costs are subject to **significant uncertainty**.

In 2030, the corridor offers access to hydrogen production ranging in costs from 1.6 to 3.5 €/kg

Hydrogen Production Cost Range [2030][1, 2, 3]



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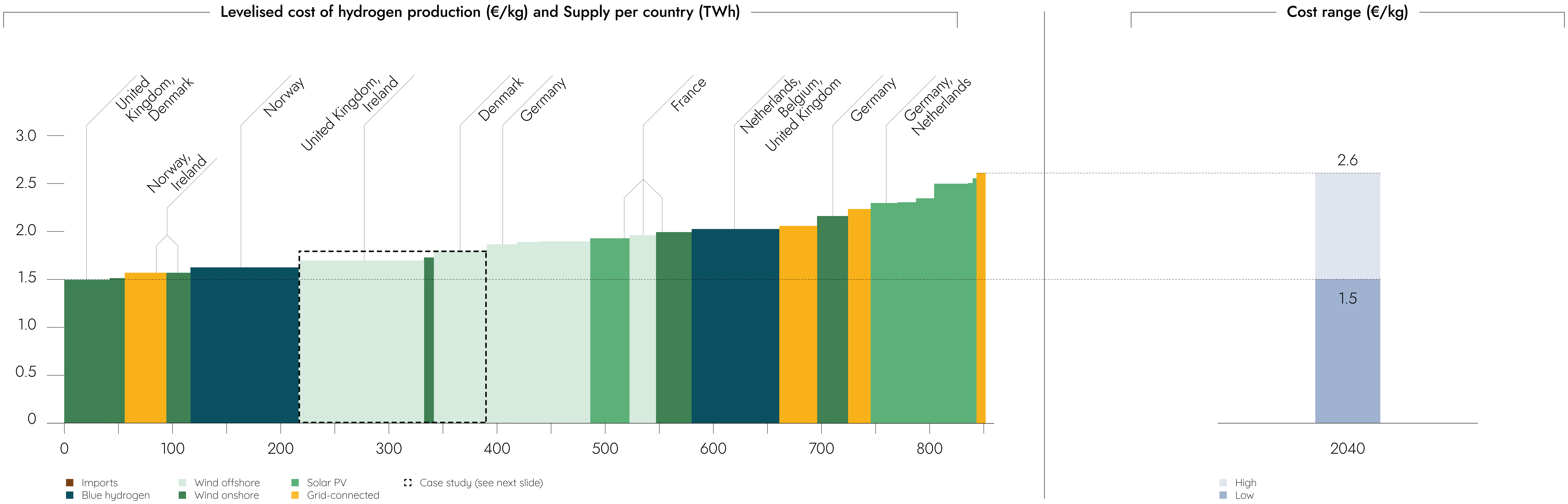
By 2040, as hydrogen supply options increase and scale up, production costs decrease to a range from 1.5 to 2.6 €/kg

Hydrogen Production Cost Range [2040][1, 2, 3]



1-4 See previous slide

Hydrogen delivered costs, incl. transport and storage costs, can be kept low and comparable to hydrogen production costs

1 This analysis assesses a **case study** of hydrogen supply from the North Sea to North Rhine Westphalia (Germany) **to explore how the costs of firm hydrogen delivery costs can be lowered**.

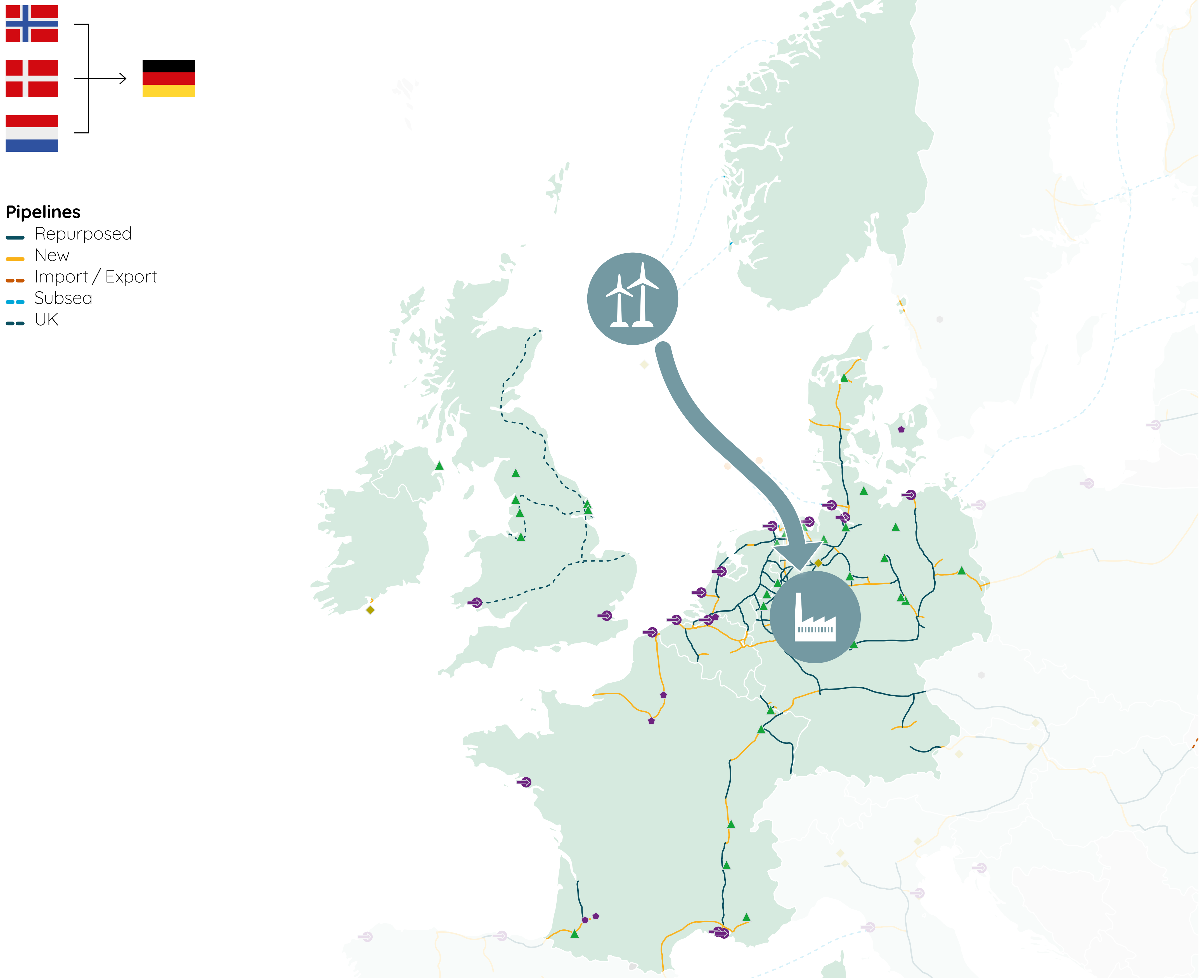
2 To assess the full cost of hydrogen delivery to Germany, **transport and storage costs are added to the cost of hydrogen production from the North Sea**.

Production Costs + Transport Costs + Storage Costs = Delivered Costs

3 Several **cost reduction levers are applied to lower firm delivery costs**, including optimised system operation, battery storage use, cost of capital reductions, among others.

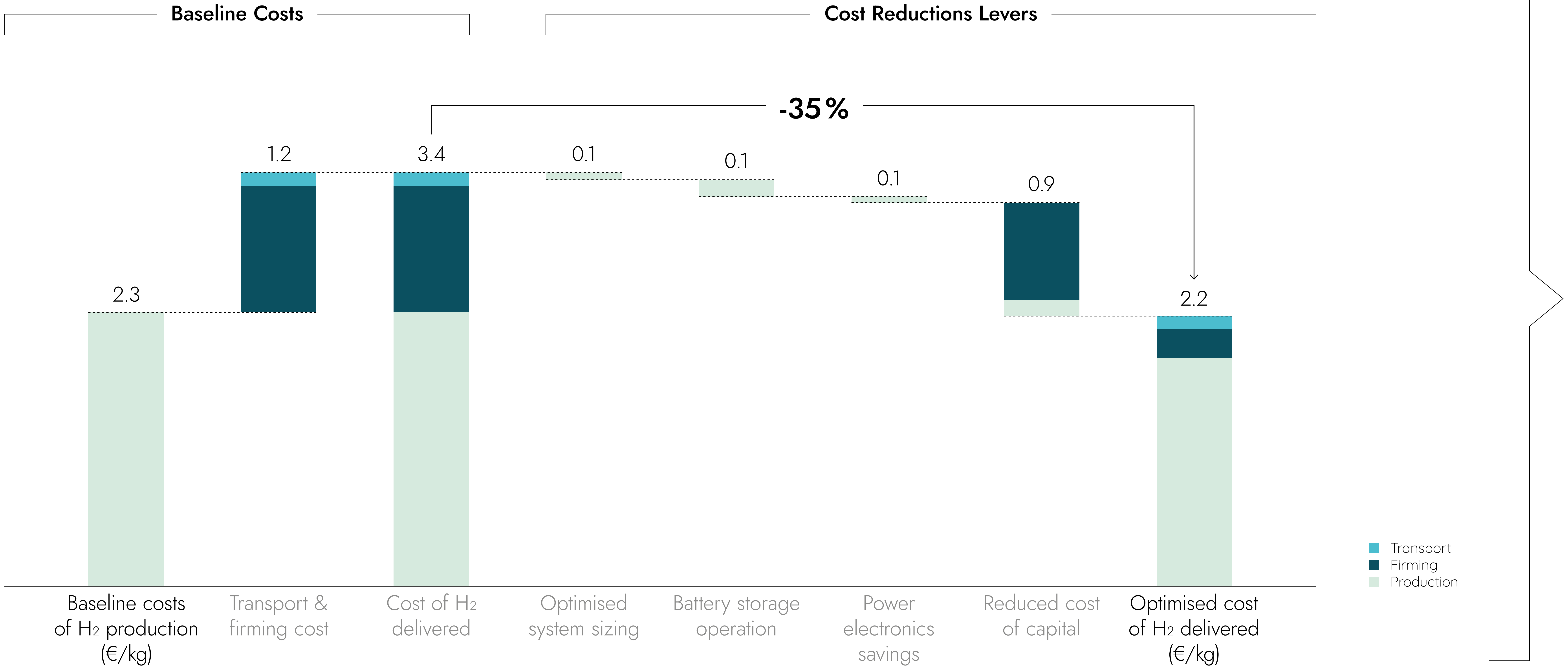
4 **These cost reduction levers achieve sufficient cost savings to keep firm hydrogen delivery costs low and cost-competitive.**

Corridor Case Study Route



Applying cost reduction levers to the North Sea-Germany case study lowers delivery costs by 35% keeping hydrogen cost-competitive

Cost of Hydrogen Delivered (€/kg) in 2030[1, 2, 3]



Cost reduction levers applied to case study of hydrogen transport from the North Sea to Germany **enable firm delivery costs to be reduced significantly**.

- **In 2030** (shown on the left), the cost of delivered hydrogen can be lowered by 35% (2.2 vs. 3.4 €/kg).
- **In 2040**, hydrogen delivered costs can be reduced by 40% (1.8 vs. 2.9 €/kg).

Delivered Costs (€/kg)
(before and after cost levers)

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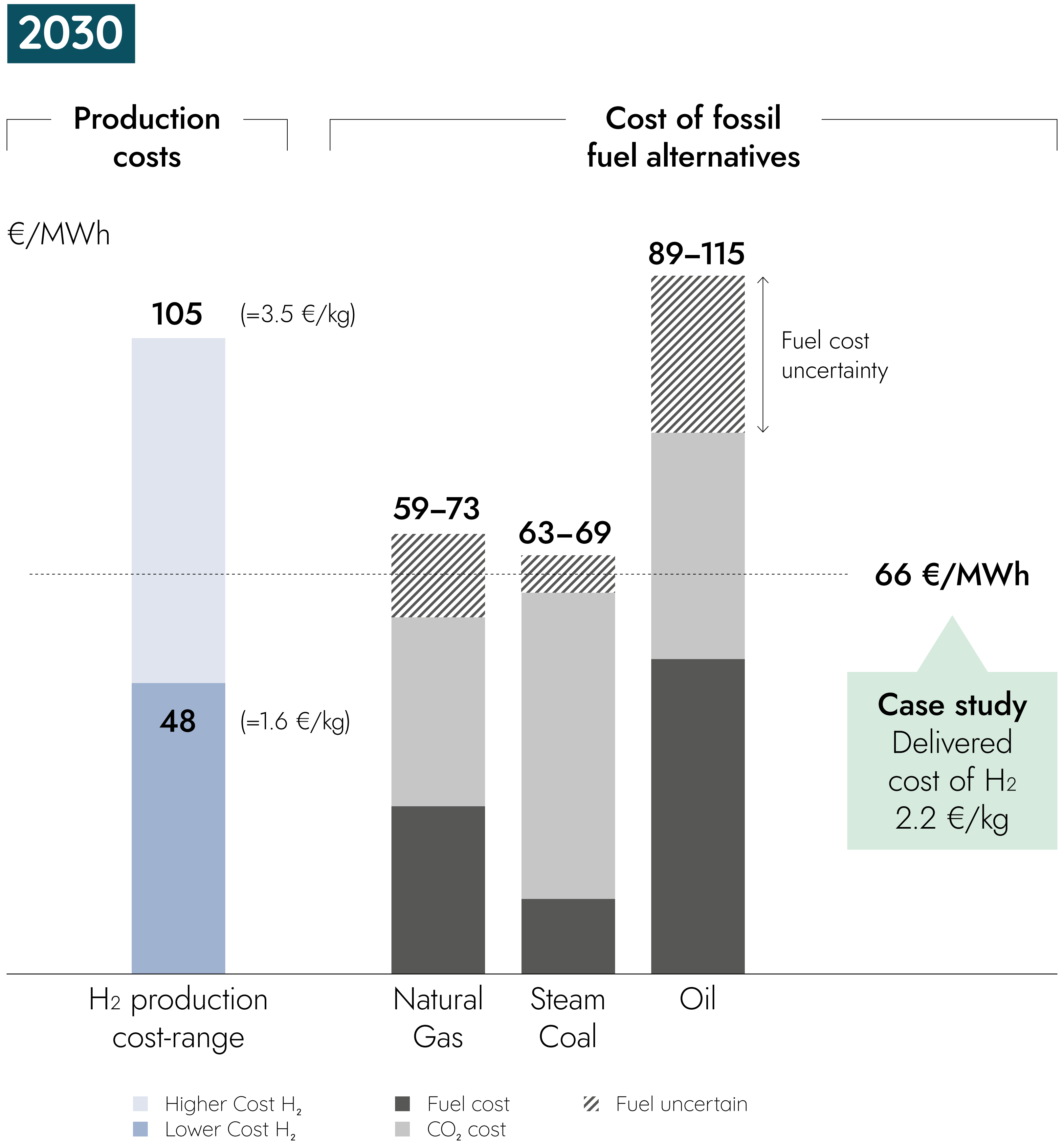

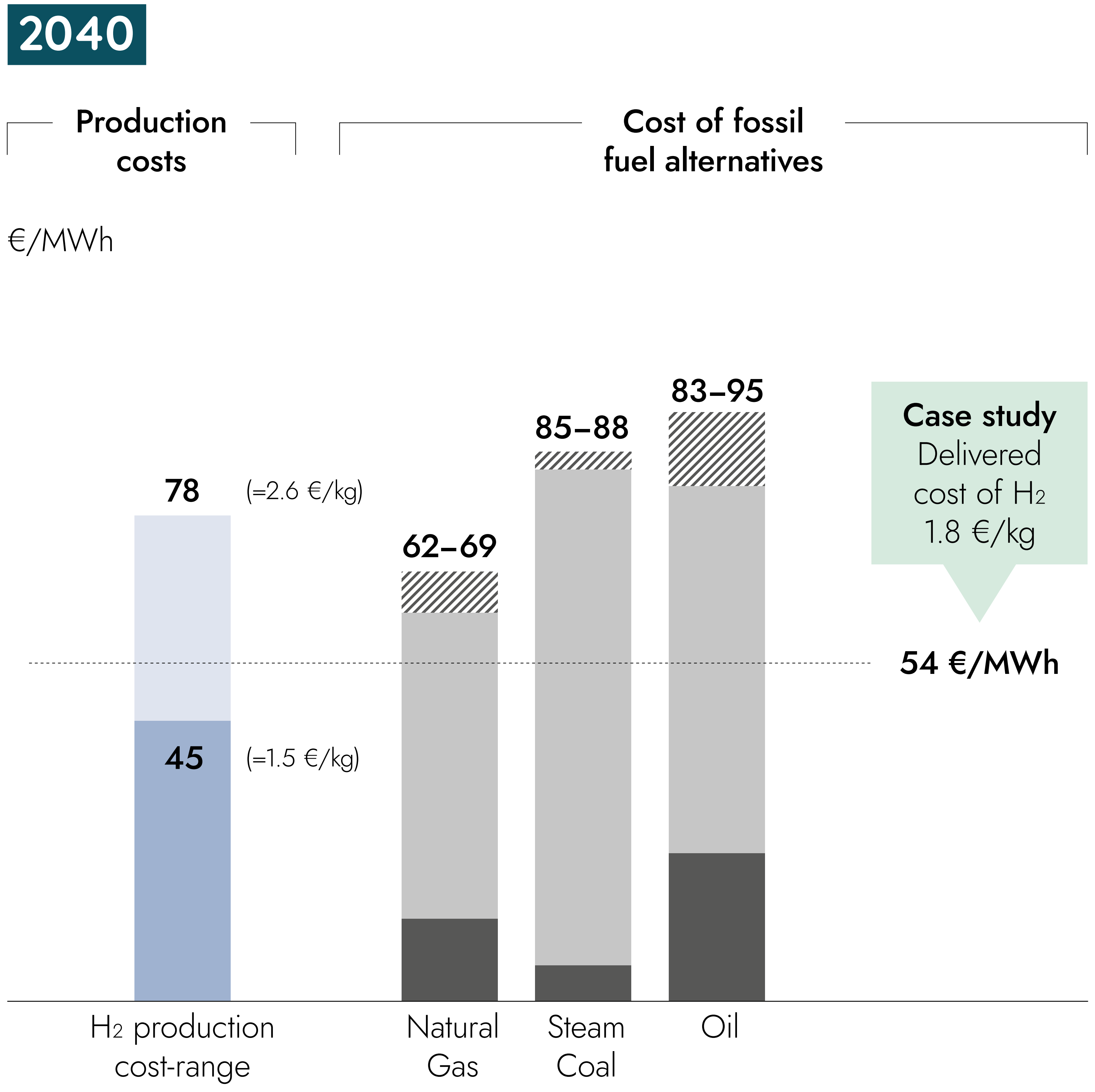

- **By 2030,** the low range of hydrogen production costs are **lower than all fossil alternatives.**
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- CO_2 price 2030: 130 €/t
- CO_2 price 2040: 205 €/t

Note: Prices for fossil alternatives (2030/2040): Natural gas (pre-invasion): 28/13 [€/MWh], Coal: 123/5.6 [€/MWh], Oil: 52/24 [€/MWh]. Natural gas prices levels are based on market conditions before Russia's invasion of Ukraine. While natural gas prices have skyrocketed since, there remains significant uncertainty on near- and medium-term European price trends and supply options. As a result, our analysis adopts the IEA's Outlook 2021 price forecast pre-invasion developed pre-invasion. Prices in 2040 are significantly lower than in 2030 because of demand-supply conditions. By 2040, decreased demand for fossil fuels would lower prices. [Source: International Energy Agency, Outlook 2021 (IEA)] and fuel-cost uncertainty is shown with +50% range]

CORRIDOR C

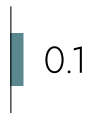
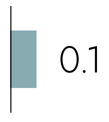
North Sea

Agenda

1. Corridor Summary
2. Hydrogen Demand & Supply
3. Supply Costs & Cost-Competitiveness
4. **National Strategies & Regulation**
5. Actions Needed

Most countries have developed national strategies and targets. Moving forward, the development of regulation is key to enable infrastructure investment.

Pre-RePowerEU targets[2]

	National Hydrogen strategy (NHS)	Network regulation & policy	Funding[1] (bn €)	Highlights
Norway	– 2025: H_2 hubs for maritime, industrial & product. – 2030: **Network of spread hydrogen hubs**	– N/A	 0.1	– Focus on maritime applications and H_2 hubs – Assessment of **CCFDs** for industrial projects
Ireland	– Government plans NHS in July, 2022	– N/A		– Early stage policy developments only
United Kingdom	– 2030: 10 GW of low-carbon hydrogen production – **Mix of green and blue hydrogen incl. funding** – Blending of 20% vol. to gas network foreseen	– Initial network regulatory and legal framework not expected before 2025	 2.3	– More clarity on H_2 funding & strategy for ind. cluster application & H_2 production – Policy decision on heat due in 2026
Denmark	– **Focus on green H_2 (4-6 GW) and Efuels, and export of Efuels and PtX technologies** to demand hubs (DE, NL, etc.)	– Proposition: Allow TSO & DSO to own and operate H_2 infrastructure	 0.2	– Transport infrastructure is seen as key to enable role as PtX producer and exporter
Netherlands	– Focus: **Production** & **network** to supply industry – **Build dedicated national hydrogen grid** – **3 – 4 GW** electrolyser capacity in 2030	– Unbundling of natural gas and H_2 grid operation and production – Integrated network planning	 1.5	– **Production** and **transport infrastructure** – **€750 m funding for national hydrogen transmission network.**
Luxembourg	– Focus on **renewable hydrogen** – Prioritized use in industry, sector coupling & transport – **Dedicated H_2 network explicitly mentioned**	– Goal to regulate transmission and distribution infrastructure in line with ambitions of the EU		– Strong need for **imports**, hence **cross border H_2 infrastructure** & **national networks** to meet industry & transport demand
Belgium	– Focus: Industry, (freight) transport, electricity storage – **150 MW for electrolysis** production by 2026 – **Import and transit** of H_2 and its derivatives via existing network and additional infrastructure	– 2026: **100-160 new km pipelines** – Open access H_2 backbone by 2030 connecting ports, industrial clusters, and neighboring countries	 0.1	– The NHS sees Belgium as an **import hub of renewable molecules for Europe** – Strong **focus on national and cross-country hydrogen network infrastructure**
France	– Implementation of local hydrogen hubs pre 2030 – Focus on **demand** (e.g. heavy transport) and **generation** (6.5 GW electrolyser in 2030) – No strategy on H_2 infrastructure yet	– Hydrogen injections to gas grid are possible, below threshold of technical restrictions	 7.2	– Strong investments in **transport sector** (heavy duty) and **hydrogen production for industry** – Need to accelerate strategy and policy around exports and imports
Germany	– National production & import focus due to supply gap – In place **since 2020, currently reviewed towards increasing its ambition** – **10 GW (2030)** electrolyser in coalition plans	– H_2 network potentially opt-in regulated and vertically unbundled – First rules and standards for high pressure pipelines are formulated	 9	– Strong focus on **international cooperation** to ensure sufficient supply – National funding

■ General funding
■ Supply
■ Network
■ Demand

Note: Sequencing of countries follows the general corridor direction but does not represent the hydrogen flows.

[1] Cumulative public funding amount by the respective state until 2030

[2] Strategies and funding is under evaluation of meeting latest targets

CORRIDOR C

North Sea

Agenda

1. Corridor Summary
2. Hydrogen Demand & Supply
3. Supply Costs & Cost-Competitiveness
4. National Strategies & Regulation
5. **Actions Needed**

ACTIONS NEEDED

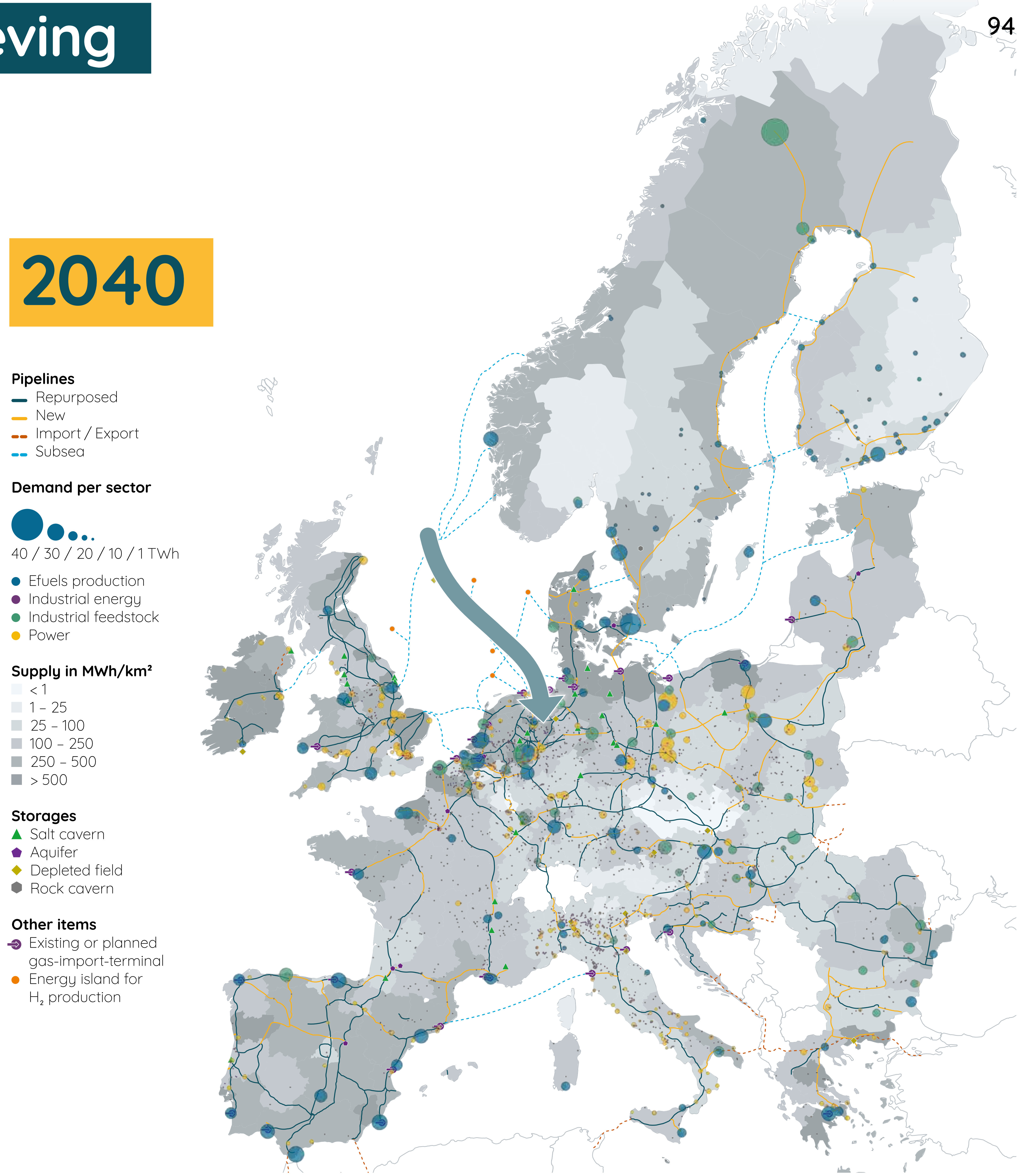
This corridor plays a fundamental role in achieving a European backbone by 2040

The need for this corridor

- The development of **this corridor ensures access to abundant, low-cost blue hydrogen supply from the North Sea** by 2030, and by 2040 diversifying its supply with green hydrogen from offshore wind resources in the North Sea.
- The **decarbonisation of the largest hydrogen demand centers along this corridor** — in **the UK, the Netherlands, Belgium, northern France and western Germany** — is dependent on the buildout of this corridor by 2030, and its expansion towards 2040.

Actions required

- The buildout of this corridor by 2030 **requires national governments to take clear and concrete actions across.**
- This includes actions associated with **infrastructure development and planning, the development of cross-national initiatives** and **securing access to early funding and long-term, low-cost financing.**



ACTIONS NEEDED

To ensure the development of this corridor by 2030, there is a need for clear and concrete actions

Fostering development of new and repurposed hydrogen infrastructure, for example, by unbundling rules facilitating the efficient use of TSO expertise and services and by allowing the adoption of different vertical unbundling models in the EU, as is the case with natural gas

+

Unlock financing to fast-track hydrogen infrastructure deployment by applying regional regulatory flexibility and other pragmatic financing solutions (including incentivizing the adoption of hydrogen by demand sectors)

+

Simplify and shorten planning and permitting procedures for renewable energy and hydrogen infrastructure projects.

+

Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure supporting the accelerated deployment and integration of renewable energy resources

→ However, speed will be of essence!

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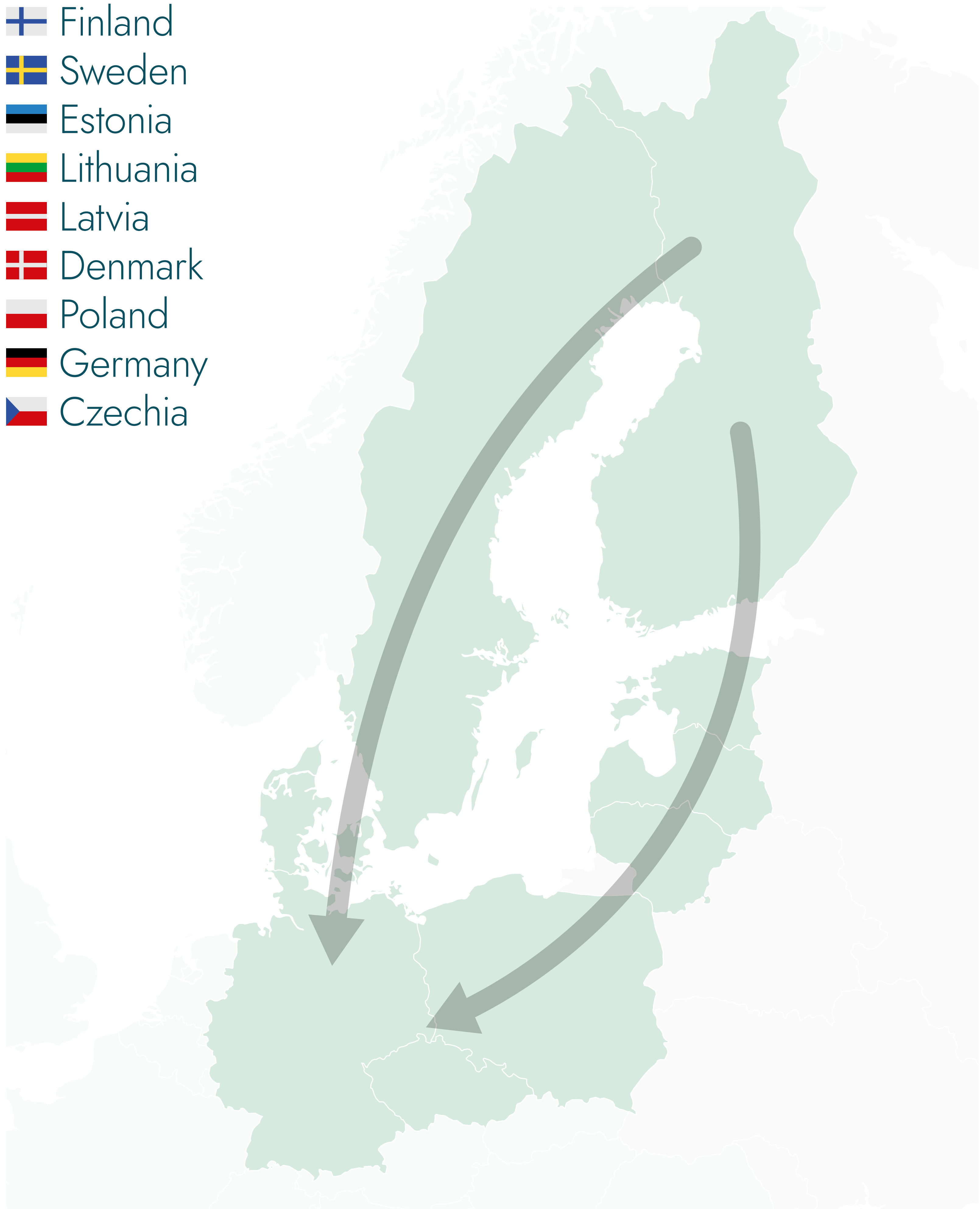
- Poland
- Germany
- Czechia



Corridor emerges in the Nordics and Baltics providing access to low-cost hydrogen supply from vast onshore and offshore wind resources

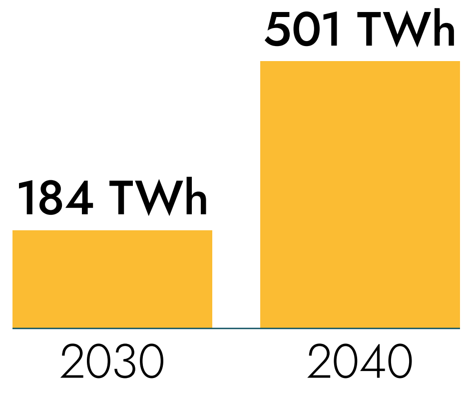
Drivers & Opportunities

Major drivers of development are **early national decarbonisation targets** of Nordic countries and **hydrogen adoption in heavy industry and transport**. Key opportunities include the **early development of new H_2 infrastructure** in the Bothnian Bay, and regional opportunities for offshore pipelines and **salt cavern storage**.

Hydrogen Supply & Decarbonization Potential

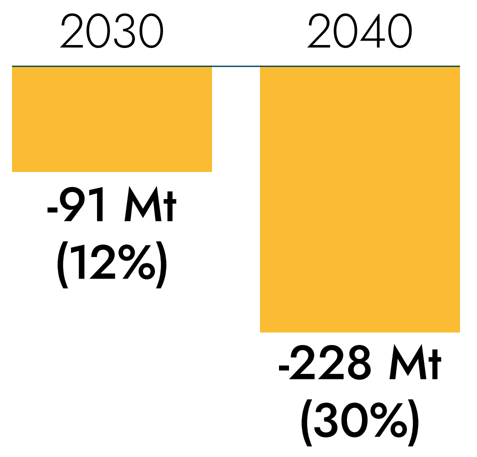
H_2 supply potential[1]

(TWh/year)



Emissions Reductions

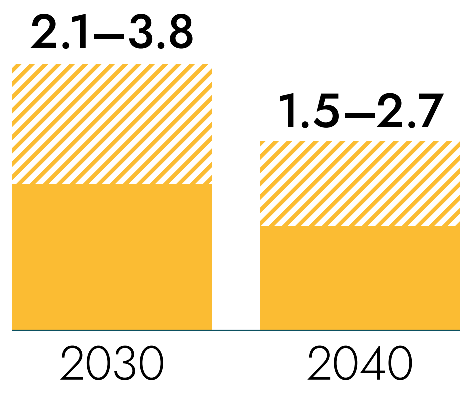
($MtCO_2$/year vs. 2019; % reduction)



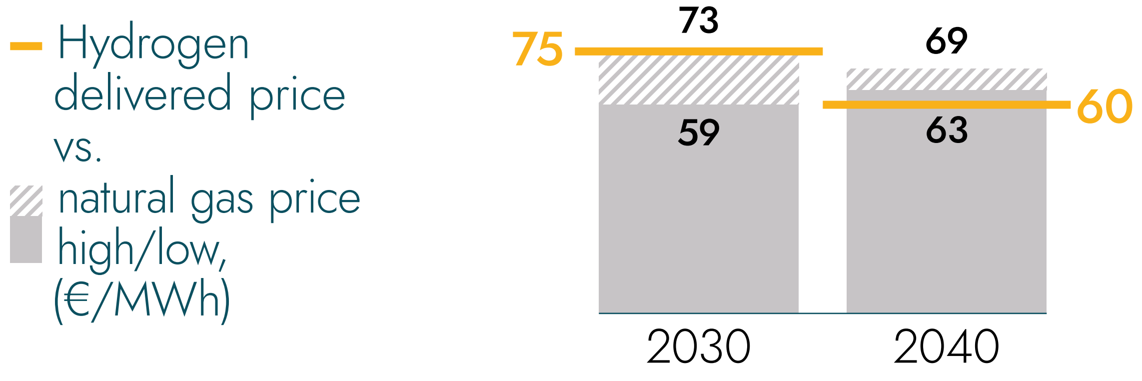
Supply Costs & Cost-Competitiveness

Cost of H_2 production[1]

(€/kg of H_2)



Cost competitiveness[2]



Actions Needed

- Fostering development of new and repurposed hydrogen infrastructure
- Unlock financing to fast-track hydrogen infrastructure deployment
- Simplify and shorten planning and permitting procedures
- Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure

---

[1] Figures reported reflect outputs for all countries included in the corridor. Even if a country is only partially in the corridor, results for the full country are included (e.g., supply potential and costs, demand, transmission network length).

[2] Savings are based on the corridor's case study of hydrogen delivered in 2030 and 2040. The cost of natural gas includes CO_2 prices. Refer to Subsection 3 (Supply Costs & Cost-Competitiveness)

CORRIDOR D

Nordics & Baltics

Agenda

Corridor offers access to low-cost supply from the Nordics to demand centers along the corridor to Poland and Germany

Drivers & Opportunities

- **The major driver** behind the development of this corridor is the adoption of hydrogen associated with the **decarbonisation of industry, transport and power** in the Nordics, the Baltics, Poland and Germany. Initially, the development of the corridor will be driven by new green steel and e-fuel projects and early national decarbonisation targets in Sweden and Finland. The speed of hydrogen adoption in these regions may be even faster than anticipated driven by increasing CO_2 prices in the EU and the RePowerEU ambitions to replace natural gas consumption.
- In the near term, the corridor offers **access to abundant low-cost, onshore wind and grid-based hydrogen supply from the Nordics**. In the longer term, the corridor also provides access to hydrogen supply from offshore wind in the Nordics and the Baltics.
- A major opportunity of this corridor is the **early and accelerated development of new hydrogen infrastructure in the Bothnian Bay**, one of the earliest, greenfield hydrogen infrastructure projects in Europe. The early buildout of hydrogen infrastructure also offers an **opportunity to pilot and operationalise new regulatory, planning and permitting processes** aiming to accelerate and streamline the rollout of hydrogen infrastructure.
- Another set of opportunities includes the **development of offshore pipelines** connecting Nordic offshore wind resources to demand centers in Germany and Central Europe, as well as the **potential development of salt cavern hydrogen storage**.
- The corridor would be stood up by 2030, covering **13,500 km** of large-scale hydrogen pipelines across all countries of the corridor, of which approximately **45% will be repurposed pipelines**.

Hydrogen Demand & Supply

- **Total hydrogen demand** in the corridor reaches **~220 TWh by 2030**, increasing substantially to **~725 TWh by 2040**. Up to 2030, most hydrogen demand is driven by the steel sector in Germany and the Nordics, along with some hydrogen adoption in transport. From 2040 to 2050, hydrogen demand expands further in industry and transport and plays a more meaningful role in power generation.
- Hydrogen adoption across all countries of the corridors enables an emissions reduction of ~290 $MtCO_2$/yr. by 2050, equivalent to a **39% emissions reduction**. Emissions reductions are notoriously higher than other corridors due to the high emissions reduction potential in the steel sector.
- The corridor enables access to **hydrogen supply potential of ~185 TWh by 2030, increasing to roughly 500 TWh by 2040**. Major sources of supply include hydrogen from onshore and offshore wind in the Nordics, along with grid-based green hydrogen, leveraging the vast, low-cost hydropower potential of the Nordics.

To successfully stand up this corridor by 2030, actions are needed to support infrastructure planning, financing and development.

Costs & Cost-Competitiveness

- **By 2030**, the corridor provides access to hydrogen ranging in production costs from **2.1 to 3.8 €/kg. By 2040**, as supply options increase and technology costs decrease, hydrogen production costs decrease to **1.5 to 2.7 €/kg**.
- In the long term, this corridor's lowest-cost hydrogen supply options are onshore and offshore wind from the Nordics.
- Based on a case-study of hydrogen supply and transport from the Bothnia Bay region of Finland to Germany, **the cost of delivered hydrogen** — inclusive of transport and storage costs — **can be lowered significantly and be cost-competitive with fossil fuel alternatives**. Lowering delivery costs can be achieved through various cost levers including optimised operation of the system and cost of capital reductions.

National Strategies & Regulation

- **Most countries have developed** — or are in the process of developing — **national strategies**. Moving forward, the **development of hydrogen regulation** in all countries will be key in enabling investment in infrastructure.
- In select countries, **substantial funding has been allocated** to support the development of the hydrogen market including funding for gas network infrastructure.

Actions Needed

To support the buildout of this corridor by 2030, clear and concrete actions related to infrastructure planning, financing and development have been identified:

- Fostering development of **new and repurposed hydrogen infrastructure**.
- Unlock financing to **fast-track hydrogen infrastructure deployment** by applying regional regulatory flexibility and other pragmatic financing solutions.
- Simplify and shorten **planning and permitting procedures** for the full value chain of renewable energies and hydrogen infrastructure projects.
- Establish **integrated energy system planning** of hydrogen, natural gas, and electricity infrastructure.

CORRIDOR D

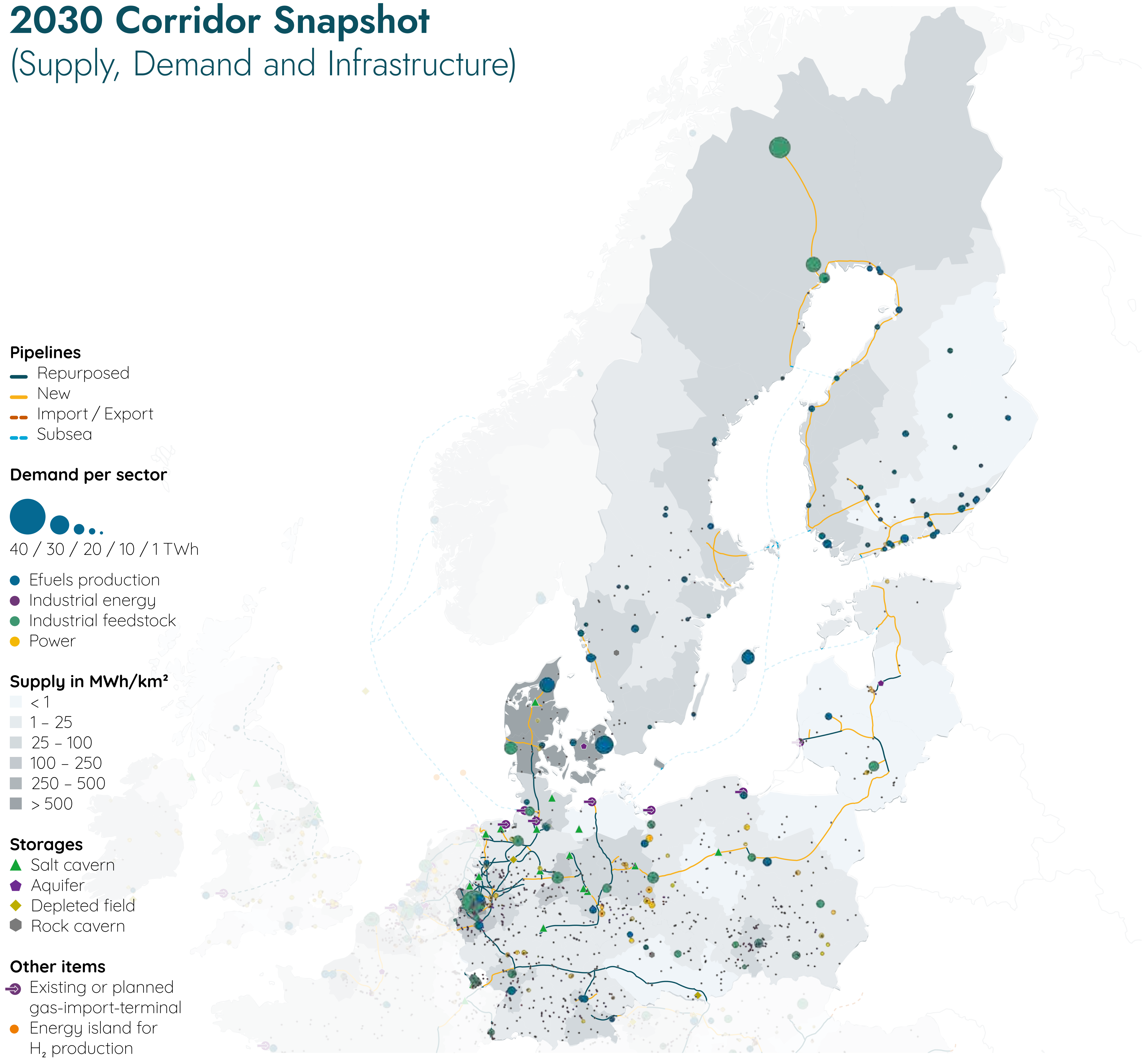
Nordics & Baltics

Agenda

This section explores the development of demand, supply and transport infrastructure in the corridor from 2030 to 2050

2030 Corridor Snapshot

(Supply, Demand and Infrastructure)



Hydrogen demand

By 2030, the corridor connects **all major industrial clusters** from the Nordics to Germany. **By 2040**, the corridor expands to **all demand centers along its route**, increasing demand from 220 to 725 TWh.

Hydrogen supply

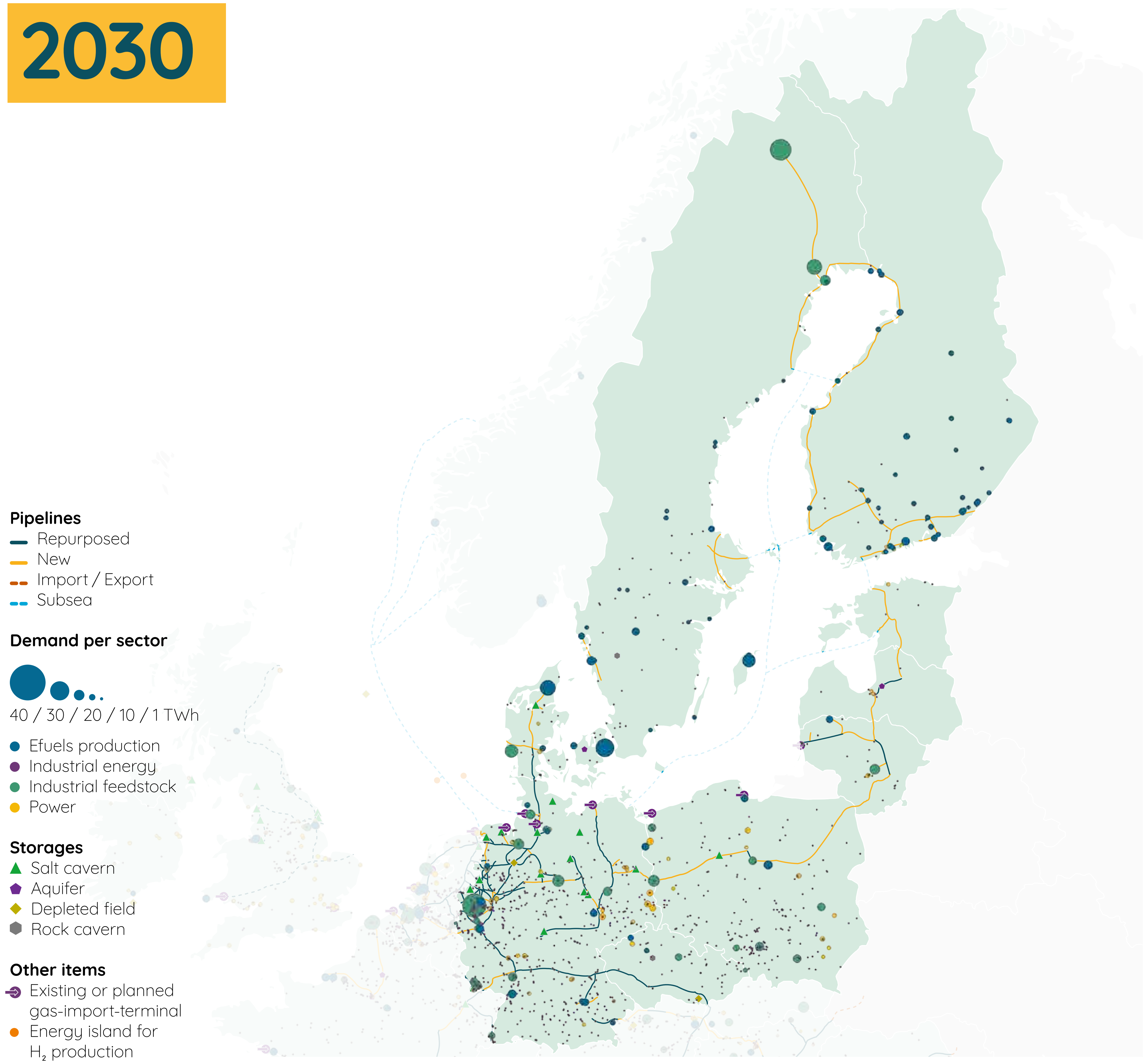
By 2030, the corridor enables access to low-cost, hydrogen supply from **parts of the Nordics**. **By 2040**, the corridor expands access to supply across the Nordics and into the Baltics.

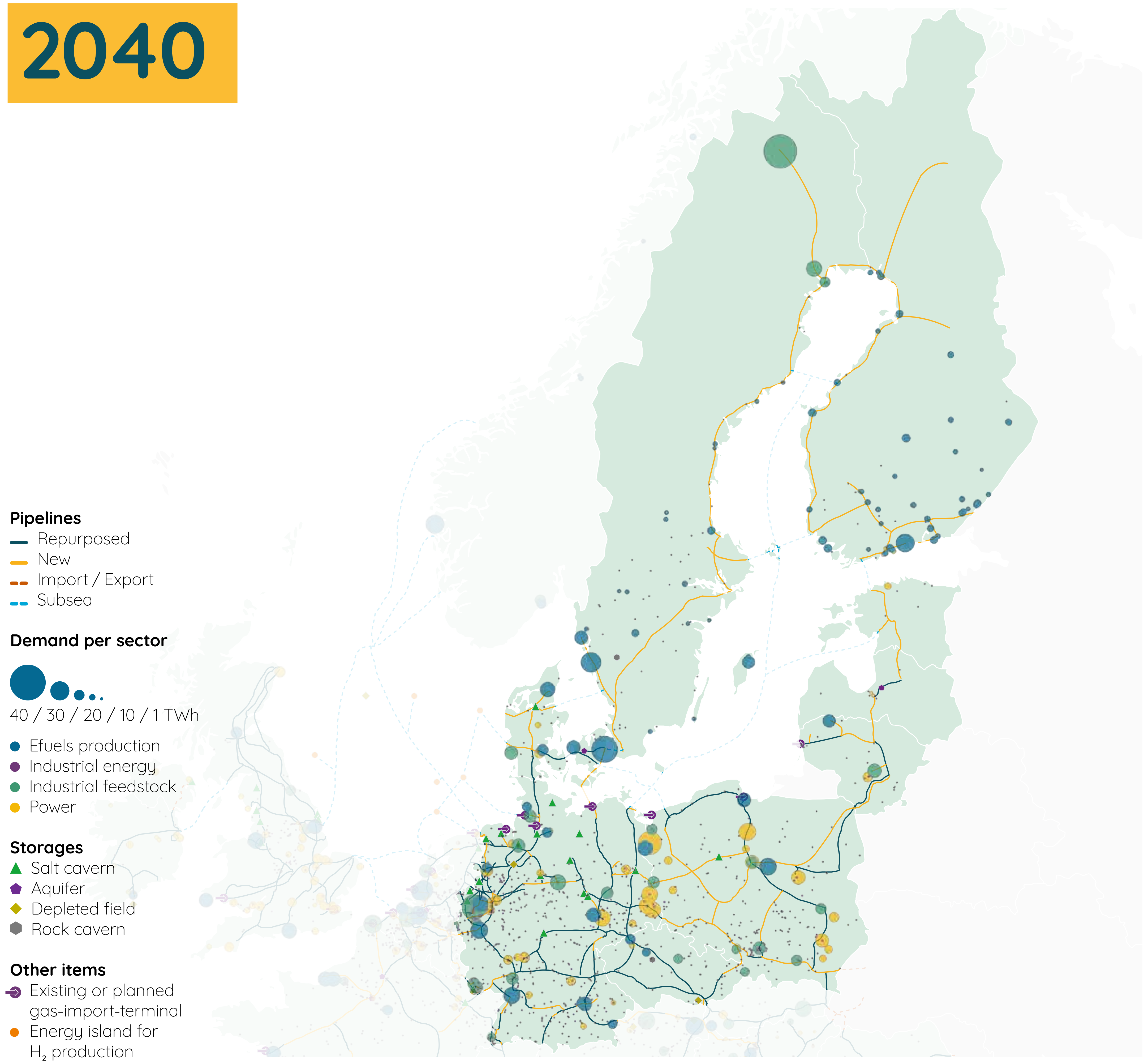
In 2030, hydrogen supply is ~185 TWh, of which nearly 70% is dedicated green hydrogen. Hydrogen supply increases significantly by 2040, reaching 500 TWh.

Hydrogen Infrastructure

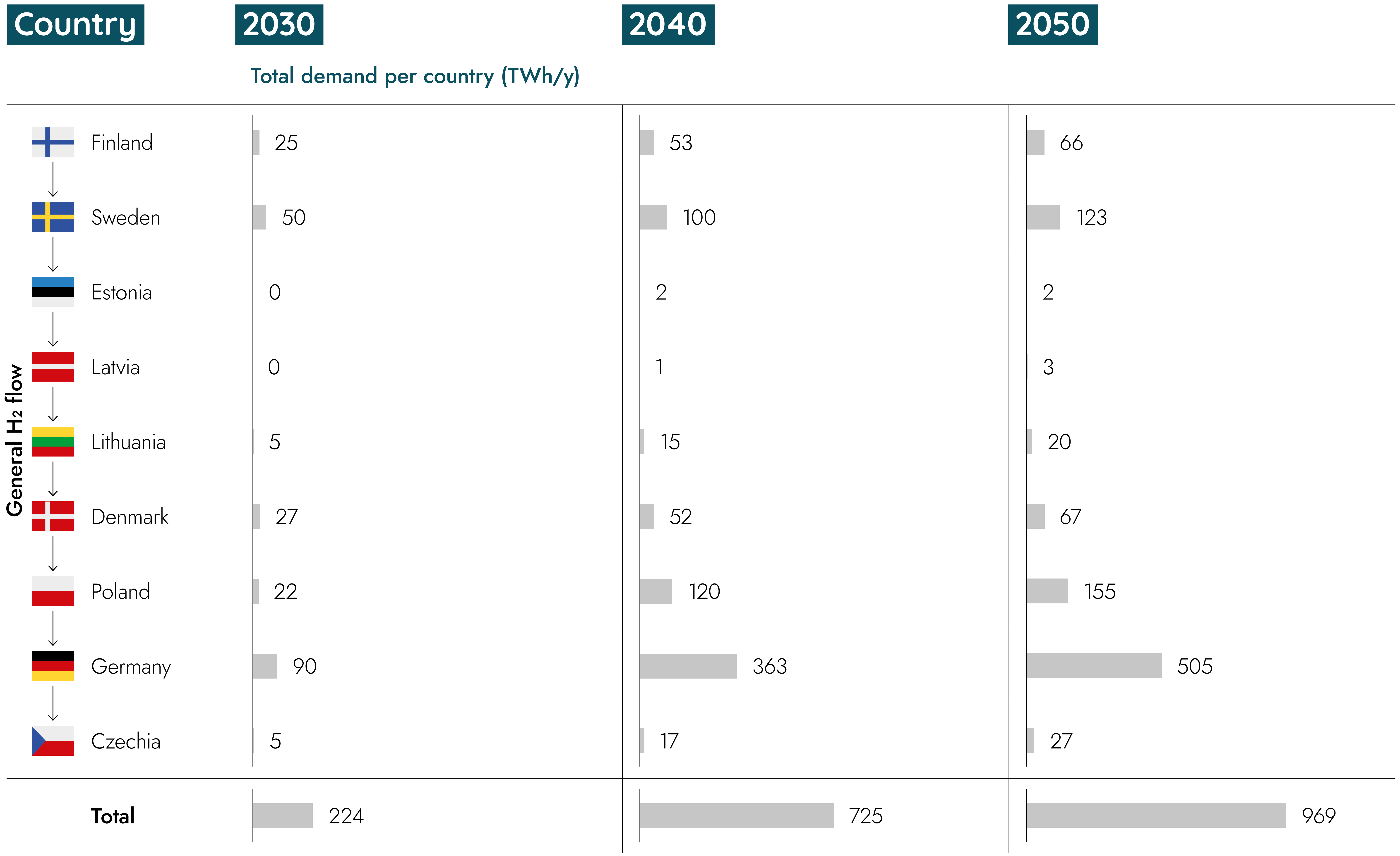
By 2030, the buildout of pipeline infrastructure across all countries of the corridor reaches **13,500 km** of large-scale pipelines. Notably, this corridor includes a **large share of new pipeline infrastructure**.

Corridor connects major hydrogen clusters from the Nordics to Germany by 2030, expanding to all major demand centers by 2040





Hydrogen demand increases rapidly from 2030 to 2040, largely driven by Germany, Poland and the Nordics



Total demand per country (TWh/y)

Country	**2030**	**2040**	**2050**
Finland	25	53	66
Sweden	50	100	123
Estonia	0	2	2
Latvia	0	1	3
Lithuania	5	15	20
Denmark	27	52	67
Poland	22	120	155
Germany	90	363	505
Czechia	5	17	27
Total	224	725	969

Note: Does not include grey hydrogen demand. Numbers represent total demand by country, even if only parts of the country are included in the corridor.

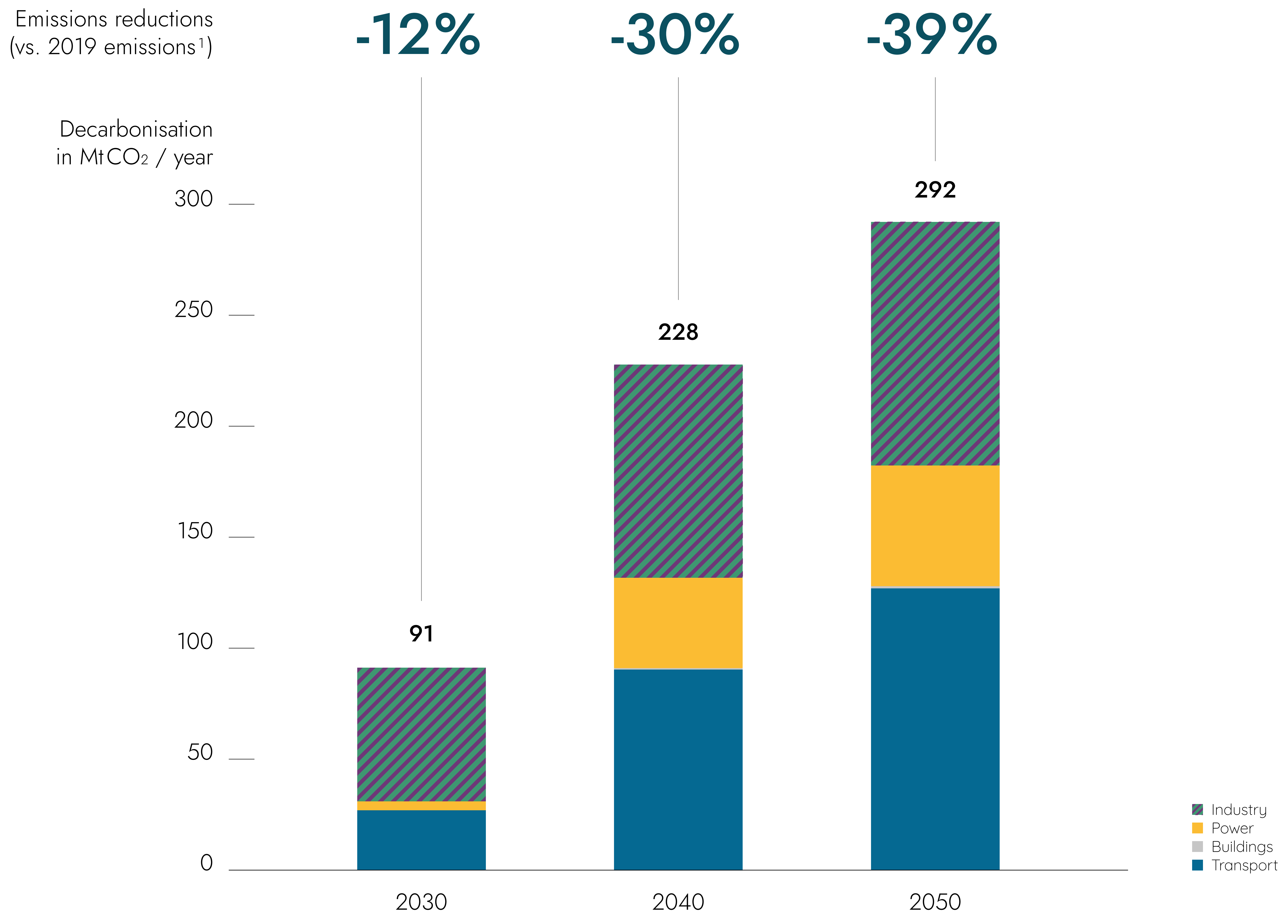
Hydrogen demand – across all countries of the corridor – increases significantly from 2030 to 2050. Demand reaches ~220 TWh by 2030, increasing to roughly 970 TWh by 2050.

Early national decarbonisation targets in Sweden (2045) and Finland (2035) also contribute to early adoption.

Hydrogen demand may accelerate and increase further than forecasted as a result of additional regulatory measures adopted in response to the RePowerEU plan.

- **Up to 2030, most hydrogen demand is driven by the industrial sector in Sweden and Germany** – primarily related to the adoption of hydrogen in the steel sector.
- **From 2040 to 2050, most new hydrogen demand is for e-fuels production and for power generation**, with demand in Finland, Denmark and Poland contributing an increasing share.

Hydrogen adoption in all countries of the corridor enables an emissions reduction of 39% by 2050



Hydrogen adoption across all demand sectors enables an **emissions reduction of ~290 $MtCO_2$/yr. by 2050**, equivalent to a **39% reduction**[2].

Emissions reductions are notoriously higher than other corridors due to the high emissions reduction potential in the steel sector.

- **Up to 2030**, the industrial sector contributes 70% of the total emissions reductions, largely driven by the steel sector in Sweden and Germany.
- **By 2040**, emissions reductions from transport (road, shipping and aviation) increase substantially and combined with industry, account for 80% of emissions reductions. The power sector account for the remaining 20% of reductions.
- **By 2050**, emissions reductions from the transport and power sector continue rising.

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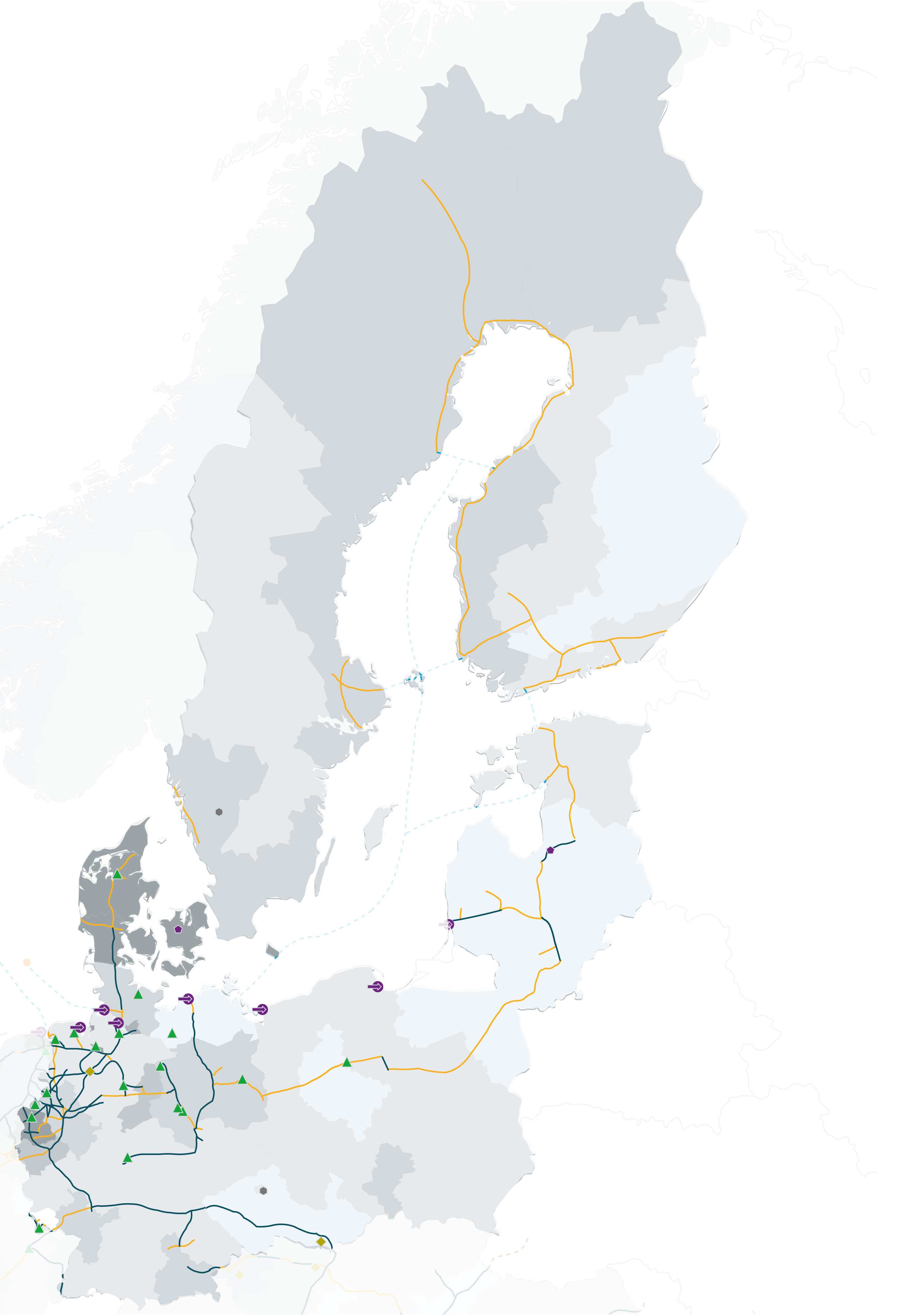
[1] CO_2-Emissions from countries and sectors included in corridor (0.75 bn t CO_2 / year), Source: EEA

[2] Emissions reductions are calculated compared to the baseline fossil fuel used in each sectors. For example, emissions reductions associated with the adoption of hydrogen by the primary steel sector are relative to the use of coal. Similarly, emissions reductions, for e-fuels production are relative to the use of fossil fuels in shipping, aviation and other uses.

Corridor enables access to supply from parts of the Nordics by 2030, expanding to supply from the Baltics by 2040

2030*



Pipelines
- Repurposed
- New
- Import / Export
- Subsea

Supply in MWh/km²
- < 1
- 1 – 25
- 25 – 100
- 100 – 250
- 250 – 500
- > 500

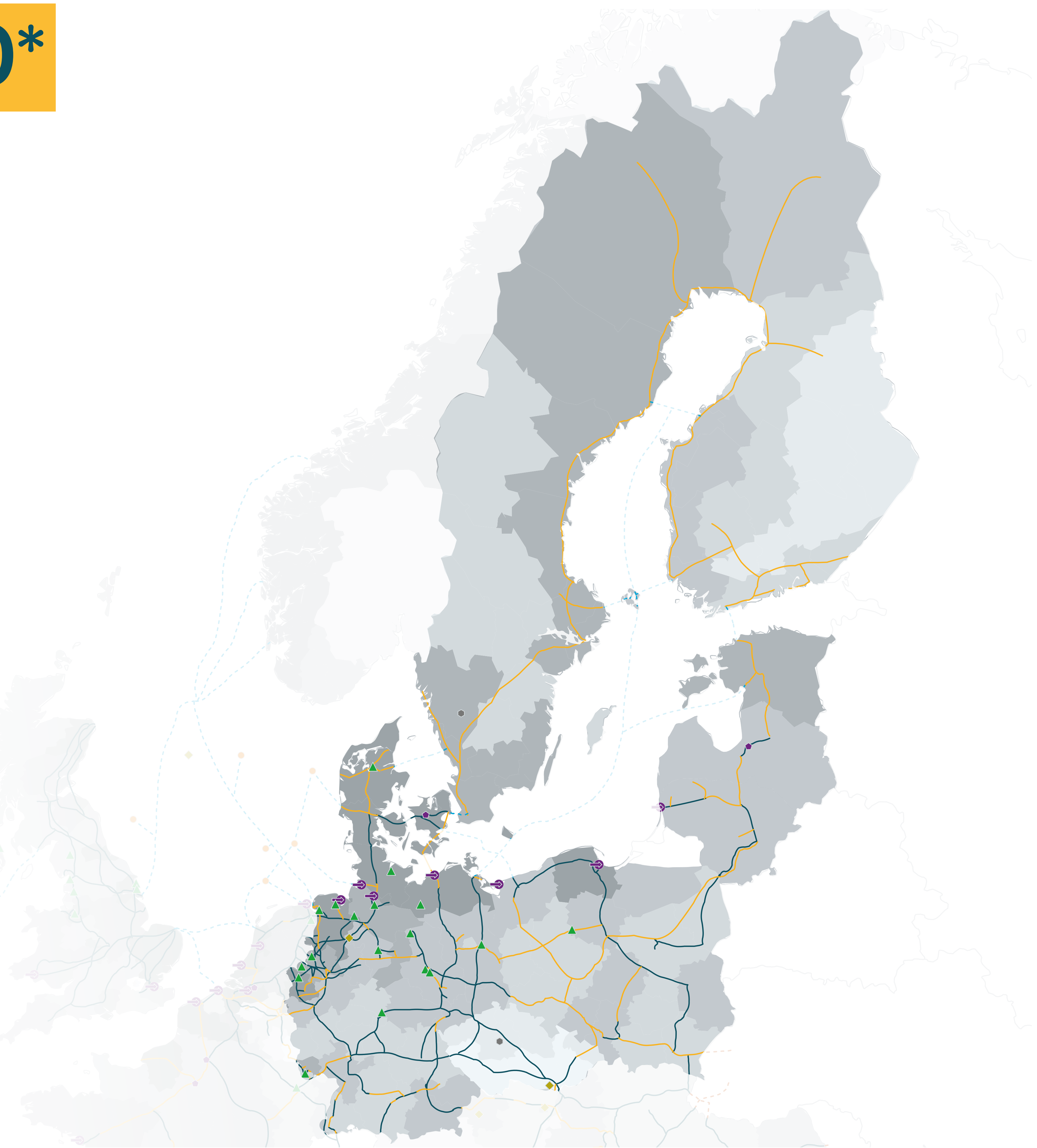
Storages
- ▲ Salt cavern
- ⬟ Aquifer
- ◆ Depleted field
- ⬢ Rock cavern

Other items
- Existing or planned gas-import-terminal
- ● Energy island for H_2 production

Total hydrogen supply shown per NUTS-2 region. MWh adjusted by the area of each NUTS-2 region in km².

* Note: Supply numbers do not include grey hydrogen.

2040*



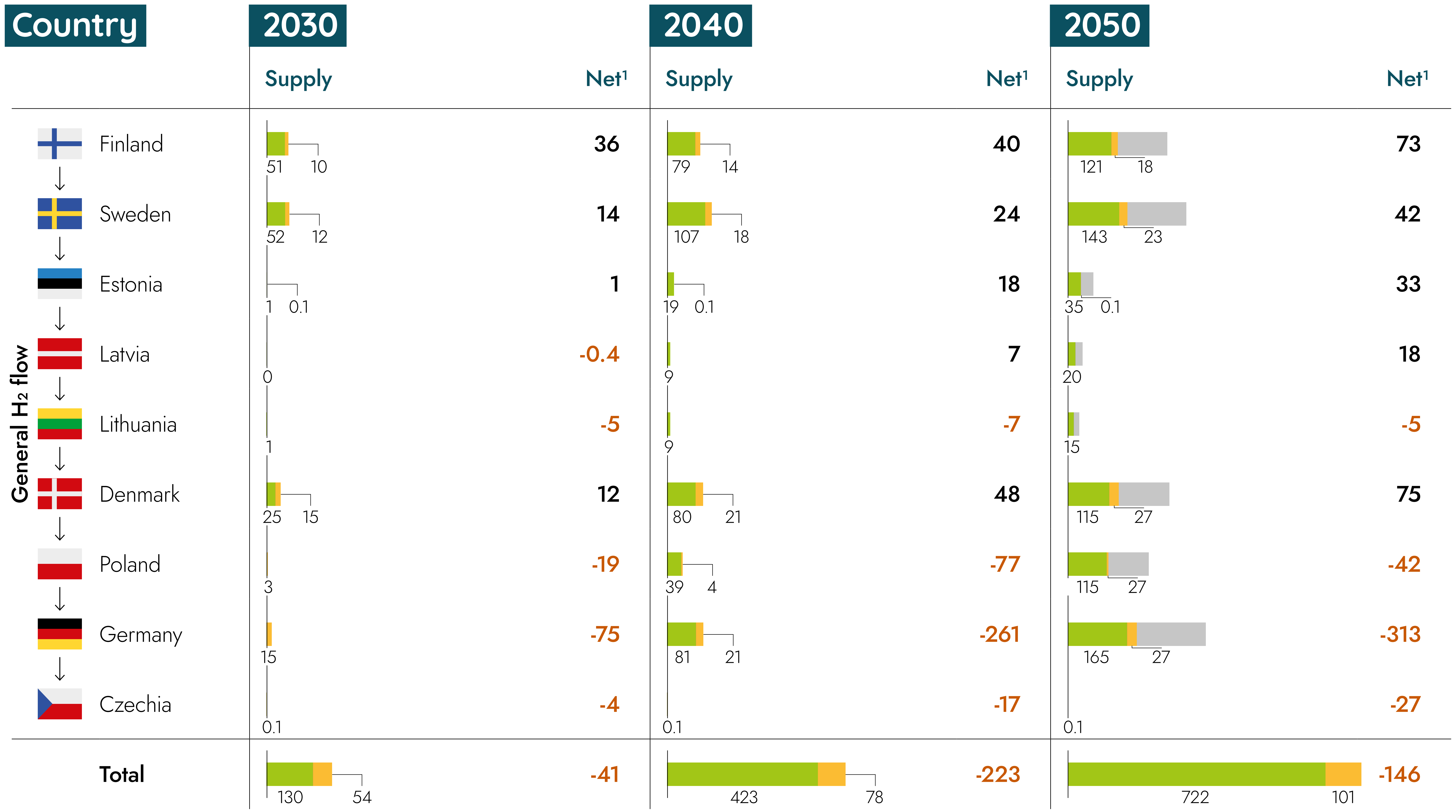
Pipelines
- Repurposed
- New
- Import / Export
- Subsea

Supply in MWh/km²
- < 1
- 1 – 25
- 25 – 100
- 100 – 250
- 250 – 500
- > 500

Storages
- ▲ Salt cavern
- ⬟ Aquifer
- ◆ Depleted field
- ⬢ Rock cavern

Other items
- Existing or planned gas-import-terminal
- ● Energy island for H_2 production

Hydrogen supply increases significantly from 2030 to 2040, largely driven by green hydrogen supply from the Nordics



The hydrogen supply mix includes **grid-based green hydrogen² and dedicated green hydrogen.**

- **By 2030, hydrogen supply reaches ~185 TWh,** largely from dedicated green hydrogen and grid-based hydrogen.
- **By 2040, hydrogen supply increases substantially to ~500 TWh,** of which roughly 85% is from dedicated green hydrogen. The remaining 15% is from grid-based hydrogen supply. Grid-based supply increases slightly from 2030 due to the increasing decarbonization of the electricity grid mix.
- **By 2050, hydrogen supply increases further to ~820 TWh.** Dedicated green supply continues to account for the largest share at roughly 90%.

Hydrogen supply may accelerate and increase further as a result of additional regulatory measures adopted in response to the RePowerEU plan.

Note: Hydrogen supply volumes do not include hydrogen imports by ship.

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1 *Net* represents excess supply after subtracting demand.
2 Grid-based is estimated using national 2030 electrolyser targets which, by 2030, are assumed to be largely grid-connected rather than dedicated. Grid-based increases over 2030-2050 with increasing RES.

CORRIDOR D

Nordics & Baltics

Agenda

This section explores the costs of hydrogen production and delivery for this corridor and their competitiveness with fossil fuels

Hydrogen production cost

Hydrogen delivered costs

Comparison with fossil alternatives

Key Questions Answered

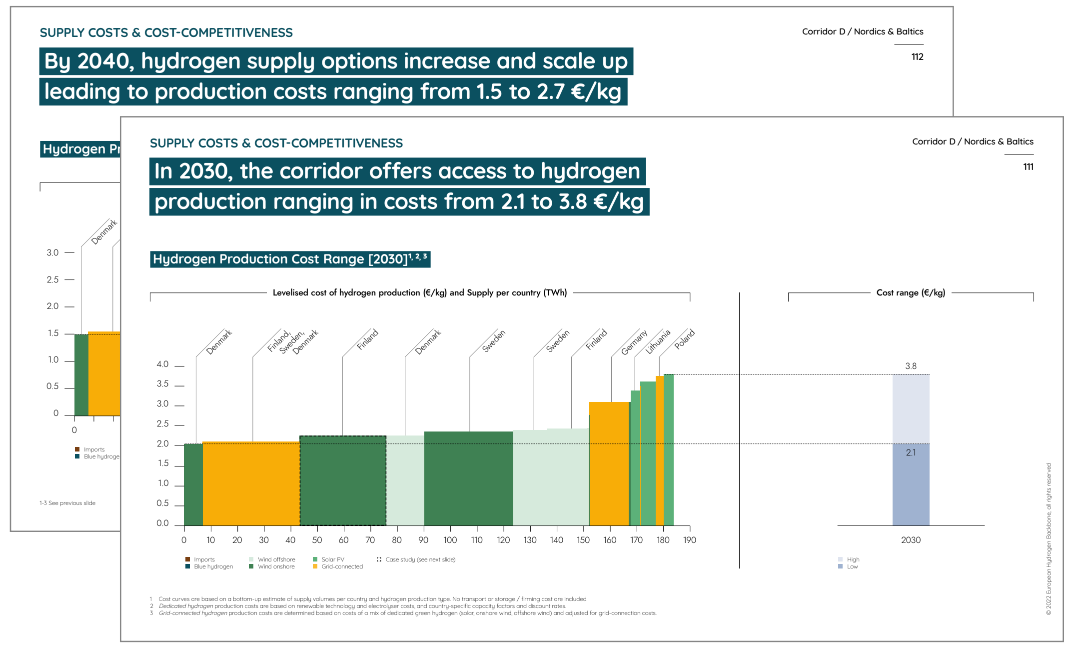
Hydrogen production cost: What **is the range of production costs** achieved by the corridor **in 2030 and 2040**?

Hydrogen delivered costs: Based on a **case-study of hydrogen supply** from the Bothnian Bay (Finland) to Germany:

- What are the **full costs of firm hydrogen delivery** after accounting for **transport** and **storage** costs?
- What cost levers are available to lower the cost of hydrogen delivery?

Comparison with fossil alternatives: How **competitive** is hydrogen supply from this corridor compared to fossil fuel alternatives?

Content Material



SUPPLY COSTS & COST-COMPETITIVENESS

Corridor D / Nordics & Baltics

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By 2040, hydrogen supply options increase and scale up leading to production costs ranging from 1.5 to 2.7 €/kg

Hydrogen Pr

1-3 See previous slide

SUPPLY COSTS & COST-COMPETITIVENESS

Corridor D / Nordics & Baltics

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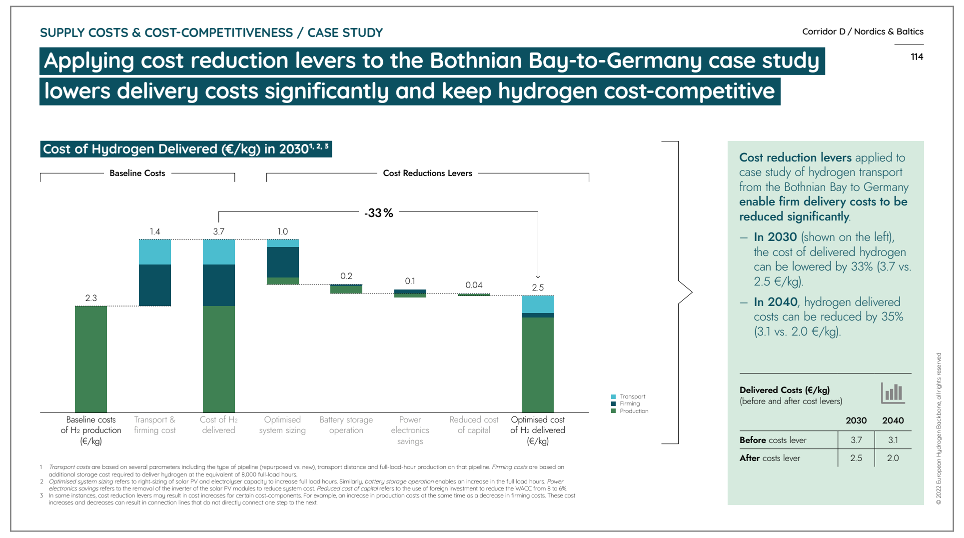
In 2030, the corridor offers access to hydrogen production ranging in costs from 2.1 to 3.8 €/kg

Hydrogen Production Cost Range [2030][1, 2, 3]

1 Cost curves are based on a bottom-up estimate of supply volumes per country and hydrogen production type. No transport or storage / firming cost are included.
2 *Dedicated hydrogen* production costs are based on renewable technology and electrolyser costs, and country-specific capacity factors and discount rates.
3 *Grid-connected hydrogen* production costs are determined based on costs of a mix of dedicated green hydrogen (solar, onshore wind, offshore wind) and adjusted for grid-connection costs.



SUPPLY COSTS & COST-COMPETITIVENESS / CASE STUDY

Corridor D / Nordics & Baltics

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Applying cost reduction levers to the Bothnian Bay-to-Germany case study lowers delivery costs significantly and keep hydrogen cost-competitive

Cost of Hydrogen Delivered (€/kg) in 2030[1, 2, 3]

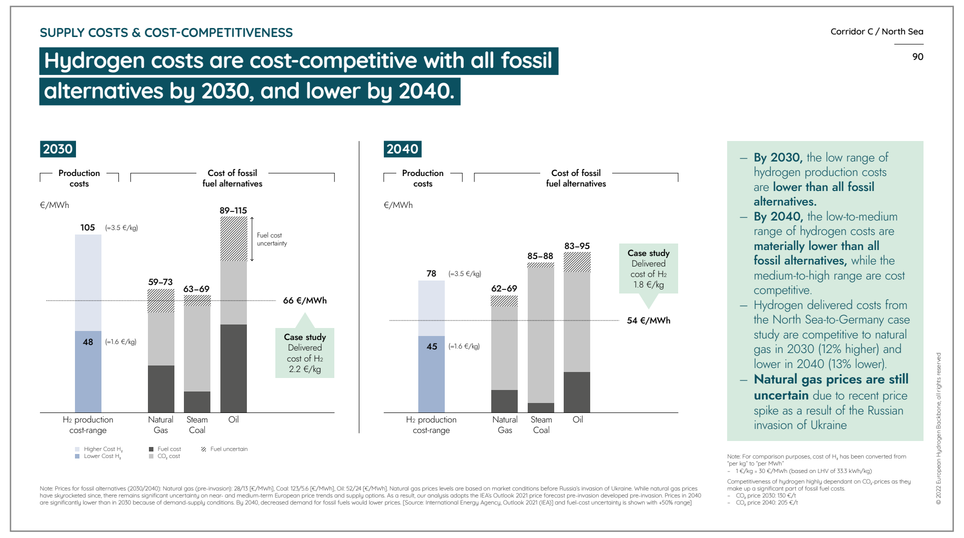
Cost reduction levers applied to case study of hydrogen transport from the Bothnian Bay to Germany **enable firm delivery costs to be reduced significantly**.

- **In 2030** (shown on the left), the cost of delivered hydrogen can be lowered by 33% (3.7 vs. 2.5 €/kg).
- **In 2040**, hydrogen delivered costs can be reduced by 35% (3.1 vs. 2.0 €/kg).

Delivered Costs (€/kg) (before and after cost levers)

	2030	2040
Before costs lever	3.7	3.1
After costs lever	2.5	2.0

1 *Transport costs* are based on several parameters including the type of pipeline (repurposed vs. new), transport distance and full-load-hour production on that pipeline. *Firming costs* are based on additional storage cost required to deliver hydrogen at the equivalent of 8,000 full-load hours.
2 *Optimised system sizing* refers to right-sizing of solar PV and electrolyser capacity to increase full load hours. Similarly, *battery storage operation* enables an increase in the full load hours. *Power electronics savings* refers to the removal of the inverter of the solar PV modules to reduce system cost. *Reduced cost of capital* refers to the use of foreign investment to reduce the WACC from 8 to 6%.
3 In some instances, cost reduction levers may result in cost increases for certain cost-components. For example, an increase in production costs at the same time as a decrease in firming costs. These cost increases and decreases can result in connection lines that do not directly connect one step to the next.



SUPPLY COSTS & COST-COMPETITIVENESS

Corridor C / North Sea

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Hydrogen costs are cost-competitive with all fossil alternatives by 2030, and lower by 2040.

- **By 2030,** the low range of hydrogen production costs are **lower than all fossil alternatives.**
- **By 2040,** the low-to-medium range of hydrogen costs are **materially lower than all fossil alternatives,** while the medium-to-high range are cost competitive.
- Hydrogen delivered costs from the North Sea-to-Germany case study are competitive to natural gas in 2030 (12% higher) and lower in 2040 (13% lower).
- **Natural gas prices are still uncertain** due to recent price spike as a result of the Russian invasion of Ukraine

Note: Prices for fossil alternatives (2030/2040): Natural gas (pre-invasion): 28/13 [€/MWh], Coal: 123/5.6 [€/MWh], Oil: 52/24 [€/MWh]. Natural gas prices levels are based on market conditions before Russia's invasion of Ukraine. While natural gas prices have skyrocketed since, there remains significant uncertainty on near- and medium-term European price trends and supply options. As a result, our analysis adopts the IEA's Outlook 2021 price forecast pre-invasion developed pre-invasion. Prices in 2040 are significantly lower than in 2030 because of demand-supply conditions. By 2040, decreased demand for fossil fuels would lower prices. [Source: International Energy Agency, Outlook 2021 (IEA)] and fuel-cost uncertainty is shown with +50% range]

Note: For comparison purposes, cost of H_2 has been converted from "per kg" to "per MWh"
- 1 €/kg ≈ 30 €/MWh (based on LHV of 33.3 kWh/kg)

Competitiveness of hydrogen highly dependant on CO_2-prices as they make up a significant part of fossil fuel costs.
- CO_2 price 2030: 130 €/t
- CO_2 price 2040: 205 €/t

Key Findings & Results

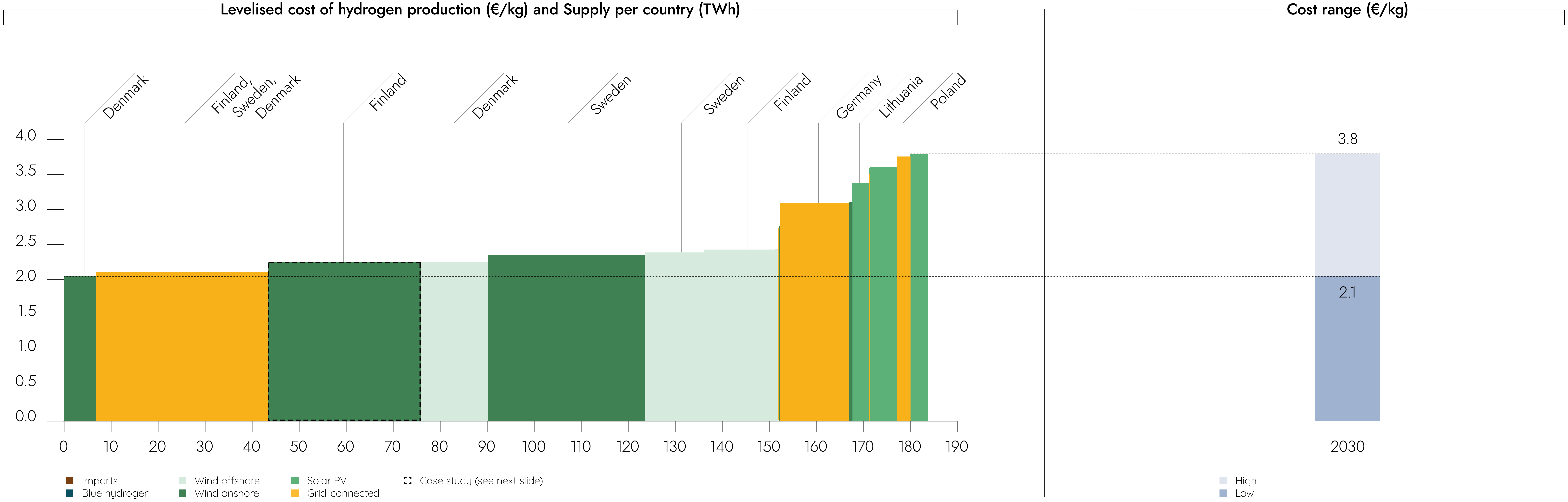
- **By 2030**, the corridor provides access to hydrogen production costs of **2.1 to 3.8 €/kg**.
- **By 2040**, hydrogen production costs decrease to the range of **1.5 to 2.7 €/kg**.

- Several **cost reduction levers** can be applied to **lower the costs of hydrogen delivery**.
- For the Bothnian Bay-to-Germany case study, **these levers achieve delivery costs that are low and cost-competitive**.

- **Hydrogen costs are competitive with fossil fuel alternatives by 2030**, and lower by 2040.
- Fossil fuel costs are subject to **significant uncertainty**.

In 2030, the corridor offers access to hydrogen production ranging in costs from 2.1 to 3.8 €/kg

Hydrogen Production Cost Range [2030][1, 2, 3]


Levelised cost of hydrogen production (€/kg) and Supply per country (TWh)

Cost range (€/kg)

---

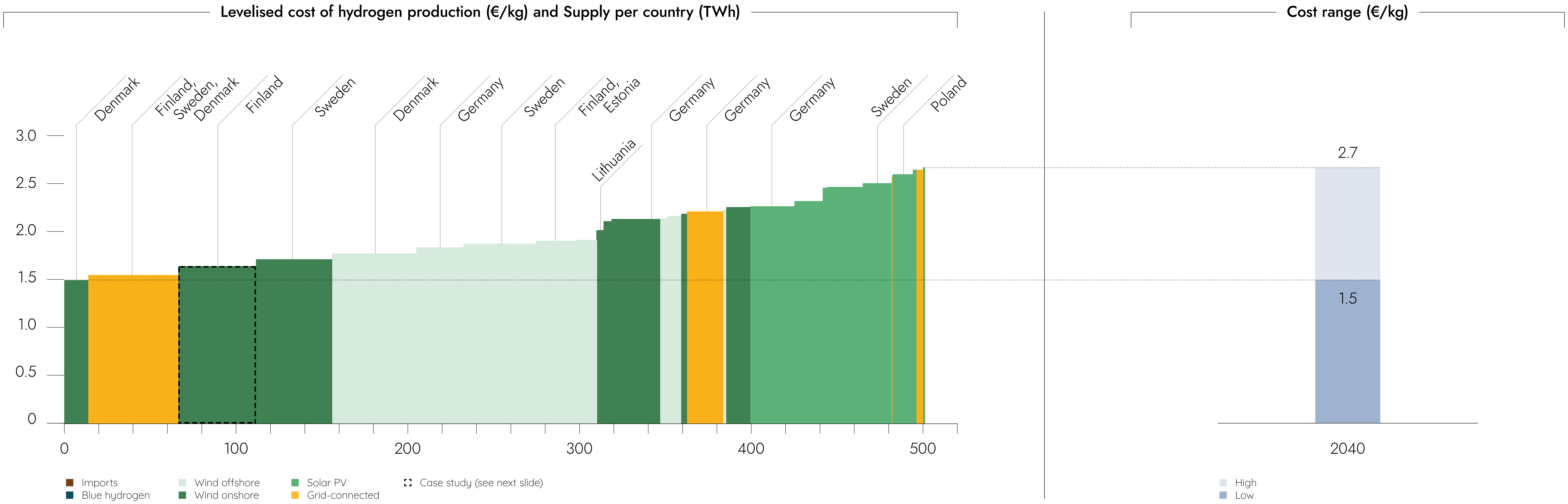
1 Cost curves are based on a bottom-up estimate of supply volumes per country and hydrogen production type. No transport or storage / firming cost are included.

2 *Dedicated hydrogen* production costs are based on renewable technology and electrolyser costs, and country-specific capacity factors and discount rates.

3 *Grid-connected hydrogen* production costs are determined based on costs of a mix of dedicated green hydrogen (solar, onshore wind, offshore wind) and adjusted for grid-connection costs.

By 2040, hydrogen supply options increase and scale up leading to production costs ranging from 1.5 to 2.7 €/kg

Hydrogen Production Cost Range [2040][1, 2, 3]



1-3 See previous slide

Hydrogen delivered costs, incl. transport and storage costs, can be kept low by applying cost reduction levers

1 This analysis assesses a **case study** of hydrogen supply from onshore wind in the Bothnian Bay (Finland) to industrial offtakers in Germany **to explore how the costs of firm hydrogen delivery can be lowered**.

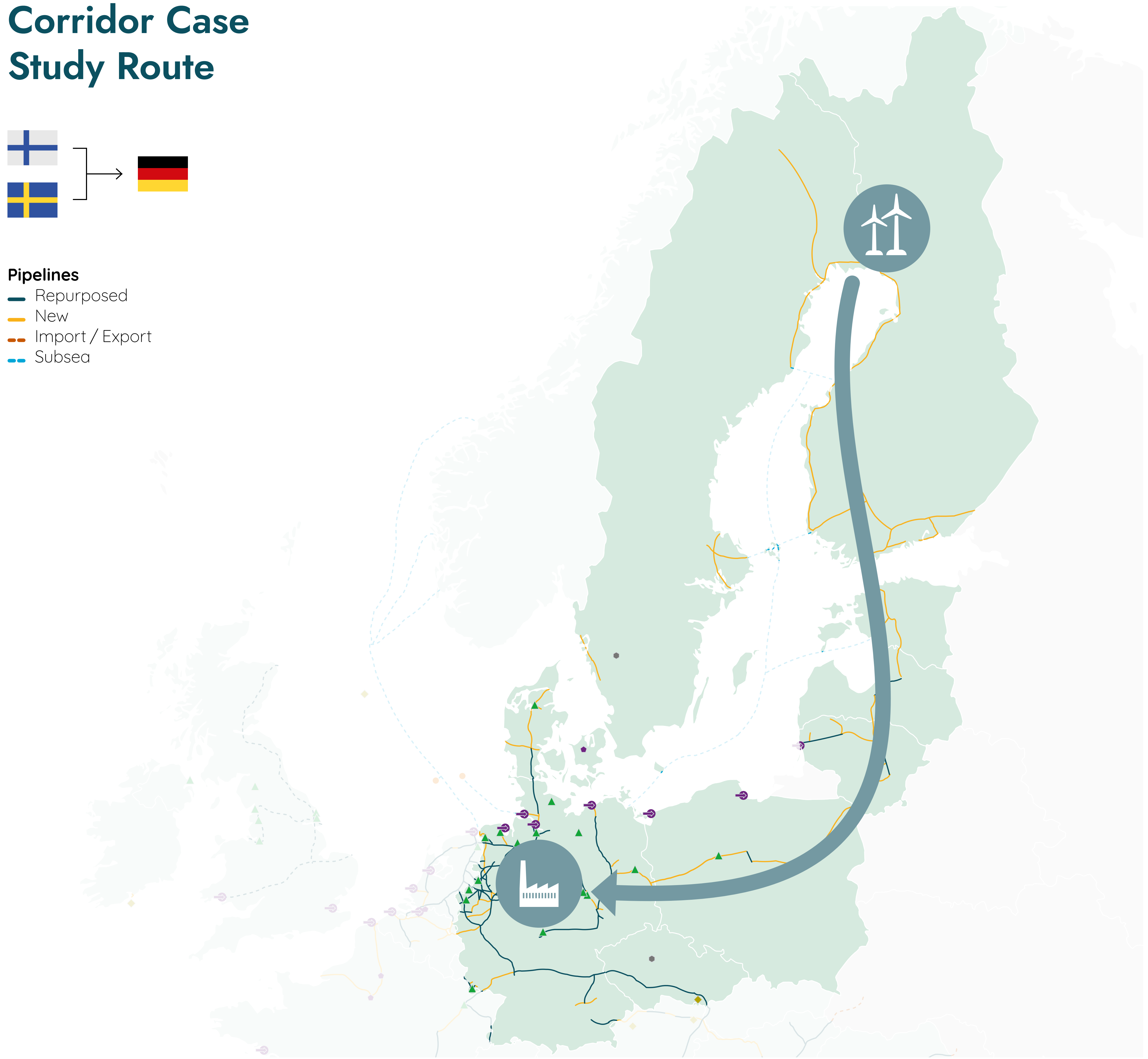
2 To assess the full cost of firm hydrogen delivery to Germany, **transport and storage costs are added to the cost of hydrogen production from the Bothnian Bay**.

Production Costs + Transport Costs + Storage Costs = Delivered Costs

3 **Several cost reduction levers are applied to lower firm delivery costs,** including optimised system operation, battery storage use, cost of capital reductions, among others.

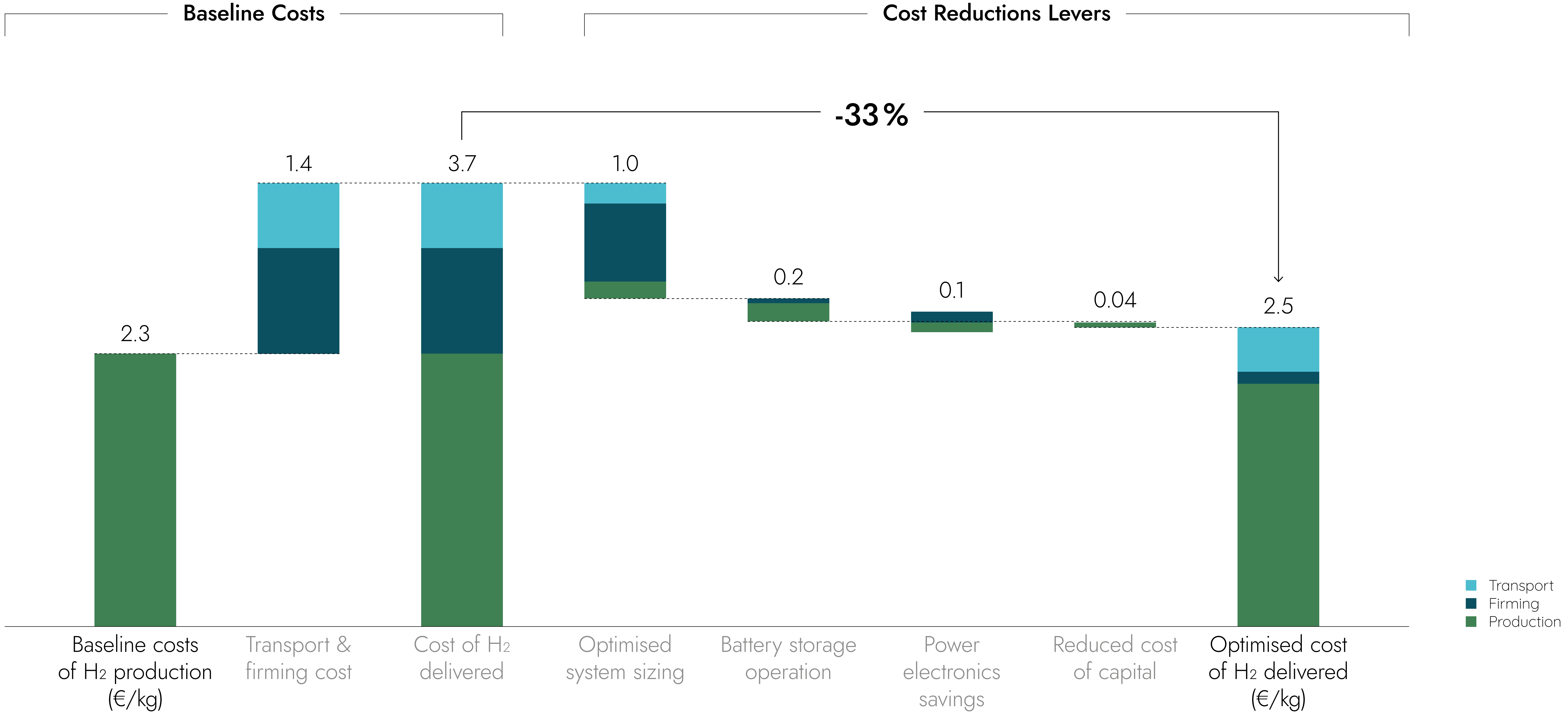
4 **These cost reduction levers achieve sufficient cost savings to keep firm hydrogen delivery costs low and cost-competitive.**

Corridor Case Study Route



Applying cost reduction levers to the Bothnian Bay-to-Germany case study lowers delivery costs significantly and keep hydrogen cost-competitive

Cost of Hydrogen Delivered (€/kg) in 2030[1, 2, 3]



Cost reduction levers applied to case study of hydrogen transport from the Bothnian Bay to Germany **enable firm delivery costs to be reduced significantly**.

- **In 2030** (shown on the left), the cost of delivered hydrogen can be lowered by 33% (3.7 vs. 2.5 €/kg).
- **In 2040**, hydrogen delivered costs can be reduced by 35% (3.1 vs. 2.0 €/kg).

Delivered Costs (€/kg)
(before and after cost levers)

	2030	2040
Before costs lever	3.7	3.1
After costs lever	2.5	2.0

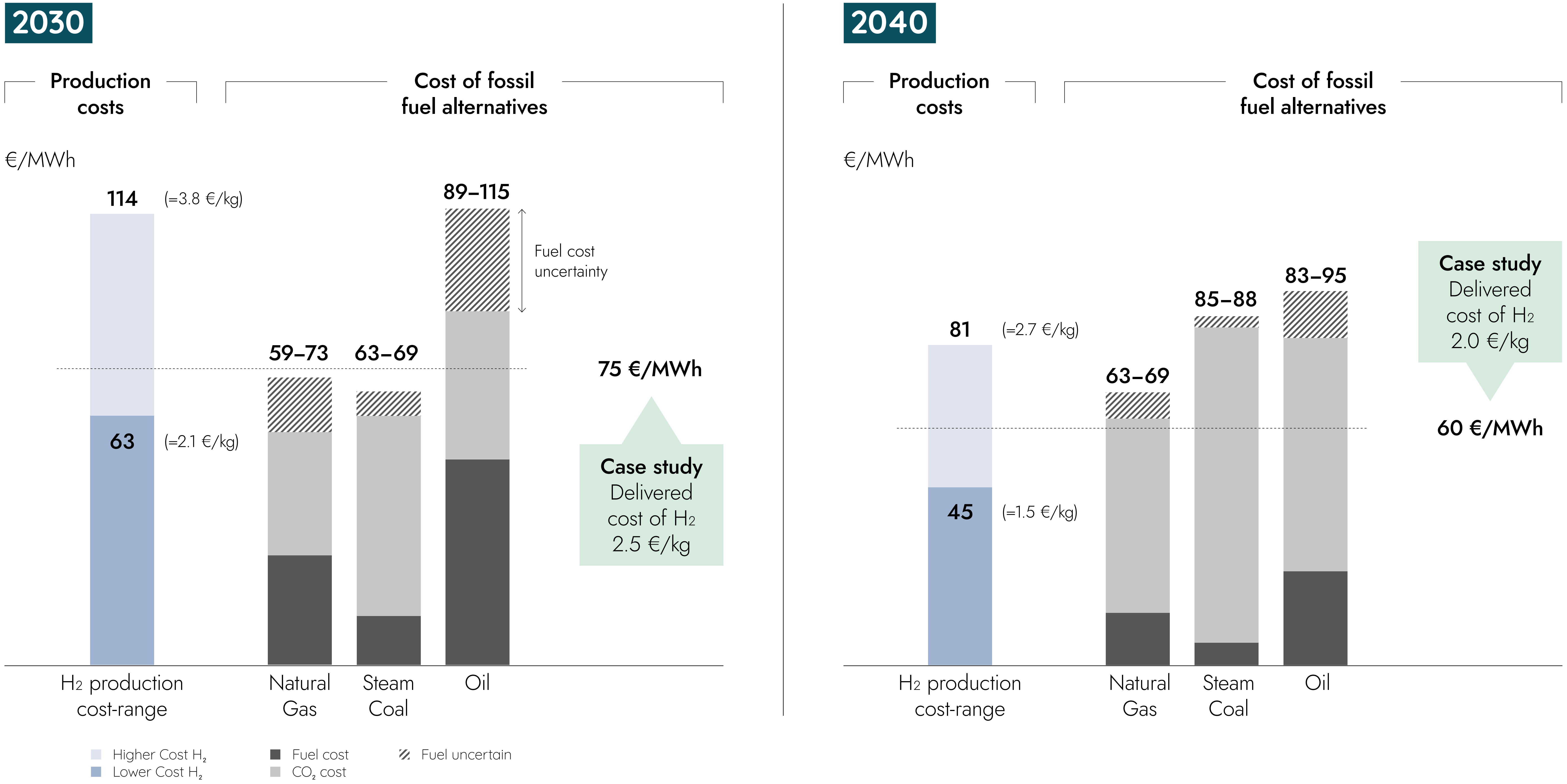
---

1 *Transport costs* are based on several parameters including the type of pipeline (repurposed vs. new), transport distance and full-load-hour production on that pipeline. *Firming costs* are based on additional storage cost required to deliver hydrogen at the equivalent of 8,000 full-load hours.

2 *Optimised system sizing* refers to right-sizing of solar PV and electrolyser capacity to increase full load hours. Similarly, *battery storage operation* enables an increase in the full load hours. *Power electronics savings* refers to the removal of the inverter of the solar PV modules to reduce system cost. *Reduced cost of capital* refers to the use of foreign investment to reduce the WACC from 8 to 6%.

3 In some instances, cost reduction levers may result in cost increases for certain cost-components. For example, an increase in production costs at the same time as a decrease in firming costs. These cost increases and decreases can result in connection lines that do not directly connect one step to the next.

Hydrogen costs are cost-competitive with all fossil fuel alternatives by 2030, and materially lower by 2040.



- **By 2030,** the low range of hydrogen production costs are **competitive with natural gas and coal, and lower than oil alternatives.**
- **By 2040,** the low range of hydrogen costs are **materially lower than all fossil alternatives,** while the medium-to-high range are cost competitive.
- Hydrogen delivered costs from the Bothnian Bay-to-Germany case study are competitive to natural gas in 2030 (27% higher) and lower in 2040 (5% lower).
- **Natural gas prices are still uncertain** due to recent price spike as a result of the Russian invasion of Ukraine

Note: Prices for fossil alternatives (2030/2040): Natural gas (pre-invasion): 28/13 [€/MWh], Coal: 123/5.6 [€/MWh], Oil: 52/24 [€/MWh]. Natural gas prices levels are based on market conditions before Russia's invasion of Ukraine. While natural gas prices have skyrocketed since, there remains significant uncertainty on near- and medium-term European price trends and supply options. As a result, our analysis adopts the IEA's Outlook 2021 price forecast pre-invasion developed pre-invasion. Prices in 2040 are significantly lower than in 2030 because of demand-supply conditions. By 2040, decreased demand for fossil fuels would lower prices. [Source: International Energy Agency, Outlook 2021 (IEA)] and fuel-cost uncertainty is shown with +50% range]

Note: For comparison purposes, cost of H_2 has been converted from "per kg" to "per MWh"
- 1 €/kg = 30 €/MWh (based on LHV of 33.3 kWh/kg)

Competitiveness of hydrogen highly dependant on CO_2-prices as they make up a significant part of fossil fuel costs.
- CO_2 price 2030: 130 €/t
- CO_2 price 2040: 205 €/t

CORRIDOR D

Nordics & Baltics

Agenda

1. Corridor Summary
2. Hydrogen Demand & Supply
3. Supply Costs & Cost-Competitiveness
4. **National Strategies & Regulation**
5. Actions Needed

Most countries have developed, or are developing, national strategies. Moving forward, the development of regulation is key to enable infrastructure investment.

Pre-RePowerEU targets[2]

	National Hydrogen strategy (NHS)	Network regulation & policy	Funding[1] (bn €)	Highlights
Finland	– H_2 strategy part of National Climate & Energy Plan, with focus on **production (via wind resources) and industrial use of green H_2**	– Act on Guarantees of Origin for Energy extended to gas & H_2	0.2	– Recommended to build 1st dedicated H_2 pipelines – Significant additional potential for wind power and e-fuels production, chemicals and fertilisers.
Sweden	– Focus on **industry & heavy-duty vehicles** – **Electrolyser capacity** 5 GW (2030) & 15 GW (2045)	– National H_2 strategy requests regulator to have commissioned revenue **framework by 2023**	0.1	– ·Funding is provided to various hydrogen projects for demand and supply by the Swedish Energy Agency
Estonia	– Intention to create national hydrogen strategy	– N/A		– Potential for local production and export
Latvia	– No specific national hydrogen strategy	– N/A		– Most potential is seen in transport sector
Lithuania	– National hydrogen strategy is in progress	– Legal framework allows issue guarantees of origin for hydrogen	0.16	– Potential for production, transit and export
Denmark	– **Focus on green H_2 and export of PtX technologies** to demand hubs (GER, NL, etc.)	– Proposition: Allow TSO & DSO to own and operate H_2 infrastructure	0.2	– Transport infrastructure is seen as key to enable role as PtX producer and exporter
Poland	– Focus: Power/heat sector, transport, industry, production, network, creating regulatory framework	– Creation of regulatory framework mentioned in H_2 strategy		– Gas network to be adapted & new build: **"Hydrogen Highway"** (North-South)
Germany	– National production & import focus due to supply gap – In place **since 2020, currently reviewed towards increasing its ambition** – **10 GW (2030)** electrolyser in coalition plans	– H_2 network potentially opt-in regulated and vertically unbundled – First rules and standards for high pressure pipelines are formulated	 9	– Strong focus on **international cooperation** to ensure sufficient supply – National funding
Czech Republic	– Focus **Transport**, then **energy** & **chemical** industry – Production also CCS and nuclear – **Import and transit country** for H_2 from the south	– N/A		– **H_2-Readiness** of gas transmission system is urged, due to potential role in **H_2 transport** from south to north and from east to west

🟦 General funding
🟦 Supply
🟦 Network
🟦 Demand

Note: Sequencing of countries follows the general corridor direction but does not represent the hydrogen flows.

1 Cumulative public funding amount by the respective state until 2030

2 Strategies and funding is under evaluation of meeting latest targets

CORRIDOR D

Nordics & Baltics

Agenda

1. Corridor Summary
2. Hydrogen Demand & Supply
3. Supply Costs & Cost-Competitiveness
4. National Strategies & Regulation
5. **Actions Needed**

ACTIONS NEEDED

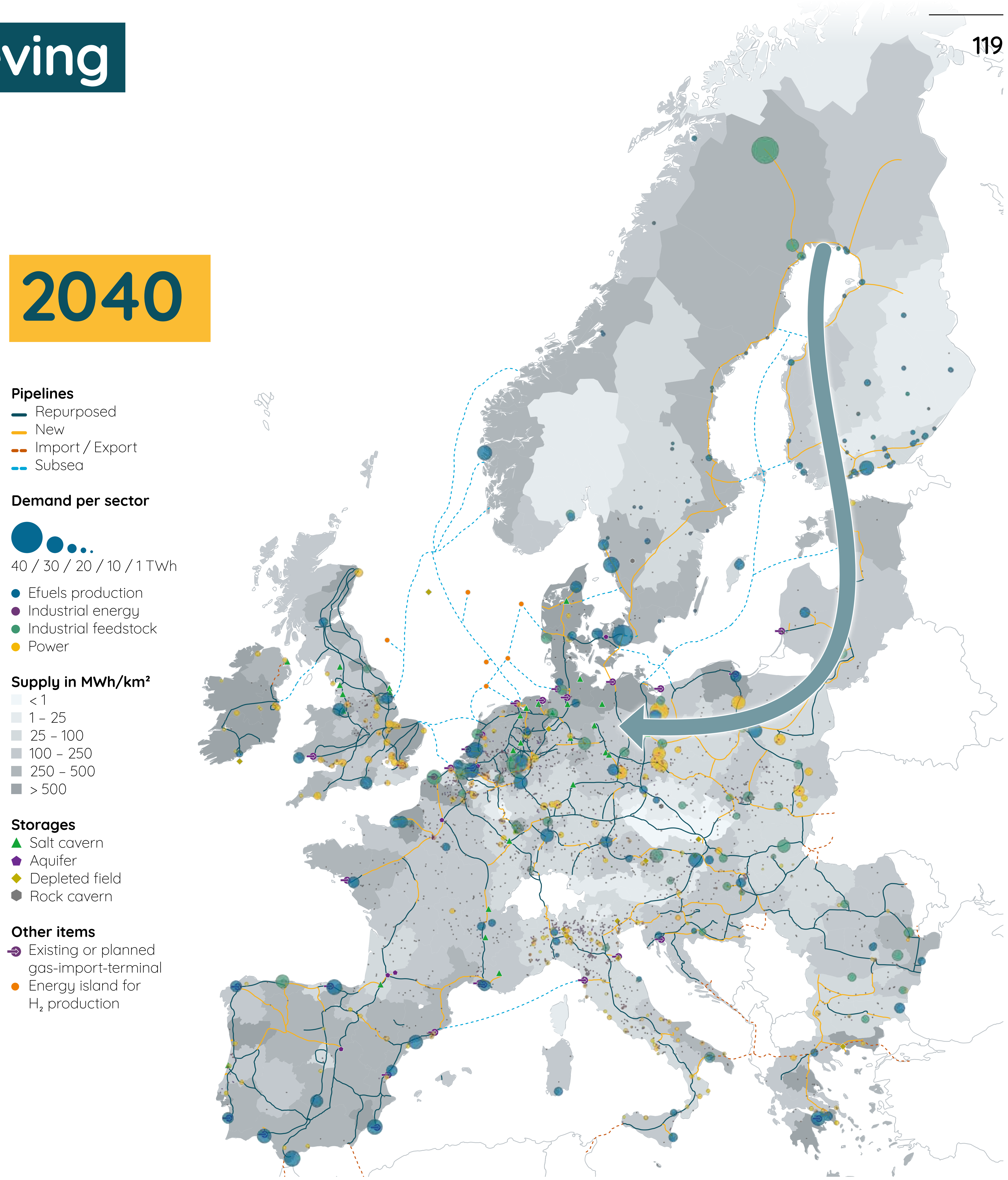
This corridor plays a fundamental role in achieving a European backbone by 2040

The need for this corridor

- The development of **this corridor ensures access to abundant, low-cost supply from parts of the Nordics by 2030,** expanding to supply from the Baltics by 2040.
- The **decarbonisation of the largest hydrogen demand centers along this corridor — in the Nordics, Baltics, Poland and Germany** — is dependent on the buildout of this corridor by 2030, and its expansion towards 2040.

Actions required

- The buildout of this corridor by 2030 **requires national governments to take clear and concrete actions across.**
- This includes actions associated with **infrastructure development and planning, the development of cross-national initiatives and securing access to early funding and long-term, low-cost financing.**



ACTIONS NEEDED

To ensure the development of this corridor by 2030, there is a need for clear and concrete actions

Fostering development of new and repurposed hydrogen infrastructure, for example, by unbundling rules facilitating the efficient use of TSO expertise and services and by allowing the adoption of different vertical unbundling models in the EU, as is the case with natural gas

+

Unlock financing to fast-track hydrogen infrastructure deployment by applying regional regulatory flexibility and other pragmatic financing solutions (including incentivizing the adoption of hydrogen by demand sectors)

+

Simplify and shorten planning and permitting procedures for renewable energy and hydrogen infrastructure projects.

+

Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure supporting the accelerated deployment and integration of renewable energy resources

→ However, speed will be of essence!

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3. Supply Costs & Cost-Competitiveness
4. National Strategies & Regulation
5. Actions Needed

CORRIDOR E

East and South-East Europe

Greece
Bulgaria
Romania
Hungary
Slovenia
Croatia
Slovakia
Czechia
Austria
Germany
Poland

Corridor emerges in Eastern & South-Eastern Europe providing access to low-cost hydrogen supply to demand centers along the corridor

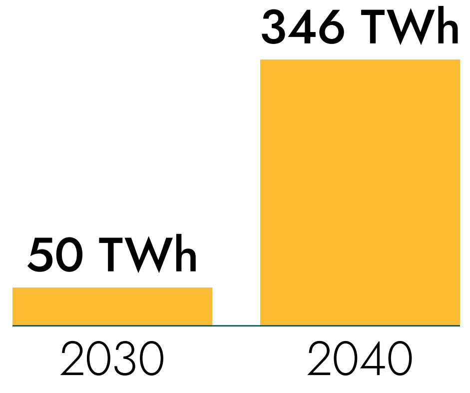
Drivers & Opportunities

Major driver of development is the need to meet **hydrogen demand from industry, transport and power** across Eastern and South-Eastern Europe. Key opportunities include leveraging the **abundant renewables potential in Eastern Europe and gaining access to hydrogen imports from Ukraine**

Hydrogen Supply & Decarbonization Potential

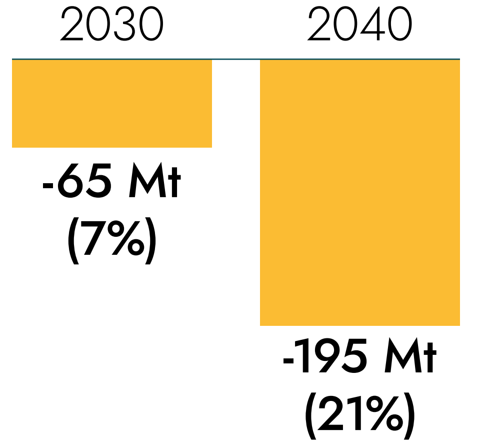
H_2 supply potential[1]

(TWh/year)



Emissions Reductions

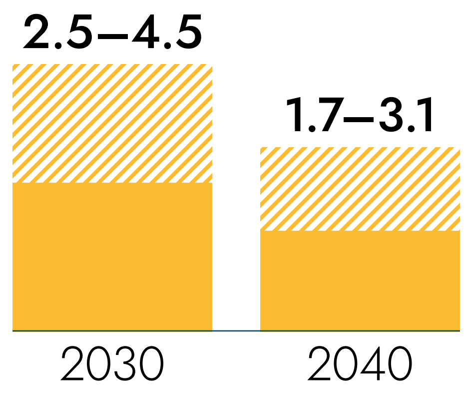
(MtCO$_2$/year vs. 2019; % reduction)



Supply Costs & Cost-Competitiveness

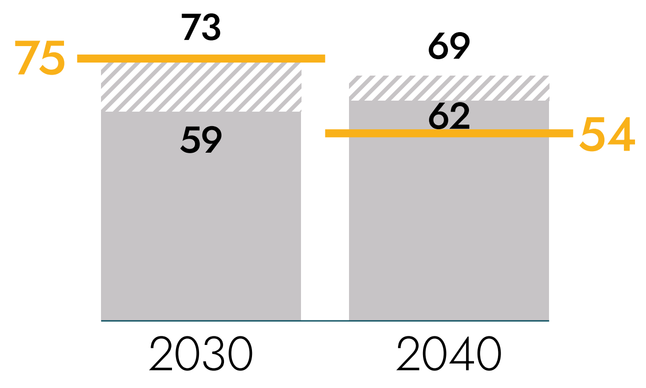
Cost of H_2 production[1]

(€/kg of H_2)



Cost competitiveness[2]

— Hydrogen delivered price
vs.
▨ natural gas price high/low,
(€/MWh)



Actions Needed

- Fostering development of new and repurposed hydrogen infrastructure
- Unlock financing to fast-track hydrogen infrastructure deployment
- Simplify and shorten planning and permitting procedures
- Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure
- Intensify energy partnerships with exporting, non-EHB countries like Ukraine

---

1 Figures reported reflect outputs for all countries included in the corridor. Even if a country is only partially in the corridor, results for the full country are included (e.g., supply potential and costs, demand, transmission network length).

2 Savings are based on the corridor's case study of hydrogen delivered in 2030 and 2040. The cost of natural gas includes CO$_2$ prices. Refer to Subsection 3 (Supply Costs & Cost-Competitiveness)

CORRIDOR E

East and South-East Europe

Agenda

CORRIDOR SUMMARY

Corridor offers access to low-cost hydrogen supply from Eastern and South-Eastern Europe to demand centers along the corridor

Drivers & Opportunities

- **The major driver** behind the development of this corridor is the adoption of hydrogen associated with the **decarbonisation of industry, transport and power** across Eastern and South-Eastern Europe, particularly new green steel projects and existing industry along the corridor through Greece, Romania, Hungary, Austria and Germany. The speed of hydrogen adoption in these regions may be even faster than anticipated driven by increasing CO_2 prices in the EU and the RePowerEU ambitions to replace natural gas consumption.
- In the near term, the corridor offers **access to low-cost, hydrogen supply from Eastern and South-Eastern Europe** – including hydrogen imports from Ukraine, Poland, Greece, and Romania among the larger sources of supply. In the longer term, this corridor gains further access to hydrogen supply across the entire region.
- A major opportunity of the corridor is to **leverage the abundant renewables potential in Eastern Europe** with its vast land availability and high-capacity factors for solar and onshore wind, particularly in relation to the high **hydrogen export potential of Ukraine. Another major opportunity relates to the potential for hydrogen storage provided by depleted fields along the corridor in Greece, Czechia, Austria and Germany**.
- The corridor would be stood up by 2030, covering **10,000 km** of large-scale hydrogen pipelines across all countries of the corridor, of which approximately **60% will be repurposed pipelines**.

Hydrogen Demand & Supply

- **Total hydrogen demand** in the corridor reaches **~165 TWh by 2030**, increasing substantially to **~660 TWh by 2040**. Up to 2030, the major driver of hydrogen adoption is the industrial sector, with hydrogen being used as feedstock. From 2040 onwards, most new hydrogen demand is for the transport and the power sectors.
- Hydrogen adoption across all countries of the corridors enables an emissions reduction of ~260 $MtCO_2$/yr. by 2050, equivalent to a **28% emissions reduction**.
- The corridor enables access to **hydrogen supply potential of ~50 TWh by 2030, increasing to roughly 350 TWh by 2040**. Major sources of supply include grid-connected hydrogen production by 2030, with a **huge potential** role for **Ukrainian imports** by 2040.

To successfully stand up this corridor by 2030, actions are needed to support infrastructure planning, financing and development

Costs & Cost-Competitiveness

- **By 2030**, the corridor provides access to hydrogen ranging in production costs from **2.5 to 4.5 €/kg**. **By 2040**, as supply options increase, technology costs decrease, and imports from Ukraine scale up, hydrogen production costs decrease to **1.7 to 3.1 €/kg**.
- In the long term, this corridor's largest amounts of low-cost supply options are hydrogen imports from Ukraine.
- Based on a case-study of hydrogen supply and transport from South-Eastern Romania to Germany, **the cost of delivered hydrogen** – inclusive of transport and storage costs – **can be lowered significantly and be cost-competitive with fossil fuel alternatives**. Lowering delivery costs can be achieved through various cost levers including optimised operation of the system and cost of capital reductions.

National Strategies & Regulation

- **Some countries have developed national strategies, while in others they are under development**. Moving forward, the development of hydrogen regulation in all countries will be key in enabling investment in infrastructure.
- In select countries, **substantial funding has been allocated** to support the development of the hydrogen market including funding for gas network infrastructure. However, most countries are yet to define and earmarked funds.

Actions Needed

To support the buildout of this corridor by 2030, clear and concrete actions related to infrastructure planning, financing and development have been identified:

- Fostering development of **new and repurposed hydrogen infrastructure**.
- Unlock financing to **fast-track hydrogen infrastructure deployment** by applying regional regulatory flexibility and other pragmatic financing solutions.
- Simplify and shorten **planning and permitting procedures** for the full value chain of renewable energies and hydrogen infrastructure projects.
- Establish **integrated energy system planning** of hydrogen, natural gas, and electricity infrastructure
- **Intensify energy partnerships** with exporting, non-EHB countries like Ukraine.

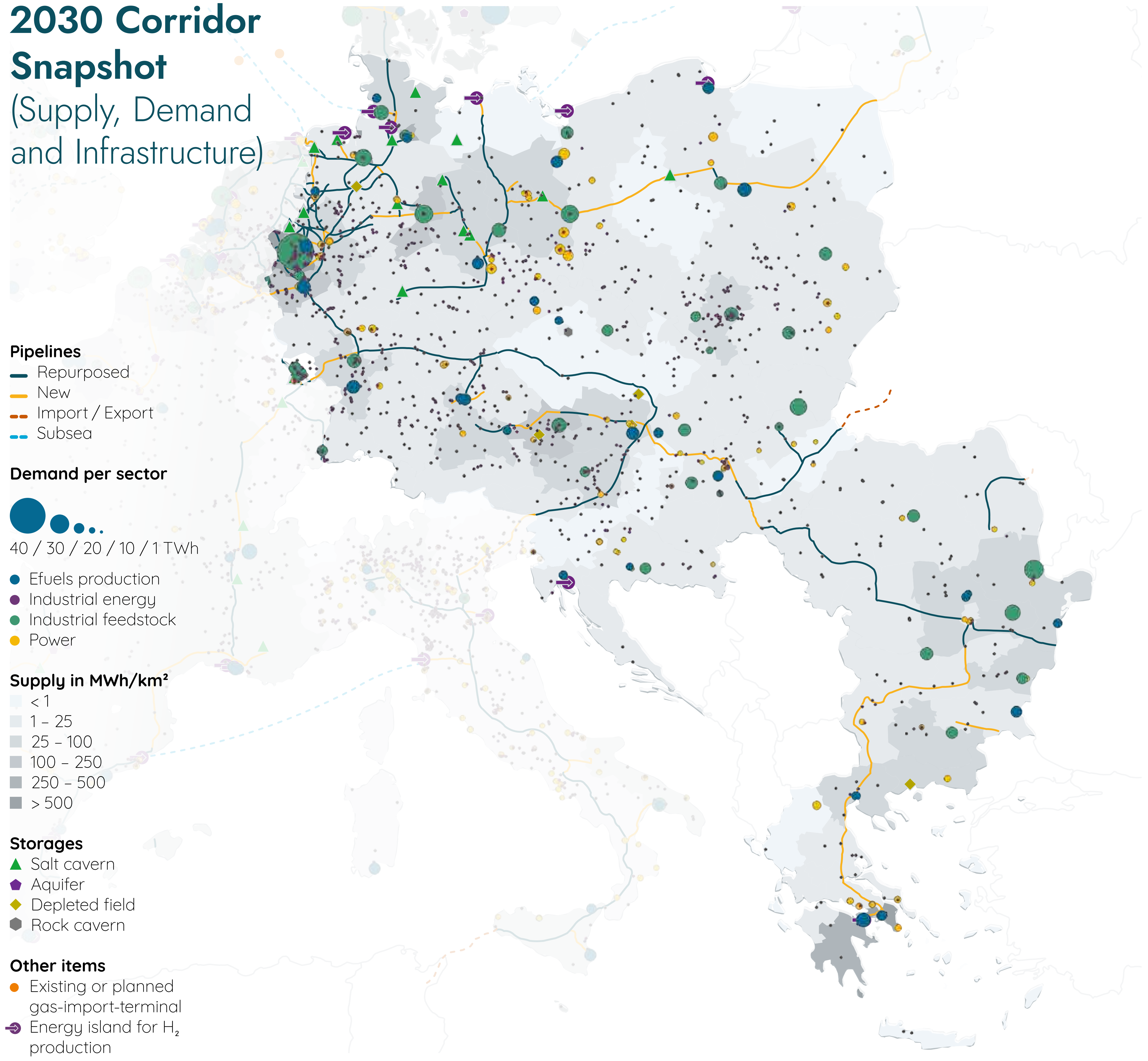
East and South-East Europe

Agenda

This section explores the development of demand, supply and transport infrastructure in the corridor from 2030 to 2050

2030 Corridor Snapshot

(Supply, Demand and Infrastructure)



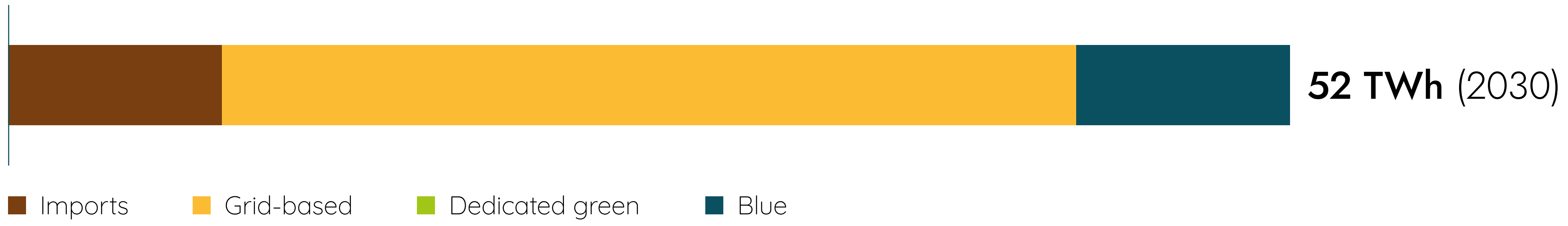
Hydrogen demand

By 2030, the corridor connects **major demand clusters** across Eastern and South-Eastern Europe. **From 2030 to 2040**, the corridor expands to **all demand centers along its route**, increasing demand from 165 to ~660 TWh.

Hydrogen supply

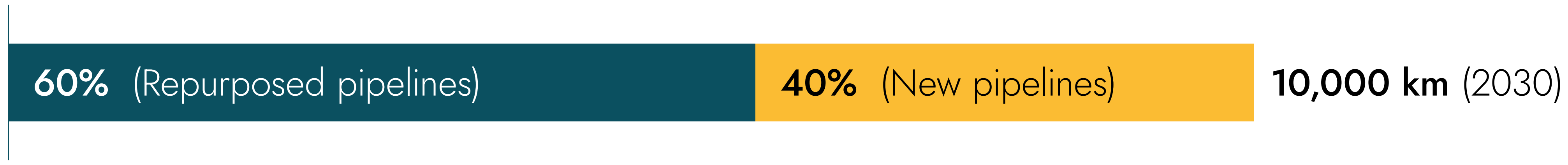
By 2030, the corridor enables access to low-cost supply from **parts of Eastern and South-Eastern Europe and Ukraine**. **By 2040**, the corridor gains additional access expanding across the region.

In 2030, hydrogen supply is ~50 TWh, of which 65% of supply is from grid-based hydrogen. Hydrogen supply increases significantly by 2040, reaching ~350 TWh.

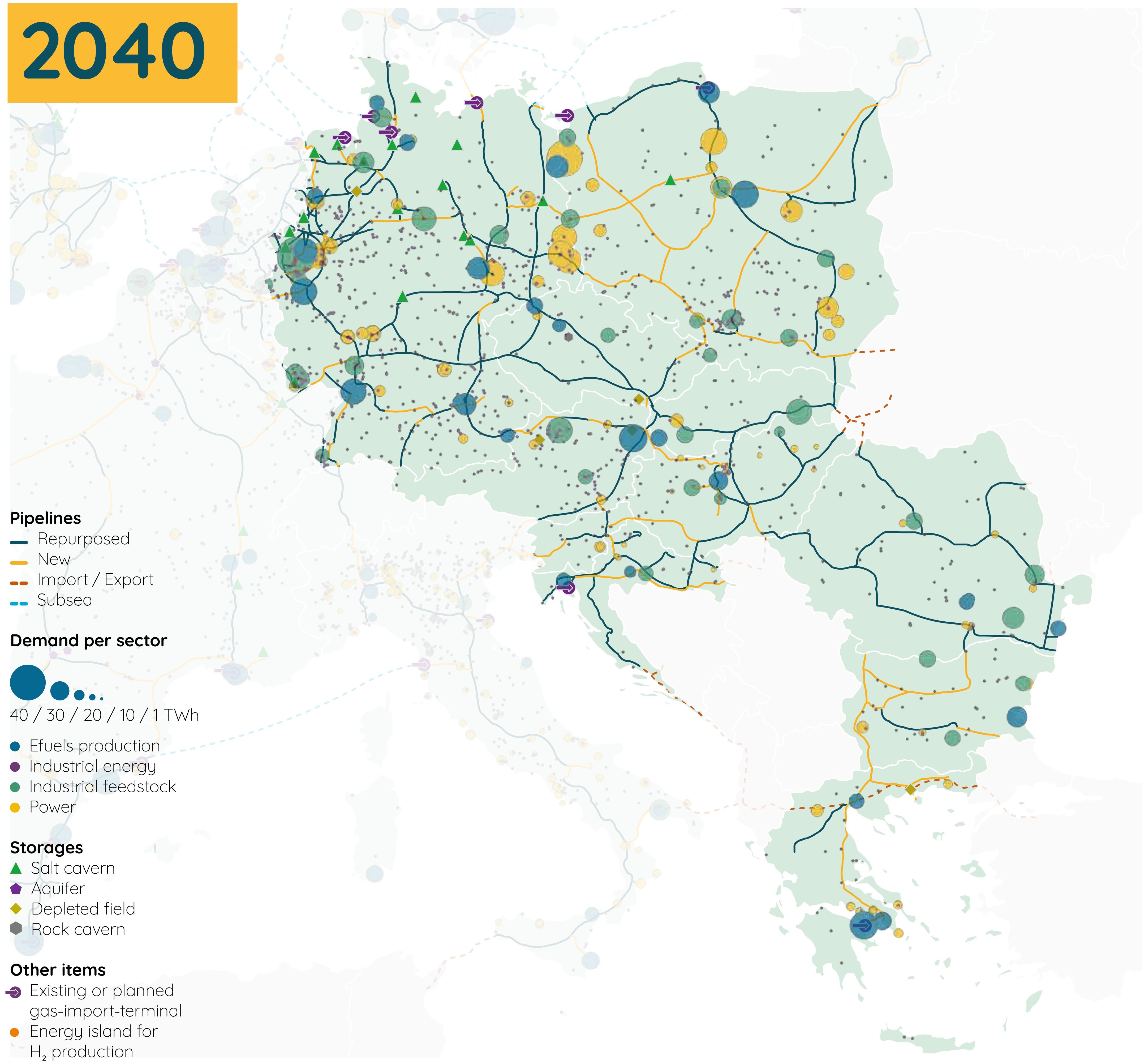


Hydrogen Infrastructure

By 2030, the buildout of pipeline infrastructure across all countries of the corridor reaches **10,000 km** of large-scale pipelines. Corridor benefits from a **large share of repurposed infrastructure**.



Corridor connects hydrogen clusters from South-Eastern Europe to Germany by 2030, expanding to major demand centers by 2040



Hydrogen demand increases rapidly from 2030 to 2040, largely driven by Germany and Poland

Total demand per country (TWh/y)

General H_2 flow ↓

Country	2030	2040	2050
Greece	7	27	42
Bulgaria	5	17	23
Romania	14	34	46
Hungary	4	15	25
Slovenia	1	5	7
Croatia	2	7	11
Slovakia	7	20	26
Czechia	5	17	27
Austria	8	36	52
Germany	90	363	505
Poland	22	120	155
Total	165	662	920

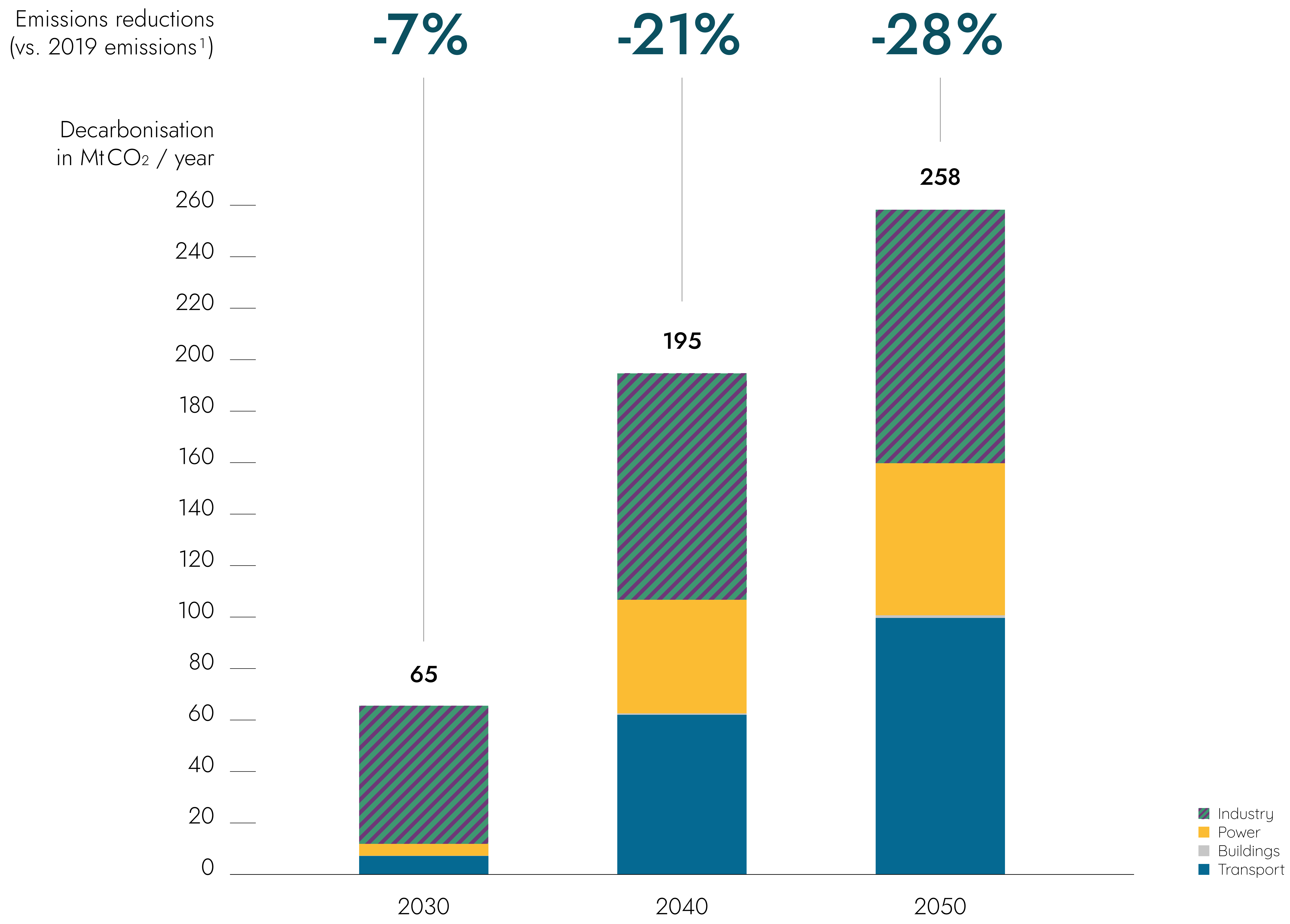
Note: Does not include grey hydrogen demand. Numbers represent total demand by country, even if only parts of the country are included in the corridor.

Hydrogen demand – across all countries of the corridor – increases significantly from 2030 to 2050. Demand reaches 165 TWh by 2030, increasing to roughly 920 TWh by 2050.

Hydrogen demand may accelerate and increase further than forecasted as a result of additional regulatory measures adopted in response to the RePowerEU plan.

- **Up to 2030**, most hydrogen demand is driven by the industrial sector in the destination countries – Germany and Poland.
- **From 2040 to 2050**, most new hydrogen demand is for e-fuels production and for power generation.

Hydrogen adoption enables a reduction in emissions of 28% by 2050 across all countries of the corridor



Hydrogen adoption across all demand sectors enables an **emissions reduction of ~260 MtCO2/yr. by 2050**, equivalent to a **28% reduction**[2].

- **Up to 2030**, the industrial sector contributes 85% of the total emissions reductions.
- **By 2040**, emissions reductions from transport (road, shipping and aviation) increase substantially and combined with industry, account for 75% of emissions reductions. The power sector account for the remaining 25% of reductions.
- **By 2050**, most incremental emissions reductions are associated with hydrogen adoption in the power and transport sectors.

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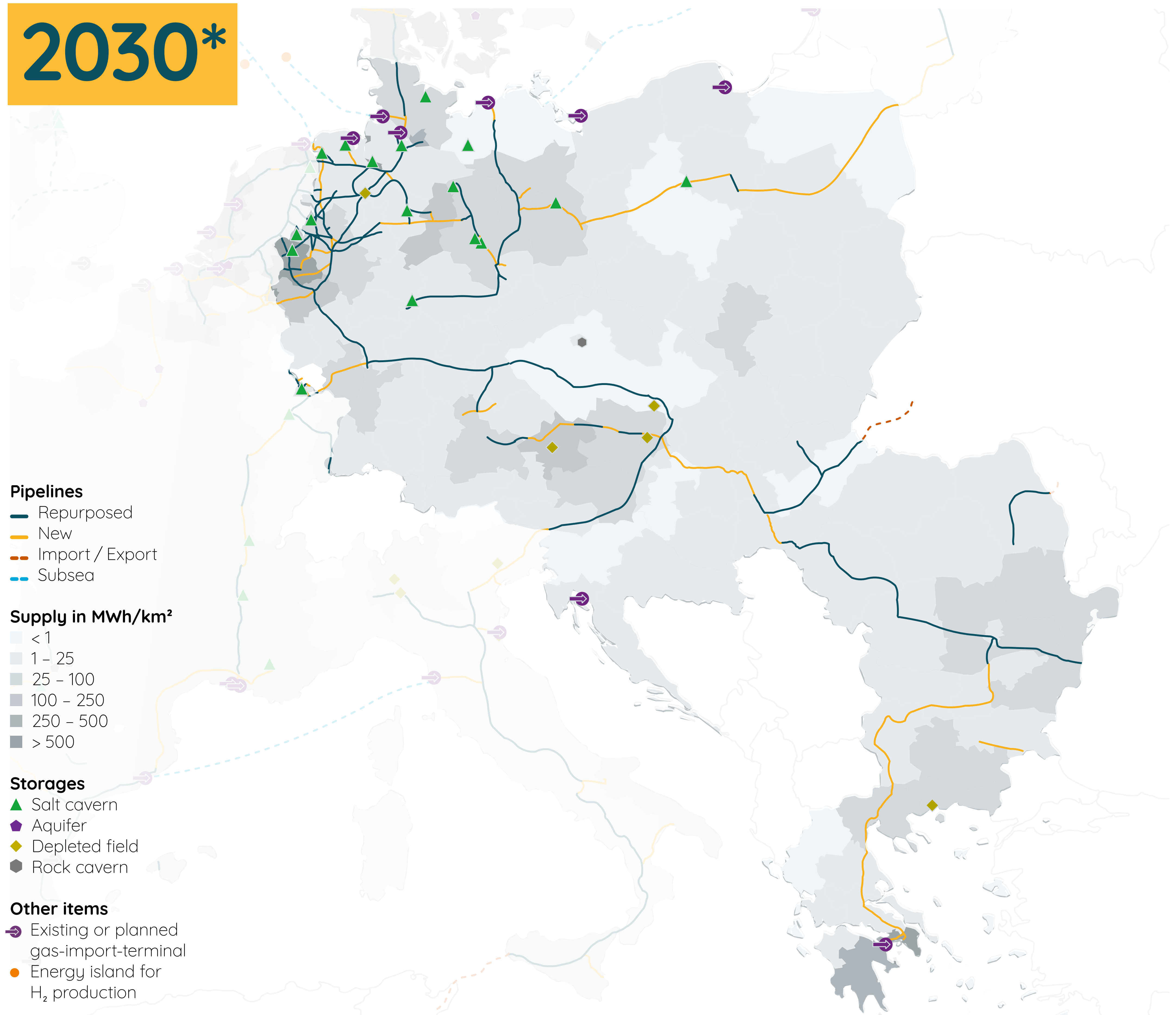
[1] CO_2-Emissions from countries and sectors included in corridor (0.91 bn t CO_2 / year), Source: EEA

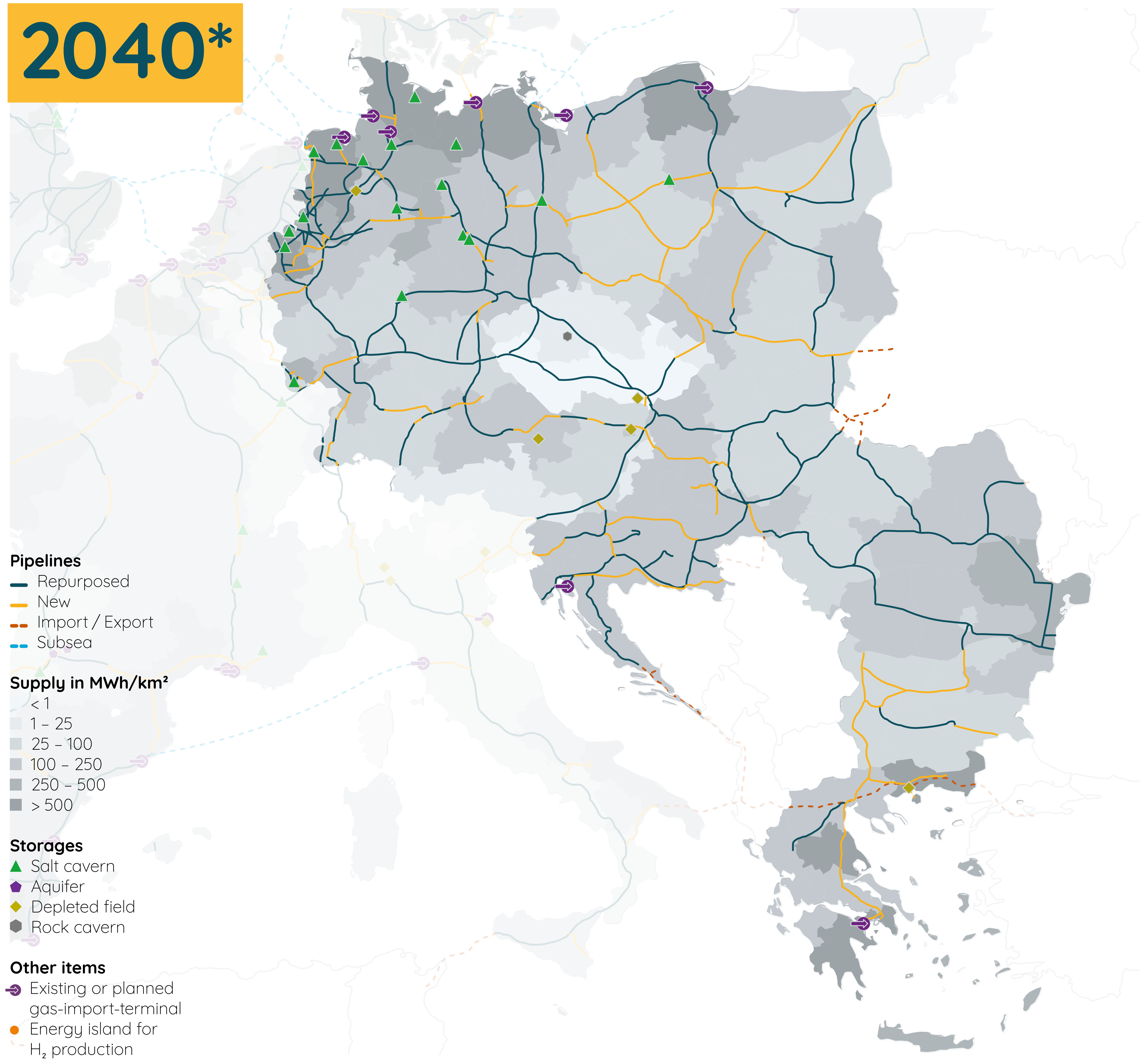
[2] Emissions reductions are calculated compared to the baseline fossil fuel used in each sectors. For example, emissions reductions associated with the adoption of hydrogen by the primary steel sector are relative to the use of coal. Similarly, emissions reductions , for e-fuels production are relative to the use of fossil fuels in shipping, aviation and other uses.

Corridor enables access to supply from Eastern & South-Eastern Europe and Ukraine by 2030, expanding across the region by 2040

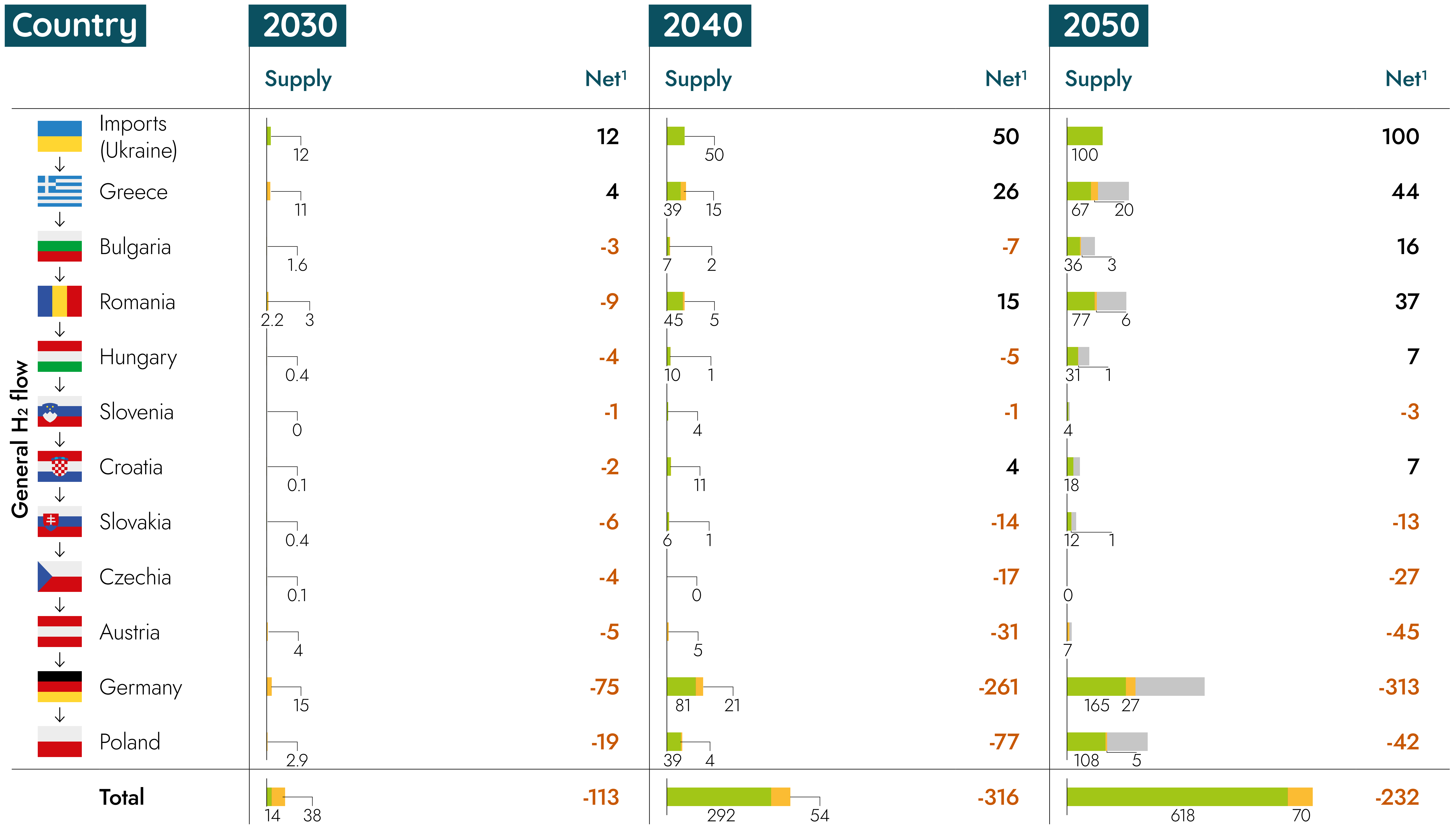


Total hydrogen supply shown per NUTS-2 region. MWh adjusted by the area of each NUTS-2 region in km^2.

* Note: Supply numbers do not include grey hydrogen.



Hydrogen supply increases significantly from 2030 to 2040, largely driven by imports from Ukraine and South-Eastern Europe



The hydrogen supply mix includes **grid-based green hydrogen² and dedicated green hydrogen**.

- **By 2030, hydrogen supply reaches 50 TWh**, largely from grid-based green hydrogen.
- **By 2040, hydrogen supply increases substantially to ~350 TWh**, of which roughly 85% is from dedicated green hydrogen. The remaining 15% is from grid-based hydrogen supply.
- **By 2050, hydrogen supply increases further to ~690 TWh**. Dedicated green supply continues to account for the largest share at roughly 90%, while grid-based hydrogen increases only slightly.

Hydrogen supply may accelerate and increase further as a result of additional regulatory measures adopted in response to the RePowerEU plan.

Note: Hydrogen supply volumes do not include hydrogen imports by ship.

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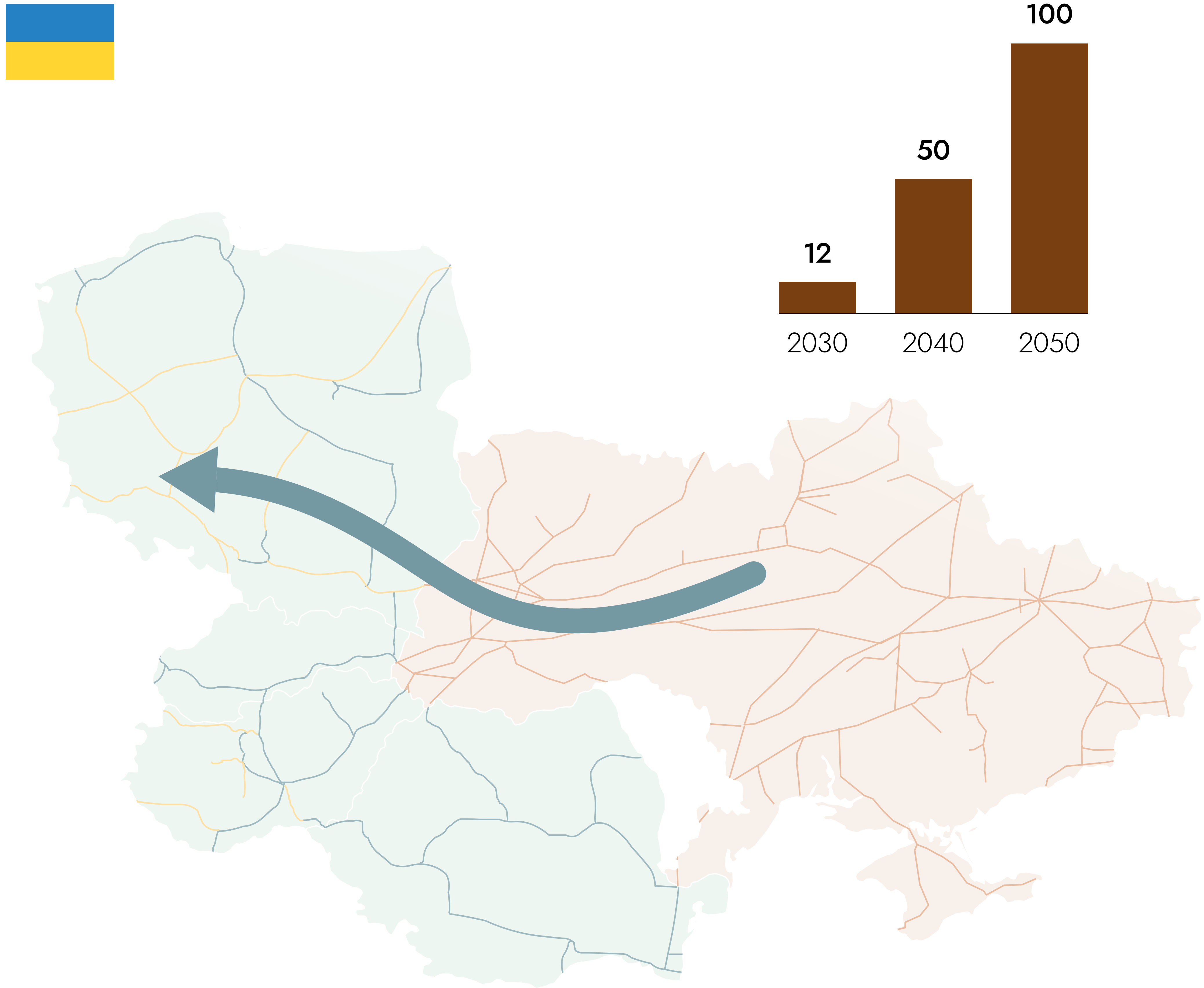
1 *Net* represents excess supply after subtracting demand.

2 Grid-based is estimated using national 2030 electrolyser targets which, by 2030, are assumed to be largely grid-connected rather than dedicated. Grid-based increases over 2030-2050 with increasing RES.

Ukraine may become a potential source of imports by 2030

Supply potential	— **Supply potential** estimated based on **Hydrogen Europe's 2x40 GW Green Hydrogen Initiative report**[1]. — This analysis assumes a delay compared to the 2x40 GW report — due to the war in Ukraine — resulting in **more moderate hydrogen export volumes**[2].
State of Gas Infra-structure	— **Ukraine is approaching H_2 as an export opportunity** and is actively investigating retrofitting existing gas pipelines to hydrogen. — The **Ukrainian Ministry of Energy** highlighted the potential of using existing gas pipelines for the domestic use and for exports to Romania, Slovakia, Hungary and Poland[3].
Market Attractive-ness	— **Technical green hydrogen potential is substantial**. Based on an estimated technical potential of ~500-800 GW of renewable energy capacity, the supply potential ranges between ~1,000-1500 TWh. — **Ukraine has a well-developed ammonia and steel production industries** (applicable for green hydrogen). — **Ukraine's Naftogaz joined the European Clean Hydrogen Alliance** with the ambition of becoming a leader in hydrogen export to EU countries. — **Partnerships**: TSO's of Slovakia, Austria and Germany — as part of an international consortium — are investigating the establishment of necessary capacities for transporting hydrogen from Ukraine via Slovakia and Austria to Germany for accessing storage facilities in Central Europe.
Market Barriers	**Mayor uncertainties relate to the current war** — The operational state of Ukraine's natural gas infrastructure — The speed of economic recovery and infrastructure investment — The development of a hydrogen market and related supply chains in Ukraine.

Hydrogen supply potential (TWh)[1]



Note: Export projections to Europe from 2030 to 2040-2050 are based on an assumed four-fold increase in exports by 2040 and two-fold increase from 2040 to 2050. These assumptions are informed by scale up projections from other export countries of this study and Hydrogen Europe's 2x40 GW report.

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[1] Hydrogen Europe (2021). 2x40 GW Green Hydrogen Initiative. https://hydrogeneurope.eu/wp-content/uploads/2021/11/Hydrogen-Europe_2x40-GW-Green-H2-Initative-Paper.pdf

[2] This report estimates 12 TWh of exports in 2030 based on of 5.5 GW of export capacity (vs. 8 GW in Hydrogen Europe's estimations). Export volumes assume an onshore wind capacity factor of 35% and an electrolyser efficiency of 70%.

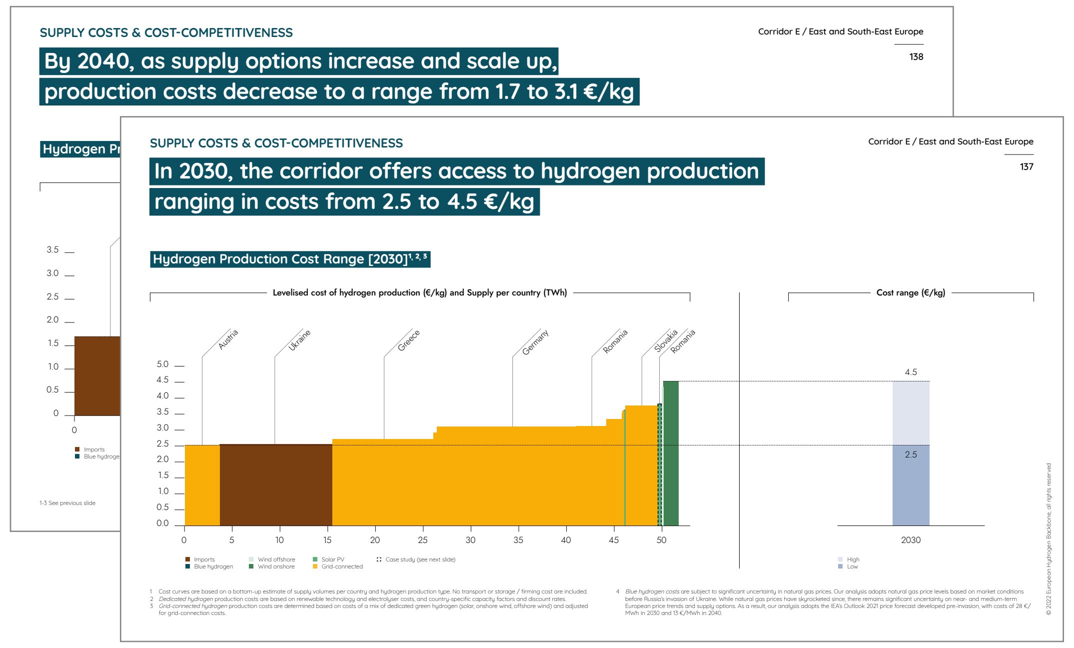
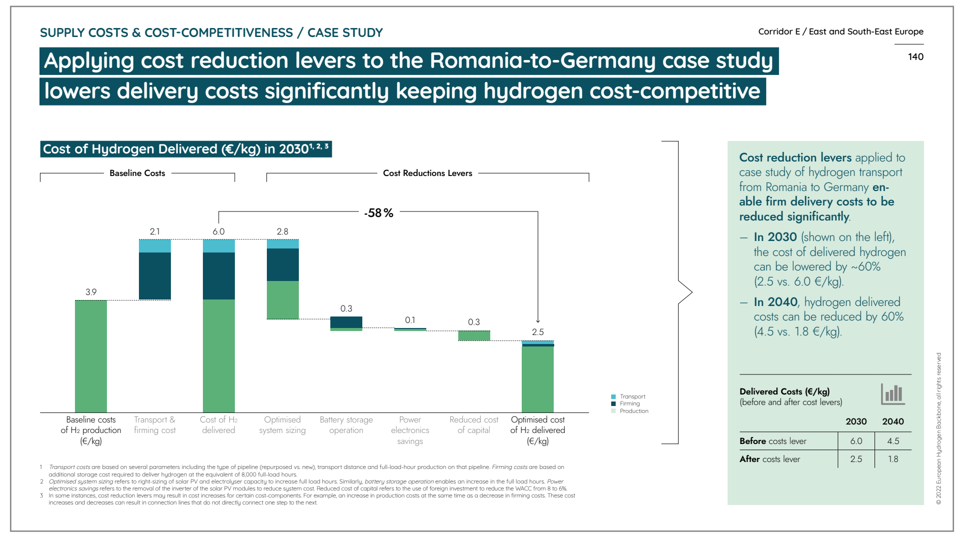
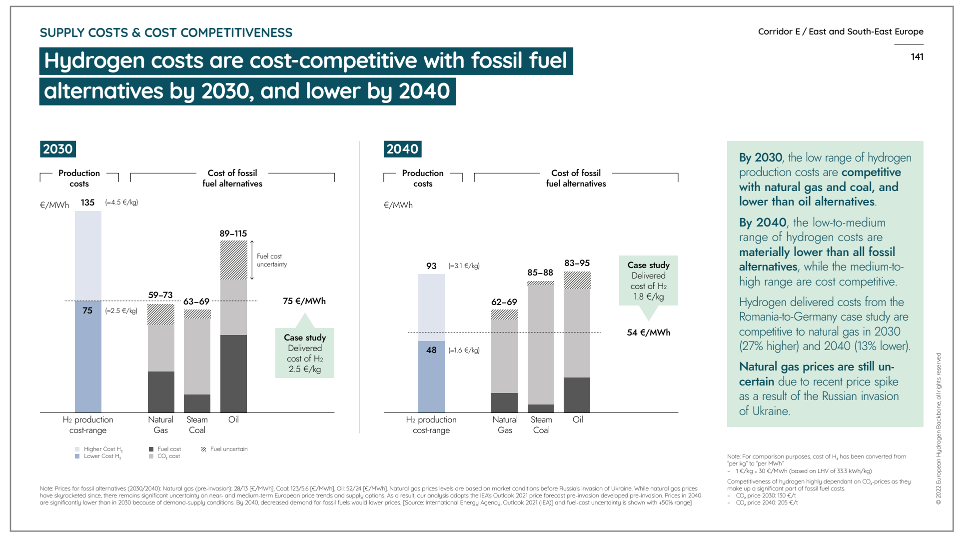
[3] UNECE – Draft Roadmap for Production & Use of Hydrogen in Ukraine (2021)

East and South-East Europe

Agenda

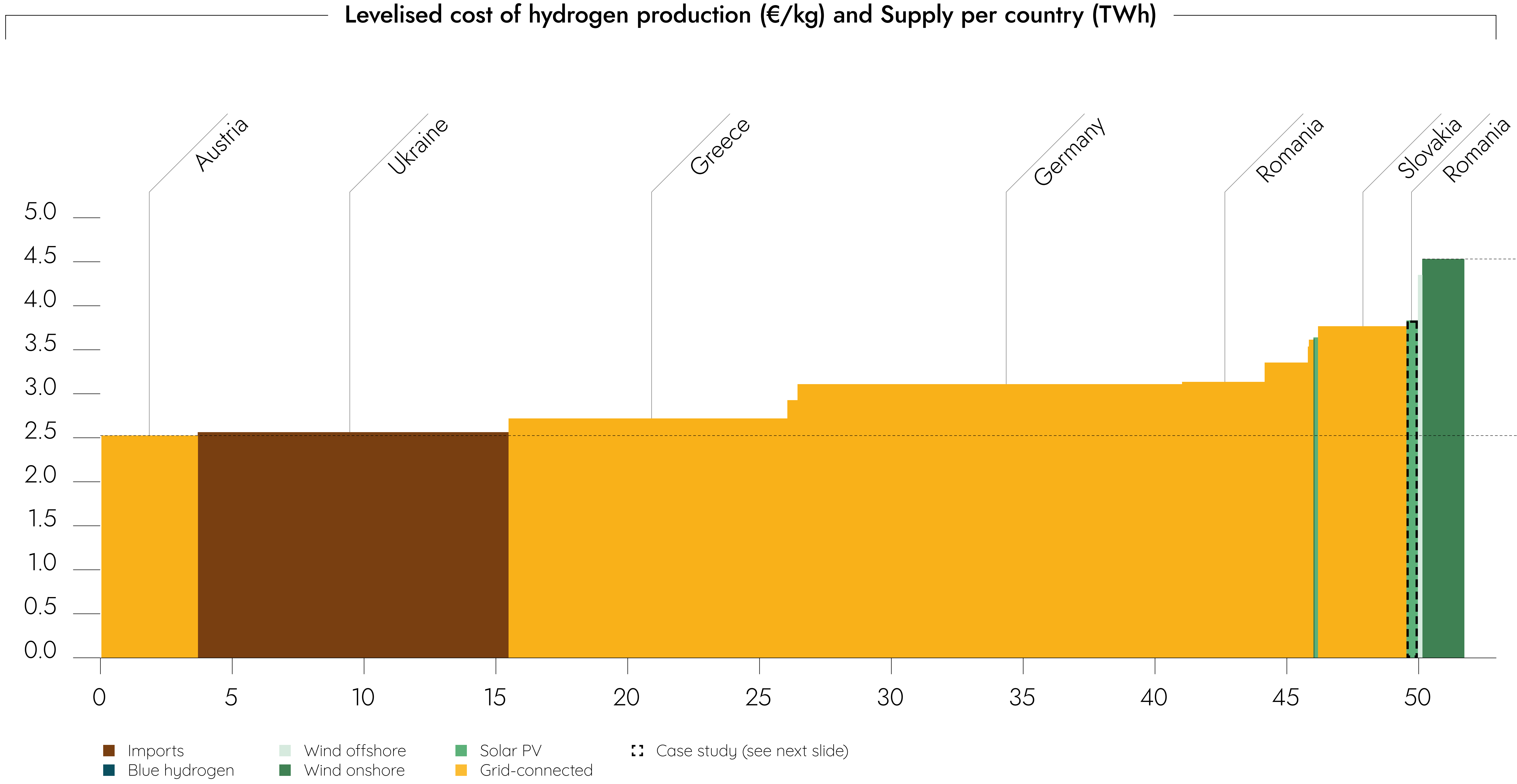
1. Corridor Summary
2. Hydrogen Demand & Supply
3. **Supply Costs & Cost-Competitiveness**
4. National Strategies & Regulation
5. Actions Needed

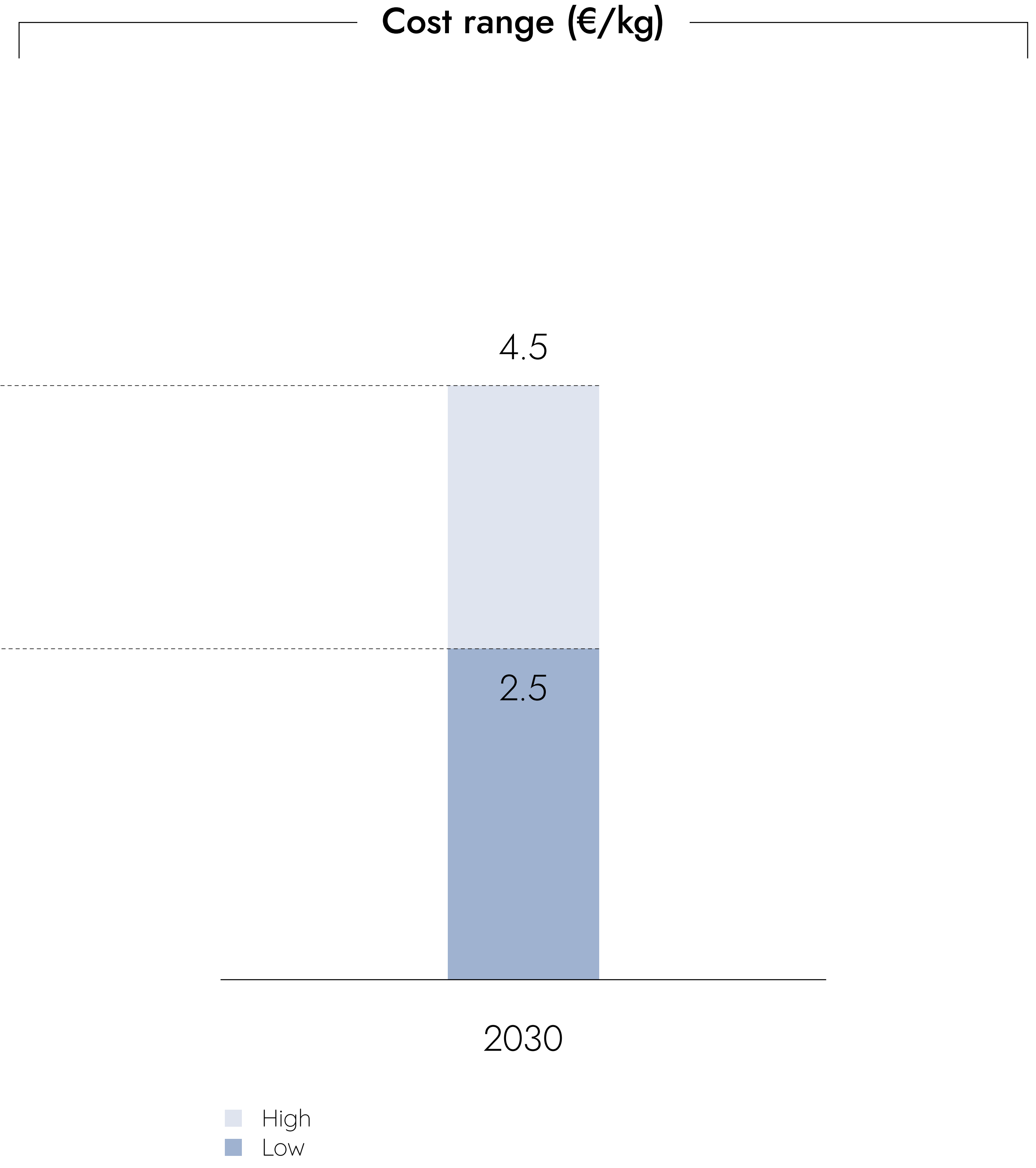
This section explores the costs of hydrogen production and delivery for this corridor and their competitiveness with fossil fuels

	Hydrogen production cost	**Hydrogen delivered costs**	**Comparison with fossil alternatives**
Key Questions Answered	What **is the range of production costs** achieved by the corridor **in 2030 and 2040**?	Based on a **case-study of hydrogen supply** from South-Eastern Romania to Germany: – What are the **full costs of firm hydrogen delivery** after accounting for **transport** and **storage** costs? – What **cost levers** are available to lower the cost of hydrogen delivery?	How **competitive** is hydrogen supply from this corridor compared to fossil fuel alternatives?
Content Material	 SUPPLY COSTS & COST-COMPETITIVENESS By 2040, as supply options increase and scale up, production costs decrease to a range from 1.7 to 3.1 €/kg SUPPLY COSTS & COST-COMPETITIVENESS In 2030, the corridor offers access to hydrogen production ranging in costs from 2.5 to 4.5 €/kg Hydrogen Production Cost Range [2030]	 SUPPLY COSTS & COST-COMPETITIVENESS / CASE STUDY Applying cost reduction levers to the Romania-to-Germany case study lowers delivery costs significantly keeping hydrogen cost-competitive	 SUPPLY COSTS & COST-COMPETITIVENESS Hydrogen costs are cost-competitive with fossil fuel alternatives by 2030, and lower by 2040
Key Findings & Results	– **By 2030**, the corridor provides access to hydrogen production costs of **2.5 to 4.5 €/kg**. – **By 2040**, hydrogen production costs decrease to the range of **1.7 to 3.1 €/kg**.	– Several **cost reduction levers** can be applied to **lower the costs of hydrogen delivery**. – For the Romania-to-Germany case study, **these levers achieve delivery costs that are low and cost-competitive**.	– **Hydrogen costs are competitive with fossil fuel alternatives** both in 2030 and 2040. – Fossil fuel costs are subject to **significant uncertainty**.

In 2030, the corridor offers access to hydrogen production ranging in costs from 2.5 to 4.5 €/kg

Hydrogen Production Cost Range [2030][1, 2, 3]





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1 Cost curves are based on a bottom-up estimate of supply volumes per country and hydrogen production type. No transport or storage / firming cost are included.

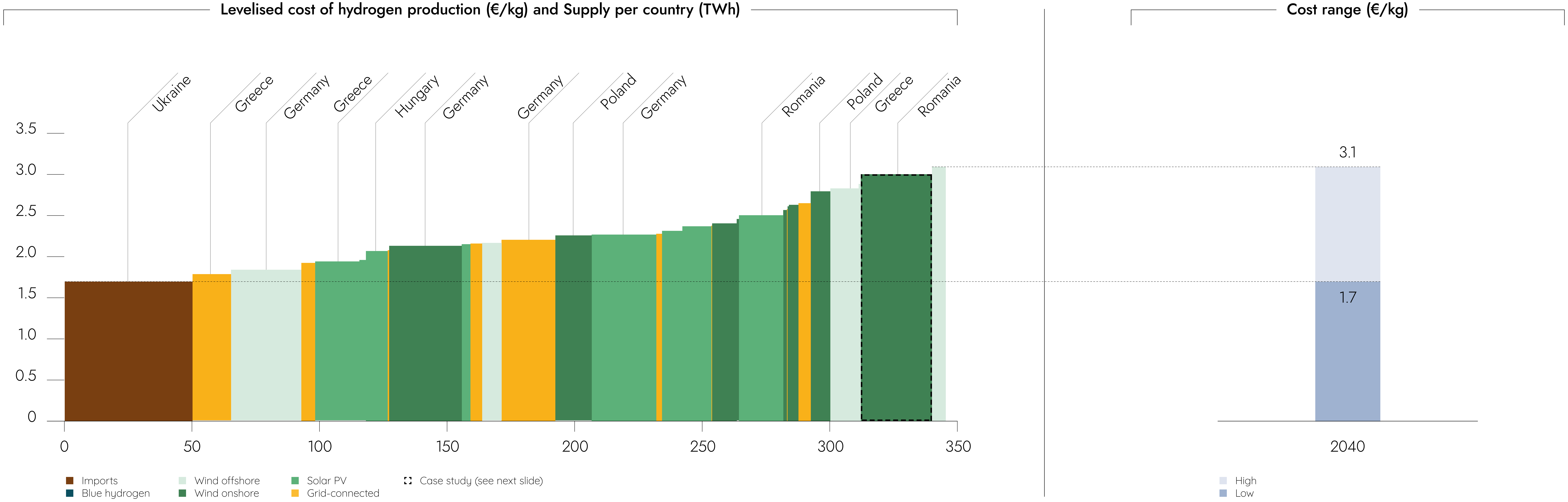
2 *Dedicated hydrogen* production costs are based on renewable technology and electrolyser costs, and country-specific capacity factors and discount rates.

3 *Grid-connected hydrogen* production costs are determined based on costs of a mix of dedicated green hydrogen (solar, onshore wind, offshore wind) and adjusted for grid-connection costs.

4 *Blue hydrogen costs* are subject to significant uncertainty in natural gas prices. Our analysis adopts natural gas price levels based on market conditions before Russia's invasion of Ukraine. While natural gas prices have skyrocketed since, there remains significant uncertainty on near- and medium-term European price trends and supply options. As a result, our analysis adopts the IEA's Outlook 2021 price forecast developed pre-invasion, with costs of 28 €/MWh in 2030 and 13 €/MWh in 2040.

By 2040, as supply options increase and scale up, production costs decrease to a range from 1.7 to 3.1 €/kg

Hydrogen Production Cost Range [2040][1, 2, 3]



1-3 See previous slide

Hydrogen delivered costs, including transport and storage costs, can be kept low by applying cost reduction levers

1 This analysis assesses a **case study** of hydrogen supply from South-Eastern Romania to industrial offtakers in Germany **to explore how the costs of firm hydrogen delivery can be lowered**.

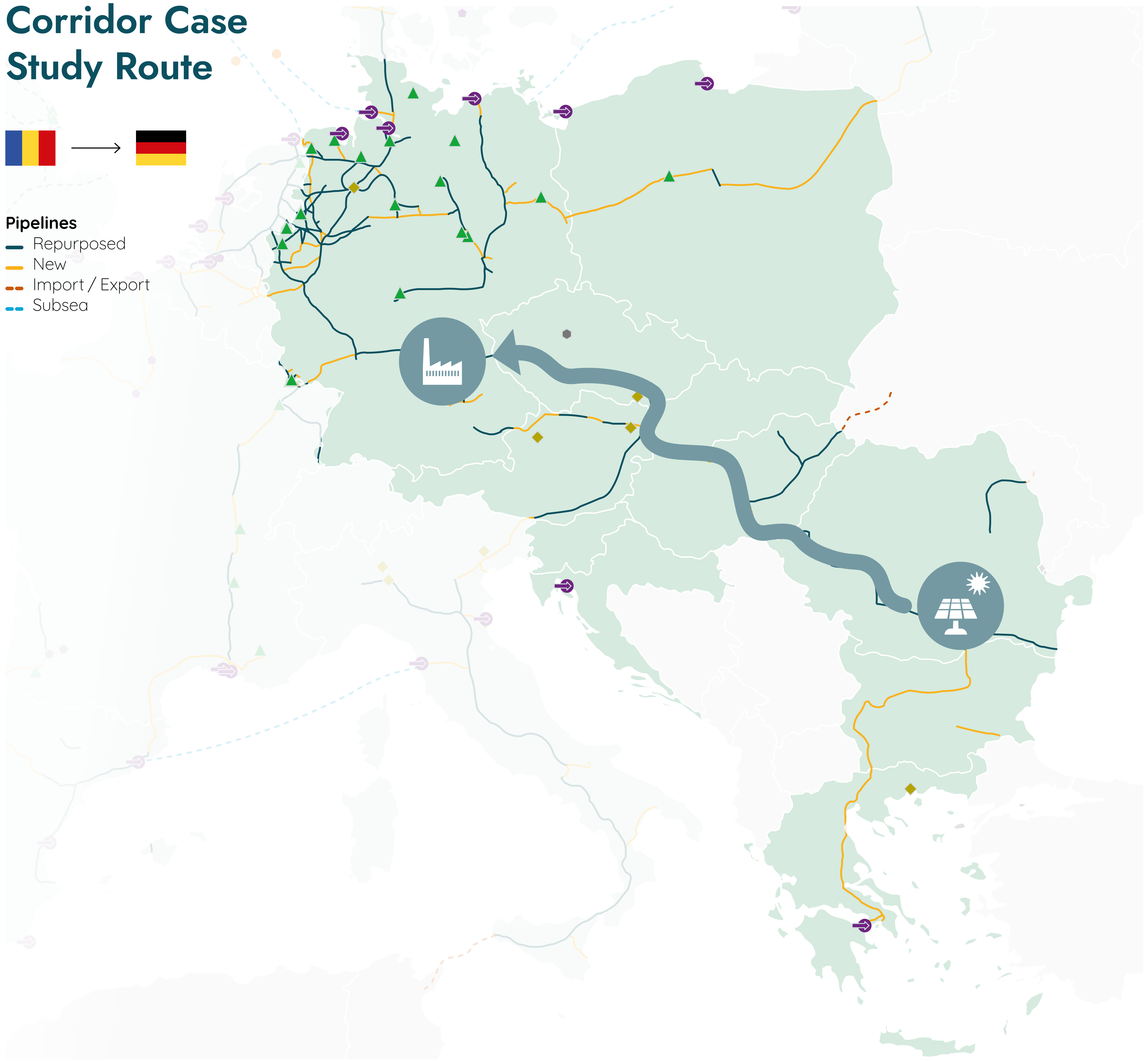
2 To assess the full cost of firm hydrogen delivery to Germany, **transport and storage costs are added to the cost of hydrogen production from Romania**.

Production Costs + Transport Costs + Storage Costs (firming costs) = Delivered Costs

3 Several **cost reduction levers are applied to lower firm delivery costs**, including optimised system operation, battery storage use, cost of capital reductions, among others.

4 **These cost reduction levers achieve sufficient cost savings to keep firm hydrogen delivery costs low and cost-competitive.**

Corridor Case Study Route



Applying cost reduction levers to the Romania-to-Germany case study lowers delivery costs significantly keeping hydrogen cost-competitive

Cost of Hydrogen Delivered (€/kg) in 2030[1, 2, 3]

Cost reduction levers applied to case study of hydrogen transport from Romania to Germany **enable firm delivery costs to be reduced significantly**.

- **In 2030** (shown on the left), the cost of delivered hydrogen can be lowered by ~60% (2.5 vs. 6.0 €/kg).
- **In 2040**, hydrogen delivered costs can be reduced by 60% (1.8 vs. 4.5 €/kg).

Delivered Costs (€/kg)
(before and after cost levers)

	2030	2040
Before costs lever	6.0	4.5
After costs lever	2.5	1.8

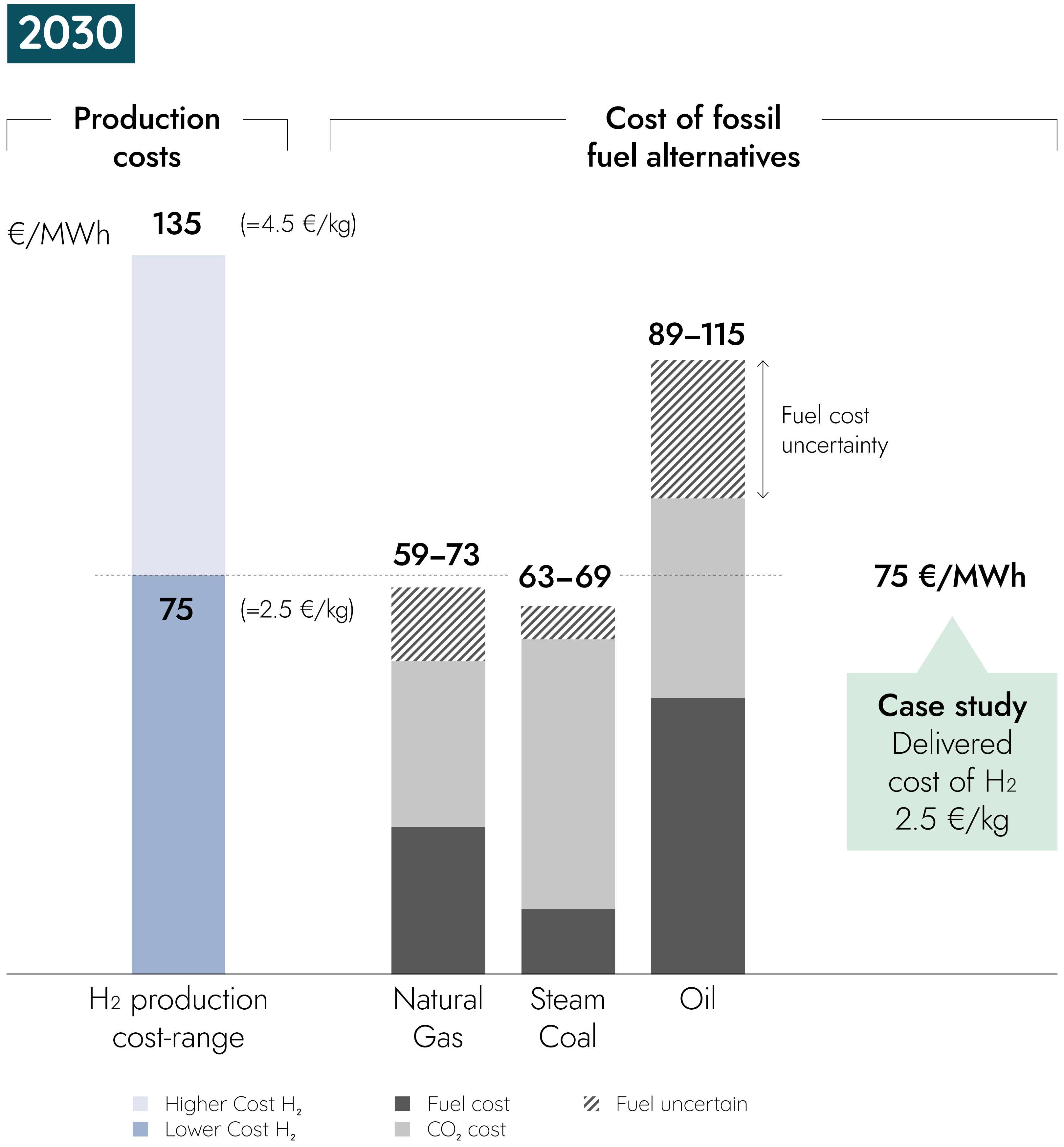
---

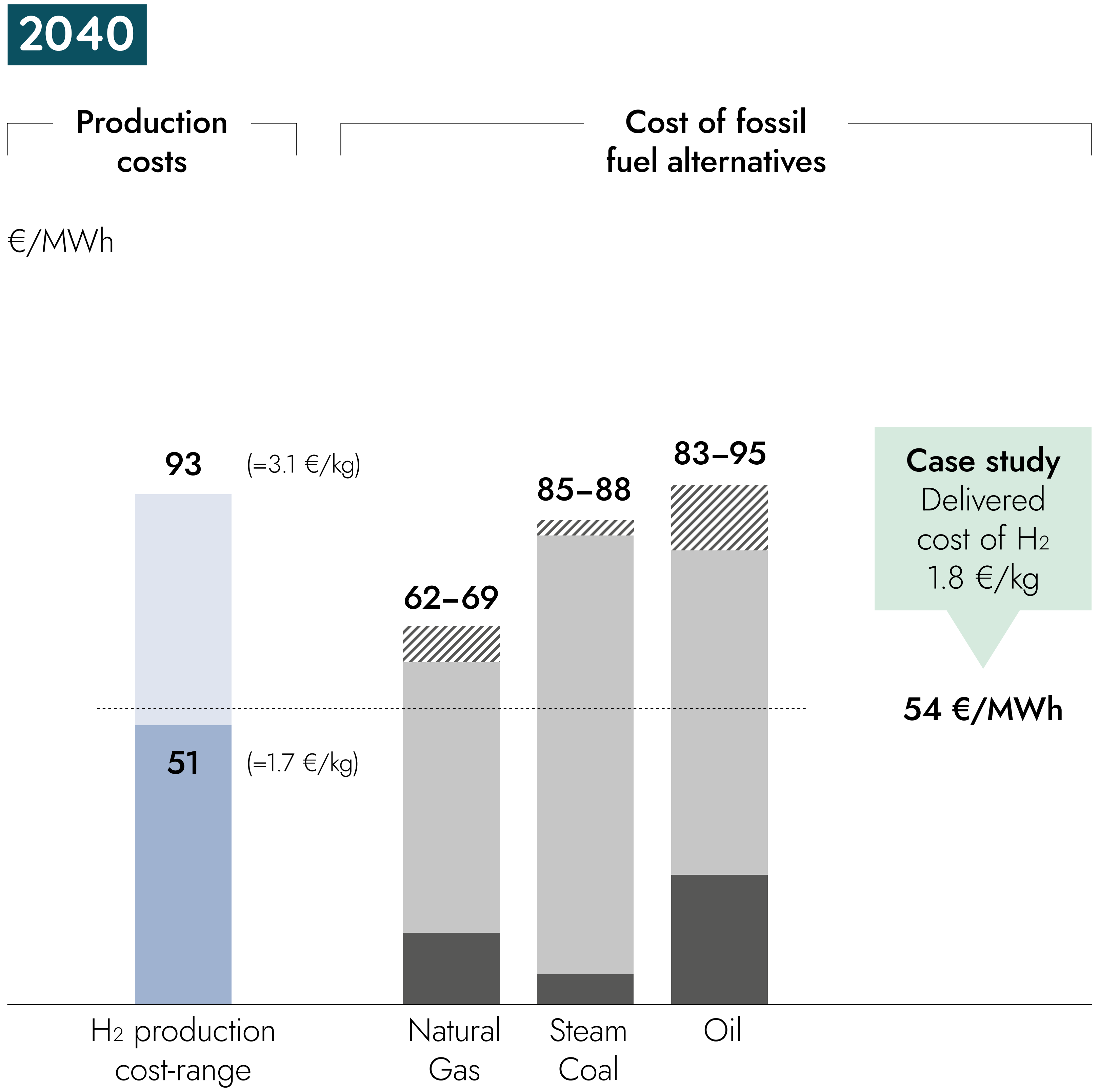
[1] *Transport costs* are based on several parameters including the type of pipeline (repurposed vs. new), transport distance and full-load-hour production on that pipeline. *Firming costs* are based on additional storage cost required to deliver hydrogen at the equivalent of 8,000 full-load hours.

[2] *Optimised system sizing* refers to right-sizing of solar PV and electrolyser capacity to increase full load hours. Similarly, *battery storage operation* enables an increase in the full load hours. *Power electronics savings* refers to the removal of the inverter of the solar PV modules to reduce system cost. Reduced cost of capital refers to the use of foreign investment to reduce the WACC from 8 to 6%.

[3] In some instances, cost reduction levers may result in cost increases for certain cost-components. For example, an increase in production costs at the same time as a decrease in firming costs. These cost increases and decreases can result in connection lines that do not directly connect one step to the next.

Hydrogen costs are cost-competitive with fossil fuel alternatives by 2030, and lower by 2040





By 2030, the low range of hydrogen production costs are **competitive with natural gas and coal, and lower than oil alternatives**.

By 2040, the low-to-medium range of hydrogen costs are **materially lower than all fossil alternatives**, while the medium-to-high range are cost competitive.

Hydrogen delivered costs from the Romania-to-Germany case study are competitive to natural gas in 2030 (27% higher) and 2040 (13% lower).

Natural gas prices are still uncertain due to recent price spike as a result of the Russian invasion of Ukraine.

Note: Prices for fossil alternatives (2030/2040): Natural gas (pre-invasion): 28/13 [€/MWh], Coal: 123/5.6 [€/MWh], Oil: 52/24 [€/MWh]. Natural gas prices levels are based on market conditions before Russia's invasion of Ukraine. While natural gas prices have skyrocketed since, there remains significant uncertainty on near- and medium-term European price trends and supply options. As a result, our analysis adopts the IEA's Outlook 2021 price forecast pre-invasion developed pre-invasion. Prices in 2040 are significantly lower than in 2030 because of demand-supply conditions. By 2040, decreased demand for fossil fuels would lower prices. [Source: International Energy Agency, Outlook 2021 (IEA)] and fuel-cost uncertainty is shown with +50% range]

Note: For comparison purposes, cost of H_2 has been converted from "per kg" to "per MWh"
- 1 €/kg = 30 €/MWh (based on LHV of 33.3 kWh/kg)

Competitiveness of hydrogen highly dependant on CO_2-prices as they make up a significant part of fossil fuel costs.
- CO_2 price 2030: 130 €/t
- CO_2 price 2040: 205 €/t

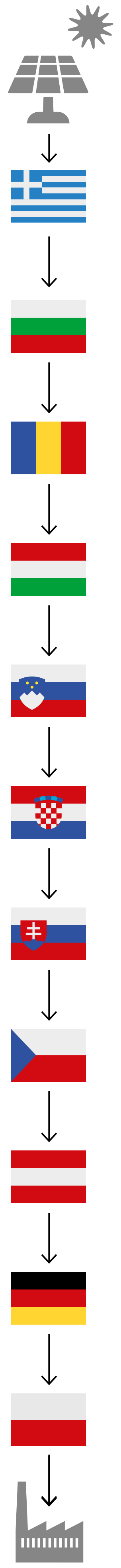
CORRIDOR E

East and South-East Europe

Agenda

A selection of countries have developed national strategies. Moving forward, the development of regulation is key to enable infrastructure investment.

Pre-RePowerEU targets[2]



	National Hydrogen strategy (NHS)	Network regulation & policy	Funding[1] (bn €)	Highlights
Greece	– In 2020, the government formed a Committee to work on NHS. The final draft of the NHS is expected in Q2 2022.	– N/A		– H_2 in shipping, power, production from renewable electricity and H_2 related R&D
Bulgaria	– No specific national hydrogen strategy, but consideration of role for hydrogen in NECP	– N/A		– 20 MW H_2 refuelling stations are planned and a demand of 32 GWh in transport by 2030
Romania	– Hydrogen strategy to be published in 2022	– N/A		– Project with 2 x 20 MW electrolysers powered by solar-PV parks is under development
Hungary	– 240MW of electrolyser capacity – Demand seen in industry and transport sector	– Min. 2% volume blending to natural gas grid		– Low carbon and renewable H_2 planned – €5.3 m for project to store H_2 underground
Slovenia	– In NECP is set indicative target to have 10 % of renewable methane or hydrogen in the network (2030)	– TSO is obliged to prepare the plan for acceptance of H_2		– Foreseen H_2 demand sectors: Transport (2030), buildings, industry (NECP)
Croatia	– Foresees demand in industry, buildings, transport and power, with a supply potential of 1.3 GW electrolysers	– N/A		– First production site by 2025
Slovakia	– H_2 used in the chemicals, petrochemicals, steel and heating industries as well as in transport	– N/A		– Use H_2 in industries/areas impossible or not cost-effective to directly engage electricity
Czech Republic	– Focus **Transport**, then **energy** & **chemical** industry – Production also CCS and nuclear – **Import and transit country** for H_2 from the south	– N/A		– **H_2-Readiness** of gas transmission system is urged, due to potential role in **H_2 transport** from south to north and from east to west
Austria	– NHS is still in discussion; known elements are: 1 – 2 GW electrolyser capacity (2030), use in industry	– H_2 mixtures of up to 10 % within Austria and 4-5 % on entry/exit points are allowed	 0.5	– Production of green H_2 is subsidised – Preferred use to decarbonise industry – Focus: Transport sector and underground H_2 storage
Germany	– National production & import focus due to supply gap – In place **since 2020, currently reviewed towards increasing its ambition** – **10 GW (2030)** electrolyser in coalition plans	– H_2 network potentially opt-in regulated and vertically unbundled – First rules and standards for high pressure pipelines are formulated	 9	– Strong focus on international cooperation to ensure sufficient supply – National funding
Poland	– Focus: Power/heat sector, transport, industry, production, network, creating regulatory framework	– Creation of regulatory framework mentioned in H_2 strategy		– Gas network to be adapted & new build: **"Hydrogen Highway"** (North-South)

Note: Sequencing of countries follows the general corridor direction but does not represent the hydrogen flows.

1 Cumulative public funding amount by the respective state until 2030

2 Strategies and funding is under evaluation of meeting latest targets

■ General funding
■ Supply
■ Network
■ Demand

East and South-East Europe

Agenda

ACTIONS NEEDED

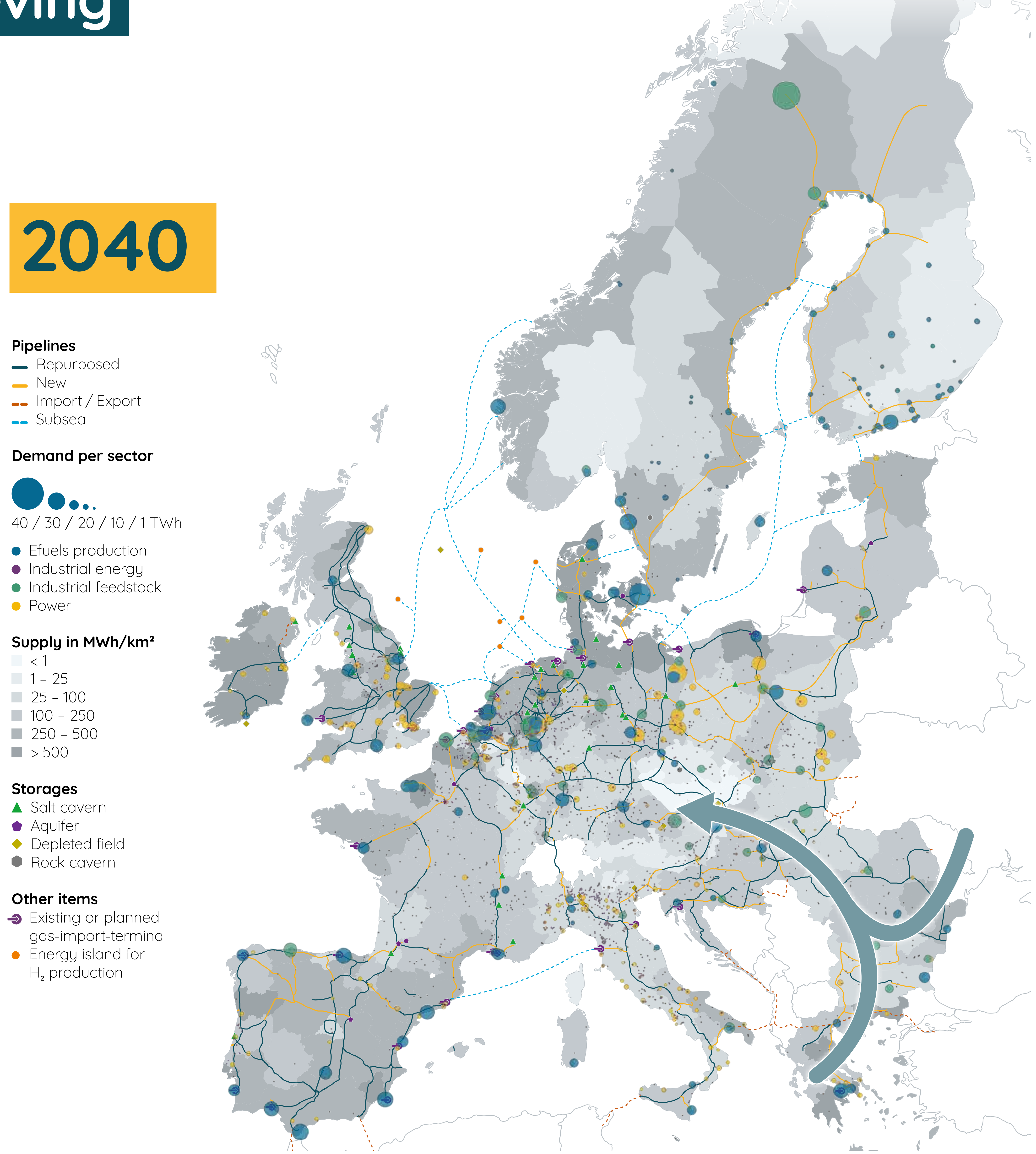
This corridor plays a fundamental role in achieving a European backbone by 2040

The need for this corridor

- The development of **this corridor ensures access to abundant, low-cost hydrogen supply from parts of Eastern and South-Eastern Europe and Ukraine by 2030**, and by 2040 expanding access to additional supply from the region.
- The **decarbonisation of the largest hydrogen demand centers along this corridor** – in **Greece, Romania, Bulgaria, Hungary, Austria and further towards Germany and Poland** – is dependent on the buildout of this corridor by 2030, and its expansion towards 2040.

Actions required

- The buildout of this corridor by 2030 **requires national governments to take clear and concrete actions across**.
- This includes actions associated with **infrastructure development and planning, the development of cross-national initiatives** and **securing access to early funding and long-term, low-cost financing**.



ACTIONS NEEDED

To ensure the development of this corridor by 2030, there is a need for clear and concrete actions

Fostering development of new and repurposed hydrogen infrastructure, for example, by unbundling rules facilitating the efficient use of TSO expertise and services and by allowing the adoption of different vertical unbundling models in the EU, as is the case with natural gas

+

Unlock financing to fast-track hydrogen infrastructure deployment by applying regional regulatory flexibility and other pragmatic financing solutions (including incentivizing the adoption of hydrogen by demand sectors)

+

Simplify and shorten planning and permitting procedures for renewable energy and hydrogen infrastructure projects

+

Intensify energy partnerships with exporting, non-EHB countries like Ukraine, and providing financing support to reduce their cost of capital

+

Facilitate integrated energy system planning of hydrogen, natural gas, and electricity infrastructure supporting the accelerated deployment and integration of renewable energy resources

→ **However, speed will be of essence!**

TABLE OF CONTENTS

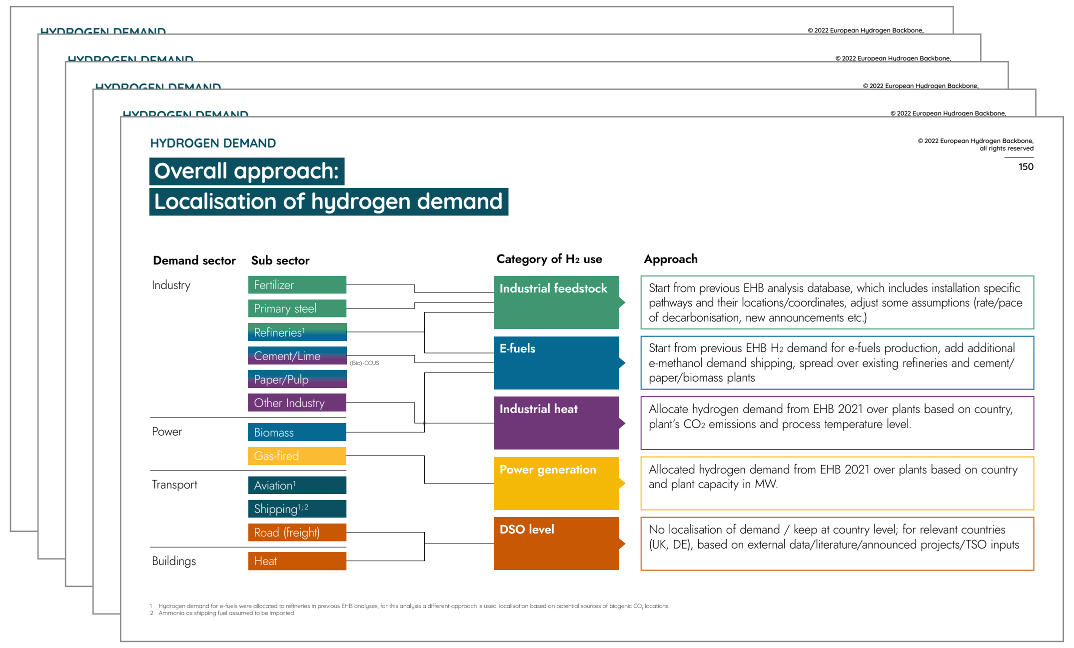
This section describes the methodology used to define hydrogen demand, supply,decarbonisation potential and cost competitiveness

H_2 demand

Objective

Forecast and localise future hydrogen demand.

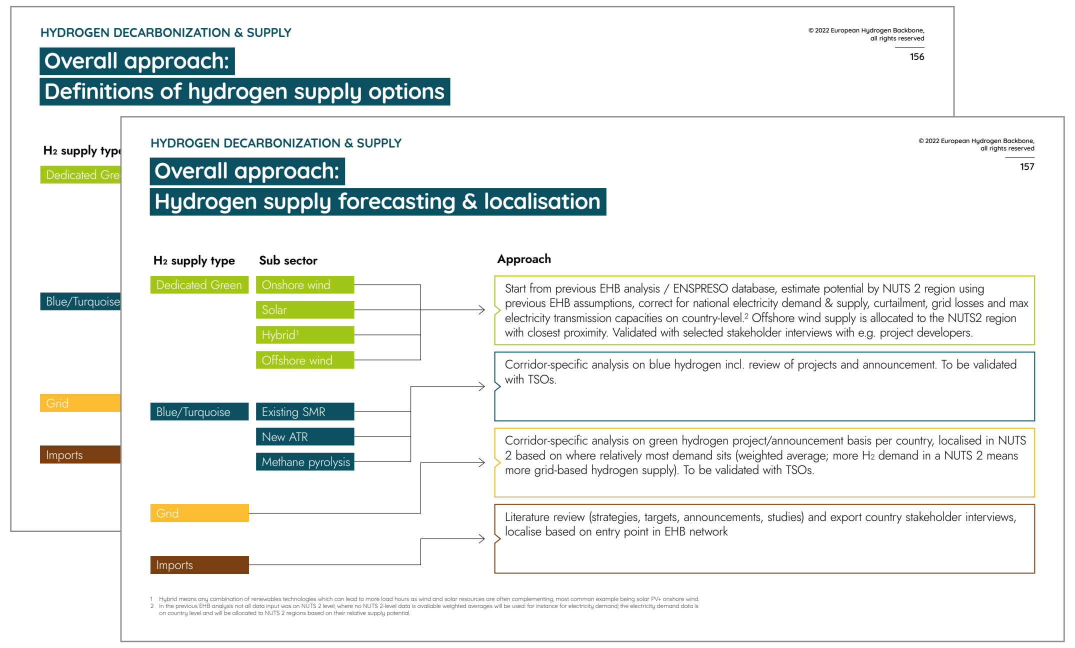
Content Material


HYDROGEN DEMAND

Overall approach:
Localisation of hydrogen demand

H_2 supply & decarbonisation

Forecast and localise future hydrogen supply and **determine the emissions reductions impact of hydrogen adoption**

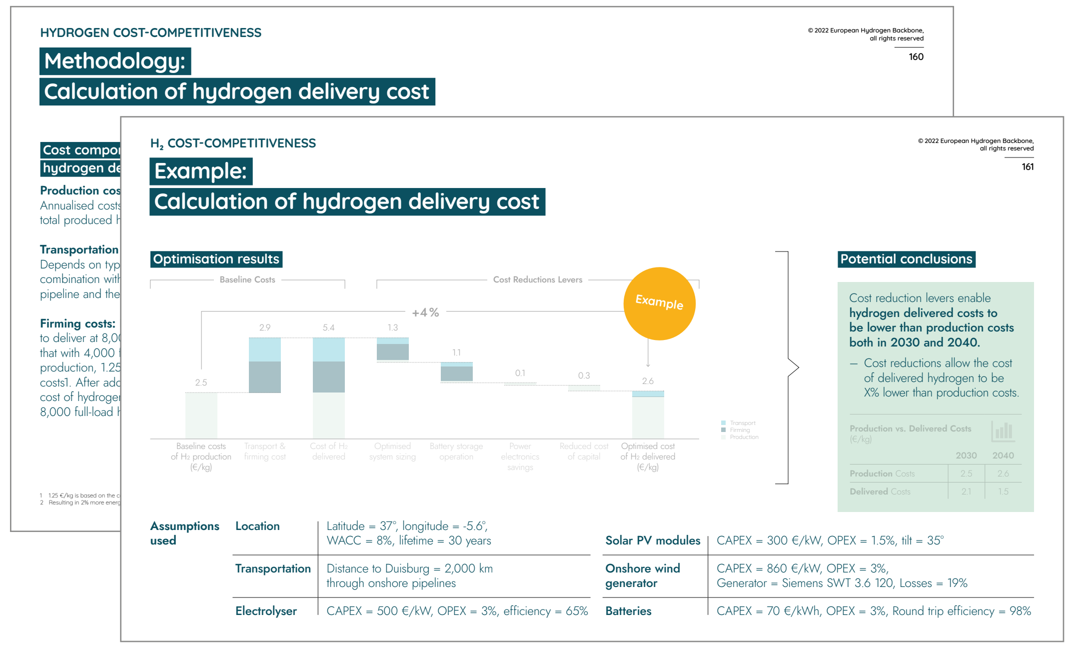

HYDROGEN DECARBONIZATION & SUPPLY

Overall approach:
Definitions of hydrogen supply options

Overall approach:
Hydrogen supply forecasting & localisation

H_2 cost competitiveness

Calculate the cost of delivered hydrogen for different corridor case studies


HYDROGEN COST-COMPETITIVENESS

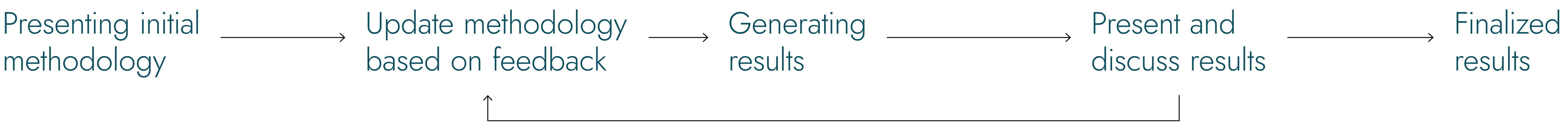
Methodology:
Calculation of hydrogen delivery cost

H_2 COST-COMPETITIVENESS

Example:
Calculation of hydrogen delivery cost

Using the iterative process the working groups provided

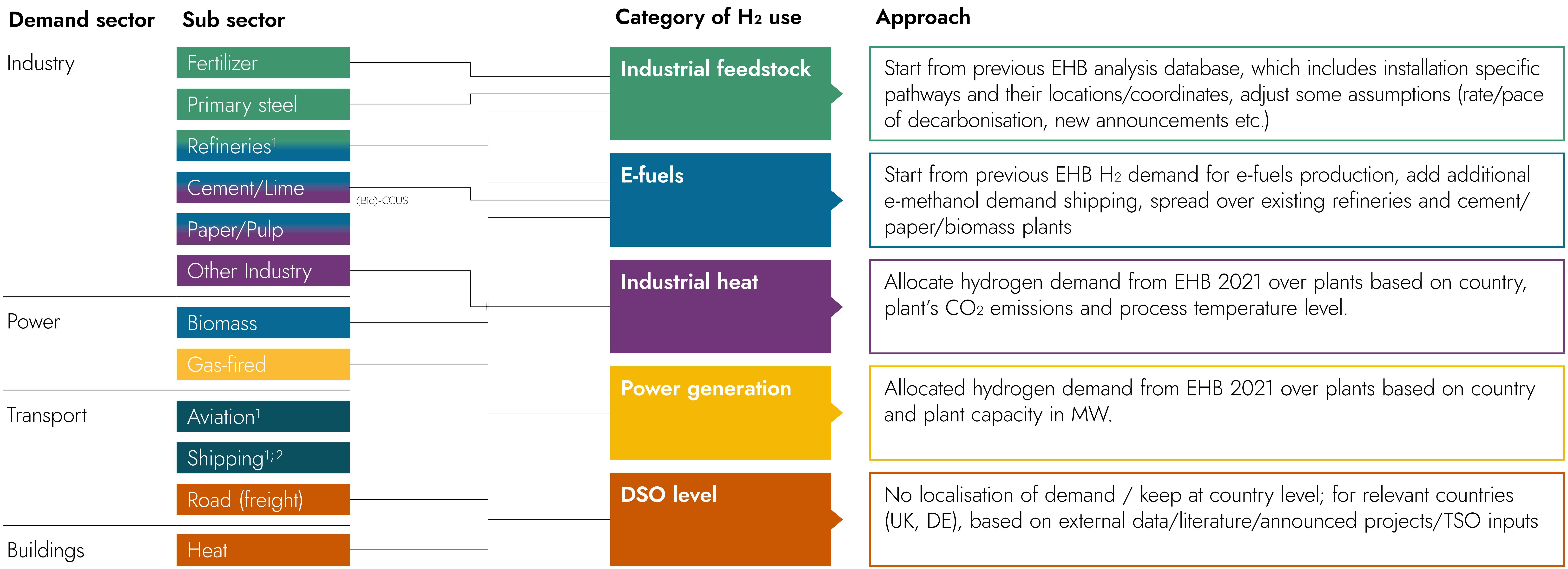
Overall Process


Presenting initial methodology → Update methodology based on feedback → Generating results → Present and discuss results → Finalized results

Detailed methodology

1. **Hydrogen demand**
2. Hydrogen supply & decarbonisation
3. Hydrogen cost-competitiveness

Overall approach:
Localisation of hydrogen demand



Demand sector

Sub sector

Category of H_2 use

Approach

Industry
- Fertilizer
- Primary steel
- Refineries[1]
- Cement/Lime
- Paper/Pulp
- Other Industry

Power
- Biomass
- Gas-fired

Transport
- Aviation[1]
- Shipping[1;2]
- Road (freight)

Buildings
- Heat

Industrial feedstock

Start from previous EHB analysis database, which includes installation specific pathways and their locations/coordinates, adjust some assumptions (rate/pace of decarbonisation, new announcements etc.)

E-fuels

Start from previous EHB H_2 demand for e-fuels production, add additional e-methanol demand shipping, spread over existing refineries and cement/ paper/biomass plants

Industrial heat

Allocate hydrogen demand from EHB 2021 over plants based on country, plant's CO_2 emissions and process temperature level.

Power generation

Allocated hydrogen demand from EHB 2021 over plants based on country and plant capacity in MW.

DSO level

No localisation of demand / keep at country level; for relevant countries (UK, DE), based on external data/literature/announced projects/TSO inputs

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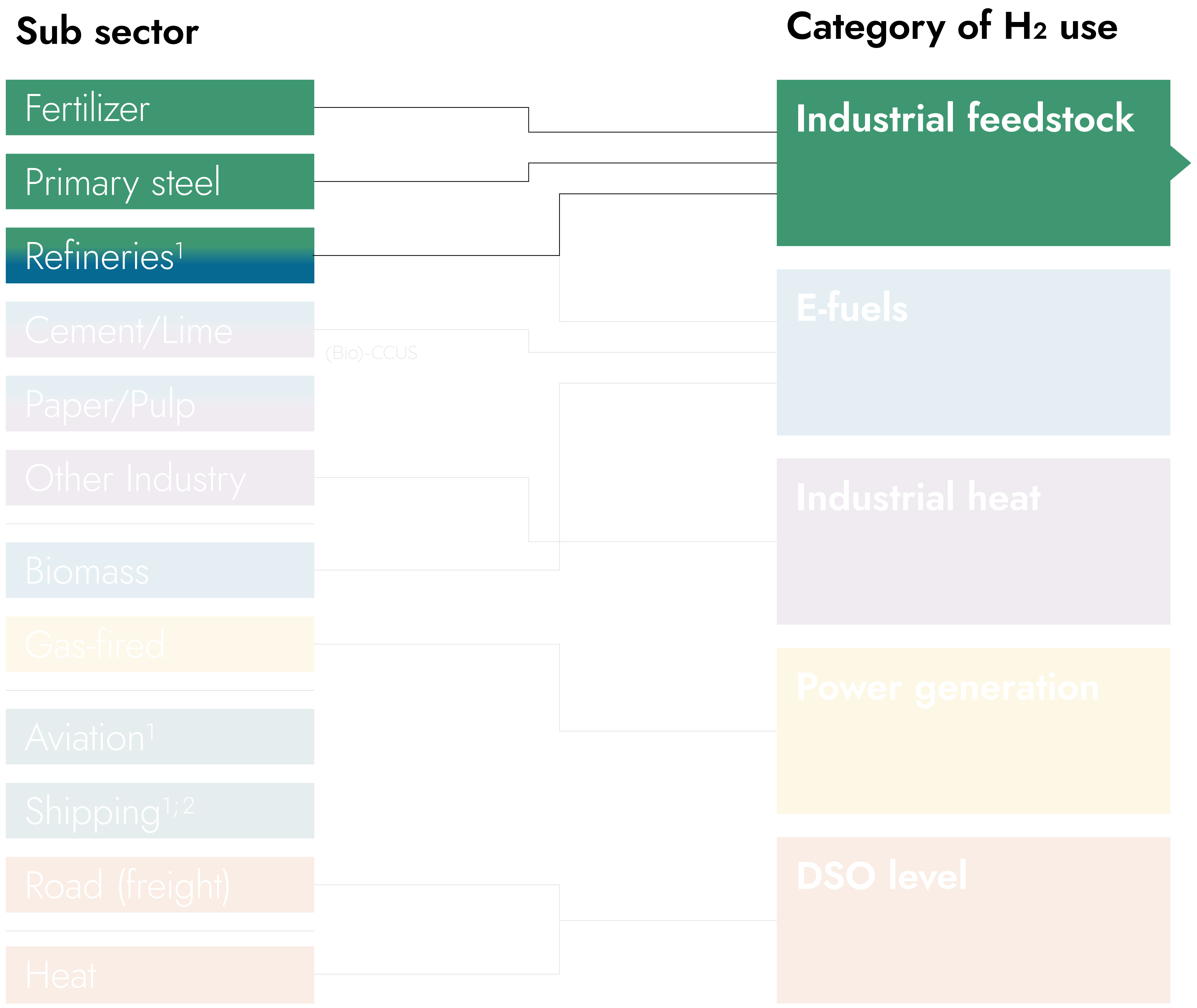
[1] Hydrogen demand for e-fuels were allocated to refineries in previous EHB analyses, for this analysis a different approach is used: localisation based on potential sources of biogenic CO_2 locations.

[2] Ammonia as shipping fuel assumed to be imported

Detailed approach: Demand for industrial feedstock



Approach

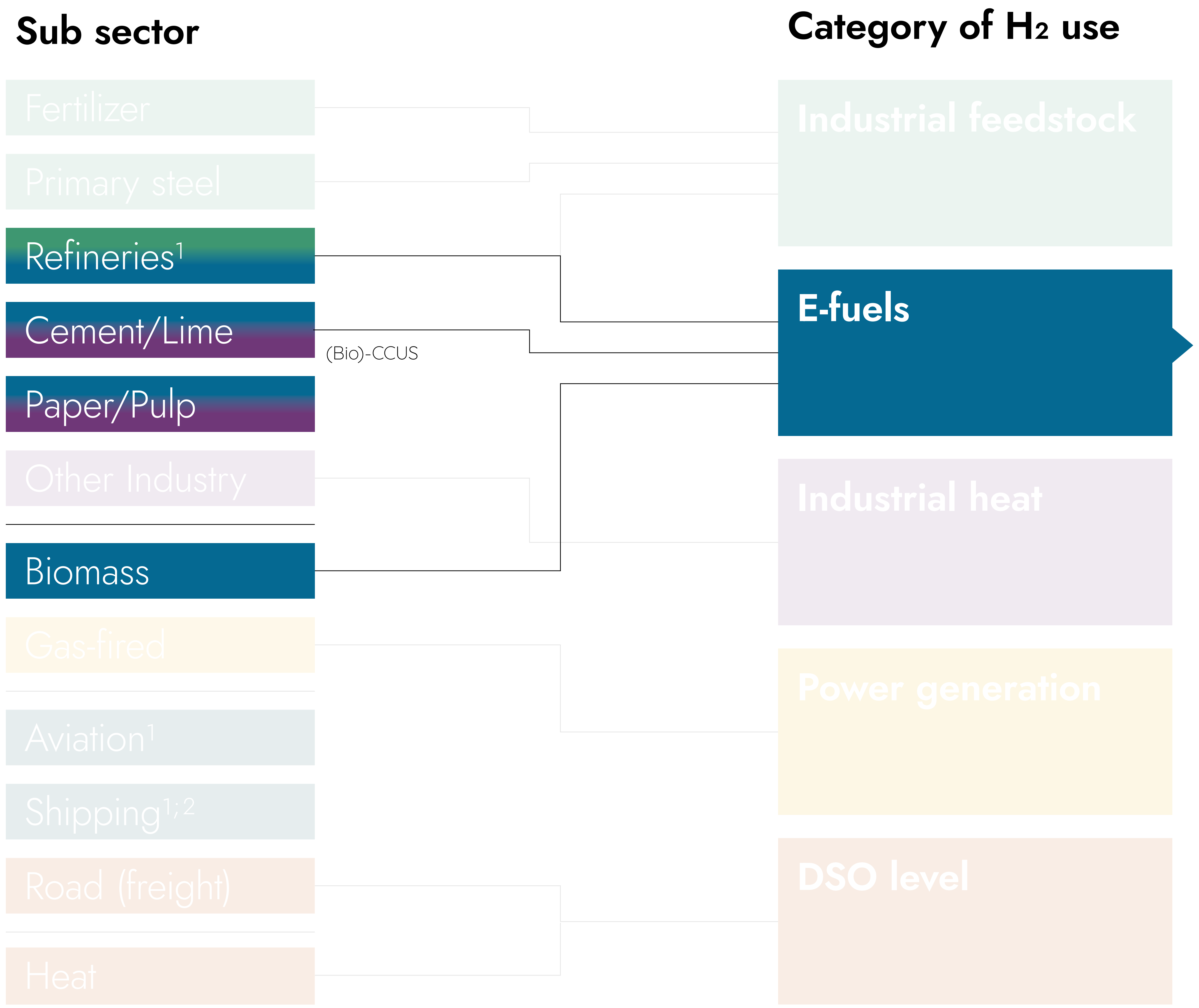
Includes hydrogen demand in refineries for desulphurisation of fossils, fertilisers (ammonia) and primary steel production (as reducing agent of iron ore).

Demand numbers are based on EHB analysis report[1], adjusted for new announcements by fertilizer and steel companies, while for steel also using the Market State and Trends report[2]. For refineries, as in the EHB analysis report[1], hydrogen demand for fossil fuels is reduced to 0 over time.

Localisation based on plant locations from databases EUtl[3], Eurofer[4], Fertilizers Europe[5] and CIEP. *In the bubble maps for visualisation, the hydrogen demand in refineries for desulphurisation of fossils is not included in the industrial feedstock sector.*

Sources:
1 EHB analysis report (June 2021);
2 GfC Market state and trends report (2021) EUtl database (2019);
3 JRC power plant database (2019);
4 Eurofer;
5 Fertilzers Europe; Company announcements, Stakeholder interviews.

Detailed approach: Demand for e-fuels



Approach

Includes e-kerosene for aviation, e-methanol for shipping and hydrogen use for bio, waste and syn-methanol/naphtha production for High Value chemicals (HVCs). HVCs are mostly used for production of plastics.

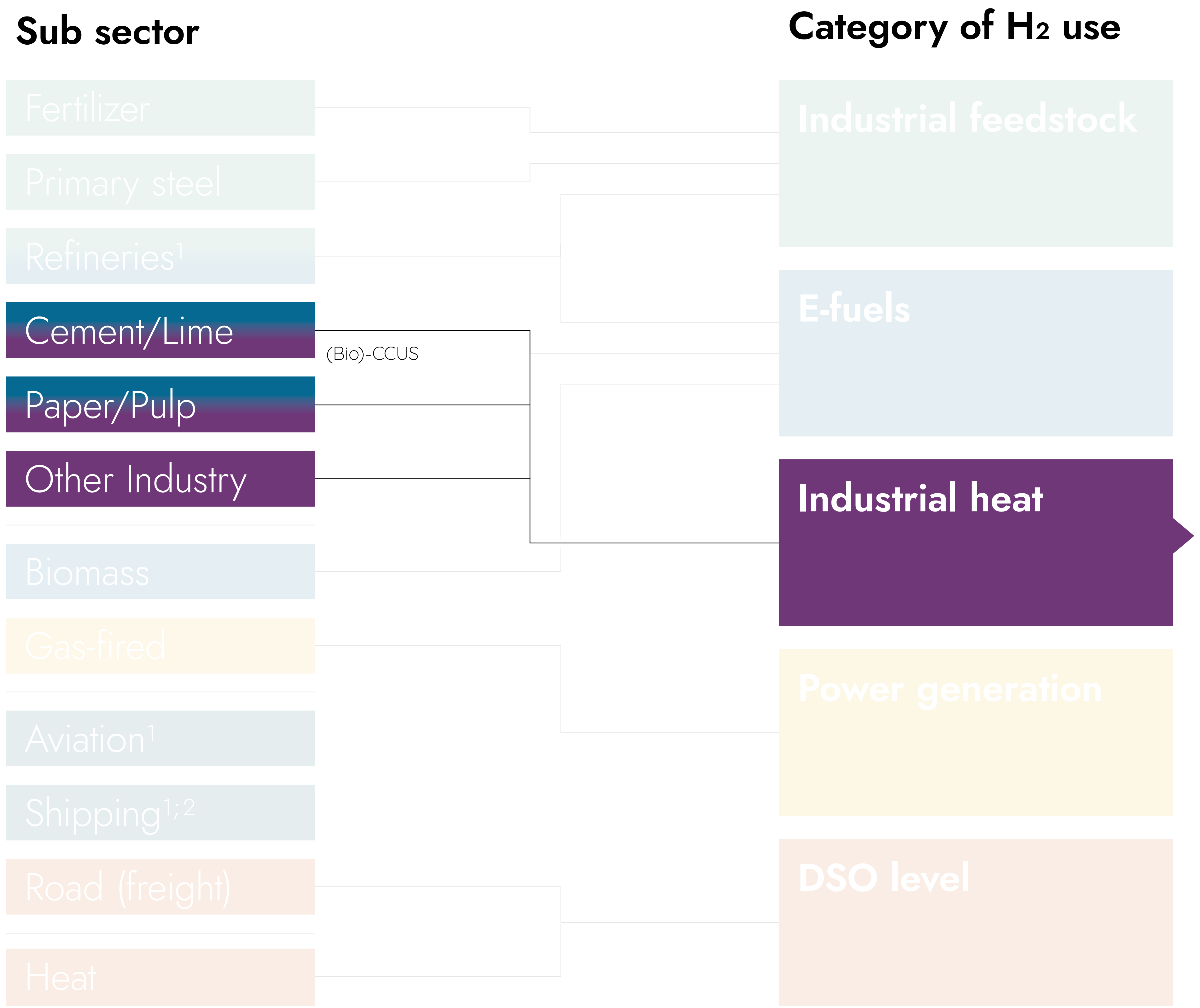
Demand numbers are largely based on EHB analysis report (June 2021)[1]. Addition is e-methanol for shipping (adds ~80 TWh H_2 in 2050), while for HVCs based on recent announcements the share of syn-methanol/naphtha is reduced vs the share of bio/waste fuels (reduces ~100 TWh H_2 in 2050). Note that the latter (bio/waste) also requires hydrogen.

Localisation at current refining installations (75%)[2], and for selected countries (Spain, Portugal, Nordics) also partly at (biogenic) carbon sources for CCU: Biomass power plants[3], Paper and Pulp, Cement and Lime[4] (25%). The selected countries also are allocated a larger share of the hydrogen demand in the refineries, only minor change on non-selected countries.

Sources:
1 EHB analysis report (June 2021),
2 Clingendael International Energy Program (CIEP) (2017);
3 JRC power plant database (2019);
4 EUtl database (2019), company announcements, stakeholder interviews.

Note:
In the bubble maps for visualisation, the efuels category also includes hydrogen demand in refineries for desulphurisation of fossils. For Paper and Pulp, Cement and lime, if a location is selected as e-fuel production location no hydrogen demand is included for industrial heat – as efuels will provide for significant demand numbers already

Detailed approach:
Demand for industrial heat



Approach

Includes hydrogen replacing natural gas for medium temperature (150-500°C) and high temperature (>500°C) industrial heating processes in all industrial sectors (cement/lime, ceramics, paper/pulp, secondary steelmaking, rockwool etc.).

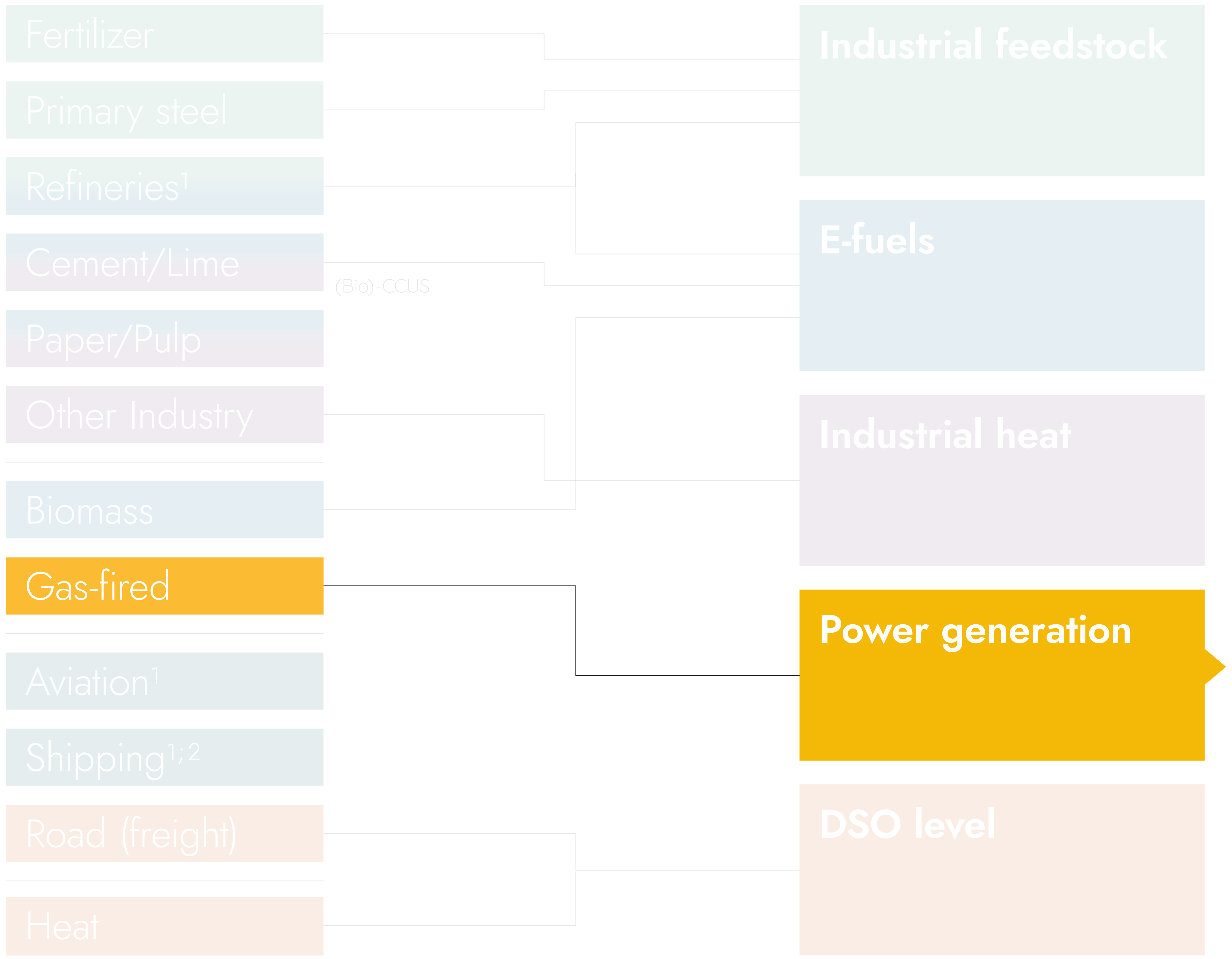
Demand numbers are based on EHB analysis report (June 2021)[1]. Adjustments have been made for a few countries due to country-specifics.

Localisation, hydrogen demand is allocated per country to the different plants based on their relative emissions intensity in 2019[2] per temperature level per country. Process emissions are excluded to calculate these shares. Note that 2019 is chosen as "pre-covid" year.

Sources:
1 EHB analysis report (June 2021),
2 EUtl database (2019);

Note:
For Paper and Pulp, Cement and lime, if a location is selected as e-fuel production location no hydrogen demand is included for industrial heat – as efuels will provide for significant demand numbers already.

Detailed approach:
Demand for power generation



Sub sector

- Fertilizer
- Primary steel
- Refineries[1]
- Cement/Lime
- Paper/Pulp
- Other Industry
- Biomass
- **Gas-fired**
- Aviation[1]
- Shipping[1;2]
- Road (freight)
- Heat

(Bio)-CCUS

Category of H_2 use

- Industrial feedstock
- E-fuels
- Industrial heat
- **Power generation**
- DSO level

Approach

Includes hydrogen replacing natural gas in gas fired powered plants, as included EHB analysis report (June 2021)[1].

Demand numbers are based on EHB analysis report (June 2021)[1]. Adjustments have been made for a few countries due to country-specifics.

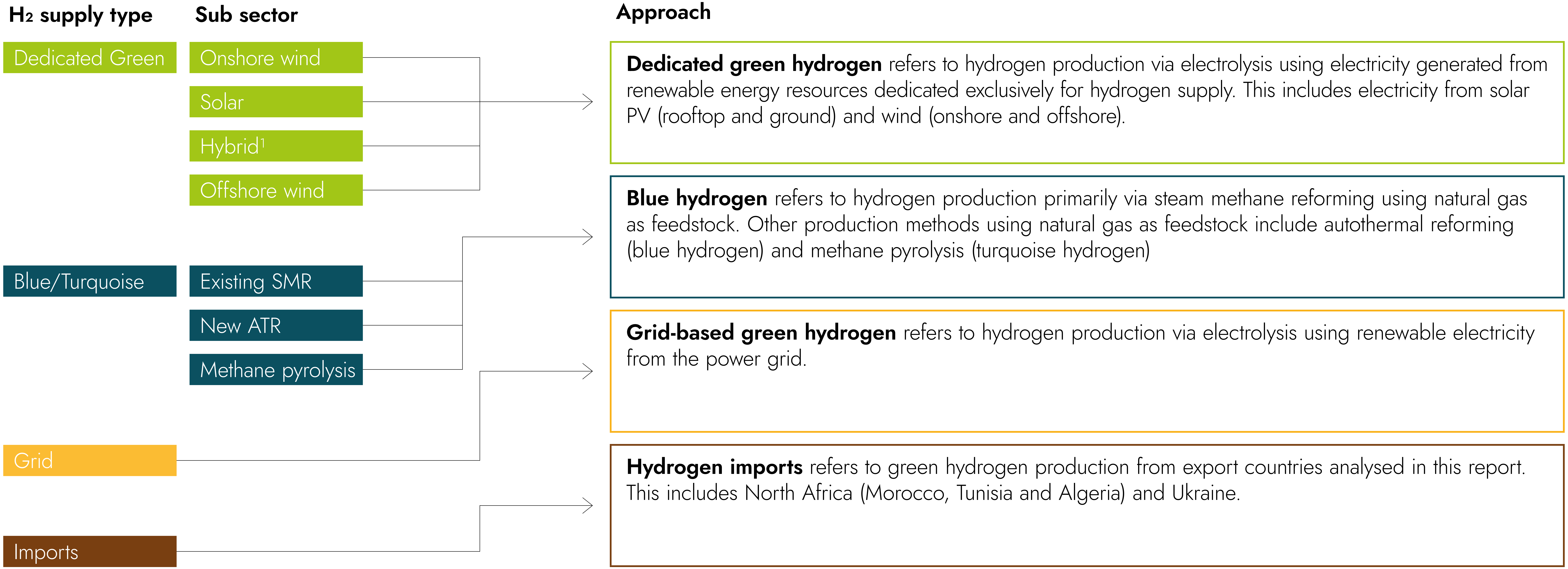
Localisation, hydrogen demand is allocated per country over the plants based on their relative capacity in MW[2].

Sources:
1 EHB analysis report (June 2021),
2 JRC power plant database (2019)

Detailed methodology

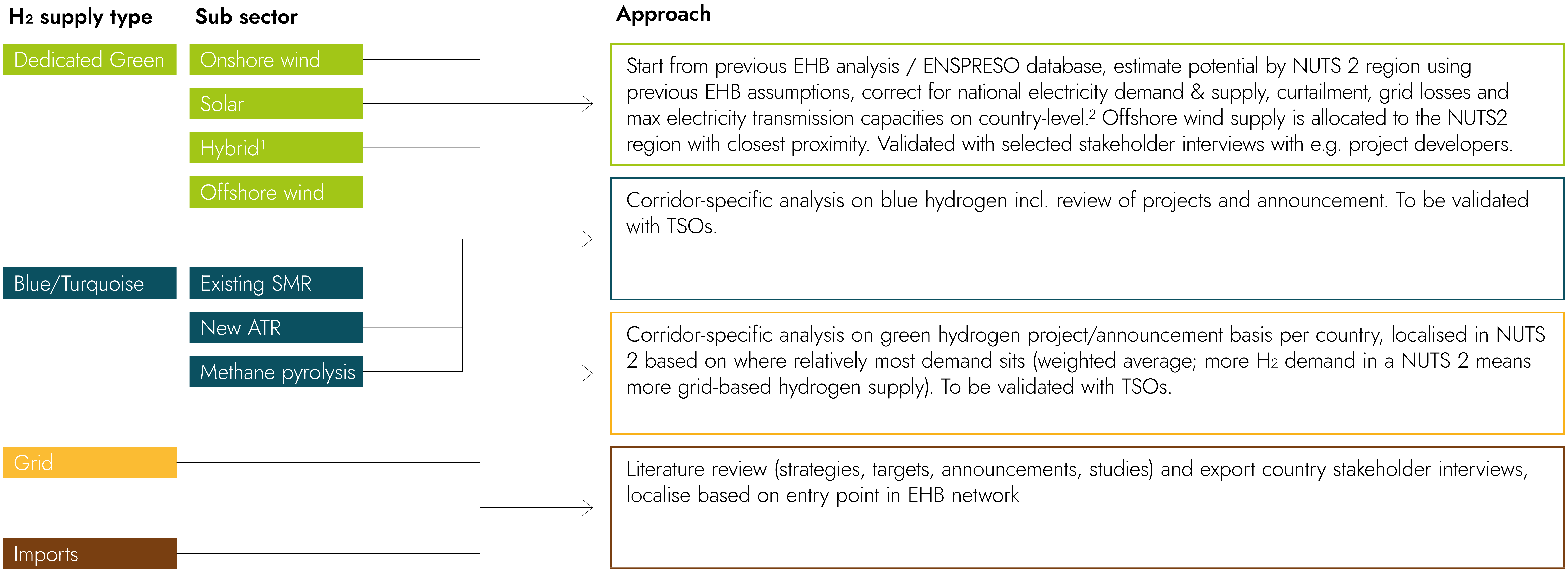
1. Hydrogen demand
2. **Hydrogen supply & decarbonisation**
3. Hydrogen cost-competitiveness

Overall approach:
Definitions of hydrogen supply options



H_2 supply type	Sub sector	Approach
Dedicated Green	Onshore wind Solar Hybrid[1] Offshore wind	**Dedicated green hydrogen** refers to hydrogen production via electrolysis using electricity generated from renewable energy resources dedicated exclusively for hydrogen supply. This includes electricity from solar PV (rooftop and ground) and wind (onshore and offshore).
Blue/Turquoise	Existing SMR New ATR Methane pyrolysis	**Blue hydrogen** refers to hydrogen production primarily via steam methane reforming using natural gas as feedstock. Other production methods using natural gas as feedstock include autothermal reforming (blue hydrogen) and methane pyrolysis (turquoise hydrogen)
Grid		**Grid-based green hydrogen** refers to hydrogen production via electrolysis using renewable electricity from the power grid.
Imports		**Hydrogen imports** refers to green hydrogen production from export countries analysed in this report. This includes North Africa (Morocco, Tunisia and Algeria) and Ukraine.

Overall approach:
Hydrogen supply forecasting & localisation



H_2 supply type	Sub sector	Approach
Dedicated Green	Onshore wind Solar Hybrid[1] Offshore wind	Start from previous EHB analysis / ENSPRESO database, estimate potential by NUTS 2 region using previous EHB assumptions, correct for national electricity demand & supply, curtailment, grid losses and max electricity transmission capacities on country-level.[2] Offshore wind supply is allocated to the NUTS2 region with closest proximity. Validated with selected stakeholder interviews with e.g. project developers.
Blue/Turquoise	Existing SMR New ATR Methane pyrolysis	Corridor-specific analysis on blue hydrogen incl. review of projects and announcement. To be validated with TSOs.
Grid		Corridor-specific analysis on green hydrogen project/announcement basis per country, localised in NUTS 2 based on where relatively most demand sits (weighted average; more H_2 demand in a NUTS 2 means more grid-based hydrogen supply). To be validated with TSOs.
Imports		Literature review (strategies, targets, announcements, studies) and export country stakeholder interviews, localise based on entry point in EHB network

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[1] Hybrid means any combination of renewables technologies which can lead to more load hours as wind and solar resources are often complementing, most common example being solar PV+ onshore wind.

[2] In the previous EHB analysis not all data input was on NUTS 2 level; where no NUTS 2-level data is available weighted averages will be used: for instance for electricity demand; the electricity demand data is on country level and will be allocated to NUTS 2 regions based on their relative supply potential.

Overall approach: Emissions reductions calculation

Demand sector	Sub sector	Approach
Industry	Fertilizer	CO_2-Emission by transforming methane (80% market share) and coal (20%) to hydrogen for ammonia production, resulting in 13.10 tons CO_2 saved by using 1 ton of green hydrogen.
	Primary steel	Using direct-reduction-plants instead of common blast-furnaces 26 tons of CO_2 can be saved by 1 ton of green hydrogen.
	Refineries	By using 1 ton green hydrogen for Hydrocracking or Hydrotreating, Steam-Methane-Reforming is not longer necessary which concludes in 10.92 tons CO_2 saved.
	Energy	A 2.4 times higher calorific value of hydrogen in comparison with methane, which emits 182 g CO_2/ kWh by burning, conclude to 0.43 t CO_2 saved using one ton of hydrogen.
Power	Gas-fired	One ton of hydrogen saves 0.74 ton CO_2 in 2030, 0.46 ton CO_2 in 2040 and 0.27 ton CO_2 in 2050, depending on the total emissions of the electricity mix in that year.
Transport	Mobility	Direct hydrogen use for heavy transport (e.g. 25 t truck) saves 4.375 litres diesel per kg hydrogen, which equals to 11.55 tons CO_2 saved by 1 ton of hydrogen.
	Efuels	Depending on the FLH of synthesis plant (e.g. 4000 h/year) 10.89 tons CO_2 can be saved by using 1 ton of hydrogen considering a diesel engine with 2.64 kg CO_2/ litre diesel as status-quo.
Buildings	Heat	A 2.4 times higher calorific value of hydrogen in comparison with methane, which emits 182 g CO_2/ kWh by burning, conclude to 0.43 t CO_2 saved using one ton of hydrogen.

Detailed methodology

1. Hydrogen demand
2. Hydrogen supply & decarbonisation
3. **Hydrogen cost-competitiveness**

Methodology:
Calculation of hydrogen delivery cost

Cost components of hydrogen delivered

Production costs per kg of hydrogen: Annualised costs of system setup, divided by total produced hydrogen per year.

Transportation costs per kg of hydrogen: Depends on type of pipelines used in combination with full load hours on that pipeline and the length of the pipeline.

Firming costs: Reflecting the additional cost to deliver at 8,000 full-load hours. It is assumed that with 4,000 full load hours of hydrogen production, 1.25 €/kg is added to the total costs[1]. After adding the firming costs, the total cost of hydrogen reflect hydrogen delivered at 8,000 full-load hours to offtakers.

Potential cost reduction levers	Cost factor	Used
Power electronics: Removing the inverter of the solar PV modules, enabling a reduction of 11% in CAPEX, which reduces the production costs.	CAPEX	All
Leveraging foreign investment: Foreign investment will reduce the Weighted Average Cost of Capital. This reduces annualised CAPEX and total production costs[2].		A, B, E
Using integrated electrolysis: Increasing total energy efficiency due to reduction of conversion inefficiencies (DC/AC and AC/DC steps)[3]. Also enabling to replace electrical infrastructure for H_2 pipeline, also reducing the peak capacity cost component of the infrastructure[4]		C
Battery energy storage: Including battery energy storage increases full load hours, and with that reduces the transport and firming costs.	Full Load Hours	All
System optimisation: Optimising electrolyser size and installed capacity of solar and wind to increase full load hours, which reduces transport and firming costs. System optimisation also reduces production costs.		All
Optimise generator capacity off offshore wind turbine based on hydrogen production: Increasing total energy output, leveraging flexibility in transmission capacity of H_2 infrastructure[5]	Energy output	C

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[1] 1.25 €/kg is based on the cost of 5 € to store 1kg of hydrogen for a year, assuming an average of 2 storage cycles. Source: U.S. Department of Energy (2019).

[2] A reduction in WACC is only applied to select corridors; for example, a reduction of 10% to 8% is applied to imports from Tunisia in Corridor A and supply from Romania in Corridor E, while a reduction of 8% to 6% is applied to imports from Spain in Corridor B. No cost reductions are applied to Corridors C and D because the credit rating of its supply countries are already relatively high.

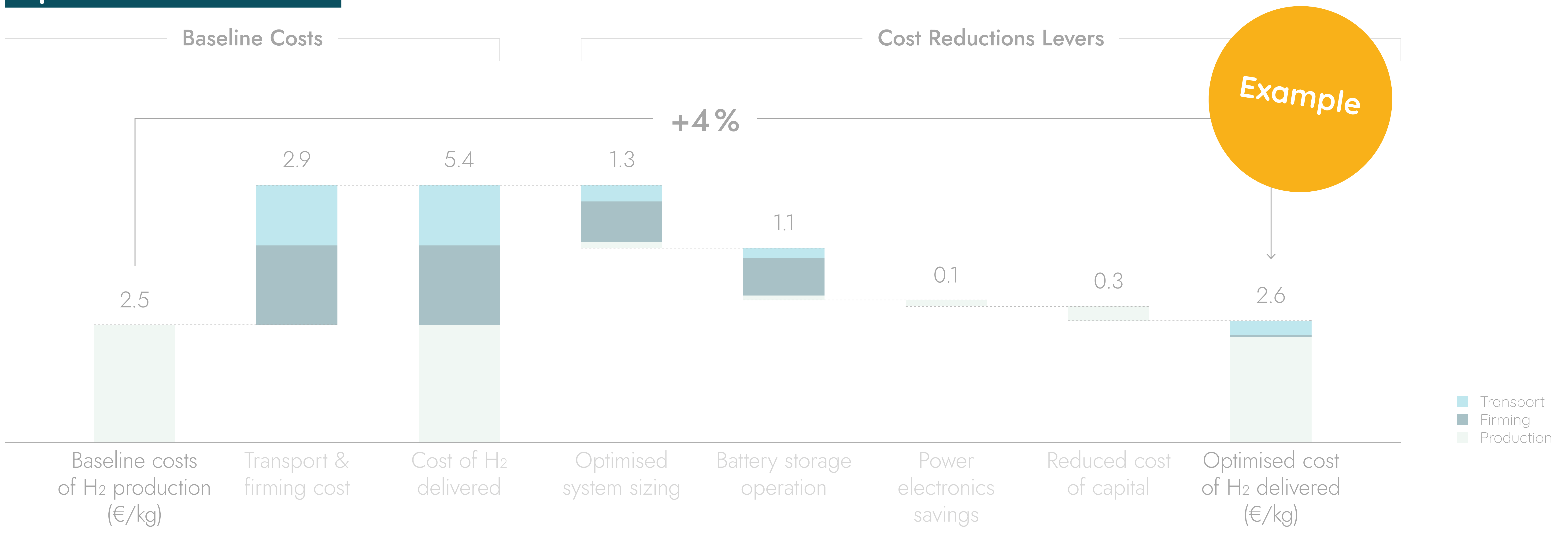
[3] Resulting in 2% more energy output due to reduction of conversion inefficiencies and 3% CAPEX reduction due to avoiding of electrical infrastructure.

[4] Resulting in a 12.4% reduction of offshore infrastructure costs in comparison with full-electric infrastructure.

[5] Resulting in a 5% higher energy yield, based on increasing the generator capacity from 15GW to 16GW.

Example:
Calculation of hydrogen delivery cost

Optimisation results



Potential conclusions

Cost reduction levers enable **hydrogen delivered costs to be lower than production costs both in 2030 and 2040.**

- Cost reductions allow the cost of delivered hydrogen to be X% lower than production costs.

Production vs. Delivered Costs (€/kg)

	2030	**2040**
Production Costs	2.5	2.6
Delivered Costs	2.1	1.5

Assumptions used

Location	Latitude = 37°, longitude = -5.6°, WACC = 8%, lifetime = 30 years	**Solar PV modules**	CAPEX = 300 €/kW, OPEX = 1.5%, tilt = 35°
Transportation	Distance to Duisburg = 2,000 km through onshore pipelines	**Onshore wind generator**	CAPEX = 860 €/kW, OPEX = 3%, Generator = Siemens SWT 3.6 120, Losses = 19%
Electrolyser	CAPEX = 500 €/kW, OPEX = 3%, efficiency = 65%	**Batteries**	CAPEX = 70 €/kWh, OPEX = 3%, Round trip efficiency = 98%