Green H2 @ Scale: Hydrogen infrastructure

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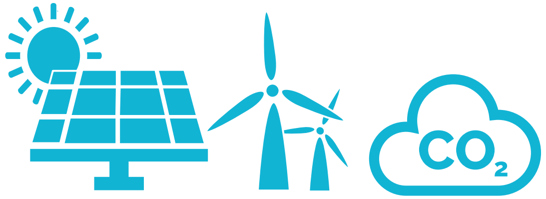
Background and scope

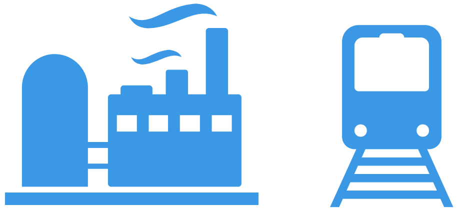
Hydrogen supply, demand, and policy trends are leading to rapidly improving prospects for affordable low-carbon hydrogen.

Hydrogen production capacity is ramping up rapidly



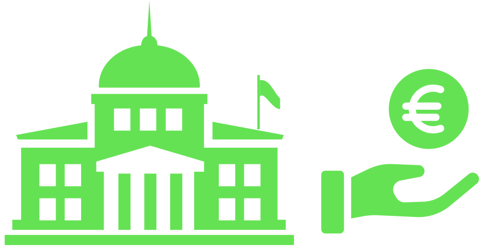
- Rapidly declining costs for renewable electricity
- Planned global investments in electrolysers increased from 3.2 to 8.2 GW between Nov 2019 and Mar 2020[1]
- Various industry initiatives: Hydrogen Europe, Hydrogen Council, Clean Hydrogen Alliance

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 (trains, 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.

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

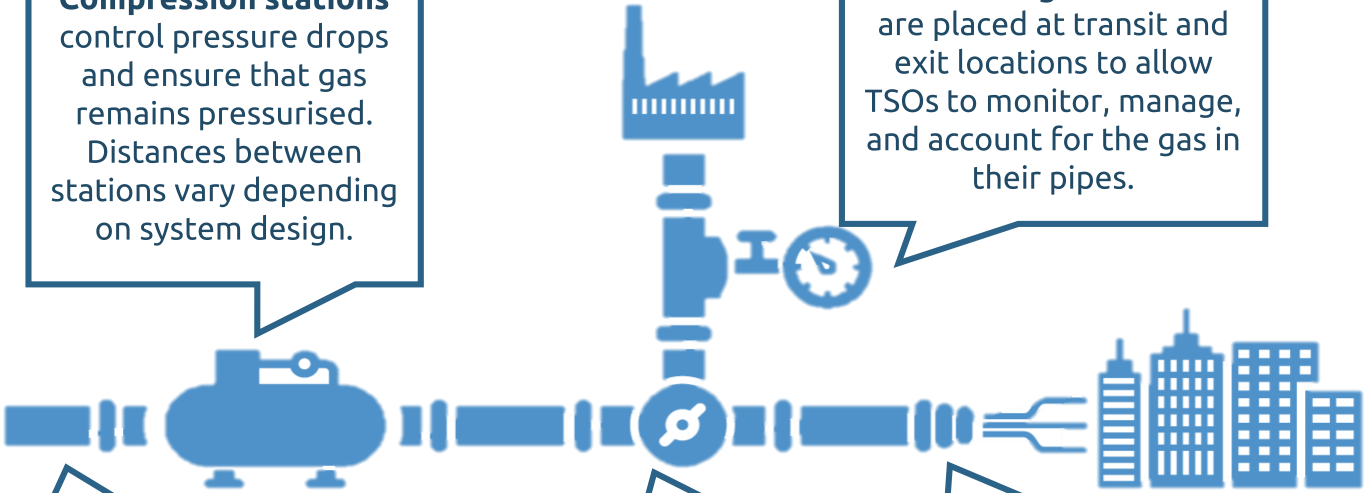
Hydrogen infrastructure

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

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

Compression stations control pressure drops and ensure that gas remains pressurised. Distances between stations vary depending on system design.

Metering stations are placed at transit and exit locations to allow TSOs to monitor, manage, and account for the gas in their pipes.



Transmission pipelines carry gas from injection points to customers via large-diameter, high-pressure steel pipes.

Valves acts as "gateways" placed at 8-30 km spacings and enable safe daily operations & maintenance works.

City gate stations reduce gas pressure levels and feed gas through to end-use systems via the distribution network if applicable.

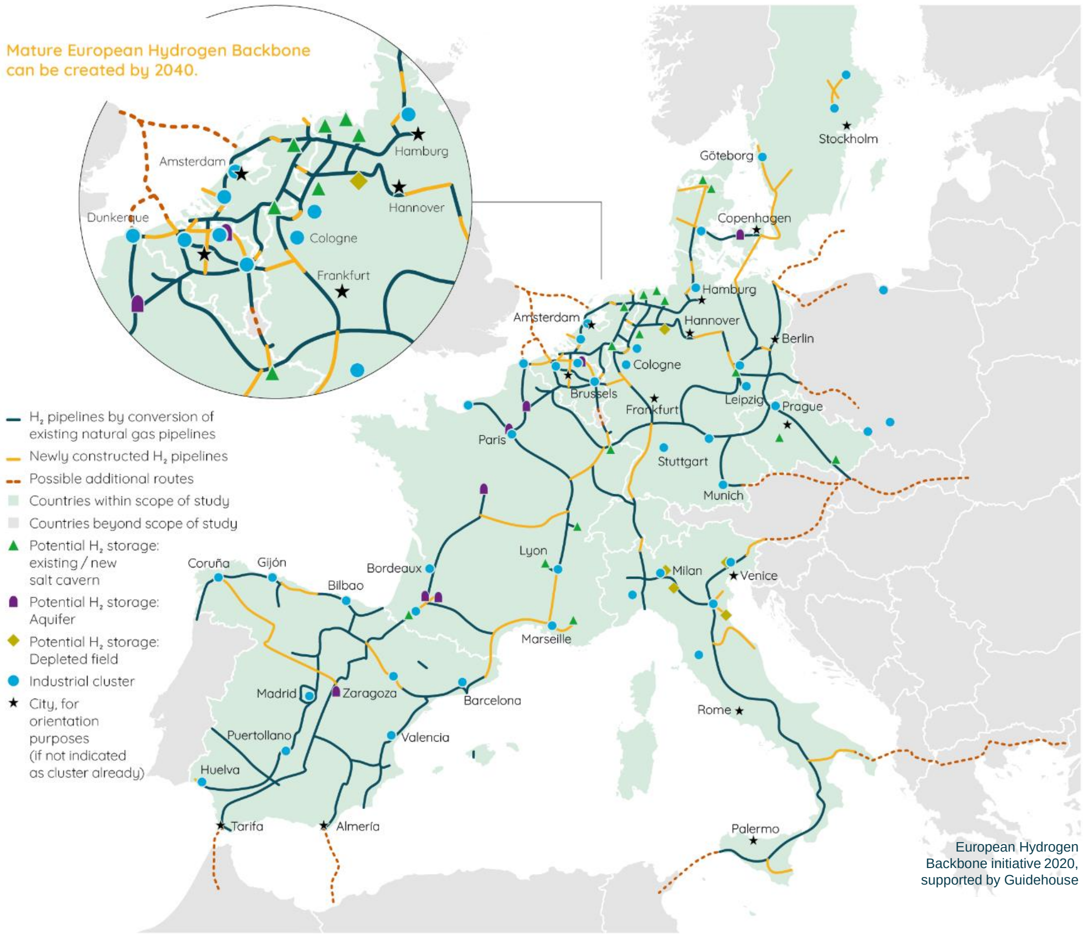
However some adaptations will be required

- 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)

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 ("EHB")

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



European Hydrogen Backbone initiative 2020, supported by Guidehouse

- 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.

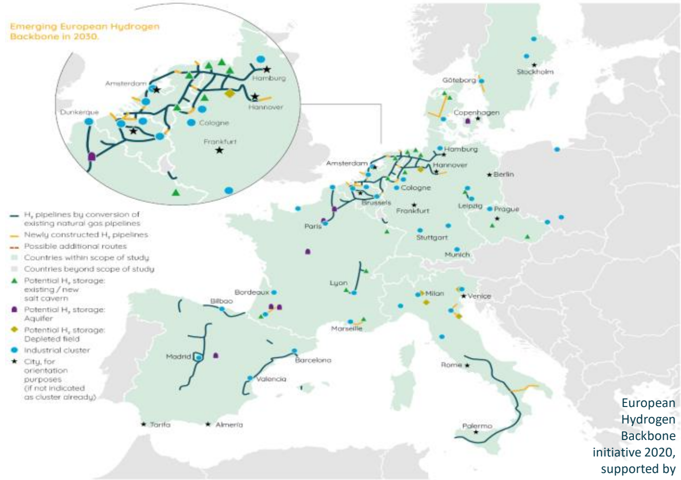
1. Includes Enagás, Energinet, Fluxys Belgium, Gasunie, GRTgaz, NET4GAS, OGE, ONTRAS, Teréga, Snam, Swedegas; covering Germany, France, Italy, Spain, the Netherlands, Belgium, Czech Republic, Denmark, Sweden, and Switzerland (indirectly through Fluxys Belgium); 2. LHV: Lower heating value, the energetic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

The European Hydrogen Backbone ("EHB"): Evolution

IMPORTANT DEVELOPMENTS AND CORRIDORS

2030 – Emerging regional networks

Connecting industrial clusters to an emerging 6,800 km infrastructure



European Hydrogen Backbone initiative 2020, supported by Guidehouse

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

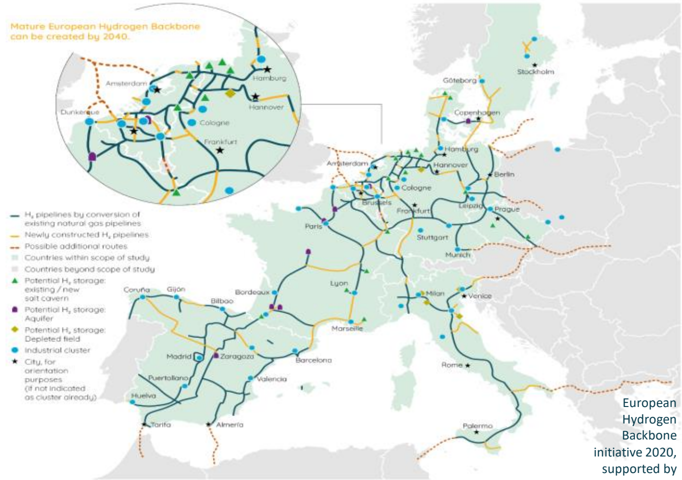
1. Between 2030 and 2035, the ambitious policy environment set by the **Green Deal** and an increasing number of projects **will drive the backbone to further expand**, covering more regions and **developing new interconnections across Member States**.

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



European Hydrogen Backbone initiative 2020, supported by Guidehouse

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

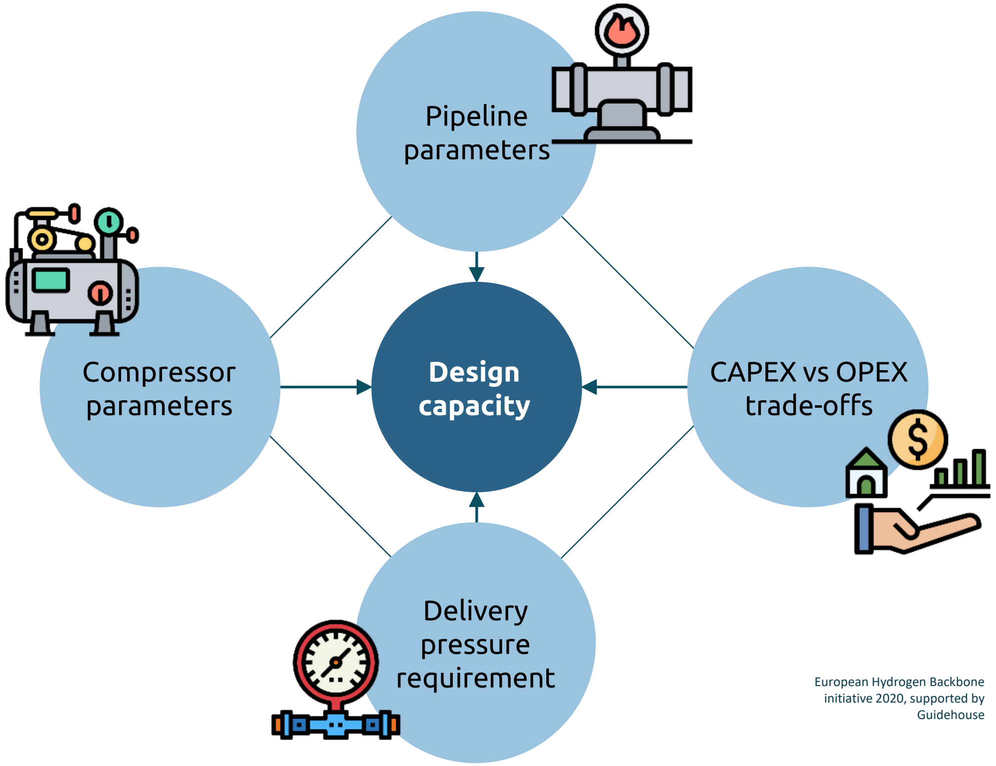
4. The 2040 backbone can be considered as a critical milestone, but not a final product. It represents a **foundational network upon which further developments can be built beyond 2040.**

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



European Hydrogen Backbone initiative 2020, supported by Guidehouse

'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 pipel**ines 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.**

Partnerships on railway sector

On 21st October 2020 FS Italiane and Snam signed a memorandum of understanding for the technical and economic feasibility and to consider new business models relating to the development of hydrogen rail transport

Key points of the agreement include:

- Analysis and feasibility studies and development of common projects on hydrogen convertible railway lines on the national territory
- Experiment with technological solutions related to the production, transport, compression, storage, supply and use of hydrogen to contribute to the development of sustainable mobility

On 18th March 2020 Snam and Alstom signed an exclusive partnership agreement for the development of hydrogen rail transport in Italy

Key points of the agreement include:

- Share of strategic studies on the Italian market
- End-to-end customized business models
- Alstom: OEM and maintenance
- Snam: infrastructures for the production, transport and procurement of H2
- Pilot projects
- Communication and dissemination activities
- Business development

On 29th December 2020 FNM, a2a and Snam signed a memorandum of understanding for the conversion from Diesel to Hydrogen of the railway service on the Brescia - Iseo - Edolo section

Key points of the agreement include:

- The project foresees the commissioning of 14 Ilint-coradia hydrogen trains supplied by Alstom by 2024
- Feasibility development for green hydrogen production sites from renewable / circular sources
- Feasibility development for hydrogen refueling stations in the terminations of the section.
- Feasibility development for logistics and hydrogen transport infrastructure from production to consumption