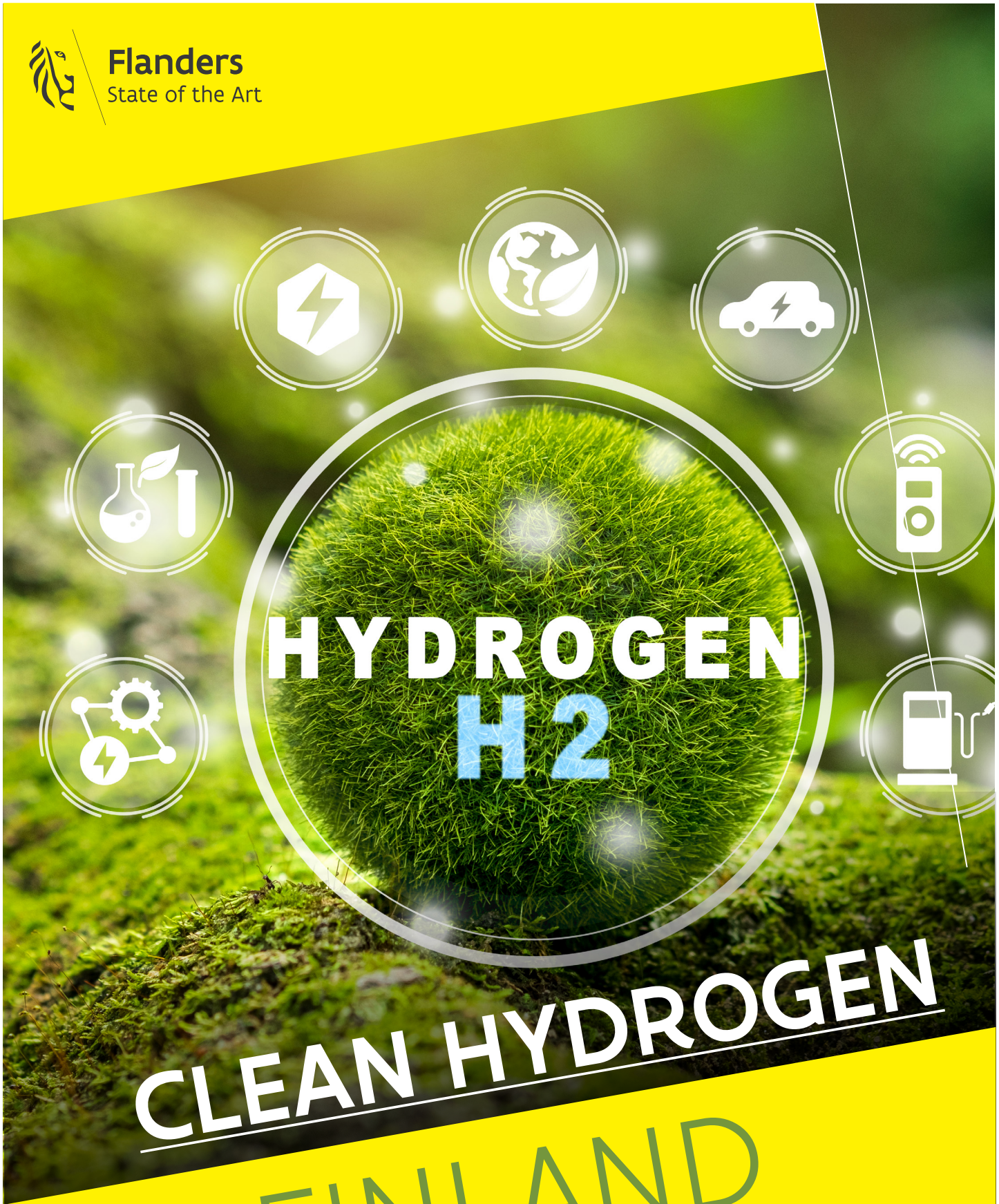
Flanders
State of the Art



CLEAN HYDROGEN IN FINLAND

FLANDERS INVESTMENT & TRADE MARKET SURVEY

FLANDERS INVESTMENT & TRADE

Market study

CLEAN HYDROGEN IN FINLAND

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Contents

Introduction 3

The current and future role and uses of hydrogen 3

Necessary conditions for a growing hydrogen ecosystem 5

- Space 5
- Inexpensive electricity 6
- Forest 6
- Water 6
- Electricity grid capacity and flexibility 6
- Workforce 6
- Waste heat utilization 7
- Political support 7

Current clean hydrogen projects in Finland 7

- Fuels 8
- Electricity storage 8
- Replacing gray with green 9
- Entirely new concepts 9
- Export 10

Clusters, sector organizations, and other actors in the market 14

Sources 15

Disclaimer 16

Introduction

Globally, there is a growing interest in clean hydrogen. Hydrogen is a very versatile substance which has been seen as a promising energy carrier, among its many other uses. It is, however, neither easy nor inexpensive to produce, store, and use efficiently. With energy demands growing and climate change increasingly impacting the world and decision making, producing hydrogen and its derivates (such as ammonia and methane) using non-renewable energy sources is no longer considered a sustainable solution.

As renewable energy is becoming less expensive and more abundant, the potential role of hydrogen is changing. Cheap, clean, and abundant energy introduces the possibility of turning away from "grey" (made from natural gas) or "black" (made from coal) hydrogen and allows for producing large amounts of "green" (made by using renewable energy) hydrogen for many different uses and to replace fossil-based solutions.

The heightened relevance of hydrogen is particularly notable in Finland, where both the wind power and the solar power sectors are booming, after having initially started off more slowly than in many other countries. While the country was still a net importer of energy in 2022, the wind power produced grew by 41% during that year, and the growth rate is projected to rise exponentially until 2030 and beyond. Wind covered 14% of the country's electricity usage in 2022, with solar power only at 0.5% - but the growth of solar is predicted to be even steeper than that of wind. While the exact point of energy self-sufficiency is hard to determine, as Finland both imports and exports energy, in September 2023 the country is close to that point.

The large expansion of the renewable energy sector, including the planned clean hydrogen projects outlined in this market study, offers many opportunities for Flemish companies active in onshore wind, offshore wind, solar power, hydrogen economy, subcontracting, consultancy, and services.

The current and future role and uses of hydrogen

Hydrogen can be used for a wide variety of purposes. Currently, its main use is in the chemical industry to refine oil or to make ammonia based fertilizers. There are only about a dozen dedicated hydrogen production sites in Finland, with a few additional facilities generating hydrogen as a by-product. As a main product, hydrogen is almost exclusively produced from fossil fuels: globally, 70% is made from natural gas and around 30% from coal. Furthermore, it is almost always produced without any carbon capture. This resulted in an estimated release of 70-100 million tonnes of CO_2 emissions in 2020 just in the EU.

In contrast to its uses in refining or for fertilizers, hydrogen used as energy represents only a small fraction of total energy used. While hydrogen is not in itself a source of energy, it could become an important means to replace fossil fuels in a number of ways. If using carbon-free energy, either renewable (yielding "green" hydrogen) or nuclear (producing "pink" hydrogen), hydrogen can be produced without any need for extraction of natural gas or coal. Further, using techniques such as methane pyrolysis, the carbon contained in natural or synthetic methane can be not just captured and

stored but even actively utilized to produce solid carbon for industrial uses. This kind of “turquoise” hydrogen can thus even be carbon negative from a climate viewpoint.

But substituting clean hydrogen where dirty hydrogen is currently used is only a small part of its potential opportunity. Its strongest prospects are as a medium between increasingly abundant production of renewable energy and the use of this energy in the form of fuels, industrial uses, heating, chemicals, etc. Technologies that would previously have been uneconomical or impractical become possible and economically viable if there is ample green energy available and efficient technologies exist to transform, store, and transport it. For example, hydrogen can replace coke in steel making and synthetic e-fuels made from hydrogen can replace transportation fuels such as diesel or kerosene. Hydrogen could also be used in entirely new roles, such as in the production of steel, cement, or even food.

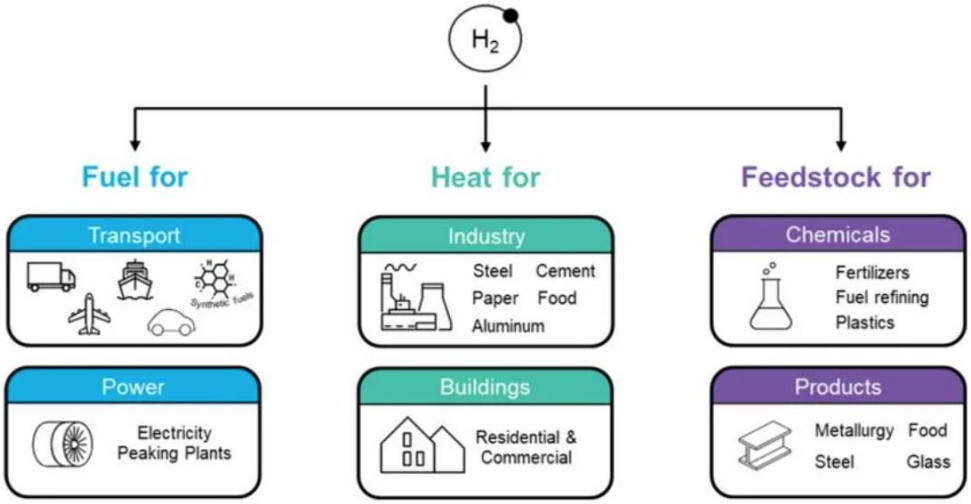


Image source: www.bloomberg.com/news/articles/2019-08-21/cost-of-hydrogen-from-renewables-to-plummet-next-decade-bnef#xj4y7vzkg

The fluctuation inherent in much of clean energy production is a challenge for the grids, even more so as usage is also variable. Fossil fuels are typically quite flexible: coal, oil, or natural gas can be sourced, stored, and used as needed. In contrast, wind and solar power are characteristically variable, and a nuclear plant is much more difficult and expensive to turn on and off than, for example, a coal plant. As the share of renewable energy (other than more flexible hydropower, biofuels, or geothermal) rises, and the share of fossil fuels drops, new solutions are needed for grid balancing and energy storage. Hydrogen can be used to store energy over days or even months with modest costs, and can be used to transport energy over long distances. Energy storage is not only important for balancing varying levels of production and demand, but can also be used to take advantage of electricity price changes over time.

By offering features electric batteries lack, engines powered by hydrogen or its derivatives could also provide solutions to problems facing the electrification of heavy road transport, the maritime sector, and aviation. In some cases, this would even involve simply using existing fuel logistics and refuelling infrastructure. There is no major dedicated hydrogen pipeline infrastructure in Finland so far, but as the use of natural gas decreased by half in the years 2005–2020, part of the existing natural gas infrastructure could be repurposed for distribution and even buffer storage of hydrogen or

its derivatives. Gas transport in tube trailers is very cost effective in Finland, as the limits for truck dimensions and weight are the highest in the EU.

As renewable energy production grows exponentially until 2030 and beyond, Finnish energy producers also simply need to find new energy users. Total energy consumption in the country has been stable or falling since 2011, so all that future renewable energy will not be used by existing local consumers or industry. The options are thus to either create new utilization - such as new industries - at home, to export energy abroad, or to do both. This calls for actions to develop both. Such actions are currently being taken, as outlined in this report.

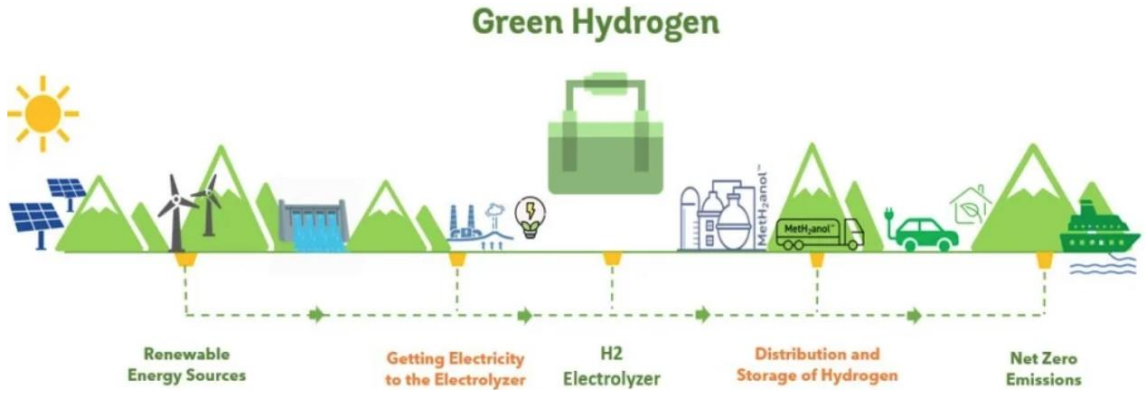


Image source: https://blogs.worldbank.org/ppps/green-hydrogen-key-investment-energy-transition

Necessary conditions for a growing hydrogen ecosystem

While Finland has so far been a net importer of energy, this is changing fast. The renewables sector is booming, and there are many reasons for this trend to continue. Finland also possesses all the other essential features for building up a strong hydrogen economy.

Space

Finland is the most sparsely populated country in the EU, with fewer than 17 inhabitants per square kilometre (compared to 376/km^2 in Belgium and 488/km^2 in Flanders). There are ample largely uninhibited areas suitable for wind or solar power parks. While many of the current wind power stations are situated along the western coast, technological advances and land use agreements that are attractive to local municipalities and residents have expanded the area where wind power is planned, permitted, and constructed. Also offshore is finally taking off, following the first offshore wind park finalized in 2017. The country's 82,000 km^2 of sea and 314,000 km of shoreline hold plentiful opportunities.

Despite the available space, Finland with its long, dark winters may not be an obvious country for solar power stations. In fact, the cooler temperatures, long hours of daylight in the summer, and angle of sunlight which allows for solar panels being efficiently placed on walls of buildings, mean that solar power is about as efficient in Finland as in northern Germany. While solar is still a very small part of

Finland's energy mix and mostly produced on a smaller scale – up to large factories producing for their own energy needs – plants are currently being planned and built that will produce electricity on a commercial basis to be fed into the grid.

Inexpensive electricity

For energy to be useful for an industry that demands a lot of it, such as the hydrogen economy, it has to be not only plentiful but also affordable. The wholesale price of electricity in Finland fluctuated heavily in the recent past, mainly because of changes in the market due to the Russian war on Ukraine and the delays in the commissioning of the new nuclear reactor in Olkiluoto. Since then, the wholesale price has fallen dramatically, at times to negative rates, and future price hikes are not predicted, as the nuclear and wind production capacity have grown abundantly.

Forest

The production of synthetic fuels from hydrogen requires a source of CO_2. Finland has the highest percentage of forest cover in the EU and well-developed forestry sector. Thus, it has a strong supply of biogenic CO_2 which has been removed from the atmosphere by photosynthesis, and which can be used for this purpose. This means lower costs and fewer regulatory hurdles compared to having to source CO_2 from direct air capture or fossil fuels.

Water

Electrolysis requires plentiful water. In some locations in the world, this involves desalination of sea water. In Finland, where the per capita amount of freshwater is the second highest in the EU and where only 3% of the renewable freshwater is used every year, this step in the process is not needed.

Electricity grid capacity and flexibility

The Finnish electricity grid is comparatively strong and modern. However, it needs to more capacity in the future, and the national electricity transmission grid operator Fingrid plans to invest 4 B€ in it during 2024–2033. Distances are large in in Finland, and current usage of electricity mostly takes place in the south, with hydrogen usage mostly in the south and south-east. In contrast, much of the renewable energy, especially the wind power, is generated further north and in the west of the country.

Workforce

With a highly educated workforce and a fairly strong tradition in industrial use of hydrogen, many Finnish companies and their staff already now form part of a complete hydrogen value chain. This includes some of the energy intensive sectors predicted to be large adopters of hydrogen and to gain most added value from using it, such as steel and chemicals. Typically, these companies have already been taking steps towards working more sustainably.

However, as many developments in the hydrogen sector are coming up, many more experts will have to be trained. Universities have started offering additional courses in hydrogen-related themes for engineering students and for people currently active in the workforce. Considering the shrinking workforce, the hydrogen sector and related industries will have to compete for skilled employees with many other potential employers.

Waste heat utilization

In electrolysis, about a third of the electricity used turns into heat. This waste heat can be very efficiently utilized in Finland, both for industrial uses and in district heating which is the most common form of heating in the country. The ability to sell the waste heat is essential in the profitability of the process.

Political support

The EU's ambitious climate goals require large emission cuts by member countries, which encourages the move towards green energy production and use. Clean hydrogen could be a critical component in meeting ambitions such as the 14% renewable energy requirement in transportation fuels by 2030. Legislation and policies, and the green premiums resulting from these, are the main drivers for the growth of sustainable solutions. The profitability of new green solutions may also be enhanced by improved properties of the products or processes or from gaining a positive reputation from using them.

Finland also has its own national goal of carbon neutrality by 2035, which has been welcomed by industry actors as a commitment to a stable operational environment for years to come. Although this goal itself is vague, it signals a direction of travel which is important in projects where the planning and construction take years and the subsequent operations continue for decades.

As a more concrete step, the government adopted a resolution on hydrogen in February 2023, setting the goal to become the European leader in the hydrogen economy in the entire value chain. According to this resolution, Finland has the capacity to produce at least 10% of the EU's emissions-free hydrogen in 2030. In the June 2023 programme of the newly elected government, this aim was reaffirmed, with the additional goal of at least as much hydrogen being used within Finland by 2030. Finland has been a member of the European Clean Hydrogen Alliance since 2020.

For some foreign companies choosing to start their projects in Finland, the country's application for NATO membership in 2022 and subsequent joining of the alliance in 2023 have played a role in the decision. Belonging to the eurozone increases economic stability.

Current clean hydrogen projects in Finland

There are currently around 40 industrial scale clean hydrogen projects planned in Finland. In total, these amount to investments of almost 20 B€, when including steel processing projects. Only a handful are currently in the construction phase. Most are at the stages of planning, environmental permits, or looking for financing. It is thus unlikely that every one of these projects will eventually materialize.

On the other hand, other projects are likely to also be launched within the next few years, including expansions of currently planned plants.

Fuels

More than half of the planned projects are plants producing fuels for road and marine traffic. In most cases, the aim is to make synthetic methane from hydrogen and carbon dioxide (sourced from waste incinerators or other factories). Synthetic methane is chemically identical to the methane currently used as fuel. The second largest hydrogen consumer in Finland is forest industry company UPM, at its biofuel production plant in Lappeenranta.

The main actor in the field of clean hydrogen-based fuels is the company Nordic Ren-Gas, which has the backing of German insurance giant Allianz as well as Finnish billionaire businessman Ilkka Herlin. Nordic Ren-Gas aims to build a total of 10 plants in Finland by the year 2030. Construction of two of these, in the cities of Tampere and Lahti, will start during 2023 and be finalized in 2026, followed in 2024 by three other ones in Kotka, Pori, and Mikkeli. The total amount of the company's investments in the planned projects is 800 M€, and it counts on supplying about 20% of all the heavy road transport fuel used in Finland by 2030.

Other companies planning to build plants making fuels out of hydrogen are:

- ET Fuels, Ranua
- CPC Finland (the Finnish company is wholly owned by CPC Germania), Kristinestad
- Green North Energy, Naantali
- St1, Lappeenranta
- P2X Solutions, Joensuu, with an IPCEI grant
- Westenergy, Korsholm
- Vantaan Energia, Vantaa
- Keravan Energia, Kerava
- Helen, Helsinki

Electricity storage

The flexibility in the Finnish electricity network has traditionally been achieved by regulating the power production of hydropower and coal-fired condensing power plants. As most of the latter have been decommissioned, the need for other solutions grows. Wind, nuclear, and solar production methods are not easily adjusted according to changing hourly, daily, or seasonal needs.

Power-to-X is a general term for technologies involving conversion, storage, and reconversion of energy using different pathways and substances. The X can be, for example, hydrogen, ammonia, or methane. There are currently a few planned projects in Finland where hydrogen would be used primarily for the purpose of storing energy for future reconversion and use:

- EPV Energia and Vaasan sähkö, Vaasa, planned start in 2024
- Helen, Helsinki, Helsinki Hydrogen Hub pilot project planned for 2024

Replacing grey with green

The current largest producer and user of hydrogen in Finland is Neste, an oil refining company. Other users include the manufacture of fertilizers, processes in the chemical industry, metal processing, and mining. In 2020, approximately 145,000 tonnes of hydrogen was produced in Finland, corresponding to 5 TWh, which made up 1.5% of the total hydrogen produced in Europe. Ammonia has so far not been produced in Finland at all, only imported.

Many companies using grey hydrogen are currently planning to start replacing it with green hydrogen. STR Tecoil in Hamina already produces green hydrogen for its own use in regeneration of lubricant oil back to base oil. The company has plans to double or triple its capacity for producing green hydrogen. Neste has received an IPCEI grant and wants to reach an investment decision on a first 120 MW green hydrogen electrolyser in Porvoo in 2024, with production starting in 2026. Neste already has further unspecified green hydrogen plans for the future, as a single electrolyser would not cover its current usage.

The overwhelmingly largest green hydrogen project being planned in Finland so far is Norwegian Blastr Green Steel's 4 B€ green steel plant in Ingå. The project, launched in January 2023, is still in an early phase, but is scheduled to start operations in 2026. The industrial-scale project closest to completion is P2X Solution's 20 MW green hydrogen and synthetic methane plant in Harjavalta, which is scheduled to be operational in mid-2024. The company targets 1 GW of electrolysis capacity by 2031.

Other companies with planned projects for green hydrogen for industrial uses, either internal or customers' needs, include:

- Solvay Chemicals Finland, Kouvola, producing green hydrogen peroxide by 2028.
- SSAB and Fortum, Raahe, hydrogen for sponge iron production and fossil free steel.
- Flexens, Kokkola, 350 MW of green ammonia (for fertilizers) and hydrogen production by 2027.
- Green North Energy, Naantali, 280 MW of green ammonia and hydrogen production by 2026.
- Meriaura , Green North Energy and Wärtsilä planning to build a cargo vessel that runs on green ammonia. Wärtsilä builds the multifuel main engines, which Meriaura have ordered and will be operating as of 2024, and Green North Energy supplies the green ammonia as of 2026.
- Aurelia Turbines, Kokkola, developing gas turbines that can utilize hydrogen by 2026.
- Plug Power, Kokkola, green ammonia for fertilizers and export; Kristinestad, hydrogen for steel production; Porvoo, hydrogen for local mobility and export as of 2027.

Entirely new concepts

In some instances, hydrogen is proposed to be produced or used in ways not seen before:

- The startup Solar Foods, the third Finnish recipient of an IPCEI grant for hydrogen projects, is building its commercial scale factory of edible protein in Vantaa, scheduled to be in commercial production in early 2024. Hydrogen provides the energy for the microbes in the bioprocess producing a finished product with a macronutrient composition similar to that of dried soy or algae.

- Whereas most hydrogen producers plan to use water electrolysis, Hycamite is building a demonstration plant in Kokkola to use methane pyrolysis instead, for so-called "turquoise"

hydrogen. This technology would require only 13% of the energy compared to electrolysis, recover high-quality solid carbon, and be carbon neutral or even carbon negative, depending on the source of the methane. The technology could be utilized in locations where the supply of green electricity is insufficient for electrolysis plants. The demonstration plant is scheduled to begin operations in 2024.

Hycamite also has a project together with Wärtsilä whereby hydrogen will be produced from LNG on board ships, thus lowering the emissions and making high-grade solid carbon as a by-product. A prototype is planned for 2024.

Export

As recently as in 2020, the national trade and investment promotion agency Business Finland (in its National Hydrogen Roadmap for Finland, p. 31) did not foresee that the country could produce so much low-carbon hydrogen that it would be exported.

While many in the sector argue that hydrogen produced in Finland should preferably be processed further for added value, Finland is nevertheless involved in three cross-border hydrogen pipeline projects. These are spearheaded by Gasgrid Finland, which argues that the pipelines will be bi-directional, and that they will both strengthen security of supply and increase market liquidity. A diversified strategy of both exporting clean hydrogen and also creating industries utilizing it at home is recommended by the sector organization Hydrogen Cluster Finland in its strategy paper from 2023.

The three cross-border hydrogen pipeline projects being planned:

- The Nordic Hydrogen Route is planning to connect Finland to Sweden in the northern parts of the countries along the Bothnian Bay. The project was launched in 2022, and the first sections of the pipeline network are expected to be operational by 2030. A total of 1,000 km of dedicated hydrogen pipelines will serve 65 TWh of identified potential hydrogen demand by 2050. Besides hydrogen itself, different chemical derivatives such as methanol and ammonia for fuel and feedstock uses are also expected to be transported using this route.

Image source: https://nordichydrogenroute.com/wp-content/uploads/2022/04/Bothnia_Bay.png

- The Baltic Sea Hydrogen Collector will connect southern Finland to Sweden, Denmark, and Germany through an offshore pipeline that collects hydrogen from offshore wind projects at strategically selected energy islands. By creating a guaranteed route from production to use, the project aims to provide confidence to producers and users to invest in the new hydrogen value chain. Also this project is set to be operational by 2030.

Image source: https://gasgrid.fi/en/2022/12/16/major-milestone-in-transforming-european-energy-market-gas-transmission-system-operators-and-leading-renewable-energy-developers-investigate-possibility-to-develop-offshore-hydrogen-infrastructure-a/

- The Nordic Baltic Hydrogen Corridor is a cooperation between six countries: going from Finland through the three Baltic countries and Poland to Germany. A pre-feasibility study of this project is being made in 2023.

Image source: https://gasgrid.fi/en/2022/12/16/from-vision-to-action-six-partners-have-signed-a-cooperation-agreement-to-develop-nordic-baltic-hydrogen-corridor/

Clusters, sector organizations, and other actors in the market

Hydrogen Cluster Finland was set up in 2021, inspired by the EU's hydrogen strategy from 2020 and at the behest of the then minister for economic affairs. It is a network of companies and industrial associations that has grown from 30 to 70 members in various parts of the value chain, and has received public funding for several research projects.

BotH$_2$nia is a network of public and private operators interested in the hydrogen energy. Its objective is to create a Nordic hydrogen cluster around the Gulf of Bothnia. The network has 100+ members from several different countries.

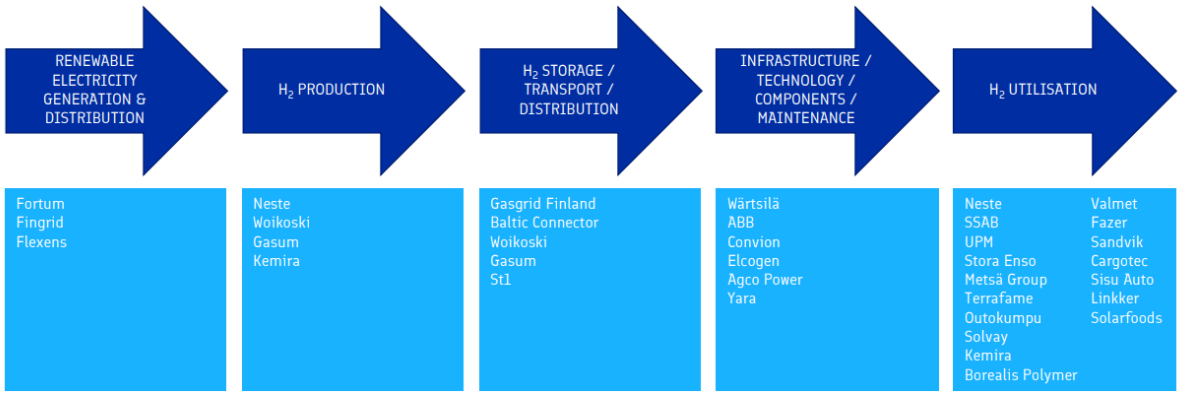
FinH$_2$ is a cooperative project between the Finnish state research institution VTT, LUT University, Aalto University, the Finnish trade and investment promotion agency Business Finland and 18 industrial partners that cover the whole hydrogen value chain. The aim is to generate novel, sector-coupled electrolyzer solutions, leading to new investments and increased business in international markets.

BalticSeaH2 is a largely EU-funded, five-year project involving 40 partners from nine Baltic Sea region countries. The large-scale, cross-border hydrogen valley focuses on the area between Finland and Estonia and will produce 25 demonstration and investment cases adding up to 4 B€ in total investments.

The **Confederation of Finnish Industries**, EK, collates most types of investment plans relating to the green transition in Finland into a map and a list: https://ek.fi/en/green-investments-in-finland/. Projects involving hydrogen and its derivates can be found by selecting *hydrogen* in the menu, and also only projects in a certain phase can be selected.

Gasgrid Finland is the gas transmission network company owned by the State of Finland, and is responsible for gas transmission within the country. It has also been mandated by the government to develop the cross-border hydrogen infrastructure outlined above.

Business Finland, in its National Hydrogen Roadmap for Finland, lists the following actors in the hydrogen economy, and describes the value chain as *well populated, but with a lot of space for new potential business opportunities*:



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