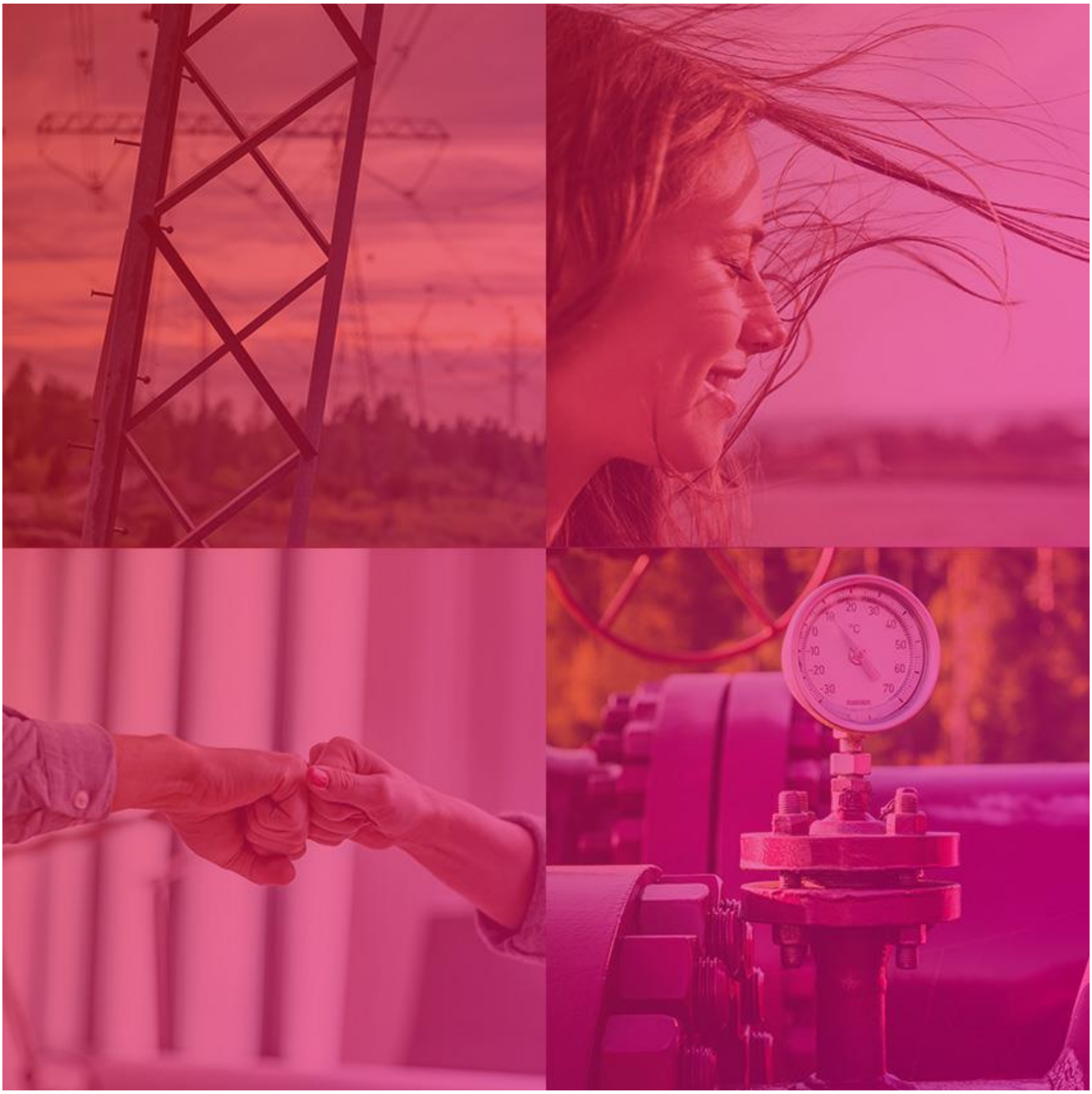


Intermediate report: Energy transmission infrastructure as enabler of hydrogen economy and clean energy system

Initial results from Fingrid and Gasgrid Finland's joint project

FINGRID

GASGRID

Foreword

The use of clean hydrogen is one of the key solutions to reduce emissions in many hard-to-abate sectors of society. In Europe, hydrogen investments are widely supported to accelerate the start-up of industry so that climate targets can be met effectively.

Finland is well placed to be a forerunner in the hydrogen economy, as we have the resources to produce and utilise clean hydrogen competitively. Finland's competitiveness in hydrogen production is increased by factors such as cost-effective renewable energy resources, strong energy infrastructure, and a high level of technical expertise. Fully exploiting the enormous potential of clean hydrogen requires significant investments. To remain competitive, it is important that energy infrastructure investments are made cost-effectively, considering the development of the entire energy system.

Fingrid and Gasgrid Finland are working together to explore the potential development paths of the hydrogen economy and their impacts on the energy system and the Finnish hydrogen industry. In this intermediate report, the companies present initial results from the joint project.

Contents

1 Fingrid and Gasgrid Finland's joint project explores the potential of hydrogen economy in Finland

Fingrid and Gasgrid are working together to study future development paths related to hydrogen production and consumption in Finland. The aim is to examine the conditions for the energy transmission infrastructure required by these development paths. Launched last year, the joint project explores how Finland's internal hydrogen transmission network, which could also enable cross-border trade of hydrogen, would have a broader impact on the energy system and the business opportunities of the Finnish hydrogen industry.

The Fingrid-Gasgrid joint project is a concrete action that promotes cooperation in planning and sector integration and supports achieving Finland's carbon neutrality target. This document highlights the key themes and preliminary findings of the joint project. It also provides a preliminary description of the development paths of the hydrogen economy and related energy transmission infrastructure, which will be further analysed in the project. The project is part of a larger HYGCEL (Hydrogen and Carbon Value Chains in Green Electrification) co-innovation joint action between research organisations and companies that has received funding by Business Finland. In the HYGCEL project, universities and companies jointly study the system level impacts of the energy transition, the energy system, and the hydrogen economy.

In the Fingrid-Gasgrid project, we interviewed several Finnish companies in autumn 2021 to find out their views on the hydrogen economy. The companies' views underlined the need to develop electricity and hydrogen infrastructure simultaneously and in a comprehensive manner. Views emphasized in the interviews are presented in the text boxes of this document. Finnish companies saw several possible roles in Finnish industry for the hydrogen network and stressed the importance of extensive cooperation both in infrastructure development and in the formation of industrial value chains.

> The interviewed companies hoped that Finland's electricity and hydrogen infrastructure would be developed together, with the aim of an overall optimal solution.

During the autumn 2021, Gasgrid and Fingrid have also outlined scenarios of the development of the hydrogen economy. The purpose of these scenarios is to find the most cost-effective infrastructure development paths for the Finnish energy system. The focus of the scenarios is on the different development alternatives for hydrogen infrastructure and the sectoral integration between the hydrogen, gas, and electricity transmission infrastructure. The draft scenarios with preliminary development paths for the hydrogen transmission system are presented in Section 7.

In addition to the joint project, Fingrid and Gasgrid both conduct their own studies, in which they investigate more detailed development needs of electricity, gas and hydrogen transmission infrastructures, respectively. For example, Fingrid will conduct Electricity System Vision, which will look more closely at the future needs of the electricity system, including in scenarios where hydrogen consumption is assumed to increase. Gasgrid is conducting its own studies together with the Baltic gas transmission system operators (TSOs) on the development needs of the existing network, related for example to the blending of hydrogen into methane.

2 Hydrogen economy as a solution to achieve carbon neutrality

The hydrogen economy is one way for companies to achieve carbon-neutrality targets profitably.

In the low-carbon roadmaps prepared by Finnish industry sectors, the utilisation of clean hydrogen is one of the key solutions for achieving Finland's carbon neutrality target for 2035[1]. Hydrogen produced from water and electricity is a scalable solution for reducing emissions, especially for processes that are difficult to electrify directly. Emissions can be effectively reduced by replacing hydrogen produced from fossil raw materials with hydrogen produced from emission-free electricity. Today, hydrogen is used in energy-intensive industries, but it is mainly produced from fossil raw materials such as natural gas, coal, or oil. In 2020, hydrogen demand in Europe was approximately 260 TWh/a[2].

The use of clean hydrogen has significant growth potential in several energy-intensive industrial sectors. For example, in oil refining, the steel industry and the chemical industry, emissions can be significantly reduced by utilising clean hydrogen. Figure 1 shows estimates of the development of hydrogen demand in Europe. Demand is estimated to grow to up to 1,500–2,300 TWh/a by 2050, considering all demand sectors.

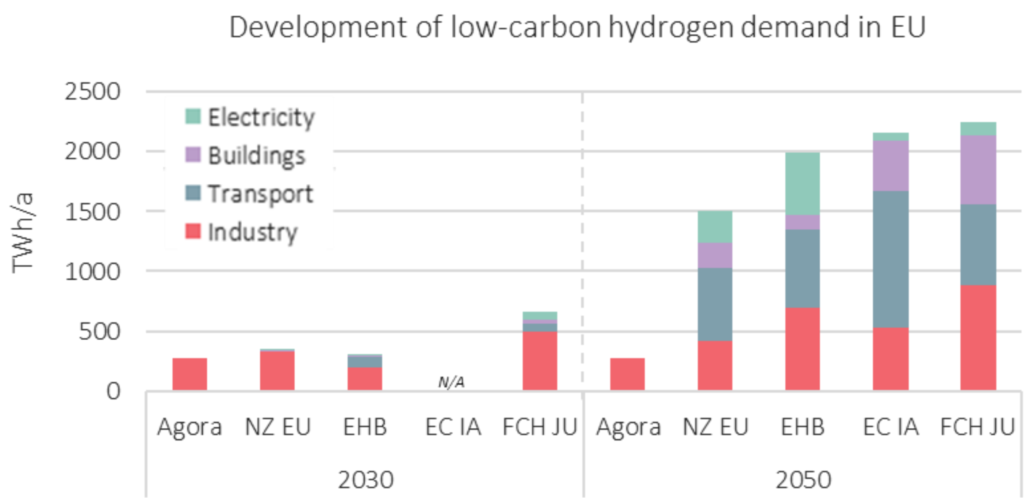


Figure 1: Estimates of clean hydrogen demand in Europe for the years 2030 and 2050[3]

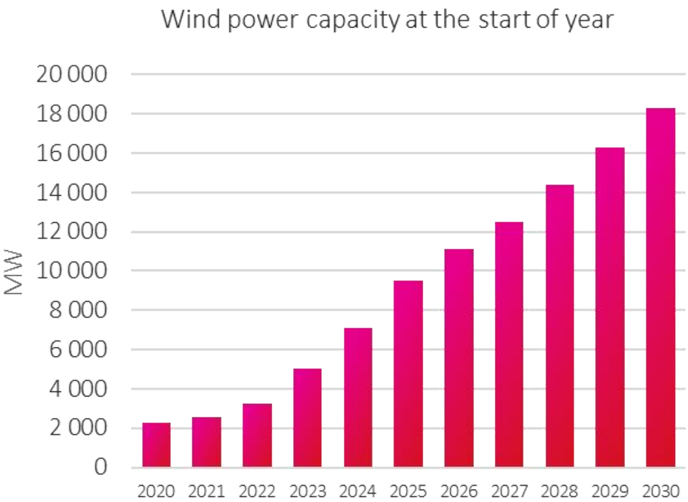
[1] Summary of low-carbon roadmaps of sectors (2020): https://julkaisut.valtioneuvosto.fi/handle/10024/162494
[2] Agora Energiewende (2021). No-regret Hydrogen – Charting early steps for H_2 infrastructure in Europe: https://www.agora-energiewende.de/en/publications/no-regret-hydrogen/
[3] Collected by Guidehouse (2021). The possibilities of Finnish hydrogen economy: https://gasgrid.fi/wp-content/uploads/Gasgrid_Selvitys-Suomen-vetytalouden-potentiaalista_FIN-FINAL.pdf
Note 1: The Agora study only considers part of hydrogen demand sectors
Note 2: For the EHB study, hydrogen used for biofuels and electricity has been transferred from industry to transport.

3 The production potential of clean hydrogen in Finland is significant – and competitive

> Several companies have plans for the production and export of hydrogen products.

Emission-free electricity production is needed to produce clean hydrogen. In 2021, 87% of electricity produced in Finland was produced carbon-dioxide neutrally and 54% with renewable energy sources[4]. Of renewable energy sources, wind power is particularly well suited to Finland and is being built at an unprecedented rate. Fingrid has signed more than 5,000 MW of wind power connection contracts for projects to be completed between 2022 and 2024. If implemented, the projects will increase Finland's wind power capacity approximately threefold by the end of 2024, when domestic wind power production would equal approximately one third of Finland's annual electricity consumption.

The construction of new electricity production is expected to continue at a brisk pace also in the late 2020s. Figure 2 presents Fingrid's estimate of the development of wind power capacity. It is estimated that the total wind power capacity will reach approximately 18,000 MW by the end of the decade. Figure 3 shows public connection enquiries on the map.



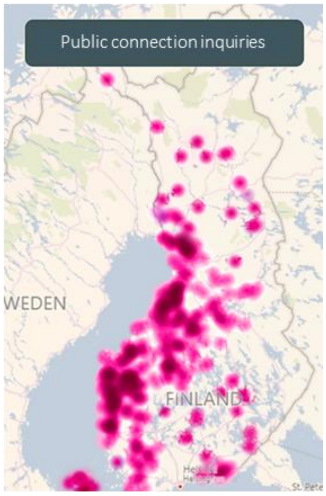


Figure 2: Projected development of wind power capacity in the 2020s and Figure 3: Public connection enquiries for wind power on the map. Source: Fingrid Oyj

Finland’s clean hydrogen production potential is sufficient for both domestic needs and exports. Fingrid has received close to 150,000 MW of enquiries for connecting to the main grid, most of which concern onshore wind power. If all projects were commissioned, they would generate about 500 TWh of electricity per year. Of this, almost 450 TWh would be available for new industries, equivalent to more than 300 TWh of clean hydrogen production (Figure 4). This is a significant potential relative to Europe's estimated demand for hydrogen (see Figure 1).

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[4] Finnish energy (2022). The energy year 2021 – Electricity: https://energia.fi/tilastot/sahkotilastot

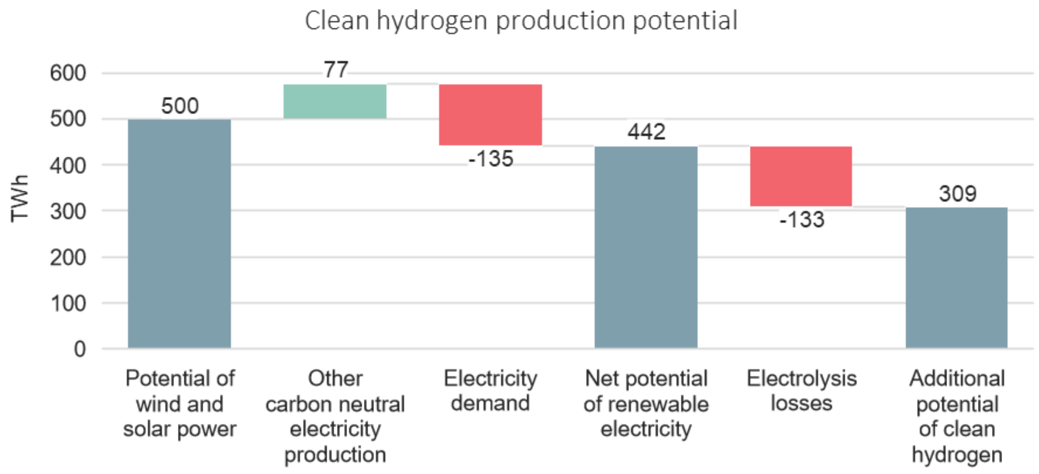

Figure 4: Potential for additional clean hydrogen production based on wind and solar potential[5]

The cost level of Finnish wind power appears to be very good in the European context, which increases Finland's competitiveness in hydrogen production. Finland combines factors such as good wind conditions with the possibility of constructing cost-effective onshore wind power based on tall hub height. In many other European countries, the focus has shifted to the construction of offshore wind power due to local opposition to onshore wind power. This has led lawmakers in many areas to limit the construction of large-scale onshore wind farms and create incentives for offshore wind power construction[6]. The cost level of Finnish onshore wind power is significantly lower than that of European offshore wind power[7].

[5] The potential for wind and solar power is based on the connection inquiries received by Fingrid Oyj by February 2022. Electrolysis losses have been calculated assuming an electrolysis efficiency of 70 %. Other carbon-neutral electricity production and consumption are based on Finnish Energy Association's (2020) low-carbon roadmap: https://energia.fi/files/5064/Taustaraportti_-_Finnish_Energy_Low_carbon_roadmap.pdf
[6] LevelTen (2020). Energy PPA Price Index: https://windeurope.org/wp-content/uploads/files/about-wind/campaigns/2020-successes/levelten/products/LevelTen-Energy-European-Q42020-PPA-Price-Index.pdf
[7] Wind Europe (2019). Economics: https://windeurope.org/policy/topics/economics/

4 Hydrogen transmission infrastructure can support both the wider utilisation of wind power potential and Finland's entire energy system

The potential of Finland's wind power production is so high that its full utilisation is unlikely to be efficient by utilising only the electricity grid, especially if the produced electricity is used for hydrogen production. A significant share of Finland's wind power projects is located in Ostrobothnia and northern Finland (Figure 3), while more than 60% of current electricity consumption is located south of Tampere. The need to transmit electricity from north to south is already high and is expected to multiply. This means that there is a need to significantly strengthen the north-south main grid.

The electricity and hydrogen markets are seen as strongly interlinked, both in terms of price and production structure.

Hydrogen transmission infrastructure would enable electrolysers to be located near electricity production sites, thus reducing the need for electricity transmission. In particular, north-south hydrogen transmission infrastructure can contribute to the full utilisation of Finland's wind power potential, when it is not necessary to transmit electricity used for hydrogen production to the consumption points of Southern Finland[8]. Instead, hydrogen can be produced in the north and moved south with the help of a hydrogen pipeline.

Figure 5 illustrates the capital costs of energy transmission as hydrogen and electricity when the energy is used for hydrogen production. The figure shows that the capital costs of hydrogen transmission fall sharply as transmission volumes increase. When large quantities of energy are transmitted, hydrogen transmission is competitive compared to electricity transmission.

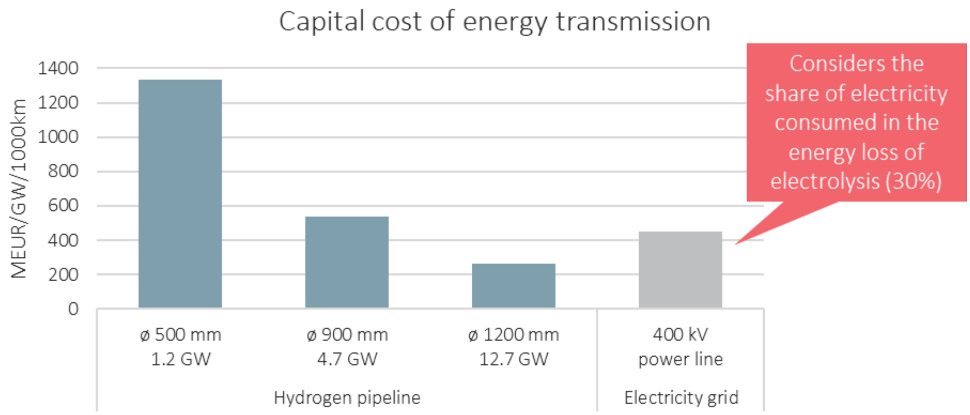

Figure 5: Capital cost of energy transmission with hydrogen pipeline and electricity grid[9,10]

[8] Business Finland (2020). National Hydrogen Roadmap for Finland: https://www.businessfinland.fi/4abb35/globalassets/finnish-customers/02-build-your-network/bioeconomy--cleantech/alykas-energia/bf_national_hydrogen_roadmap_2020.pdf

[9] The capital cost and transmission capacity of hydrogen pipelines are based on the European Gas TSOs' estimates of the cost of a new hydrogen pipeline including compressors for the pipeline at the following capacities: 100% (500 mm: 1.2 GW, 900 mm: 4.7 GW) and 75% (1200 mm: 12.7 GW). Source European Hydrogen Backbone (2021): https://gasforclimate2050.eu/wp-content/uploads/2021/06/EHB_Analysing-the-future-demand-supply-and-transport-of-hydrogen_June-2021_v3.pdf

[10] The capital cost of electricity grid is based on Fingrid's actual 400 kV AC overhead line network investment costs.

The figure shows that unit costs are lowest at the highest transmission volumes. The capital costs are lowest per km and per amount of energy transmitted for the largest pipeline, with a diameter of 1.2 meters and a transmission capacity of up to 13 GW of hydrogen. The capital costs shown in the figure are based on the European Hydrogen Backbone study for the hydrogen pipeline and on Fingrid's actual investment costs for the electricity grid. The cost of the electricity grid considers that the electricity grid should also transmit the share of electricity consumed in the energy loss of the electrolysis process, so that the amount of electrical energy transmitted is almost one and a half times the amount of hydrogen energy transmitted. The significance of energy loss in transmission volumes is illustrated in Figure 6.

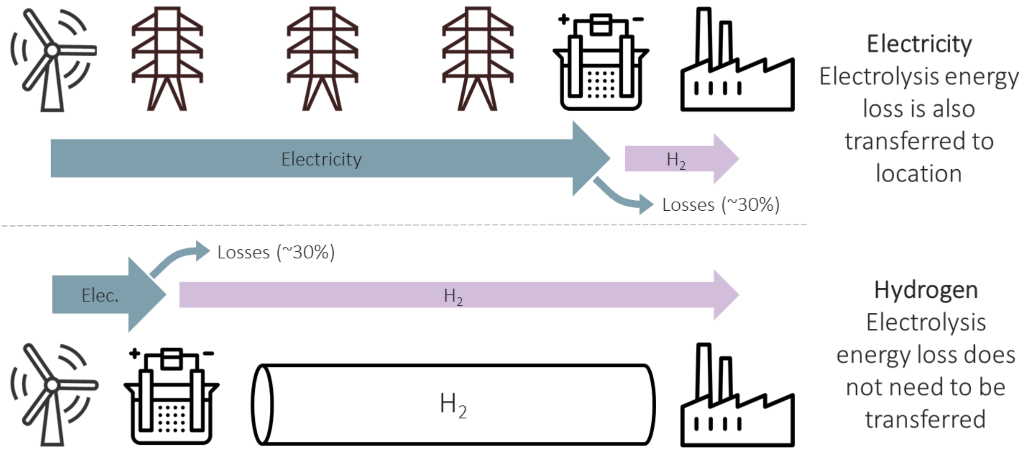

Figure 6: Producing hydrogen near the electricity production site reduces the need for energy transmission to deliver the same amount of hydrogen for the end-user

An electrolyser can be connected to the electricity grid even when energy is transmitted over a longer distance as hydrogen. Connection to the grid enables the use of the electrolyser independently of local electricity production and, as a result, at a higher utilisation rate. In addition, the utilisation of the electrolyser's flexibility in the reserve market may reduce hydrogen production costs[8]. Electrolyser location decisions may also be influenced by utilisation opportunities of by-products (heat and oxygen), such as utilising the by-product heat of electrolysis in district heating, primed with heat pumps.

The transmission of large quantities of energy in the form of hydrogen is also more efficient in terms of land use than transmission in the form of electricity. As illustrated in Figure 7, electricity transmission corresponding to a large 13 GW hydrogen pipeline would require around 15 high-voltage power lines.

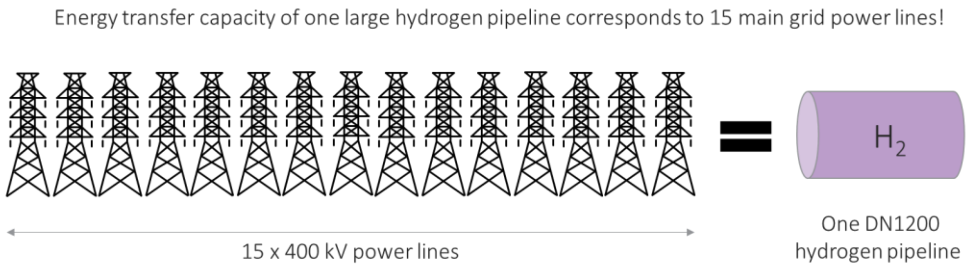

Figure 7: Illustration of the energy transmission capacity of the electricity and hydrogen networks

5 Hydrogen transmission infrastructure enables the emergence of an efficient hydrogen market

Transmission infrastructure contributes to the emergence of a competitive hydrogen market. The hydrogen network connects several different hydrogen producers and consumers and enables open trading within the network. Extensive competition would bring efficiency and risk management benefits to operators compared to a situation where each hydrogen user produces and stores the hydrogen, they need locally at their consumption point.

In many industrial processes, hydrogen use is continuous, and it must be deliverable in all situations. This is promoted, for example, by the integration of operators into the same network or by hydrogen storage.

Within a large market, production and consumption can be flexible according to the market situation, and storage opportunities may also arise in the market. A large hydrogen network would in itself act as an energy buffer that can even out a temporal imbalance between production and consumption. The storage capacity of the hydrogen network for a 13 GW pipeline is estimated at 100 GWh/1000 km, which would allow at a minimum intra-day flexibility in hydrogen production and consumption in the already developed hydrogen market. This would make it possible to use hydrogen even if its production is not momentarily profitable for example due to a high price of electricity. For the electricity market, this would increase flexibility that balances electricity price peaks.

In Europe, the construction of a hydrogen network seems likely, as it is cost-effective, especially in areas where the existing natural gas network can be converted for use in hydrogen transmission. European hydrogen transmission infrastructure is expected to be formed to support the local hydrogen demand, regardless of Finnish developments. Hydrogen transmission connections from Finland to the rest of Europe would enable hydrogen exports, wider hydrogen market development and integration, and access to Central European hydrogen storage sites for seasonal storage.

6 The hydrogen economy can create new industries and new value chains

> Value chains and competitiveness arise from cooperation between companies – a company can't compete on the international markets alone.

Finland is well equipped to be a forerunner in the hydrogen industry. High-level technical expertise in energy-intensive industries provides a basis for international competitiveness[11]. With the development of hydrogen market and the hydrogen economy, new industries and new industrial value chains may emerge in Finland. These could be related, for example, to the production and transmission of electricity and hydrogen, the production of Power-to-X i.e., P2X-products such as synthetic fuels, the production of hydrogen-based raw materials, and industrial decarbonisation solutions. Figure 8 illustrates potential hydrogen value chains in Finland.

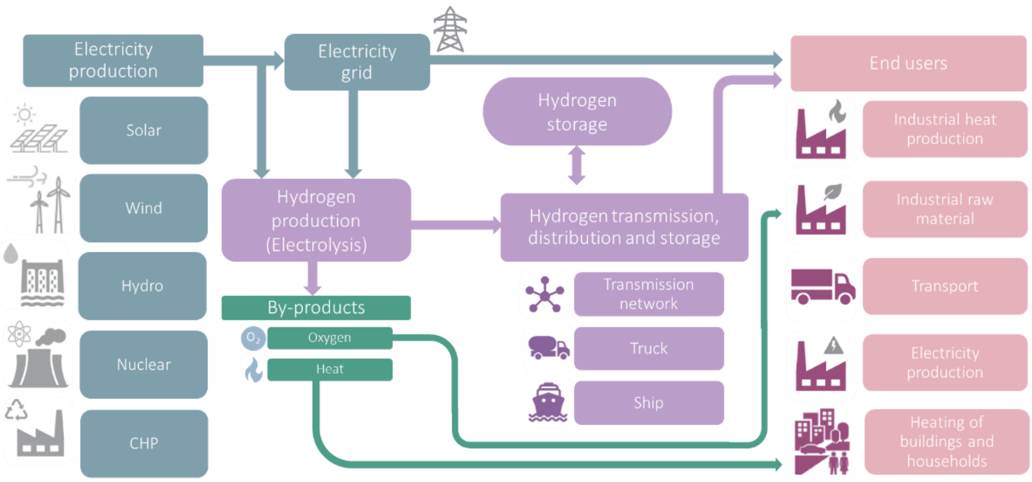

Figure 8: Potential hydrogen value chains in Finland

Each area of the hydrogen economy has the potential to generate significant economic benefits for Finland. These include an improvement in the trade balance as a result of the shift from imported fossil energy to clean hydrogen, enabling hydrogen exports, developing national know-how and research, and developing logistics and energy systems for future investments. The economic impact of investments is multiplied when their entire life cycle is considered, including planning, construction, maintenance, operation and decommissioning. These effects are studied in more detail in the upcoming phases of the joint project.

[11] Hydrogen Cluster Finland (2021). A systemic view to the Finnish Hydrogen economy today and in 2030: https://h2cluster.fi/wp-content/uploads/2021/09/H2Cluster-Whitepaper-09-2021.pdf

7 Gasgrid and Fingrid's hydrogen economy draft scenarios

Gasgrid and Fingrid have outlined three scenarios for the development of the hydrogen economy, presented in Table 1. In all scenarios, it is assumed that Finland will achieve its carbon neutrality target. Electricity consumption increases in several sectors due to electrification of transport, heating and industries.

Table 1 Description of Gasgrid and Fingrid's hydrogen economy draft scenarios

SCENARIO	DESCRIPTION
Strong Regional Hydrogen Economy	• Hydrogen production in Finland grows strongly. Demand for hydrogen is boosted by Finland's development as a major exporter of P2X-products, such as electric fuels. • Cross-border hydrogen transmission infrastructure will not be built except from Finland to Northern Sweden. • The lack of cross-border transmission infrastructure reduces the flexibility of the hydrogen system compared to other scenarios and increases the need for domestic hydrogen storage.
European Hydrogen Market	• Hydrogen production in Finland grows strongly. Hydrogen is produced in Finland especially for export. • Domestic use of hydrogen is limited to meeting the carbon neutrality targets of the existing industries. • Pipeline transmission infrastructure will be built for large-scale hydrogen exports to both Northern Sweden and Central Europe. • Hydrogen cross-border connections to the rest of Europe improve the flexibility of the system.
Leading Hydrogen Ecosystem	• Hydrogen production in Finland grows very strongly. Production is driven by both strong growth in domestic demand and hydrogen exports. • The very high hydrogen production level maximizes the utilisation of renewable electricity resources. • Pipeline transmission infrastructure will be built for hydrogen exports to both Northern Sweden and Central Europe. • Hydrogen cross-border connections to the rest of Europe improve the flexibility of the system.

The aim of the scenarios is to study the most cost-effective alternatives for the Finnish energy system. One of the key background assumptions in the scenarios is the different hydrogen network development alternatives, which are illustrated in Figure 9. The benefits of the different development alternatives are assessed by comparing them with a situation where an extensive hydrogen network is not built.

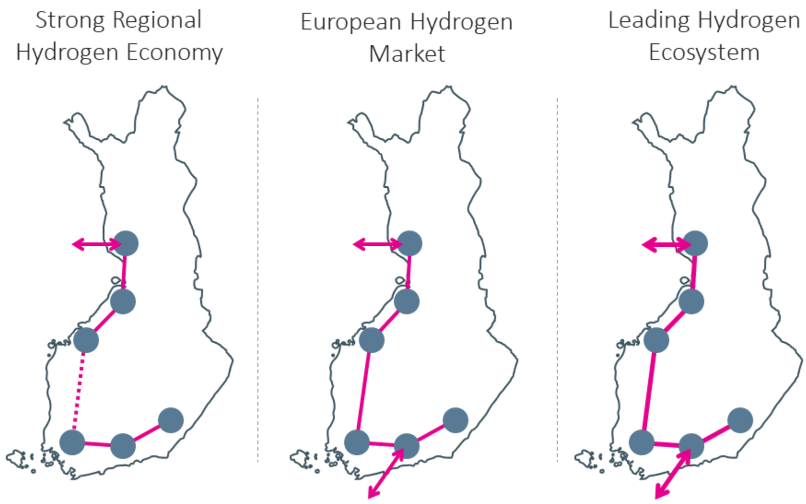

Figure 9: Illustrative hydrogen transmission networks in the scenarios

The first development alternative is that strong regional hydrogen value chains emerge that benefit from regional hydrogen infrastructure.

The second development alternative is the utilisation of Finland's wind power potential to produce hydrogen for export. In addition to the development of regional networks, this would require the development of north-south hydrogen transmission infrastructure within Finland and to other European countries.

The third development alternative is similar to the second in terms of hydrogen network development. The key distinguishing factor is the higher capacity of the hydrogen transmission infrastructure, which is needed to maximize the utilisation of Finland's clean energy potential for both the domestic P2X industry and the export of hydrogen.

8 Gasgrid and Fingrid's joint project continues until the end of 2022

Fingrid and Gasgrid Finland interviewed several companies about their views of the hydrogen economy during autumn 2021 and outlined scenarios on the effects of the hydrogen economy on the energy system. Next, the project will specify the scenarios in more detail and perform preliminary system modelling. The views collected in the interviews are used to support the modelling of the scenarios. In addition, the research project studies and evaluates different hydrogen value chains and development paths and assesses the impact on the development needs of gas, electricity and a possible hydrogen transmission system. The scenarios will be widely consulted with stakeholders during 2022 to obtain comprehensive feedback. The final report of the project will be completed at the end of 2022, and a joint stakeholder event will be held in connection with the publication.

In spring 2021, Gasgrid Finland, the Finnish gas transmission system operator, and Fingrid, the Finnish electricity transmission system operator, started a cooperation aimed at exploring the potential of the hydrogen economy in Finland, as well as the role of energy infrastructure in enabling the hydrogen economy. The cooperation continues concretely in Gasgrid and Fingrid's joint research and development project, which is implemented as part of the broader HYGCEL research project consortium consisting of several Finnish companies and research institutes. On 28 October 2021, Business Finland granted support for both the Fingrid-Gasgrid joint project and the broader entity.

Gasgrid Finland Oy is a Finnish state-owned company and transmission system operator with system responsibility. 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. Find out more: www.gasgrid.fi

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