European Hydrogen Backbone

How a dedicated infrastructure can pave the way to large-scale competitive hydrogen for the European market

Enagás, Energinet, Fluxys Belgium, Gasunie, GRTgaz, NET4GAS, OGE, ONTRAS, Snam, Swedegas, Teréga

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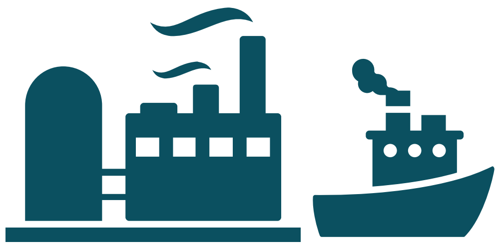
Background and scope

Hydrogen supply, demand, and policy trends are leading to rapidly improving prospects for affordable low-carbon hydrogen

Hydrogen production capacity is ramping up rapidly

- Rapidly declining costs for renewable electricity
- Planned global investments in electrolysers increased from 3.2 to 8.2 GW between Nov 2019 and Mar 2020[1]
- Various industry initiatives: Hydrogen Europe, Hydrogen Council, Clean Hydrogen Alliance

Rising demand as sectors look to fully decarbonise



- Decarbonisation of heavy industrial processes (steel, cement, chemical, refineries)
- Complement electrification in hard-to-abate parts of the transport system (aviation, shipping, heavy duty trucking)
- Long-duration storage to support an electricity system with a large share of wind and solar.

Supported by a clear policy direction at EU-level

- Renewable fuels are one of three central pillars of the EU's Energy System Integration Strategy, together with circular energy systems and electrification[2]
- EU's Hydrogen Strategy launched in July 2020 targets 1 Mt green hydrogen by 2024 and 10 Mt by 2030[3]
- Various financing mechanisms and funds have been announced.

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1. Source: Wood Mackenzie; 2. Source: European Commission, COM(2020)299; 3. Source: European Commission, COM(2020)301

The role of infrastructure

The availability of infrastructure connecting supply and demand is a key condition for widespread use of hydrogen as an energy carrier

Driving hydrogen development past the **tipping point** requires a large-scale infrastructure network that only the EU and the single market can offer

An EU-wide infrastructure will enable transport of hydrogen over **long distances** from areas with large renewable potential to demand centres located in other Member States, as well as **international trade** with EU's neighbouring countries in Eastern Europe, and Southern and Eastern Mediterranean countries

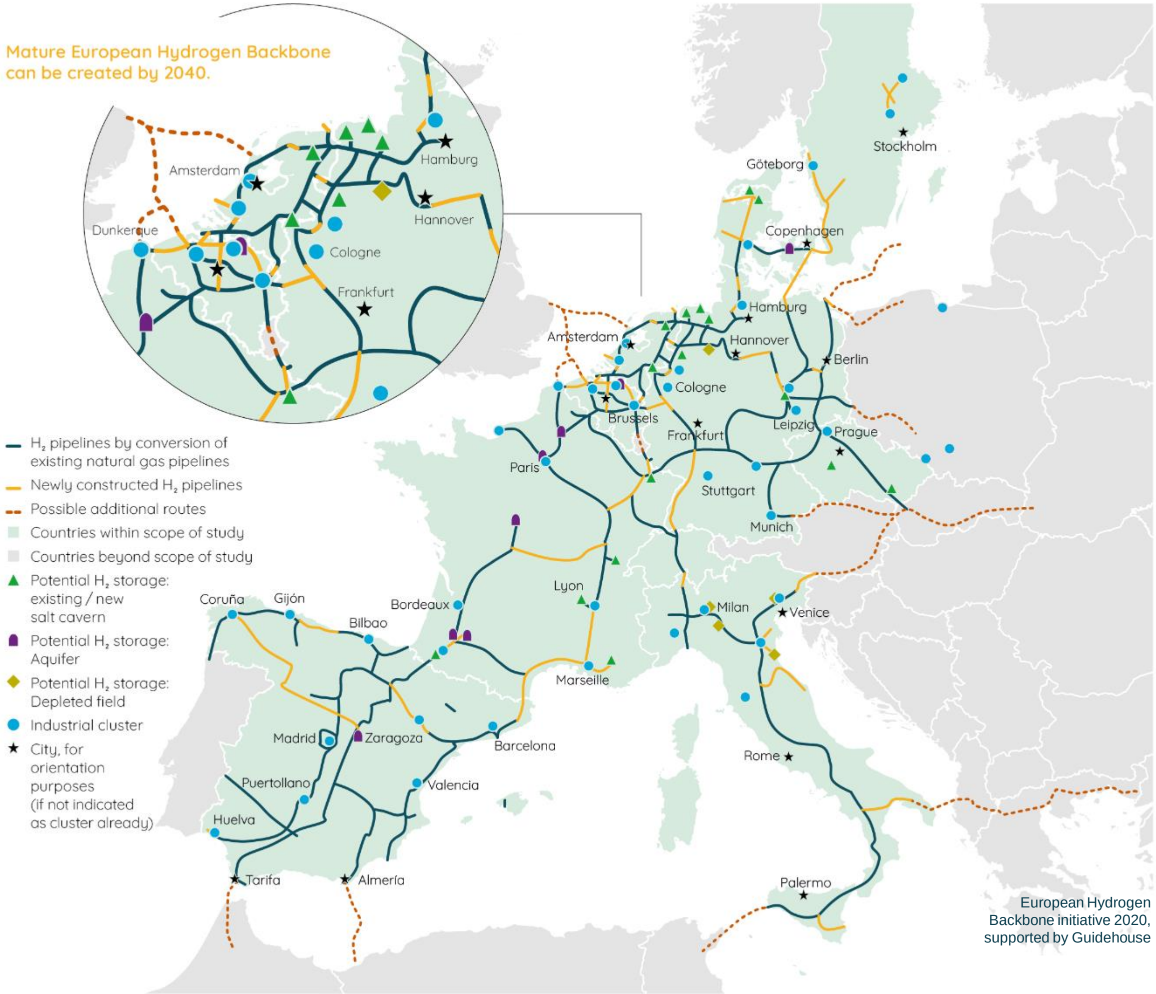
Infrastructure plays a facilitating role within a **full value chain approach**, whereby scale-up of production, infrastructure, and market demand go in parallel to activate a **virtuous circle** of increased supply and demand for hydrogen with reduced supply costs

With increasing demand, an **efficient and interoperable** transport network is needed to create an **open and competitive EU market** that provides clean and safe hydrogen at the lowest cost to end users who value it most

The existing gas grid can be partially repurposed, providing an opportunity for a **cost-effective transition** in combination with limited newly built dedicated hydrogen infrastructure

The European Hydrogen Backbone (“EHB”)

The EHB is a shared vision from eleven TSOs[1] to engage in a truly European undertaking

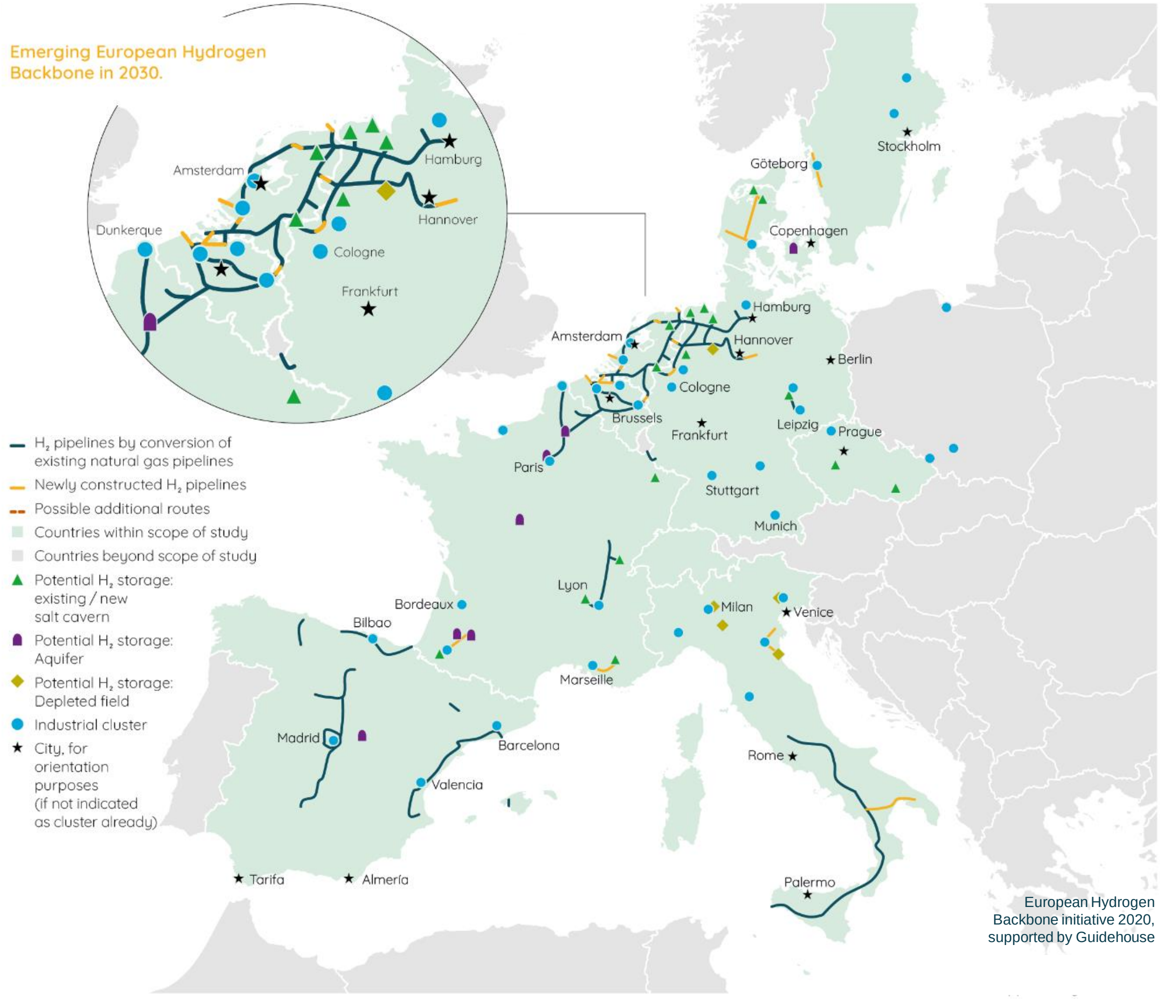


- A proposal for a **dedicated hydrogen transport infrastructure**, connecting supply and demand from north to south and west to east.
- Starting with an emerging 6,800 km pipeline network connecting hydrogen valleys by 2030; then stretching into all directions with a length of about **23,000 km by 2040**, with expected further expansion up to 2050.
- Converted 36- and 48-inch hydrogen pipelines, commonly used for long-distance gas transport in the EU, can provide **7 and 13 GW** (at LHV[2]) of hydrogen capacity per pipeline, respectively.
- The proposed backbone requires an estimated total investment cost of **€27-64 billion by 2040**, based on using 75% repurposed natural gas pipelines connected to 25% newly built dedicated hydrogen pipelines.
- Levelised transport costs amount to 0.09-0.17 €/kg per 1000 km, enabling **cost-effective long-distance transport** across Europe.
- The EHB is an **open initiative** – all European gas infrastructure companies and associations GIE and ENTSOG are encouraged to join in the thinking, to further develop this pan-European undertaking.

1. Includes Enagás, Energinet, Fluxys Belgium, Gasunie, GRTgaz, NET4GAS, OGE, ONTRAS, Teréga, Snam, Swedegas; covering Germany, France, Italy, Spain, the Netherlands, Belgium, Czech Republic, Denmark, Sweden, and Switzerland (indirectly through Fluxys Belgium); 2. LHV: Lower heating value, the energetic value of a gas, after subtracting the heat of vaporisation from the higher heating value.

2030 – Emerging regional networks

Connecting industrial clusters to an emerging 6,800 km infrastructure

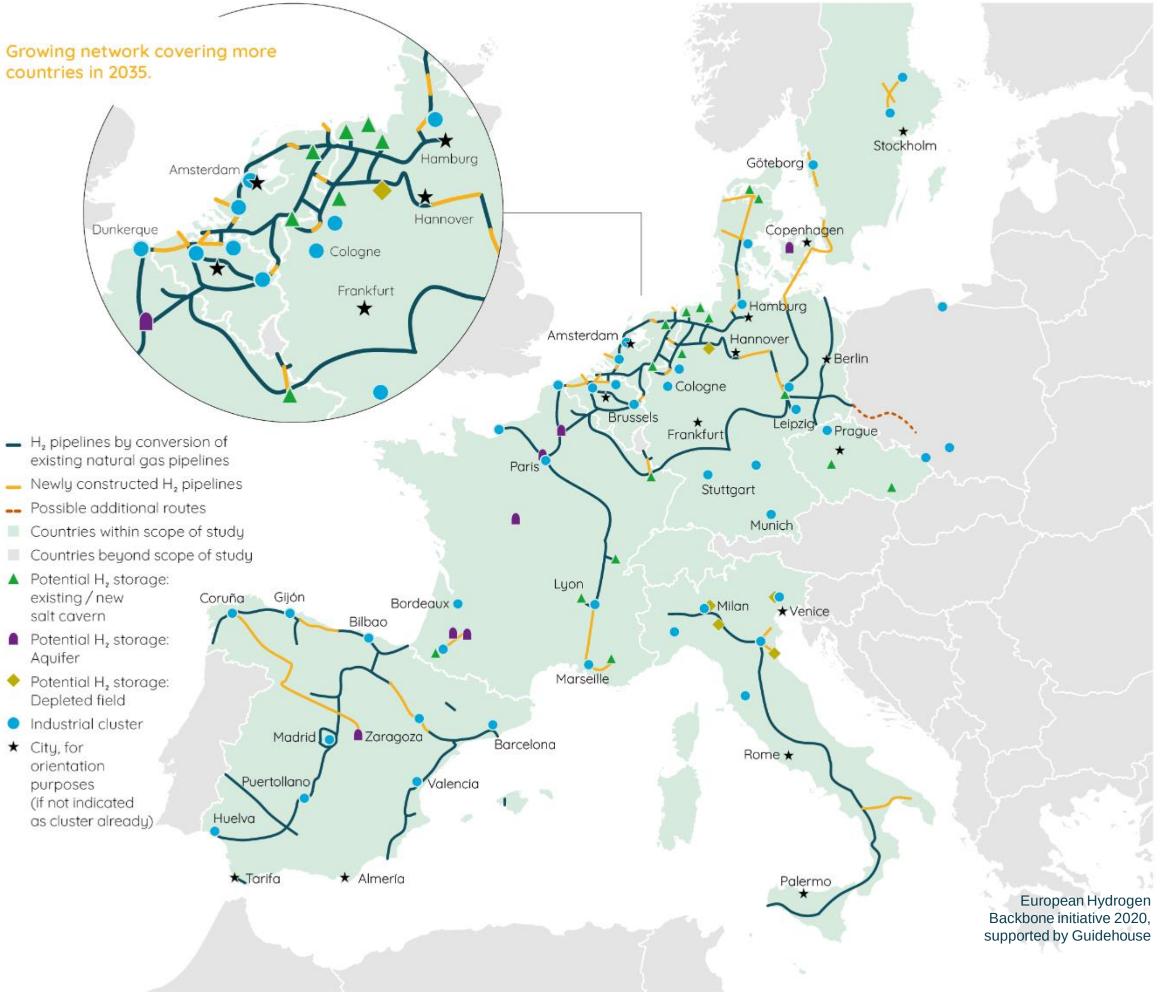


Important developments and corridors

1. By 2030, a dedicated EHB can develop with a length of approximately 6,800 km; consisting mainly of repurposed existing natural gas pipelines. This requires work to start in the 2020s
2. The backbone includes the proposed Dutch and German national hydrogen backbones, with additional branches extending into Belgium and France.
3. Additional regional backbones are likely to emerge in Italy, Spain, Denmark, Sweden, France, and Germany in and around hydrogen valleys such as industrial clusters, ports, and cities which are already embracing hydrogen pilots today.
4. The coordinated 2030 backbone will be a “first-mover” project, providing commercial security and project bankability to industry players and market actors.

2035 – Growing backbone

Expanding network covering more countries, linking sources and sinks across Europe



European Hydrogen Backbone initiative 2020, supported by Guidehouse

Important developments and corridors

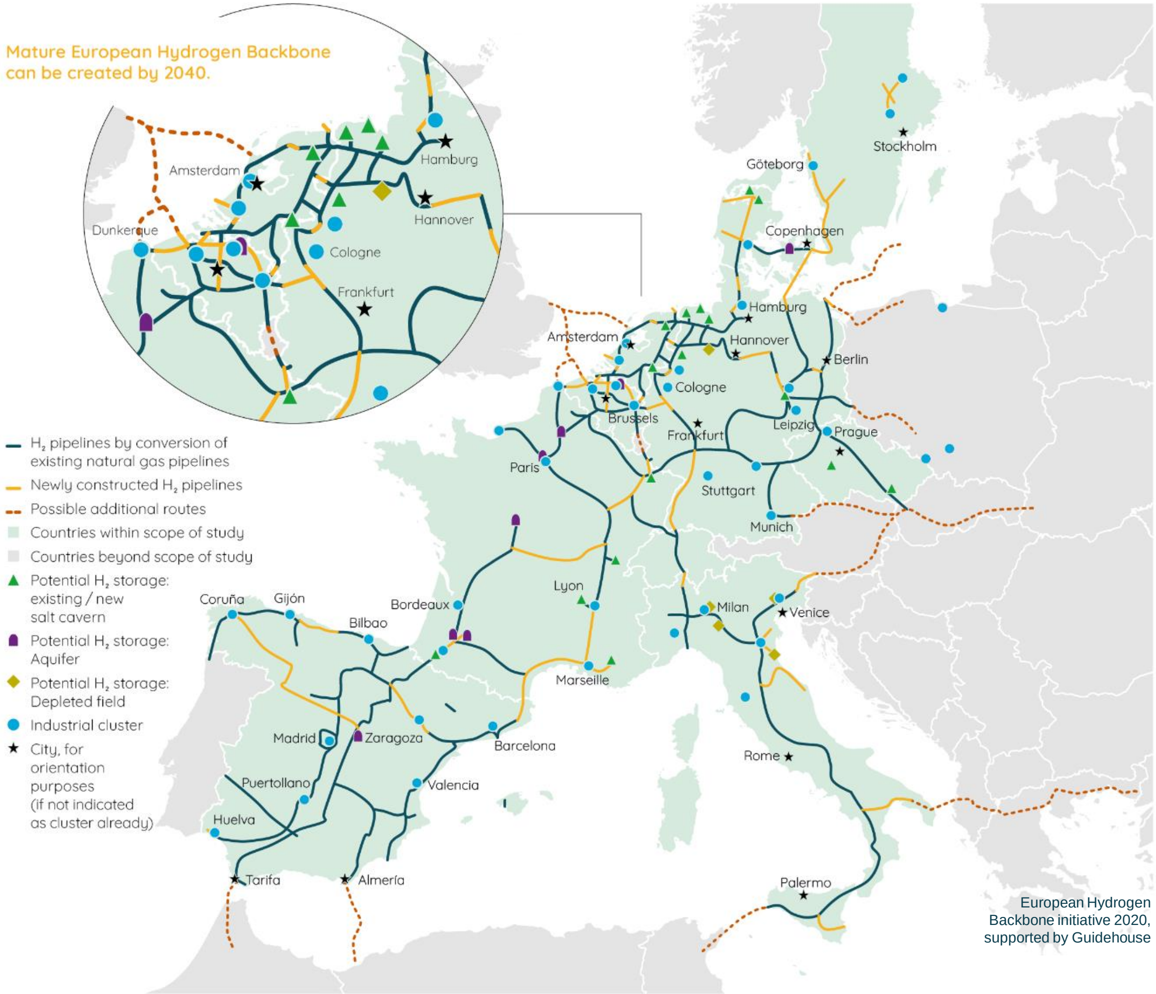
1 Between 2030 and 2035, the ambitious policy environment set by the Green Deal and an increasing number of projects will drive the backbone to further expand, covering more regions and developing new interconnections across Member States.

2 Notable additions to the backbone include: (1) the interconnection between Denmark and Germany; (2) extension of the north-south French corridor; (3) additional coverage in central and eastern Germany; (4) and a dedicated hydrogen microgrid in the east of Sweden.

3 These developments pave the way for hydrogen imports from further south including Spain, Italy, which are likely by 2040, and from North Africa.

2040 – A European hydrogen highway

A pan-EU backbone stretching into all directions, with a length of almost 23,000 km



Important developments and corridors

1. A core, pan-EU hydrogen infrastructure of almost 23,000 km, with large corridors connecting most of Western Europe with valuable extensions into Central and Eastern Europe.

2. The backbone will consist of 75% retrofitted pipelines, with diameters ranging from 24-48 inch, providing 3-13 GW_{LHV} transport capacity per pipeline. Combined with a fit-for-purpose compression system, the backbone should be able to meet currently expected annual hydrogen flows in Europe by 2040.[1]

3. The EHB enables connection to global hydrogen flows, including North Africa, the North Sea (UK and Norway), possibly Ukraine and Russia

4. The 2040 backbone can be considered as a critical milestone, but not a final product. It represents a foundational network upon which further developments can be built beyond 2040

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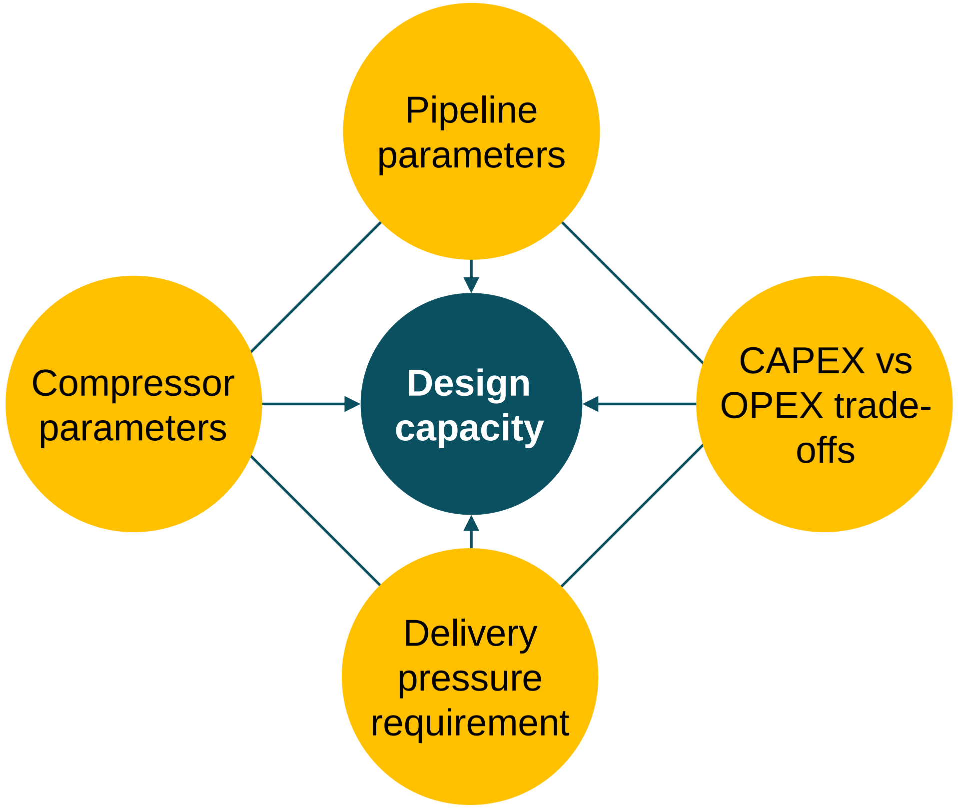
1. Preliminary estimation, the actual capacity of the meshed grid requires more detailed analysis

System design and optimisation

Network optimisation can create a "first-mover", facilitating backbone

Gas network design is a multi-faceted optimisation challenge



'Maximising' flow capacity is not the optimal solution

- Due to hydrogen's physical and chemical properties, the energy that can be transported through a hydrogen pipeline is approximately 20% lower compared to a natural gas pipeline with similar diameter.
- Previous analyses recommended operating hydrogen pipelines at up to 80% of the capacity it has when transporting natural gas, or approximately 17 GW for 48-inch and 9 GW for 36-inch pipelines.
- However, to "maximise" the value of retrofitted natural gas pipelines, exploratory analyses by gas TSOs shows that it is more attractive to operate hydrogen pipelines at less than their maximum capacity, e.g. 13 GW and 7 GW for 48- and 36-inch pipelines.
- The opportunity to repurpose existing pipelines means that the EHB benefits from a gradual ramp-up of investment need – limited compression requirements in the early years will lead to modest start-up costs – enabling the creation of a **"first-mover", facilitating backbone.**

Cost of the European Hydrogen Backbone

Total investment and operating costs are lower than previously estimated

Total investment, operating, and levelised costs of the EHB

			Low	Medium	High
Investment cost	Pipeline	€ billion	17	23	28
	Compression	€ billion	10	17	36
	Sub-total	**€ billion**	**27**	**40**	**64**
Operating cost	O&M (excluding electricity)	€ billion	0.7	0.9	1.1
	Electricity	€ billion	0.9	1.2	2.4
	Sub-total	**€ billion**	**1.6**	**2.1**	**3.5**
Levelised cost	100% new	€/kg/1000km	0.16	0.20	0.23
	100% retrofitted	€/kg/1000km	0.07	0.11	0.15
	EHB: 25% new, 75% retrofitted	**€/kg/1000km**	**0.09**	**0.13**	**0.17**

Key messages

- Total investment cost of the envisaged 2040 EHB is expected to be between **€27 to €64 billion**. This translates to a levelized cost of **0.09-0.17 €/kg/1000km**[1]; compared to a previous estimate of **0.23 €/kg/1000km**.[2]
- In the medium case, 60% of total investment cost will be dedicated to pipeline works and the remaining 40% will be spent on compression equipment.
- At 13 GW_{LHV}, initial analysis suggests that compression needs are 190-330 MW_e per 1000 km; which translates to 1.5-2.3% of the transported hydrogen's energy content consumed for compression purposes per 1000 km transported.
- There is more scope for cost optimisation[3], yet reducing pipeline capacity as described previously already shows the importance of optimisation to provide long-distance hydrogen transport at modest cost.

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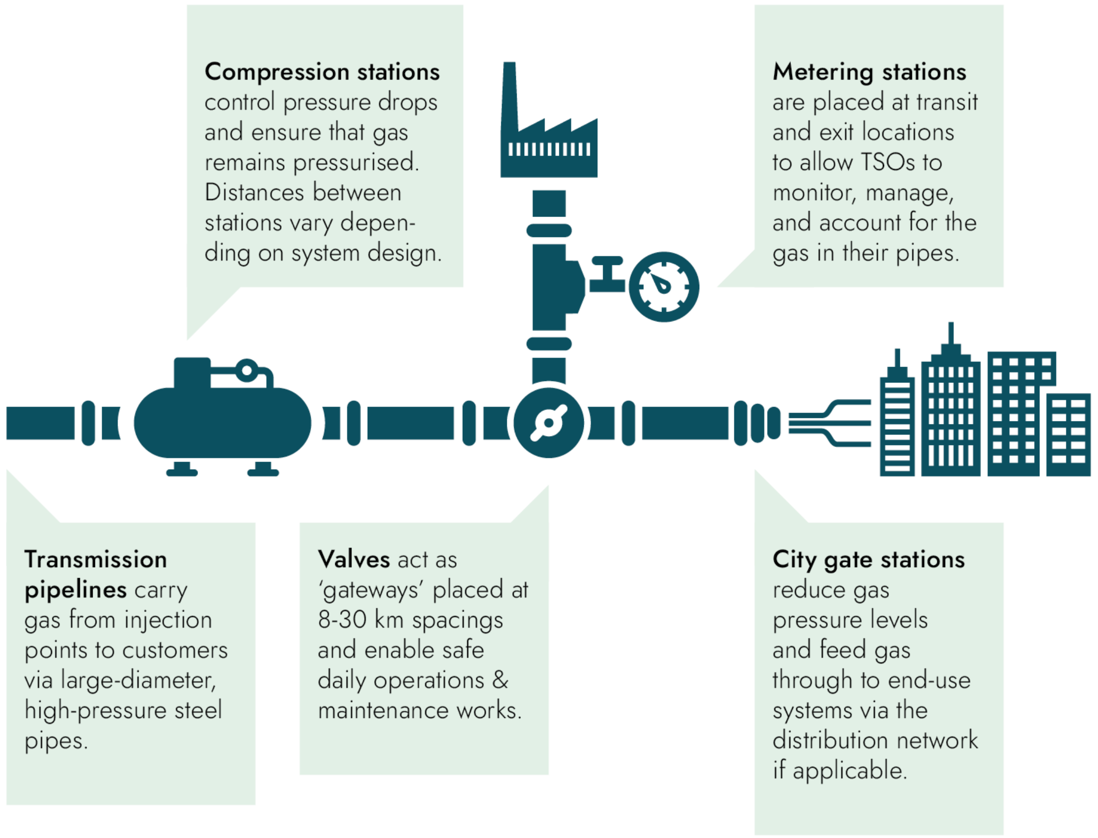
1. Conversion factors for hydrogen: 1 kg = 0.033 MWh (at lower heating value); 1 kg = 0.039 MWh (at higher heating value); 2. Source: Gas for Climate*: The optimal role for gas in a net zero emissions energy system (2019)*; 3. For example by optimising compression ratio.

Hydrogen infrastructure

Hydrogen can be transported through pipelines that were built for natural gas

The EHB will have similar underlying principles as the existing gas grid



However some adaptations will be required

- The main elements of the conversion process include nitrogen purging, pipeline crack monitoring, and valve replacements (where needed)
- Inner coating of an existing natural gas pipeline – though not technically required – might allow for higher pressures when switching to hydrogen[1]
- Adapt operational strategies to minimise hydrogen embrittlement risk
- Adapted or new compressors to provide higher compression capacities as well as a different approach to compression system design (sizing, power capacity, distance between compressors)

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1. According to R&D results and exploratory analysis by TSOs, technical details regarding coating vary by region depending on the state of the existing natural gas network.

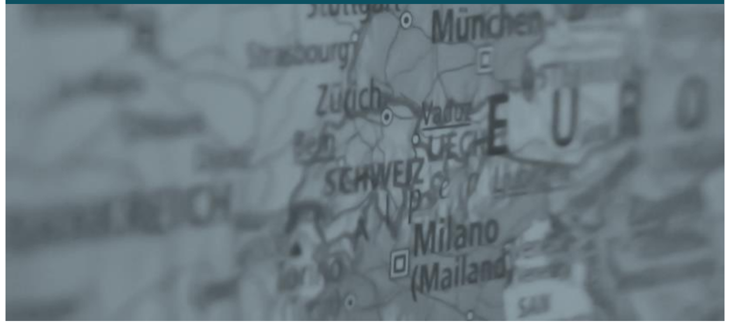
The European Hydrogen Backbone

A dedicated infrastructure can pave the way to large-scale competitive hydrogen for the European market

A hydrogen network can emerge from the mid-2020s onwards to an initial **6,800 km** pipeline network by 2030.

By 2040, a hydrogen network of **23,000 km** is foreseen, 75% of which will consist of converted natural gas pipelines, connected by 25% of new pipeline stretches.

A pan-EU hydrogen backbone



The backbone has an estimated cost of **€27 to €64 billion**, which is relatively limited in the overall context of the European energy transition.

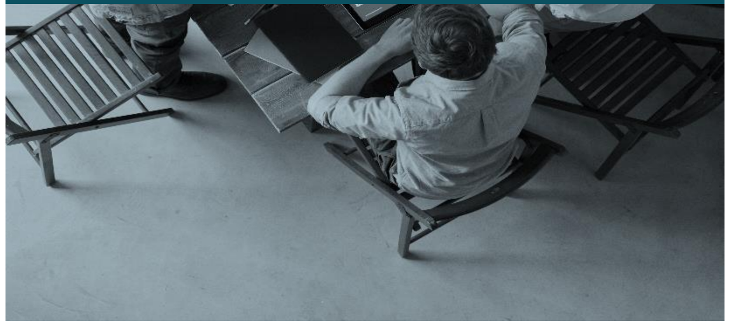
The levelised cost is estimated to be between **€0.09-0.17 per kg per 1000 km**, allowing hydrogen to be transported cost-efficiently over long distances across Europe.

At affordable cost

The group of gas infrastructure companies is convinced that the hydrogen backbone will eventually cover **the entire EU**.

The group **invites** other European gas infrastructure companies to join in the thinking to further develop the backbone plan.

An open initiative



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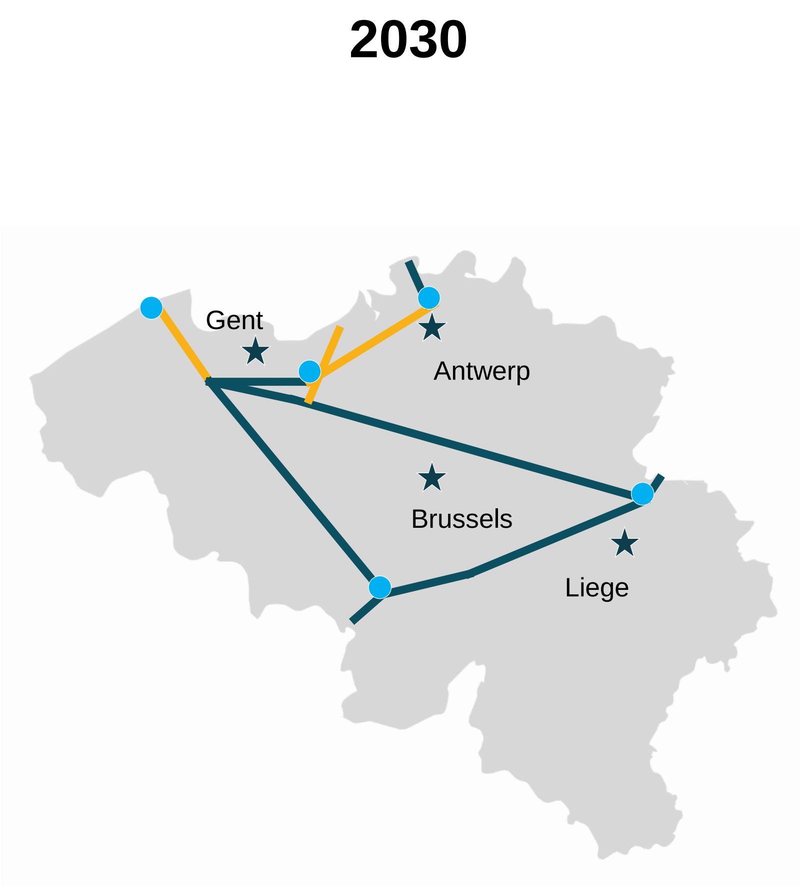
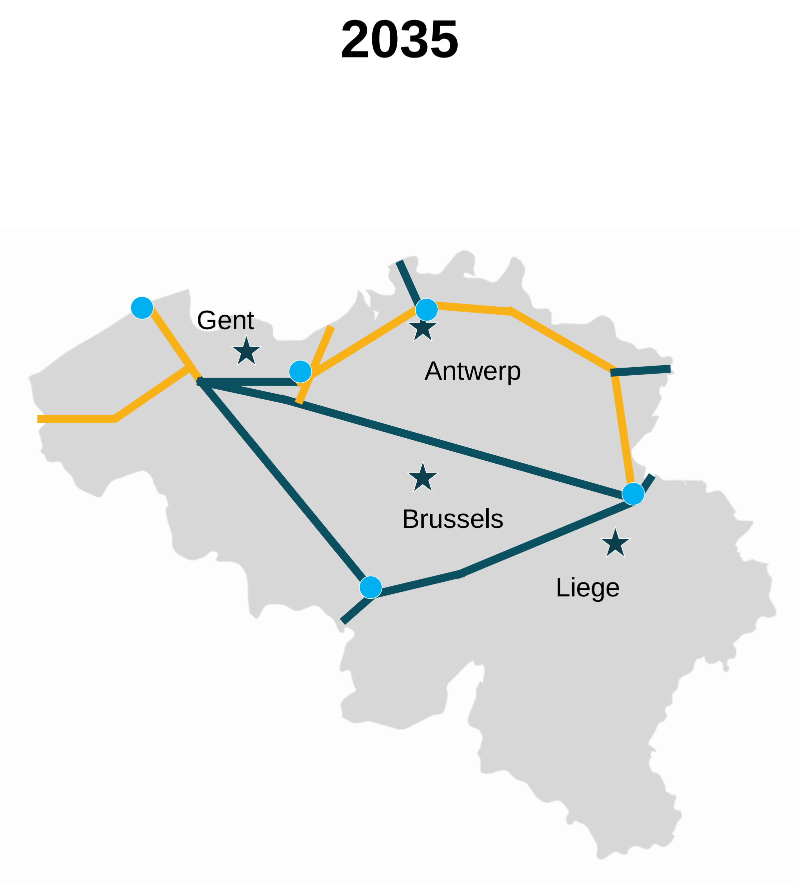
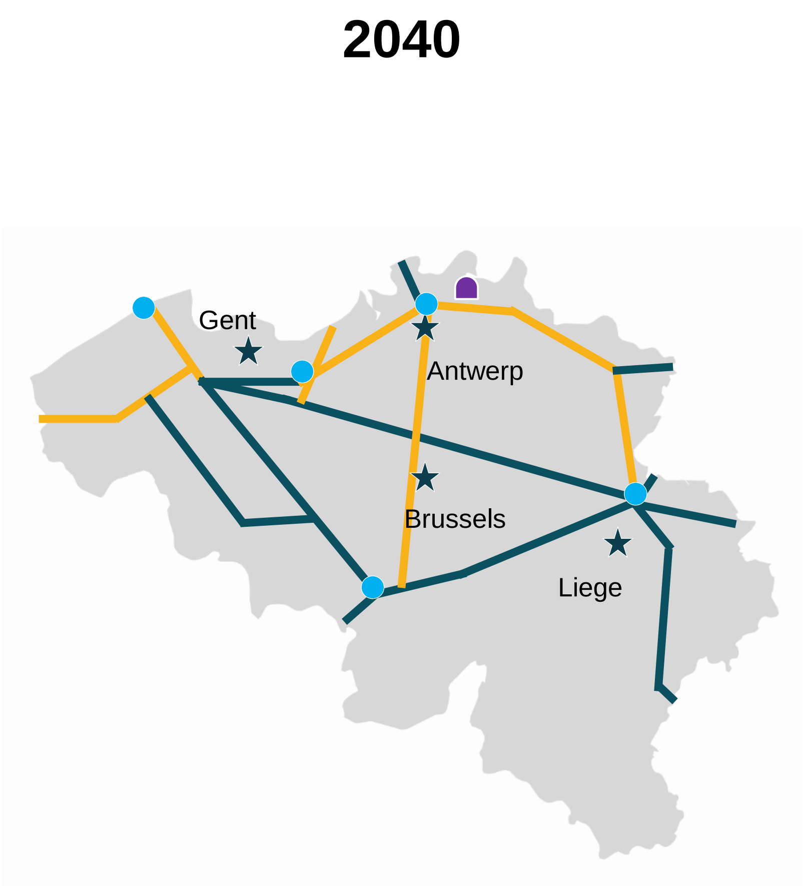
Individual country maps

Belgium, Fluxys Belgium







- H2 pipelines by conversion of existing natural gas pipelines
- Newly constructed H2 pipelines
- Potential H2 storage: Aquifer
- Potential H2 storage: Existing / new salt cavern
- Potential H2 storage: Depleted field
- Industrial cluster
- City, for orientation purposes (if not indicated as cluster already)

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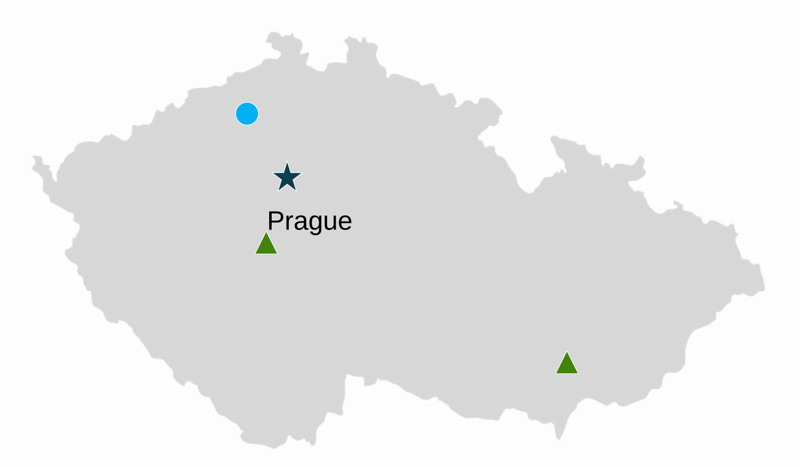
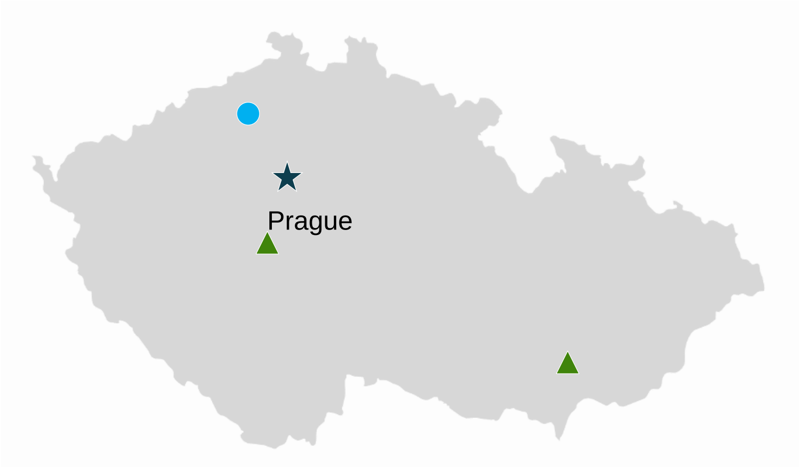
Czech Republic, NET4GAS

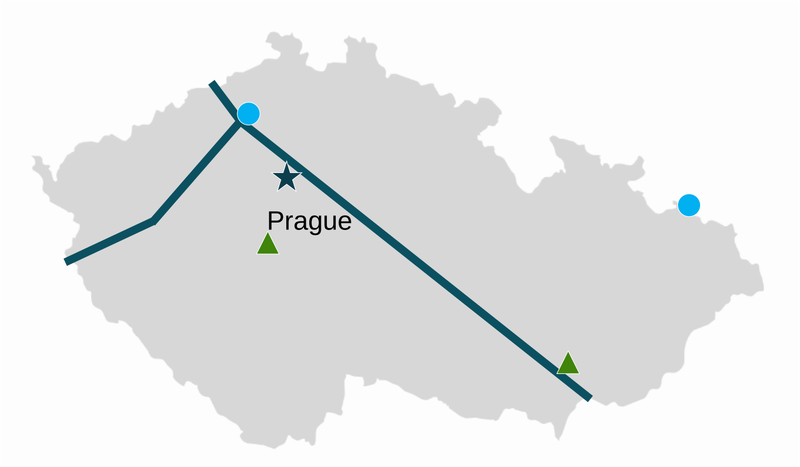
2030



2035



2040



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Denmark, Energinet

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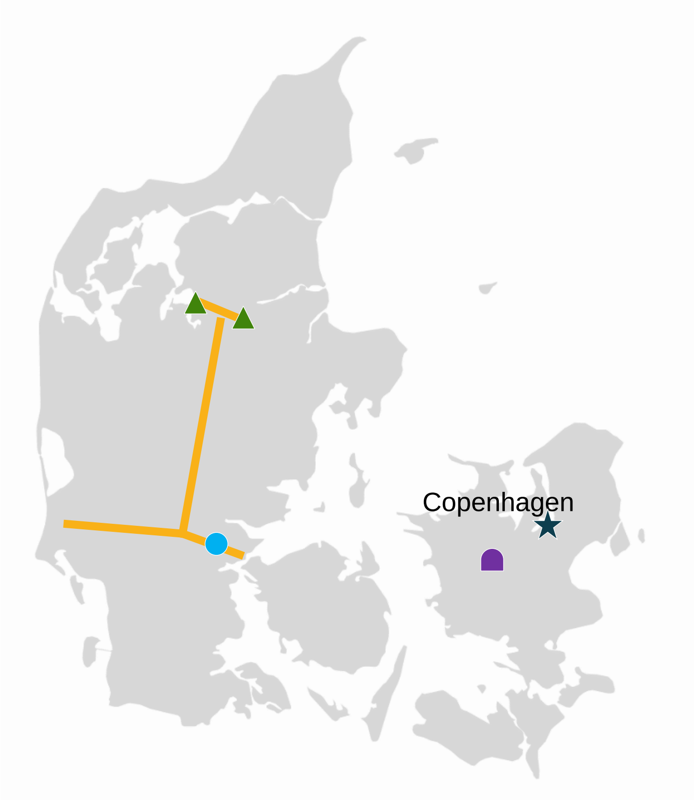
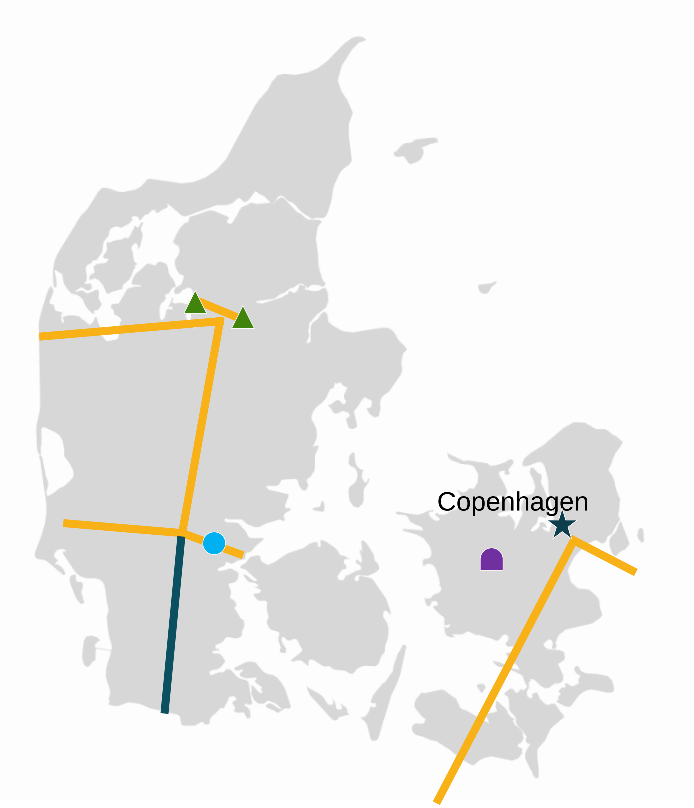
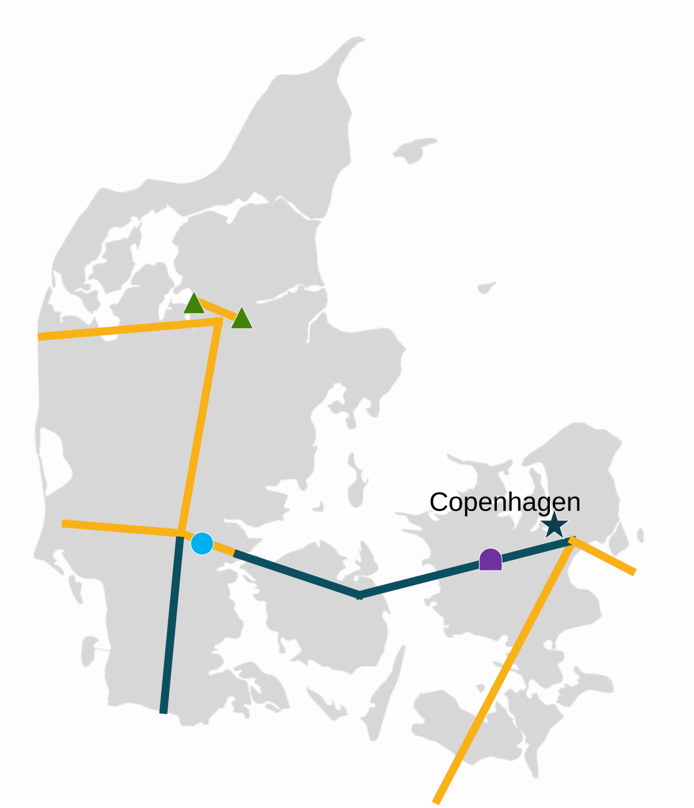


2035



2040



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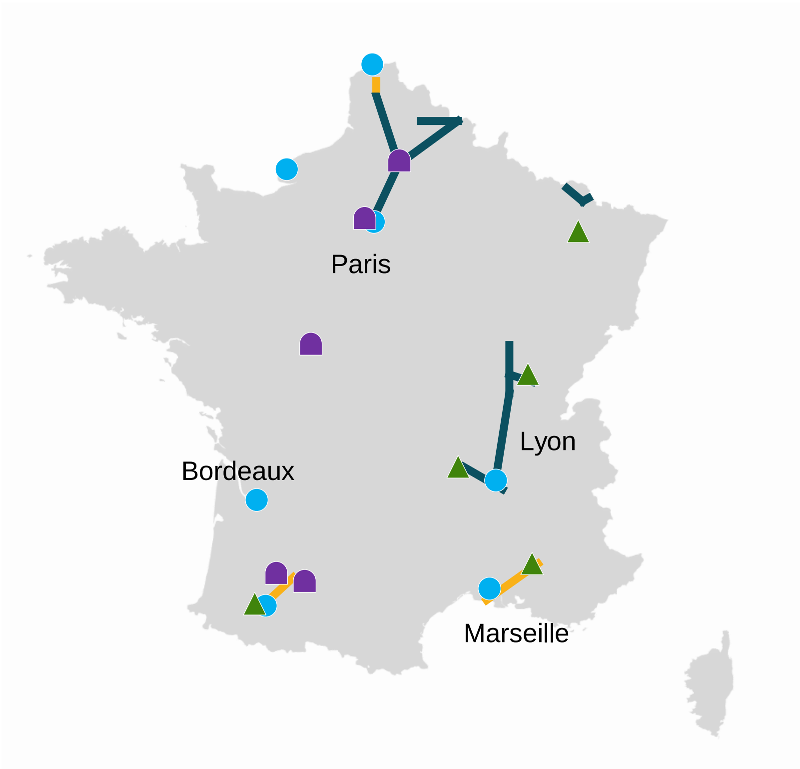
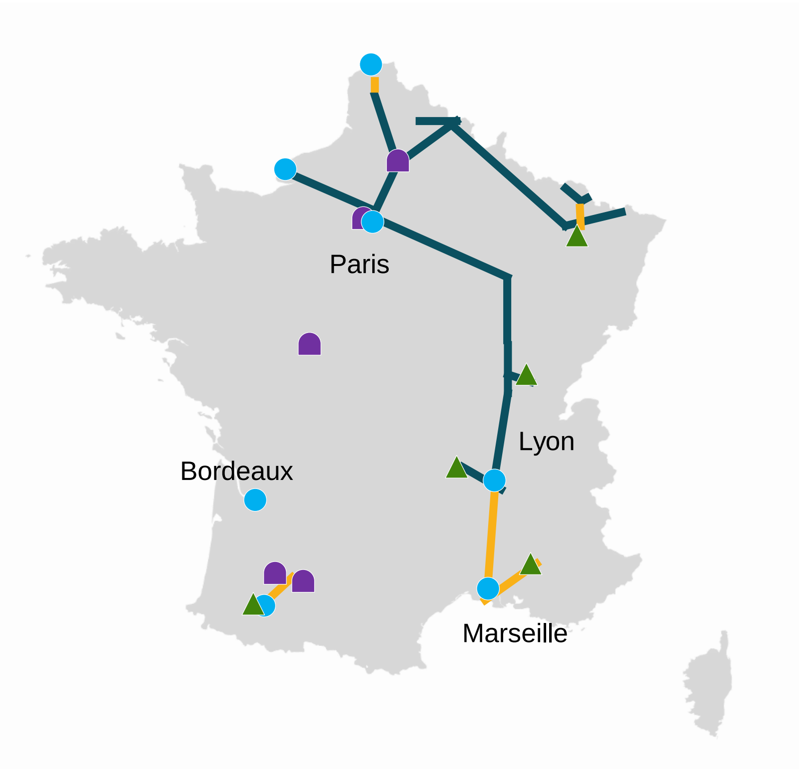
France, GRTgaz & Teréga

2030



2035



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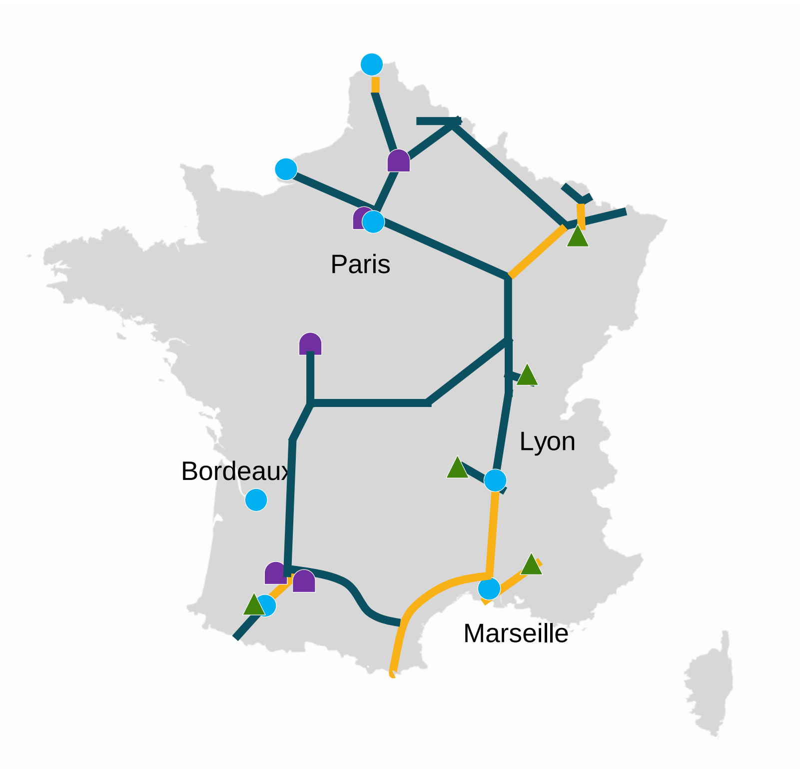

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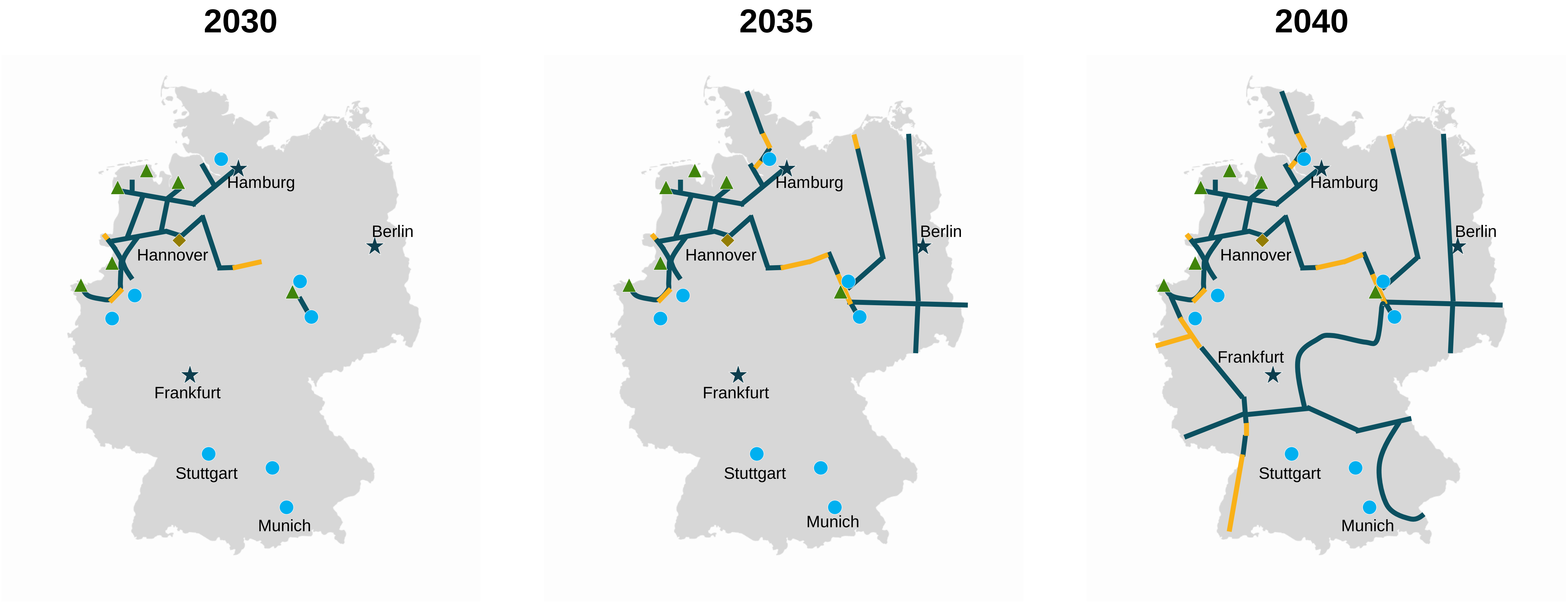
Germany, OGE & ONTRAS



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Italy, Snam

2030

2035

2040

H2 pipelines by conversion of existing natural gas pipelines

Newly constructed H2 pipelines

Potential H2 storage: Aquifer

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Potential H2 storage: Depleted field

Industrial cluster

City, for orientation purposes (if not indicated as cluster already)

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The Netherlands, Gasunie

2030

2035

2040

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Spain, Enagás

2030

2035

2040

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Sweden, Swedegas (part of Nordion Energi)

2030

2035

2040

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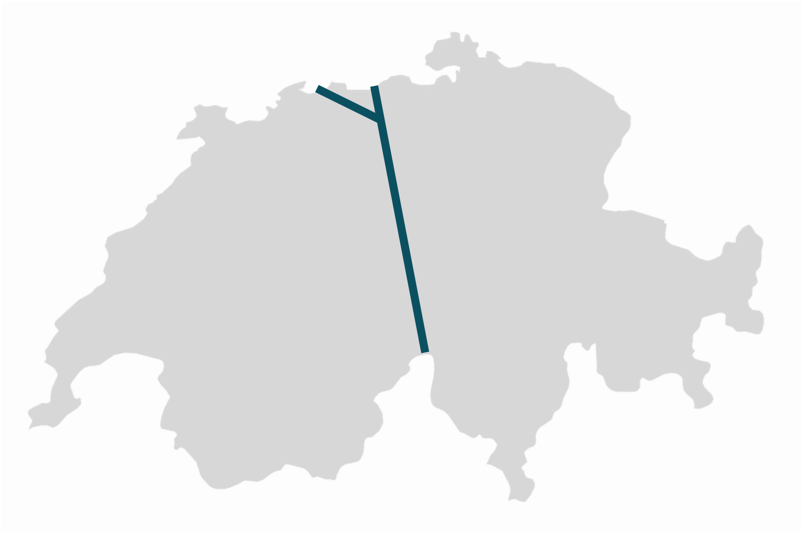
Switzerland

2030

2035

2040



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