Suomen vetytalouden mahdollisuudet

2021

Sisältö

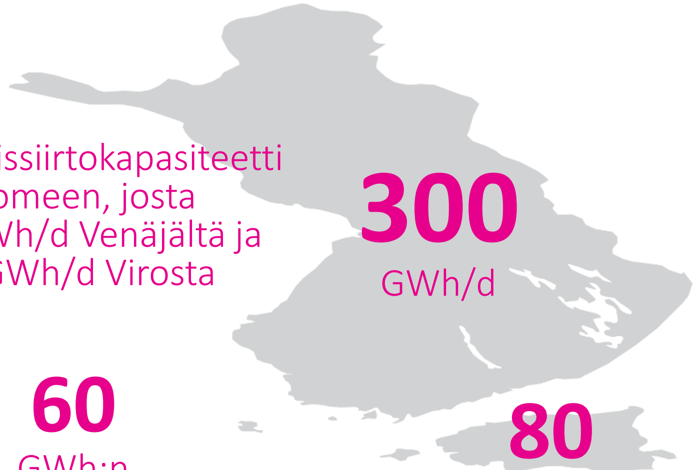
- Gasgrid Finland lyhyesti
- Vedyn rooli energiamurroksessa
- Euroopan vetytalous ja Suomen rooli

Gasgrid Finland lyhyesti

Gasgrid Finland Oy

Tarjoamme asiakkaillemme turvallista, luotettavaa ja kustannustehokasta kaasujen siirtoa. Kehitämme aktiivisesti ja asiakaslähtöisesti siirtoalustaamme, palveluitamme ja kaasumarkkinoita edistääksemme tulevaisuuden hiilineutraalia energia- ja raaka-ainejärjestelmää.

Kaasut kattaa
5-10 %
Suomen energiatarpeesta



300 GWh/d
enimmäissiirtokapasiteetti Suomeen, josta 220 GWh/d Venäjältä ja 80 GWh/d Virosta

60
GWh:n kaasuvarasto putkessa

80
GWh/d enimmäissiirtokapasiteetti Viroon*

Järjestelmään liitettyä **6** biokaasulaitosta

220 jakelupistettä

100 %
toimitusvarmuus

2 rajan ylittävää yhdysputkea: Imatra ja Balticconnector

1300
km putkea,
9 kompressoriyksikköä,
4 eri sijaintia

0
tapaturmaa**

Sidosryhmäkyselyn mukaan
88 %
vastaajista kokee, että Gasgrid on vastuullinen yritys

49
Työntekijää

Henkilöstötyytyväisyys
4,2/5***

*Viron balticconnectoriin liittyvää siirtokapasiteettia kasvatetaan vuoden 2021 aikana.
**Gasgridin oman henkilökunnan poissaoloon johtaneiden tapaturmien lukumäärä
***Keskiarvo

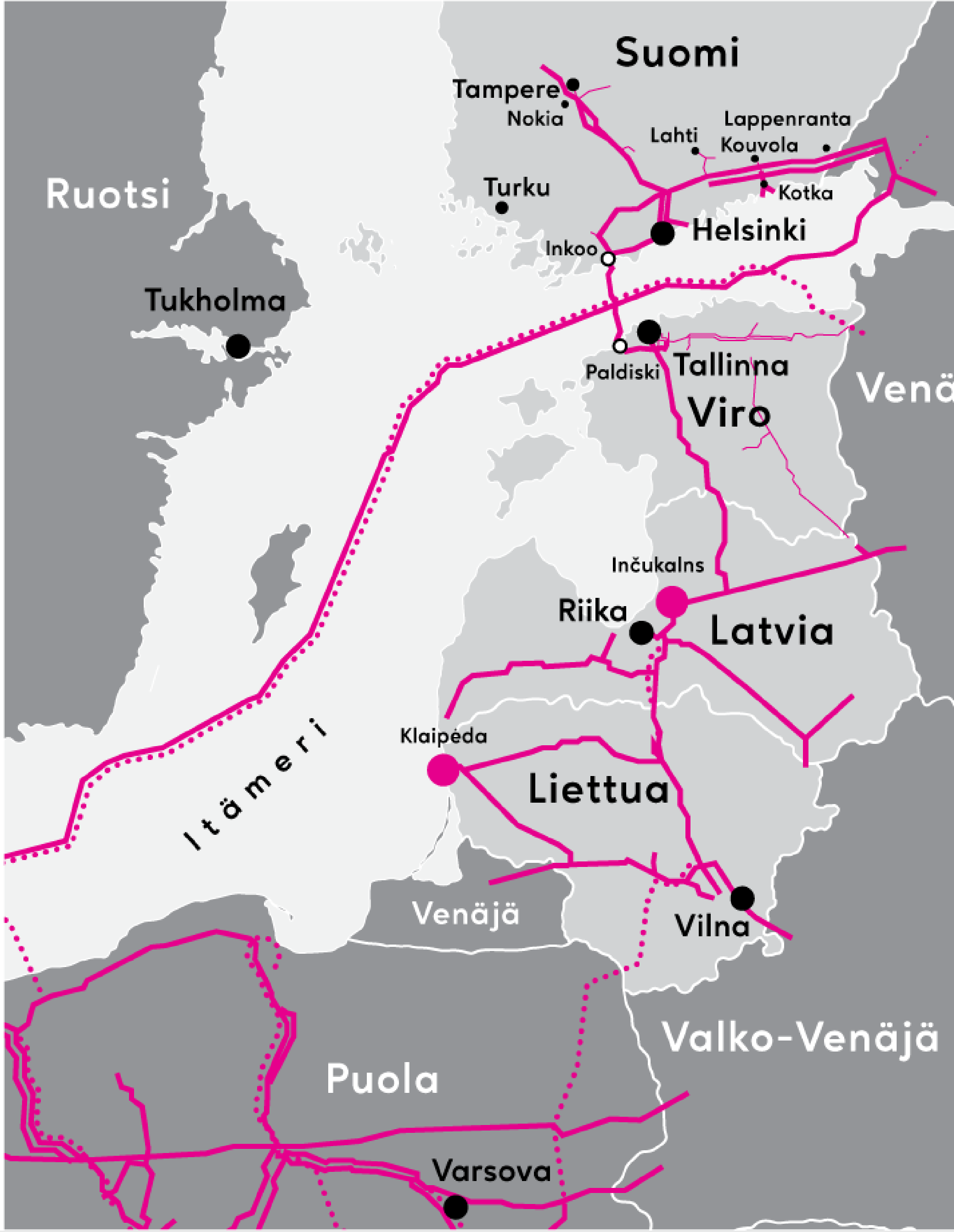
Palvelumme

Markkinapalvelut

- Tasehallintapalvelu
- Virtuaalinen kauppapaikka
- Keskitetty tiedonvaihto vähittäismarkkinalle (Datahub)
- Alkuperätakuupalvelu
- 24 h –asiakaspalvelu
- Raportointipalvelut ja datapankki

Verkkopalvelut

- Kaasun siirto
- Siirtoverkkoon liittyminen



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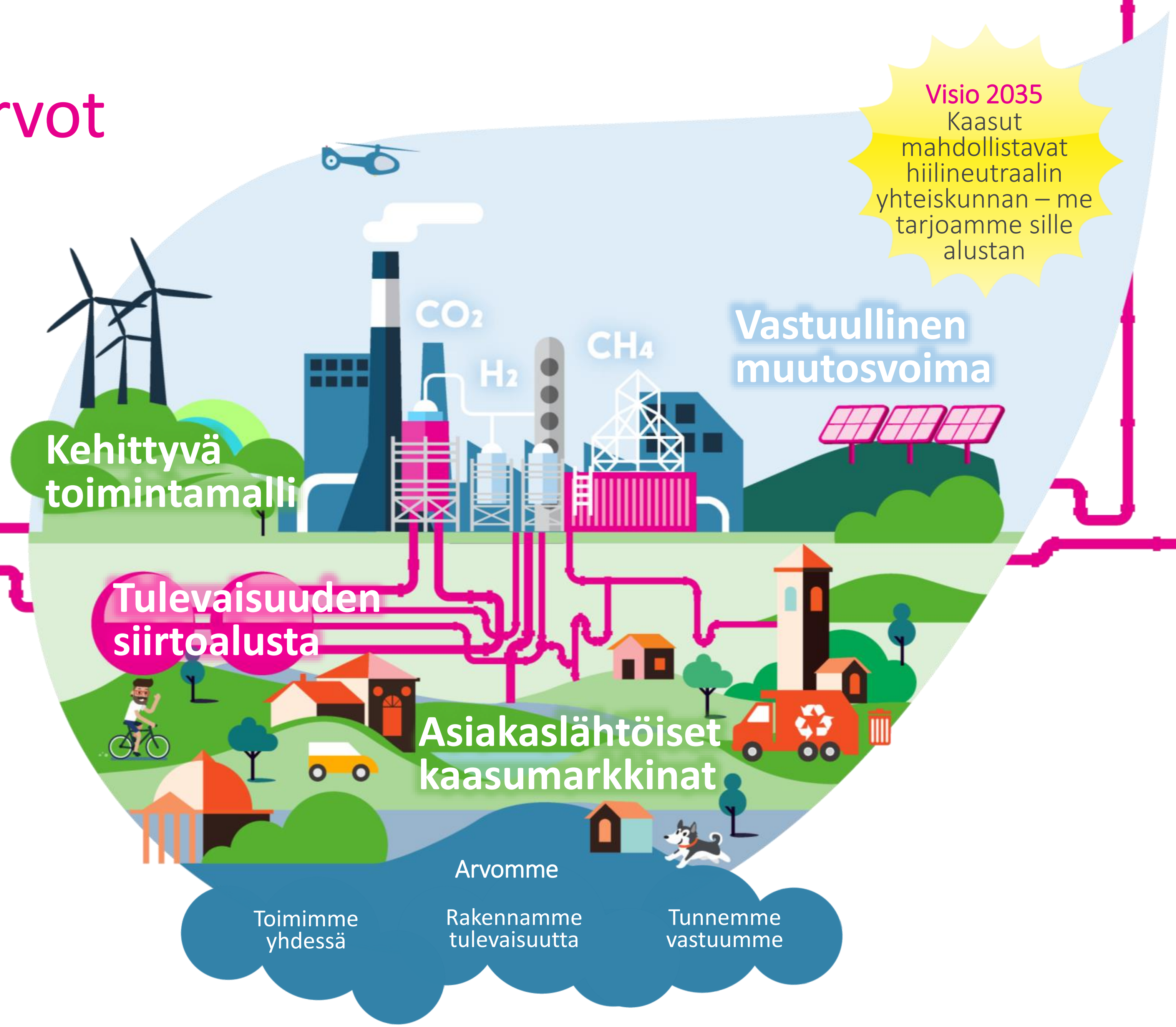
Strategia ja arvot



Toiminta-ajatuksemme

Tarjoamme asiakkaillemme turvallista, luotettavaa ja kustannustehokasta kaasujen siirtoa. Kehitämme aktiivisesti ja asiakaslähtöisesti siirtoalustaamme, palveluitamme ja kaasumarkkinoita edistääksemme tulevaisuuden hiilineutraalia energia- ja raaka-ainejärjestelmää.

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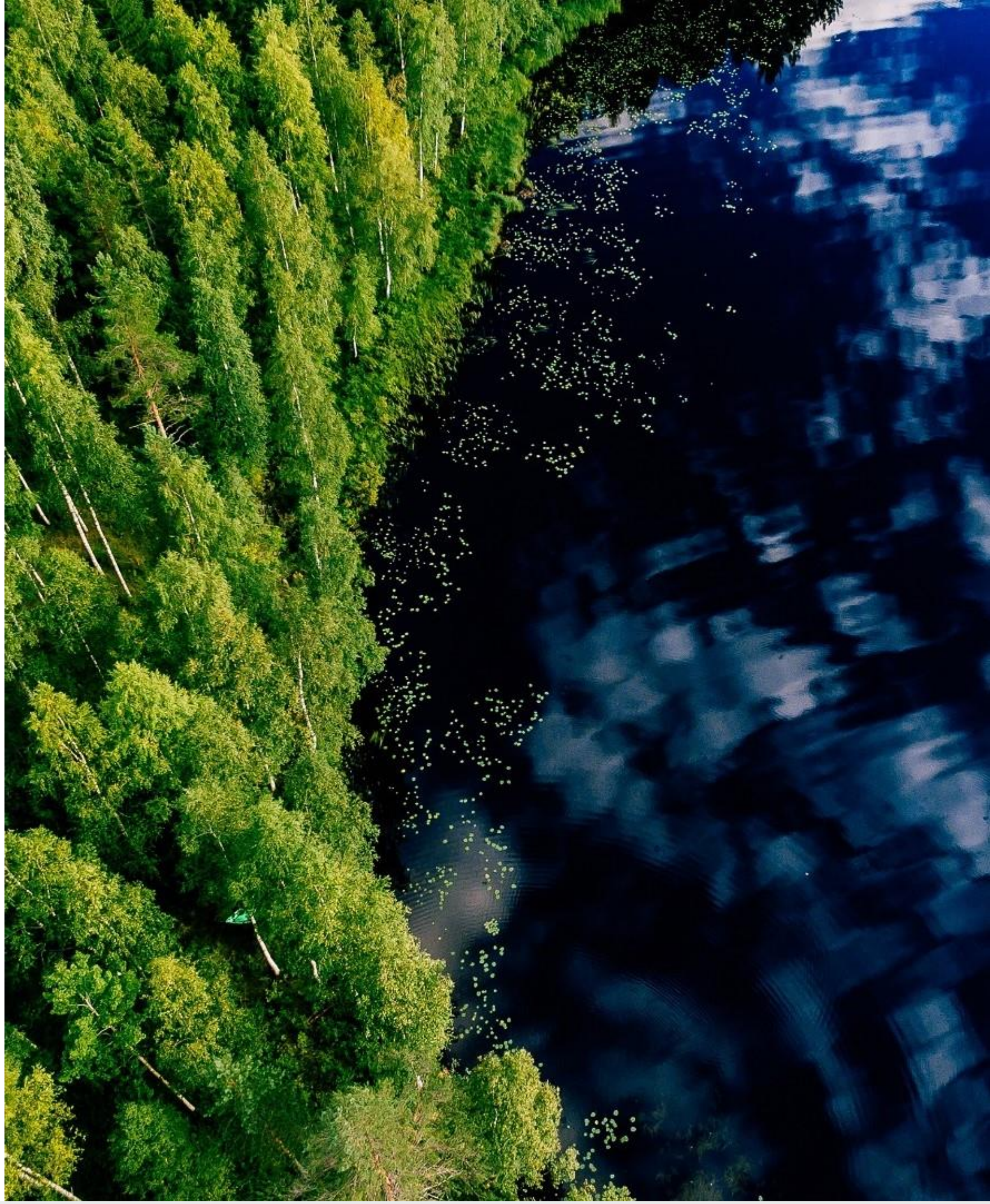
Vedyn rooli energiamurroksessa

Vedyllä rooli tulevaisuuden energiajärjestelmässä

- Vety mahdollistaa:
  - Ratkaisuja toimialoille, joilla CO_2-päästöjen vähentäminen on vaikeaa
  - Tehokasta energiansiirtoa, energiavarastointia ja uusiutuviin energialähteisiin perustuvan tuotannon kasvua
  - Merkittävän uuden liiketoiminnan syntymisen eri toimijoille uusien arvoketjujen, tuotteiden ja palveluiden kehittämisen kautta

Suomi – Alusta tulevaisuuden vetytaloudelle

- Suomella on erinomaiset edellytykset muodostua merkittäväksi Euroopan puhtaan energian tuotantoalueeksi.
  - Suomen hiilineutraaliustavoitteet vuodelle 2035 tukevat energiamurrosta
  - Erinomaiset uusiutuvan energian resurssit ja kilpailukykyinen sähkön hinta
  - Energiateollisuuden vahvat näytöt uusien ratkaisujen kehittämisessä
  - Vahvat energiaverkot, kilpailukykyiset energiansiirtohinnat ja mahdollisuus hukkalämmön hyödyntämiseen kaukolämpönä
  - Korkeatasoinen tekninen osaaminen sekä sektori-integraation ja digitaalisten ratkaisujen edelläkävijyys
  - Hiilikädenjäljen mahdollistaminen mm. biomassan CO_2-päästöjä hyödyntämällä



Gasgridin vetykehitystoimet hiilineutraalin energia- ja raaka-ainejärjestelmän tueksi

- Vuoden 2021 alussa liityimme:
  - Suomen vetyklusteriin, joka on Suomen vetykehitystä edistävien yritysten ja teollisuustoimijoiden verkosto. Lisätietoja (englanniksi): Hydrogen Cluster Finland
  - European Hydrogen Backbone (EHB) -aloitteeseen, joka on 23 eurooppalaisesta kaasun siirtoverkonhaltijasta (TSO) koostuva ryhmä. Lisätietoja (englanniksi): Gas for Climate / European Hydrogen Backbone
- Aloitimme myös Fingridin kanssa yhteisen TKI-hankkeen, jossa selvitetään vetytalouden mahdollisuuksia Suomessa sekä energiainfrastruktuurin roolia vetytalouden mahdollistajana. Lisätietoja: Yhteinen tutkimushanke

Vedyn potentiaali Suomessa

Ylätason selvitys

- Syksyn 2021 aikana toteutimme selvityksen syventääksemme ymmärrystä siitä, kuinka vedyn kysyntä, tarjonta ja siirto voisivat kehittyä Suomessa.
- Selvitys perustui European Hydrogen Backbone (EHB) -analyysiin ja keräsi tietoa myös muista eurooppalaisista ylätason selvityksistä.
- Selvityksen toteutti Guidehouse.

Euroopan vetytalous ja Suomen rooli

Ylätason selvityksen tulokset (englanniksi)

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Hydrogen development in Finland

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

Authors:
Benjamin Grunfeld
Anthony Wang
Jaro Jens

August 2021

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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 H_2 Strategy and the 10 EU countries that have announced national hydrogen plans[1]
- 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 construction[2]

… 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.

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[1] European Commission (2020): A hydrogen strategy for a climate-neutral Europe; [2] Hydrogen Council (2021): Hydrogen Insights Updates.

Hydrogen development in Finland

Scope of this quick-scan assessment

In scope:
Quick scan of the future role & timing of H_2 in Finland

- Review of European macro-level studies & state-of-the-art H_2 value chain technologies
- H_2 demand in Finland (including export potential)*
- Renewable H_2 supply in Finland – supply potential & cost-competitiveness*
- H_2 transfer needs in Finland

Out of scope:
Not analysed (in detail)

- Hydrogen demand in shipping
- Detailed assessment of cross-border flows of H_2 and H_2-based derivatives or products (ammonia, methanol, etc.)
- Flow-based energy system modelling study
- Policy and regulatory assessment

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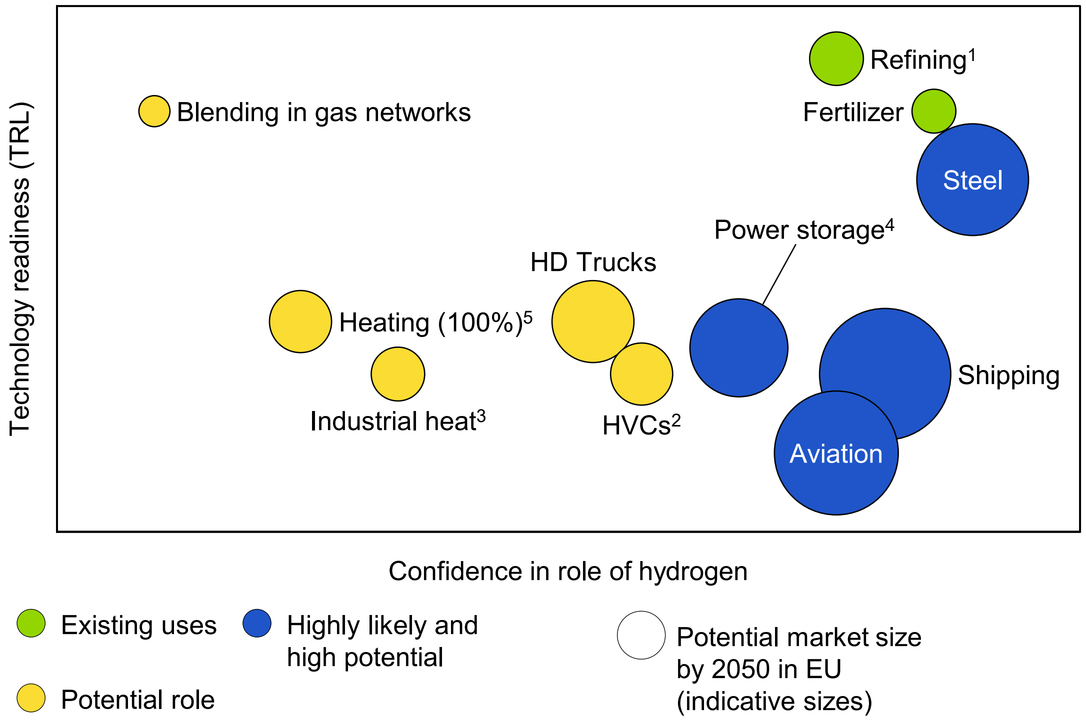
* Based on European Hydrogen Backbone (2021) analysis with additional Finland-specific details and insights.

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…

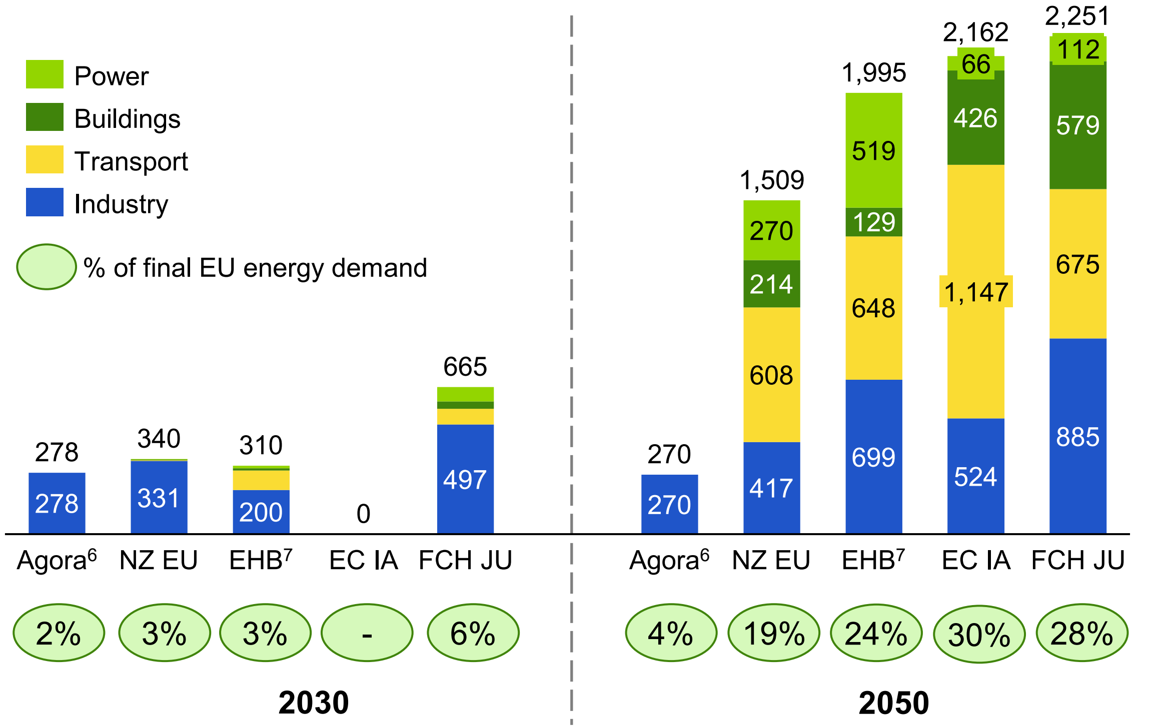
TRL, potential market size and confidence in role of hydrogen by 2050



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 H_2 infrastructure (**only includes industrial H_2 demand and excludes H_2 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

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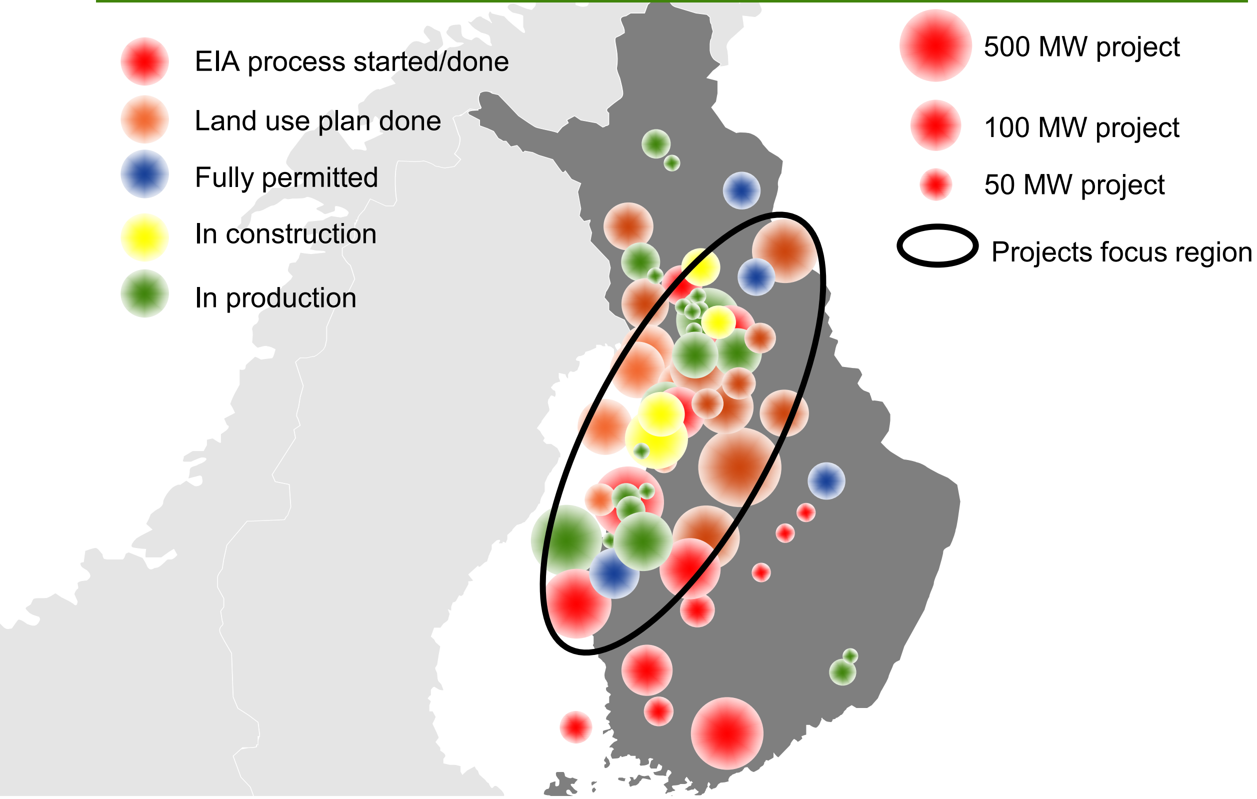
[1]Short term potential in refining fossils, smaller longer term potential in refining biofuels, as biofuels will not reach capacities of fossil today; [2]High Value Chemicals (HVC) like ethylene/propylene are the basis for production of plastics; [3] Hydrogen could replace gas in industrial heating applications in e.g. Cement and Glass; [4] Long-term energy storage for the power system; [5]Building heating with hydrogen boilers via hydrogen distribution grid [6]Agora/Afry only includes industrial hydrogen demand and assume all e-fuels are imported; [7]For EHB and Agora/Afry, final energy demand is taken from the EC IA scenario; [8]Assuming 1,700 TWh or 50 Mt of hydrogen demand by 2050 at a price of 1.5€/kg H_2

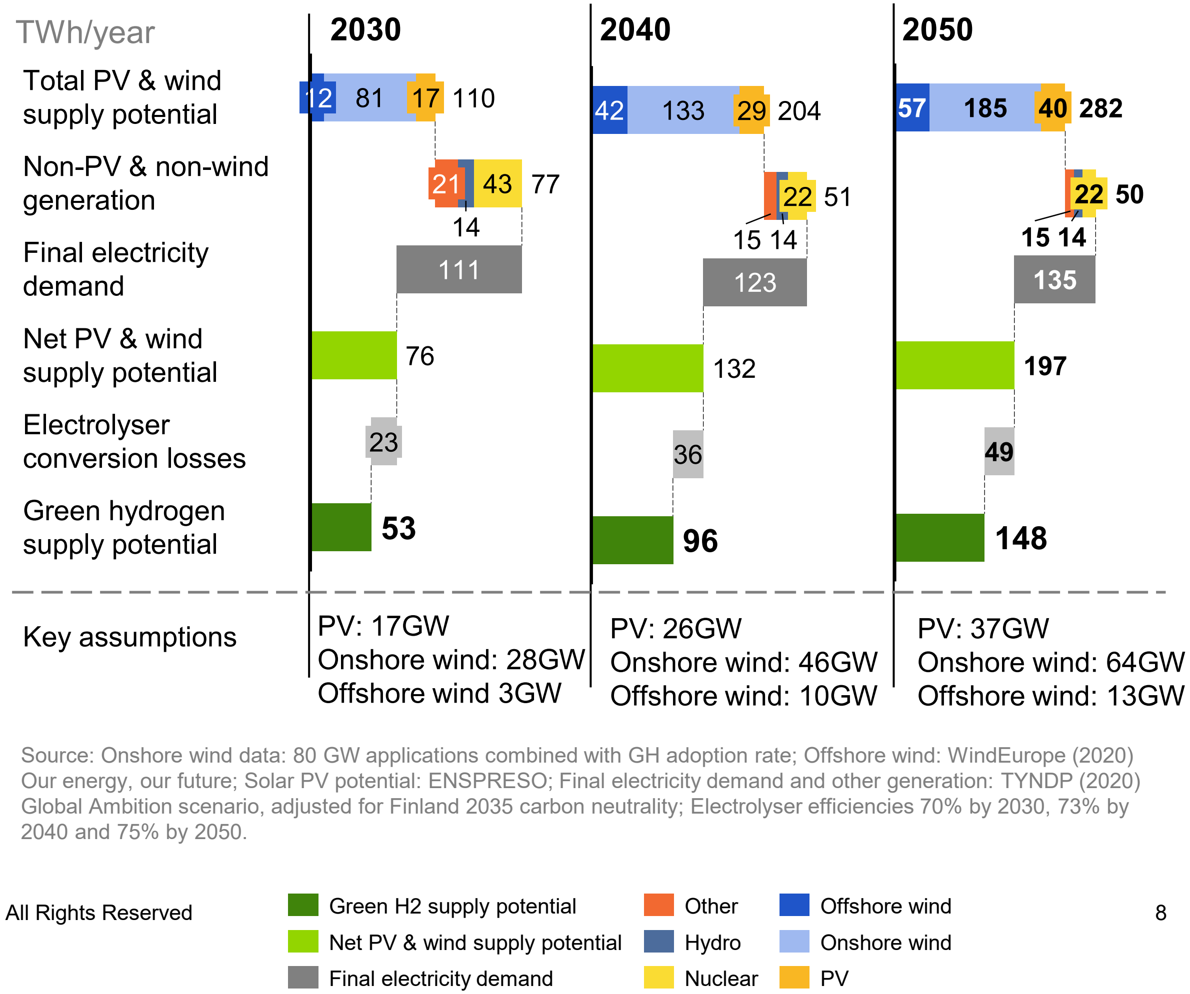
Finland possesses a substantial green hydrogen supply potential of ~50 TWh/y by 2030, although this requires delivering on its vast onshore wind potential – with 20 GW under development today and 90 GW of grid applications received.

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.

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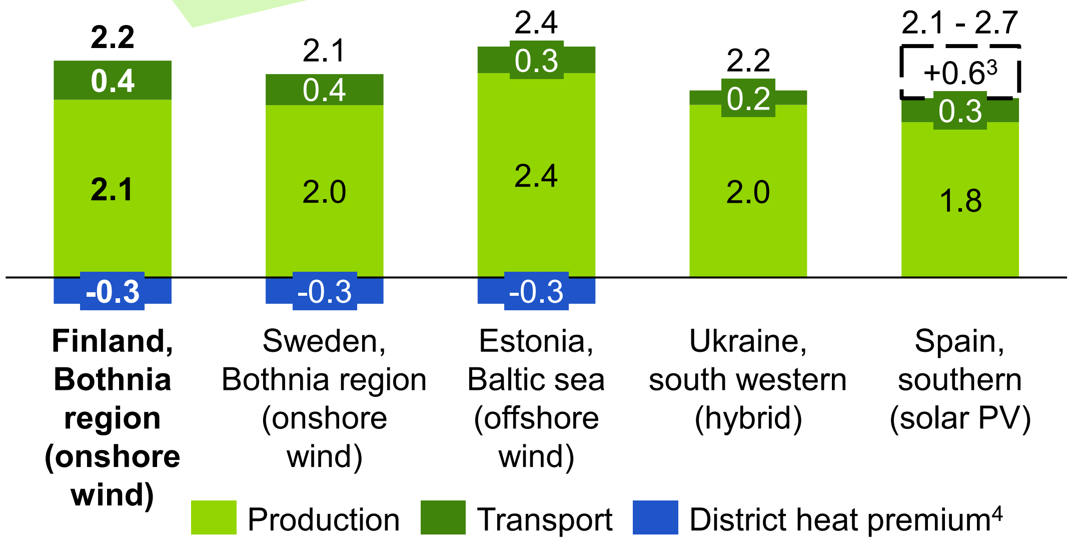
Finnish hydrogen production from dedicated onshore wind is one of several competitive options to supply the 70 TWh, or ~€4 billion[1], potential hydrogen market in Germany by 2030, while also meeting domestic Finnish demand.

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 H_2)[2]

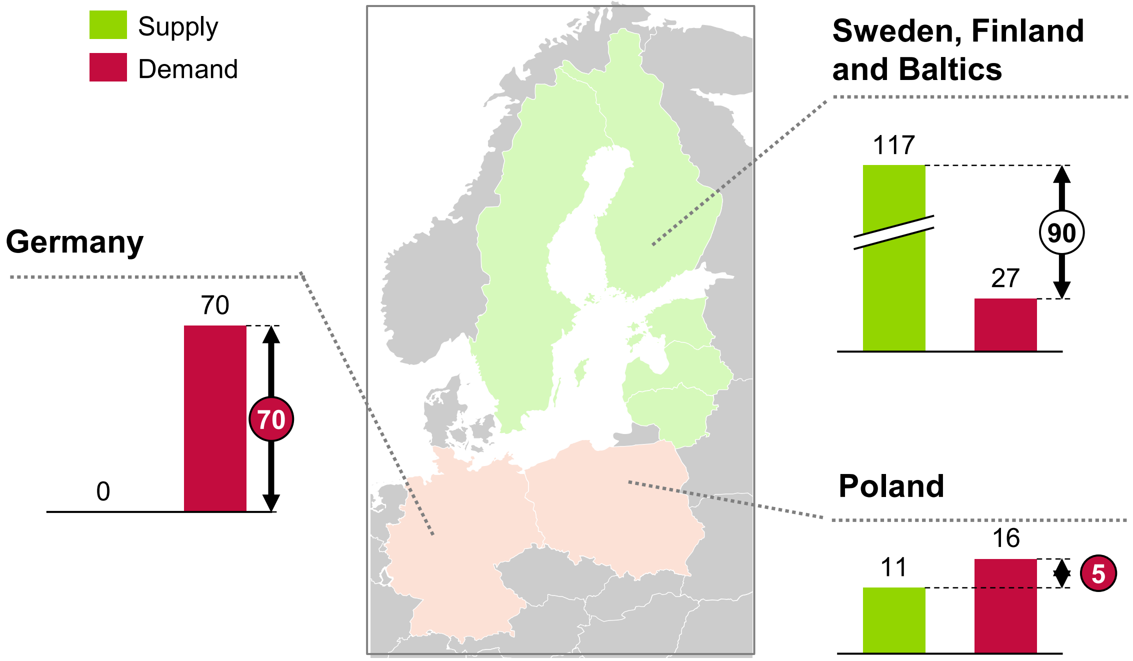
Margins between supply options are modest meaning that other factors, not considered here,[2] can make an important difference (investment climate, ease of permitting, etc.)



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 billion[1] 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;

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[1] Assuming hydrogen's lower heating value and a price of 2€/kg; [2]Cost projections include production and transport, excluding storage and local distribution – LCOH calculation assumes hydrogen production from dedicated renewables; [3]Range for Spain represents different pipeline options, from using small partly repurposed ~20 inch pipelines (high estimate) or large new ~48 inch pipelines (low estimate); [4]Simplified estimation assuming waste heat from electrolysis can be used in district heating – in reality value will differ based on regional and project-specific factors , method described in detail in Appendix.

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

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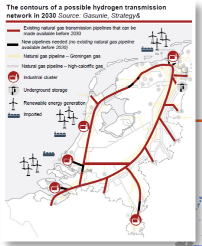
Note: Local communities and NGOs are not represented here but also play in important role in ensuring that decarbonisation measures and activities are in step with societal needs.

Some first-mover countries are starting to develop concrete national infrastructure plans with a view to realise the first H_2 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-

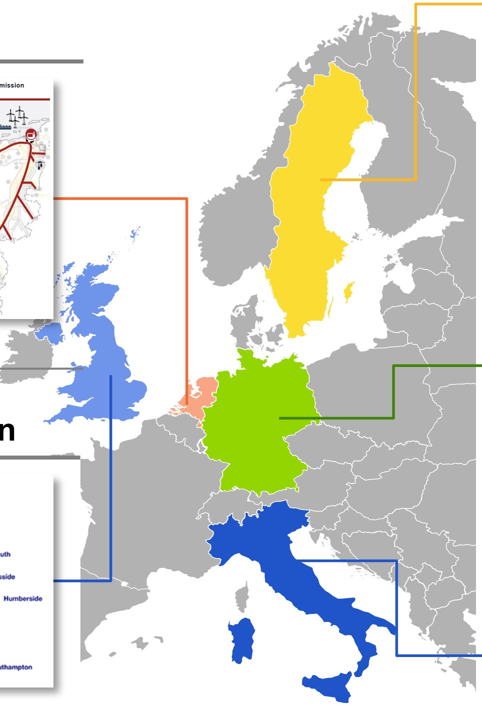
Netherlands – HyWay27

- Conclusion by the Ministry of Economic Affairs and Climate to develop a national H_2 backbone by 2027 (HyWay27)
- Investment of €1.5 billion in dedicated H_2 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 H_2 network of around 5,900 km
- Parliament has proposed an interim opt-in regulation for dedicated H_2 transport infrastructure

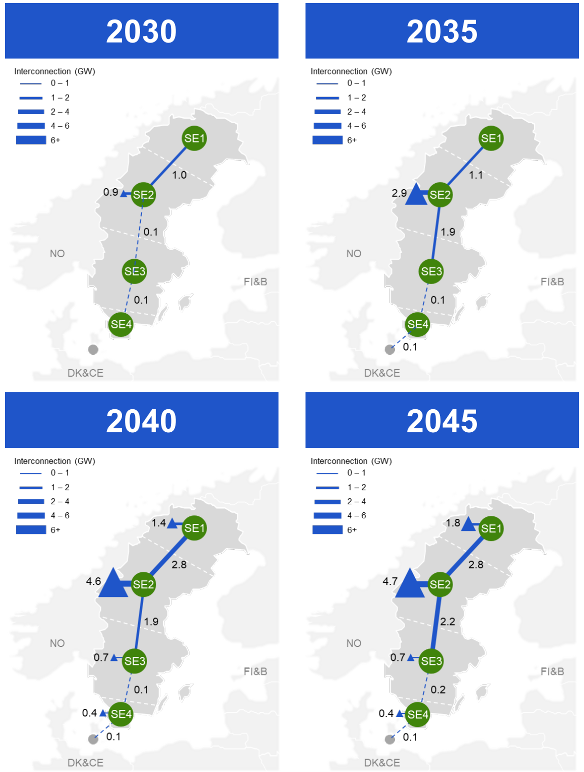
Italy – Snam's investment plan

- 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 H_2 network

Swedish H_2 network



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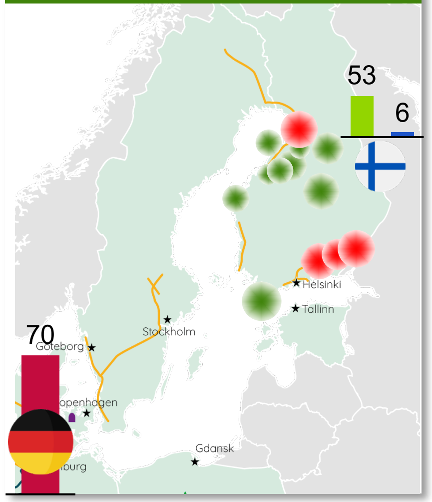
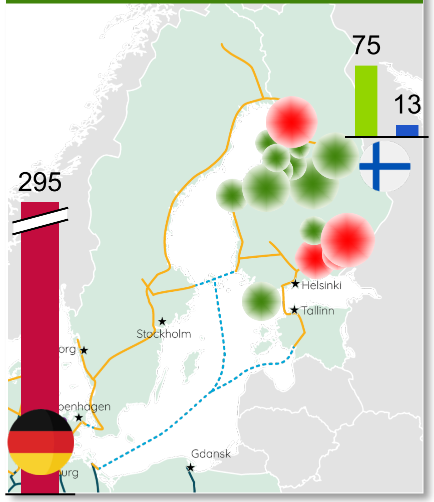
Hydrogen demand will be geographically distant from supply regions – at Finnish and EU-level – creating a clear transfer need. Meeting this need requires proactive collaboration between the TSO, market players, policy makers, and regulators.

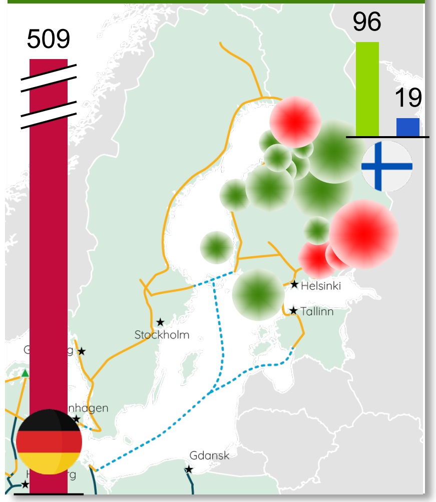
Map of 2030



Map of 2035



Map of 2040



- H_2 pipelines by conversion of existing natural gas pipelines (repurposed)
- Newly constructed H_2 pipelines
- Subsea H_2 pipelines (repurposed or new)
- Potential H_2 storage: Salt cavern
- Finnish demand region (bubble size illustrative)
- Finnish supply region (bubble size illustrative)
- German hydrogen demand (TWh/y)
- Finnish hydrogen supply from dedicated renewables (TWh/y)
- Finnish hydrogen demand (TWh/y)

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

Meeting H_2 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.

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Note: Germany's 70 TWh/year hydrogen demand by 2030 represents a market of approximately €4 billion euros assuming a market price of €2/kg.

Executive summary
Summary

Guidehouse GASGRID

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 market[1]
- **Finland possesses substantial green hydrogen supply potential of ~50 TWh by 2030 and ~150 TWh by 2050** (€3B and €9B[1]), 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 H_2 demand by 2030 (€4B[1]).
- 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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[1]Assuming hydrogen's lower heating value and a price for hydrogen of 2 €/kg.

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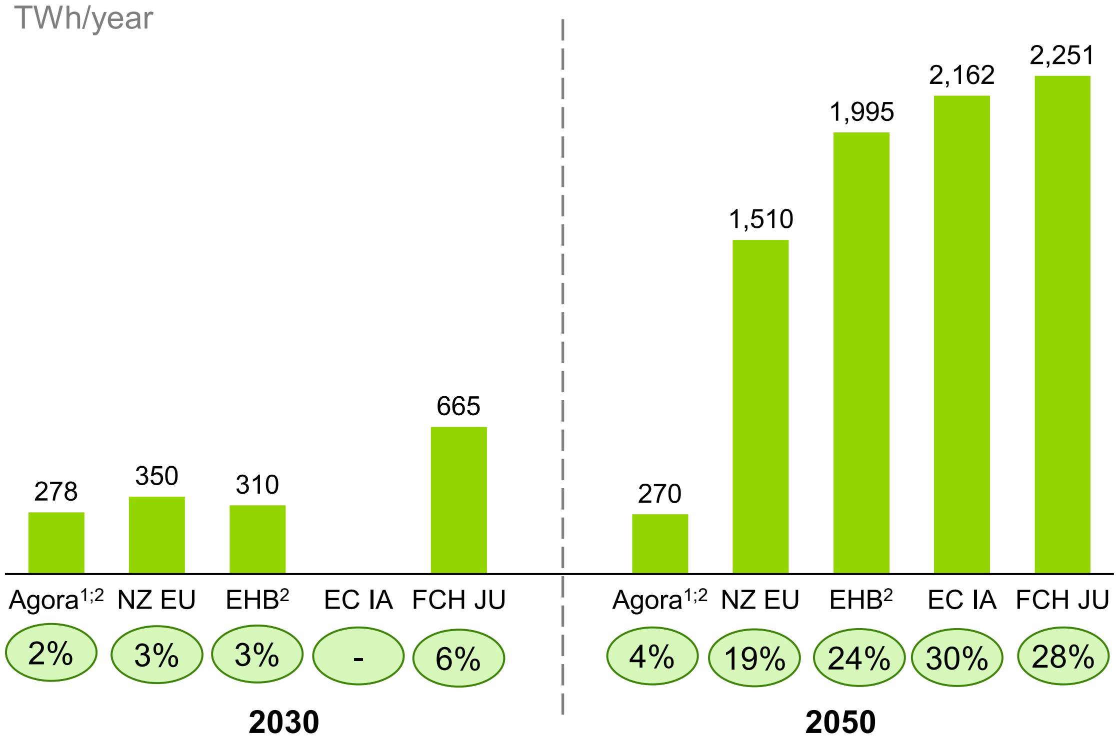
Hydrogen demand across EU macro-studies

Energy scenarios foresee an important role for H_2 in EU's energy system by 2050 at ~25% of energy demand. Current projections assume a modest role for H_2 in 2030 but increasingly strict decarbonisation targets could raise volumes.

Hydrogen demand in different EU energy studies, 2030 & 2050



Sources: Agora (2021) No regret H_2 infrastructure (**only includes industrial H_2 demand and excludes H_2 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 H_2 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 IRENA[3].
- **Stricter decarbonisation targets could raise 2030 H_2 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 CO_2 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 H_2 demand and excludes H_2 for e-fuel production.

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(green oval) % of final EU energy demand

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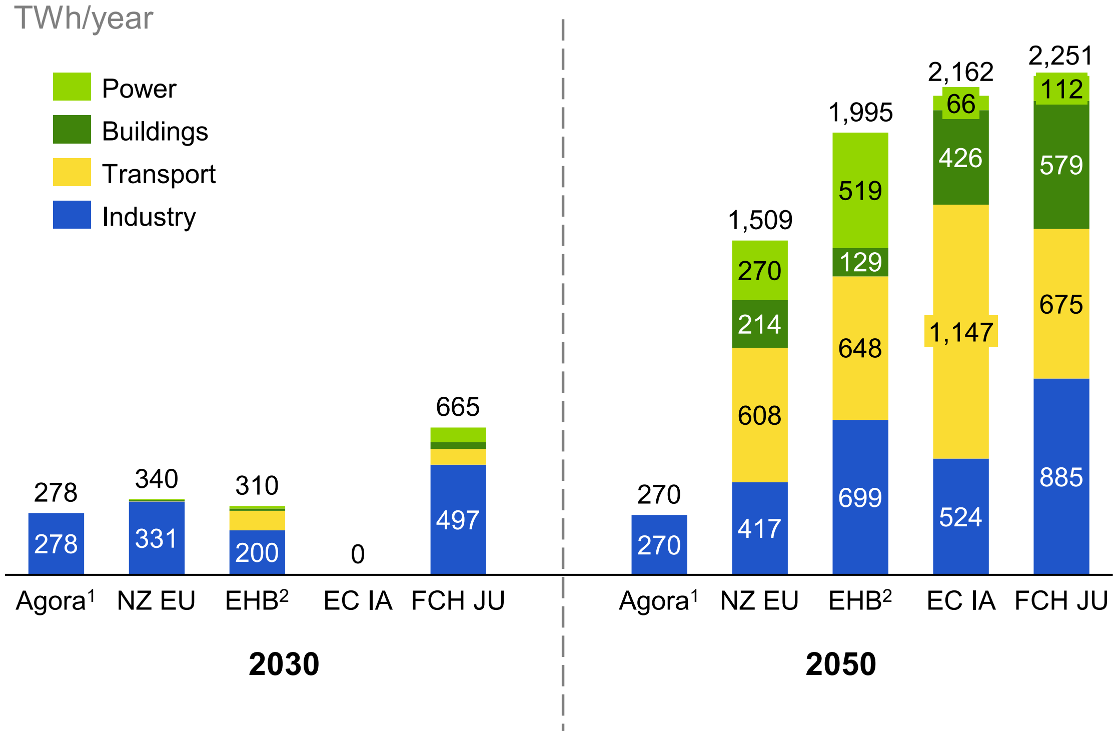
[1]Agora/Afry only include industrial hydrogen demand and assume all e-fuels are imported; [2]For EHB and Agora/Afry, final energy demand is taken from the EC IA scenario; [3]From ETC (2021) Exhibit 1.5 – comparison of global H_2 demand estimates

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 H_2 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 H_2 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 H_2 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 H_2 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.

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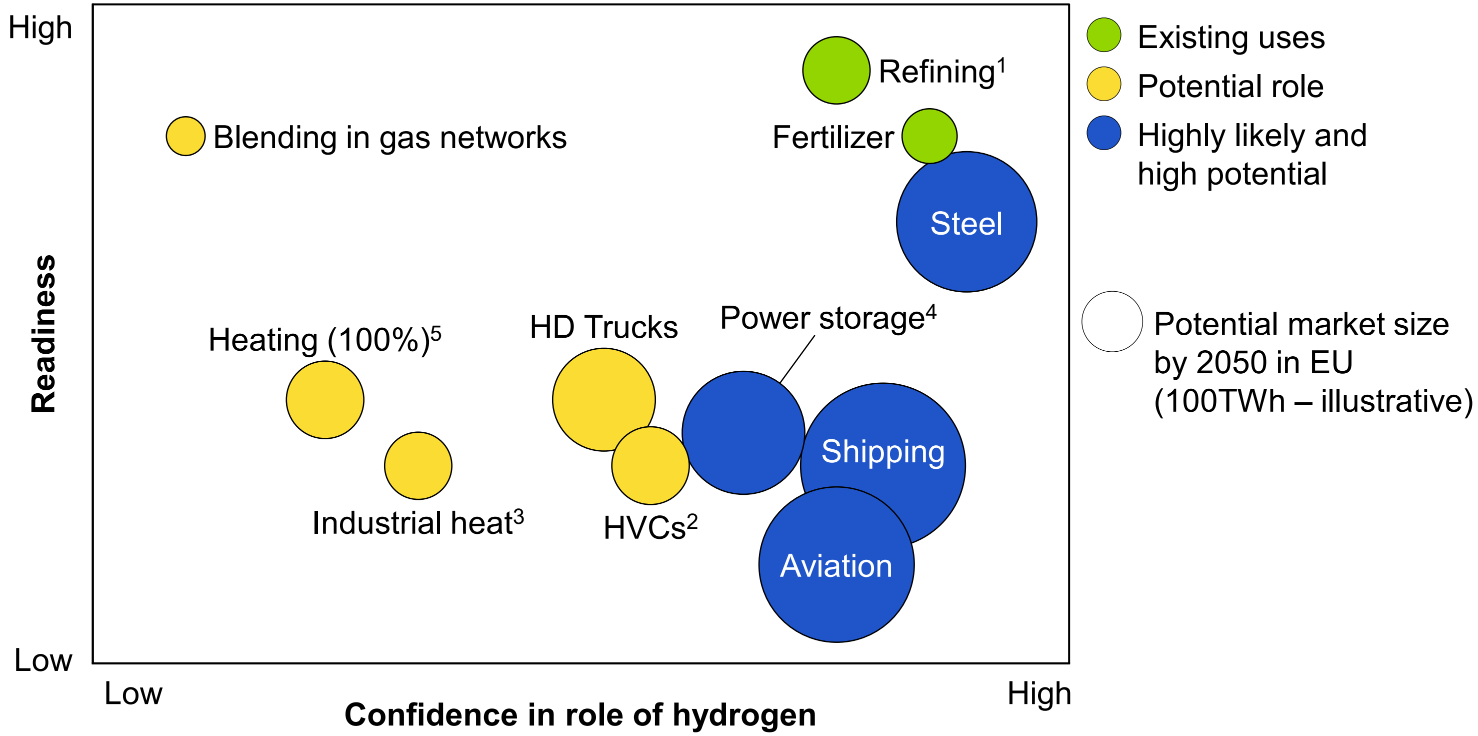
[1]Agora/Afry assumes all e-fuels are imported; [2]For EHB, hydrogen demand for bio and-e-fuel production was moved from industry to transport for the sake of comparison;

Hydrogen readiness in end-use sectors

Green H_2 will become competitive in several sectors. Early adoption of green H_2 replaces existing grey H_2 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



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.

Key messages

- **Early offtake replacing grey H_2**
  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-methanol[6] (short-term) and ammonia[7] (long-term). In aviation, as e-kerosene[8] (shorter term) or gaseous (longer term). E-fuels (e-kerosene and e-methanol) are assumed as having the largest market size in terms of H_2 demand.
- **Steel sector has no other viable option than H_2**
  Using Direct Reduction of Iron (DRI) with H_2, which is a readily available technology but dependent on large amounts of decarbonised, constant supplied H_2
- **Competitiveness H_2 depends on carbon price**
  Green H_2 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 technology[6].

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[1]Short 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; [5]Building heating with hydrogen boilers via hydrogen distribution grid [6]See recent Maersk announcement here; [7] Ammonia energy; [8] Projects like Norsk e-Fuel; [9]Airbus; [10]Appendix 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 (-33%)	0,5 (-44%)	0.5 (-76%)	0.5 (-89%)
	2050	0,2	0,2	0.3	0.2
Technology specific insights		• Large-scale projects • Flexibility to respond to RES has improved, land footprint decreased • Pressure level varies per OEM (3-30 bar)	• Low footprint due to high current density • Integration with RES possible, even inside wind turbine • Noble metals need key obstacle	• High efficiency with steam as input from industrial source; or • Steam from FT[1]/e-fuels production • Combine with AEL • Stack lifetime still low	• PEMEL 2.0; does not need noble metals • Used in micro-grids • Today at kW scale used decentralised • Stack lifetime still low

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 Europe[2] and already before 2030, GW-scale projects could be expected[3].
- **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**
  Eelectricity costs will make up 70-90% of costs, also dependent on load hours and efficiency[5].

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.

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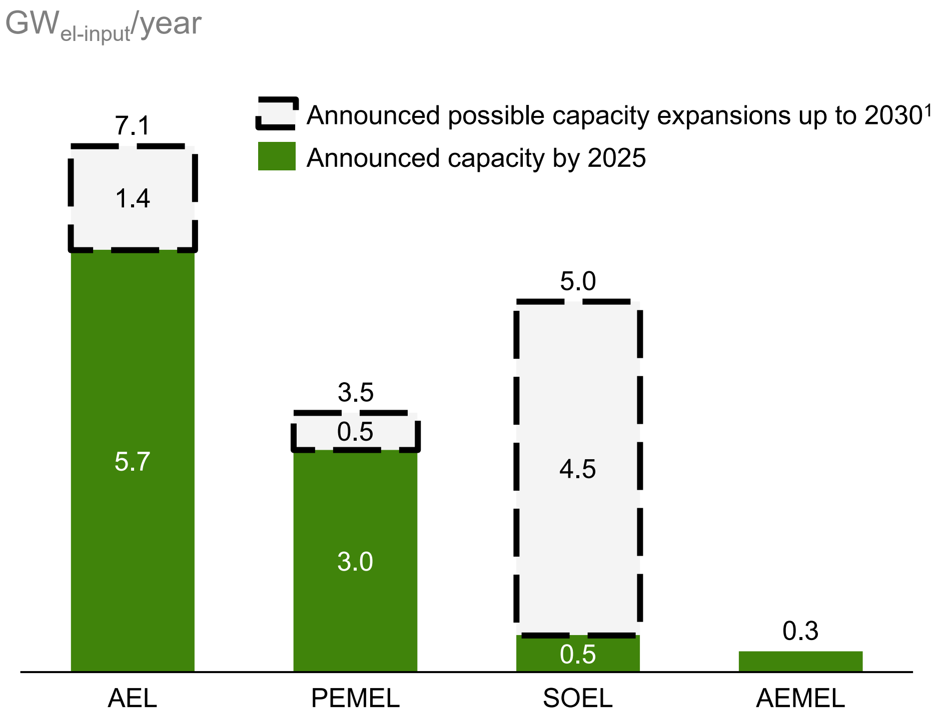
[1]Co-electrolysis of CO_2 and H_2 using SOEL followed by Fischer-Tropsch (FT) synthesis to produce e-fuels is efficient due to heat exchange between the two processes; [2]See for instance Dutch and German IPCEIs; [3]Multiple projects announced, e.g. offshore by Aquaventus - but also confirmed by the EC: "concrete plans for large wind and solar plants dedicated to GW-scale renewable hydrogen production before 2030" taken from Reuters; [4] Some examples are ITM (PEMEL), Nel (AEL), ThyssenKrupp (AEL), McPhy, (AEL) and Haldor Topsoe (SOEL). 5 Confirmed by Nel, IRENA (2020) Green hydrogen cost reduction and BNEF (2020) Hydrogen cost competitiveness.

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



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 $GW_{el\text{-}input}$/year by 2025, which will be more than enough to meet EU target of 6 GW of electrolysers 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 PV[2]**
  Similarly, substantial cost decreases could be expected with large scale deployment

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[1]Most announcements state that if demand for their electrolyser technology takes off, manufacturing capacity could be further increased. [2]IRENA (2020), Green Hydrogen Cost reduction

Role of pipelines and imports

All studies acknowledge the role of H_2 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 then 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.

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

Key messages

- **All studies see role for imports**
  Although Agora/AFRY and NZ EU question the economics
- **All studies see role for H_2 pipeline infra**
  Especially for repurposed natural gas pipelines, but new dedicated hydrogen pipelines are also competitive.
- **H_2 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.

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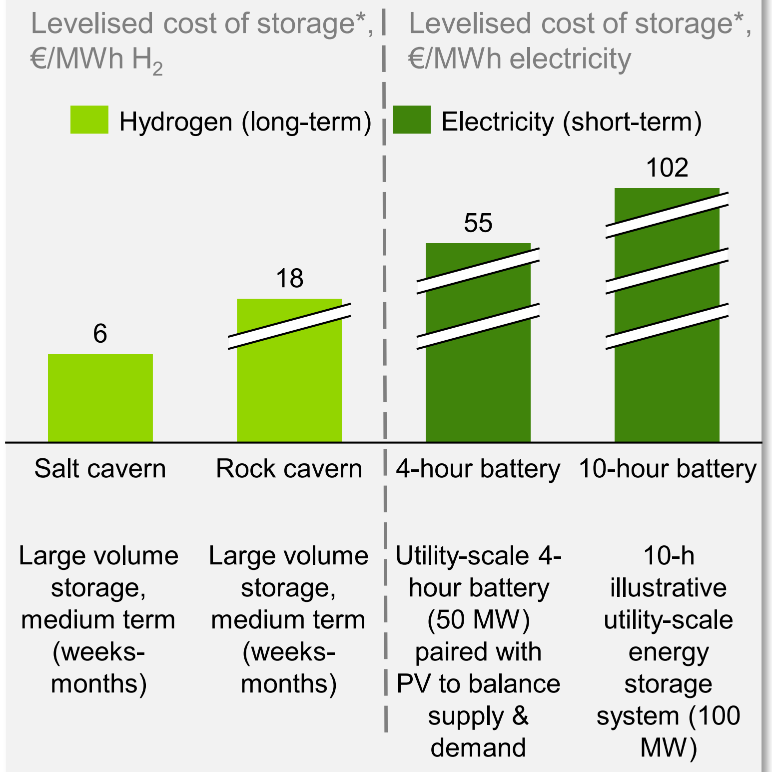
Hydrogen storage and linepack

H_2 storage costs range from 6-18 €/MWh for underground storage, to 30-60 €/MWh for liquefied H_2, and up to 1,900 €/MWh for compressed H_2 – the latter are only used for last-mile transport and are not economically feasible energy storage options today

Various forms of H_2 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 H_2** 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 H_2 tanks can cost between 1,200-1,900 €/MWh[3,4]

H_2 storage is particularly well-suited for long-duration storage applications



Like NG, H_2 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.

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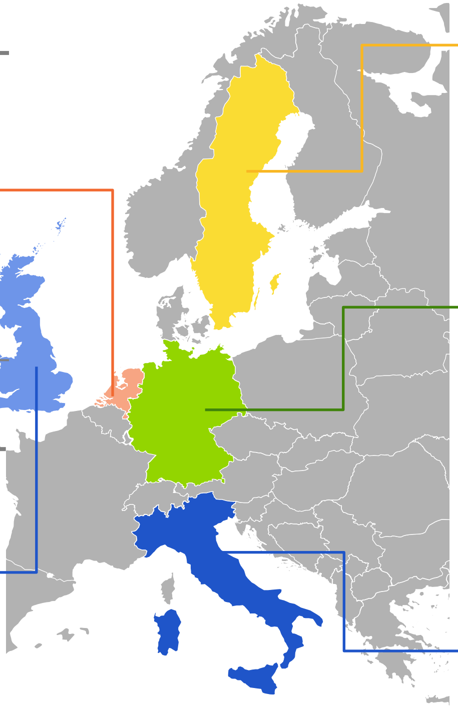
Source: GIE (2021); ETC (2021); Dodds (2013); D. Haeseldonckx (2007). [1]Liquefaction and reconversion each consume ~30% of the hydrogen's energy content based on NREL and e1na; [2]EHB (2021); [3]Rivard et al (2019); [4]Kiessling (2021); *Levelised storage costs are shown for reference, even though short- and long-duration storage technologies are not directly comparable given that they serve different purposes

Hydrogen infrastructure developments in the EU

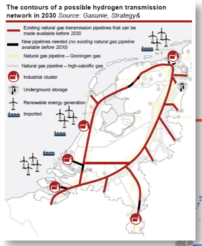
First-mover countries are starting to develop concrete national infrastructure plans with a view to realise the first H2 pipelines before 2030 and to overcome the 'chicken-and-egg' problem between market creation and infrastructure development.

Hydrogen infrastructure plans across Europe



Netherlands – HyWay27

- Conclusion by the Ministry of Economic Affairs and Climate to develop a national H_2 backbone by 2027 (HyWay27)
- Investment of €1.5 billion in dedicated H_2 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

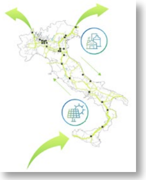
- A stakeholder-led study commissioned by Energiforsk indicates the necessity of a national hydrogen backbone by 2045

Germany – Wasserstoffnetz

- German TSOs are planning a H_2 network of around 5,900 km
- Parliament has proposed an interim opt-in regulation for dedicated H_2 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 H_2 and energy system integration could make for a powerful position.

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Source: HyWay 27, Project Union, Sweden report, Wassterstofnetz, Snam investment plan

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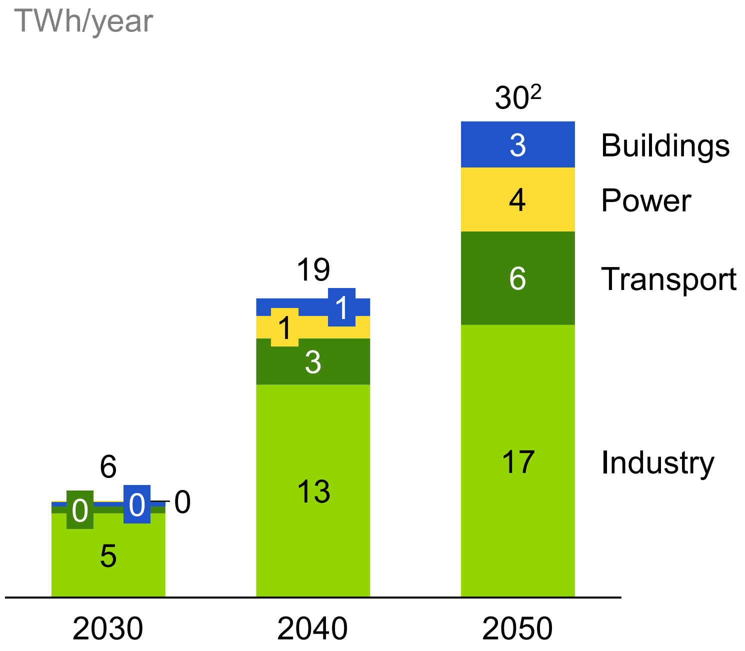
Hydrogen demand in Finland

European Hydrogen Backbone analysis concludes that Finland could see domestic hydrogen demand of 6 TWh by 2030 and 30 TWh – or a ~€2 billion market[1] – by 2050, driven by the industry and transport sectors.

Green hydrogen demand Finland*



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

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

Hydrogen demand localization

Future H_2 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

Existing industrial site
Potential new development

Nouryon/Eastman Oulu

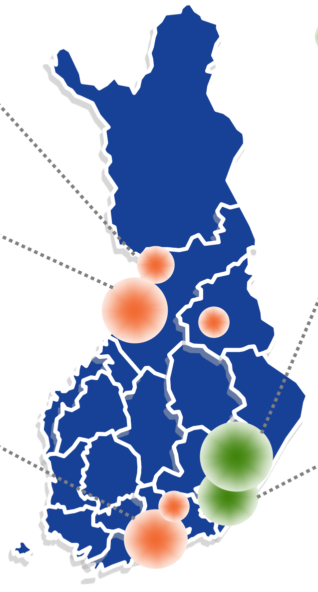
Chemical production

SSAB Raahe[1]

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



PtX[2], Joutseno

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

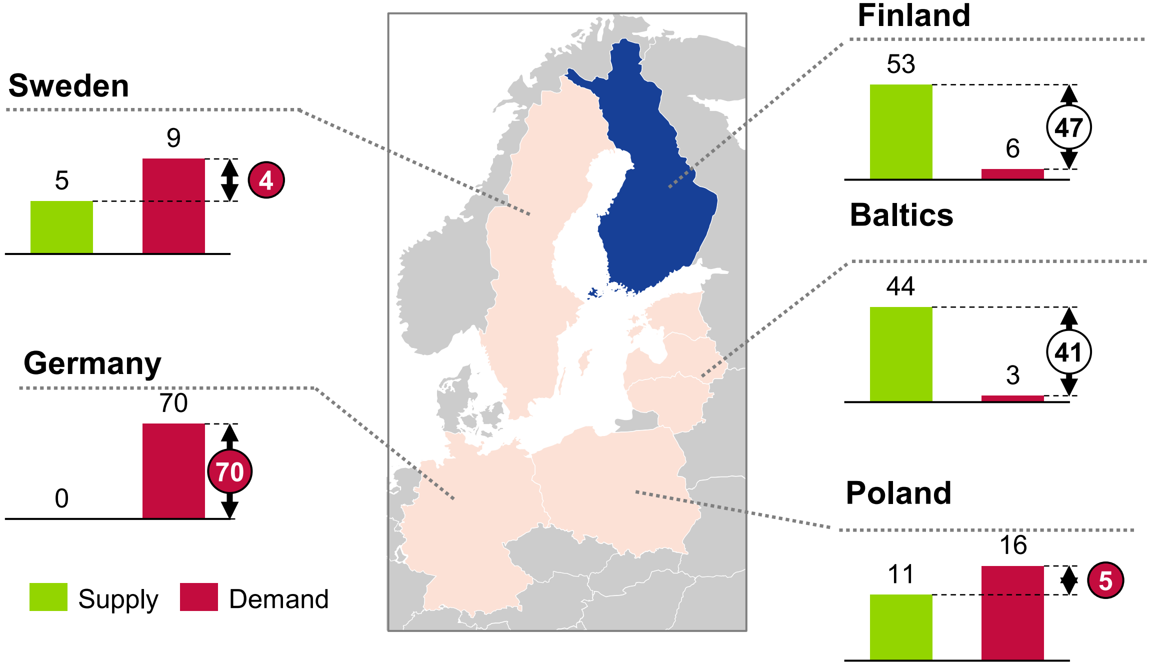
UPM Lappeenranta[3]

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 billion[4] 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;

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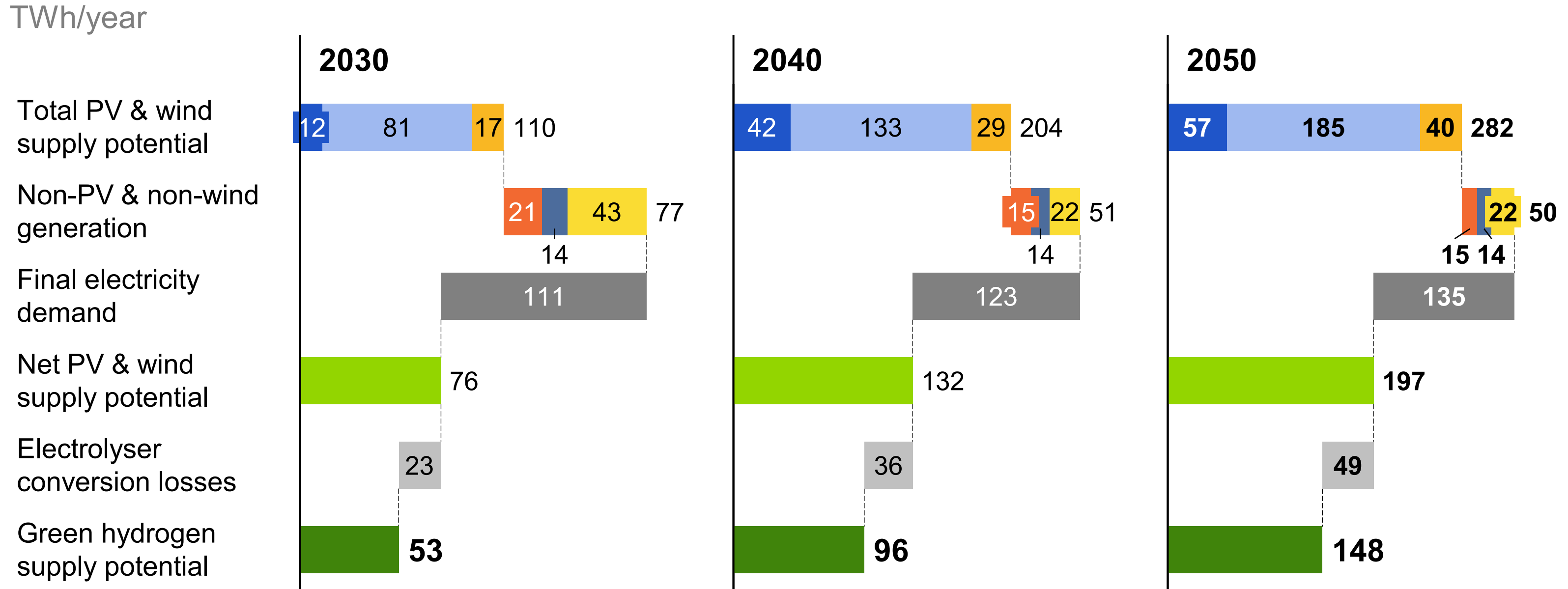
SSAB has announced to replace the Blast Furnace to EAF in Raahe, but not yet announced a actual hydrogen-based DRI in Finland – it could be that sponge iron from LKAB in Sweden is imported instead (SSAB);[2] Consortium consisting of Finnsement and Kemira, Neste, St1, Wärtsilä, Finnair and the Shell Research Centre Amsterdam (STCA) (Fingrid); [3]UPM will also review two other potential locations for the new 500,000 tonnes biorefinery (including sustainable jet fuel) in their commercial and basic engineering study: Kotka and Rotterdam (UPM). [4]Assuming 70 TWh hydrogen demand for hydrogen in Germany at cost/market price of 2€/kg

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 assumptions	2030	2040	2050
	PV potential: 17 GW Onshore wind potential: 28 GW Offshore wind potential: 3 GW	PV potential: 26 GW Onshore wind potential: 46 GW Offshore wind potential: 10 GW	PV potential: 37 GW Onshore wind potential: 64 GW Offshore wind potential: 13 GW

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.

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 H_2-based industry**
  Alternatively to exports of gaseous H_2 attracting production of steel/sponge iron, or e-fuels and e-chemicals, could be an option.

Green H2 supply potential | Net PV & wind supply potential | Final electricity demand | Other | Hydro | Nuclear | Offshore wind | Onshore wind | PV

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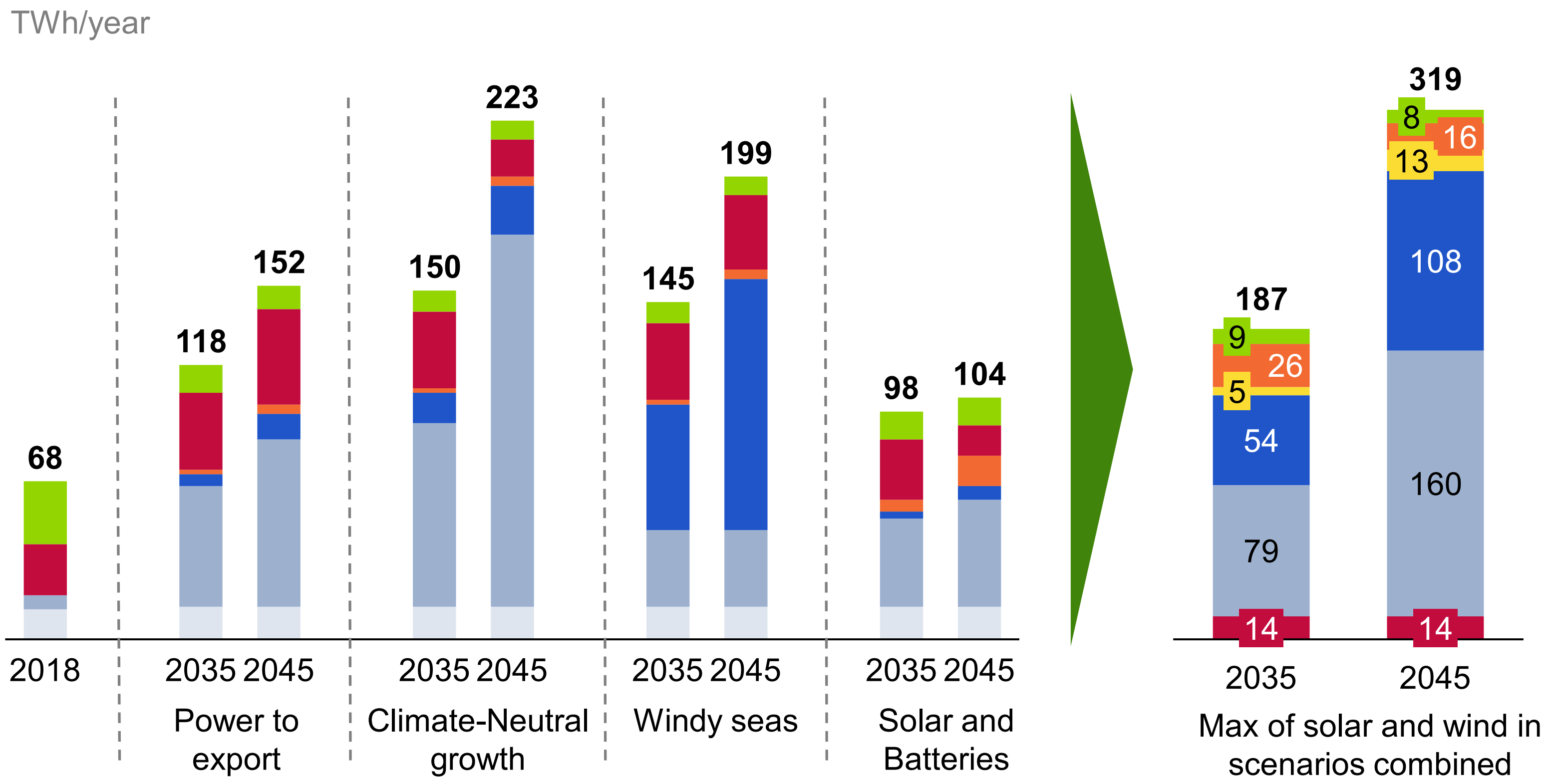
[1]Finnish wind power association has a 30 TWh/y objective for annual wind power production by 2030 (link). 2.5 GW of onshore wind is currently installed, and there are plans to add an additional 21 GW, of which 7 GW of projects already have a land use plan/land use plan and building permit (link)

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



Source: Fingrid (2020) Network Vision

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

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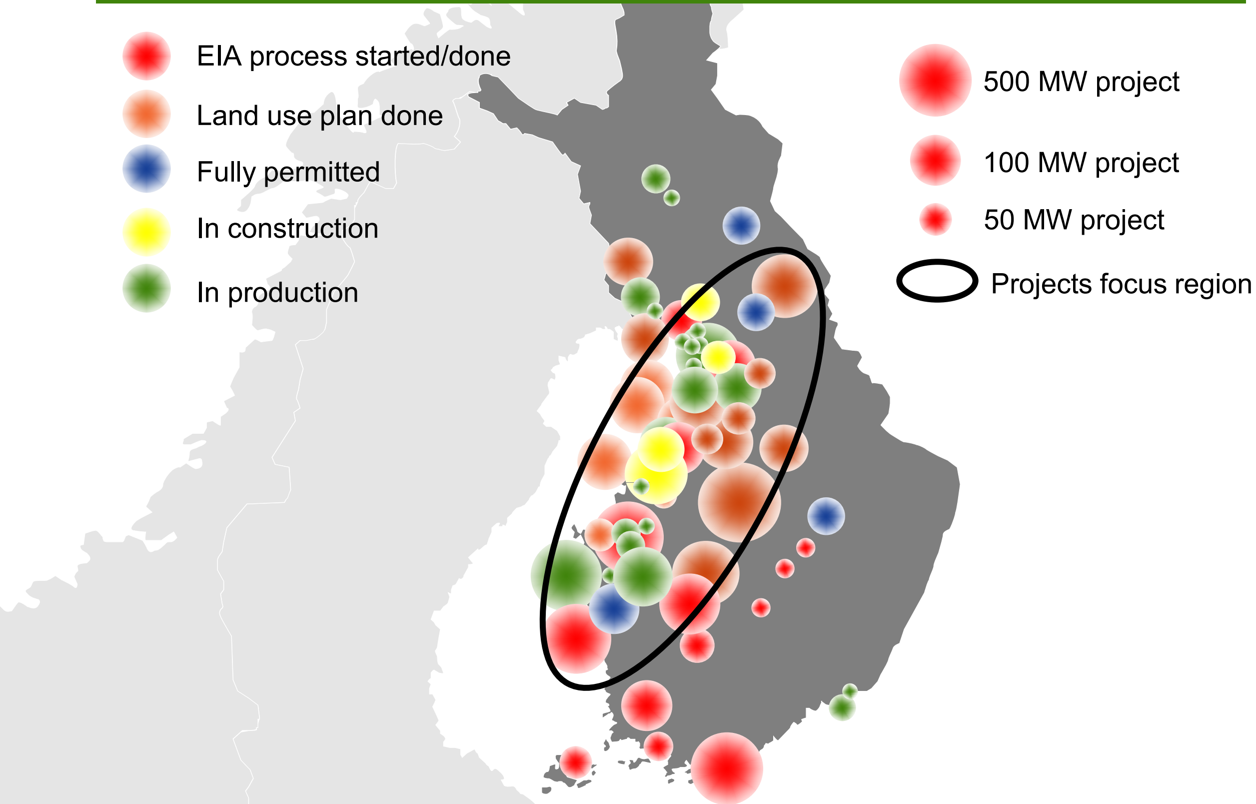
Renewable hydrogen supply potential in Finland

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



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

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

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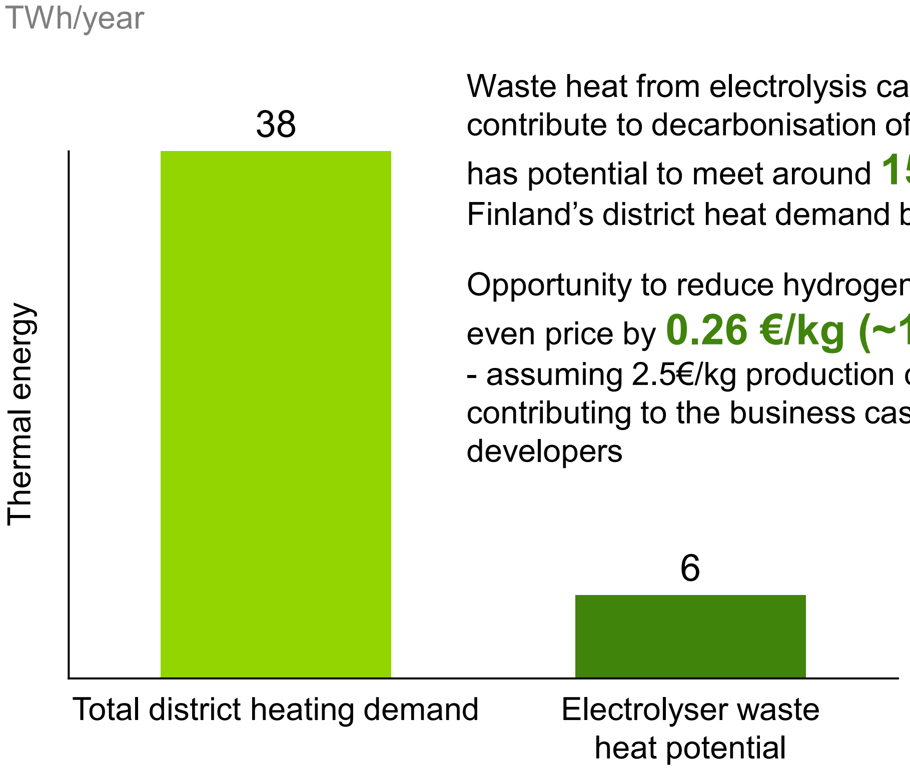
Hydrogen in Finland – benefits from existing district heat

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 H_2 for Finland District Heating Supply



Waste heat from electrolysis can materially contribute to decarbonisation of heat and has potential to meet around **15%** of Finland’s district heat demand by 2050

Opportunity to reduce hydrogen break-even price by **0.26 €/kg (~10%)** - assuming 2.5€/kg production costs - contributing to the business case for project developers

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 area[1].
- **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 Plants[2]

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. H_2 production 30 TWh in 2050 of which 50% can be used for district heating; See appendix for more assumptions

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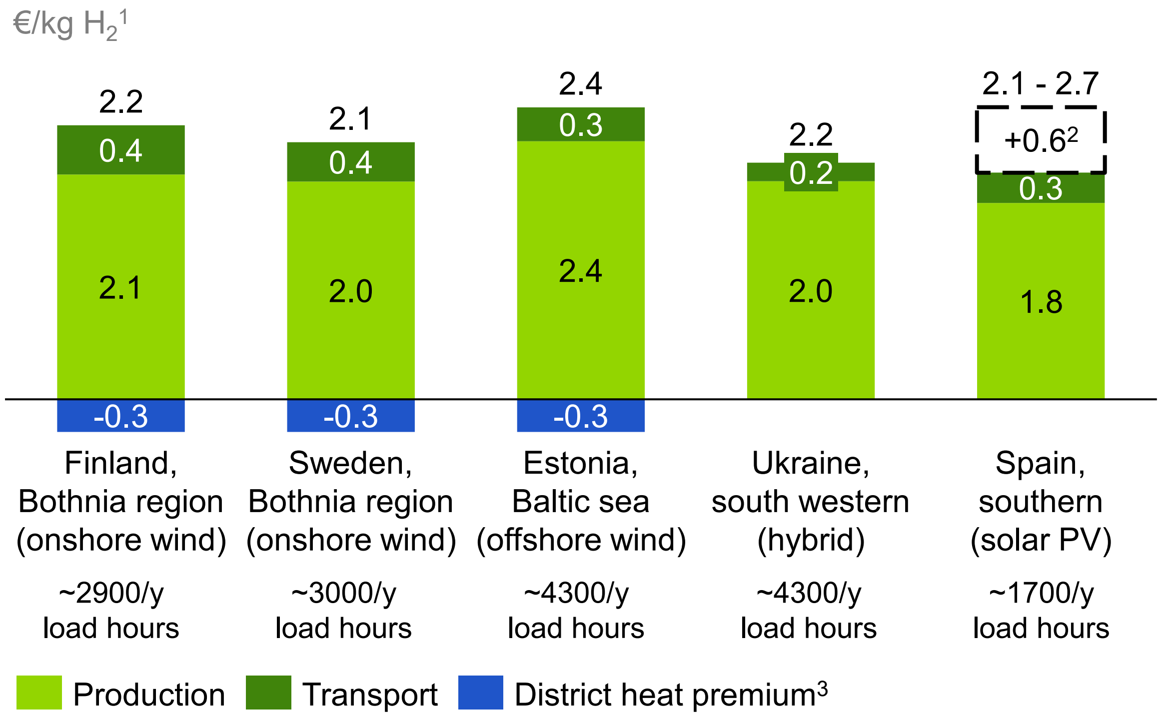
Sources: [1]Netherlands DH [2]Espoo, Finland

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.

H_2 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 competitivity**
  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 renewables[4].

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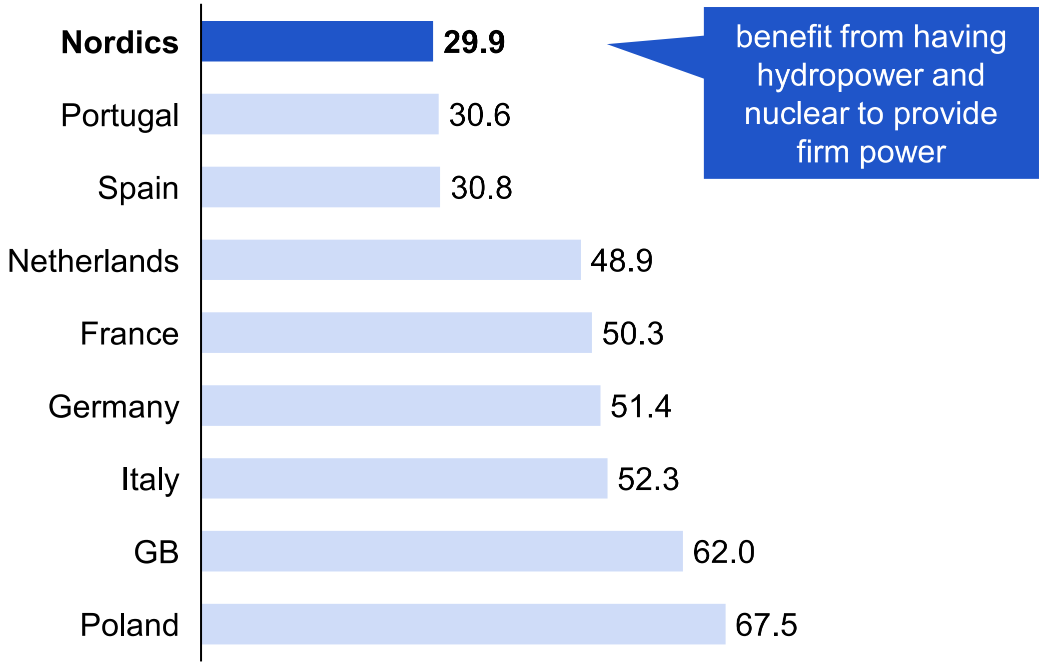
[1]Cost projections production and transport, excluding storage and local distribution – LCOH calculation assumes dedicated hydrogen production from dedicated renewables; [2]Range for Spain represents different pipeline options in southern France, from using small partly repurposed ~20 inch pipelines (high estimate) or large new ~48 inch pipelines (low estimate); [3]Based on the value of waste heat from electrolysis in district heating, as per slide 18. [4]Grid-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 water[1].
- **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 Finland[2] is on average 18 inhab./km^2 and could go as low 0.2 inhab./km^2 in the north, compared to for instance the averages of 240 in Germany or 508 inhab./km^2 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.

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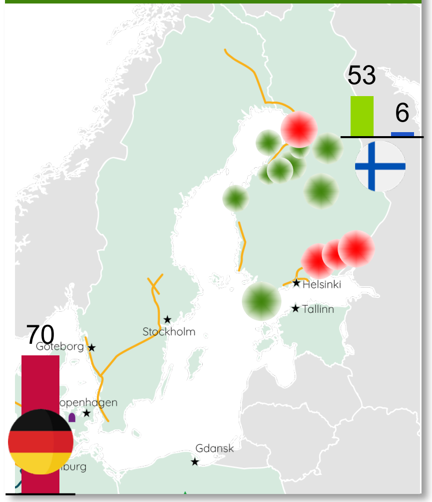
[1]Green hydrogen' water consumption from Energypost (link), water availability Finland from Europe environmental agency (link); [2]Eurydice (link)

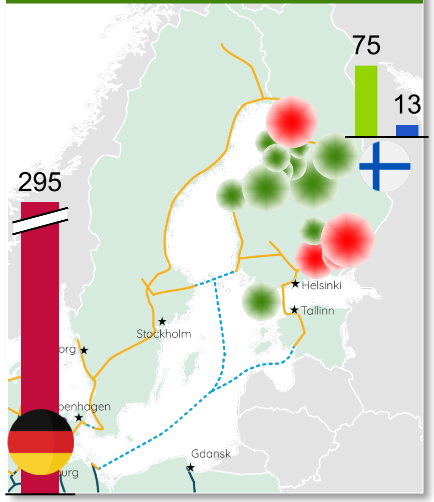
Hydrogen transfer needs

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.

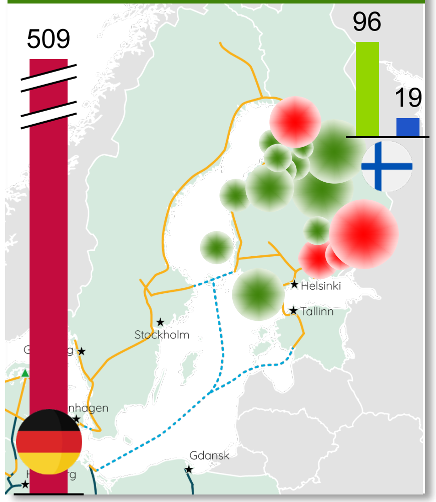
Map of 2030



Map of 2035



Map of 2040



- H_2 pipelines by conversion of existing natural gas pipelines (repurposed)
- Newly constructed H_2 pipelines
- Subsea H_2 pipelines (repurposed or new)
- Potential H_2 storage: Salt cavern
- Finnish demand region (bubble size illustrative)
- Finnish supply region (bubble size illustrative)
- German hydrogen demand (TWh/y)
- Finnish hydrogen supply from dedicated renewables (TWh/y)
- Finnish hydrogen demand (TWh/y)

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

Meeting H_2 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.

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[1]The 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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Appendix

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	Producers / suppliers	Infrastructure providers / TSOs	Policy makers & Regulators
Unable to commit demand volumes without clarity of supply options, infrastructure, and policy incentives	To make final investment decisions, need proper demand side commitments and infrastructure solutions	Need for clarity on regulation, funding, and flexibility to overcome funding gap during market development	Hesitancy to interfere with market mechanisms & 'choose winning technologies', focus on protecting end-consumers
Waiting on infrastructure providers and policy makers, for financial support	**Waiting on infrastructure providers and policy makers for market signals**	**Waiting on regulators to create enabling frameworks, and waiting on market players for flows**	**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

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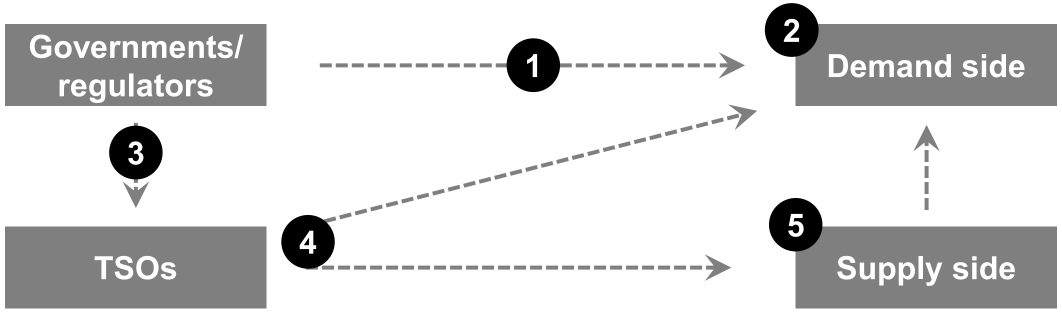
Note: Local communities and NGOs are not represented here but also play in important role in ensuring that decarbonisation measures and activities are in step with societal needs.

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

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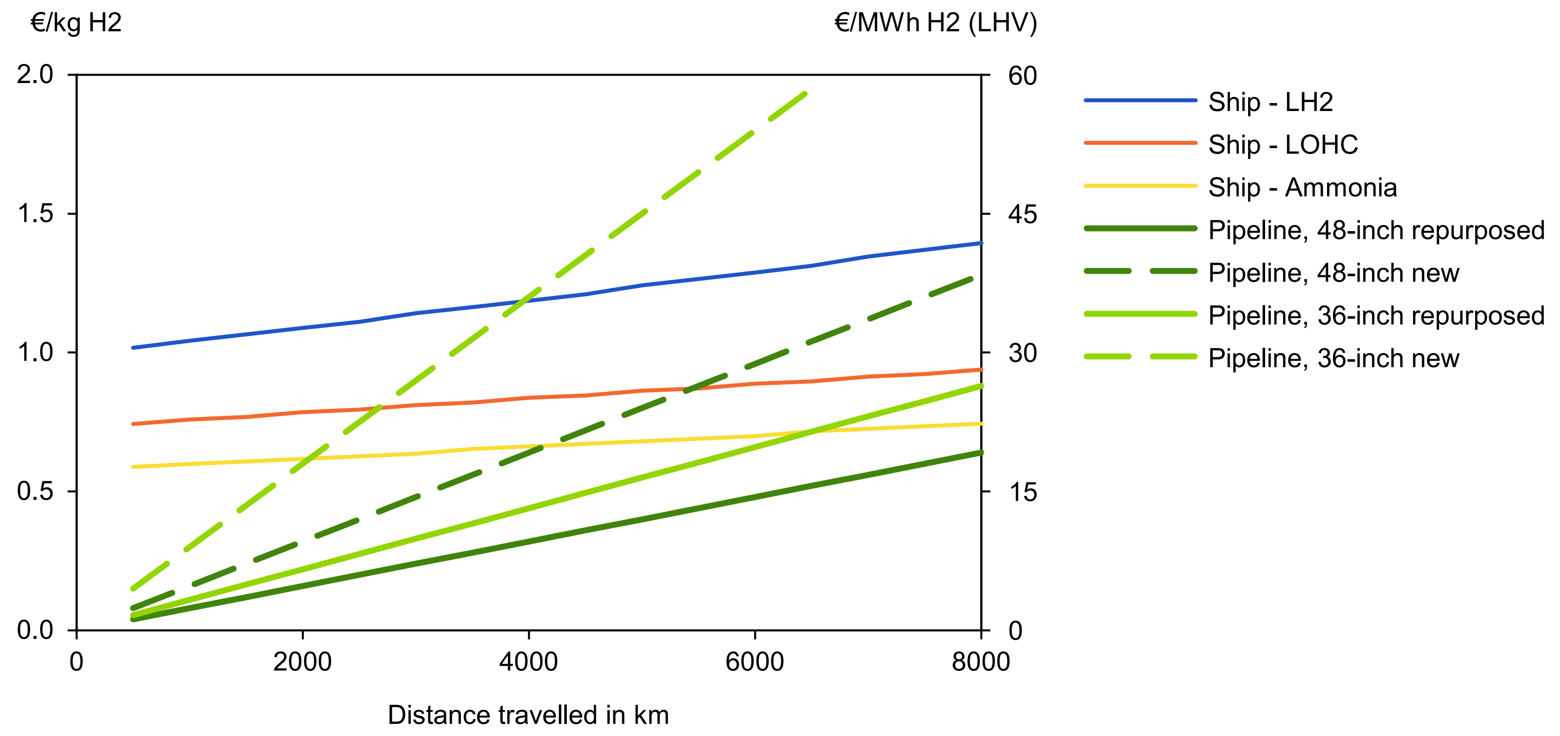
Hydrogen transport by pipeline vs by ship

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

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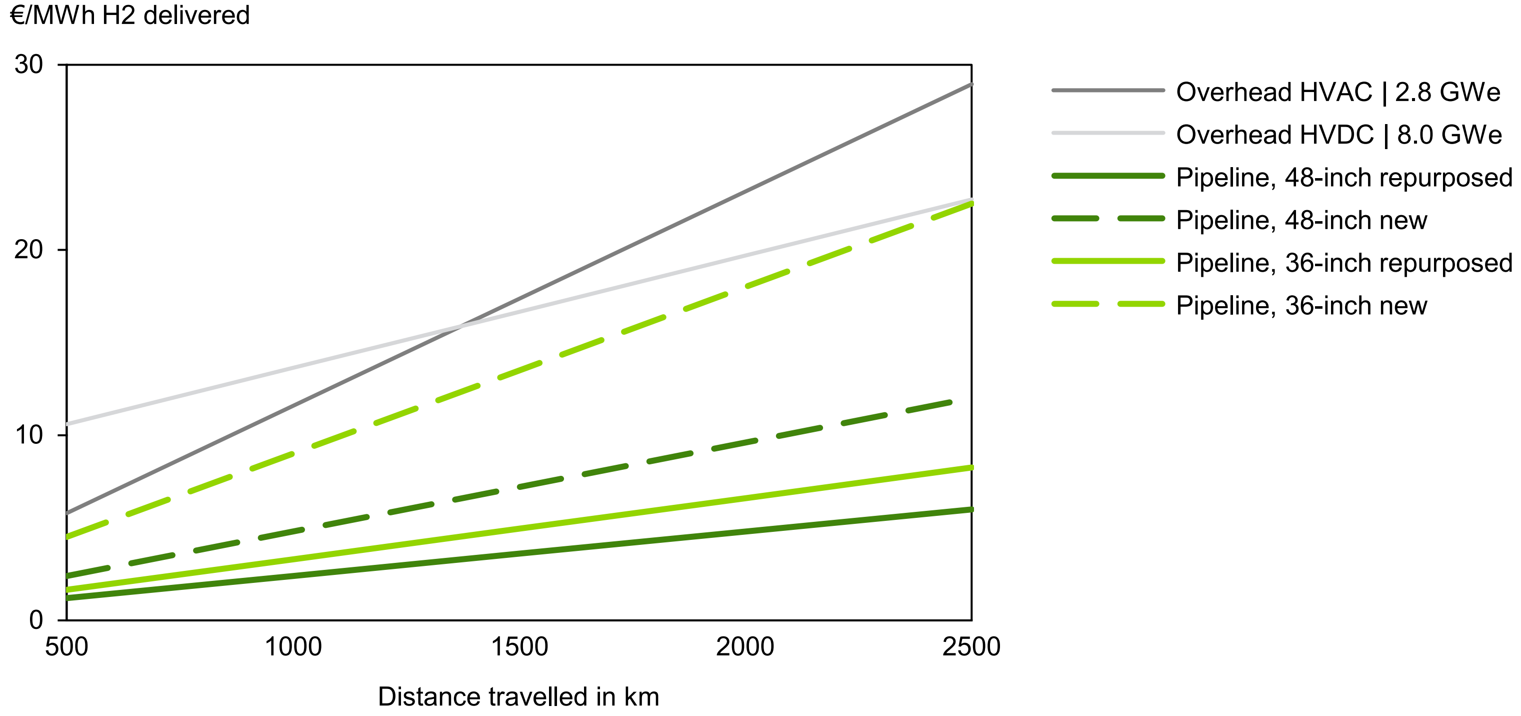
Source: European Hydrogen Backbone (2021)

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



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, electrolysers 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.

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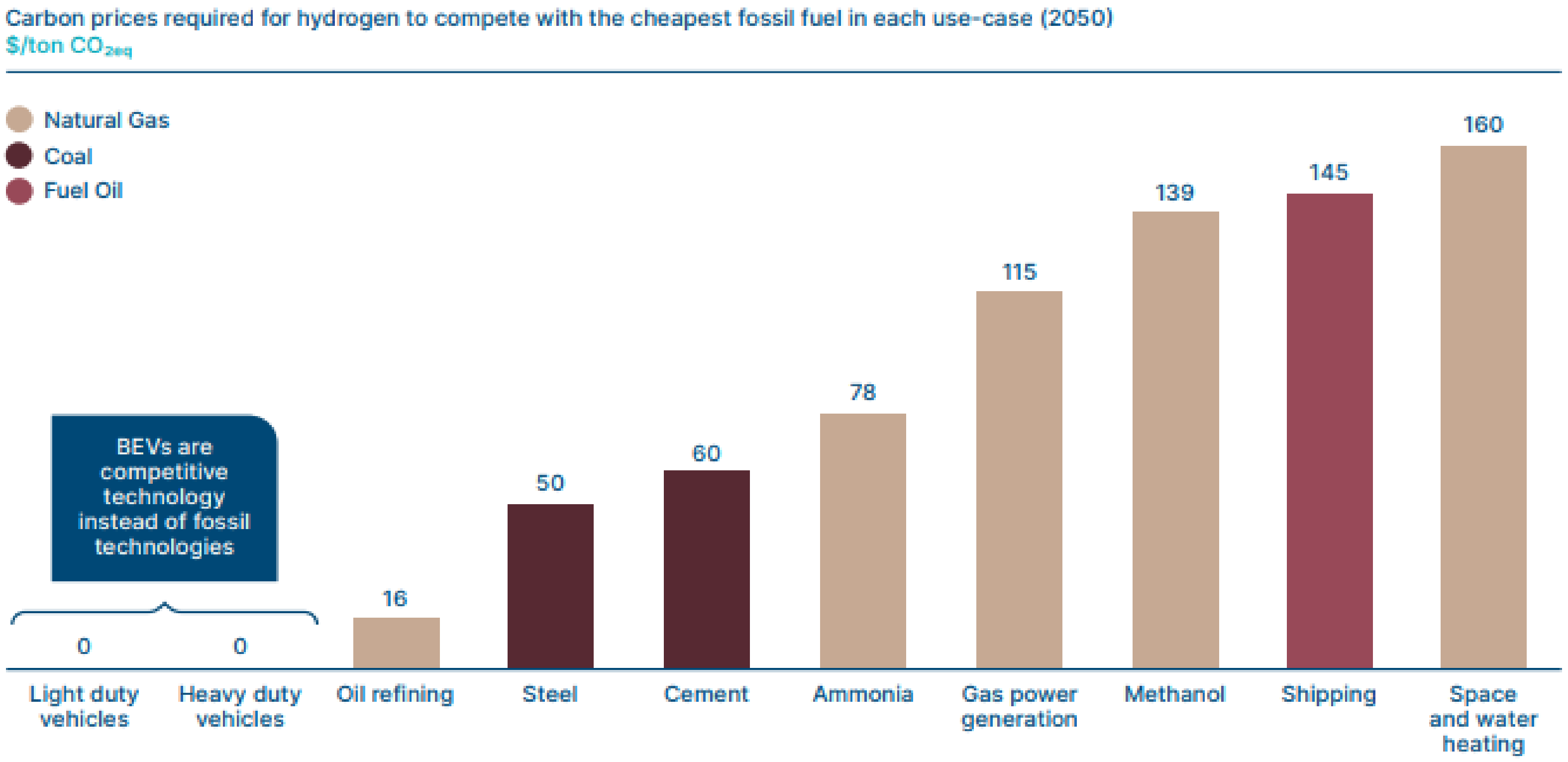
Source: European Hydrogen Backbone (2021))

Hydrogen competitiveness in end-use sectors

Break-even price of H_2 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"

CO_2 price required for H_2 competitiveness by 2050, assuming green H_2 price of $1/kg (0.85€/kg)



Sources: BNEF (2020) Hydrogen economy outlook

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 CO_2 price required depends on two parameters: (1) H_2 price; (2) volume of CO_2 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 CO_2 avoided stays constant, there is a linear relation between H_2 price and CO_2 price. E.g. for steel, if the hydrogen price doubles to $2/kg the required CO_2 price would also double by 2, to 100 $/t$CO_2$ (based on the BNEF analysis).

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Sara Kärki
Yksikön päällikkö, Strateginen analyysi & TKI
sara.karki@gasgrid.fi, puh. +358 40 158 1722

Kaasut mahdollistavat hiilineutraalin yhteiskunnan **– me tarjoamme sille alustan**

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