Pre-study on transition to hydrogen economy, specifically in Northern Ostrobothnia

Final report

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1. Objectives

1. Objectives

- This report is conducted by **VTT Technical Research Centre of Finland** and produced as part of the *National Hydrogen Network* and *R4H2 - REACTions for Hydrogen* projects managed by the **Raahe Region Development** and funded by the **Council of Oulu Region**
- The aim of the report is to support the regional actors to anticipate their future hydrogen-related business opportunities especially in Northern Ostrobothnia region, but also in the Finnish context
- The study is conducted by:
  - Summarizing existing information on hydrogen demand, use, infrastructure, and hydrogen related plans and projects
  - Compiling a snapshot of the existing and forthcoming political and regulatory framework in relation to hydrogen economy
  - Providing an overview of hydrogen production and utilization possibilities in Northern Ostrobothnia by mapping current and future wind power production and power grid capacities, regional CO_2 sources, and potential regional hydrogen users
  - Evaluating the potential hydrogen infrastructure alternatives in the region
  - Mapping current and potential actors for hydrogen economy in Northern Ostrobothnia
  - Evaluating the business-related drivers, barriers and suggestions for ramping up hydrogen economy in Northern Ostrobothnia
- The outcomes of this study can be used as a basis for a more detailed and in-depth analysis for hydrogen economy development in the Northern Ostrobothnia, but also in Finland

2. Introduction

2.1. Premise for hydrogen economy in Northern Ostrobothnia

- Northern Ostrobothnia has a long coastal line with potential locations for hydrogen hubs, such as Raahe and Oulu, where hydrogen production and use can take place in the same area [1]
- The region has suitable conditions for wind power and a lot of ongoing wind power projects in various stages, enabling the supply of low-cost electricity for hydrogen production
- The region has large point sources of CO_2 in pulp and paper and energy sector [2] that, with hydrogen, can be used for Power-to-X (P2X) processes to produce e.g., methane and methanol
- On-going Nordic Hydrogen Route –project [3] aiming to build a greenfield cross-border hydrogen pipeline network to Bothnia Bay region, partly on the coastline of Northern Ostrobothnia
  - Coastal area with ports for potential exports
- Potential large-scale hydrogen user in SSAB Raahe steel mill, when hydrogen-reduced iron will be adopted as the raw material
- Potential for sector coupling: excess heat from electrolysis can be utilized in district heating

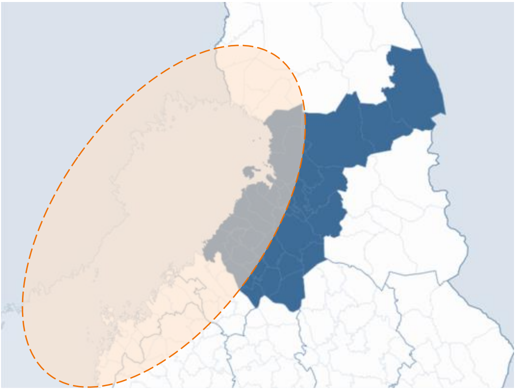


Figure 1. Location of Northern Ostrobothnia (blue) and Bothnia Bay (orange). Adapted from [4]

2.2. Previous studies (1/2)

- In the report **“Bothnian Bay Hydrogen Valley – Research report”** [5] Lappeenranta University of Technology (LUT) has analyzed the availability of local wind power resources in the Bothnian Bay area, including both Finnish and Swedish sides, to meet the increased electricity consumption from steel decarbonization and power-to-methanol systems
  - The conclusion of the study is that the wind availability is sufficient, but capacity additions are needed for both wind power plants and the power grid
- In a study **“Hydrogen study of Bay of Bothnia”** University of Oulu [1] mapped hydrogen related activities and plans of companies around the area of Bay of Bothnia and conduced a SWOT analysis to map strengths, weaknesses, opportunities, and threats related to hydrogen economy in the region
  - The conducted analysis is relevant for Northern Ostrobothnia as the industrial activities are concentrated on the coastal line of the Bothnia Bay
  - The SWOT analysis was conducted via a questionnaire and interviews aimed for regional actors and actors with strategic importance for the hydrogen economy in the region
  - The results of the SWOT analysis conduced by [1] are presented on the next slide

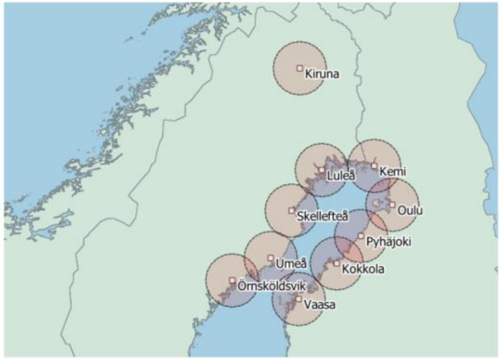


Figure 2. Studied area of the report by LUT [5].

Figure 3. Bothnia Bay: the area of SWOT analysis in [1].

2.2. Previous studies (2/2)

Strengths

- On-going hydrogen production in the Bothnia Bay area
- Opportunities in using hydrogen for fossil-free steel making
- Increase of regional wind power production and availability of low-carbon electricity for green hydrogen production
- Near-term grid expansions and improvements by Fingrid
- Safety issues related to hydrogen are technically solvable

Weaknesses

- Low current availability of green hydrogen
- No sufficient hydrogen transport and storage infrastructure: lack of large-scale storage facilities and no current transport infrastructure
- Large amounts of hydrogen not available for industrial-scale experiments yet

SWOT: hydrogen economy in the Bothnia Bay

Opportunities

- Hydrogen provides a pathway to reduce industrial CO_2 emissions
- Strong national and EU level political support
- Large companies have shown interest to hydrogen and have ongoing or planned R&D activities
- Sector integration opportunities with electrolysis by-products (oxygen, heat) and electricity storage opportunities via Power-to-X

Threats

- Uncertainties in EU regulation (unclear hydrogen classification and taxonomy)
- High production costs of green hydrogen in comparison to fossil-fuel based hydrogen
- Chicken-egg-problem hinders progress in hydrogen use, transport and storage: low green hydrogen production due to low demand and vice versa

Table 1. SWOT analysis for hydrogen economy in Bothnia Bay conducted by [1].

3. Hydrogen demand, use and infrastructure in Finland

3.1. Hydrogen production and use in Finland

[6]:

- Dedicated hydrogen production in Finland is estimated to be 145 kt/a (2020), from which 88% is used in oil refining and biofuel production (mainly in Neste Oyj's refinery in Porvoo and in UPM BioVerno production plant in Lappeenranta)
  - In addition, some of the dedicated hydrogen is used in chemical industry (7%) and in mining and ore refining (5%)
- Dedicated hydrogen is mainly produced via steam reformation of methane (SMR) (96%), but also partial oxidation (POX) of fossil fuels (3%) is used
  - Less than 1% of the dedicated hydrogen is produced via electrolysis
- 23 000 tonnes of by-product hydrogen is produced during sodium chloride (NaCl) electrolysis
  - By-product hydrogen is mainly used to generate process steam, district heat and some electricity
  - Few tonnes of by-product hydrogen from chlor-alkali electrolysis is also used to produced hydrogen chloride, sodium borohydride and sweeteners

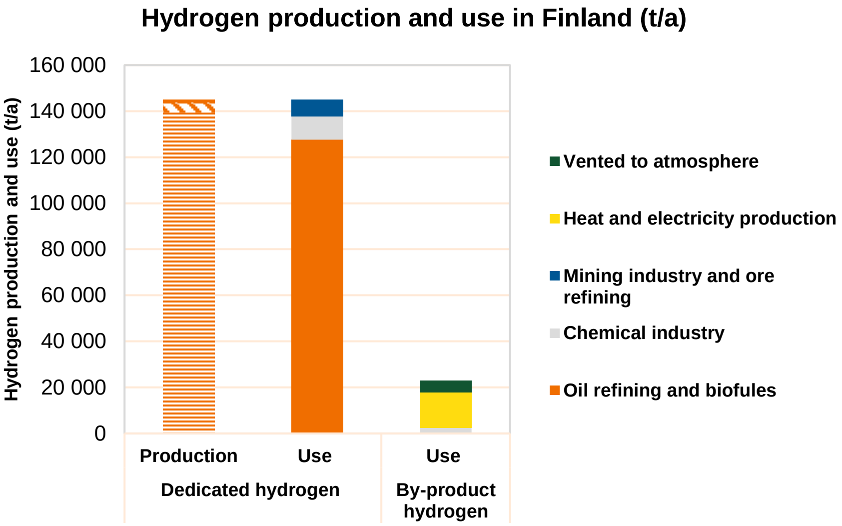


Figure 4. Hydrogen production and use in Finland (t/a) Adapted from [6].

3.2. Hydrogen production and use in Northern Ostrobothnia

- Most of the current hydrogen producers and users are located in the south and south-eastern part of Finland [6]
- Eastman Chemical Company, located in Oulu, produces hydrogen (~4 000 t/a) via partial oxidation [7]
  - Hydrogen delivered to Kemira Chemicals for hydrogen peroxide production
- Nouryon Chemicals Finland (former Akzo Nobel Finland), located in Oulu, produces by-product hydrogen (~2 200 t/a) in chlorine production [7]
  - Hydrogen used as a fuel in Stora Enso's lime kiln and in HCl production
- So far, the only plant producing hydrogen through electrolysis is Woikoski Ab, located in Kokkola, Central Ostrobothnia
  - The annual hydrogen output is estimated to be 1320 t/a and the hydrogen is mainly used by Freeport Cobalt in the reduction of cobalt [7]

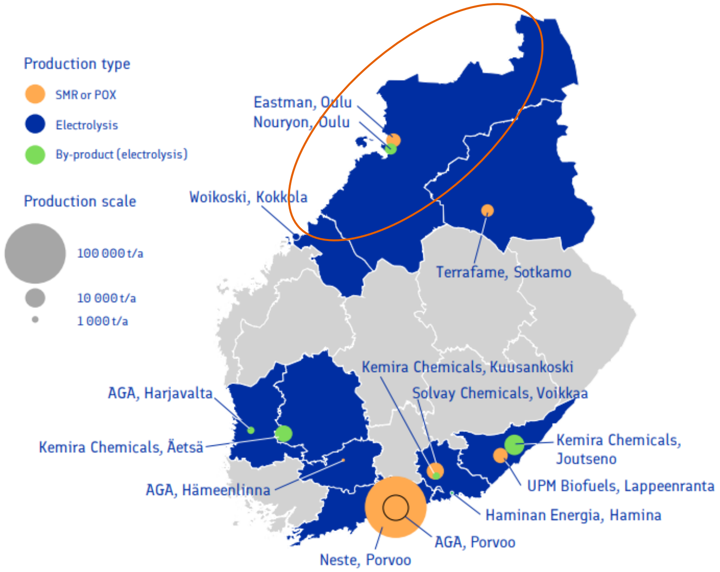


Figure 5. Locations, production technologies and capacities of hydrogen production plants in Finland [6]. Northern Ostrobothnia circled.

3.3. Existing hydrogen infrastructure in Finland

- Natural gas pipelines, operated by Gasgrid Finland Oy, the Finnish transmission system operator (TSO) for gas, are 1 150 km (high pressure) and 60 km (low pressure) in length and located in the south and south-east part of Finland [8]
- No national hydrogen transmission or distribution pipelines currently exist in Finland
  - Two dedicated hydrogen pipelines exist between industrial sites: from Borealis Polymers Oy to Neste Oyj (Porvoo) and Nouryon Chemicals Finland Oy to Stora Enso Oy (Oulu) [6]
- Gasgrid Finland has an ongoing project to build the first hydrogen pipeline outside an industrial site – the project received funding from EU's RRF funding instrument in February 2023 [9]
  - The first pipeline, approximately 15 km in length, is to be built between Kemira Oyj's Joutseno plant and Ovako's Imatra Oy Ab's steel mill in Imatra: the plan is to transmit by-product hydrogen from chemical industry to be used in steel industry
  - Gasgrid's on-going projects related to national and cross-border hydrogen pipeline infrastructure development (Nordic Hydrogen Route, Nordic-Baltic Hydrogen Corridor and Baltic Sea Hydrogen Collector) are presented later in the study
- P2X Solutions Oy announced to build hydrogen refueling stations to Harjavalta and Järvenpää by 2024 [10]
  - Woikoski Oy built two hydrogen refueling stations to Helsinki in 2014-2015, but the stations are no longer in use [11]

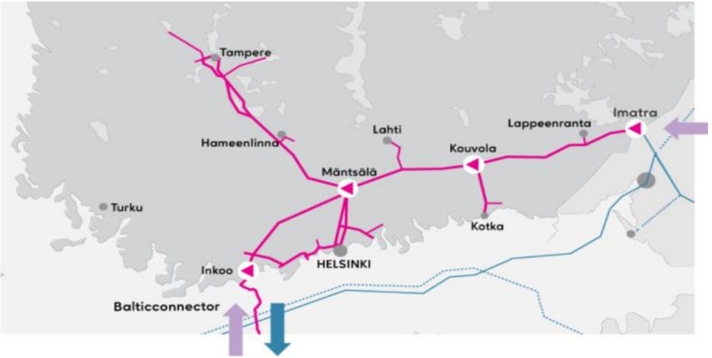


Figure 6. Existing natural gas pipeline in Finland [8].

Figure 7. Hydrogen refuelling station from Woikoski [11].

4. Plans and projects related to hydrogen economy

4.1. Hydrogen-related projects and plans in Finland

- Most of the hydrogen-related projects and investments in Finland are related to green hydrogen production with electrolyzers
  - The total capacity of new projected electrolyzers is >760 MW_{el} based on the publicly announced capacities
- All of the currently on-going projects at different stages are to be finished by 2030, but many of them already by 2025
- Most of the projects are located further south than Northern Ostrobothnia
- Currently on-going commercial hydrogen projects in and nearby Northern Ostrobothnia are:
  - Vierivoima project, Utajärvi (Skarta)
  - HYBRIT project, Raahe (SSAB, LKAB, Vattenfall)
  - Halla & Laine projects, Bothnia Bay (OX2)
  - Green hydrogen production and storage (Raahen Monivoima)
  - Green ammonia production, Kokkola (Flexens)
  - Methanol production, Ranua (ETFuels)
  - Hydrogen production by methane decomposition, Kokkola (Hycamite)
- List of current plans and projects related to hydrogen economy in Finland are presented on the next slides
  - In total 47 hydrogen related projects were identified in Finland
- On-going projects related to national and cross-border hydrogen pipeline projects are presented in detail later in the study

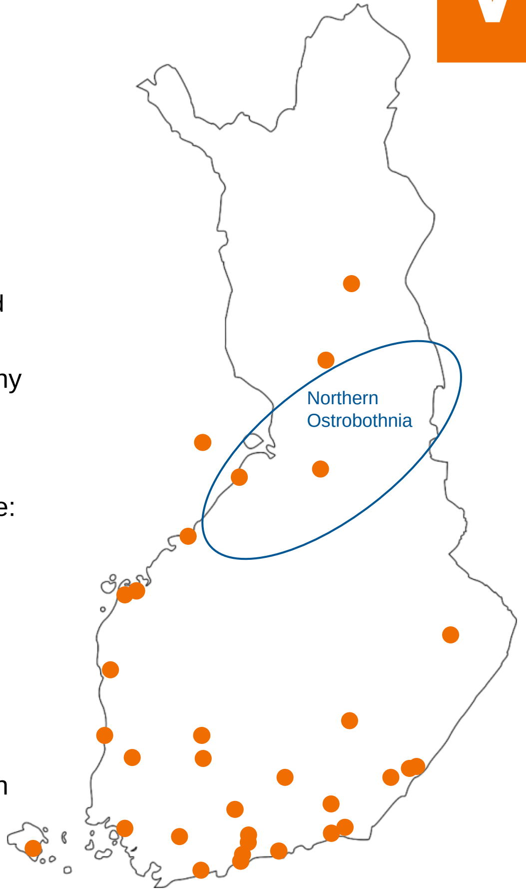


Figure 8. Locations of current plans and projects related to hydrogen economy in Finland.

Project phase explanations

Phase	Explanation
1	Concept study / letter of intent
2	Preliminary assessment
3	Pre-feasibility
4	Feasibility
5	Final investment decision
6	Under construction
7	In operation

- In case no public information of the project phase of an individual project was found, VTT estimated the project phase based on the best available public information
- Disclaimer: it is possible, that the project phases have changed in the course of conducting this study and hence the project phase information presented in the following slides should only be taken as indicative

4.2. Plans and projects related to hydrogen economy in Finland (1/6)

Companies	Location	Est. project time	Project phase	Value (MEur)	Capacity	H_2 production/use?	Intended H_2 use
Ren-Gas, Lahti Energia	Lahti	2023-2030	3-4	250	120 MW_{el}	Production & use	Gaseous heavy duty fuels
Ren-Gas, Tampereen Sähkölaitos	Tampere	2024-2026	3-4	150	60 MW_{el}	Production & use	Gaseous heavy duty fuels
Ren-Gas, Kotkan Energia	Kotka	2023-2030	3-4	100	40 MW_{el}	Production & use	Gaseous heavy duty fuels
Ren-Gas, Etelä-Savon Energia	Mikkeli	2024-2026	3-4	100	40 MW_{el}	Production & use	Gaseous heavy duty fuels
Ren-Gas, Porin Prosessivoima	Pori	2024-2026	3-4	n/a	20 MW_{el}	Production & use	Methanation
P2X Solutions	Harjavalta	2022-2024	6	50	20 MW_{el}	Production & use	Methanation
Neste	Porvoo	2025-	4	88[a]	50 MW_{el}	Production & use	Transportation fuels
P2X Solutions, Savon Voima	Joensuu	2022-2025	2	n/a	30-50 MW_{el}	Production & use	Transportation fuels

[a] = EU-grant

Data gathered from several public sources, such as companies webpages and [12], [13].

4.2. Plans and projects related to hydrogen economy in Finland (2/6)

Companies	Location	Est. project time	Project phase	Value (MEur)	Capacity	H_2 production/use?	Intended H_2 use
Vantaan Energia, Wärtsilä	Vantaa	2022-2025	2	85	10 $MW_{methane}$	Production & use	Synthetic methane
Green H2UB, Turun Seudun Energiantuotanto	Naantali	2023-2025	1	100	n/a	Production	Marine & heavy duty transportation
Keravan Energia, Q Power	Kerava	2021-2024	3	60	21 MW_{el}	Production & use	Methanation
EPV Energia, Wärtsilä, Vaasan Sähkö	Vaasa	2022-2024	3-4	35	4.3 MW_{H_2}	Production	Power-to-gas-to-power
SSAB, LKAB, Vattenfall	Raahe	2016-2026	4	2 000	n/a	Use	Steel production
Flexens, Elomatic	Åland	-2024	4	15	5 MW_{el}	Production & use	Fuel for ferries
National hydrogen clusters in Finland and Sweden (BotH2nia)	Gulf of Bothnia	2021-	-	-	-	-	Infrastructure for large use of H_2
Q Power, Lounais-Suomen jätehuolto	Salo	2020-	7	n/a	n/a	Use	H_2 for synthetic methane production

Data gathered from several public sources, such as companies' webpages and [12], [13].

4.2. Plans and projects related to hydrogen economy in Finland (3/6)

Companies	Location	Est. project time	Project phase	Value (MEur)	Capacity	H_2 production/use?	Intended H_2 use
Hycamite, Sweco	Kokkola	2022-	3-4	30	n/a	Production	H_2 production by methane decomposition
Woikoski, Neovolt	Kokkola	Finished in coming years	3-4	n/a	>9 MW_{el}	Production	Green H_2 to customers
Skarta Finland	Utajärvi	2021-	1-2	n/a	n/a	Production	Transportation
Green NortH2 Energy	Naantali	Finished in coming years	3-4	n/a	n/a	Production & use	Ammonia production
Gasgrid Finland, Kemira, Ovako	Joutseno, Imatra	2022-	2	n/a	n/a	-	13,5 km pipeline for H_2 transportation
Gasgrid Finland (Vetyverkko Oy)	Finland	-	-	-	-	-	Development of national H_2 network
OX2	Bothnian Bay	2021-	2 (for wind power)	-	-	Production	Industry
Raahen Monivoima, Kokkolan Energia	Kokkola, Raahe	2022-2024	3-4	5.8[b]	6 MW_{el}	Production	Industry

[b] = energy investment aid granted by the Ministry of Economic Affairs (TEM)

Data gathered from several public sources, such as companies' webpages and [12], [13].

4.2. Plans and projects related to hydrogen economy in Finland (4/6)

Companies	Location	Est. project time	Project phase	Value (MEur)	Capacity	H2 production/use?	Intended H_2 use
Fortum, Q Power	Riihimäki	2022-	7	n/a	n/a	Production & use	Methane and other product (e.g. plastic) production
St1	Lappeenranta	-2026	3-4	125	17 MW	Production & use	Methanol production
Hycamite, Jervois Finland	Kokkola	n/a	1	n/a	n/a	Use	Reduction of Cobalt
Gasgrid Finland, Nordion	Bothnian Bay region	2022-	-	-	-	-	Acceleration of the creation of a hydrogen economy
STR Tecoil	Hamina	n/a	7	n/a	n/a	Production & use	Sludge regeneration (plan for production increase)
UPM-Kymmene	Lappeenranta	n/a	2	n/a	n/a	Use	Biofuel production
Ilmatar Energy	n/a	n/a	3-4	35[c]	n/a	Production	n/a
P2X Solutions	n/a	n/a	3-4	67[c]	n/a	n/a	n/a

[c] = applied energy investment aid from the Ministry of Economic Affairs (TEM)

Data gathered from several public sources, such as companies' webpages and [12], [13].

4.2. Plans and projects related to hydrogen economy in Finland (5/6)

Companies	Location	Est. project time	Project phase	Value (MEur)	Capacity	H2 production/use?	Intended H_2 use
Solvay Chemicals	Kouvola	2020-2028	3-4	40	n/a	Production & use	Hydrogen peroxide production
Vataset Teollisuus	Kemijärvi	n/a	3-4	36[c]	n/a	n/a	n/a
Helen	Helsinki	-2024	3-4	6.0[c]	2 MW_{el}	Production & use	Heavy transportation vehicles, heat, electricity, stroaging
Kemira Chemicals	Joutseno	n/a	3-4	8.4[c]	n/a	n/a	n/a
Flexens, HydRe	Lempäälä	-2025	1	4.3[c]	2.5 MW_{el}	Production	Heavy transportation vehicles
P2X Solutions	n/a	n/a	3-4	12.2[c]	n/a	n/a	n/a
Koppö Energia	Kristiinankaupunki	-2025	3-4	450	200 MW_{el}	Production & use	Production of synthetic methane
Flexens	Kokkola	-2027	1	500	300 MW_{plant}	Production & use	Green ammonia production

[c] = applied for energy investment aid from the Ministry of Economic Affairs (TEM)

Data gathered from several public sources, such as companies' webpages and [12], [13].

4.2. Plans and projects related to hydrogen economy in Finland (6/6)

Companies	Location	Est. project time	Project phase	Value (MEur)	Capacity	H2 production/use?	Intended H_2 use
Blastr Green Steel	Inkoo	-2026	1	4 000	2.5M t_{steel}	Production & use	Fossil-free steel production
ETFuels	Ranua	n/a	1	800	n/a	Production & use	Methanol production
Fortum	Inkoo	n/a	1	n/a	n/a	Production & use	Green ammonia production
Westenergy	Mustasaari	-2025	3-4	90	7300 t_{LSNG}	Production & use	Production of liquid synthetic methane (LSNG)
Solar Foods	Vantaa	-2023	6	40	n/a	Production & use	For protein in food production
P2X Solutions	Järvenpää	-2024	3-4	0.8[d]	n/a	Use	Hydrogen refuelling station
Neste	Porvoo	2023-2025	4	28[a]	120 MW_{el}	Production	Replacement of gray H_2

[d] = grant from the Finnish Energy Authority
[a] = EU-grant

Data gathered from several public sources, such as companies' webpages and [12], [13].

5. Snapshot of hydrogen-related policies and regulations

5.1. EU's ongoing plans for hydrogen

- **The Renewable Energy Directive (RED3) is one of the most important hydrogen-related regulations**
  - RED3 + DAs* determine the criteria for renewable hydrogen and renewable fuel of non-biological origin (RFNBO) production (criteria for electricity production and the maximum carbon footprint of H2/RFNBO use and allowed CO_2 sources)
  - Transport: binding renewable H_2 and RFNBO shares
  - Industry: binding share for RFNBOs in industry (50% of the fossil hydrogen replaced by RFNBOs by 2030, 70% by 2035, exact values still negotiated)

- Other important regulations include
  - **Carbon border adjustment mechanism (CBAM)** and **Emission Trading System (EU ETS)**
    - **CBAM:** importers outside of EU have to buy certificates to cover for emissions (includes hydrogen)
    - **ETS:** renewable hydrogen and larger hydrogen plants going to included, free allowances phased out in the future
  - **Alternative Fuel Infrastructure Regulation (AFIR)**
    - Defines the required amount of H_2 refuelling stations for liquid and gaseous hydrogen
  - **Distribution obligations of renewable fuels**
    - EU has plans to introduce distribution obligations for renewable fuels in aviation and maritime
    - *Finnish legislation already includes a renewable fuel distribution obligation with RFNBOs included*

- More information of the hydrogen-related policies and regulations in Appendix 1. Hydrogen-related politics & regulations

*DA = Delegated Act (Currectly 2 delegated acts introduced to complement the RED, DA on additionality and DA on methodology, status 2/2023)

5.2. Future regarding regulation of hydrogen

- **What is going to be counted as renewable hydrogen?** (information about the delegated acts)
- *Delegated Act on Additionality* determines when electricity for electrolysis is counted as renewable
  - Grid electricity is counted as "fully" renewable in the following cases:
    1. If >90% renewable energy sources (RES) in grid and full load hours of the electrolyser are less than this %
    2. Grid emission intensity of <18gCO2e/MJ (64.8 g/kWh) with power purchase agreement (PPA) and temporal and geographical correlations are complied with
    3. PPA present and complied with the additionality, temporal and geographical correlations, or
    4. imbalance settlement when RES are redispatched downwards (e.g. curtailment) and RFNBO production prevents this
  - Electricity from a direct RES installation is counted as renewable if it starts operation no earlier than 36 months before the RFNBO production
  - *In general, Additionality is complied with if power production has a renewable PPA with new production (max. 36 months older than the RFNBO production, temporal correlation requires the electricity and hydrogen to be produced within the same month before 2030 and within the same hour since 2030, geographical correlation requires the electrolyser and the power installation to be located within the same bidding zone or an interconnected one in the case of offshore wind power*
- Methodology delegated act
  - A maximum CO_2 footprint of renewable hydrogen use (3,38 tCO2eq/tH2) defined in the DA of methodology)
  - **The CO_2 for RFNBO production cannot be fossil starting from 2035** (methodology DA) – only direct air capture, CO_2 captured from the production or combustion of biomass, -fuels and -liquids, CO_2 released naturally from a geological source, or CO_2 incorporated fuels produced from sources within ETS before 2036
  - Includes calculation rules of GHG emission savings of RFNBOs and the GHG emission intensity of electricity

DA = Delegated Act

6. Setting the scene for hydrogen economy in Northern Ostrobothnia

6.1. Electricity production in Northern Ostrobothnia

- Total electricity production in Northern Ostrobothnia was 8 549 GWh in 2021 [14]
  - Total electricity production in Finland was 69 010 GWh
  - Northern Ostrobothnia's share of the total electricity production in Finland was 12.4%

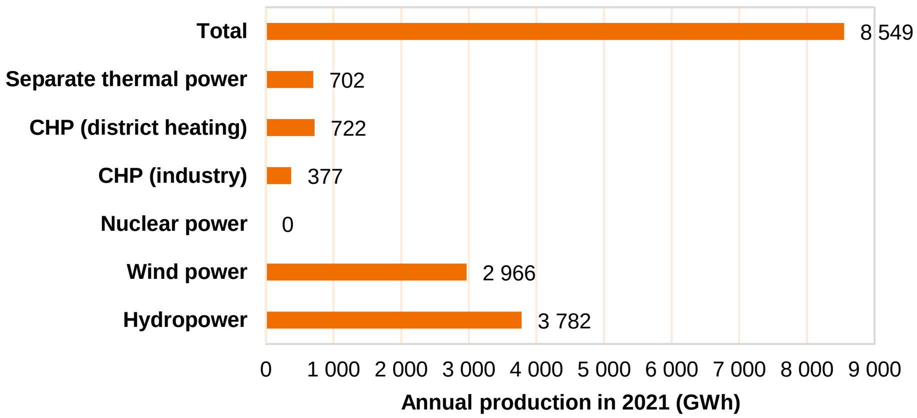


Figure 9. Electricity production (GWh) in Northern Ostrobothnia in 2021. Adapted from [14].

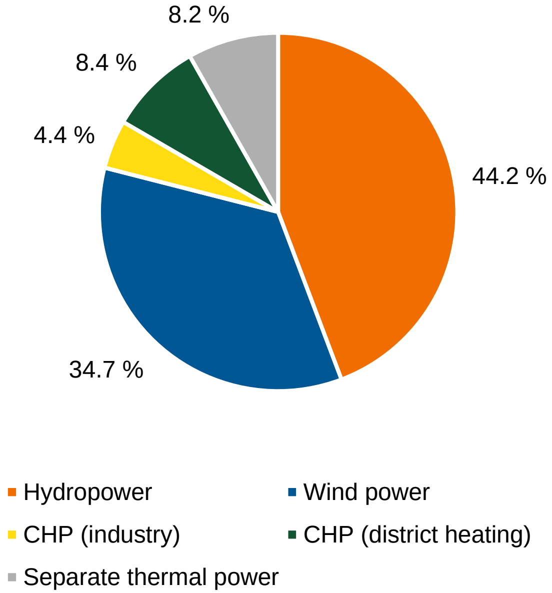


Figure 10. Technology shares of electricity production (GWh) in Northern Ostrobothnia in 2021. Adapted from [14].

6.2. Recent trends in electricity production in Northern Ostrobothnia

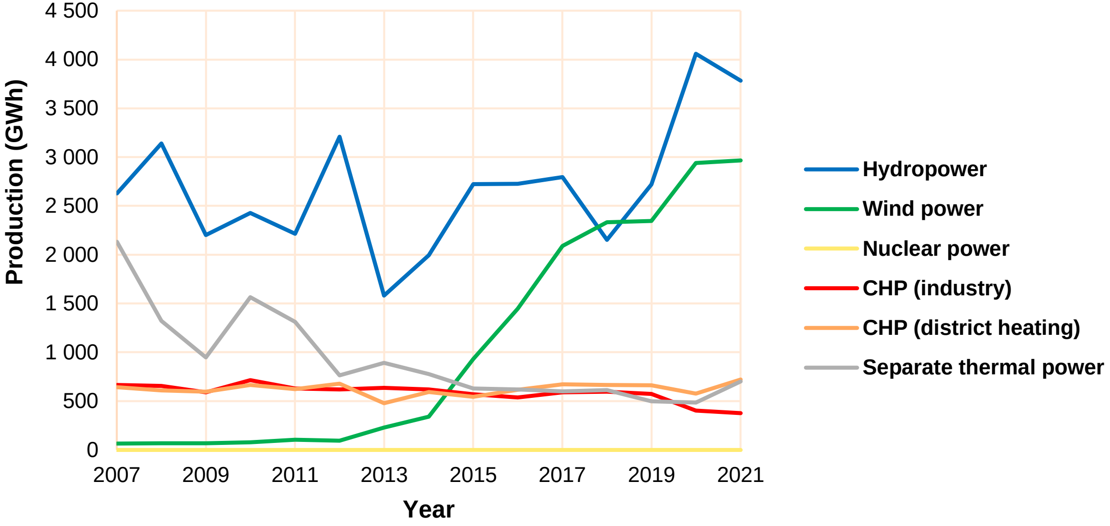


Figure 11. Electricity production in Northern Ostrobothnia by production technology between 2007-2021. Adapted from [14].

- Wind power capacity has grown significantly in Northern Ostrobothnia during the last decade [14]
- When considering other renewable energy technologies, solar PV capacity is likely to grow in Northern Ostrobothnia
- Construction of new hydropower plants is unlikely in Finland due to environmental reasons [15]
  - No >1 MW hydropower plants have been built in Northern Ostrobothnia since 1970

6.3. Estimating future wind power capacity in Northern Ostrobothnia (1/2)

- Current wind power capacity in Northern Ostrobothnia is approximately **2.3 GW** while the regional capacity currently under construction is approximately **0.8 GW**, that is to be completed in 2023-2025 [16]
- The maximum capacity of the planned wind power projects in the region by 2030 is **30 GW** [16, 17] including all regional on-going wind power projects in different stages
  - Planned maximum onshore and offshore wind power capacities are **25.3 GW** and **4.7 GW**, respectively
  - The offshore wind power projects in the sea area near Northern Ostrobothnia are accounted as projects in the region
  - The public plans do not cover the timeframe from 2040 and beyond
- The total planned wind power capacity estimate of 30 GW assumes, that all the planned onshore wind power projects reported by the Finnish Wind Power Association (FWPA) are commissioned on their maximum capacity
  - The actual capacity by which each individual wind power park will be commissioned depends on several factors, e.g., on the results of Environmental Impact Assessment
- It should also be noted that solar PV production is increasing in Finland, and can even out the seasonality of wind power for hydrogen production in the future
  - However, solar PV is outside of the scope of this study as comprehensive data from planned solar PV projects, similar to wind power, was not available

Project phase	Number
Identificated project / pre-design	55
Zoning started	19
EIA ongoing / zone draft	20
EIA done / zone proposal	4
Zoning done	11
Approved	21
Under construction	8
Total	**139**

Table 2. Project phase of on-going onshore and offshore wind power projects in Northern Ostrobothnia. Based on [16] and [17].

6.3. Estimating future wind power capacity in Northern Ostrobothnia (2/2)

- Table 3 below presents estimates for additional wind power production in Northern Ostrobothnia by 2030
  - The estimates are evaluated so that the wind power projects currently in different planning stages will be completed a) at their maximum capacity and b) at half of their maximum capacity
  - Capacity factors of 33% and 40% were used for onshore and offshore wind power plants, respectively, to convert capacity estimates (GW) to production estimates (TWh/a)
  - Onshore capacities are based on wind power projects reported by Finnish Wind Power Association (FWPA) [16] and the offshore capacities (projects Halla 4 GW, Suurhiekka 0.4 GW and Maanahkiainen 0.3 GW) are based on information available at Fingrid Oyj's Grid Scope map [17]

Table 3. Current and future estimates for additional wind power production in Northern Ostrobothnia by 2030. Capacities are based on [16] and [17].

Year	Onshore wind power capacity (GW)	Offshore wind power capacity (GW)	Capacity factor (onshore)	Capacity factor (offshore)	Production, onshore (TWh/a)	Production, offshore (TWh/a)	Production (TWh/a)
Current	2.3	0	33%	40%	6.7	0	**6.7**
Additional production in 2030 (max)	**25.3**	**4.7**	33%	40%	73.1	16.5	**89.6 (total: 6.7 + 89.6 = 96.3)**
Additional production in 2030 (half)	**12.7**	**2.4**	33%	40%	36.7	8.3	**45.0 (total: 6.7 + 45.0 = 51.7)**

Maximum capacity of planned wind power projects by municipality in Northern Ostrobothnia (1/2)

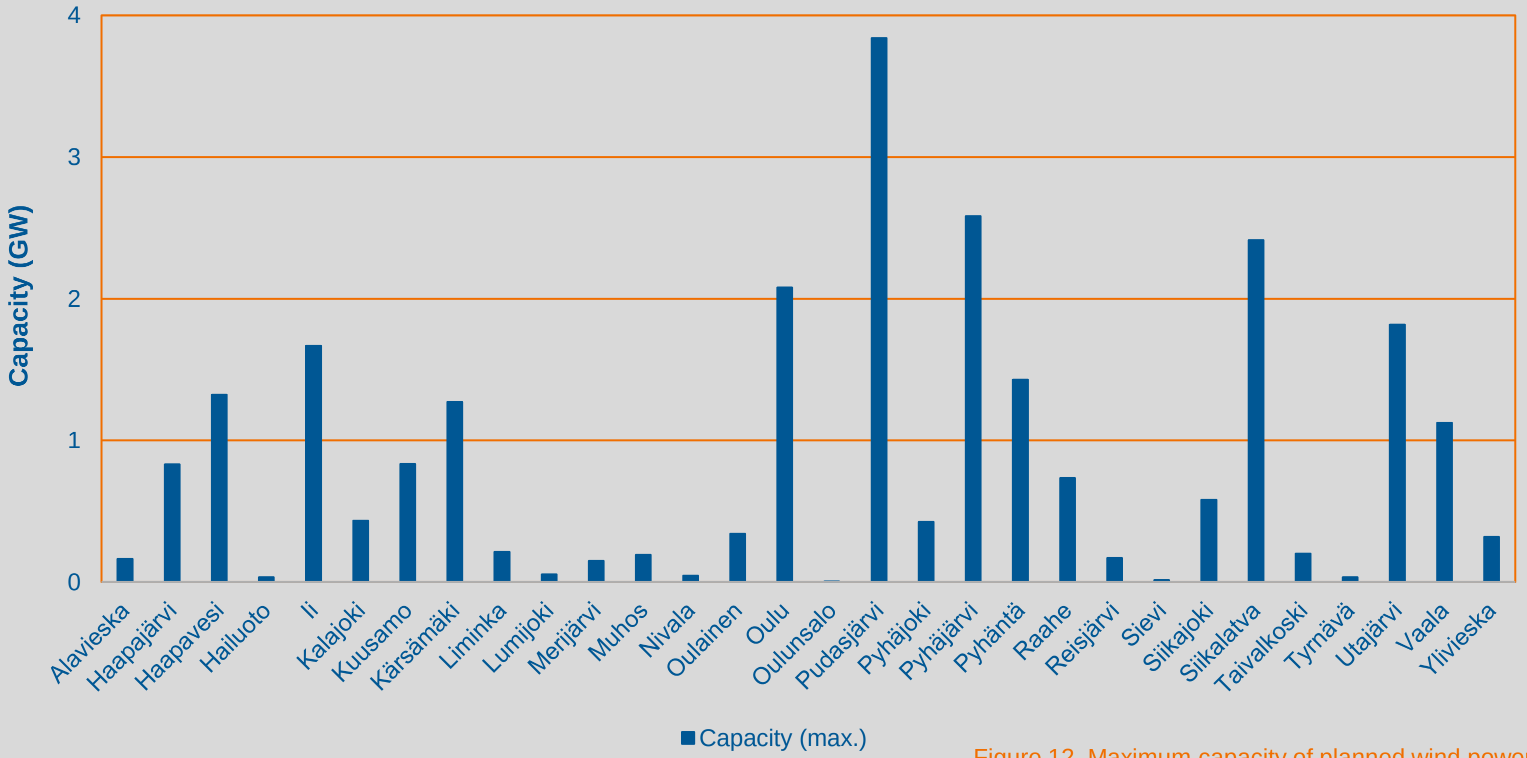


Figure 12. Maximum capacity of planned wind power projects by municipality in Northern Ostrobothnia. Includes the onshore turbines. Data from [16].

Maximum capacity of planned wind power projects by municipality in Northern Ostrobothnia (2/2)

- Municipalities with largest volume of planned wind power in terms of capacity (GW):
  1. Pudasjärvi
  2. Pyhäjärvi
  3. Oulu

Total capacities:

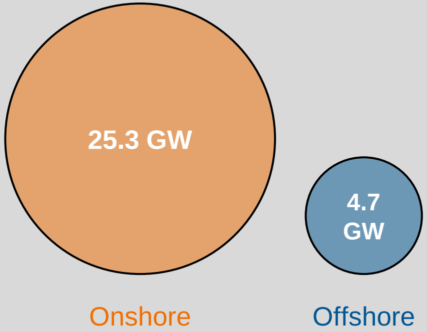
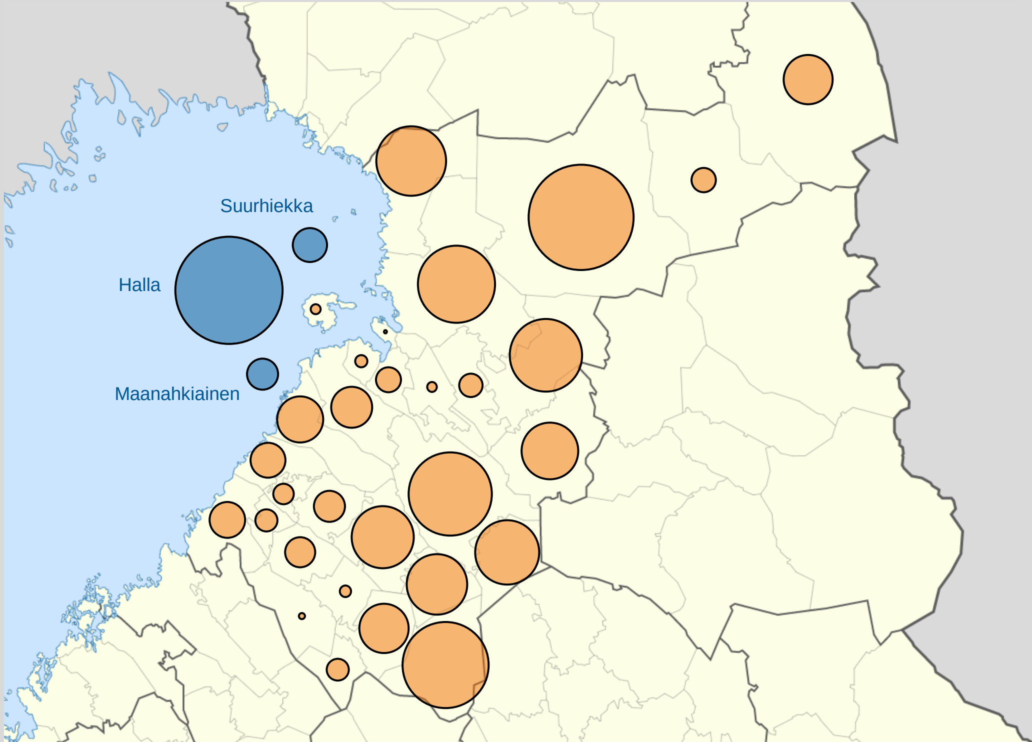


Figure 13: Maximum capacities of planned on- and offshore wind power projects in Northern Ostrobothnia. Data from [16] and [17].

The circles present the relative size of planned maximum wind power capacities by municipality.



Wind power in Finland

- Current wind power capacity in Finland is ~**5.7** GW [16]
  - Current wind power capacity in Northern Ostrobothnia is ~2.3 GW
- Based on the report of planned wind power projects by the Finnish Wind Power Association (FWPA), the maximum capacity of planned wind power in Finland is ~**66** GW (11/2022) [16]
  - A large share of the planned wind power capacity in Finland is located in Northern Ostrobothnia, as the maximum planned wind power capacity in the region is ~30 GW [16,17], however, this includes some offshore wind parks, that are not included in the FWPA's report
- For comparison, the current wind power capacity in Sweden is ~12.1 GW (2021) [18]
  - Wind power capacity in Northern Sweden (price area SE1) is ~1.9 GW [18]
  - Wind capacity estimation in 2030 in SE1 is ~7.2 GW [19]

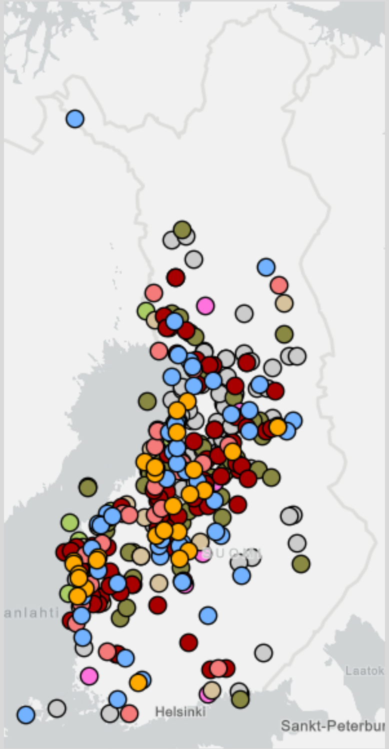
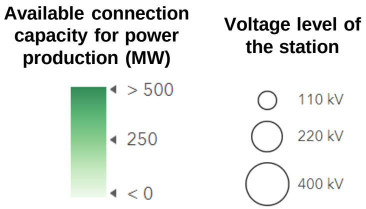


Figure 14. Planned wind power projects in Finland. Includes all wind power projects in different project phases (wind power parks in production excluded). Source: [20]

6.4. Connection capacity in Northern Ostrobothnia (1/2)



- Connection capacity defines the amount of additional power production that can be connected to the power grid
- The estimates for available connection capacity to Fingrid's main grid in Northern Ostrobothnia were evaluated by using Fingrid's Grid Scope map [17] and are (2/2023):

2023	2030
2.15 GW	6.33 GW

Table 4. Connection capacities to Fingrid's main grid in Northern Ostrobothnia in 2023 and 2030.

- The connection capacity is limited if the projected wind power plants in Northern Ostrobothnia (up to 30 GW by 2030) are connected to the main grid
- Based on the Grid Scope map, there is no planned (2030) grid connection capacity to the main grid in Northeast part of Northern Ostrobothnia
  - This can be a possible a constraint for additional wind power investments in the region

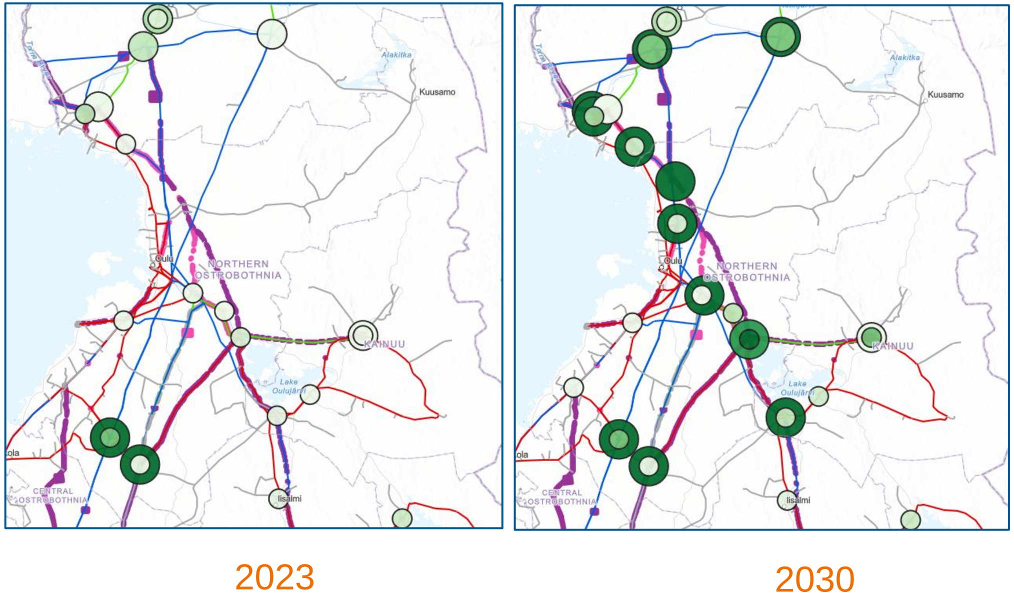


Figure 15: Available connection capacity to Fingrid's main grid in 2023 and 2030 [17].

6.4. Connection capacity in Northern Ostrobothnia (2/2)

- Connection capacity to private power grids in Northern Ostrobothnia has been studied earlier in TUULI-project, which studied sustainable construction of wind power plants in the region [21]
  - During the TUULI-project, local distribution network operators were interviewed to evaluate the available connection capacity to private grids
  - The study was completed in 12/2021 and thus the data may be partly outdated
- Based on Figure 16 [21], available connection capacity to privately operated grids and the main grid in the region was ~ 4 GW in 2021 from which ~ 0.33 GW is assumed to be from privately operated grids
- As mentioned in the previous slide, based on Fingrid's Grid Scope map [17], there are no plans related to strengthening Fingrid's main grid in the northeast part of Northern Ostrobothnia
  - As can be seen from Figure 16, only one private power grid (110 kV) is operated in the region (Caruna Networks Oy)
  - The capacity of the grid is already fully sold, and hence, based on the map, there is no available connection capacity to private grids in Kuusamo, Taivalkoski or Pudasjärvi
  - To point out, Pudasjärvi is the municipality in Northern Ostrobothnia with largest volume of planned wind power in terms of capacity (GW)

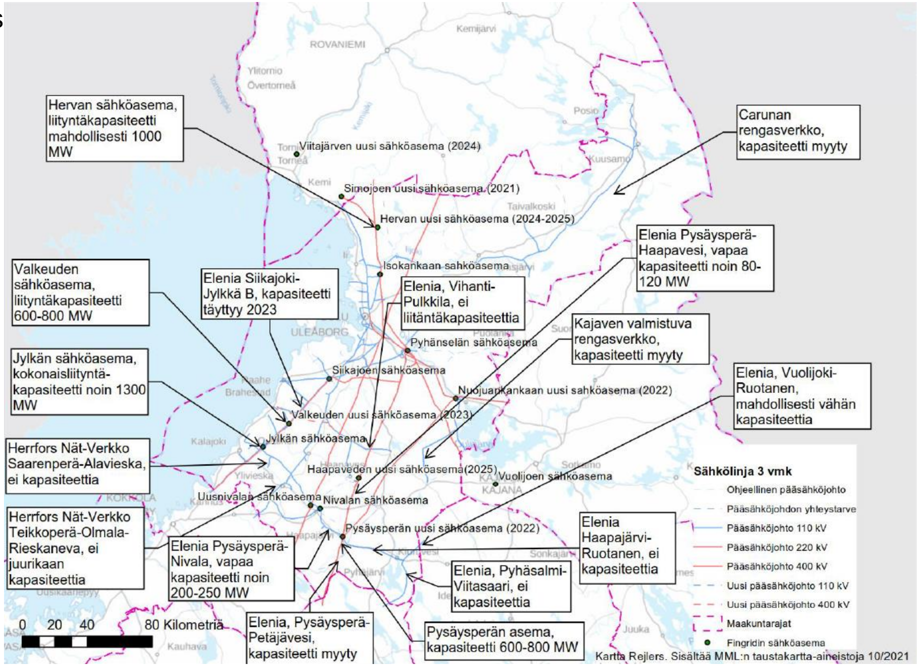


Figure 16: Status of grid connection in privately operated grids in Northern Ostrobothnia [21].

National grid development plans

- As seen from Figure 17, available grid connection capacity is currently (2022) concentrated to southern Finland, but by 2030, the connection capacity is planned to increase especially in the coastline of the Bothnia Bay [17]
  - This is also the location, where a great share of the planned wind power projects are located [20]
  - Updated information of the planned main grid connection capacities in Finland can be seen from Fingrid's Grid Scope map
- In addition to Fingrid's main grid, there may also be available access capacity in the private local distribution networks
- Fingrid has also published a Network vision [22] to examine the development needs of the main grid to match the long-term electricity production and consumption plans via different scenarios
  - In all examined scenarios, the north-south electricity transmission demand in Finland will increase significantly
- An overview of the grid development needs is presented in Figure 18, in which the blue lines present likely needed additional connection capacity and the purple lines represent capacity needs that are partially alternatives and depend on the future needs

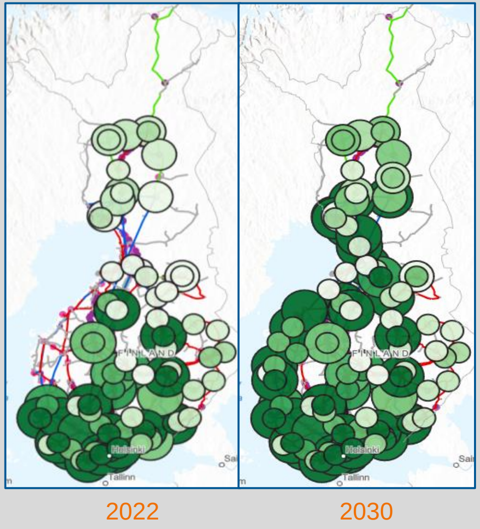


Figure 17. Fingrid's available grid connection points in Finland. Source [17].

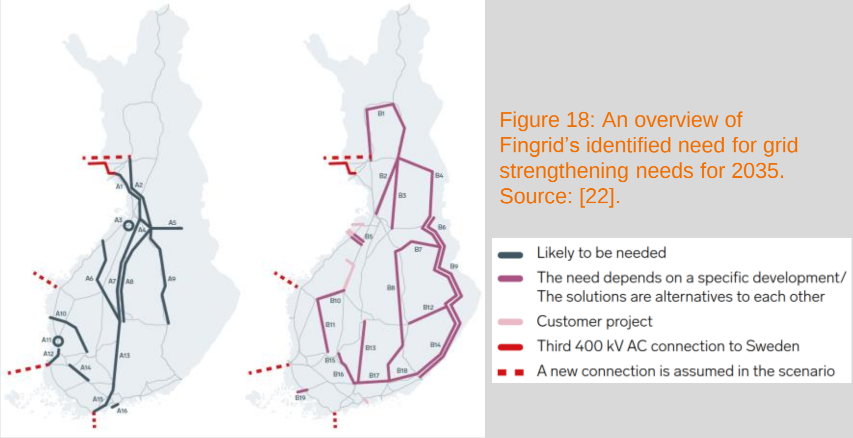
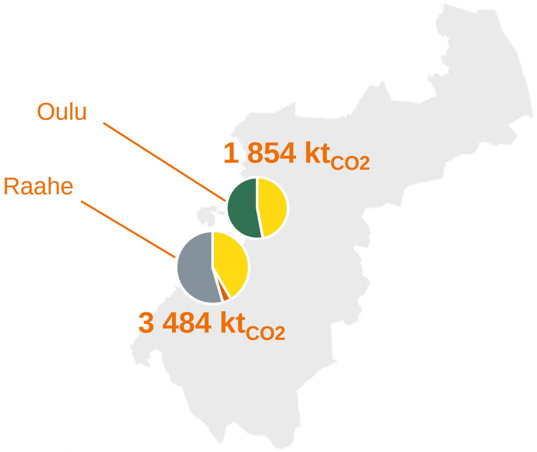
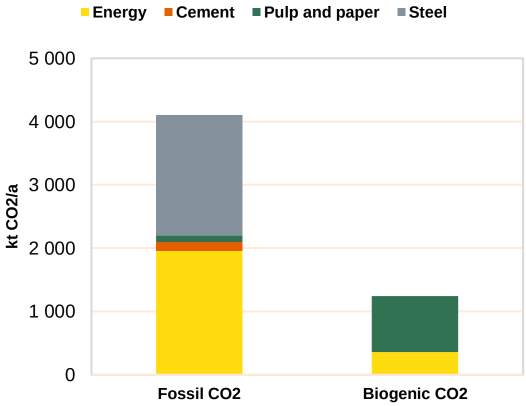


Figure 18: An overview of Fingrid's identified need for grid strengthening needs for 2035. Source: [22].

6.5. Main CO_2 sources in Northern Ostrobothnia (1/2)

- A potential field for industrial hydrogen utilization is P2X production (e.g., methane, methanol and ammonia production)
  - In addition to availability of low-cost hydrogen, availability of low-cost point source CO_2 streams is an important parameter when choosing the most promising location for P2X production
- Main point sources and quantities of available CO_2 in Northern Ostrobothnia are derived from the E-PRTR database [2]
  - Also, smaller point sources of CO_2 exist in the region, that are not reported in the E-PRTR database, related to e.g., power and heat production and biogas production
- Based on public E-PRTR data from 2020 [2], the largest point source CO_2 emitters in the region are: SSAB Europe Oy steel factory and energy producer Raahen Voima Oy in Raahe, Stora Enso Oyj's pulp and paper mill, and energy production plants of Oulun Energia Oy in Oulu
  - Main CO_2 sources in Northern Ostrobothnia are presented on the next slide





Figures 19 and 20. Main CO_2 sources in Northern Ostrobothnia. Adapted from [2].

6.5. Main CO_2 sources in Northern Ostrobothnia (2/2)

Company	Location	Sector	Fossil CO_2 (kt_{CO2})	Biogenic CO_2 (kt_{CO2})	All CO_2 (kt_{CO2})	Comments
SSAB Europe Oy	Raahe	Steel	1 900	0	**1 900**	Decarbonized in 2030s [23]
Raahen Voima Oy	Raahe	Energy	1 450	0	**1 450**	
Stora Enso Oulu Oy	Oulu	Pulp and paper	101	881	**982**	
Oulun Energia Oy, Toppila power plant	Oulu	Energy	348	259	**607**	To be decommissioned in 2030s [24]
Oulun Energia Oy, Laanila biopower plant	Oulu	Energy	24	521	**545**	Commissioned in 2020, was not included in [2]. Own estimate based on 215 MW capacity, with 70% wood and 30% SRF fuels [24] and 8000 h of total operating hours
Laanilan Voima Oy	Oulu	Energy	100	36	**136**	Decommissioned in 2021 [25]
Nordkalk Oyj Abp	Raahe	Cement	134	0	**134**	
Oulun Energia Oy, Laanila ecopower plant (WtE)	Oulu	Energy	65	64	**129**	

Table 5. Main CO_2 sources in Northern Ostrobothnia. Adapted from [2].

7. Evaluating hydrogen production potential in Northern Ostrobothnia

7.1. Scope and methodology

- Hydrogen production and demand potentials are evaluated for Northern Ostrobothnia
- Hydrogen production potential is based on the planned onshore and offshore wind power projects in the region (Table 3.)
  - Other forms of electricity production are outside the scope of this study
- Various simplifications are made to evaluate the hydrogen production in the region
  - For instance, it is assumed that all planned wind power projects in the region are completed at their maximum capacity, which is not the most probable outcome: the actual capacity of each wind power project is affected by several factors, e.g., the Environmental Impact Assessment and available grid connection capacity
  - It is also assumed that hydrogen is produced by electrolyzer at all times, when there is available excess wind power: in reality, the operation of the electrolyzers is expected to be optimized based on multiple factors, e.g., the electricity spot price
- Several assumptions are also used to evaluate the regional hydrogen demand
  - It is assumed that all CO_2 from selected industrial plants is utilized in P2X processes
    - In reality, it is possible that instead of the total amount of emitted CO_2 , only a selected fraction of the emissions of an industrial plant is utilized in P2X
  - The focus is on the industrial hydrogen demand: transport sector is outside the scope of this study
- Both hydrogen production and demand potentials are highly speculative, but are estimated to illustrate future opportunities and key parameters in the region
  - The estimated parameters related to hydrogen production and demand should only be taken as assumptions for indicative potentials that can be used as a starting point for further research

7.2. Hydrogen production potential in 2025 in Northern Ostrobothnia

- The estimated wind capacity (**3.1 GW**) was evaluated based on wind capacity currently in operation (2.3 GW) and under construction (0.8 GW) [16]
- The electricity consumption (5.9 TWh) is based on electricity consumption in Northern Ostrobothnia in 2021 [14]
  - Includes electricity consumption housing, agriculture, industry, service and buildings
- After electrolyzer losses (70% efficiency), the net hydrogen potential in the region is **2.1 TWh/a** or **62 kt/a** of hydrogen
  - To compare, the current hydrogen use in the region is approximately 6.2 kt/a [7]

1 TWh H_2 = 0.03 MtH_2
Capacity factors: onshore: 33%, offshore: 40%

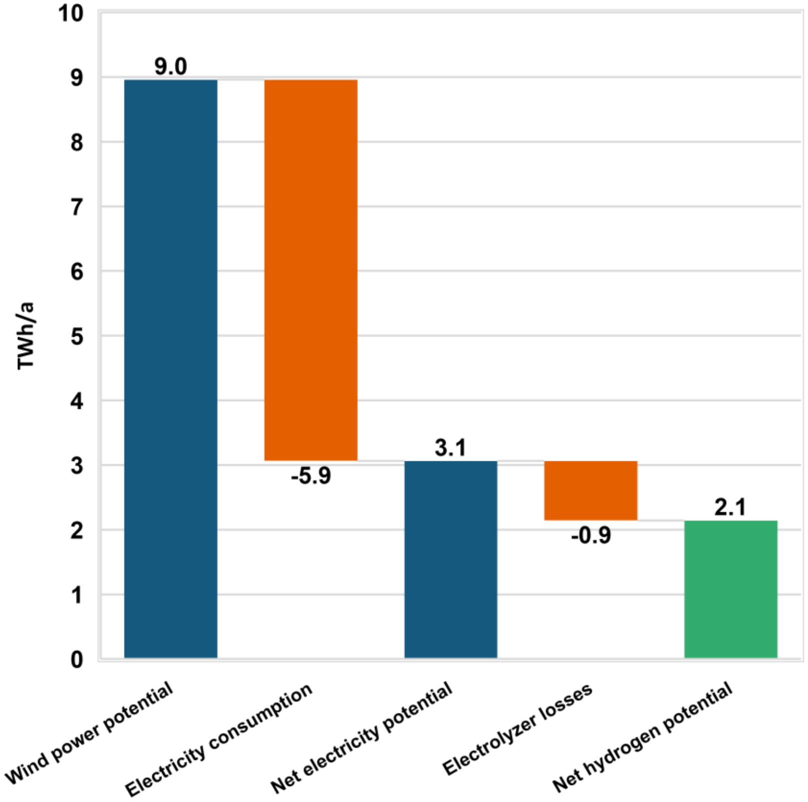


Figure 21. Net hydrogen potential in 2025 in Northern Ostrobothnia.

7.3. Hydrogen production potential in 2035 - Maximum wind capacity

- The estimated wind power capacity (**32.3 GW**) in Northern Ostrobothnia is based on the existing wind power capacity (**2.3 GW**) and to the assumption that all the planned wind power projects currently in different planning stages (**30 GW**) are completed at their **maximum capacity**
  - While the assumption in question may not be the most probable, it is used to evaluate different possibilities
  - It is assumed that there is enough grid capacity to meet the demand
- The regional electricity consumption was evaluated so that additional electricity demand was added to the estimate of the current regional electricity consumption (5.9 TWh) [14]:
  - 0.6 TWh/a from electric vehicles assuming that 75% of passenger cars are electric by 2035 (13 600 km/a [26] and 20 kWh/100 km [27])
  - Additional 2 TWh/a consumption from electric furnaces at SSAB Europe Oy Raahe steel mill [28]
  - It is expected that there will be further electrification e.g., in industry and heating, however, this possibility is not considered within the scope of this study
- After regional electricity consumption and electrolyzer losses (70 % efficiency), the net hydrogen potential in the region is approximately **61.5 TWh/a** and **1.8 Mt/a** assuming that all the net electricity potential is converted to hydrogen

1 TWh H_2 = 0.03 MtH_2
Capacity factors: onshore: 33%, offshore: 40%

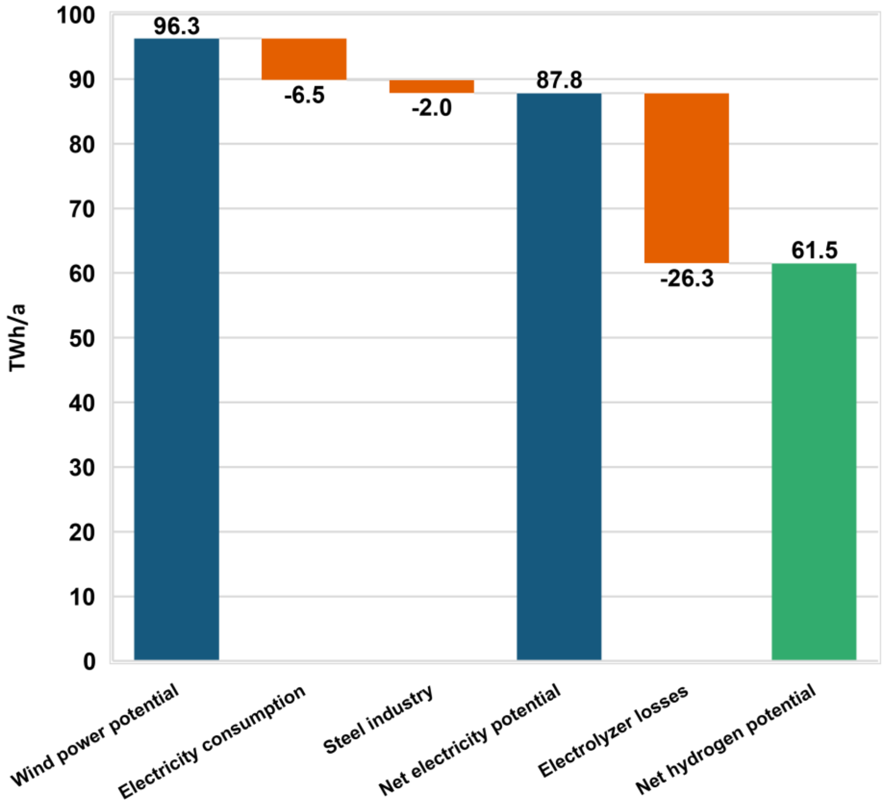


Figure 22. Net hydrogen potential in 2035 in Northern Ostrobothnia with maximum projected wind power capacity.

7.3. Hydrogen production potential in 2035 - Half of the maximum wind capacity

VTT

- A sensitivity analysis was conducted, where total wind power capacity in Northern Ostrobothnia is **17.3 GW**
  - In this assumption the existing wind power capacity (**2.3 GW**) is combined with the assumption that all the planned wind power projects (**30 GW**) are completed with **half of their planned maximum capacity**
  - It was assumed that there is enough grid capacity to meet the demand
- The regional electricity consumption was evaluated with the same assumptions as in the previous slide
- After electrolyzer losses (70% efficiency), the net hydrogen potential in the region is **30.3 TWh/a and 0.9 Mt/a** assuming that all the net electricity potential is converted to hydrogen
  - To compare, the estimated amount of hydrogen needed for iron reduction in SSAB Europe Oy Raahe steel mill is approximately 150 kt/a [1]

1 TWh H_2 = 0.03 MtH_2
Capacity factors: onshore: 33%, offshore: 40%

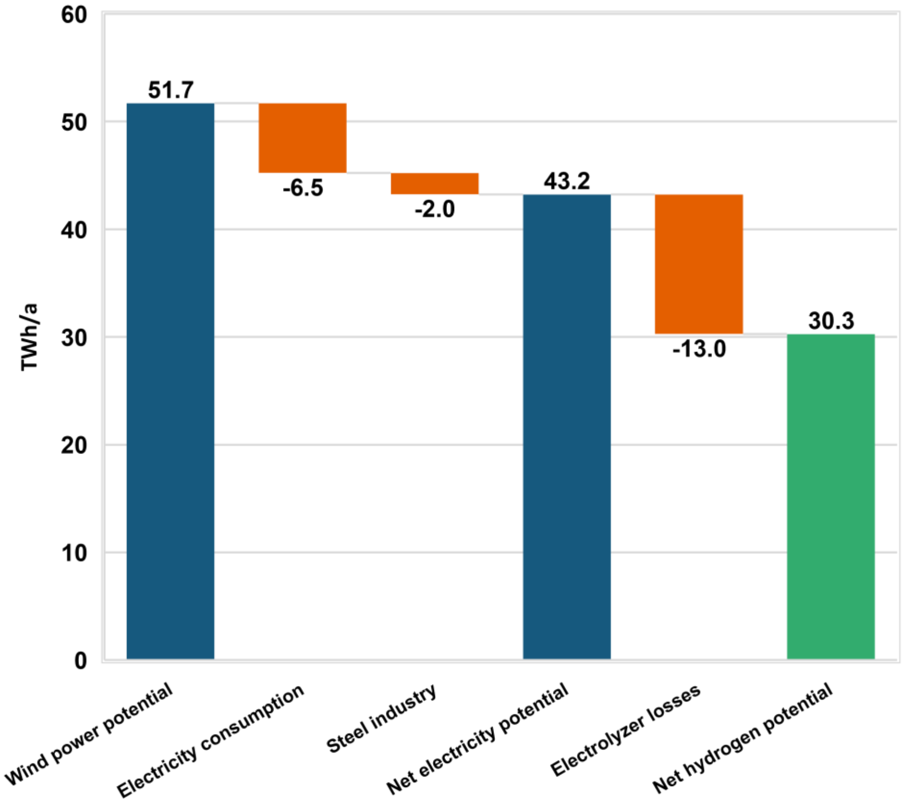


Figure 23. Net hydrogen potential in 2035 in Northern Ostrobothnia with half of the maximum projected wind power capacity.

7.4. Hydrogen production potential in Northern Ostrobothnia - Summary

VTT

- Based on the on-going wind power plans and applied assumptions, the hydrogen production potential by 2035 **(30-62 TWh/a and 0.9-1.8 Mt/a)** in Northern Ostrobothnia is significant
  - The projected wind power capacity has a direct impact on the hydrogen potential in the region
- For comparison, the current hydrogen production in Finland is approximately **5 TWh/a** and **0.2 TWh/a** in Northern Ostrobothnia [6]
  - Study by Fingrid Oyj and Gasgrid Finland Oy [29] has evaluated that based on the grid connection inquiries, the national hydrogen potential from wind and solar power in Finland is 309 TWh/a
- The REPowerEU plan by European Commission has the target to produce **10 Mt/a** (336 TWh/a) of domestic renewable hydrogen by 2030 [30]
- In February 2023, the Finnish Government adopted a resolution on hydrogen with the target to produce 10% of EU's green hydrogen in 2030 [31], meaning, that the target in Finland is to produce **1 Mt/a (33.6 TWh/a)** of hydrogen in 2030
  - Depending on the pace of investments and by using the assumptions applied in this study, this amount of hydrogen could potentially be produced in Northern Ostrobothnia
- It is acknowledged that hydrogen will not be produced without demand – the presented hydrogen production potentials aim to evaluate the scale of what hydrogen production in the region could be, if the planned wind power plants were commissioned at their maximum capacity (or half of the maximum capacity), there would not be grid congestions and most of the additional wind power would be used for hydrogen production
- Potential hydrogen demand sources in the region are discussed in the next slides

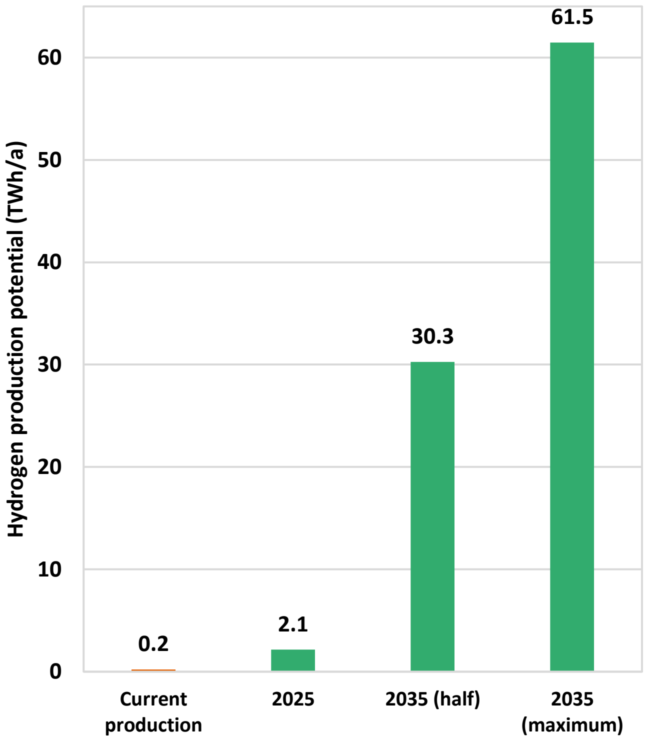


Figure 24. Net hydrogen potential in 2025 and in 2035 (based on maximum and half of the maximum wind power capacity) in Northern Ostrobothnia.

8. Evaluating hydrogen demand in Northern Ostrobothnia

8.1. Potential regional hydrogen demand (1/2)

Current hydrogen production in local chemical industry

- Eastman Chemical Company produces approximately **4 000 tons** of hydrogen annually through partial oxidation [7], corresponding to a potential hydrogen output of **0.13 TWh** through electrolysis
- Nouryon Finland Oy produces approximately **2 200 tons** and **0.07 TWh** of by-product hydrogen annually in chlorine production [7] that in theory could be fed to a hydrogen pipeline

Iron reduction in steel industry

- The blast furnaces at SSAB Europe Oy in Raahe steel mill will be replaced with electric arc furnaces in 2030s [23] consuming approximately 2 TWh/a of electricity [28]
- Hydrogen demand for iron reduction in the Raahe mill would be approximately **150 kt/a** and **5 TWh/a** of hydrogen [1]
  - However, there is a possibility that the sponge iron will be produced in Sweden and transported to the Raahe steel mill, hence hydrogen reduction would not take place in Raahe [32]
  - Using hydrogen to replace heating processes in which propane and methane are used, could also be a possibility to use hydrogen in a steel mill [28]

8.1. Potential regional hydrogen demand (2/2)

Methanol production from local CO_2

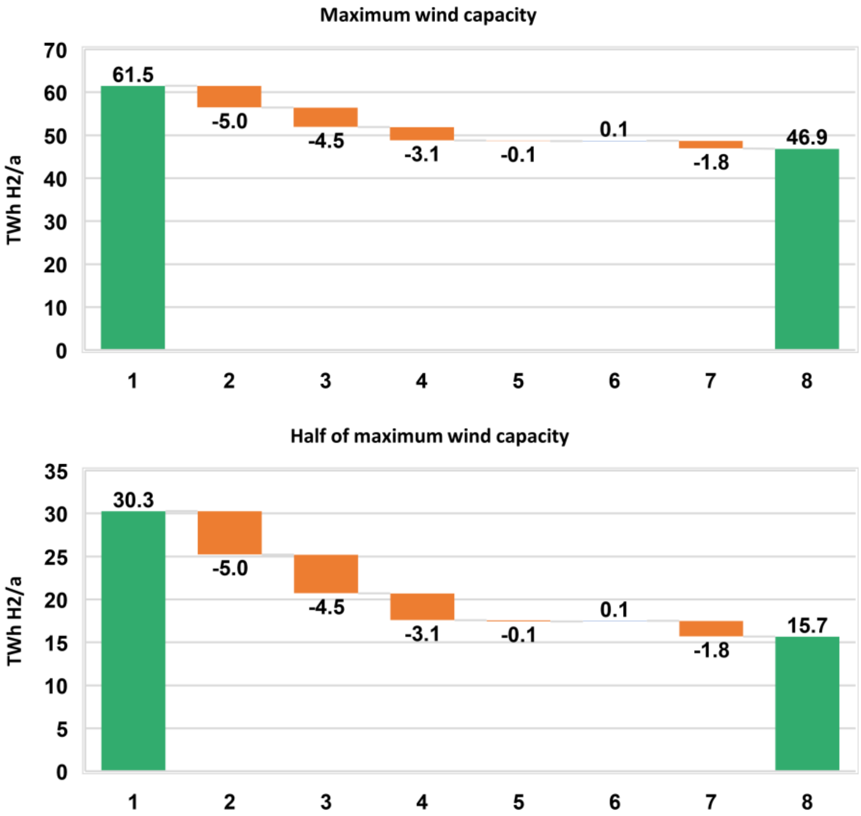
- Hydrogen demand for methanol production is evaluated by considering the current CO_2 emissions, both biogenic and fossil, from the pulp and paper plant (Stora Enso Oulu Oy) and combustion-based energy production plants (Laanila biopower plant and Laanila ecopower plant, WtE) located in Oulu (Table 5.)
  - The plants are selected as they are expected to be in operation for decades from now and are in close proximity to each other
- The theoretical maximum hydrogen demand to convert CO_2 from the selected point sources to methanol is **4.5 TWh/a** and **135 kt/a** for the pulp and paper plant and **3.1 TWh/a** and **93 kt/a** for the energy production units
  - Also, other smaller potential point sources of CO_2 for methanol production exist in the Oulu, for instance, local biogas plant in Oulu produces 3 200 t/a of CO_2 [33], theoretically requiring **0.015 TWh/a** and **420 t/a** of hydrogen to be converted to methanol

Ammonia production

- Flexens Oy Ab and KIP Infra Oy have published a plan to produce green hydrogen and ammonia in Kokkola Industrial Park, with an electrolyzer capacity of 300 MW_{el} [34]
  - Assuming 70% efficiency with constant operation, in this study, the plant is assumed to generate **1.8 TWh/a** and **55 kt/a** of hydrogen
- For the purpose of this study, although the plant is located in Central Ostrobothnia and the plan is to produce hydrogen on-site, the hydrogen output of the plant is subtracted from the Northern Ostrobothnia net hydrogen potential to give insight of the scale (see Figure 25, bar 7)

8.2. Potential regional hydrogen demand - Summary

- Based on the assumptions applied in this study, the potential hydrogen demand in Northern Ostrobothnia is approximately **15 TWh and 0.4 Mt/a** by 2035
- With the applied hydrogen demand assumptions, the hydrogen potential after regional use is approximately **16-47 TWh/a** and **0.5-1.4 Mt/a**
- According to a study by [19], Northern Sweden's hydrogen demand is projected to exceed **20 TWh by 2030**, and double to over 40 TWh by 2040.
- However, hydrogen production in Northern Sweden is estimated to only reach **7.7 TWh by 2030** and 23.4 TWh by 2040 [19]
  - Large hydrogen consumer in the region is expected to be hydrogen-based iron and steel making [19]
- It is possible that the upcoming hydrogen demand in Northern Sweden will accelerate the hydrogen production also in Northern Ostrobothnia and in Finland
- In addition to industrial use and exports, AFIR regulation (Alternative Fuel Infrastructure Regulation) by the EU will obligate to construct a defined amount of hydrogen refueling stations to Finland, and thus part of the hydrogen can also be used in transportation, however, transportation use is excluded from this study



1	**H_2 potential before regional use**	5	Fossil H_2 replacement in local chemical industry
2	H_2 for iron reduction	6	Available by-product H_2 for pipeline
3	H_2 for methanol production (CO_2 from pulp and paper industry)	7	H_2 for ammonia production
4	H_2 for methanol production (CO_2 from combustion-based energy production)	8	**H_2 potential after regional use**

Figure 25. Net hydrogen potentials before and after regional use with maximum and half of the maximum projected wind power capacities in 2035.

Case example: Indicative techno-economics for hydrogen production and transportation

Case example: Indicative techno-economics for hydrogen production and transportation

- Indicative techno-economic evaluations (TEAs) are made to evaluate energy (electricity/hydrogen) transmission costs in relation to hydrogen production costs
  - Aim to evaluate costs from hydrogen user/producer perspective
- The hydrogen demand is evaluated so that CO_2 emissions from selected industrial plants can be converted to methanol via hydrogenation process
  - Hydrogenation: $CO_2 + 3H_2 = CH_3OH + H_2O$
  - Methanol is used as a feedstock e.g., in plastics industry and to produce fuels, methanol use as a fuel is growing in maritime traffic: this study does not evaluate the feasibility of methanol production
- For the indicative TEAs, current CO_2 emissions, both biogenic and fossil, from the following industrial plants located in the region are considered (Table 5: total 1 656 kt CO_2/a):
  1. **Pulp and paper plant (Stora Enso Oulu Oy)**
  2. **Biopower plant (Oulun Energia Oy, Laanila plant)**
  3. **Ecopower plant (WtE) (Oulun Energia Oy, Laanila ecopower plant)**
  - These plants were chosen for the assessment as they are expected to be in operation for decades from now and are in close proximity to each other
- The theoretical hydrogen demand to convert the CO_2 (1 656 kt/a) from the selected plants is 228 kt/a (7.65 TWh/a)

Figure 26. Location of the industrial plants.

Case example: Input parameters for hydrogen production and transmission

- Electrolyzer capacity for hydrogen production is evaluated so that the annual hydrogen demand can be met with annual hydrogen operation hours of 6 500 h
  - The electricity price used is the average onshore wind PPA price in Finland in 2022 [35]
  - The transmission grid output fee is avoided when power grid is not used for energy transmission
- It is assumed that a power grid and hydrogen pipeline already exists in the region
- To provide indicative estimations of hydrogen storage, LRC storage with 7 days hydrogen capacity is incorporated to the case where hydrogen is produced on-site (energy transported via power grid)
  - It should be noted that many factors affect the optimal size and operation of the storage and that the storage capacity in this study is not optimized
- Main assumptions for hydrogen storage are presented on the next slide

Table 6. Input parameters for hydrogen production and transmission.

Electrolysis	Value
CAPEX	420 €/kWe [36]
Fixed O&M	4 % of CAPEX [37]
Electricity consumption	55 kWh/kg H_2 [37]
Annual operation hours	6 500 h
Electricity price (spot)	35 €/MWh [35]
Economic lifetime	20 a [37]
WACC	4 % [37]
Transmission grid consumption fee	2.55 €/MWh [38]
Transmission grid output fee	0.92 €/MWh [38]

Pipeline	Value
H_2 transmission costs (1200 mm)	0.2 €/kg [39]

Case example: Input parameters for hydrogen storage

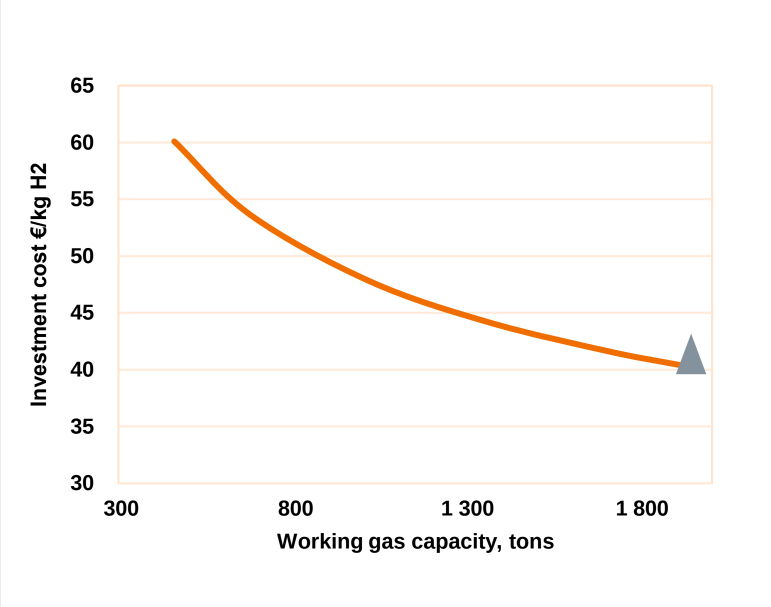


Figure 27. Investment costs for LRC storage in relation to working gas capacity [40]. The value used in the TEA is marked with a triangle.

Table 7. Input parameters for hydrogen production and transmission.

Component	Value
CAPEX	>40 €/kg_{H2} [40]
Fixed OPEX	2 % [37]
Volume	<120 000 m^3 [41]
Pressure range	20-250 bar [41,16]
Injection – empty to full	20 d [41]
Discharge – full to empty	7 d [41]
Buffer gas	8 % of total gas volume [40]
Economic lifetime	30 a [43]
WACC	5 % [37]

- 120 000 m^3 is assumed to be the maximum capacity for one LRC storage [41], corresponding approx. 2000 tons of working gas capacity

Case example: Hydrogen production and transportation costs

- Hydrogen demand to convert CO_2 (1 656 kt/a) from the selected industrial plants to methanol is 228 kt/a and 7.65 TWh/a
  - Assuming 6 500 h of total operating hours, 1.93 GW_e of electrolyzer capacity, and 12.5 TWh/a of electricity is needed for the methanol production
- With the applied assumptions, total cost of hydrogen varies between 2.52-2.67 €/kg H_2
  - The differences in the total cost are quite small and hence the assumptions used have higher importance
  - Depending on the regional gas prices, the cost of fossil-based hydrogen globally is 0.45-1.60 €/kg H_2 [44]
- As seen from Figure 28., electricity cost is the main cost component in hydrogen production and transportation/storage costs
- When power grid is used for the energy transportation, electricity transmission fees include the transmission grid consumption fee and transmission grid output fee
  - When hydrogen is produced at the wind power production site and transmitted to the demand source via pipeline, it is still assumed that the transmission grid consumption fee is paid
  - When compared to hydrogen production and transmission, the hydrogen storage cost is small
  - To meet the demand for hydrogen over a period of 7 days, it was estimated that two LRC storages with a capacity of 120,000 m^3 each would be needed
- The infrastructure costs for building new power grid or hydrogen pipeline are discussed later in the study

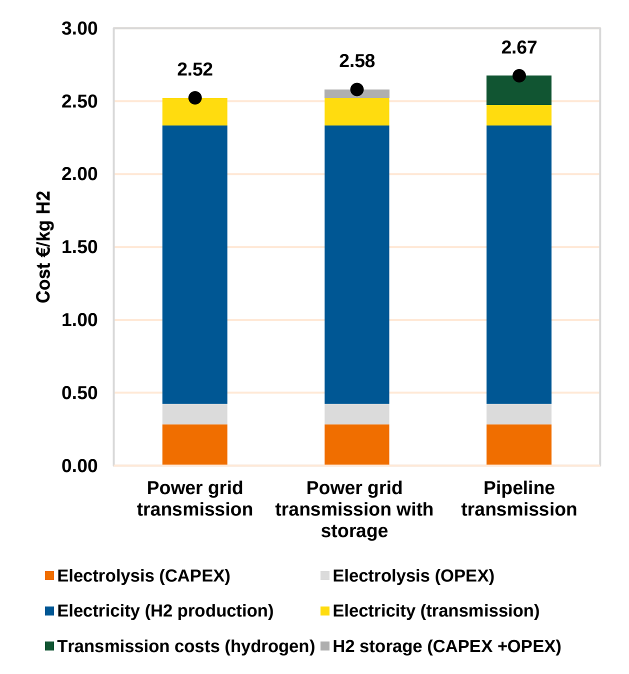
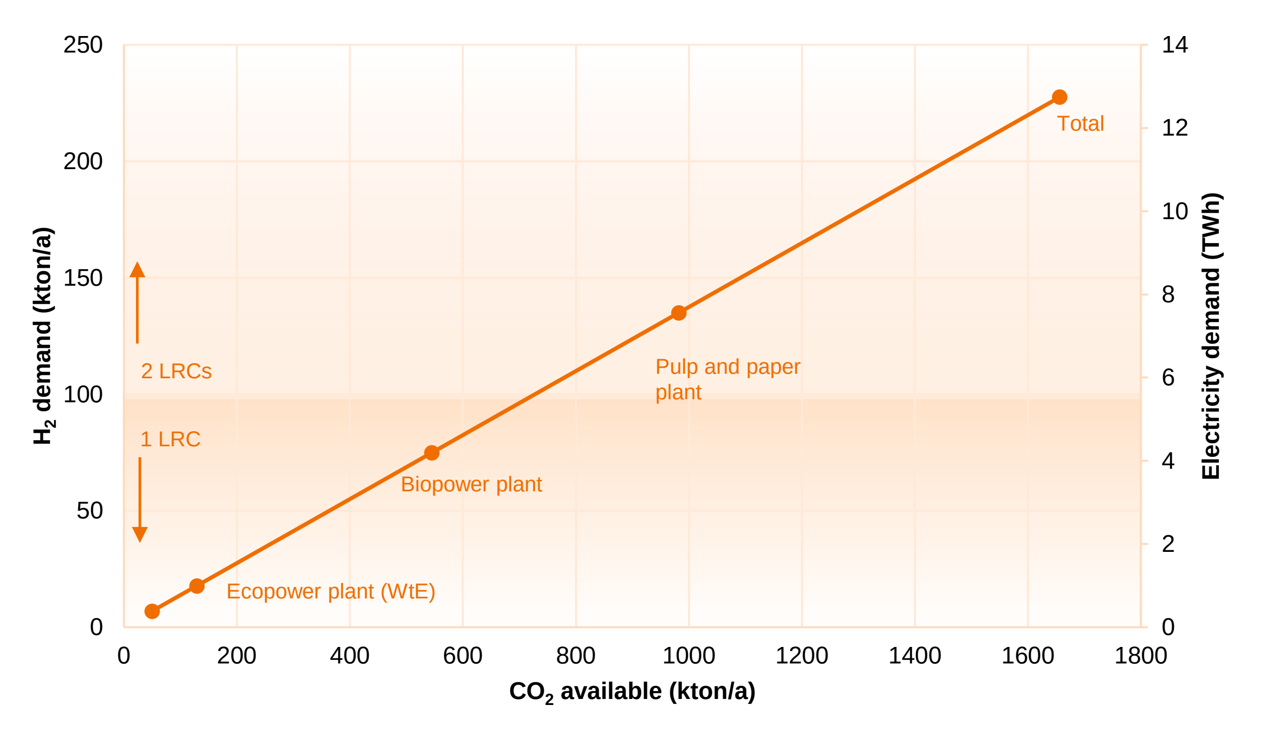


Figure 28. Indicative comparison of hydrogen production and transportation costs with different transportation options.

Case example: Hydrogen and electricity demand in relation to CO_2 availability when producing methanol



- Figure 29 illustrates the relations between available CO_2, the amount of hydrogen needed to produce methanol from the CO_2, as well as the related electrical power needed for electrolysis (electricity consumption 55 kWh/kg H_2)
- Moreover, the approximate boundaries for LRC storage are estimated

Figure 29. Relations between available CO_2, hydrogen demand to produce methanol and electricity demand to power electrolysis.

9. Evaluating hydrogen transmission in Northern Ostrobothnia

9. Hydrogen transmission (1/5)

- Hydrogen can be distributed and transported via pipelines and with road-, rail-, and ship transportation
- The most cost-effective transport method depends on several factors such as the distance of transportation, transported hydrogen volume, hydrogen end-use application and geographical aspects [45]
- According to IEA, hydrogen pipelines are the most cost-effective long-term solution if large and stable hydrogen production and demand is secured [45]
  - The main near-term transport method is expected to be truck transportation where hydrogen is transported as a gas or liquid
    - Truck transport can remain a viable option for small hydrogen quantities and short distances in the future
  - Ammonia and liquid organic hydrogen carriers (LOHCs) may be feasible options especially when overseas transmission is considered
- Due to the massive anticipated hydrogen potential in Northern Ostrobothnia (0.9-1.8 MtH_2/a), hydrogen transmission via pipeline is seen as the most feasible transportation method from the regional perspective and is discussed in the following slides
  - In addition, the question of whether hydrogen production should take place through decentralized or centralized means is discussed
  - Decentralized production refers to the generation of hydrogen at the site where electricity is produced, while centralized production denotes that hydrogen is produced at the site of demand

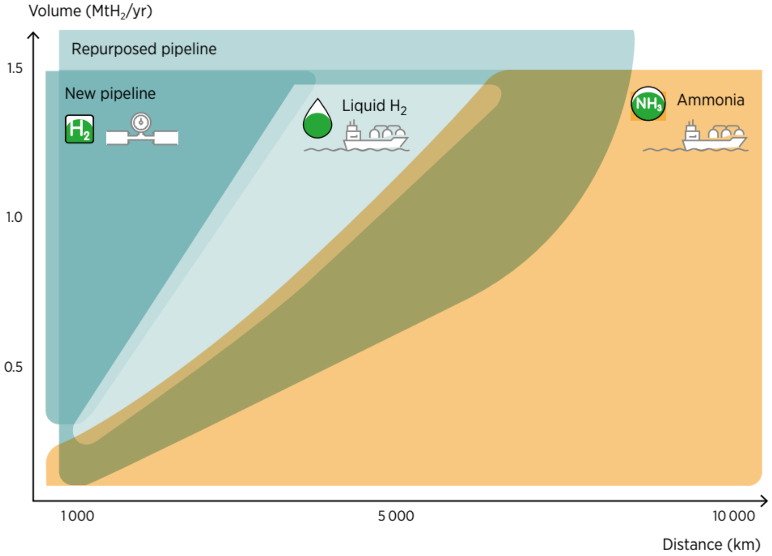


Figure 30. Cost-efficiency of hydrogen transport options in relation to volume and distance [46].

9. Hydrogen transmission (2/5)

- Hydrogen production through electrolysis can take place either at the site where electricity is generated or at the site where hydrogen demand exists
  - Hence energy can be transmitted to the demand site as electricity or hydrogen
- With the applied assumptions related to available wind power, net hydrogen potential in Northern Ostrobothnia is **30-62 TWh/a** in 2035
  - The expected potential for 2025 is **2.1 TWh**, however, the hydrogen transmission network should be designed to meet the expected future flows
- Based on [47], the estimated size of a hydrogen pipeline needed to transmit the anticipated level of output (30-62 TWh/a) is **1200 mm** and **12.7 GW** when operating at 75% capacity
- Figure 31 from [47] shows, that large-scale hydrogen transmission via new pipeline is more cost-effective at any distance for a 1200 mm pipeline in comparison to new overhead HVAC (2.8 GW and 380 kV) lines

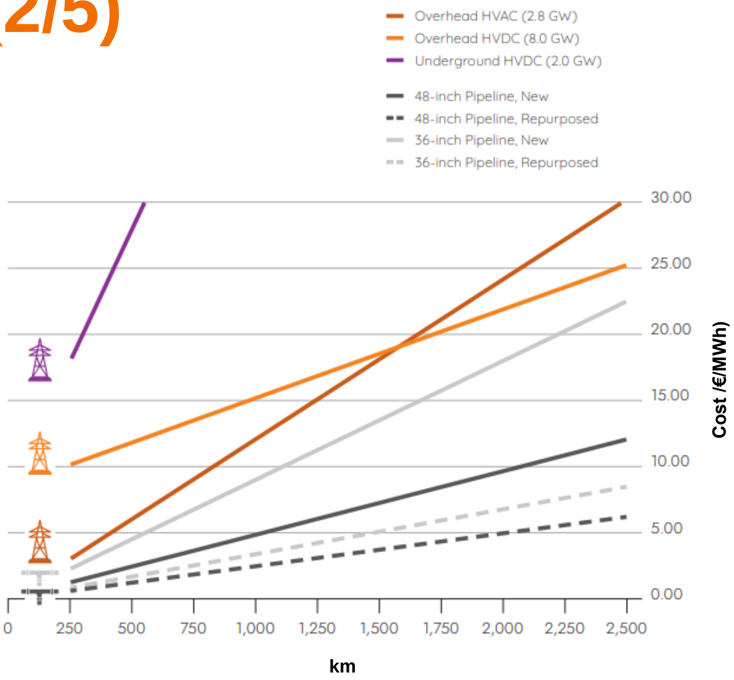


Figure 31. Cost comparison of electricity and hydrogen infrastructure assuming hydrogen as end product. Source: [47].

9. Hydrogen transmission (3/5)

- With regards to cost, calculations by [29] also suggest that investing to a **1200 mm pipeline** results in a lower cost compared to a **400 kV power transmission line**, which is used in Finland
- However, the assumption of a 1200 mm diameter is based on the fact that all generated hydrogen is transported via single pipeline
- As seen from Figure 33, the wind power projects with largest maximum capacities in Northern Ostrobothnia are located away from the coastline and from the location where the hydrogen pipeline is envisioned to be placed
- Producing hydrogen at the source of electricity generation (wind power plants), a branching pipeline could be built to connect the pipeline on the coast with the wind power plants in the northeast and southern parts of Northern Ostrobothnia
  - This could reduce the optimal capacity of the pipeline increasing the capital expenditures in comparison to building a new 400 kV power transmission line network
- The optimal location of branching pipelines would naturally depend also on the wind power plants planned to nearing regions such as Lapland and Kainuu

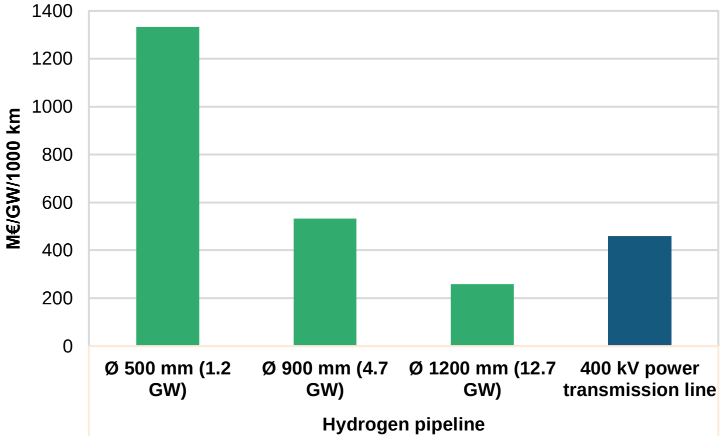


Figure 32. Comparison of electricity and hydrogen infrastructure costs assuming hydrogen as end product. Source: Adapted from [29].

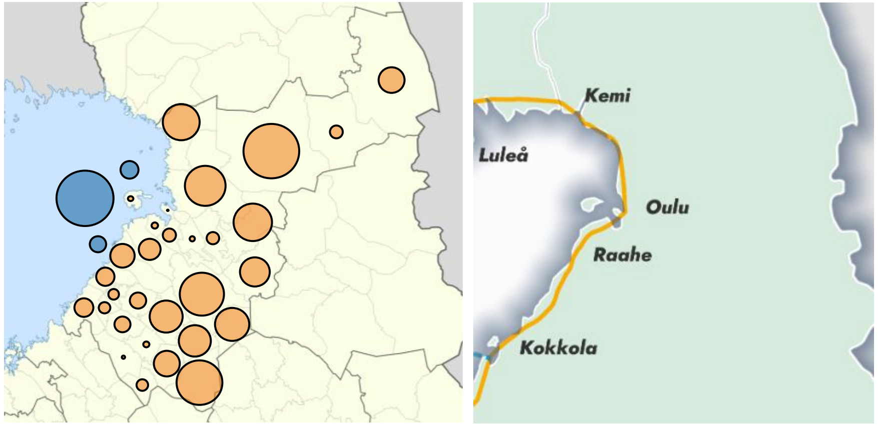


Figure 33. The upcoming wind power projects by municipality in Northern Ostrobothnia based on [16] and [17] and the envisioned new hydrogen infrastructure by Nordic Hydrogen Route [3].

9. Hydrogen transmission (4/5)

- When considering the most suitable method for energy transmission, either through hydrogen pipeline or a power transmission grid, it is crucial to consider not just the financial aspect, but also other elements that may impact the decision
- **In terms of land-use,** large-scale hydrogen transmission is more efficient in comparison to power grid transmission, which can also have impacts on the **social acceptance**
  - To transfer the energy amount of one 1200 mm and 12.7 GW pipeline, **15 power lines** of 400 kV is needed [29]
- **By-product utilization**: hydrogen production via electrolysis also produces oxygen and heat as a by-product
  - The possibility of generating revenue from the heat produced during electrolysis can play a role in selecting the most optimal location for hydrogen production which, in turn, may impact transportation requirements

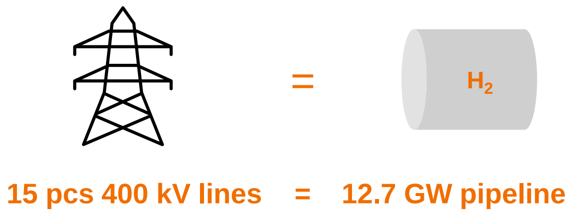


Figure 34. According to [29], to transfer the energy amount of one 1200 mm and 12.7 GW pipeline, 15 power lines of 400 kV are needed.

9. Hydrogen transmission (5/5)

- **Hydrogen pipeline can enable greater exploitation of wind energy potential**
- The pace of investments for new power transmission grid infrastructure may become a bottleneck for new renewable energy investments
  - Fingrid Oyj, the electricity TSO in Finland, has received more than 200 GW of inquiries for new power connections, mainly for onshore wind power [48]
- In Northern Ostrobothnia, the grid connection capacity is expected to be 6.33 GW in 2030, while the estimated wind additional power capacity for 2030 and could be up to 30 GW
  - Grid connection limitations may constrain renewable electricity production in the region
- The production of hydrogen at the renewable energy generation site and its subsequent transmission through a hydrogen pipeline enables the detachment of the renewable energy production unit from the grid
  - This facilitates the reduction of pressure on the power grid, enabling to connect of additional renewable energy production to the grid, that may not have been designated specifically for hydrogen production

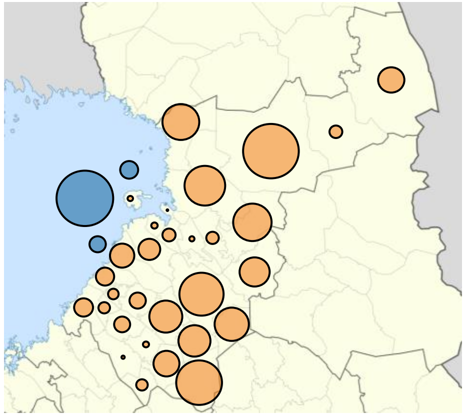


Figure 35. Upcoming wind power projects by municipality in Northern Ostrobothnia. Adapted from [16] and [17].

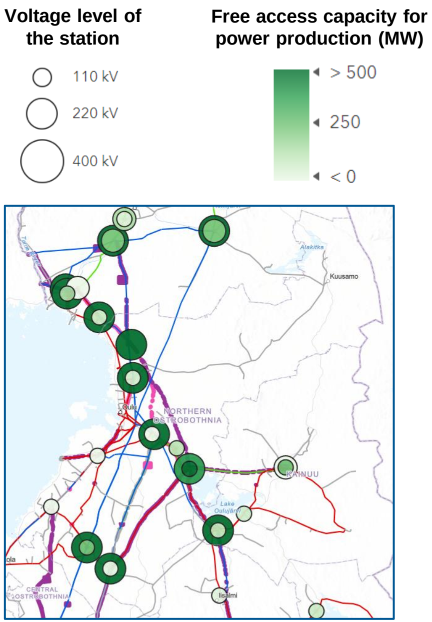


Figure 36. Grid connection capacity to Fingrid's main grid by 2030 [17].

10. Hydrogen transmission initiatives in Finland

10. Hydrogen transmission initiatives in Finland (1/3)

- The Finnish inland hydrogen transmission network is currently being developed based on three geographical areas [49]:
  - Bothnia Bay and west-coast with available renewable energy sources and identified hydrogen demand
  - South and south-east Finland with existing and future hydrogen demand
  - South-west Finland and Satakunta areas with expected hydrogen demand and renewable energy
- The hydrogen transmission infrastructure around Bothnia Bay is planned to be in operation already by 2030
- By 2040, the hydrogen transmission network in the northern regions could also be expanded to reach even further north, and there may also be opportunities to build additional north-south pipelines [49]
  - A potential further expansion of the Finnish hydrogen network to northern and eastern parts of Finland can enable to fully deploy the wind power potential in the region with limited power grid infrastructure
- In 2023, Gasgrid Finland Oy, is gathering data from industrial stakeholders regarding their interest in joining the hydrogen pipeline along with their proposed schedule, and hydrogen volumes: the data is used to help determine the optimal routing of the hydrogen pipeline
  - The Finnish TSO is also open to update the preliminary plans and routes of the hydrogen pipeline based on the industrial needs [50]

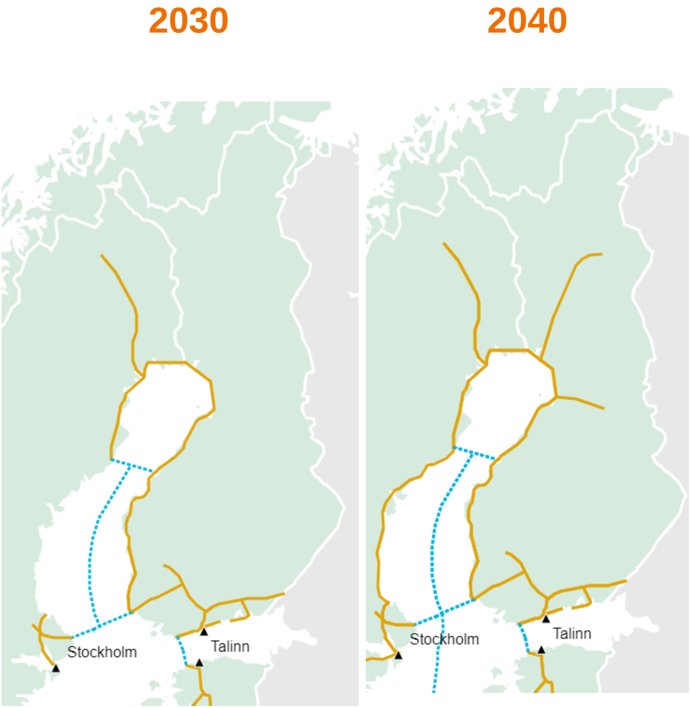


Figure 37. The envisioned hydrogen pipelines in Finland in 2030 and 2040 [49].

10. Hydrogen transmission initiatives in Finland (2/3)

- Gasgrid Finland Oy has several on-going projects related to cross-border hydrogen transmission, Nordic Hydrogen Route being at present the most advanced of the projects [50]
  - If all projects were implemented by 2030, the hydrogen transmission routes would enable an efficient hydrogen market, even on a global scale, to the Baltic Sea region enabling excellent hydrogen-related investment opportunities to both Finland and Northern Ostrobothnia
- **Nordic Hydrogen Route** is a joint initiative between Finnish and Swedish national gas transmission operators Gasgrid Finland Oy and Nordion Energi AB, published in 4/2022 [51]
- The aim of the initiative is to build a **greenfield cross-border hydrogen pipeline network to Bothnia Bay** region, partly on the coastline of Northern Ostrobothnia
- The pipeline is estimated to be in operation by **2030** [51]
  - The total length of the new pipeline network would be 1000 km with a cost estimate of 3.5 B€
  - The estimated hydrogen potential in the Bothnian Bay region is 65 TWh by 2050
  - The hydrogen transport cost estimate is 0.1-0.2 €/kg
- The long-term vision is to link the pipeline of the Nordic Hydrogen Route to a wider European hydrogen infrastructure

Figure 38. The envisioned new hydrogen infrastructure by Nordic Hydrogen Route [3].

10. Hydrogen transmission initiatives in Finland (3/3)

- In addition to Nordic Hydrogen Route, two other cross-border hydrogen pipeline projects are currently starting
- **Nordic-Baltic Hydrogen Corridor**: six TSOs from Finland, Estonia, Latvia, Lithuania, Poland, and Germany have signed a cooperation agreement in December 2022 to develop joint hydrogen transmission infrastructure [52]
  - The aim is to transfer green hydrogen produced in the Baltic Sea area to consumption sources along the hydrogen corridor and central Europe
- Offshore hydrogen infrastructure and market to support the significant offshore wind power potential in the Baltic Sea region is being developed by Gasgrid Finland Oy and Nordion Energi AB, together with industry companies OX2 and Copenhagen Infrastructure Partners in a project called **Baltic Sea Hydrogen Collector (BHC)** [53]
  - The offshore pipeline would connect Finnish and Swedish mainlands with Åland Islands and Germany by 2030
  - Connections to energy islands such Gotland and Bornholm in Sweden and Denmark are also possible
- Pre-feasibility studies for both projects are planned to be conducted during 2023 [50]

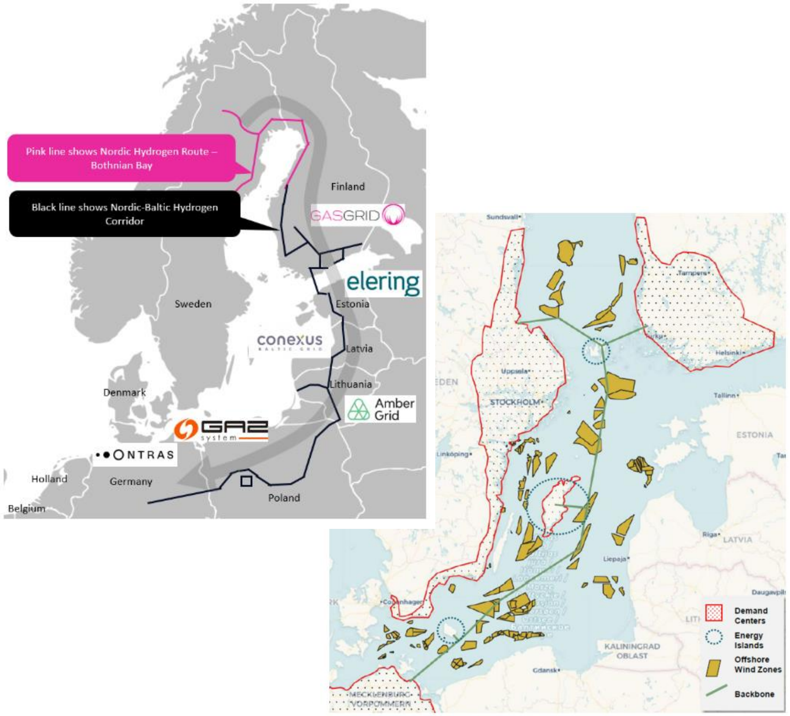


Figure 39. Locations of Nordic-Baltic Hydrogen Corridor [52] and Baltic Sea Hydrogen Collector (BHC) [53].

11. Hydrogen-related companies and actors in Northern Ostrobothnia

11.1. Mapping of hydrogen-related companies

- Potential hydrogen-related companies in Northern Ostrobothnia are mapped and placed on a hydrogen value chain
  - In addition, a short description of the hydrogen-related companies, among with other regional actors with hydrogen-related activities in Northern Ostrobothnia, is given
- The hydrogen value chain includes companies from:
  - *Electricity production and distribution*
  - *Hydrogen production*
  - *Hydrogen distribution and storage*
  - *Hydrogen applications*
  - *Concept design, consulting and engineering companies*
- The mapped companies either:
  a) Already operate in the region and have hydrogen-related plans
  b) Have on-going hydrogen-related projects that could be replicable also in Northern Ostrobothnia
- The list is not exhaustive and may exclude companies that would fit the described criteria
- The mapped value chain was used to contact companies for interviews and a workshop to discuss drivers, barriers and suggestions for hydrogen economy in Northern Ostrobothnia from business-perspective
  - Outcomes from the interviews and workshop are described in Chapter 12

11.2. Potential actors for a hydrogen value chain in Northern Ostrobothnia

VTT

Electricity production and distribution	Hydrogen production	Distribution and storage	Applications
OULUN ENERGIA, FINGRID, OX2, PUHURI	EASTMAN, Nouryon	GASGRID	Kemira, SSAB
	P2X solutions, hycamite, Raahen Monivoima, REN GAS	EPV, RECION	St1, Gasum, Q POWER, SOLAR FOODS

Concept design, consulting & engineering

- skarta Part of SkartaNYAB
- SWECO
- REJLERS
- RAMBOLL
- kiwa
- AFRY ÅF PÖYRY
- ELOMATIC Visions of Tomorrow, Engineered Today (potential)

= Companies with on-going activities or public plans related to hydrogen economy in the region

= Potential companies to operate in hydrogen economy in the region

11.3. Companies with on-going hydrogen-related activities or public plans in Northern Ostrobothnia

VTT

Company	Description
AFRY	Conducted a report about the possibilities and limitations of hydrogen economy in Finland.
Eastman Chemical Company	Produces carbon monodixe and hydrogen by partial oxidation of natural gas in formic acid production process in Laanila industrial area, Oulu.
Fingrid Oyj	Joint project with Gasgrid Finland to clarify the role of energy infrastructure as an enabler of the hydrogen economy.
Gasgrid Finland Oy	Joint initiative with Swedish Nordion Energi to build a cross-border hydrogen pipeline network to Bothnia Bay region, partly on the coastline of Northern Ostrobothnia
Kemira Oyj	Uses hydrogen as feedstock in hydrogen peroxide production in Laanila industrial area, Oulu.
Kiwa Inspecta Oy	Offers testing, inspection and certification services, training and expert consultancy in a wide variety of international markets and subjects – also related to hydrogen
Nouryon Finland Oy	Produces natrium chlorate and hydrogen via electrolysis in Nuottasaari, Oulu. Nouryon plans to increase the production capacity and might have a need for hydrogen storage in the future.
Oulun Energia Oy	Interested in exploring different hydrogen applications, such as producing hydrocarbons from hydrogen and carbon dioxide, as well as utilizing electrolysis heat in district heating. Oulun Energia is looking for collaboration partners.
OX2 Finland Oy	Investigating the possibility to produce electrolytic hydrogen in its' offshore wind project called Halla in the sea area next to Oulu and Raahe.
Puhuri Oy/Raahen Monivoima Oy	Joint initiative with Kokkolan Energia Oy to produce hydrogen and methane via Power-to-X in Kokkola. The concept would also include solar and wind power production and a battery storage.
Ramboll Finland Oy	Conducted a report about potential hydrogen production site in the city of Raahe.
Rejlers Finland Oy	Conducted a technology report about hydrogen economy potential in Meri-Lappi area. Provides concept design services regarding hydrogen.
Skarta Group Oyj	Design and execution of projects with Near Energy (Vierivoima) -concept, where renewable energy (solar, wind) is produced for on-site use and potentially also for hydrogen production. Ongoing project in Utajärvi for solar and wind production with near term plans also for hydrogen production, storage and fueling station.
SSAB Europe Oy	SSAB Raahe steel mill is a potential hydrogen consumer, if the mill starts producing direct reduced iron using hydrogen.
Sweco Finland Oy	Carried out the engineering work in the pilot plant for Hycamite in Kokkola Industrial Park. Will be responsible of the engineering work of Hycamite's industrial-scale hydrogen production plant. Conducted a study of the business opportunities of hydrogen economy for local companies in Meri-Lappi area.

11.4. Potential companies to operate in Northern Ostrobothnia

Company	Description
Elomatic Oy	Consulting, design and product development services for industrial companies and public organizations. Did a research study for Flexens in Power2AX-project regarding hydrogen production for new vessels in Åland archipelago.
EPV Energia Oy	EPV Energy, Vaasan Sähkö and Wärtsilä aim to build a Power-to-X-to-Power hydrogen system in Vaasa to store renewable energy.
Gasum Oy	Biogas and biomethane production in Oulu. Investigates the opportunity to convert methane into hydrogen and carbon with Hycamite. In addition, potential company for synthetic methane production via hydrogen biomethanation.
Hycamite TCD Technologies Oy	Produces hydrogen and carbon by processing methane via non-oxidative thermal decomposition on pilot-scale. Plans to expand the production to industrial scale. Currently operating in Kokkola.
PX2 Solutions Oy	Develops Power-to-X projects to produce green hydrogen and synthetic biofuels. On-going activities e.g., in Harjavalta Industrial Park and in a power plant located in Joensuu.
Q-Power Oy	Technology start-up specialized in Power-to-Methane technology. Synthetic methane projects with different scale e.g., at Kerava bioenergy plant, Harjavalta Industrial Park and at Riihimäki waste incineration plant.
Recion Oy	Piping engineering company with production facility in Ylivieska. Interest in piping solutions for hydrogen.
Ren-Gas Oy	Project development company investing in Power-to-X gas production and distribution sites in Finland. On-going Power-to-X projects e.g., in Lahti, Tampere, Kotka, Mikkeli and Pori.
Solar Foods Oy	Food technology start-up company producing food protein from carbon dioxide and hydrogen.
St1 Nordic Oy	Investigating Power-to-X and hydrogen use in sustainable fuel production for road transport, marine and aviation. Currently planning synthetic methanol pilot plant in Lappeenranta with the aim to develop a replicable and scalable synthetic methanol production concept.

11.5. Actors with hydrogen-related activities Northern Ostrobothnia

Actor	Description

University of Oulu	• Coordinates the Hydrogen Research Forum Finland, launched 6/2022 [54]
	  • Seminar organized 10/2022 at the University of Oulu
	• Interdisciplinary research [55]:
	  • Photocatalytic hydrogen production
	  • Hydrogen reducing technologies for steelmaking and development of hydrogen-resistant steel
	  • Use of hydrogen in traffic
	  • Business models in the future hydrogen economy

Oulu University of Applied Sciences	• SMARTrenew project team to identify future competence needs for hydrogen economy in Northern Finland [18] • Final conference held 3/2022
City of Oulu / Business Oulu / Council of Oulu region	• Founded a study by University of Oulu to study the companies' and organizations' plans related to hydrogen economy in Bothnia Bay in 2021 [1] • Council of Oulu region is partly funding a project in which the possibilities of renewable energy production and hydrogen economy in North Ostrobothnia is evaluated among with the land use aspects (EMMI-project) [57]
City of Kemi	• Ordered three reports assessing the hydrogen potential in Kemi and Meri-Lappi area, the results were published 9/2022 [58]
City of Raahe	• Founding member of two hydrogen initiatives [59]: Kansallinen vetyverkosto and R4H2 – REACTions for Hydrogen • Ordered a report mapping potential locations for hydrogen-related operations, published 2/2022
VTT Technical Research Center of Finland	• Conducted a report "National Hydrogen Roadmap for Finland" [6] • Conducted a report "Pre-study on transition to hydrogen economy, specifically in Northern Ostrobothnia"
Lappeenranta-Lahti University of Technology LUT	• Conducted a report "Research report on Bothnian Bay Hydrogen Valley" [5], ordered jointly by Fortum and St1, to perform a hydrogen ecosystem analysis on for the Bothnian Bay.

All mentioned actors are members of Kansallinen Vetyverkosto

12. Drivers, barriers and suggestions for hydrogen economy from business-perspective

12.1. PESTEL analysis - Introduction

- Five interviews and a workshop were organized during the study to map current business-related drivers, barriers and suggestions for hydrogen economy in Northern Ostrobothnia
  - The individually interviewed companies were Oulun Energia, SSAB Europe, OX2 Finland, Hycamite TCD Technologies, and Gasgrid Finland
  - The regional stakeholders attending to the workshop were AFRY, Sweco, Recion, Sitowise Group, TEVO, Raahe Region Development, Business Oulu and VTT Technical Research Centre of Finland
- The synthesis of the discussions was compiled in the form of a PESTEL table, with topics grouped under three headings: “Drivers”, “Barriers” and “Suggestions/Opportunities”
  - PESTEL is a framework to analyze political, economic, social, technological, environmental, and legal factors that affect a company's operations
- The PESTEL analysis is not a comprehensive inventory of the region's strengths and needs; rather, it represents a snapshot of the prevailing perspectives among actors
  - As the PESTEL analysis was conducted from business perspective, certain topics emerged with greater frequency than others during the course of the interviews

Five interviews with companies:

Business-oriented workshop for regional stakeholders:

12.2. PESTEL analysis for hydrogen economy in Northern Ostrobothnia (1/3)

	Drivers	Barriers	Suggestions / Opportunities
Political	National mandate for H_2 infrastructure: Nordic Hydrogen Route encourages investments	Complex requirements for public funding Few support instruments for scaling up innovations	Cross-border cooperation on projects to become eligible for EU funding
Economic	Access to hydrogen market in addition to power market improves risk management for wind producers Substantial renewable energy surplus fosters regional H_2 production as the need for long-distance power transmission decreases Synergy benefit via sector coupling: excess heat from electrolysis utilized in district heating Existing industry in the area with potential to use hydrogen Potential large user for H_2 (steel industry)	No market for H_2 currently exists: no investment decisions for H_2 consumption creates uncertainties in H_2 production investment decisions (chicken-and-egg) Lower electricity prices in Northern Sweden wrt Finland Few actors who could use large volumes of H_2 in the region	More public estimations on costs and quantities to provide information for investors Cooperation outside the region, e.g., Sweden to accelerate the technology uptake Tax reduction for green H_2 production Business clusters and/or joint ventures

12.2. PESTEL analysis for hydrogen economy in Northern Ostrobothnia (2/3)

	Drivers	Barriers	Suggestions / Opportunities
Social	Municipal actors (especially in Raahe) interested and open, e.g., in zoning proposals Possibility for sustained growth and positive impact on employment Educational actors are mapping the educational needs with industry Good corporate image via decarbonization	Lack of skilled workforce might divert investments elsewhere Attractiveness of Northern Ostrobothnia to workforce Customers' willingness to pay higher price for green products Negative attidudes towards H_2 or green transition	Vocational and academic education to reflect the needs Active communication towards stakeholders about the opportunities Engaging and employing local people Concretizing the subject for stakeholders through good examples
Technology	Possibility to replace LNG with methane in Laanila industrial area Substantial renewable electricity production in the region: wind power production leader in Finland H_2 production as wind power capacity building accelerator and vice versa	Few companies with experience in hydrogen production technology Hydrogen infrastructure does not exist No demonstrated wind-hydrogen storage systems Storing H_2 is challenging Limited grid access capacity	There is experience on demanding industrial piping services in the region H_2 transmission pipeline alleviates storage needs in the first phases Acquiring knowledge about H_2 materials and technological solutions outside Finland

12.2. PESTEL analysis for hydrogen economy in Northern Ostrobothnia (3/3)

	Drivers	Barriers	Suggestions / Opportunities
Environmental	CO_2 spot emitters geographically close to wind production Possibility to contribute to industry decarbonization via CCU and fuel production Possibility to contribute to heating sector decarbonazation via sector coupling Coastal area and ports are a key element for H_2 market	Scarcity of available land areas for new industrial activities, especially on the coastal area	
Legal		Uncertainty of EU regulation on CCS/CCU Uncertainty about safety regulations; danger zones, safety distances for transmission lines,… Legal proceedings and slow permitting process cause significant delays on projects EU regulation is slow and stiff; National legislation subordinate for EU funding gets delayed as a consequence	The priority procedure for green transition investments (including H_2 investments) in the permitting process entered into force at the beginning of 2023 [60].

13. Summary

13. Summary (1/4)

- The regional wind power capacity in Nothern Ostrobothnia can increase from the current **2.3 GW** to even up to **32.3 GW** by 2030, assuming that all the planned wind power projects currently in different planning stages (**30 GW**) are completed at their maximum capacity
  - In short term, the regional wind power capacity is expected to increase to **3.1 GW,** after wind power plants currently under construction (**0.8 GW**) are added to the current capacity
- With the assumptions applied in this study, **32.3 GW** of wind power capacity could generate up to **96.3 TWh/a** of electricity
  - However, this is not the most probable wind power capacity and generation output: the actual capacity of each wind power project is affected by several factors, e.g., the Environmental Impact Assessment and available grid connection capacity
  - Thus, the projected wind power capacity and generation output should be taken as the upper limit based on the announced projects
- The grid connection capacity in 2030 is expected to be **6.33 GW** in Northern Ostrobothnia, which is low compared to the wind power projects in the pipeline
  - Therefore, grid connection limitations may constrain renewable electricity production in the region
- The regional hydrogen potential is based on the available regional wind power production
  - Regional electricity use with preliminary assumptions related to electrification in industry and transportation is deducted to derive net wind power production available for hydrogen production

13. Summary (2/4)

- Assuming that all wind power projects would be completed at their maximum capacity or by half of their maximum capacity, and after deducting other regional electricity use and electrolyzer losses, the hydrogen production potential in the region is estimated to be **1.8 Mt/a** (61.5 TWh/a) and **0.9 Mt/a** (30.3 TWh/a) by 2035, respectively
  - For comparison, current regional hydrogen production in Northern Ostrobothnia is approximately 6.2 kt/a, which is less than 5% of the total domestic production in Finland (168 kt/a, of which 145 kt/a is dedicated hydrogen production and 23 kt/a is produced as a by-product)
- The Finnish Government has adopted a resolution on hydrogen with the target to produce 10% of EU's green hydrogen in 2030, meaning, that the target in Finland is to produce **1 Mt** (33.6 TWh) of hydrogen in 2030
  - The hydrogen production potential in Northern Ostrobothnia could potentially satisfy this target
- Based on the assumptions applied in this study, the potential hydrogen demand in Northern Ostrobothnia is approximately **0.4 Mt/a** and 15 TWh by 2035
  - This includes hydrogen use in steel industry, methanol production from regional CO_2, ammonia production and substituting current regional hydrogen use with green hydrogen
- ´"Excess" hydrogen potential from the regional wind power is approximately **0.5-1.4 Mt/a** and 16-47 TWh/a after deducting regional hydrogen use
  - It is acknowledged that hydrogen will not be produced without demand

13. Summary (3/4)

- Transmitting the energy as electricity or as hydrogen is discussed in the study
  - The estimated size of a hydrogen pipeline needed to transmit the level of potential hydrogen output in the region (30 - 62 TWh/a) is 1200 mm and 12.7 GW when operating at 75% capacity, and hence, **the projected hydrogen potential in Northern Ostrobothnia could justify building a hydrogen pipeline** up to ø1200 mm, e.g., for inland-coast transmission.
  - In this scale, the investment costs for a hydrogen pipeline are lower in comparison to building a new power grid
  - In addition to cost, land use and by-product utilization aspects should also be considered when selecting the transportation method
- **Hydrogen pipeline could facilitate greater exploitation of wind energy potential** especially in regions, where electricity transmission network is insufficient to meet the transportation needs
  - In Northern Ostrobothnia, the access capacity to power grid is expected to be **6.33 GW in 2030**, while the additional wind power capacity for 2030 and beyond can be up **30 GW**
- Production of hydrogen at the renewable energy generation site, and its subsequent transmission through a hydrogen pipeline can enable at least a partial detachment of the renewable energy production unit from the grid
  - This enables to connect of additional renewable energy production to the grid, that may not have been designated specifically for hydrogen production
- The Finnish TSO Gasgrid has several on-going projects related to hydrogen pipeline transmission and if implemented, would connect both Finland and Northern Ostrobothnia to the hydrogen market in the Baltic Sea region
  - At the moment, Nordic Hydrogen Route being is the most advanced of the projects
  - The aim of Nordic Hydrogen Route is to build a greenfield cross-border hydrogen pipeline network to Bothnia Bay region, partly on the coastline of Northern Ostrobothnia
  - The optimal routing of the pipeline will be based on industrial needs: active participation of the regional industrial stakeholders required to define the needs

13. Summary (4/4)

- Interviews and a workshop to map the drivers, barriers and suggestions for development for hydrogen economy in Northern Ostrobothnia were conducted during the study
  - Based on the interviews and workshop, there is interest in hydrogen throughout the value chain in Northern Ostrobothnia
- The main barriers identified are the absence and uncertainty of hydrogen demand, as well as unsure hydrogen supply, creating a "chicken-and-egg" problem
  - Co-developing projects covering the whole hydrogen value chain, such as the HYBRIT joint venture, could help address these barriers
  - Joint ventures/local business clusters would create synergies and offer a streamlined way to attain synergies in addition to the benefits of economies of scale and risk management
  - This is relevant for Northern Ostrobothnia, as the region does not yet have significant hydrogen actors as “engines” for green hydrogen transition nor hydrogen as core business
- From business perspective, potential substantial renewable electricity surplus, stable political environment, and high-level research combined with industry cooperation creates an inviting environment for hydrogen-related investments in the region
  - Slow permitting and inadequate zoning are identified as frequent concerns, highlighting the importance of dialogue with public actors and ensuring proper resources and education
- The emergence of a hydrogen economy in the Northern Ostrobothnia would have a positive impact on employment and could create sustained growth in Northern Finland
  - It is important to ensure that the region remains attractive to the workforce to fully realize this potential
- On a wider perspective, the successful exploitation of Northern Ostrobothnia's hydrogen potential would significantly contribute to the decarbonization goals of the Northern Europe
  - The need to cooperate within but also across regional and national borders is seen as an essential element for further development

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Appendix 1.

Hydrogen-related politics & regulations

Relevant directives, regulations and legislations

- The Finnish legislation does not include many mentions of hydrogen
    - Mentions included mostly within the distribution obligation of renewable fuels (446/2007) and clean vehicle procurement targets (740/2021)
- The EU has ongoing plans to introduce new regulations and directives and to renew old ones to reduce GHG emissions
    - Hydrogen targets introduced as a part of these plans and packages
    - The Renewable Energy Directive (REDII/III) and its delegated acts (DAs) play important roles
    - More mentions of renewable hydrogen to be included in the Finnish legislation when EU directives are adapted

Definitions (1/3)

- Renewable Energy [61]
  - *energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, osmotic energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas* (Article 2, RED II)

- Recycled Carbon Fuels (RCF) (low-carbon fuels) [61]
  - *“liquid and gaseous fuels that are produced from liquid or solid waste streams of non-renewable origin which are not suitable for material recovery in accordance with Article 4 of Directive 2008/98/EC, or from waste processing gas and exhaust gas of non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations.”*

    = CCS + fuel production
    → synonym to ”low-carbon fuels” as explained in directive 2009/73/EC most recent proposal

Definitions (2/3)

- Renewable Hydrogen [61]

  - Hydrogen produced with electrolysis powered by renewable electricity, reforming of biogas or biochemical conversion of biomass (as long as the sustainability criteria presented in RED II (2018/2001) are met)

    → The recognized definition by the EU (clean and green hydrogen sometimes used interchangeably)

- Renewable fuels with no biological origin (RFNBO) [61]

  - Article 2, point 36 of RED II:

    "'renewable fuels of non-biological origin' means liquid and gaseous fuels the energy content of which is derived from renewable sources other than biomass"

  - (includes hydrogen, methane, synthetic petrol and diesel, aviation and marine fuels...)

Definitions (3/3)

- Sustainable aviation fuels (SAFs) include… [62]

  - *synthetic aviation fuels (RFNBOs used in aviation),*
  - *liquid and gaseous fuels that are produced from waste processing gas and exhaust gas of non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations,*
  - *advanced biofuels (as defined in Article 2, 2nd paragraph, point 34 of RED II),*
  - *biofuels produced from the feedstock listed in part B of Annex IX of RED II (that comply with the sustainability criteria), and*
  - *biofuels that comply with the sustainability criteria given in RED II and that are not produced from "food and feed crops" are also classified as SAFs before 2035*

Requirements for renewable hydrogen (1/3)

General requirement for hydrogen/RFNBOs/RCFs: [63]

- The use of H2 results in GHG emission savings of at least **70%** (also for recycled carbon fuels)
    - Fossil fuel comparator 94 gCO2e/MJ

→ GHG footprint threshold: **3,38** tCO2eq/tH2

(the calculation rules given in the methodology delegated act)

Requirements for renewable hydrogen (2/3)

General requirements for RFNBO production: [63]

Carbon source for RFNBOs and RCFs cannot be fossil after 2035

- Acceptable sources of CO_2 after 2035 are

1. Direct air capture
2. Biogenic and geological sources
3. Biofuels, bioliquids, and biomass production or combustion that complies with sustainaility criteria
4. Activitities included in ETS that are part of carbon pricing and the CO_2 is incorporated in the fuel before 2036

→ Although the CO_2 cannot be derived from fuel combustion that is combusted solely for the purpose of attaining CO_2

Mentioned in the ”Methodology delegated act” draft of RED II/III

Requirements for renewable hydrogen (3/3)

Guarantees of origin (GO) [64-66]

Required for electricity and hydrogen in case advertised as renewable

- Finextra and Gasgrid Finland responsible parties
- State supported renewable energy no longer exempt from GOs
- Given for a 1 year period at a time for 1 MWh units

When producing renewable hydrogen from renewable electricity

→ the GOs for <u>used</u> electricity need to be cancelled as soon as possible after producing the unit of H2

→ after cancellation new GOs can be permitted for the produced renewable H2

How should renewable H2 be produced? (1/10)

Requirements given the additionality delegated act for renewable electricity production (electrolysis) for renewable H2 or RFNBO production: [67]

Production is renewable if

1. RFNBO production is directly connected to a renewable installation that
   1) starts operation at the same time or later than the fuel production plant (not earlier than 36 months)
   2) not connected to the grid or no power is taken from the grid

2. Connected to the grid but evidence is provided that the power taken from the grid is renewable (rules defines in the additionality delegated act, several scenarios included)

3. Through complying with **additionality**, **geographical** and **temporal correlations** given in the additionality delegated act

How should renewable H2 be produced? (2/10)

RED II/RED III

Additionally delegated act

Draft introduced	20.5.2022
Removed by EP	14.9.2022
Published version	10.2.2023

Additional requirements for power production

Methodology delegated act

Draft introduced	20.5.2022
Published version	10.2.2023

How to calculate GHG emissions of RFNBOs

How should renewable H2 be produced? (3/10)

- Additionality rules

Additionality delegated act introduces more specific criteria for renewable electricity production than RED III: [67]

- Electricity from a direct connection to a renewable installation is counted as fully renewable when:
  - Renewable electricity installation came into operation not earlier than 36 months before the RFNBO production installation, additional capacity can be added no later than 36 months after the renewable installation started operation
  - A smart metering system can be used to monitor that no power is taken from the grid in case there is a grid connection

How should renewable H2 be produced? (4/10)

- Additionality rules

- When is grid electricity counted as renewable? [67]

1. Average production of renewable electricity exceeds 90% in the bidding zone in the previous calendar year
    - the hours of RFNBO production do not exceed the proportion of renewable electricity in the bidding zone
    - Once fulfilled, this share is concidered to be more than 90% in the next five years

2. Emission intensity of the grid is lower than 18 gCO2eq/MJ
    - Once fulfilled, grid electricity in the bidding zone in question considered renewable for the next five years
    - Power purchase agreement required (no more electricity used than produced with the PPA)
    - Conditions on **temporal** and **geographical** correlation must be fulfilled

→ explained in the following slides

How should renewable H2 be produced? (5/10)

- Additionality rules

- When is <u>grid electricity</u> counted as renewable? (continued)

3. Imbalance settlement when can be demonstrated that
   - Renewable power generating installation was redispatched downwards
   - The electricity consumed (for RFNBO production) reduced the need to redispatch by an equal amount
   - E.g. renewable production curtailment (if already a lot of renewable production available)

→ If these three rules are not complied with then electricity can be counted as renewable if the **additionality**, **temporal** and **geographical** correlation are complied with

How should renewable H2 be produced? (6/10)

- Additionality rules

- Additionality [67]
  - Power purchase agreement(s) required
  - Renewable electricity installation came into operation not earlier than 36 months before the RFNBO production installation, additional capacity can be added no later than 36 months after the renewable installation started operation
  - If the renewable installation complied with 36 month rule with a PPA (the rule above) that has now ended, the future PPA for the same renewable installation is also concidered to comply to this rule
  - The renewable electricity installation has not received operating or investment aid, excluding support received by installations before their repowering, financial support for land, or for grid connections, support that does not constitute to new support (e.g. support that is fulle repaid and support for installations generating renewable electricity that are supplying instllations producing RFNBOs used for reserch, testing and demonstration.

How should renewable H_2 be produced? (7/10)

- Additionality rules

- Temporal correlation [67]
  - Before 2030, the temporal condition is fulfilled if the RFNBO is produced during the same <u>calendar month</u> as the renewable electricity
    - Also applies to new storage assets if connected behind the same network connection
  - From 1.1.2030, the temporal condition is fulfilled if the RFNBO is produced during the one-hour period as the renewable electricity
    - Electricity from a new storage asset can be used for RFNBO production if it is charged during the same one-hour period during which renewable electricity that is taken from the grid has been produced
  - Always complied with if the RFNBO is produced during the one-hour period during which the electricity clearing price is lower or equal to 20 €/MWh or lower than 0,36 times the CO_2 tonne ETS allowance price during that period (e.g. if allowance cost $= 80$ €/tCO_2 $\rightarrow 0{,}36 \cdot 80 = 28{,}8$ €/MWh)

How should renewable H2 be produced? (8/10)

- Additionality rules

- Geographical correlation [67]
  - Complied with if at least one of the following conditions is fulfilled

    1. The renewable electricity installation with PPA must be located (or was when it came into operation) at the same bidding zone as the electrolyser

    2. The renewable electricity installation is located in an interconnected bidding zone (also another member state) and the electricity price at the relevant time period is either equal or higher when RFNBO is produced

    3. The renewable electricity installation is located in an offshore bidding zone that is interconnected with the electrolyser's bidding zone

How should renewable H2 be produced? (9/10)

- Additionality rules

Methodology DA:

What are the GHG emissions of the electricity used to produce RFNBOs/H2/RCFs? (per calendar year) [63]

Three scenarios:

1. GHG emission intensity of electricity calculated as in Annex C, methodology DA
2. Enough RES in grid to classify production as fully renewable (0 gCO2e/MJ)
   Condition: ($FLH_{electrolyser} \leq hours_{grid\ marginal\ price\ =\ RES\ price}$)
   If condition not met → grid carbon intensity of **183** gCO2eq/MJ used
3. GHG emission value of the marginal unit in grid (at the time of production)

Additional requirements for renewable hydrogen (1/2)

- Emission Trading System (ETS) [68]
  - Has before only concerned grey hydrogen and synthesis gas produced through reforming or partial oxidation in a larger scale (over 25 tonnes per day) (2003/87/EC)
  - Proposed change
    - Would extend the scope of the regulation to renewable hydrogen and synthesis gas with a production capacity over 5 tonnes per day (Free allowances for renewable production)
    - Free allowances are going to be phased out by 2032

Additional requirements for renewable hydrogen (2/2)

- Carbon Border Adjustment Mechanism (CBAM) [68]
  - Purpose is to prevent the GHG emission leakage to countries outside of the EU
  - Importers of certain goods have to buy certificates to cover the emissions
    - Weekly average price of ETS allowance auctions (€/tCO_2eq)
  - Has been extended to hydrogen (before only applied to iron and steel, cement, aluminium, fertilisers incl. ammonia and electricity)
    - Does NOT include e.g. methanol and e-fuels
  - Into force in October 2023, certificates required after 2026
  - No limit on certificate amounts, a max third of the certificates can be repurchased by the CBAM authority

  - What about H_2 that is exported outside of the EU? Still competitive?
  - HE: risk of H_2 carriers being imported into the EU which are not included in CBAM

Hydrogen targets within transport (1/4)

Transport targets given in RED II amendments:

- **General GHG intensity reduction target 14% reduction target by 2030** (currently in REDII) [62]

The baseline to which the GHG emissions savings is compared to is calculated by the amount of energy supplied to the transport sector times the fossil fuel comparator of 94 gCO2e/MJ.

Binding H2 targets

- At least a **2,6%** share of RFNBOs in the energy supplied to the transport sector by 2028 (**5,7%** by 2030) [69]

→ *RFNBOs (incl. H2) counted 1,2 times their energy content towards this goal*

- At least **1,2%** of RFNBOs and renewable H2 delivered by fuel suppliers to maritime mode starting from 2030 [69]

⟶ Changes not in force yet (uncertainty of the exact values)

Hydrogen targets within transport (2/4)

Alternative fuel infrastructure regulation (AFIR) [70]

- H2 refuelling stations at least <u>every 100 km</u> with a minimum capacity of 2 t/day and 700 bars dispenser [71]
- Liquid H2 at a distance of <u>max 400 km</u> and at freight terminals [71]
- H2 refuelling stations also at urban nodes (passenger terminals, airports, railway stations etc…) [71]

→ AFIR still being debated

Hydrogen targets within transport (3/4)

Distribution obligations (in EU legislation)

- **1,2%** of RFNBOs and renewable H2 to maritime mode (amendments, RED II) [69]
- Distribution obligations on sustainable aviation fuels (SAFs) (ReFuelEU Aviation –plan) [72]

Proposed SAF shares (January 2025-) [72]

Minimum share requirement of SAFs	Minimum share requirement of synthetic aviation fuels (incl. H2)	Minimum shares requirement fulfilled by
2%	0,04%	2025
6%	2%	2030
20%	5%	2035
37%	13%	2040
54%	27%	2045
85%	50%	2050

Hydrogen targets within transport (4/4)

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- **Distribution obligation for renewable fuels**
  (Finnish legislation (446/2007)) [73]
  - A certain percentage of transport fuels must be renewable (~20-30% depending on the year)
    - Includes an additional obligation that must be covered with biofuels and biogas produced from certain raw materials (e.g. waste or straw) or RFNBOs (starting from 2023)
  - Additional obligation
    - An indirect subsidy to RFNBOs since they can be used to cover the minimum share requirement instead of certain biofuels and biogas
    - Includes a minimum requirement (0,2-3,5%) also for certain biofuels and biogas so a small amount of them needs to be used regardless of RFNBOs present (fin. vähimmäisosuusvelvoite)

Additional obligation

Minimum share requirement	Minimum shares requirement fulfilled by
2%	2021-2023
4%	2024-2025
6%	2026-2027
8%	2028
9%	2029
10%	2030

Hydrogen goals within industry (1/1)

- In industry, **50%** of the fossil H2 should be replaced by RFNBO-fuels by 2030, **70%** by 2035 (RED II, article 22a) [69]
  - This concerns energy and non-energy purposes (mining and quarrying, manufacturing, construction, information and communication (e.g. data centres)), but does not include renewable hydrogen other than RFNBOs! (hydrogen from e.g. biomass not counted)
  - Excluding…

    1. hydrogen used as an intermediate product for the production of conventional transport fuels

    → H2 used in production of e.g. methanol and biofuels not counted
    → to avoid double counting (separate goal for transport provided)

    2. hydrogen produced as a by-product or derived from by-products

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