

Hydrogen potential in Finland

2021



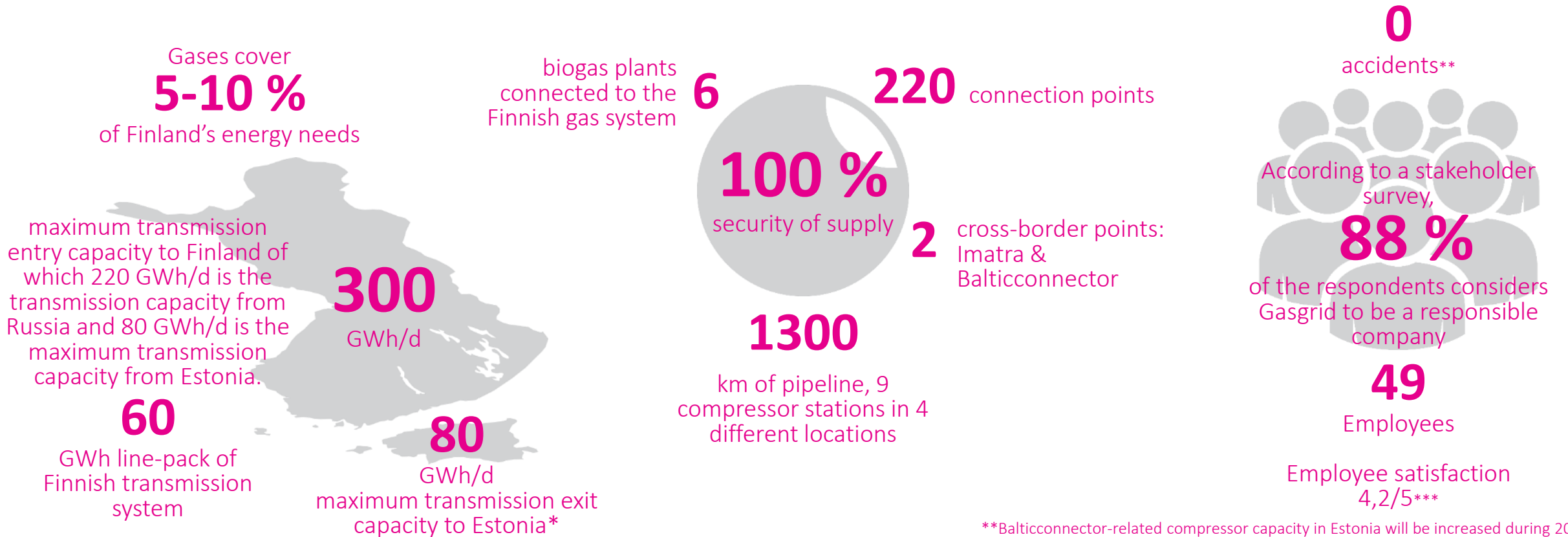
Content

- Gasgrid Finland briefly
- The role of hydrogen in the energy revolution
- The European hydrogen economy and Finland's role

Gasgrid Finland briefly

Gasgrid Finland Oy

We offer our customers safe, reliable and cost-efficient transmission of gases. We actively develop our transmission platform, services and the gas market in a customer-oriented manner to promote the carbon-neutral energy and raw material system of the future.



**Balticconnector-related compressor capacity in Estonia will be increased during 2021.
**Number of accidents resulting in the absence of Gasgrid Finland's own employees
***average

Our services

Market services



Balancing service



Virtual trading point



Centralised data exchange for the retail market (Datahub)



Biogas certificate service



24 h customer service



Reporting service and database

Network services



Gas transmission

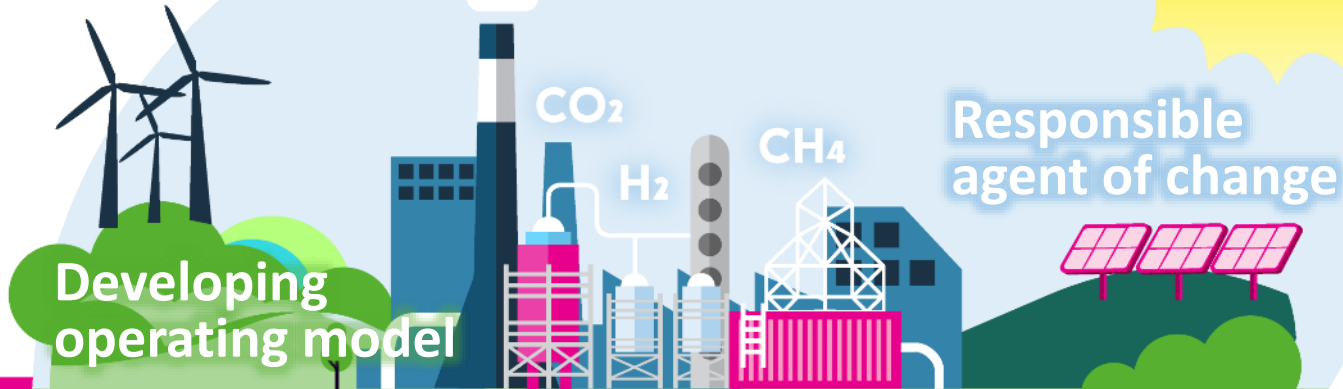


Connecting to the transmission network



Strategy and values

Vision 2035
Gases enable a carbon-neutral society – we provide a platform for it.



Our mission

We offer our customers safe, reliable and cost-efficient transmission of gases. We actively develop our transmission platform, services and the gas market in a customer-oriented manner to promote the carbon-neutral energy and raw material system of the future.

Transmission platform of the future

Customer-oriented gas market

Our values

We work together

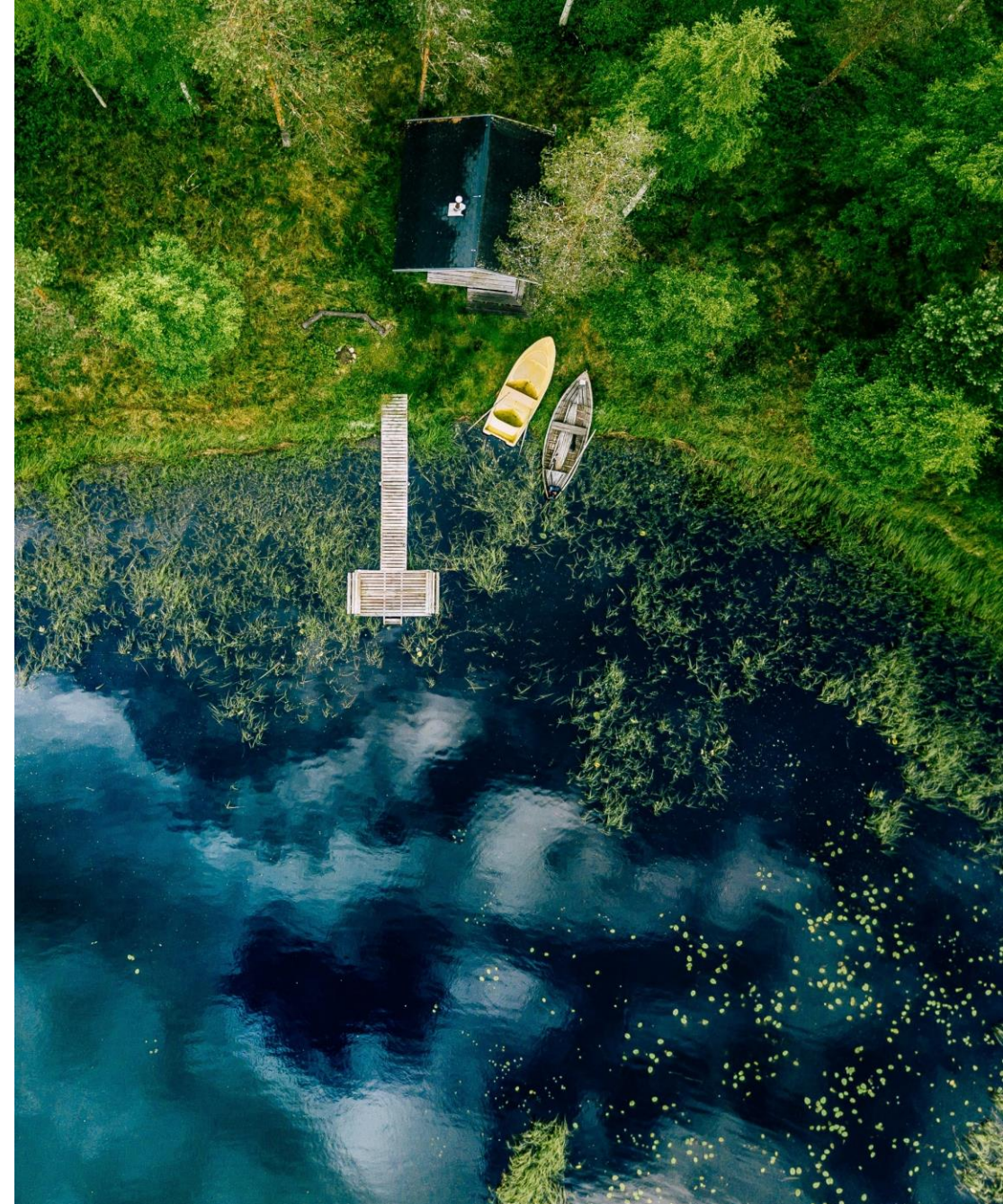
We build the future

We acknowledge our responsibility

The role of hydrogen in the energy revolution

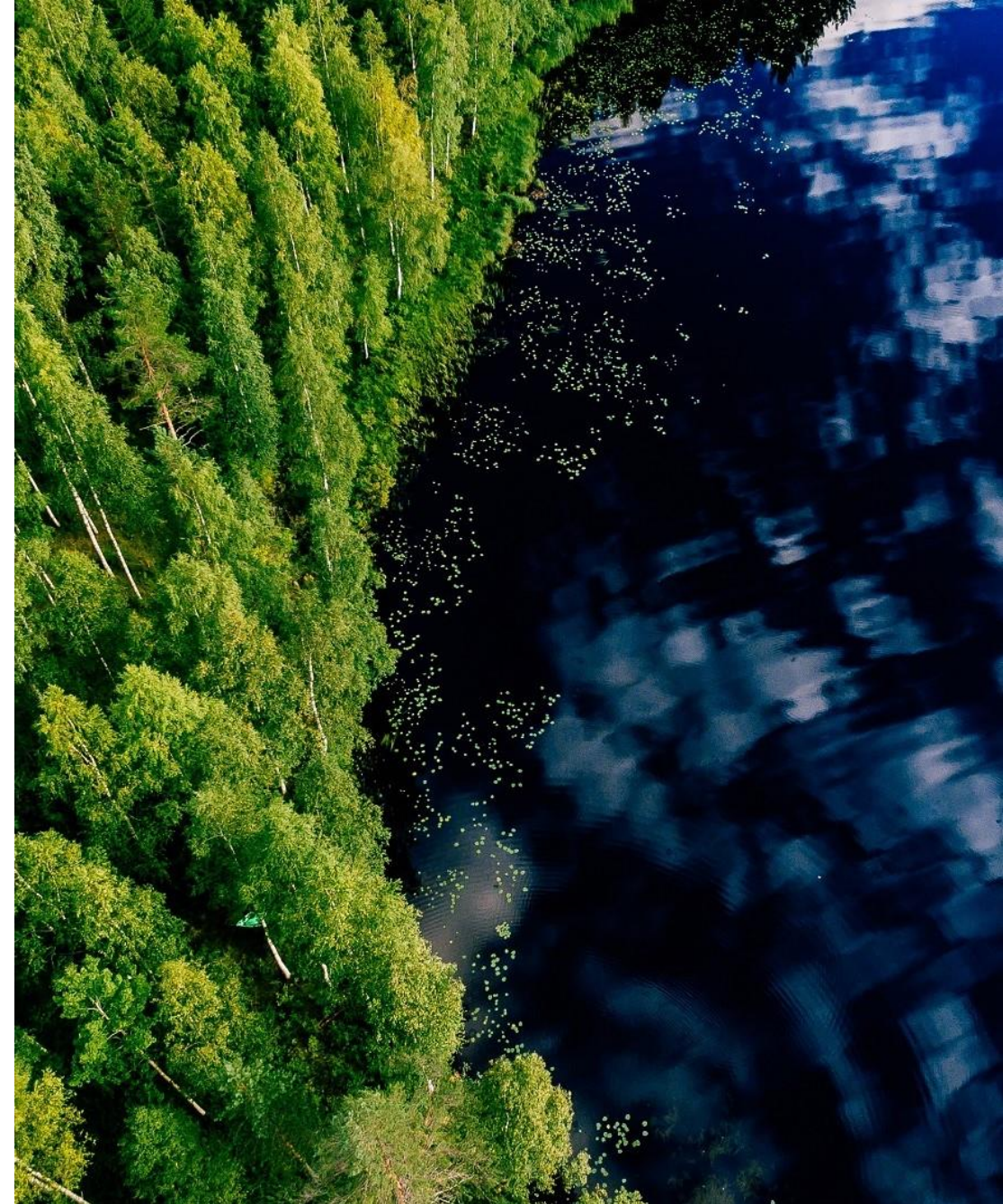
Hydrogen has a significant role in future energy system

- Hydrogen enables:
 - Solutions for sectors that are hard to decarbonise
 - Efficient energy transfer, storing of energy and increased utilisation of renewables
 - Significant new business potential for various actors through development of new value chains, products and services.



Finland – A potential platform for future hydrogen economy

- Finland has excellent possibilities to become a key clean energy supply region in Europe, with its enabling factors of:
 - Finland's carbon-neutrality goals for 2035 support energy transformation
 - Excellent clean energy sources and competitive electricity price
 - Energy industry's strong “track record” for being a positive part of the solution
 - Strong energy networks, competitive energy transfer costs and possibility to utilize waste heat in district heating
 - High level technological knowhow as well as forerunner in sector integration and digital solutions
 - Potential for negative emissions through the utilization of CO₂ from e.g. biomass



Gasgrid's development activities related to hydrogen

- To support the formation of carbon neutral energy and raw material system of the future, Gasgrid has started hydrogen development activities.
- In the beginning of 2021, we joined
 - The Hydrogen Cluster Finland, a network of companies and industrial associations advancing hydrogen development in Finland. More info: [Hydrogen Cluster Finland](#)
 - European Hydrogen Backbone (EHB) initiative, group consisting of 23 European gas transmission system operators (TSO). More info: [Gas for Climate / European Hydrogen Backbone](#)
- We also started a joint RDI project with Fingrid to identify opportunities of the hydrogen economy in Finland and clarify the role of energy infrastructure as an enabler of the hydrogen economy. More info: [Joint research project](#)



Hydrogen potential in Finland

High-level study

- During fall 2021, we carried out a study to deepen the understanding how hydrogen supply, demand and transport would develop in Finland.
- The study was building on the European Hydrogen Backbone (EHB) analysis and was gathering information from other European high-level studies.
- The study was carried out by Guidehouse.



The European hydrogen economy and Finland's role

Results of high-level study of Hydrogen potential in Finland

Hydrogen development in Finland

Scan of hydrogen supply, demand
and transport in Finland –building
on EHB analysis

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Executive summary

Introduction and context



Hydrogen development in Finland

Context and objectives

Hydrogen has gained a lot of traction in recent years...

Hydrogen has gained a lot of traction as a decarbonisation technology in the last two years:

- Governments around the world, and especially in Europe, are considering hydrogen as an important part of the future energy system – as demonstrated by the EU's H₂ Strategy and the 10 EU countries that have announced national hydrogen plans¹
- Substantial volumes of capital are flowing into the hydrogen sector, with the Hydrogen Council reporting 359 large-scale projects announced globally; with an investment pipeline estimated at \$500 billion through to 2030 – of which \$150 billion is associated with projects that have passed final investment decision or are under construction²

... but how fast is the hydrogen market really going to develop and what is the role of infrastructure companies?

Despite ambitious decarbonisation targets and project announcements, the creation of a (mostly) new market – as is needed for hydrogen – comes with a range of risks and uncertainties at national and EU level:

- How fast will hydrogen supply and demand ramp up?
- How and at what pace will infrastructure legislation develop at EU and national level?
- How fast can the market develop?
- Different countries are moving at different speeds – who are the first movers and how might this affect future cross-border trade and hydrogen market characteristics in individual countries?
- What is the role of infrastructure companies?

Quick-scan assessment of hydrogen and hydrogen infrastructure in Finland

In this context, Gasgrid Finland has commissioned Guidehouse to conduct a quick-scan assessment of the future role of hydrogen and hydrogen infrastructure in Finland to gain insights to:

- The strategy and required speed of hydrogen development in Finland – is Gasgrid doing and thinking about the right things?
- Is Finland able to – beyond reaching carbon neutrality by 2035 – become an exporter of renewable energy and hydrogen?

The study is based on Guidehouse's European Hydrogen Backbone work, which draws on analysis of the Swedish hydrogen market potential as well as other relevant experiences in the hydrogen industry.

This phase is a conversation starter, and aims to raise key focus areas and questions, rather than provide definite conclusions. A possible larger follow-up modelling study can lead to additional and better substantiated insights regarding the future of hydrogen infrastructure in Finland and Gasgrid's role in developing this.

Hydrogen development in Finland

Scope of this quick-scan assessment

In scope:

Quick scan of the future role & timing of H₂ in Finland



Review of European macro-level studies & state-of-the-art H₂ value chain technologies



H₂ demand in Finland (including export potential)*



Renewable H₂ supply in Finland – supply potential & cost-competitiveness*



H₂ transfer needs in Finland

Out of scope:

Not analysed (in detail)

Hydrogen demand in shipping

Detailed assessment of cross-border flows of H₂ and H₂-based derivatives or products (ammonia, methanol, etc.)

Flow-based energy system modelling study

Policy and regulatory assessment

Executive summary

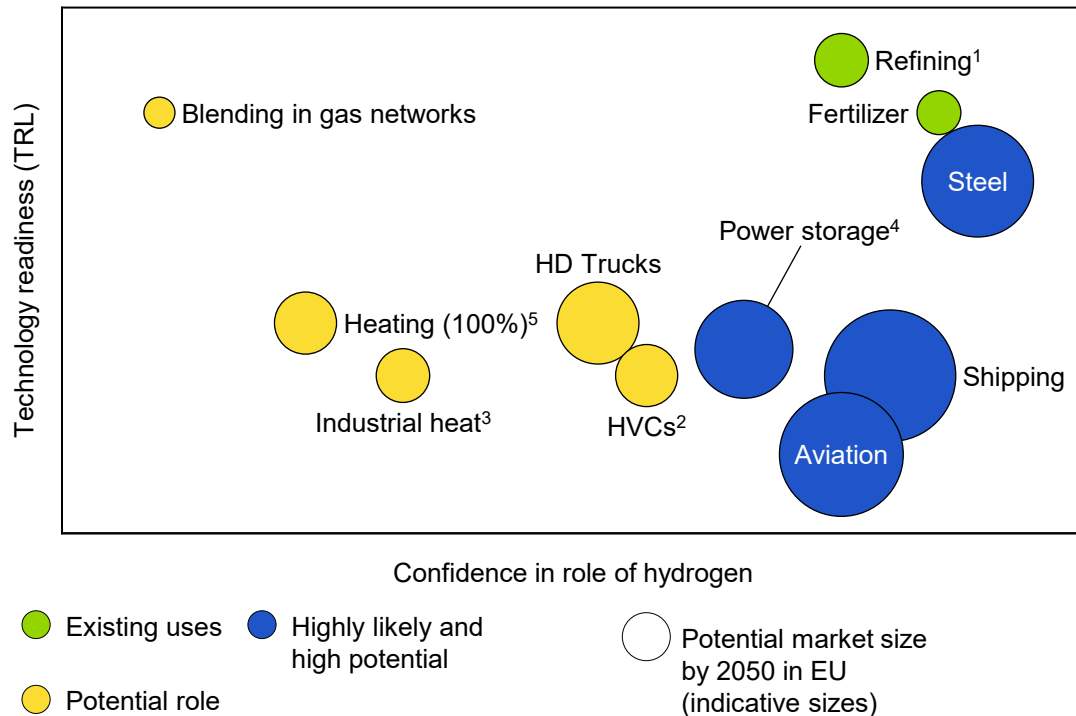
Key findings



Hydrogen is expected to make up 19-30% of energy demand in a decarbonised EU energy system, creating a ~€70B market by 2050. Hydrogen's role is particularly crucial in abating sectors with no alternative decarbonisation pathway such as industry and heavy transport.

Hydrogen will see early adoption in industry and in the long term will have a role in transport and dispatchable power...

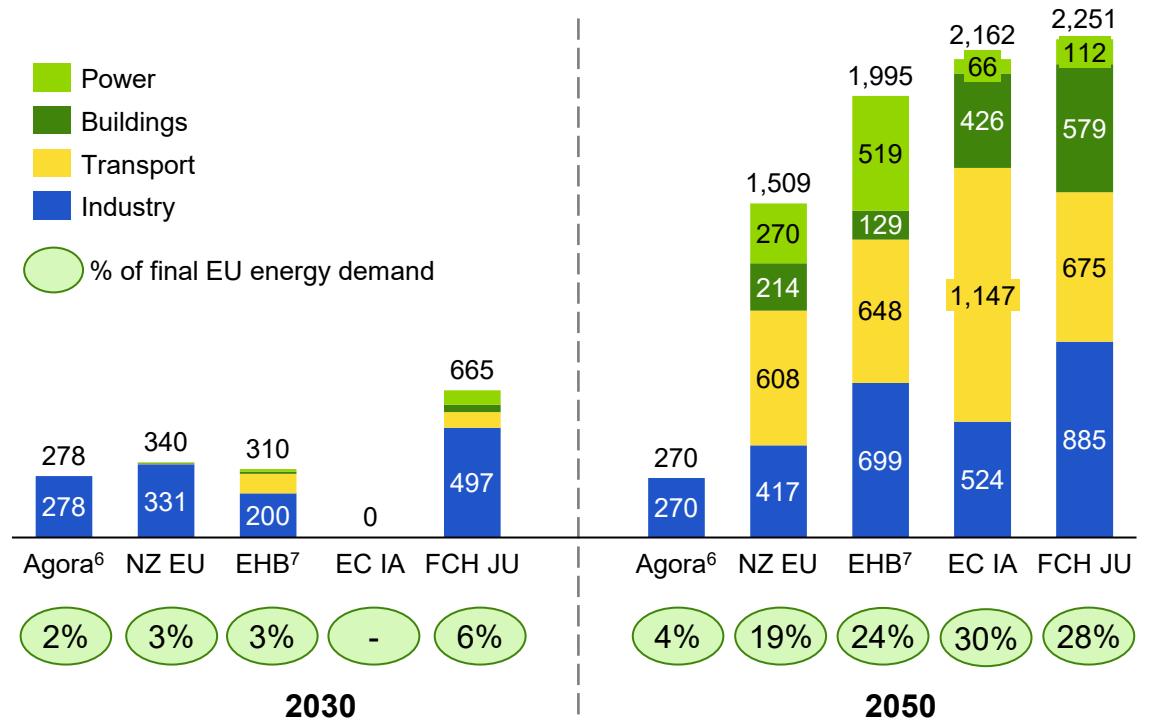
TRL, potential market size and confidence in role of hydrogen by 2050



Sources: Based on Exhibit 1.3 from ETC (2021), Global Hydrogen report, adjusted for EU focus and according to Guidehouse own insights based on industry expert views, company interviews and sector roadmaps.

... giving it a crucial role in EU's energy system by 2050. More ambitious targets could increase demand by 2030.

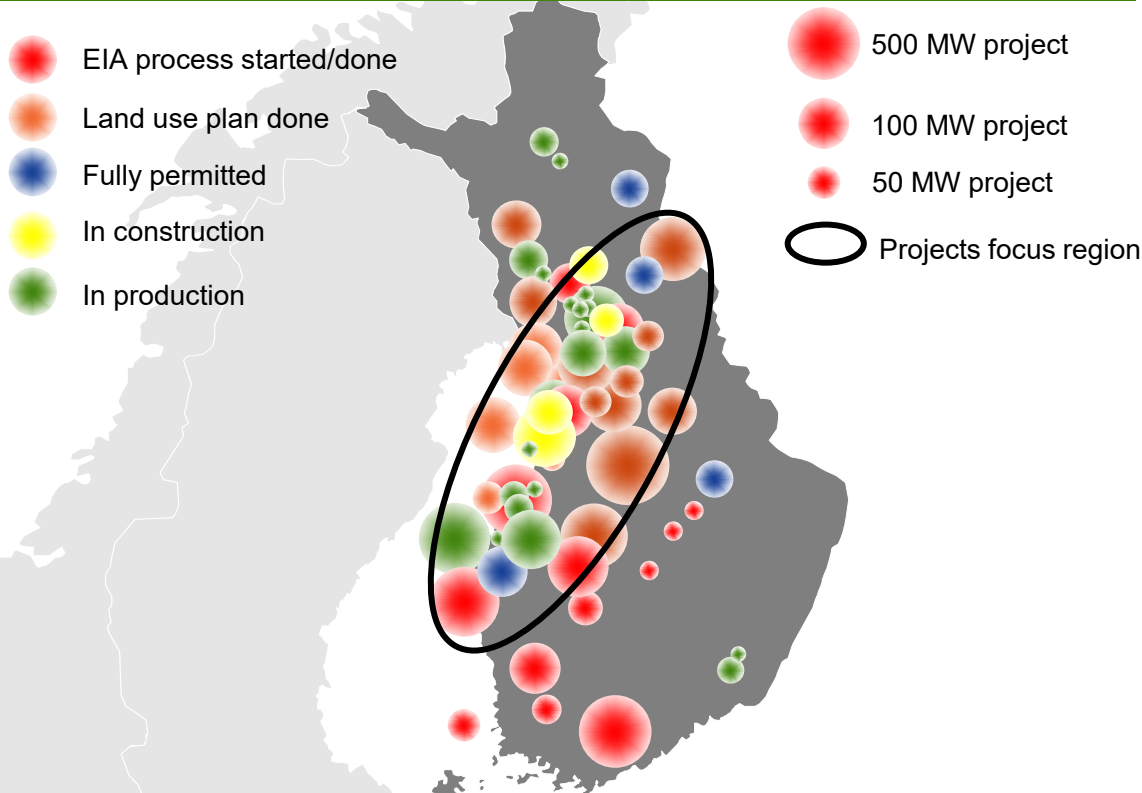
Hydrogen demand in the EU in different studies (TWh/year)



Sources: Agora (2021) No regret H₂ infrastructure (only includes industrial H₂ demand and excludes H₂ demand for e-fuels); McKinsey (2021), Net-zero Europe; EHB (2021), Analysis of hydrogen demand, supply and transport, EC (2020) impact assessment SWD (176) MIX scenario; FCH JU (2019) Hydrogen Roadmap Europe Ambitious Scenario; ETC (2021), Global Hydrogen report

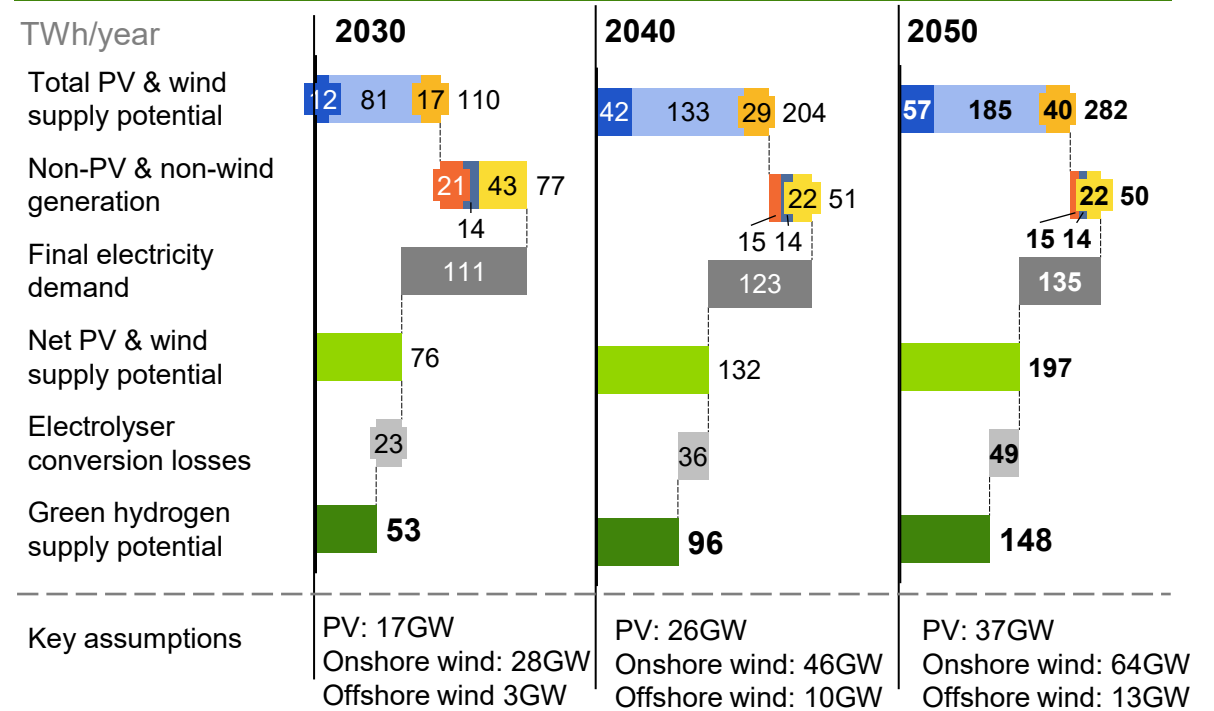
Finland possesses a substantial green hydrogen supply potential of ~50 TWh/y by 2030, although this requires delivering on its vast onshore wind potential – with 20 GW under development today and 90 GW of grid applications received.

Almost 10x times more wind projects under development than installed, and 90 GW of grid applications received



Source: Guidehouse analysis based on Finnish Wind Power association – illustrative only, not all wind projects under development are projected on the map

Leading to a significant excess supply potential in Finland, driven by onshore wind

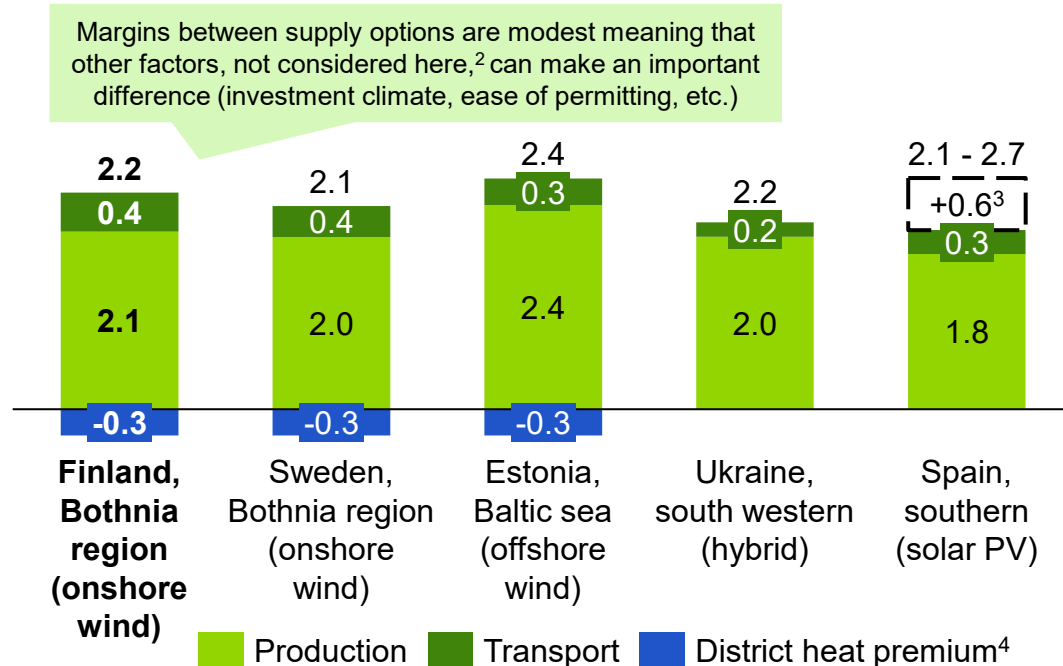


Source: Onshore wind data: 80 GW applications combined with GH adoption rate; Offshore wind: WindEurope (2020) Our energy, our future; Solar PV potential: ENSPRESO; Final electricity demand and other generation: TYNDP (2020) Global Ambition scenario, adjusted for Finland 2035 carbon neutrality; Electrolyser efficiencies 70% by 2030, 73% by 2040 and 75% by 2050.

Finnish hydrogen production from dedicated onshore wind is one of several competitive options to supply the 70 TWh, or ~€4 billion¹, potential hydrogen market in Germany by 2030, while also meeting domestic Finnish demand.

Finnish and Nordic green hydrogen is one of several competitive supply options in and around Europe.

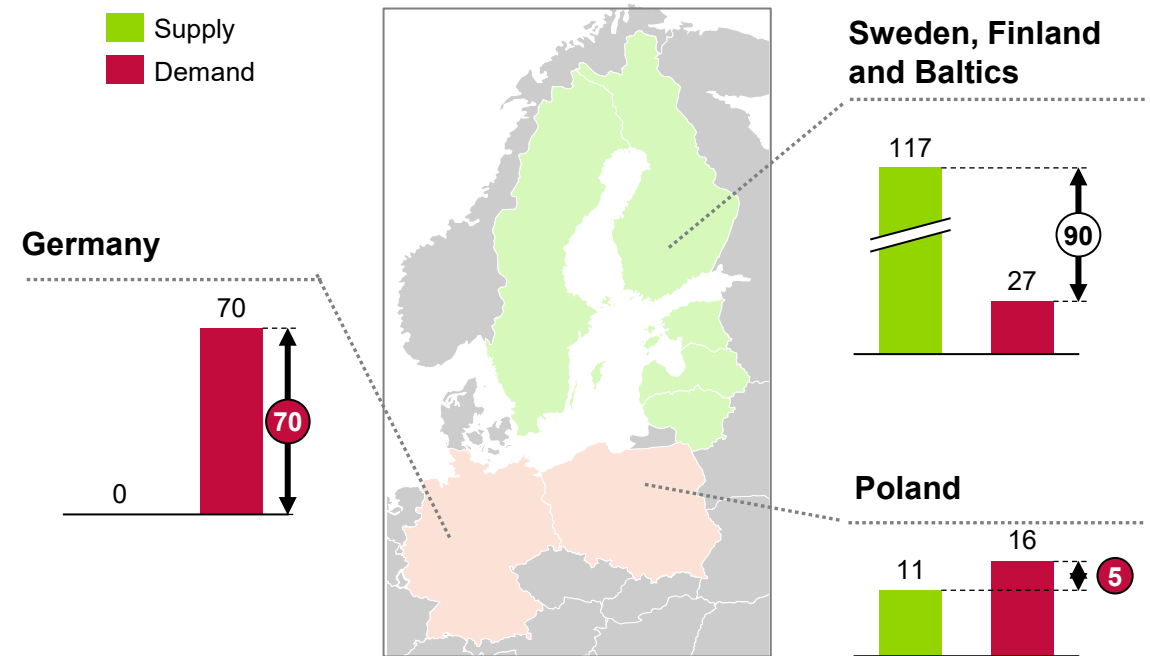
Delivered cost of hydrogen to the Ruhr Area, Germany (€/kg H₂)²



Sources: EHB (2021) analysis on transport costs using hydraulic scenarios and EHB (2021) analysis of production costs with capacity factors based on ENSPRESO, other KPIs based on BNEF (2019): Hydrogen's plunging price boosts role as climate solution

Germany is expected to be in a substantial hydrogen deficit by 2030 – creating a €4 billion¹ opportunity for export countries.

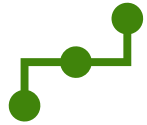
Green hydrogen supply and demand in neighbouring regions in 2030, TWh/year



Source: EHB (2021) Analysis of hydrogen demand, supply and transport;

However, the key barrier to scaling up the hydrogen market is the chicken and egg problem between supply, demand, and infrastructure. Today’s siloed approach means most players are in “wait-and see” mode.

One goal: decarbonisation



Consumers / off-takers

Unable to commit demand volumes without clarity of supply options, infrastructure, and policy incentives

Waiting on infrastructure providers and policy makers, for financial support



Producers / suppliers

To make final investment decisions, need proper demand side commitments and infrastructure solutions

Waiting on infrastructure providers and policy makers for market signals



Infrastructure providers / TSOs

Need for clarity on regulation, funding, and flexibility to overcome funding gap during market development

Waiting on regulators to create enabling frameworks, and waiting on market players for flows



Policy makers & Regulators

Hesitancy to interfere with market mechanisms & ‘choose winning technologies’, focus on protecting end-consumers

Waiting for public support and for market to prove benefits for the end-consumer in the form of demand/supply commitments

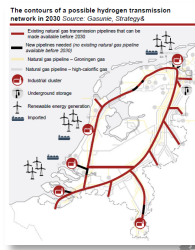
Siloed approach → no actor moves → no actor achieves goals

Some first-mover countries are starting to develop concrete national infrastructure plans with a view to realise the first H₂ pipelines before 2030 to create momentum and activate the market.

With an EU strategy in place, countries and TSOs are developing their hydrogen infrastructure plans – to create investment certainty and reduce risk for producers and off-

Netherlands – HyWay27

- Conclusion by the Ministry of Economic Affairs and Climate to develop a national H₂ backbone by 2027 (HyWay27)
- Investment of €1.5 billion in dedicated H₂ infrastructure



United Kingdom – Project Union

- Development of a network to connect five industrial clusters in the UK, creating a hydrogen network of 2,000 km by 2030



Sweden – Role of Gas Infrastructure

- A stakeholder-led study commissioned by Energiforsk indicates the necessity of a national hydrogen backbone by 2045



Germany – Wasserstoffnetz

- German TSOs are planning a H₂ network of around 5,900 km
- Parliament has proposed an interim opt-in regulation for dedicated H₂ transport infrastructure



Italy – Snam's investment plan

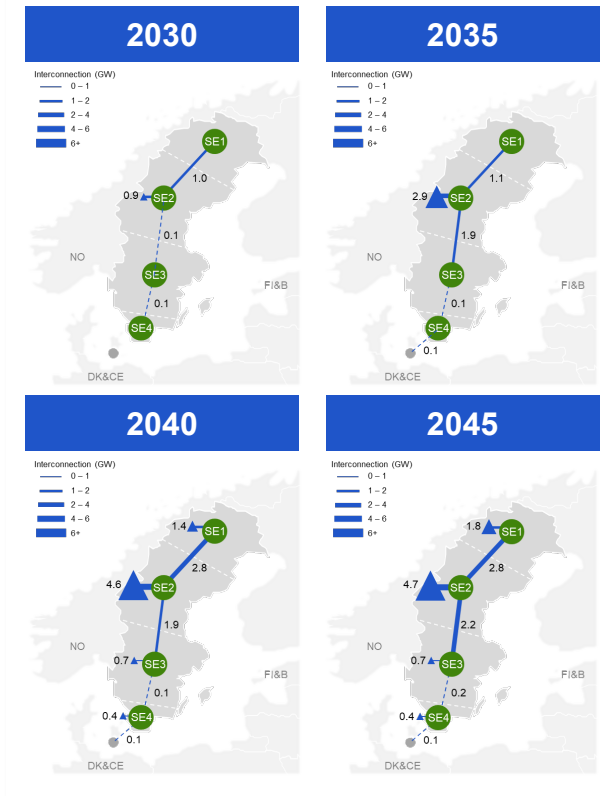
- 50% of Italian TSO Snam's 2020-2024 investment plan is dedicated to preparing the network to be hydrogen-ready
- Hydrogen strategy aims to position Italy as a hydrogen transit hub, with imports from North Africa



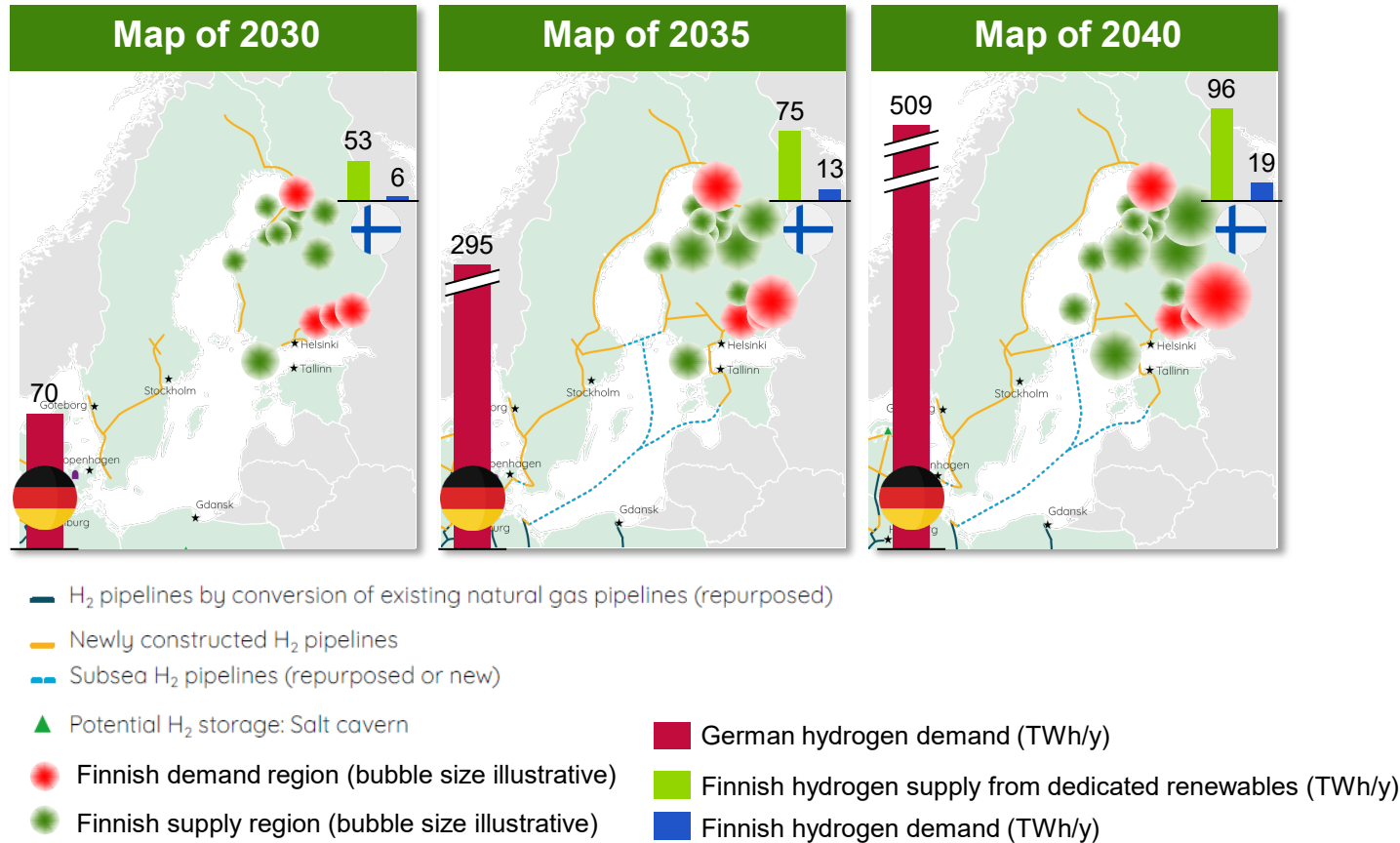
Source: [HyWay 27](#), [Project Union](#), [Sweden report](#), [Wassterstofnetz](#), [Snam investment plan](#)

Sweden has developed a vision for a future H₂ network

Swedish H₂ network



Hydrogen demand will be geographically distant from supply regions – at Finnish and EU-level – creating a clear transfer need. Meeting this need requires proactive collaboration between the TSO, market players, policy makers, and regulators.



Source: Guidehouse analysis based on maps from EHB (2021) Extending the European Hydrogen Backbone

Meeting H₂ transfer needs requires collaboration between stakeholders

- **Infrastructure companies** can help demand sectors decide decarbonisation technologies by sending clear market signals about plans of future infrastructure development.
- **Infrastructure companies** can help policy makers and regulators by offering a clear vision of the future energy system and how their infrastructure can increase societal benefits.
- **Policy makers and regulators** can encourage market and infrastructure development by creating enabling legislative frameworks, adopting flexible regulatory models, and offering support instruments.
- **Market players** can demonstrate their intentions by committing to decarbonisation technologies, and making proper volume commitments on the supply and demand side.

Executive summary

Summary



Summary of main findings

Finland is well-positioned to benefit from the emerging hydrogen economy, but successful market creation will depend on the decisions and actions taken by industry and government today.



Technological and political conditions are ripe for large-scale uptake of renewable hydrogen in the EU, but market creation will need coordinated action from policy makers, regulators, and industry, at both EU- and MS-level to simultaneously scale-up supply, demand, and infrastructure.

- **Demand** | Hydrogen is crucial to abate sectors where there are no alternative decarbonisation pathways, such as steel, aviation and shipping. There is consensus regarding the key role of hydrogen to achieve deep decarbonisation in no-regret sectors.
- **Supply** | By 2030, electrolyser technology will be mature, production capacity will be sufficient, and green hydrogen can be economically competitive in several – but not all – end-use sectors.
- **Infrastructure** | Numerous European studies identify the role of hydrogen pipelines, storage, and imports to meet a potential supply shortage in Europe. Other EU countries are starting to develop concrete hydrogen pipeline and storage infrastructure plans.
- **Policy** | Coordinated action from policy makers, regulators, and industry is needed to simultaneously and rapidly scale-up demand, supply, and supporting transport infrastructure needed to create a hydrogen market.



Finland is well-positioned to benefit from the emerging hydrogen economy because of abundant renewable energy resources and substantial export potential – but success requires overcoming the ‘chicken-and-egg’ challenge which depends on decisions and actions taken by stakeholders across industry and government today.

- **To achieve carbon neutrality**, Finland’s future hydrogen demand is estimated to be 30 TWh, based on a bottom-up assessment of current industrial installations (compared to 25 TWh natural gas in 2020). This could be a ~€2B market¹
- **Finland possesses substantial green hydrogen supply potential of ~50 TWh by 2030 and ~150 TWh by 2050** (€3B and €9B¹), driven by abundant wind resources. Finland can meet its own hydrogen needs and potentially export to other countries – already by 2030.
- **Wind-based hydrogen from Finland** can be a cost-effective supply option, already by 2030, to address import needs in RES-constrained EU countries like Germany, which is expected to have 70 TWh H₂ demand by 2030 (€4B¹).
- Given the uncertainties for Finnish market actors and lack of clarity regarding infrastructure regulation in Finland – **there is a role for players in the hydrogen industry, including Gasgrid** – to collaborate and proactively shape and develop the hydrogen market together.



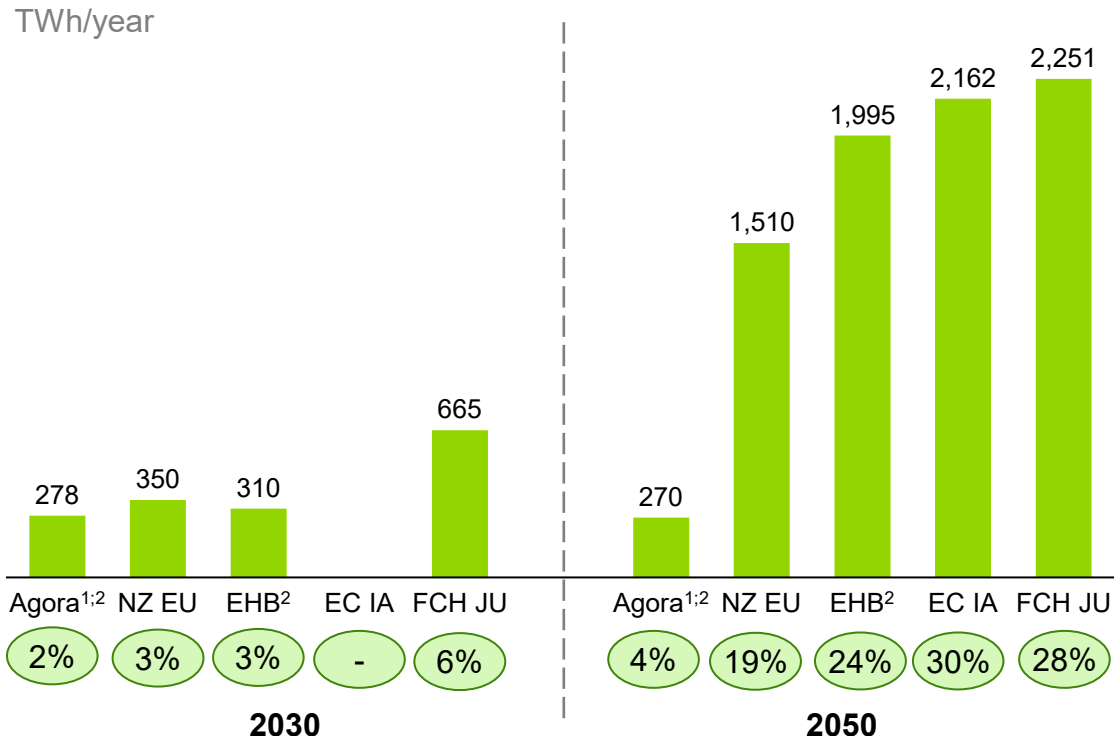
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Hydrogen demand across EU macro-studies

Energy scenarios foresee an important role for H₂ in EU's energy system by 2050 at ~25% of energy demand. Current projections assume a modest role for H₂ in 2030 but increasingly strict decarbonisation targets could raise volumes.

Hydrogen demand in different EU energy studies, 2030 & 2050



Sources: Agora (2021) No regret H₂ infrastructure (only includes industrial H₂ demand and excludes H₂ demand for e-fuels); McKinsey (2021), Net-zero Europe; EHB (2021), Analysis of hydrogen demand, supply and transport, EC (2020) impact assessment SWD (176) MIX scenario; FCH JU (2019) Hydrogen Roadmap Europe Ambitious Scenario; ETC (2021), Global Hydrogen report

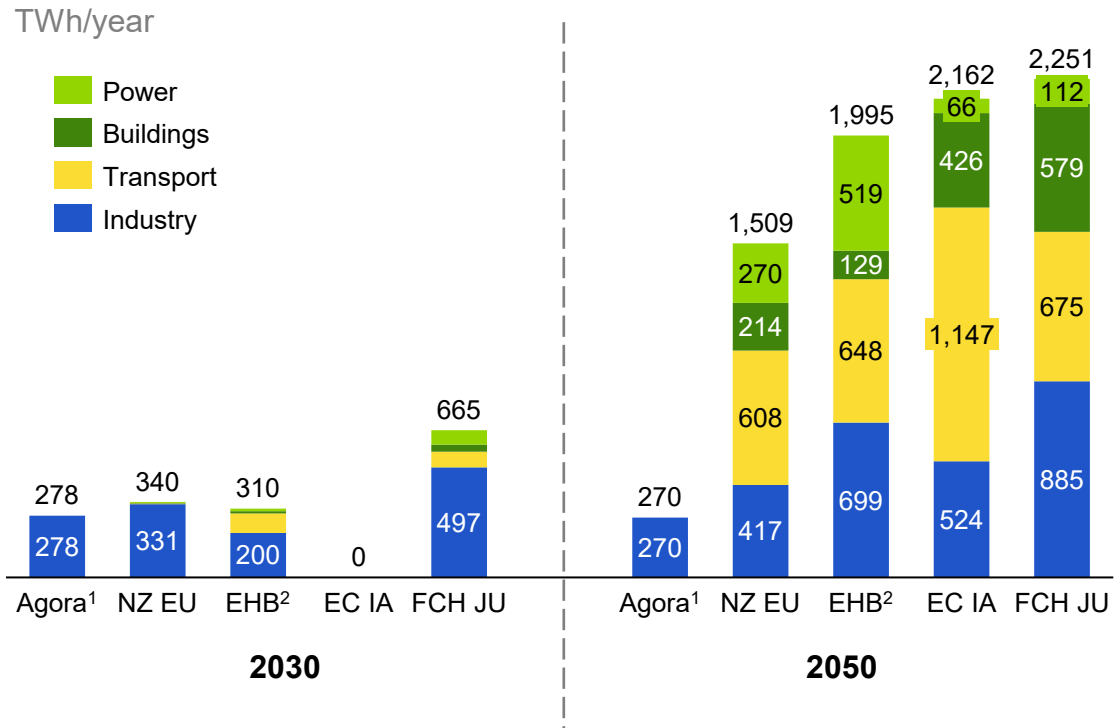
Key messages

- **Important role for H₂ in EU by 2050 at ~25% of final energy demand**
Average of 25% excludes Agora. This compares to global shares of H₂ of 13% of final energy demand forecasted by IEA and IRENA³.
- **Stricter decarbonisation targets could raise 2030 H₂ demand**
Studies expect H₂ demand to make up 2-6% of EU energy demand by 2030, however results do not capture recently raised regional decarbonisation targets which could lead to accelerated H₂ adoption:
 - EU-wide studies are based on reaching net-zero emissions or 1.5-2-degree targets by 2050, whereas Finland aims at carbon neutrality by 2035, Sweden by 2040 and Germany by 2045.
 - Germany has recently raised its 2030 CO₂ emissions reduction target to 65%, above the 55% assumed in EC scenarios. In the NZ EU study Germany is even assumed to fall short of its 2050 emissions target, compensated by other MS.
- EHB also reports 2040 hydrogen demand; 1,201 TWh/year.
- Main reason for lower 2050 hydrogen demand in the NZ EU scenario is that study assumes a larger role for CCUS across the various sectors.
- The Agora report has a different scope than the other studies – it only includes industrial H₂ demand and excludes H₂ for e-fuel production.

Hydrogen demand across EU macro-studies

There is consensus regarding early, no-regret, hydrogen adoption in industry. Longer-term demand will be driven by both transport – mostly as e-fuels – and industry. Views differ on hydrogen use in buildings & power.

Hydrogen demand in different studies 2030 and 2050 per sector



Sources: Agora/AFRY (2021) No regret hydrogen infrastructure (only industrial H₂ demand); ; McKinsey (2021), Net-zero Europe; EHB (2021), Analysis of hydrogen demand, supply and transport, EC (2020) impact assessment SWD (176) MIX scenario; FCH JU (2019) Hydrogen Roadmap Europe Ambitious Scenario; ETC (2021), Global Hydrogen report

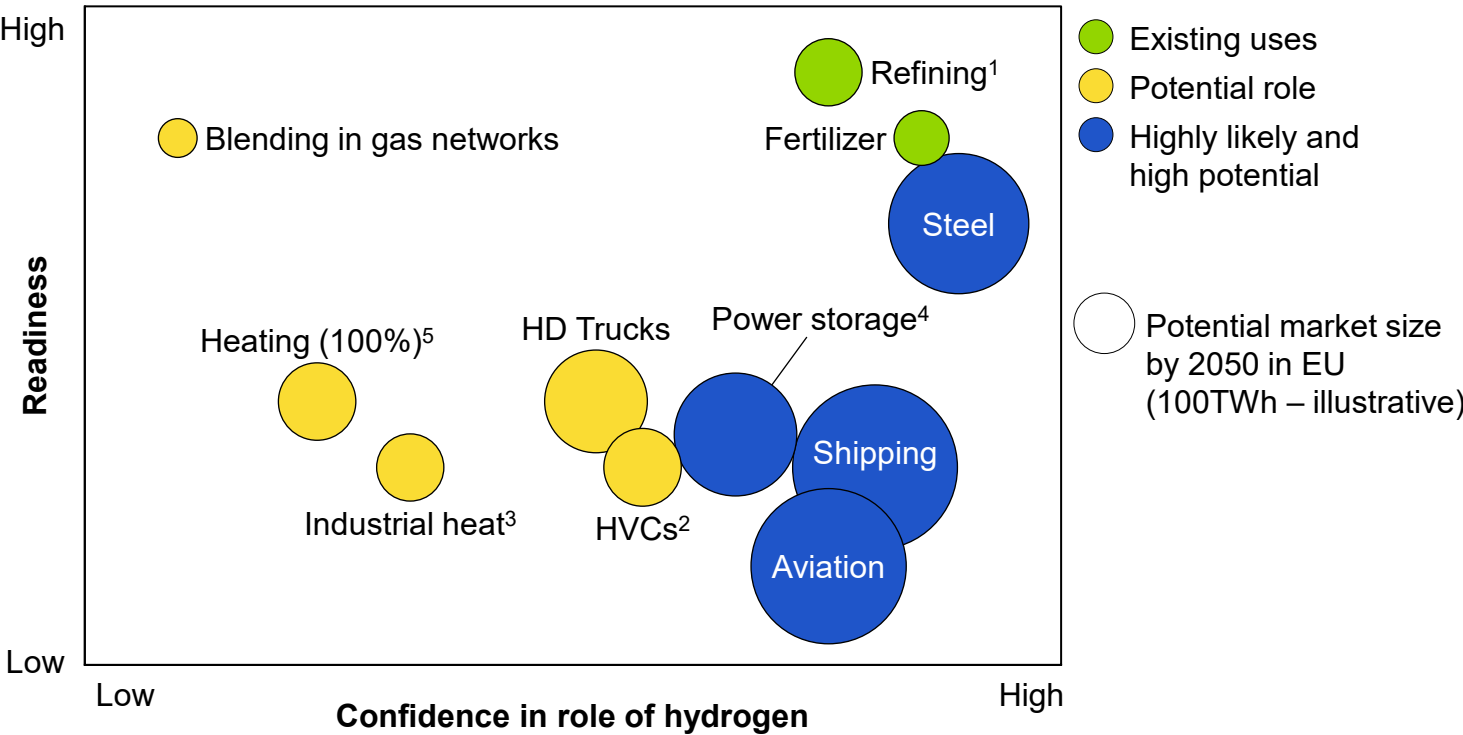
Key messages

- Hydrogen is essential for deep decarbonisation**
 It is the only decarbonisation pathway for certain sectors (see below)
- Studies agree on clear role for H₂ in industry - already by 2030**
 Replacement of existing hydrogen production (mostly in refining, fertilizer/ammonia and methanol), supported by a 50% target in EC's FF55.
- By 2050 most hydrogen demand will be in transport**
 Mobility will become the major driver of hydrogen demand, driven by e-fuels demand in aviation and shipping.
- Role of H₂ in buildings and power sector is a contested topic**
 Hybrid heat pumps are often seen as a more efficient alternative in buildings. In the power sector, EHB sees a large role for hydrogen balancing the EU-wide energy system enabled by H₂ storage and reconversion to electricity.
- Agora's study only considers "no-regret" industrial hydrogen demand**
 Only includes oil refining, steel and chemical sector and further assumes:
 - All e-fuels for transport and chemicals/plastics are imported from outside the EU and thus not included in the hydrogen demand estimate.
 - No role for hydrogen in buildings and industrial heating, as the study sees the use of direct electricity as more efficient.

Hydrogen readiness in end-use sectors

Green H₂ will become competitive in several sectors. Early adoption of green H₂ replaces existing grey H₂ in refining and fertiliser production. Adoption in new transport and heavy industry use-cases is expected in the medium to long-term.

Readiness and confidence in role of hydrogen in the different end-use sectors



Key messages

- Early offtake replacing grey H₂**
 In refining, ammonia and methanol production - supported by EC with a 50% green hydrogen target in industry by 2030
- Major future markets in transport**
 In aviation and shipping. Potential of hydrogen in shipping is in gaseous form, liquefied (long-term) and/or as e-methanol⁶ (short-term) and ammonia⁷ (long-term). In aviation, as e-kerosene⁸ (shorter term) or gaseous (longer term). E-fuels (e-kerosene and e-methanol) are assumed as having the largest market size in terms of H₂ demand.
- Steel sector has no other viable option than H₂**
 Using Direct Reduction of Iron (DRI) with H₂, which is a readily available technology but dependent on large amounts of decarbonised, constant supplied H₂
- Competitiveness H₂ depends on carbon price**
 Green H₂ breaks even at different price levels in various end-use sectors depending on the respective business-as-usual, emissions savings and carbon price, but also on the alternative decarbonisation technology⁶.

Sources: Based on Exhibit 1.3 from ETC (2021), Global Hydrogen report, adjusted for EU focus and according to Guidehouse own insights based on industry expert views, company interviews and sector roadmaps.

¹Short term potential in refining fossils, smaller longer term potential in refining biofuels, as biofuels will not reach capacities of fossil today; ² High Value Chemicals (HVC) like ethylene/propylene are the basis for plastic production; ³ Hydrogen could replace gas in industrial heating applications in e.g. Cement and Glass; ⁴ Long-term energy storage for the power system; ⁵Building heating with hydrogen boilers via hydrogen distribution grid ⁶See recent Maersk announcement [here](#); ⁷ [Ammonia energy](#); ⁸ Projects like [Norsk e-Fuel](#); ⁹ [Airbus](#); ¹⁰Appendix on hydrogen competitiveness per sector.

Electrolyser techno-economic parameters

By 2030, electrolyser system CAPEX is projected to fall to more than 30% to ~0.5 million €/MW, driven by electrolyser mass production and GW-scale projects – making electricity costs and load hours count for 70-90% of the costs in most projects.

KPIs of four different electrolyser technologies

		Alkaline (AEL)	Proton Exchange Membrane (PEMEL)	Solid Oxide/High temperature (SOEL)	Anion Exchange Membrane (AEMEL)
TRL		Mature	Early commercialisation	Demo plants (MW)	Demo plants (kW)
System efficiency (%_{el} LHV)	Today	67%	61%	83%	61%
	2030	69%	67%	90%	69%
	2050	74%	74%	91%	74%
System CAPEX (M€/MW_{el})	Today	0,6	0,9	2.1	4.0
	2030	0,4	0,5	0.5	0.5
	2050	0,2	0,2	0.3	0.2
Technology specific insights	Today	<ul style="list-style-type: none"> Large-scale projects Flexibility to respond to RES has improved, land footprint decreased Pressure level varies per OEM (3-30 bar) 	<ul style="list-style-type: none"> Low footprint due to high current density Integration with RES possible, even inside wind turbine Noble metals need key obstacle 	<ul style="list-style-type: none"> High efficiency with steam as input from industrial source; or Steam from FT¹/e-fuels production Combine with AEL Stack lifetime still low 	<ul style="list-style-type: none"> PEMEL 2.0; does not need noble metals Used in micro-grids Today at kW scale used decentralised Stack lifetime still low
	2030				
	2050				

Key messages

- Project scale increase**
 Today, AELs and PEMELs are being deployed on 10-20 MW scale. By 2025, first 100-200 MW electrolyser expected to have materialized, mostly in NW Europe² and already before 2030, GW-scale projects could be expected³.
- Electrolyses mass production**
 Electrolyser stacks will from being manually produced today be mass produced before 2025, but BoP and EPC increase cost of a project substantially which could vary per project from 30-70% of total costs.
- Electricity costs most important**
 Electricity costs will make up 70-90% of costs, also dependent on load hours and efficiency⁵.

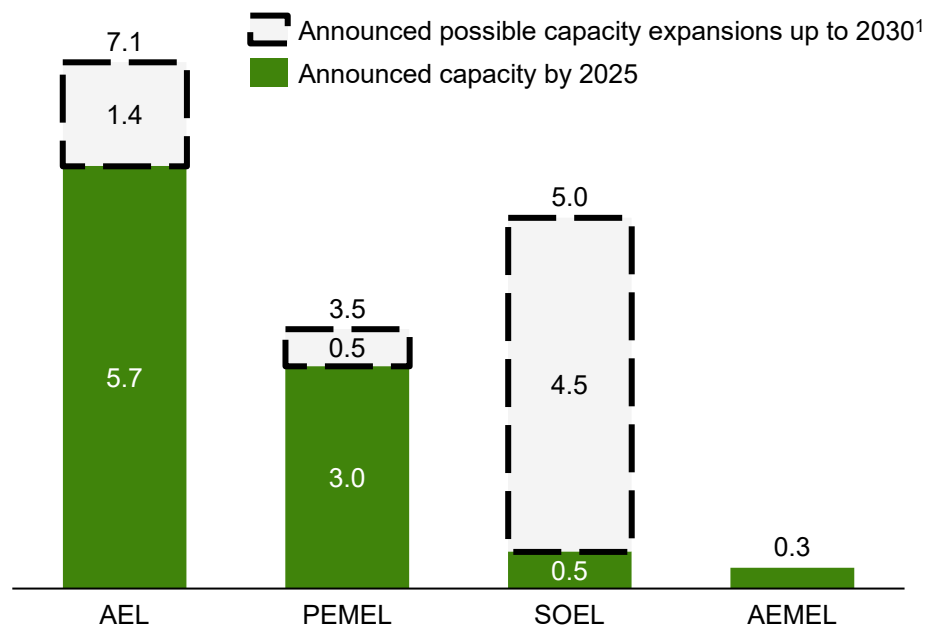
Sources: For 2050 estimates: IRENA (2020) Green hydrogen cost reduction; For today and 2030 estimates: Hydrogen Europe (2020) SRIA; Guidehouse own insights. Regards 100 MW_{el} system, 30 bar hydrogen output. Installed on pre-prepared site, excluding transformers/rectifiers.

Electrolyser manufacturing capacity

Electrolyser manufacturing capacity is expected to be sufficient to cover demand, considering the announced new plants totalling almost 10 GW/y by 2025, all located in Europe.

Announced electrolyser manufacturing capacity

GW_{el-input}/year



Sources: Announced capacities from [Nel](#) (AEL), [ITM](#) (PEMEL), [McPhy](#) (AEL), [Haldor Topsoe](#) (SOEL), [Enapter](#) (AEMEL), [John Cockerill](#) (AEL), [Siemens](#) (PEMEL), [ThyssenKrupp](#) (AEL), [Green Hydrogen Systems](#) (AEL), [Cummins/Iberdrola](#) (PEMEL)

Key messages

- **Electrolyser availability not a limiting factor**
 - Electrolyser manufacturing capacity announced of almost 10 GW_{el-input}/year by 2025, which will be more than enough to meet EU target of 6 GW of electrolyzers installed by 2025 and 40 GW installed by 2030.
 - ~2 GW/y is under construction or installed already, while most other plants have received or applied for funding (under IPCEI) and/or chosen their site.
 - Further expansion of manufacturing plants to meet possible further increases of demand is possible.
 - Even technologies with lower technology readiness levels, SOEL and AEMEL, expected to reach industrial manufacturing scales before 2025.
- **Europe is leading player in worldwide electrolyser market**
Manufacturing plants announced in Germany, France, Norway, Denmark, Spain and Italy.
- **Demand for critical raw materials could impact PEMEL**
PEMEL needs iridium and platinum, but research is going into recycling of stacks and alternative stack materials. For AEL (ruthenium) and AEMEL (IrOx and Pt/C) this is less of a problem, problem non-existent for SOEL, which does not require any rare metals.
- **Electrolysers show similar learning curve rates as Solar PV²**
Similarly, substantial cost decreases could be expected with large scale deployment

Role of pipelines and imports

All studies acknowledge the role of H₂ pipeline infrastructure and imports to varying degrees. It is now up to policy makers and regulators to decide their regions' and countries' infrastructure and trade strategies.

View studies on hydrogen imports and pipeline infrastructure

	Agora/AFRY	NZ EU	EHB	FCH JU	ETC
Imports from outside EU	Imports can be competitive in some cases, but this is subject to transport costs.	A scenario considering imports leads to 10-20% higher transition costs, but local opportunities in H ₂ pipeline imports clearly exist.	H ₂ pipeline imports are cost competitive from adjacent areas like North Africa and Ukraine and could help meet supply shortages which arise from e.g. social acceptance of RES deployment	Hydrogen provides link between low-cost renewable areas such as North Africa.	Countries should indicate import/export role in national hydrogen strategy and develop international collaborations accordingly.
Pipeline infra	Small local backbones expected due to limited role of hydrogen in energy system, but study does mention clear cost advantages by repurposing gas pipes.	Hydrogen and CO ₂ pipeline infrastructure is essential - needs collaboration and regulatory certainty.	Gaseous hydrogen transport using pipelines is the most cost-optimal to transport hydrogen at scale, also cheaper than electricity infra when hydrogen is the desired end-product.	Important role for hydrogen pipeline infrastructure: blended and dedicated; H ₂ pipelines have advantages over e-infrastructure.	Pipelines are the most cost competitive H ₂ transport option, especially when repurposed. Power lines are cheaper to transport electricity.

Key messages

- **All studies see role for imports**
Although Agora/AFRY and NZ EU question the economics
- **All studies see role for H₂ pipeline infra**
Especially for repurposed natural gas pipelines, but new dedicated hydrogen pipelines are also competitive.
- **H₂ pipelines cheapest transport option**
Even competitive with e-infra when hydrogen is the desired end-product
- **Role of governments essential**
Governments to consider positioning country as exporter/importer, develop international collaborations accordingly and provide regulatory certainty in order to allow public/private investment to set up the emerging infrastructure.

Sources: Agora/AFRY (2021) No regret hydrogen infrastructure; McKinsey (2021), Net-zero Europe; EHB (2021), Analysis of hydrogen demand supply and transport; FCH JU (2019) Hydrogen Roadmap Europe Ambitious Scenario; ETC (2021), Global Hydrogen report

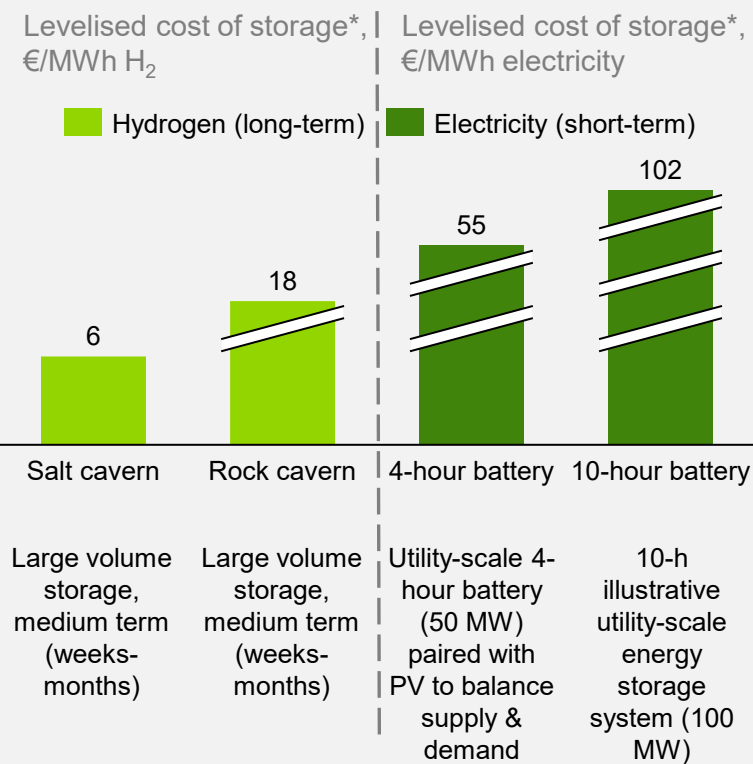
Hydrogen storage and linepack

H₂ storage costs range from 6-18 €/MWh for underground storage, to 30-60 €/MWh for liquefied H₂, and up to 1,900 €/MWh for compressed H₂ – the latter are only used for last-mile transport and are not economically feasible energy storage options today

Various forms of H₂ storage have been technologically proven

- **Salt caverns are a proven and suitable storage option** for large-scale hydrogen storage but are limited by their geographical availability across Europe.
- **Rock caverns are on a lower technology readiness level (TRL) of 5-6** and require additional R&D but could provide a smaller capacity seasonal storage of max 0.08 TWh per rock cavern versus 0.33 TWh per salt cavern – for countries without salt deposits like Finland.
- **Liquid state and compressed H₂** are used to transport hydrogen today, but are not economically competitive for energy storage:
 - Hydrogen storage via liquefaction and reconversion is estimated to cost between 30-60 €/MWh^{1,2}
 - Above ground, compressed H₂ tanks can cost between 1,200-1,900 €/MWh^{3,4}

H₂ storage is particularly well-suited for long-duration storage applications



Like NG, H₂ can provide some flexibility when transported via pipeline, but:

- **In energy-terms, linepack of hydrogen can be more than 4 times smaller** than that of natural gas due to a 3x lower energy density and higher normal flow rate.
- **To manage material defect (crack) growth**, pressure fluctuations in hydrogen pipelines need to be controlled – meaning that the range of acceptable pressures may be less than in the case of natural gas.
- **Meshed, interconnected networks are needed to get the most out of linepack** – these dense networks will not be available in the initial stages of the hydrogen market's development.
- **These factors mean that hydrogen pipelines offer less linepack flexibility than natural gas pipelines**, with corresponding implications on short-term security of supply.

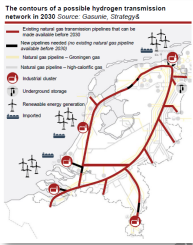
Hydrogen infrastructure developments in the EU

First-mover countries are starting to develop concrete national infrastructure plans with a view to realise the first H2 pipelines before 2030 and to overcome the ‘chicken-and-egg’ problem between market creation and infrastructure development.

Hydrogen infrastructure plans across Europe

Netherlands – HyWay27

- Conclusion by the Ministry of Economic Affairs and Climate to develop a national H₂ backbone by 2027 (HyWay27)
- Investment of €1.5 billion in dedicated H₂ infrastructure



United Kingdom – Project Union

- Development of a network to connect five industrial clusters in the UK, creating a hydrogen network of 2,000 km by 2030



Sweden – Role of Gas Infrastructure

- A stakeholder-led study commissioned by Energiforsk indicates the necessity of a national hydrogen backbone by 2045



Germany – Wasserstoffnetz

- German TSOs are planning a H₂ network of around 5,900 km
- Parliament has proposed an interim opt-in regulation for dedicated H₂ transport infrastructure



Italy – Snam’s investment plan

- 50% of Italian TSO Snam’s 2020-2024 investment plan is dedicated to preparing the network to be hydrogen-ready
- Hydrogen strategy aims to position Italy as a hydrogen transit hub, with imports from North Africa



Key messages

- Now that an European vision has been outlined, different countries and regions are developing their national plans in more detail.
- The different regions vary in their level of maturity, from visions in the UK to flow studies in Sweden up until FID stage in the Netherlands.
- In parallel, regulatory and policy advocacy at both a national and EU level is essential.
- Gasgrid Finland has a window of opportunity to provide input to the FF55 discussions by informing the Finnish government on the topic.
- Teaming up with other Nordic countries with similar stances on H₂ and energy system integration could make for a powerful position.



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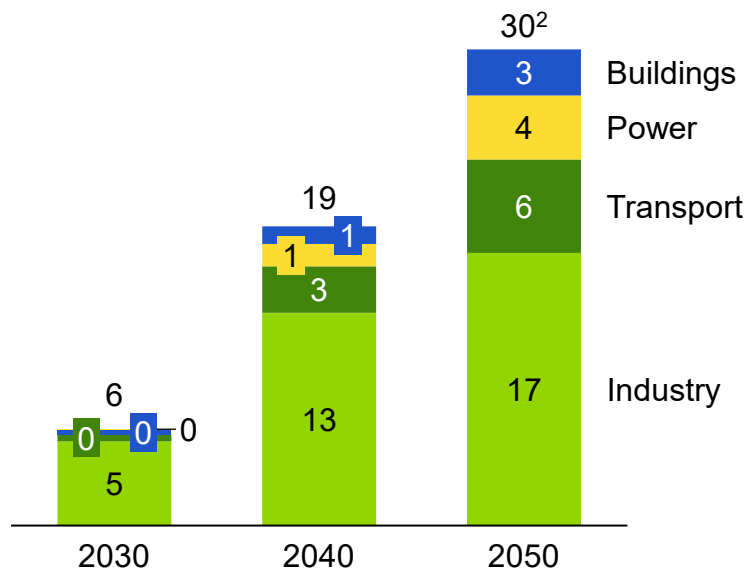
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Hydrogen demand in Finland

European Hydrogen Backbone analysis concludes that Finland could see domestic hydrogen demand of 6 TWh by 2030 and 30 TWh – or a ~€2 billion market¹ – by 2050, driven by the industry and transport sectors.

Green hydrogen demand Finland*

TWh/year



Source: EHB (2021) Analysis of hydrogen demand, supply and transport.
 *Note: hydrogen demand estimation is based on existing industrial installations, using a generic approach developed for the EHB analysis applied across all EU countries. A Finland-specific analysis has not been performed. The latter would require a thorough analysis and discussion with stakeholders.

Assumptions

- **Industry** | Includes steel, refining (including e-fuels), high value chemicals and high temperature heat. Transition pathways are applied to current industrial sites based on public announcements, sector roadmaps, and interviews.
- **Transport** | Includes hydrogen for heavy duty trucks and direct use in aviation. Total energy demand per transport mode is based on forecasted annual distance travelled, energy demand per technology, and technology share. Ammonia and methanol for shipping are not included.
- **Power** | Based on the forecasted power mix from ENTSO-E’s TYNDP 2020 Scenario Report and Gas for Climate 2020 electricity generation values. Assumes 1%, 35%, and 70% of gas-generated electricity in 2030, 2040, and 2050 is produced from hydrogen, based on Gas for Climate 2020 Pathway study.
- **Buildings** | Hydrogen is used as a fuel for district heating systems (CHPs). Floor space data, fuel shares, building renovation rates, and technology adoption rates based on EHB analysis report.
- EHB results represents a first order approximation, limitations of the analysis include:
 - EHB assumes 2050 EU-wide carbon neutrality, Finland’s 2035 target will in reality lead to earlier adoption/higher demand in early years
 - Potential relocation of industry to RES-abundant regions, such as Finland, is not considered.
 - Exclusion of new sources of demand in neighbouring regions or new demand-side projects

¹Assuming 30 TWh/y of demand for hydrogen at cost/market price of 2€/kg; ²Compared to 25 TWh of natural gas flows in the Finnish transmission system today.

Hydrogen demand localization

Future H₂ demand is expected to be concentrated in southern Finland. Additional sources of demand include new industrial developments and import needs in resource-scarce but energy-intensive neighbouring countries

Hydrogen demand will likely be localised in industrial clusters in the south of Finland

Potential additional hydrogen demand developments in Finland

Nouryon/Eastman Oulu

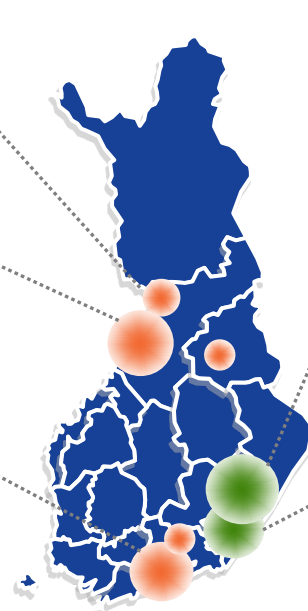
Chemical production

SSAB Raahe¹

Steel production with potentially ~2 TWh/year demand by 2030

Neste Porvoo

Refinery with 2.5 TWh/year forecasted demand for refining of fossils/bio-fuels and production of e-fuels by 2030



- Existing industrial site
- Potential new development

PtX², Joutseno

Potential syn. methanol production, also for aviation, using CO₂ from cement/chemical production

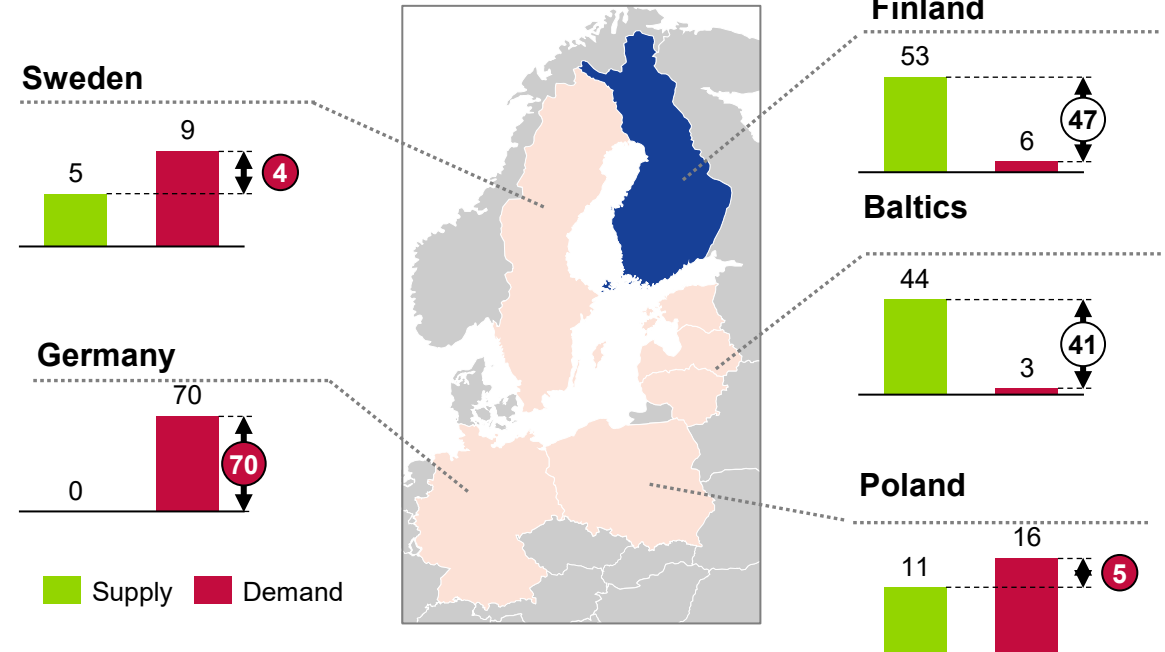
UPM Lappeenranta³

Biofuel refinery with small existing demand but expected expansion to 500 kt/y incl. sustainable jet fuel

Source: EHB (2021) Analysis of hydrogen demand, supply and transport; Business Finland (2020) National Hydrogen Roadmap

Especially Germany is expected to be in a substantial hydrogen deficit by 2030 – creating a €4 billion⁴ opportunity for Finland

Green hydrogen supply and demand in neighbouring regions in 2030, TWh/year

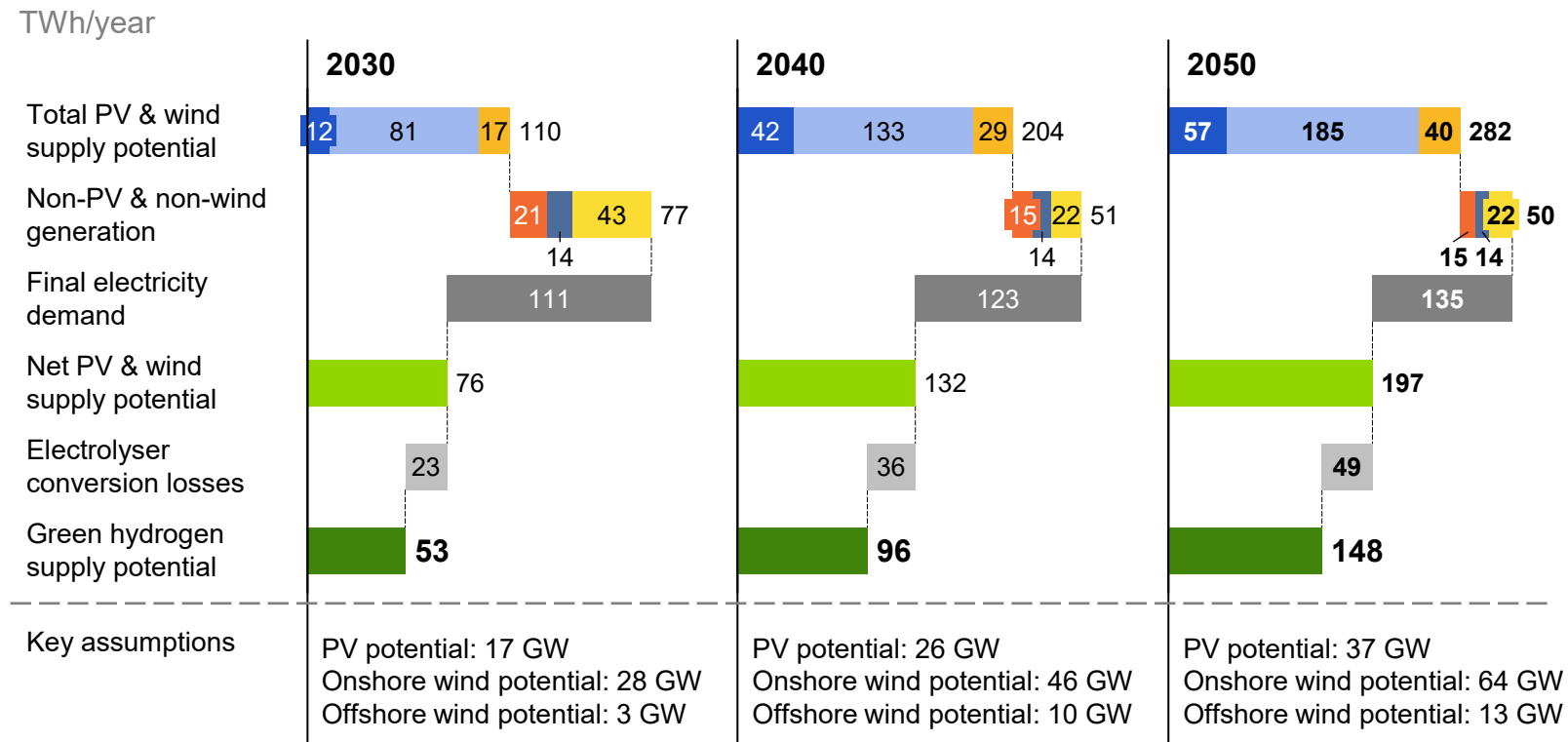


Source: EHB (2021) Analysis of hydrogen demand, supply and transport;

Renewable hydrogen supply potential in Finland

Finland possesses substantial green hydrogen supply potential - of 53 TWh/y in 2030 - even after considering increasing final electricity demand due to electrification. This supply potential is made possible by abundant wind resources.

Green hydrogen supply potential after taking into account electricity demand and losses



Key messages

- Finland has substantial H2 supply potential**
 Even after subtracting the increasing final electricity demand and assuming decreasing nuclear production.
- Driven by onshore wind**
 Generating between 65-73% of electricity over the years, next to an ~equal share of solar PV and offshore wind.
- Providing opportunities for exports**
 Oversupply creates opportunity for exports of hydrogen via pipelines to countries with renewable energy/hydrogen shortages such as Germany
- Attract H₂-based industry**
 Alternatively to exports of gaseous H₂ attracting production of steel/sponge iron, or e-fuels and e-chemicals, could be an option.

Source: Onshore wind data: 80 GW applications combined with GH adoption rate; Offshore wind: WindEurope (2020) Our energy, our future; Solar PV potential: ENSPRESO; Final electricity demand and other generation: TYNDP (2020) Global Ambition scenario, adjusted for Finland 2035 carbon neutrality; Electrolyser efficiencies 70% by 2030, 73% by 2040 and 75% by 2050.

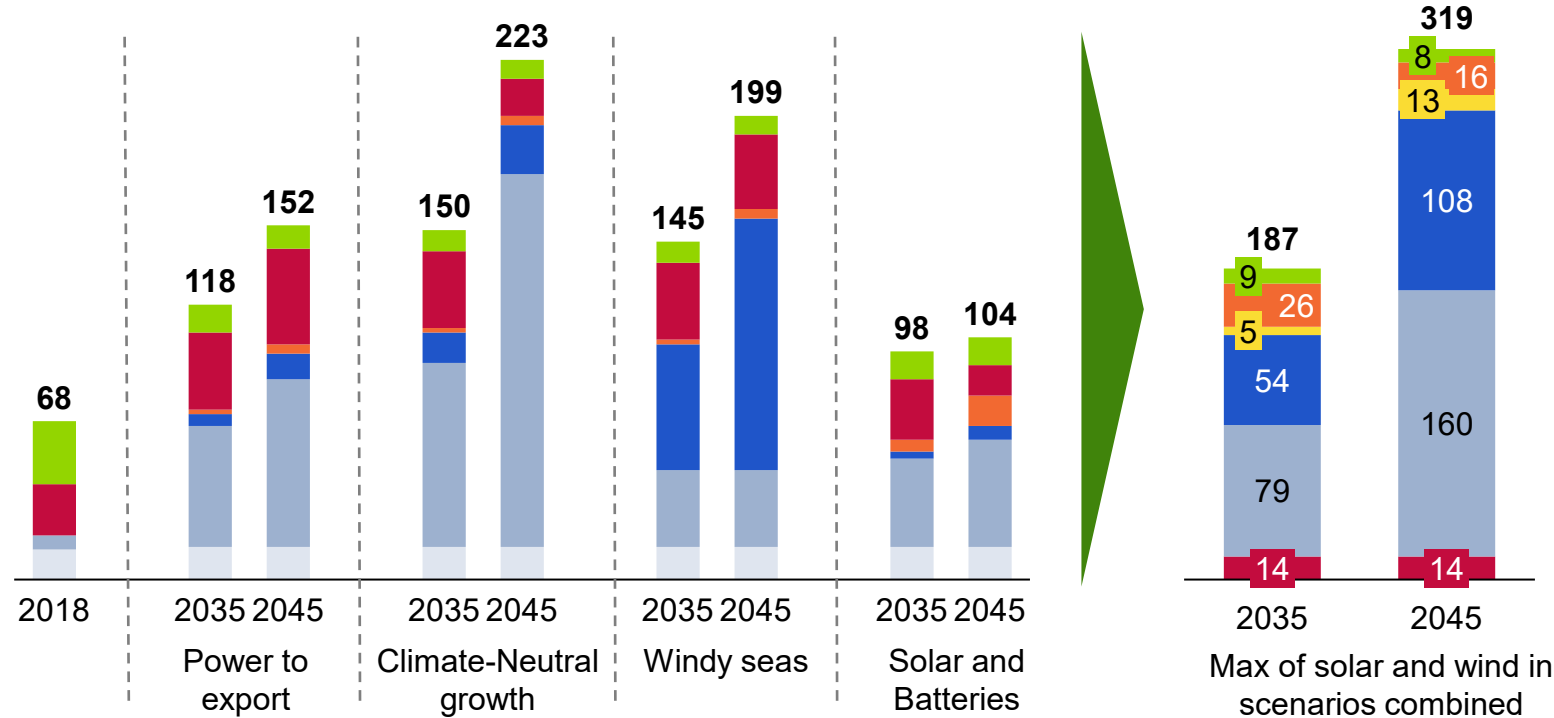
¹Finnish wind power association has a 30 TWh/y objective for annual wind power production by 2030 ([link](#)). 2.5 GW of onshore wind is currently installed, and there are plans to add an additional 21 GW, of which 7 GW of projects already have a land use plan/land use plan and building permit ([link](#))

Renewable hydrogen supply potential in Finland

Finland possesses substantial green hydrogen supply potential - of 53 TWh/y in 2030 - even after considering increasing final electricity demand due to electrification. This supply potential is made possible by abundant wind resources.

Fingrid electricity generation scenarios

TWh/year



Key messages

- **Fingrid scenarios confirm supply potential**
 - The scenarios for electricity generation result in high installed capacities of either onshore wind, offshore wind or solar PV.
 - When combining the high potentials of renewables in the different scenarios, Guidehouse assumptions are confirmed, especially for onshore wind
- **Offshore wind potential more than expected**

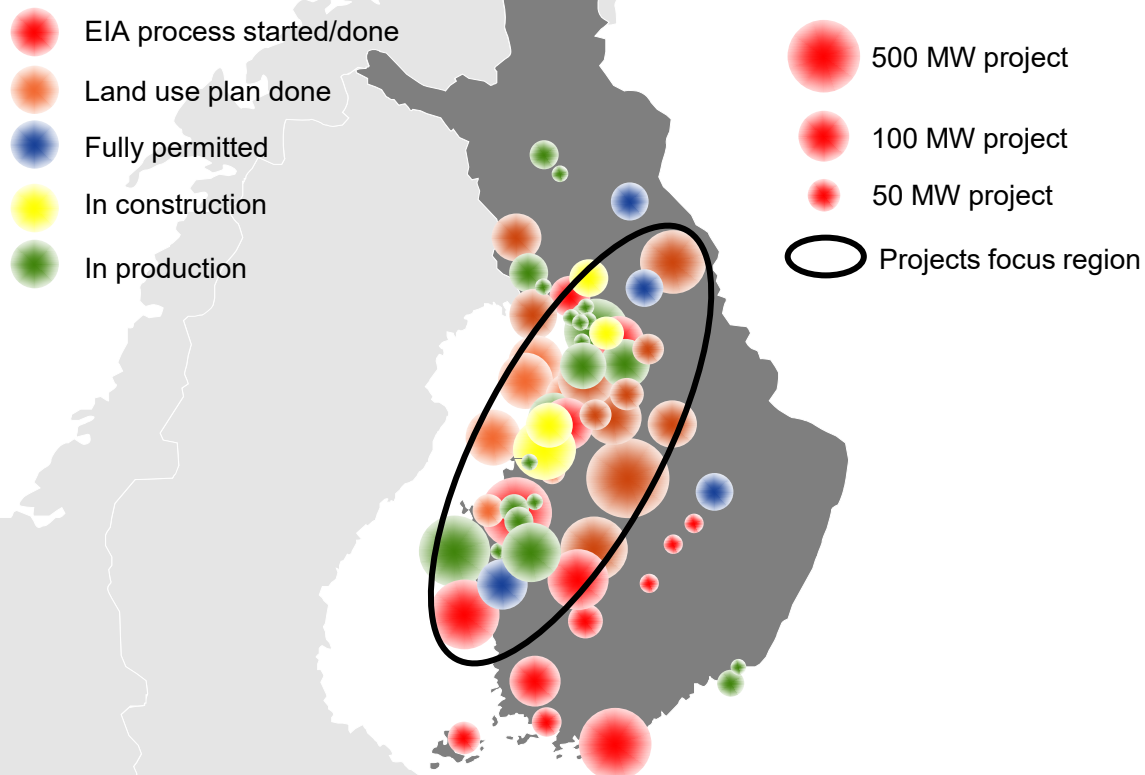
The ‘Windy Seas’ scenario shows far greater installed capacities than anywhere else (e.g. BEMIP shows 8 GW or WindEurope 6 GW as potentials)
- Additionally, Fingrid mentions more than 90 GW of grid connection applications for wind energy

Source: Fingrid (2020) Network Vision

Renewable hydrogen supply potential in Finland

Renewable hydrogen supply in Finland will be concentrated near the more windy Bothnia/West coast, however also larger 100-500 MW projects have been announced more land inwards in central Finland and offshore.

Wind power projects in Finland



Key messages

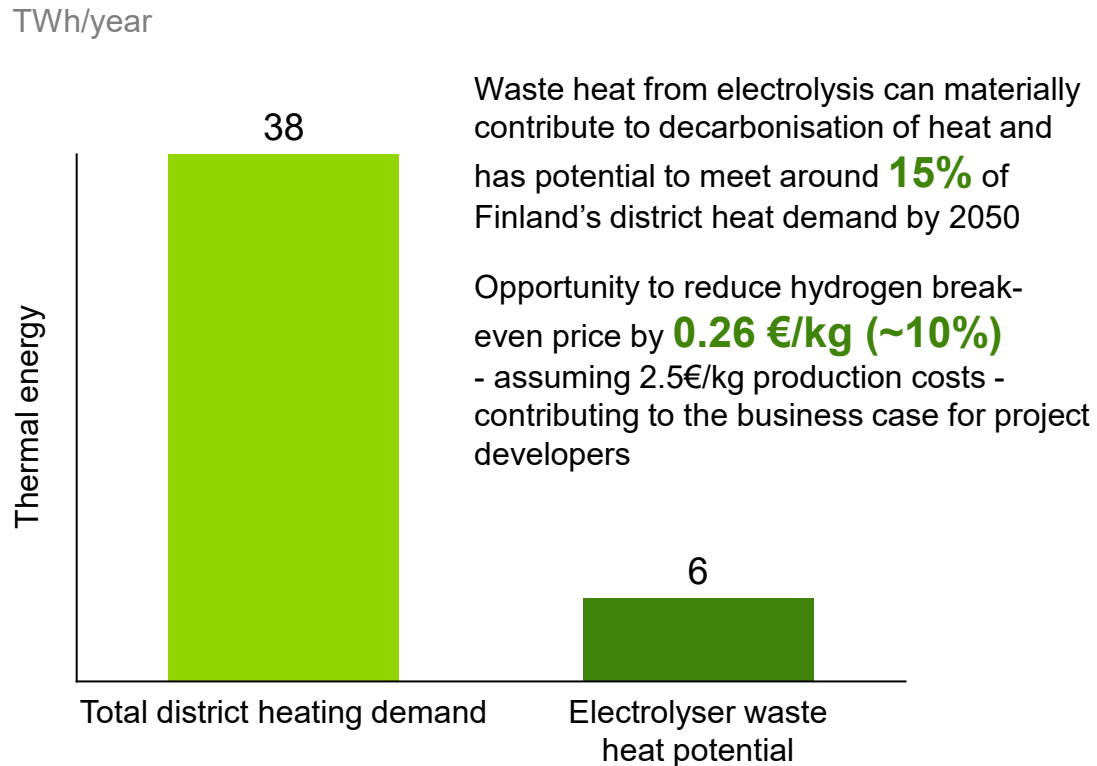
- **Almost 10x times more wind projects under development than installed**
2.6 GW (7.8 TWh) installed, 3 GW under production and 7 GWs have a land use plan or land use plan and building permit and in total 21.3 GW is under development. Additionally - Fingrid has received more than 90 GW applications for grid connections for wind projects
- **Most current projects are near the Bothnia coast along the west**
Where most favourable wind conditions/capacity factors sit
- **New projects announced more land inwards and offshore**
In earlier phase are 100-500 MW projects more inland in central Finland, and offshore in the Bothnia Bay and Baltic Sea. This shows a project scale increase, while also that less windy areas located more centrally in Finland are being considered for wind projects
- **Electrolysers connection to new or older projects**
Especially in the early phase – electrolysers could be connected to:
 1. New projects which need to wait/cannot get a grid connection or;
 2. Old projects which will be outcompeted by new projects and could therefore possibly face curtailment at times or early repowering

Source: Guidehouse analysis based on Finnish Wind Power association – illustrative only, not all wind projects under development are projected on the map

Hydrogen in Finland – benefits from existing district heat

Utilising waste heat from electrolysis in Finland’s district heating network can lead to business case improvement of ~10% or 0.26 EUR/kg and meet up to 15% of Finland district heating demand, but limited by supply location & technology competition

Potential Benefits of H₂ for Finland District Heating Supply



However this benefit is...

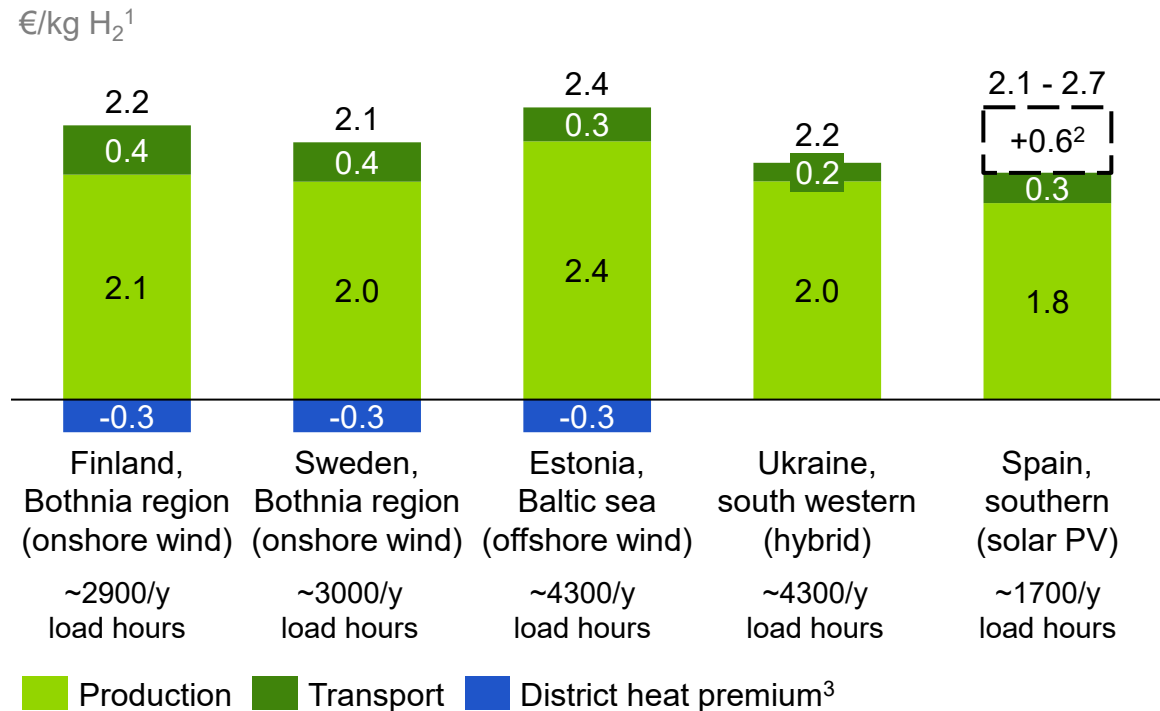
- **Location dependent** | Demand for heat & heat network infrastructure must be located next to supply source i.e. close to industrial clusters, ports and supply hubs. Due to residential nature of district heat and magnitude of hydrogen supply it is unlikely significant benefits can be reached.
- **Not fully unique to Finland** | Although district heat in Finland has 46% market share, in Estonia/Sweden district heat has a 60%/50% share respectively. Finland would not be the only country able to capitalise on the benefits of waste heat from hydrogen production, e.g. district heat plans in the Netherlands already aim to use waste heat from electrolysers within port industrial area¹.
- **In competition with alternative decarbonisation pathways** | There are potentially other suitable methods of decarbonising district heat in Finland that are not restricted by hydrogen supply location, quantity and future market. For example Espoo, Finland, aims to use waste heat from Data Centres and Geothermal Plants²

Based on district heat price of 20 EUR/MWh; Electrolyser efficiency (LHV) of 65% and 25% of energy input can be recovered as waste heat. H₂ production 30 TWh in 2050 of which 50% can be used for district heating; See appendix for more assumptions

Cost competitiveness of renewable hydrogen from Finland

Based on average renewable energy capacity factors in different supply countries, dedicated wind-based hydrogen from Finland can be a cost-effective option for imports in supply-constrained EU countries.

H₂ delivery cost to Ruhr Area, DE for import options in 2030



Sources: EHB (2021) analysis on transport costs using hydraulic scenarios and EHB (2021) analysis of production costs with capacity factors based on ENSPRESO, other KPIs based on BNEF (2019): Hydrogen's plunging price boosts role as climate solution

Key messages

- Margins are small thus other factors could decide on competitiveness**
 Other important factors – not considered here – can make Finland/Sweden competitive, seeing the small margins between the import options. Examples could be investment climate, cost of capital, relative ease of permitting. Multiple countries have a chance - eventual 'winner' depends on governments decisions and actions today
- Ukraine hybrid is most competitive, but**
 Higher cost of capital and current political situation could worsen the economics and potential significantly. The ability to use repurposed large diameter 48-inch pipelines leads to low transport costs from Ukraine.
- Spanish hydrogen most competitive production costs, but**
 the long transport distance partly using smaller (20-30 inch) pipelines could add significantly to transport costs.
- Capacity factors main factor in production costs**
 More detailed analysis needed optimizing system set-up by adding batteries, solar PV, under/over sizing the electrolyser and also considering storage / capacity factor of pipelines.
- Note:** Transport costs calculated based supply routes assuming accelerated deployment of 2035 EHB maps to 2030. Production costs calculation assumes hydrogen production from dedicated renewables⁴.

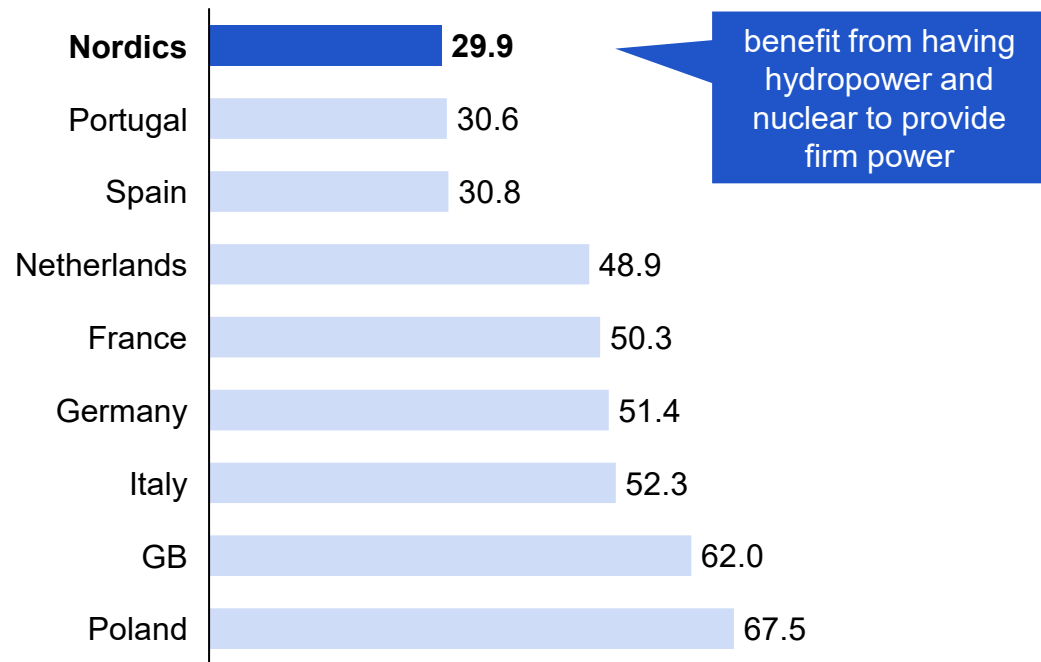
¹Cost projections production and transport, excluding storage and local distribution – LCOH calculation assumes dedicated hydrogen production from dedicated renewables; ²Range for Spain represents different pipeline options in southern France, from using small partly repurposed ~20 inch pipelines (high estimate) or large new ~48 inch pipelines (low estimate); ³Based on the value of waste heat from electrolysis in district heating, as per slide 18. ⁴Grid-based electrolysis can lead to lower marginal costs when electricity prices are low (or negative), but prices are volatile as they depend on the power market and it remains to be seen whether grid-based electrolysis will meet renewable hydrogen criteria (additionality, carbon intensity).

Cost competitiveness of renewable hydrogen from Finland

Low power prices and favourable conditions for project development can further improve the attractiveness and cost-competitiveness of green hydrogen supply in Finland compared to other EU countries

Low power prices lead to (a) cheaper grid-based hydrogen and (b) developers looking for higher-value off-takes, e.g. hydrogen

10-year renewable PPA index prices per region as of August 2021, €/MWh



Sources: Pexapark

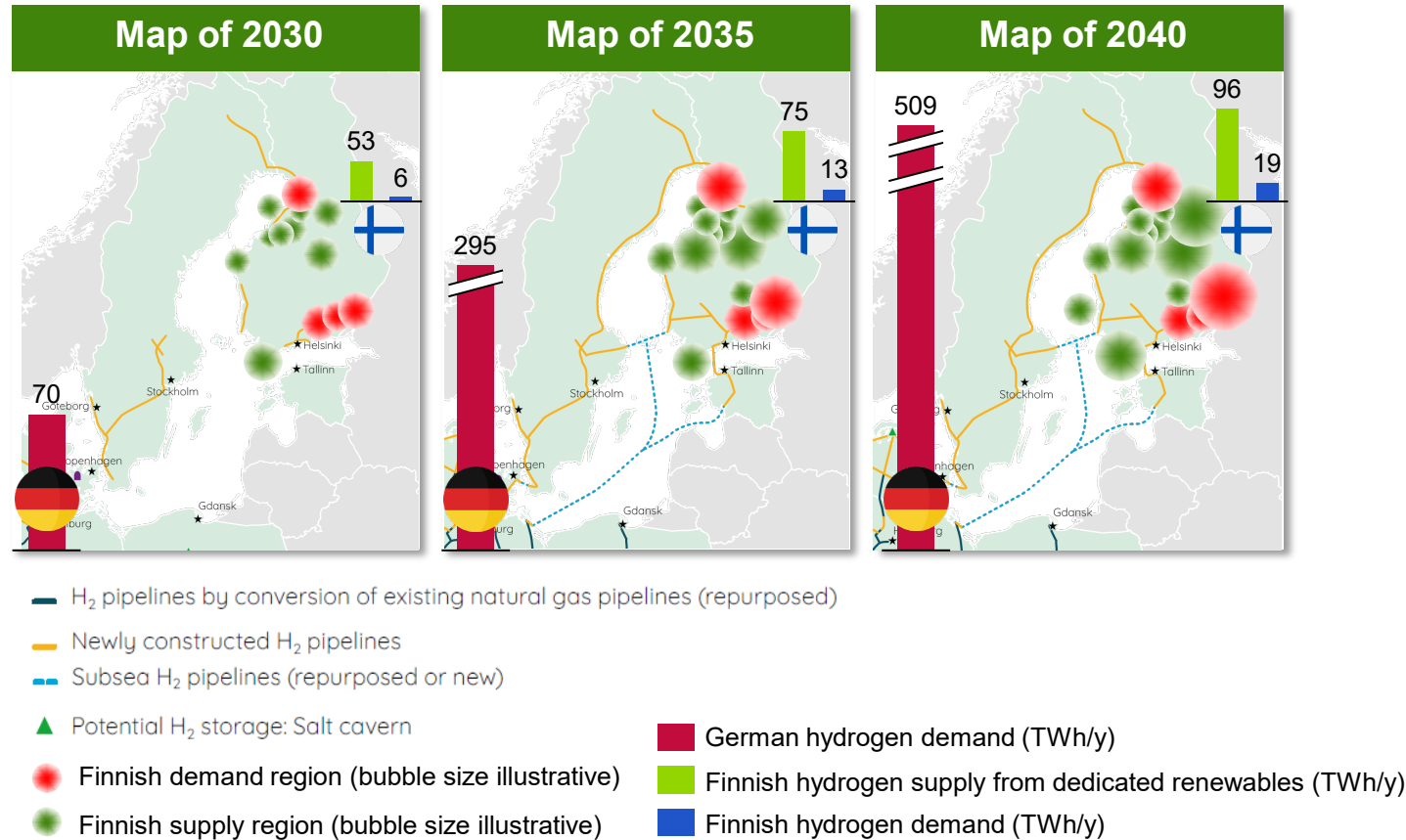
Other favourable conditions for renewable hydrogen development in the Nordics

- Water availability** | Water consumption of green – but also of grey and blue hydrogen – could pose challenges, especially in desert-like areas. If available, using desalinated seawater could be a solution. But Finland and the other Nordics would not face this issue seeing the large amounts of available water¹.
- District Heating** | The existing extensive district heating network in Finland could, as discussed before, provide a clear advantage to the business case of green hydrogen by absorbing the waste heat of the electrolysers, while this also helps decarbonize heating in Finland, and the other Nordics.
- Land availability** | Population density in the Finland² is on average 18 inhab./km² and could go as low 0.2 inhab./km² in the north, compared to for instance the averages of 240 in Germany or 508 inhab./km² in the Netherlands. Leaving more land for (larger) onshore wind projects and significantly reducing possible NIMBYism.
- Carbon impact** | Carbon impact could be lower when importing green hydrogen from countries with more decarbonised energy systems like Finland. This could be attractive for importing countries, although additional research is needed to confirm this.

¹Green hydrogen' water consumption from Energypost ([link](#)), water availability Finland from Europe environmental agency ([link](#)); ²Eurydice ([link](#))

Hydrogen transfer needs

Hydrogen demand will be geographically distant from supply – at national and EU-level – creating a clear transfer need. Meeting this need requires proactive collaboration between the TSO, market, policy makers, and regulators.



Source: Guidehouse analysis based on maps from EHB (2021) Extending the European Hydrogen Backbone

Meeting H₂ transfer needs requires collaboration between stakeholders

- **Infrastructure companies** can help demand sectors decide decarbonisation technologies by sending clear market signals about plans of future infrastructure development.
- **Infrastructure companies** can help policy makers and regulators by offering a clear vision of the future energy system and how their infrastructure can increase societal benefits.
- **Policy makers and regulators** can encourage market and infrastructure development by creating enabling legislative frameworks, adopting flexible regulatory models, and offering support instruments.
- **Market players** can demonstrate their intentions by committing to decarbonisation technologies, and making proper volume commitments on the supply and demand side.

¹The Dutch actually had to pay Denmark in a so-called statistical transfer to hit the 14% target ([Euractiv](#)); ²[Statistics Finland](#)

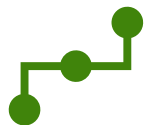


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<ul style="list-style-type: none">- The “chicken and egg” problem of market activation- Hydrogen transport cost comparison- Hydrogen cost competitiveness in end-use sectors	

The key barrier today is the chicken and egg problem of hydrogen market creation – a siloed approach means most players are playing “wait-and see”

One goal: decarbonisation



Consumers / off-takers

Unable to commit demand volumes without clarity of supply options, infrastructure, and policy incentives

Waiting on infrastructure providers and policy makers, for financial support



Producers / suppliers

To make final investment decisions, need proper demand side commitments and infrastructure solutions

Waiting on infrastructure providers and policy makers for market signals



Infrastructure providers / TSOs

Need for clarity on regulation, funding, and flexibility to overcome funding gap during market development

Waiting on regulators to create enabling frameworks, and waiting on market players for flows



Policy makers & Regulators

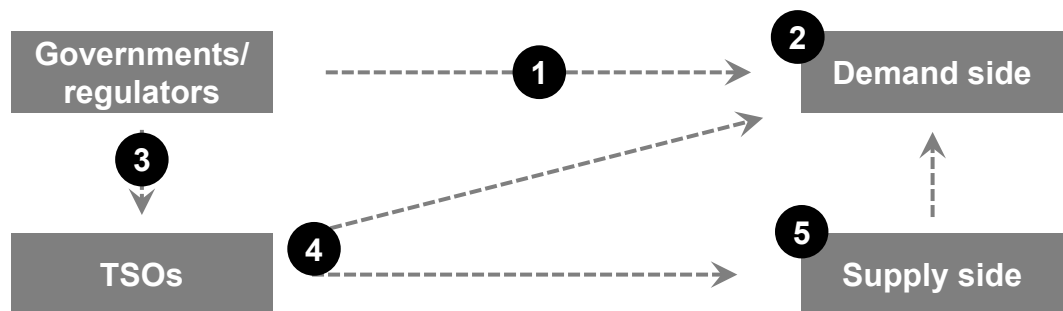
Hesitancy to interfere with market mechanisms & ‘choose winning technologies’, focus on protecting end-consumers

Waiting for political support and for market to prove benefits for the end-consumer in the form of demand/supply commitments

Siloed approach → no actor moves → no actor achieves goals

Regulation, supply, demand, and funding need to be sufficiently certain before TSOs can develop infrastructure – unregulated might be easier

A complex chicken-and-egg problem exists between various stakeholders, driven by market uncertainty



1. Demand sectors need to decide for decarb technology (or relocation) and require an enabling policy environment. **Already partially in place** (EU ETS) and partially in development (REDII, national policies), for specific sectors (refineries, steel)
2. Unable to commit to demand volumes without having **clarify about supply options and hydrogen infrastructure planning and policy incentives**
3. TSOs are not allowed to work on hydrogen within their regulated business. To start **large scale infrastructure investments**, they need **clarity on regulation & funding** and need flexibility in the early market development to find models that reduce risks
4. For governments to develop & sign-off on **regulation** (and justify large investments), **commitments from demand side** are needed
5. To enable suppliers to make final investment decisions, proper **demand side commitments** and **infrastructure solutions** are needed

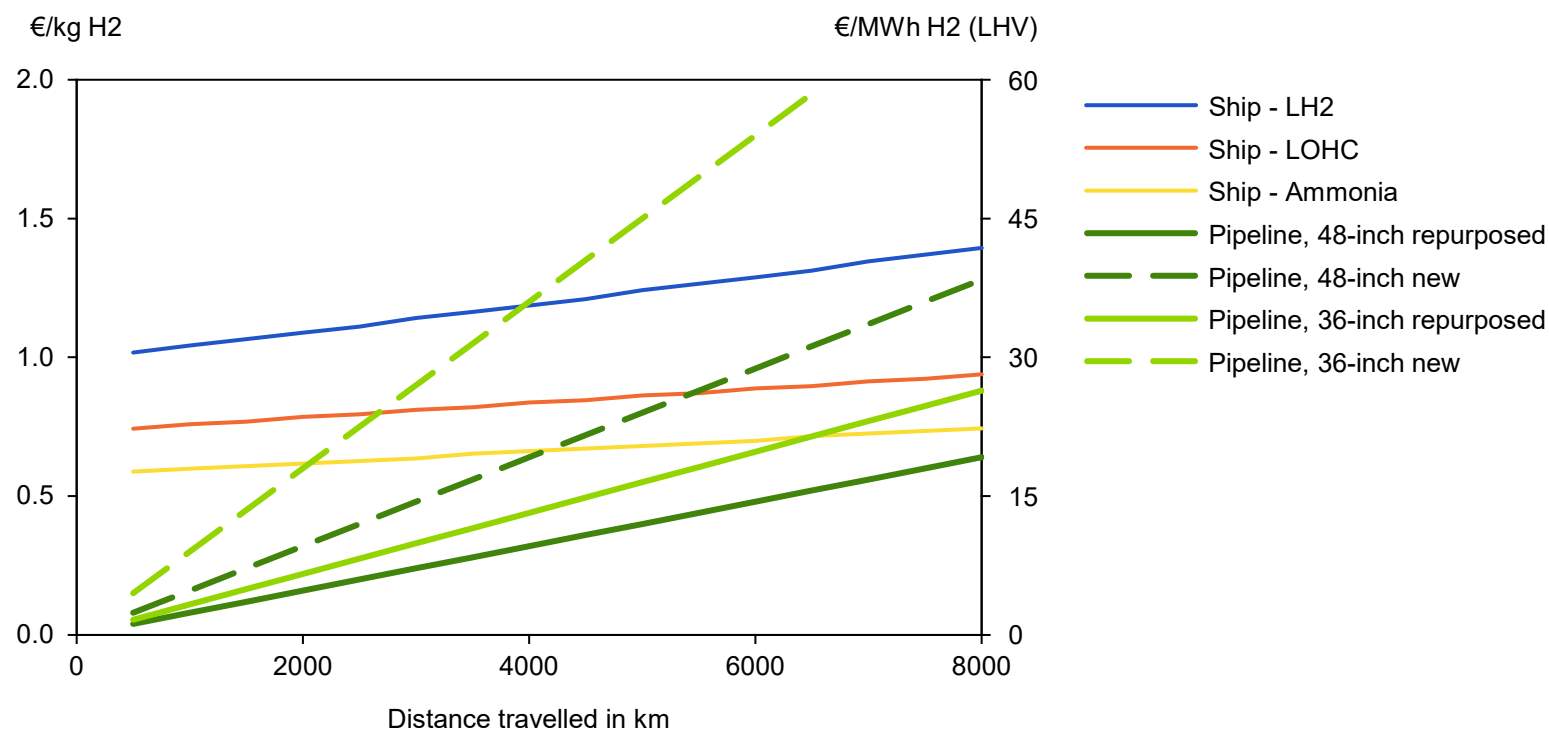
Unregulated pipeline transport might unblock this dynamic

- The problems #3 and #4 on the left are mainly an issue with **regulated** pipeline operators
- An **unregulated** pipeline operator could realize hydrogen pipelines **more easily** under higher market uncertainty
- Following the analogy with natural gas regulation, it is likely that **exemptions from regulation are possible** in certain situations, especially with a more direct linkage between supply and demand (e.g. a electrolyser at the coast linked to inland steel plant)
- In the hydrogen valleys such direct linkages are quite likely to emerge, but also beyond that a direct linkage could be possible

Hydrogen transport by pipeline vs by ship

Pipeline transport of hydrogen is more cost-competitive up to 6,000 km for 48-inch pipelines and 2,000 km for 36-inch pipelines

Hydrogen transport by pipeline vs by ship



Key messages

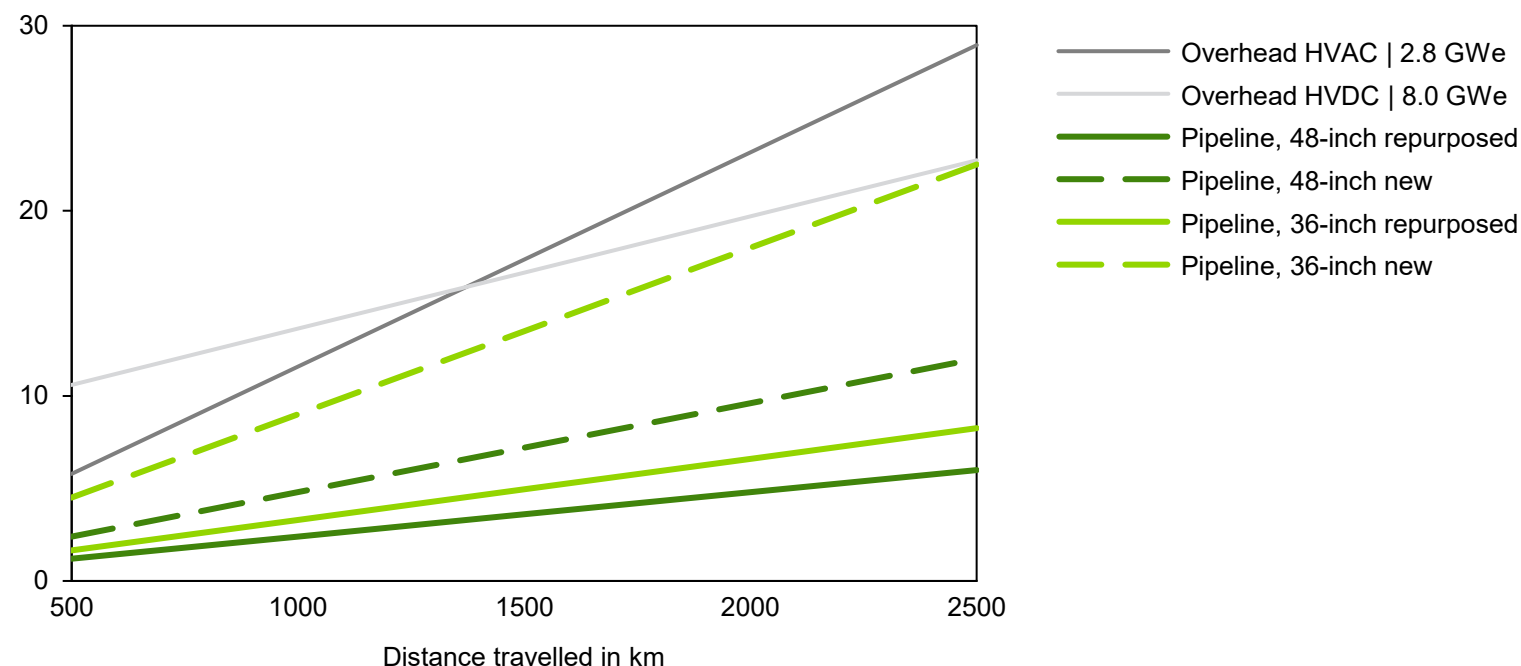
- EHB analysis indicates that even under aggressive (optimistic) cost estimations for shipping, pipeline transportation remains more cost-competitive up to 6,000 km for 48-inch pipelines and 2,000 km for 36-inch pipelines
- The main advantages of pipelines over shipping include greater economies of scale and lower conversion and reconversion losses from switching between carriers
- The incremental cost of transporting 1 additional km by ship is lower than doing so by pipeline by a factor of 2 to 5, so for overseas routes, it is sensible to ship to the import terminal closest to the end destination

Hydrogen transport by pipeline vs power line

Hydrogen transport by pipeline is more cost-effective than transporting electricity via power line when considering large throughput volumes and when the desired end-product is hydrogen

Hydrogen transport by pipeline vs power line

€/MWh H2 delivered



Key messages

Assumptions:

- Asset utilisation is 57% of the rated design capacity across all transport situations
- The desired end product is hydrogen, meaning that in the case transport by power line, electrolyzers need to be located at the customer-side and power lines need to be oversized to compensate for conversion losses
- This analysis has only considered overhead power lines. In densely populated areas or through nature reserves new power lines are increasingly constructed below-ground (e.g. in Germany)

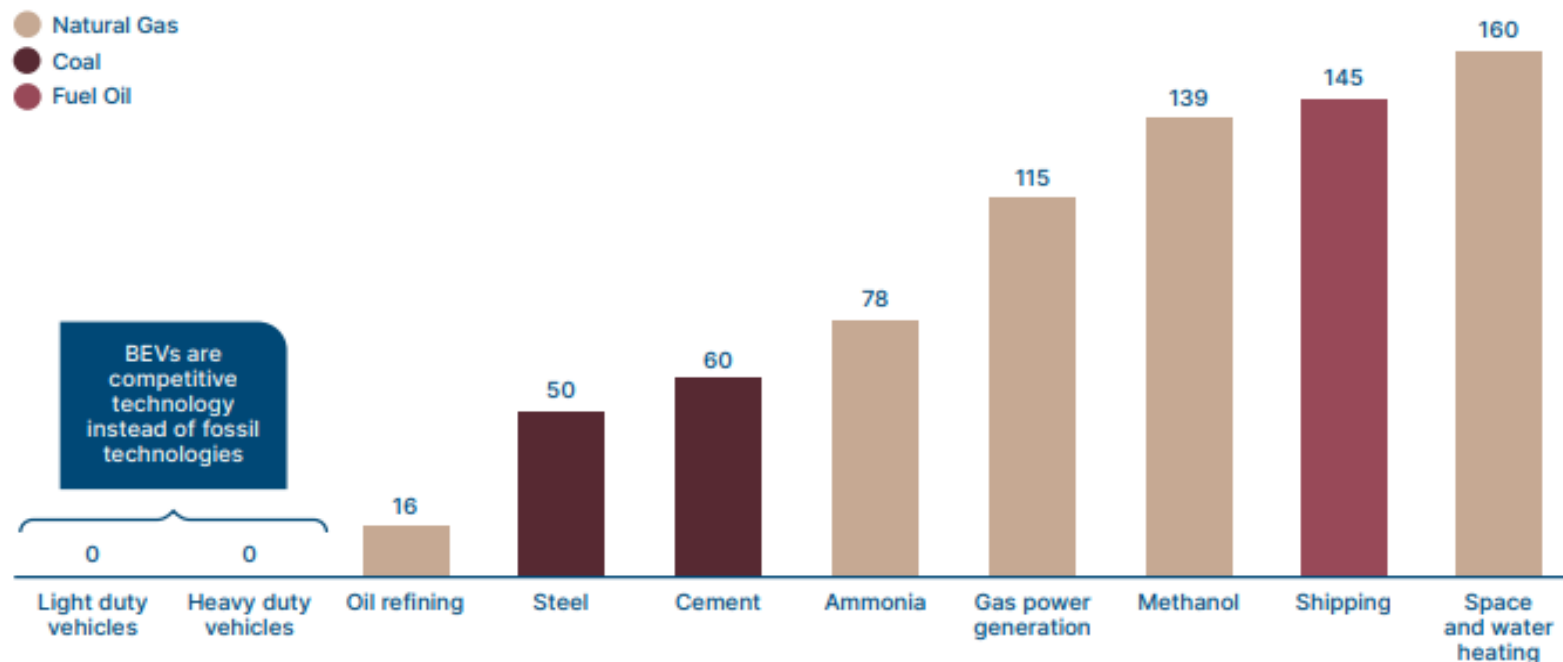
The results show that hydrogen transport by pipeline is more cost-effective than transporting electricity via power line when considering large throughput volumes (~13 GW) and when the desired end-product is hydrogen.

Hydrogen competitiveness in end-use sectors

Break-even price of H₂ depends, next to the carbon price, on the fuel it replaces - e.g. diesel, gas or coal and the alternative decarbonisation technologies – e.g. CCUS/fossil-based, bio-based, electricity-based"

CO₂ price required for H₂ competitiveness by 2050, assuming green H₂ price of \$1/kg (0.85€/kg)

Carbon prices required for hydrogen to compete with the cheapest fossil fuel in each use-case (2050)
\$/ton CO_{2eq}



Comments

- Hydrogen price of \$1/kg is unrealistic when compared to other studies, such as IRENA's Green Hydrogen Cost reduction or IEA's Future of Hydrogen. BNEF is known to have a bullish view on green hydrogen.
- The CO₂ price required depends on two parameters: (1) H₂ price; (2) volume of CO₂ avoided by using hydrogen. For any end-use technology considered in this graph, assuming that the 'business-as-usual' technology stays the same and the amount of CO₂ avoided stays constant, there is a linear relation between H₂ price and CO₂ price. E.g. for steel, if the hydrogen price doubles to \$2/kg the required CO₂ price would also double by 2, to 100 \$/tCO₂ (based on the BNEF analysis).

Sources: BNEF (2020) Hydrogen economy outlook

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Gases enable a carbon-neutral society –
we provide a platform for it

