A common vision and roadmap for a hydrogen economy in Ostrobothnia

Work package 3 of the H2 Ecosystem Roadmap -project

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H2 ECOSYSTEM ROADMAP
FOR OSTROBOTHNIA

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HANKEN
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Executive Summary WP 3

The goal of transitioning to a climate-neutral and sustainable society is a key driver for both public and private actors to collaborate on finding new alternatives to the current energy system. The fossil-based system must be replaced by a combination of different clean and renewable alternatives. Green hydrogen can have a significant role in enabling this transition, especially in the decarbonization of otherwise hard-to-abate sectors and as a link coupling different industries together.

Some of the pioneering projects that have to date been initiated and, once realized, will have a significant impact on the development of the hydrogen economy in the region of Ostrobothnia include the demonstration of energy system flexibility (H-Flex-E led by EPV), carbon capture and synthetic fuel production (EnergySAMPO CCU, led by Westenergy), green steel production (HYBRIT led by SSAB), as well as building large scale wind power and methane production plants along the west-coast (such as the CPC Finland led project in Kristinestad) and infrastructure for hydrogen transmission (Nordic Hydrogen Route led by Gasgrid Finland).

The roadmap presented in this work package is a description of the opportunities and key issues related to the development of a hydrogen economy in the region of Ostrobothnia. Different actors across sectors will need to work together, including companies, education and research institutions, as well as public authorities and development organizations.

Based on the project work we give several recommendations for different regional actors to support the development of a hydrogen economy in Ostrobothnia:

- Local decision-makers should put focus on determining the role of hydrogen in municipal and regional strategies and include it as one piece in the puzzle toward climate neutrality. The strategic focus should be combined with directing public funding accordingly.

- Business leaders in pioneering projects are encouraged to be transparent and involve local stakeholders (suppliers, researchers, and public authorities) already in the development process, so that knowledge can accumulate in the region among a broad base of actors.

- There are specific knowledge needs that research and education institutions in the region should respond to. Building a demonstration environment where hydrogen as part of the larger energy system can be studied is one of the areas that should be prioritized. Other important areas include the business models related to the hydrogen economy and developing knowledge of hydrogen safety and standards.

- An actor that coordinates the hydrogen development activities in the region and a structure that continuously supports these activities should be defined. We suggest that the regional development companies establish a Hydrogen Ostrobothnia team that can coordinate activities in the region and do matchmaking between different actors, so that concrete new pilot and demonstration projects related to hydrogen are started.

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1.1 Background

The H2 Ecosystem Roadmap project's goal has been to create an updated picture and common vision regarding green hydrogen in Ostrobothnia. The founding principle of the project work has been that knowledge and plans to develop the hydrogen ecosystem in the region must be developed in collaboration with different actors. In addition to an updated picture of the status of hydrogen activities and projects in the region, a common vision is needed that drives development forward.

1.2 Objectives

The objective of the work has been to organize events for actors in the region to discuss opportunities and challenges related to the development of the hydrogen economy in Ostrobothnia A. Furthermore, the objective has been to identify the most significant demonstration projects and their impact on the development of the hydrogen economy. In addition to disseminating knowledge of the already started demonstration projects around hydrogen, the objective has also been to identify possible new pilot projects and R&D activities around hydrogen production, distribution, storage, or usage that various actors in the region could have an interest in collaborating on.

1.3 Activities and questions of interest

In WP 3 our activities included arranging five seminars/webinars with workshop activities, compiling and analyzing the information gathered during these workshops, and summarizing the results of these into a vision and a roadmap for a hydrogen economy in Ostrobothnia. Tables 1 and 2. summarize the content and results of the workshops that were arranged.

This WP has specifically sought to answer the following questions of interest:

- What concrete pilot projects are the actors in the area undertaking?
- Which scenarios for the hydrogen economy in Ostrobothnia (-2030) can be presented? (Moved from work package 1)
- What types of models (technical, business, and ecosystem) and demonstration environments related to green hydrogen solutions can be created that benefit both training and the development of business skills in SME companies in the region?
- How can we in practice promote the conditions for a hydrogen economy in Ostrobothnia and support business and export opportunities for companies in the region?

Table 1 Workshops that were arranged in the H2 Ecosystem Roadmap -project

WORKSHOP THEME	1. Opportunities and challenges with the hydrogen economy for the region of Ostrobothnia	2. From ideation to project plan - facilitating the development of new hydrogen project initiatives	3. Vision and Scenario Workshop of the Hydrogen Economy in Ostrobothnia
Date	11.11.2021	10.2.2022	2.9.2022
Number of participants	32	62	30
Business	13	23	12
Research and Education	8	17	12
Regional development/ Municipalities	11	22	6

Table 2 Workshop content and main results

WORKSHOP THEME	1. Opportunities and challenges with the hydrogen economy for the region of Ostrobothnia	2. From ideation to project plan - facilitating the development of new hydrogen project initiatives	3. Vision and Scenario Workshop of the Hydrogen Economy in Ostrobothnia
Content	The workshop was arranged face-to-face as part of the kick-off seminar for the H2 Ecosystem project and the first meeting for the National Hydrogen Network led by the City of Raahe. The workshop participants brainstormed around key issues regarding the opportunities and challenges with the development of the hydrogen economy in the Ostrobothnia region. The workshop was facilitated and documentation was done on the screen.io digital platform.	The workshop was held as a webinar, where 5 different project ideas were presented and discussed in 5 different thematic groups. The thematic groups included were: Theme 1. Green hydrogen-powered CHP systems: Case H-Flex-E (Kenneth Widell, Wärtsilä & Niko Toppari, EPV) Theme 2. Transport and tanking stations: Case REH2 (Martina Wettin, Nilsson Energy) Theme 3. Large-scale hydrogen storage: Case Kanäs (Mats Brandt, Österbottens förbund) Theme 4. Energy community: Case Southern Ostrobothnia (Rasmus Hautala, Dynamo Närpes & Kristiinan kaupungin elinkeinokeskus) Theme 5. Digital solutions for market synergies: Case H2 Market Platform (Ashkan Fredström & Emma Buss, Hanken). The workshop content was documented on the digital platform Flinga.	The workshop was arranged face-to-face and key actors in the network were invited to participate to create a common vision of the future hydrogen economy in the region of Ostrobothnia. The future scenarios were discussed by dividing participants into three themes: Hydrogen production, including the source of green hydrogen, method of production, and minimizing production costs. Hydrogen transmission and storage, including storage and transmission technologies and local business opportunities with these. Hydrogen usage and consumption, including the end-users of green hydrogen, households, and/or industrial usage, the role of the hydrogen as energy storage. The scenarios were to be evaluated both in the short term (2-3 years) and the long term (5-10 years). Questions that were discussed focused on: What are the key success factors of developing the hydrogen economy in our region? How can we avoid the obvious and not-so-obvious pitfalls? Who are the different actors that will be needed and what are their roles?
Main results	The views of the participants were gathered and thematized. Key issues with the development of the hydrogen economy: 1. Defining the business cases and focus areas in the region, 2. Developing the capabilities and know-how needed/talent acquisition, 3. Bringing public authorities up-to-date with regulations and standards, 4. Mapping the hydrogen value chain and actors in the region, 5. Focused flag-ship pilot projects in the region and securing funding for these, 6. Coordination of actors and activities with different roles, 7. Combination of different financing instruments for initial projects. These issues have been taken into consideration in forming the recommendations from the project.	Three of the five themes that were discussed are presented in this report as new project initiatives, which could be attractive for regional actors to start new RDI collaboration projects. Themes 1 and 2 are presented in this report under already initiated pioneering projects since the actors leading them are defined. More focused matchmaking should be done for detailed planning of the new project ideas to be started. Additionally, every project idea will need a dedicated leader with proper funding for the planning phase. These activities were outside this project's scope and need to be continued in the next phases of developing the hydrogen ecosystem in the region.	Based on the discussions in the three different groups, the discussion leaders made summaries of the main points and issues that were raised by the participants. These views were gathered and are incorporated into the presentation of the vision for the hydrogen economy in Ostrobothnia -chapter (4) in this report.

1.4 Introduction

The goal of transitioning to a climate-neutral and sustainable society is a key driver for both public and private actors to collaborate on changing the current energy system (European Commission 2020). The fossil-based system must be replaced by a combination of different clean and renewable alternatives. Green hydrogen can have a significant role in enabling this transition, especially in the decarbonization of otherwise hard-to-abate sectors and as a link coupling together different industries (Capurso et al. 2022). Transitioning to a hydrogen economy means replacing the existing hydrogen markets, that use grey fossil-based hydrogen, with green and carbon-neutral hydrogen alternatives and using them in new applications that are otherwise hard to decarbonize.

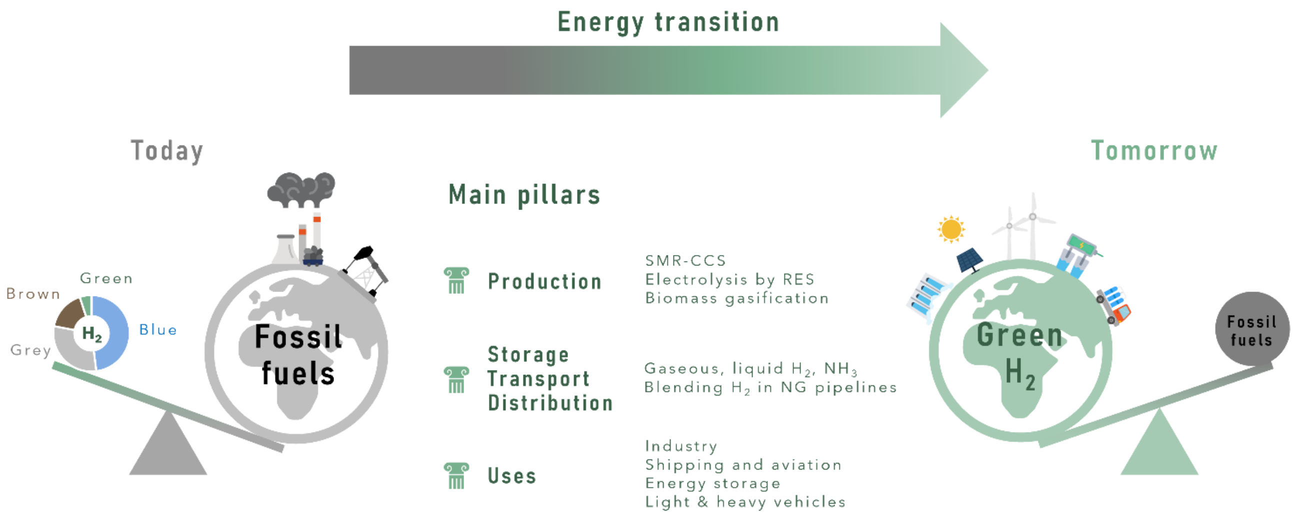

Figure 1 Transitioning from a fossil-based energy system to a green hydrogen economy (adapted from Capurso et al., 2022)

Besides being at the forefront of fighting climate change, developing the hydrogen economy is seen as a pathway to support the energy self-sufficiency of regions. This has during the year 2022 become an increasingly topical question due to the international security and energy crisis.

The European Union and many other nations have formed their own hydrogen strategies, which direct public innovation and infrastructure investments into developing the hydrogen sector. The aim is to support climate neutrality goals and at the same time support business opportunities and the EU's economic growth. The government of Finland has also included hydrogen as one part of its climate- and energy strategy for 2035, where different measures are presented for enabling the development of the Finnish hydrogen sector. There is now strong political support for hydrogen, P2X, and carbon capture initiatives, and up to 150 million euros of public funding is directed toward initiating different collaboration and demonstration projects related to these green technologies.

When we look at the hydrogen economy's development today, we need to understand that we are on the first steps of a new and emerging socio-technical environment (Geels 2010). Transitioning from a fossil-based energy system to a system relying on renewable and intermittent electricity is not only a technical and technological challenge but a great social challenge as well. When new socio-technical environments are being formed, varying technologies are tested and experimented with (Walrave et al. 2018).

H2 Ecosystem roadmap (for Ostrobothnia)

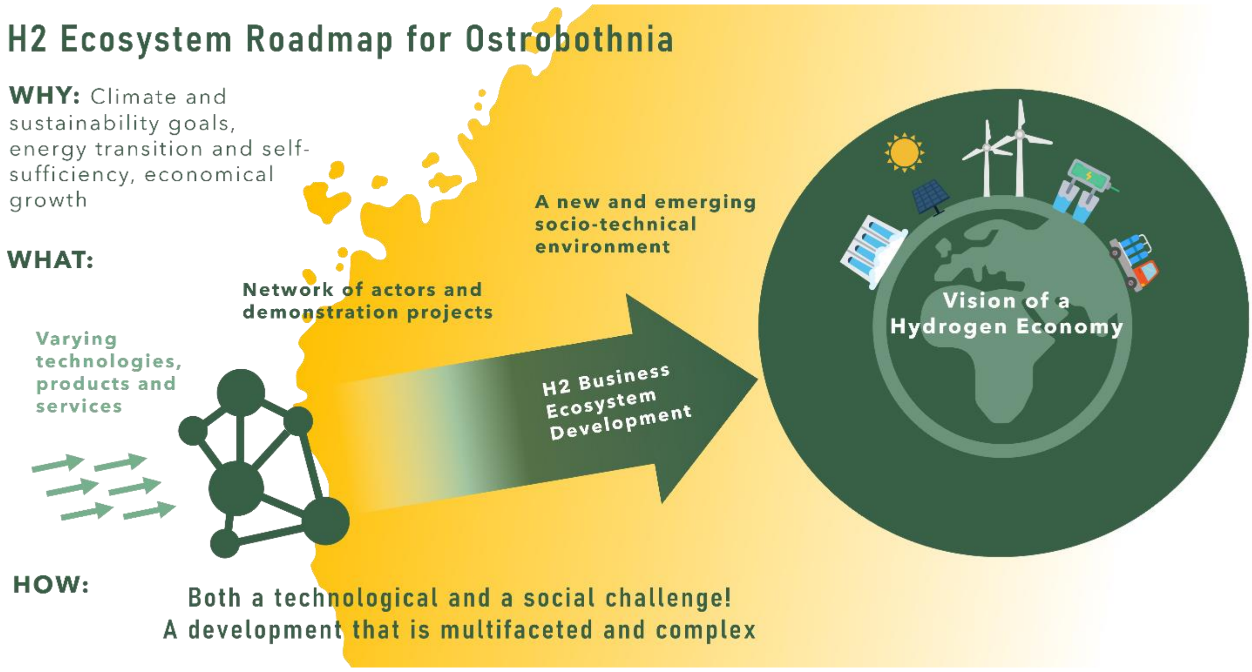

Figure 2 The hydrogen economy as a new socio-technical environment

At the moment the technical solutions for the hydrogen economy include both market-ready solutions that have been in use for decades as well as new solutions that are still in the technological development and testing phase (IEA 2020). However, the system-level solutions that are visioned as part of the emerging hydrogen economy and the specific value propositions that they aim to offer are now developed for the first time. This means that they will require a substantial amount of modeling and experimenting to find the optimal business model for how the ecosystem can operate (Talmar et al. 2020; Walrave et al. 2018).

Local pilot and demonstration projects are vital for the development of hydrogen-related system-level know-how and business opportunities in our region. It is in the pilot and demonstration projects that are realized that knowledge is built up and working business models are designed and implemented. When a new socio-technical environment is emerging, the different technologies that are commonly developed in siloed innovation niches within research institutions or in the industry need to become aligned. For green hydrogen business cases to be realized complementary technological products and services from a multitude of different actors need to be integrated. The pioneering projects that are now being initiated in our region are good examples of all the required system-level alignment that needs to take place for green hydrogen-related solutions to be realized.

The following chapter presents six significant pioneering hydrogen projects that have had an impact on the region of Ostrobothnia. In chapter 3, four new project ideas that have been identified are presented, that could provide feasible collaboration opportunities for business actors and research institutions. Chapter 4 presents the roadmap and vision of the hydrogen economy in Ostrobothnia for 2025 and 2026. The report is concluded with a summary section on recommendations for promoting the development of a hydrogen economy in the Ostrobothnia region.

2 Pioneering hydrogen demonstration projects that impact the development of the hydrogen economy in the region

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2.1 H-Flex-E - Balancing the energy grid

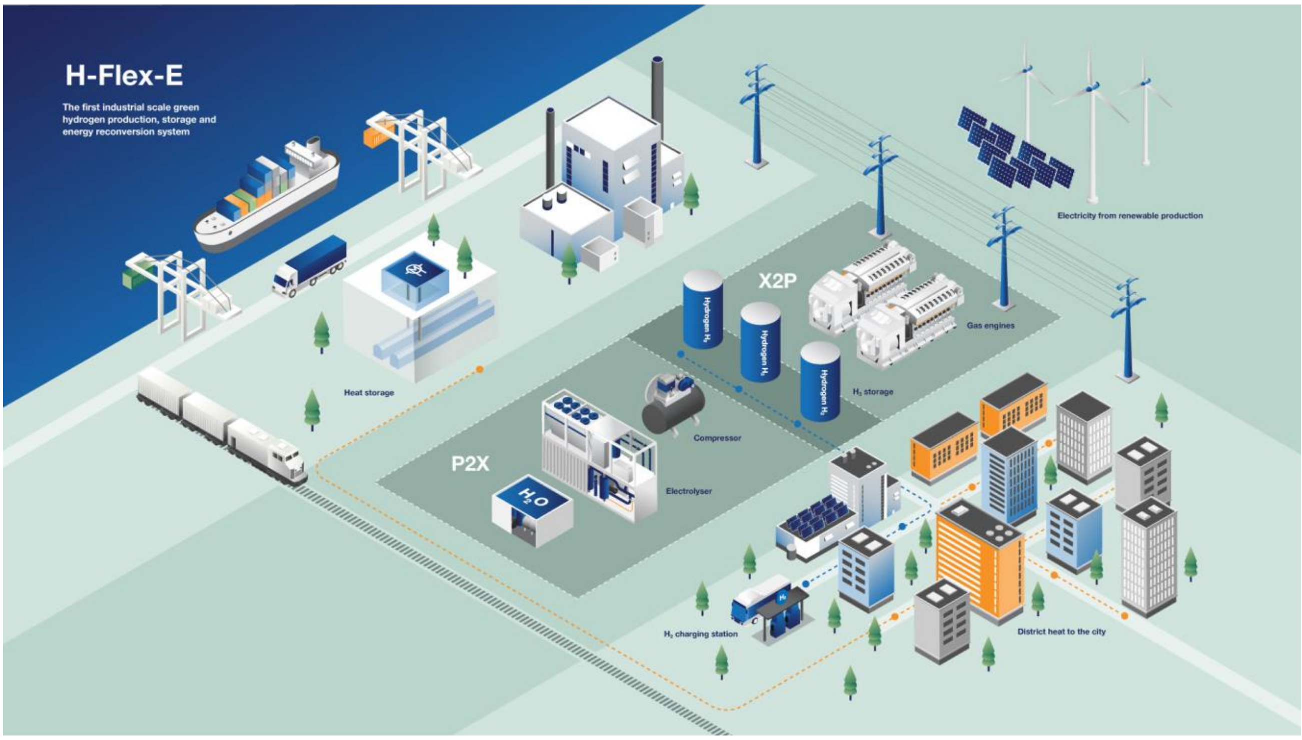

Figure 3 The H-Flex-E system solution (Vuola, 2021)

At the beginning of January 2021, Wärtsilä, EPV, Vaasan Sähkö, and the City of Vaasa, presented a joint development project regarding green hydrogen named H-Flex-E (Vaasa, 2021). This project aims to develop the first green hydrogen production, storage, and energy reconversion system (P2X2P) at an industrial scale, based on the involved actors' common vision of a decarbonized future. The project was granted investment support of 14 million euros by the Ministry of Economic Affairs and Employment of Finland (EPV, 2021). The H-FLEX-E project can provide balancing power to the electricity grid and has the potential to become a flexible, green grid stabilator for future energy markets.

The partners involved in the joint project each have a complementary role and contribute with different important resources that are needed for the ecosystem to operate. The system operation is described on a general level in Figure 1. The energy companies (EPV and Vaasan Sähkö) are responsible for producing and distributing electricity from renewables, such as wind and solar. The excess energy is converted into hydrogen through electrolysis of water and then stored as compressed gas in a power-to-x (P2X) process. The reconversion to electricity through gas engines is handled by Wärtsilä, marked as X2P. Wärtsilä is at the moment developing the technology for combustion engines operating with 100% hydrogen. By integrating the P2X2P system into the local heat storage for district heating, the overall efficiency of the hydrogen conversion can be maximized.

The project is a full-scale demonstration project, in which the participating actors have the opportunity to test and develop the technology and know-how needed in the production, storage, and use of hydrogen. The electrolyzer size is planned at 7,1 MW and the plant is estimated to be in service for the local area for up to 20 years. For Wärtsilä's part, the interest is to develop innovative sustainable energy solutions, and in this project, especially the efficiency and safety of hydrogen-running combustion engine technology. The local energy companies want to build the capacity for storing renewable energy in integration with the district heating system and increase control mechanisms related to the energy markets. The planned solution could provide a significant part of future emission-free systems for heat and electricity production. The plant will be located in Vaasa and its operation is estimated to start in 2024. The goal is to demonstrate a motor power plant running on 100% renewable hydrogen by the end of 2026, and after that to use 100% renewable hydrogen or other renewable fuels in the plant.

Business Case

The business case is built on the idea that, when there is an overflow of energy on the market and the electricity price drops, it can be converted and stored as hydrogen for future needs. Then, when the demand increases and prices are high, hydrogen can be reconverted into electricity. The customer is the energy company EPV Energia which sees the value of the system in its ability to bring more flexibility into the energy market and optimize renewable energy production and storage on the system level.

Additionally, the partners see a business opportunity in piloting an energy production solution that is suitable for global export markets. This type of system-level solution would be unique on the global market and demonstrate a new way of thinking in the integration of different entities using renewables and carbon-free fuels. The future export potential for this type of solution is estimated to be up to 5 billion euros in annual export.

Impact on the regional development of the hydrogen ecosystem

The H-Flex-E project is the first industrial-scale ecosystem demonstration project in the region that has received national innovation funding. It is one of the two flagship projects in EnergySAMPO, that provides a new model for leading companies to innovate and develop new technological solutions together for global export. The launch of the H-Flex-E project has been central for directing media attention toward the hydrogen activities that are commencing in the region and high expectations are put on it as a case example of the system-level solutions that can be built through ecosystem partnerships.

The specific operation model of this system solution is developed for the first time, which means that modeling and experimenting need to be done to find the optimal model for how the ecosystem will operate. Knowledge is thus built up gradually and interactively with the partners in the process, as the projects move forward. The project owners will need to define what are all the specific components needed, establish the technological and safety-related standards, and coordinate the value-creating activities of all the partners involved. Close cooperation with the local permitting authorities and experts with knowledge regarding hydrogen safety is required.

Knowledge sharing is a critical aspect of how the pioneering demonstration projects can support the development of hydrogen-related know-how and the overall business opportunities in the region. It is within and through these that knowledge is built up and accumulated and the development trajectory of the hydrogen economy in our region will take shape.

2.2 Energy Sampo CCU - Producing green e-fuels

The Energy Sampo CCU project is the second ecosystem project that is planned under the EnergySAMPO innovation platform (Westenergy, 2022). The project aims to build a new generation liquefied synthetic methane (LSNG) production plant for Westenergy's waste-to-energy plant in Mustasaari municipality, located next to the city of Vaasa. The goal is that the plant would be operational already in 2025. The central idea of the concept is to utilize carbon capture (CCU) to produce a carbon-neutral synthetic fuel that could become an addition to biogas that is already produced in the area.

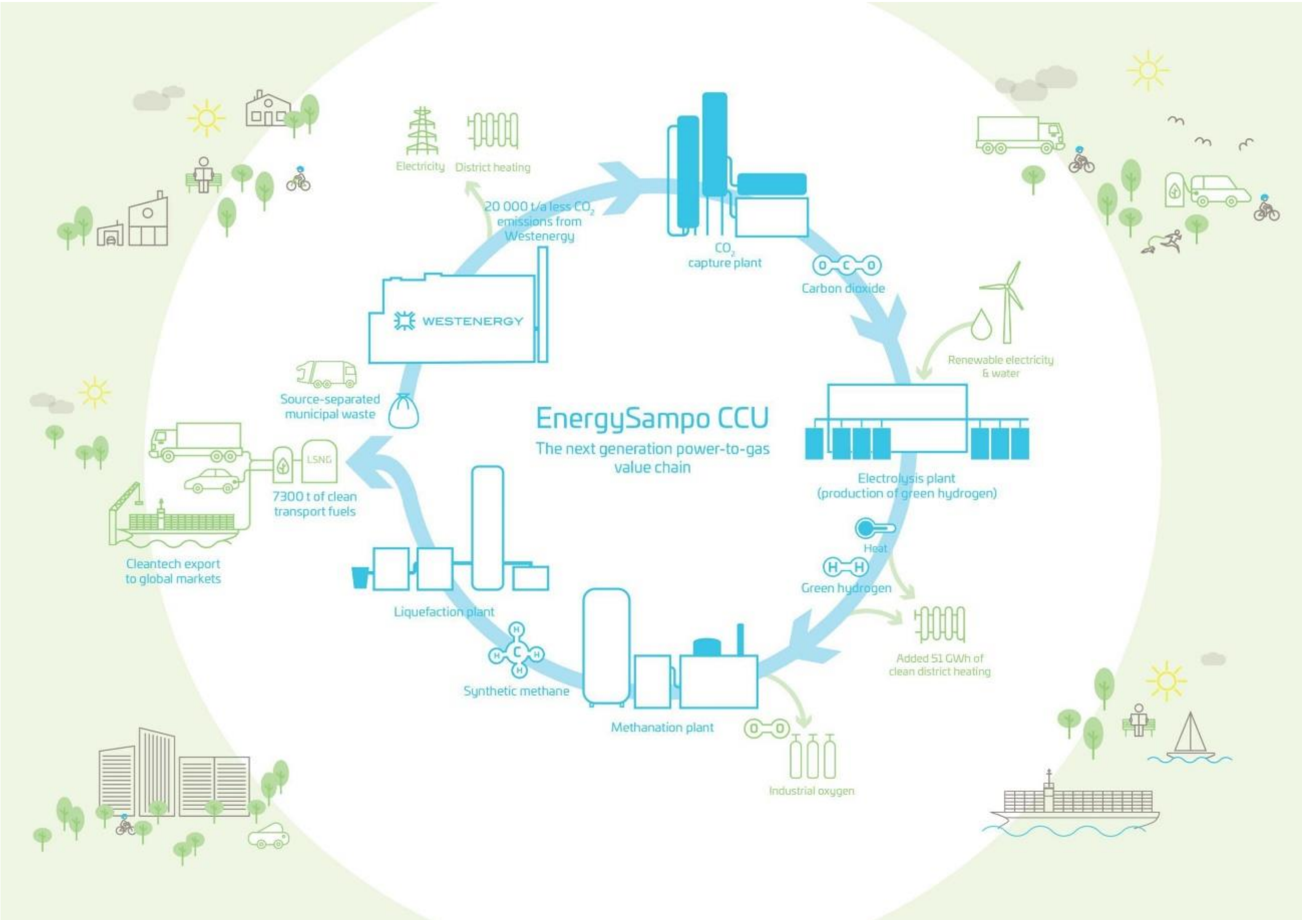

Figure 4 EnergySAMPO CCU (Westenergy Oy 2022)

H2 Ecosystem roadmap (for Ostrobothnia)

The planned production capacity would be 7300 tons of LSNG per year (112 GWh), which would be enough for the annual needs of nearly 500 heavy-duty vehicles, a thousand trucks, or even two passenger car ferries sailing between Vaasa and Umeå in Merenkurkku (Ripatti, 2022).

The operation model of the plant can be divided into four main processes. The first process starts at Westenergy where carbon dioxide emissions from the flue gasses of its waste-to-energy plant can be captured. Apart from capturing carbon dioxide, Westenergy is also producing electricity and heat from burning the waste. The second process that is integrated into the solutions is water electrolysis which produces hydrogen and oxygen gas. The electrical power needed is mainly supplied from renewable wind energy and the water used is recycled water, thus minimizing the use of natural resources. The third process combines carbon dioxide from the carbon capture unit and hydrogen from the electrolysis through a methanation process into synthetic methane gas. The fourth process strives to optimize storage size and capacity for the synthetic methane by cooling it down to -162 degrees Celsius, to produce the liquified synthetic methane (LSNG).

The EnergySampo CCU ecosystem is described as a platform for cooperation and development and is led by Westenergy. The other partners that have been announced are Oy Danfoss Ab, EPV Energia Oy, Ab Stormossen Oy, Vaasan Sähkö Oy, WOIMA Finland Oy, and Wärtsilä Finland Oy. AFRY Finland Oy acts as the technical and economic planning consultant for the project and the Technology Centre Merinova has an assisting role in the consortium.

Business Case

For Westenergy's part the business case of the project resides on the company being able to decrease its carbon emissions by 25%, and through the further capture and utilization of biogenic CO_2, have the potential to even a carbon negative footprint. Through a modular scale-up of the project, Westenergy could reach carbon neutrality by 2030. On top of the existing business of providing heat and electricity production, further revenues from the plant can come from selling the produced synthetic methane (together with partners) for example to the local heavy-duty transport sector, and the oxygen that could be sold to the battery industry sector that is also developed in the region. The solution utilizes existing gas infrastructure in the region, which gives a further advantage to the business case of converting green hydrogen to a synthetic e-fuel.

As in the case of the H-Flex-E project, the LSNG plant will provide a test bed for new technological solutions that can be developed in the region and have an export potential that extends to billions of euros. For the technology partners, the demonstration project can act as a showpiece of their know-how of building innovative modular and scalable solutions in the field of low-emission carbon capture and power-to-gas technologies. The vision is that the technology partners can offer their products developed for this solution either as self-standing components or together as a total system solution, depending on the future customer needs. Potential future customers include over 500 European waste-to-energy plants alone, adding up to a several billion euros market potential. The solution could also be offered to a range of other industries with points of carbon capture such as steel, concrete, pulp&paper as well as bioenergy.

Impact on the regional development of a hydrogen ecosystem

The goal of the project is to support both the regional and national goals of reaching a carbon-neutral future in line with the EU's "Fit for 55" goals, both by offering a solution for decreasing the carbon footprint of the local region as well as providing a demonstration platform for a new type of energy solution that can have a global handprint. This project, once realized, has equally significant potential as the H-Flex-E project, to demonstrate and build up the knowledge base for the integration of technologies across business and industry segments and to build up the level of sector coupling in the region.

The project can also become an example of how the orchestration of an ecosystem of partners can be achieved, which is crucial, for all of the different technologies and the actors providing them to become aligned. This will benefit especially the know-how of the partners involved. However, it will also provide an opportunity for know-how to accumulate in the region, if the project partners are willing to share learnings in the project with the regional network.

Because the orchestrator firm (Westenergy Oy AB) is a so-called mankala operator, they have been active and willing to collaborate with the local universities and education institutions, which has greatly benefitted the local knowledge accumulation. This exchange has a mutually beneficial positive impact on the development of the hydrogen ecosystem as well. By including locally present companies in the demonstration project ecosystem, it gives these companies a chance to demonstrate their technologies and get important visibility and a reference towards future potential customers. It also promotes the capacity of regional actors to collaborate and build the required knowledge and capacity to offer these solutions for global export.

2.3 Hycamite – From methane to hydrogen and pure carbon

Hycamite TCD Technologies is a Kokkola-based company developing technology for producing clean hydrogen and pure coal from methane. More specifically the business idea is to decompose methane from natural gas or biogas into hydrogen and carbon. By doing so, no emissions are released into the atmosphere. The company's goal is to commercialize a technology that has been developed by several European universities. The process is built around removing carbon from the methane molecule (CH4), and as a result, producing both pure carbon and clean hydrogen. Pure carbon is the more valuable raw material, but both pure carbon and clean hydrogen are the products that can be sold to customers. (Hycamite, 2022)

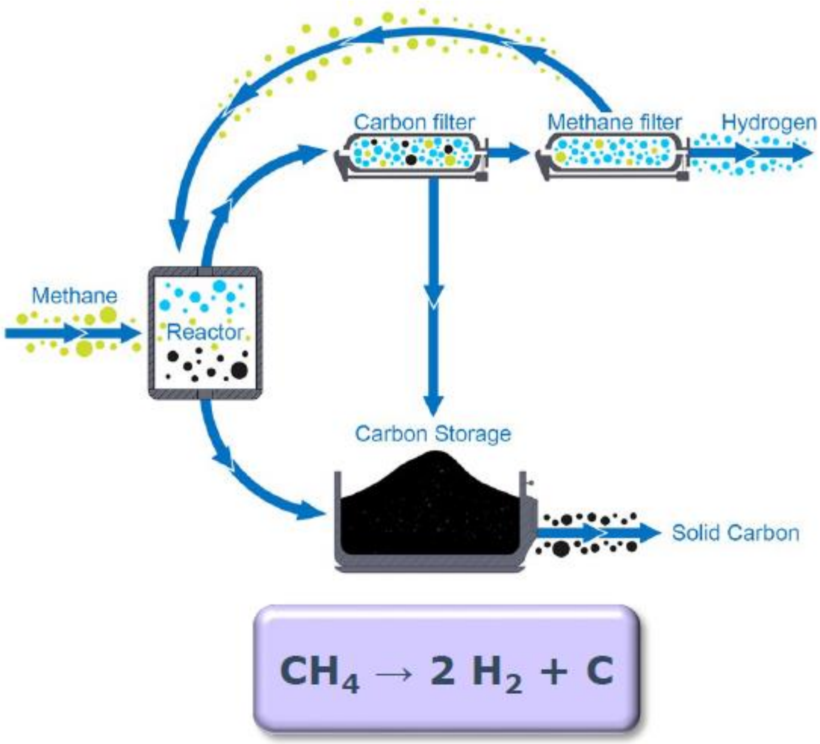

Figure 5 Hycamite hydrogen production process (Hycamite 2022)

Business Case

The technology that Hycamite is commercializing is targeted to fulfill a growing demand within the industry for decarbonized industrial processes and provide crucial raw materials that are carbon-free. The two products that are offered, clean hydrogen and pure carbon, both have their specific customer groups and markets that are targeted. The first potential off-taker that is announced includes Jervois Global, that is a cobalt producer with operations also in the Kokkola Industrial Park, and will explore the possibility of using Hycamite's hydrogen in its reduction process. Potential off-takers of pure carbon are especially seen in the electric automotive industry.

Because the technology uses methane as raw material, the price of natural gas will of course impact the business case. However, it is possible to use biogas equally well, thus enabling the production of hydrogen to be decoupled from fossil sources and to rely on locally produced methane as well.

Impact on regional development of the hydrogen economy

Despite its small size, Hycamite TCD Technologies is one of the central actors driving forward hydrogen network activities both on the National level in Finland and the region of Ostrobothnia. Through its memberships in different international and national hydrogen organizations, it is well-positioned to promote the hydrogen economy's development and the sustainable energy transition in general. It's leaders are among others a members of the European Clean Hydrogen Alliance (ECH2A), which lobbies for an ambitious deployment of hydrogen technologies by 2030 establishing the EU as a global leader in the sector. The company also has presence in the European Clean Hydrogen CEO roundtable on renewable and low-carbon hydrogen production as well as in the CEO roundtable on clean hydrogen in the energy sector.

Another significant network that the company is co-leading is the BotH_2nia network, which goal is to support the building of a large-scale hydrogen economy around the Gulf of Bothnia. *BotH_2nia* is the umbrella brand for hydrogen-related initiatives in the region and the network serves as a collaboration platform for different actors in the Baltic Sea area, including SME companies, research and education institutions, as well as municipalities, and other governmental actors. It aims to facilitate communication between projects and promote hydrogen-related technologies and products in the Gulf of Bothnia.

Hycamite is developing novel technologies through several project partnerships with researchers, with partners inside the Kokkola industrial park area in which it is headquartered, and for global exports. The company is a case example of how also small actors can have a significant impact on the development of an emerging technological field and the knowledge ecosystems that develop around it. By having a clear vision and being able to communicate it persuasively, a strong mission, and capabilities for leadership, a small company can have an impact that is greater than its size. By networking and mobilizing resources from an ecosystem of actors, it is possible to drive forward the development of the sustainable energy transition and the business opportunities related to it.

2.4 Decentralizing energy production and storage integrated with buildings and HRS

Operators within the construction- and real estate sectors are looking for ways to decrease building emissions and increase energy self-sufficiency (Berg, 2022). Since it has been calculated that buildings stand for about 35 percent of the CO2 -emissions in the EU (European Commission, 2019), the possibility of constructing emission-free buildings combined with hydrogen refueling stations (HRS) could be an attractive opportunity for regional actors to cut emissions and develop new business. Additionally, the decentralized production of energy and energy self-sufficiency is seen as an important factor in increasing regional energy self-sufficiency and security of energy supply (Skarta, 2022).

Figure 6 Emission-free buildings (WasaGroup 2022)

The decentralized green hydrogen solutions are based on providing a solution for energy self-sufficiency using renewables to produce green energy (heat and electricity) coupled with hydrogen production for providing intermittent energy storage. The decentralized and nearby production of renewable energy can be a feasible option for municipalities and industries, that are not connected to a district heating system, to make the green transition toward carbon neutrality. The solution combines the construction of a renewable energy power source with solar panels or wind turbines, a green hydrogen production unit (with optional oxygen and waste heat capture), hydrogen gas storage, and fuel cells for the reconversion of hydrogen to electricity and heat.

Business Case

The business case is based on the idea that hydrogen is the best decentralized way of storing energy that is produced by wind power or solar panels. When decentralized overproduction of electricity is used to make hydrogen in the summer, there is no need to buy electricity for heating in the winter. Hydrogen can provide long-term storage of energy even for years. In the long term, if the waste heat can be used to heat the property, the round-trip efficiency of hydrogen is better than that of batteries. This can increase efficiency to over 90 percent.

Especially at moments when energy prices are fluctuating, this solution can provide a valuable option for customers that want to secure a steady flow of electricity to a predetermined fixed price. The value proposition relies on offering independence from external energy price changes and disruptions in energy input, by providing an option of a self-sufficient energy system. The system includes residential-scale electrolysis equipment, hydrogen storage, and fuel cells, all installed at the customer site.

A significant piece in making the solution commercially feasible is to combine the construction of an energy-self-sufficient building with a hydrogen refueling station. Because hydrogen systems are scalable, the same equipment can be used for making energy both for real estate and to be provided as a transport fuel for sale. This way the profitability of the investment will improve even more.

Impact on the regional development of a hydrogen ecosystem

The building and construction industry is in dire need of solutions that can lower the carbon footprint of the sector, and this solution could become a feasible alternative for actors also in the region of Ostrobothnia. Although hydrogen has been used safely in the industry for decades, its use is strictly regulated, and the requirements for equipment are strict, there is a lack of knowledge of its use in the proximity of residential areas. The municipal residential area planners and fire/security departments are not yet knowledgeable of the specific regulatory standards, thus pioneering actors will be required to do a substantial amount of educating all stakeholders involved.

For the real estate business, this solution is already a viable option, but industry experts are still waiting for stronger signals of a turning point for the traffic sector. In Finland, the focus for decarbonization of the personal vehicle sector has focused on BEVs and the first phase of decarbonizing heavy-duty road transport is focusing on e-fuels. Only a few actors are promoting FCEVs for person or heavy-duty traffic in Finland, compared to Sweden and other European countries for example, where investments into hydrogen fueling stations and hydrogen fuel-cell-driven vehicles have been much more pronounced. A dedicated demonstration project for the region that would involve a partnership of actors from the building sector, a decentralized hydrogen solution provider, as well as the transport sector would be required to pilot and showcase the feasibility of the solution. This type of demonstration project is at the moment being planned in Utajärvi, in the Northern Ostrobothnia region. But it could also be a good option for other smaller municipalities in the Ostrobothnia region to support their climate neutrality targets and fast-track the green transition.

2.5 CPC Finland and Prime Capital AG - project Kristinestad

On the 27th of September the wind power company, CPC Finland Oy announced that it has entered a joint venture with Prime Green Energy Infrastructure Fund (PGEIF) for the development, construction, and operation of an up to 200 MW green hydrogen/e-methane facility in Kristinestad, Finland. Prime Capital AG, which manages the PGEIF is the main investor of the project and an asset manager specializing in alternative assets including i.a. renewable energy. The role of CPC Finland is to provide engineering, procurement, and construction services to the wind farm during the construction phase. During production, the company will provide technical and commercial asset management services. (CPC Finland, 2022)

Figure 7 CPC Finland and Prime Green Energy Infrastructure Fund to form a joint venture for constructing up to 200 MW green hydrogen/e-methane facility in Kristinestad, Finland (CPC Finland 2022)

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On top of the green hydrogen/e-methane facility, CPC Finland is building new wind power facilities, with a total capacity of 600 MW. The wind farm is going to be connected to the grid through Fingrid KD Kristinestad and later KD Arkkukallio substation. The estimated electricity production is calculated to cover at least 80 percent of the total electricity needs of the green hydrogen/e-methane facility. The permitting process of the site, located in Karhusaari, Kristianstad, has already started. The permitting is expected to last for 18-24 months after which construction of the plant is started. The estimated start of the operation of the facility is Q4 2025. (CPC Finland, 2022)

Business Case

The business case of the project is based on the production of synthetic e-fuels for Central European gas markets, where actors, prompted by Europe's green policies and a phase-out of Russian fossil gas, are looking for alternatives to replace the existing gas supply with green alternatives. The business case is further supported by that the infrastructure for the use of synthetic fuel is already in place since the chemical composition of the gas is equivalent to the fossil alternative. Estimations have been made of the possible production volumes of the plant that can equal up to 27 000t methane annually, which would result in an estimated revenue of 27 M€ and addition of 3,75 M€ from emissions trading through the carbon captured to produce the methane. Additionally, connection to the Finnish national electricity grid provides the opportunity to sell electricity directly, when spot prices are high. (Hautala, 2022)

The technological solutions used in the project are well-proven and approved, thus no technological development is included in the solution. The project company has experience with similar types of projects elsewhere in the world, and this particular project is building on the know-how that has been acquired through previous projects. The availability of cheap green electricity from the wind parks is a prerequisite for producing the green hydrogen at a low cost, which will be guaranteed through PPA contracts, and is a central factor supporting the investment to be made on the west coast of Finland. Additionally, the location in close connection to a harbor will provide ample opportunities for the export of the product to customers who are located away from the place of production.

Impact on the regional development of a hydrogen ecosystem

This is the first scale-up project of large-scale hydrogen production that has been announced in Finland. Thus, the project is not a pilot project, but an industrial scale-up, but would nevertheless be the first bench-mark project of its kind. In the visions that have been presented, such as the one Minister of Economic Affairs Mika Lintilä presented at the Wasa Future Festival in 2021, several of these types of production plants could be built along the Finnish west coast, utilizing the good wind conditions, the availability of CO2 emission points of capture, the strong electricity grid network, as well as the harbor infrastructure (Hautala, 2022). Foreign investors' interest in directing investment funds into these types of sustainable business projects has in recent years increased significantly. This is both a huge potential for the Ostrobothnia region, but also a challenge to secure that the local interests and benefits of the projects are protected.

If these types of large-scale production plants are built in the region of Ostrobothnia, they will also start to have a significant impact on the need for a trained workforce, who have the skills and education to work in this type of industrial environment. One production plant is estimated to employ 30-40 persons full-time, most of them being blue-collar workers (Hautala, 2022). Preparing for this talent need is therefore an important part of the impact on regional development that needs to be considered, especially due to the particular requirements related to the use and utilization of hydrogen.

On top of the talent requirements of the company operating the plant, there is a substantial amount of knowledge development that needs to take place in the region also outside the company building the project and operating it. The regional permitting authorities, land planning in municipalities as well as national Finnish Safety and Chemicals Agency (Tukes) need to be up-to-date with the requirements that a realization of an industrial-scale plant of this size will involve. National, as well as regional knowledge exchange and coordination, therefore needs to take place.

2.6 Hybrit – Decarbonizing the hard-to-abate steel industry

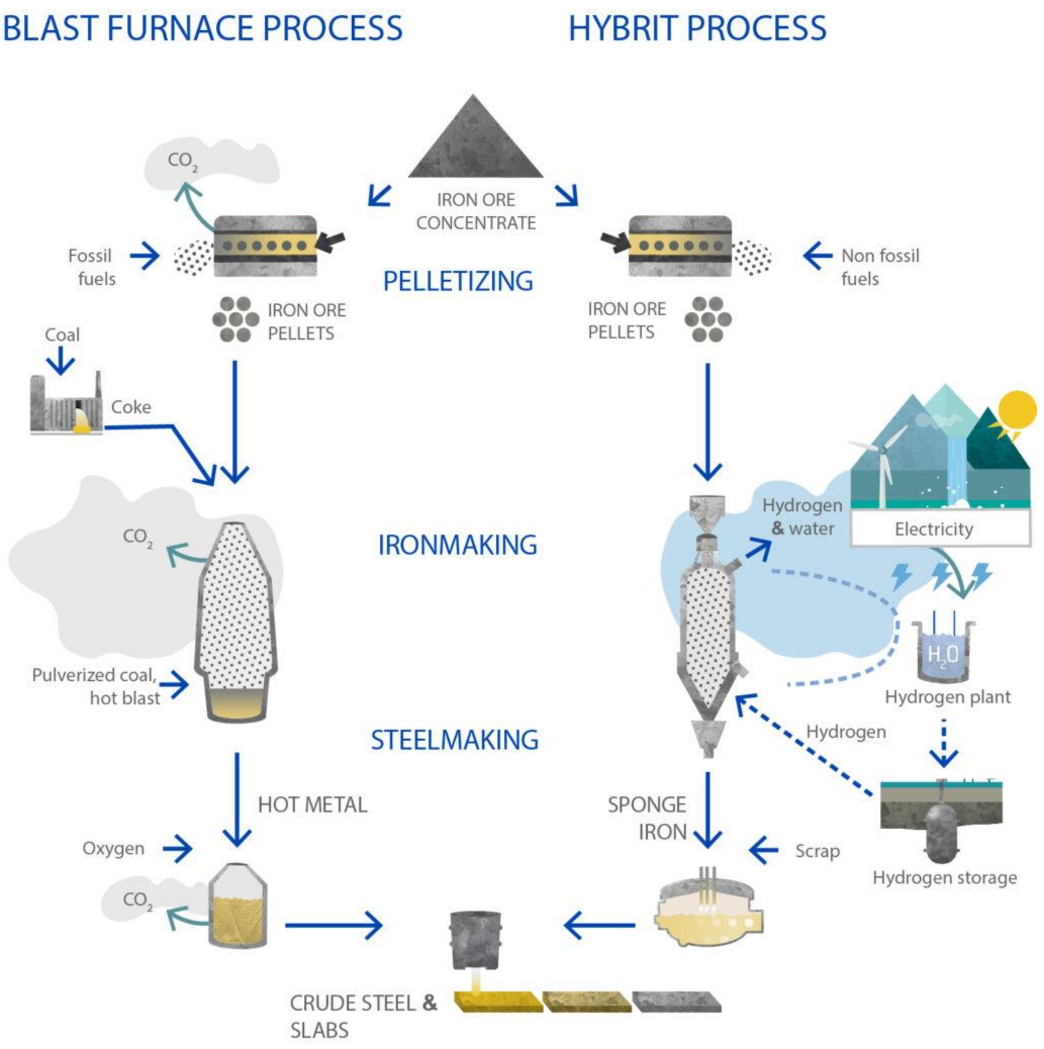


Figure 8 Comparison of the blast furnace and the direct reduction steel-making processes (HYBRIT Development Ab 2022)

The HYBRIT project was established in 2016 and stands for Hydrogen Breakthrough Ironmaking Technology (HYBRIT, 2022). Currently, this is the largest demonstration site for green hydrogen in Sweden. This project has also the potential to have a substantial impact on green hydrogen demand in Ostrobothnia through the connection with Raahe's SSAB steel production plant. The technology developed within the HYBRIT project has the potential to reduce almost all the carbon dioxide emissions from the production process. The first commercial deliveries are planned to be on the market in 2026. When it is implemented on large scale by 2030, it means that also the Raahe SSAB plant will be largely fossil-free, cutting the amount of Finland's total industrial emissions by at least 7 %.

The production process is illustrated in Figure 6. The mining company LKAB provides iron ore. The energy company Vattenfall is responsible for providing fossil-free electricity and hydrogen to the iron production process. SSAB produces green steel. In the first stage of the steelmaking process, iron ore is turned into iron by removing oxygen. Coal and coke have traditionally been used in a blast furnace process, which has made steel production highly carbon-intensive. This step is now carried out using the hydrogen-based HYBRIT process. The hydrogen that is used is produced from water by electrolysis using only fossil-free electricity. The byproduct of this process is water and no CO2. The result of the HYBRIT process is solid iron (iron sponge), which is then melted in an electric arc furnace. Only fossil-free electricity and fossil-free fuels are used in the entire process, which makes the end product fossil free.

Business Case

SSAB is committed to the green transformation of industry and eliminating CO2 gas emissions from its processes and promotes the agenda as a critical environmental and business decision. Although the production costs and therefore also the end price of green steel products are higher than for the traditional alternative, SSAB sees that customers along the value chain are demanding more environmentally friendly alternatives. It is therefore also a significant image issue for all actors in the industry. SSAB and partners from the automotive industry have already announced partnerships for introducing fossil-free steel into vehicle production. SSAB is at the moment the leading steel producer that has committed to and is investing in fossil-free steel production, but other steel producers are already following suit. By getting a head-start in the green race, SSAB believes that investing now in infrastructure and processes that meet future environmental standards will make it even stronger in competing in the future.

Impact on the regional development of a hydrogen ecosystem

The SSAB steel plant in Raahe is estimated to demand up to 12 TWh of fossil-free electricity and up to 150 000 tons of green hydrogen annually (BotH2nia, 2022). The total estimated demand for fossil-free electricity for steel carbonization in the Bothnia Bay area is in a conservative development scenario estimated to be 25 TWh annually (LUT, 2021). The importance of abundant and affordable electricity is a central concern among a majority of industry leaders when considering hydrogen's role in the decarbonization of energy-intensive industries as a whole, but also regarding the steel sector in particular (Öhman, 2022; Valtioneuvoston kanslia, 2022). According to the latest estimates and analysis provided by Fingrid and Gasgrid, Finland has good potential to meet this demand and even exceed it to start exporting green hydrogen for global markets (Fingrid&Gasgrid, 2022). The steel industry's need for green hydrogen is also one of the major drivers for the vision and plans of constructing a hydrogen pipeline around the Bothnia Bay ranging from the Vaasa-Kokkola region, through Kemi, Tornio all the way to Luleå and Örnsköldsvik on the Swedish side (LUT, 2021).

From a regional development perspective, the impact of the HYBRIT project and the decarbonization of the steel industry in the Bothnia Bay region is one of the most demanding in terms of infrastructure needs and investment costs. There is an increase in wind power production planned in the region at the moment, which will result in substantial investments in building the wind parks themselves, grid capacity extension, as well as energy transfer infrastructure either through grid connections or if the electricity is converted into hydrogen, through hydrogen gas pipelines. A moderate estimate for the hydrogen economy infrastructure in the Bothnia Bay area sums up to a total of 78 billion euros and an ambitious estimate of up to 129 billion euros. (LUT, 2021)

The availability of affordable energy will be the critical bottleneck in realizing the carbon neutrality targets. A prerequisite for this is the massive and timely investments that are needed and require both political support in terms of land use and permitting as well as substantial public funding. Since the impact on nature and the landscape overall are pervasive, careful consideration and more comprehensive studies on the sustainability impacts of this development trajectory are acutely needed.

2.7 Nordic Hydrogen Route - Bothnia Bay hydrogen pipeline

Figure 9 Bothnia Bay hydrogen pipeline (Gasgrid Finland Oy, 2022)

Gasgrid Finland Oy and Nordion Energi Ab (Sweden) have started a cooperation under the European Hydrogen Backbone (EHB) initiative, which is an initiative that plans a pan-European dedicated hydrogen transport infrastructure. This initiative has joined 31 European gas infrastructure companies to work together to accelerate the development of the hydrogen economy and respond to the critical demand of building up necessary transport infrastructure for hydrogen. The Nordic Hydrogen Route is according to the partnering companies a natural next step for assessing on a more advanced level the hydrogen- and hydrogen infrastructure potential in the Nordic region.

H2 Ecosystem roadmap (for Ostrobothnia)

The stated long-term objective is to "build up a cross-border hydrogen infrastructure in Bothnian Bay region and an open hydrogen market by 2030" and this way "drive decarbonization, support regional green industrialization, economic development, and European energy independence" (Gasgrid 2022). This is planned to be achieved by building a network of pipelines through which hydrogen can be efficiently and reliably transported from producers to customers. In the first phase of the pipeline development, the infrastructure can provide a cost-efficient local hydrogen storage option. In the following phases of the project, the infrastructure that is built will enable the operation of an effective and reliable Nordic hydrogen market.

The companies have estimated that the total system investment is expected to be in the range of 3.5 billion Euros. This estimation includes both the expected funds needed to build new pipelines as well as the systems closely connected to this infrastructure, such as the compression systems. Reservations to the scale of the investment are still made because several factors will have a significant impact on the total investment cost of the system. These include for example the number of connections and compressors, routing specifics, and more precise supply and demand figures. The investigation phase is funded by the partnering companies themselves, while a strategy for raising development capital for the following phases is prepared.

H2 Ecosystem roadmap (for Ostrobothnia)

Figure 10 Estimated timeline for planning, design, construction, and operation of the Bothnia Bay pipeline network (Gasgrid Finland Oy, 2022)

Business Case

The reason for the collaboration project is rooted in both companies' shared view of hydrogen as a technology that will have a significant impact on the future energy system. For many sectors, such as steel and fertilizer industries, direct electrification is not feasible as a decarbonization solution. To reach the EU's climate goals renewable, and low-carbon gases like low-carbon hydrogen have an important role to play. A central customer promise of the project is thus to guarantee a regional supply of hydrogen to regional demand and enable climate neutrality for both the industries using it and Finnish and Swedish citizens.

The companies estimate that there is a potential demand for hydrogen at around 65 TWh/a and foresee that developing the cross-border transmission infrastructure and a Nordic hydrogen market will enhance domestic actors' ability to meet this demand.

Gasgrid Finland and Nordion Energi estimate that building hydrogen pipelines will be up to 2-4 times more cost-efficient, than transporting renewable energy through powerlines from the site of electricity production to the final user of hydrogen. Transportation of hydrogen through pipelines is seen as a central means to reduce the overall cost of using hydrogen. The cost of transporting hydrogen through pipelines is expected to be in the range of 0.1-0.2 €/kg H2 / 1-2 SEK/kg H2.

A further justification for the project is that economies of scale can be attained through building an extensive transmission network, which will allow diverse actors open access to the hydrogen market. This will also further the commodification of hydrogen and decrease risks and costs for new investors. The project can also enhance energy system integration and ensure full utilization, by alleviating some of the central issues related to the increase of wind energy, by providing an alternative storage option.

Impact on the regional development of a hydrogen ecosystem

The Nordic Hydrogen Route is to date the most ambitious cross-border hydrogen infrastructure project that has been announced in the Bothnian Bay region. By building up this infrastructure the partnering companies can accelerate the creation of a hydrogen economy in the region and boost new investments that support the local regions' access to green and competitive energy. If realized, the hydrogen pipeline infrastructure around Bothnia Bay will have a significant impact on the energy system transformation and the overall development of the hydrogen economy in the region. Significant potential for businesses to operate in different parts of the hydrogen economy value chain will then emerge and the development of a new hydrogen industry can create opportunities for new jobs and economical opportunities.

However, the societal aspects of the project have not yet been studied in detail. The project partners claim that the project most probably has high social acceptance because there is only limited visual interference related to a gas grid compared to electricity grids. However, building the grid connections underground through vast land areas will certainly have a substantial impact on nature, although robust permitting processes are in place to ensure that community needs are addressed in the project.

For the project to succeed, there will be a need for clear regulatory standards and funding schemes at both national and European levels. The project partners have actively lobbied for the Nordic Hydrogen Route project and started to work with the respective political bodies to help shape regulations. For a project of this scale, it will be vital to leverage the knowledge and experience of all stakeholders involved. Thus, also a new type of cross-sector collaboration, not only between businesses, but also between the government, regional authorities, and landowners (municipalities and private) will be needed.

3 New identified pilot- and demonstration project ideas

Besides the pilot and demonstration projects that have been identified as the key initiatives driving forward the development of the hydrogen economy in the Ostrobothnia region, the H2 Ecosystem Roadmap -the project has identified several new pilot- and demonstration project ideas that could support the development of the hydrogen economy in the region. Next, we shortly present three identified new project ideas, which were among those discussed in the second project workshop that was arranged on the 10th of February 2022. The summaries presented below are based on the cases discussed at the event, where 62 people participated in 5 different thematic groups (the two other themes discussed involved H-Flex-E and the decentralized energy solutions that were presented in the previous chapter). The participants represented the good distribution of different triple-helix actors: 17 from universities, 23 from company representatives, and 22 from regional development or municipalities. The three pilot projects that are presented here in this report are being developed further by some of the involved actors in the workshop. The fourth demonstration project idea has been taken by the company representatives in the steering group of the project and both researchers in the project team and other steering group members expressed interest in collaborating further on this project.

For each project, a short summarizing presentation is given of the background and the key challenge that were discussed by the participants in the workshop. We also present the basic idea of a new pilot or demonstration project that could be initiated to support the development of the hydrogen economy in the region of Ostrobothnia.

3.1 Case Kristinestad - sustainable ecosystem development project

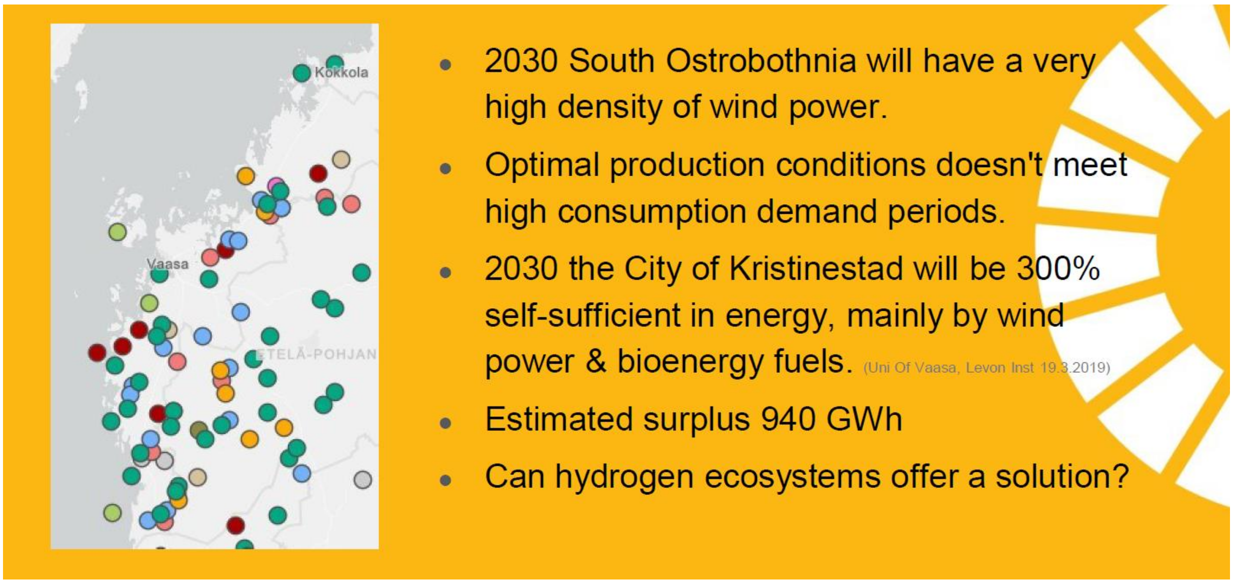


Figure 11 Case Kristinestad - background

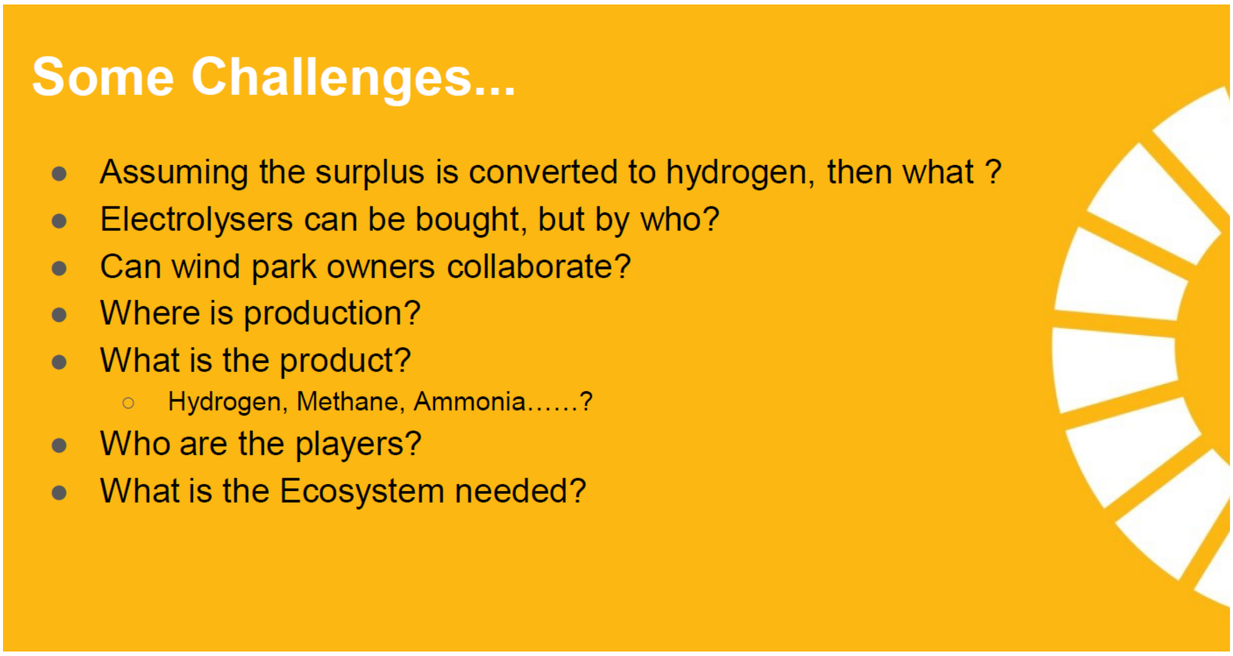


Figure 12 Case Kristinestad - stated challenges

The energy system-level solutions for the vast amounts of new wind power that are going to be built in the region in the coming years need to be solved. As was discussed in the presentation of both the HYBRIT project and the CPC Finland case previously, converting renewable energy into hydrogen and further refining it into synthetic e-fuels is seen as an alternative to feeding all the produced electricity into the national grid.

International project development companies are looking for large-scale sustainable investment projects and leading both wind park building projects and production plant construction projects, have actively started to negotiate these types of investments to be located in Finland. The national grid company is interested in the projects from the point of view of grid balancing and building the connection to the national grid. Municipalities on the other hand in which these wind parks and the hydrogen and synthetic e-fuel plants are being built are looking for ways to increase the benefit of these projects for the local region.

Thus, many different interests and motivations play a role in directing the development of these initiatives. Contrary to a general perspective, the question is not so much technical since these systems rely on off-the-shelf technology. Neither is it a question of project financing either, because there is a strong consensus among industry experts that funding is available, and for example, large foreign investment funds are actively looking for "green" big-scale investments, especially in the Nordic countries. However, the specific business cases that would be most beneficial to the local region, the ecosystem models, and the possible sector coupling and industry synergies of the projects are still far from clear. These are currently done case by case and there is a clear need to get better insight into both the development process, the final operation model of the ecosystem, as well as the business cases that can be built. From a local development point of view, it would be important to support the development in a direction that is most favorable to the sustainability and economic and social prosperity goals of the region.

A pilot project should be initiated that focuses on building up the knowledge of best practices for organizing the network of actors involved in building a sustainable ecosystem solution. Special focus should be put on producing an "*Ostrobothnian model*" for organizing actors on the ecosystem level, where the different needs and interests of the local actors are aligned for the sustainable transition of the hydrogen economy to be realized.

3.2 Case Kanäs - Hydrogen storage demonstration project

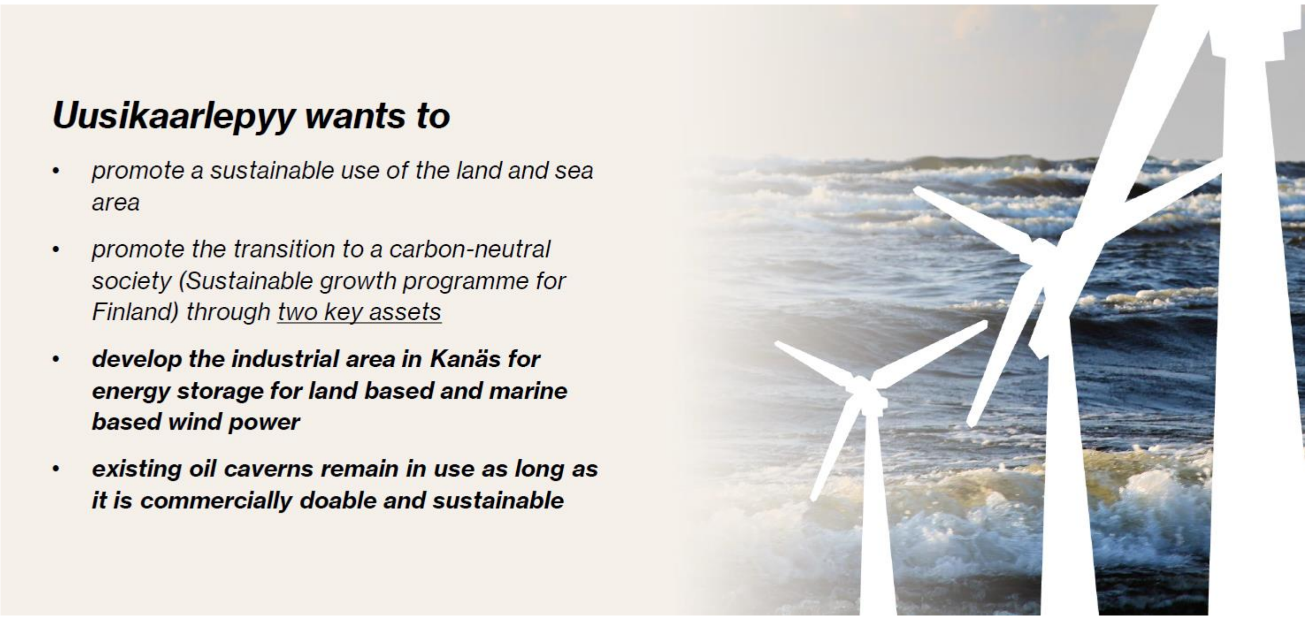


Figure 13 Case Kanäs - background

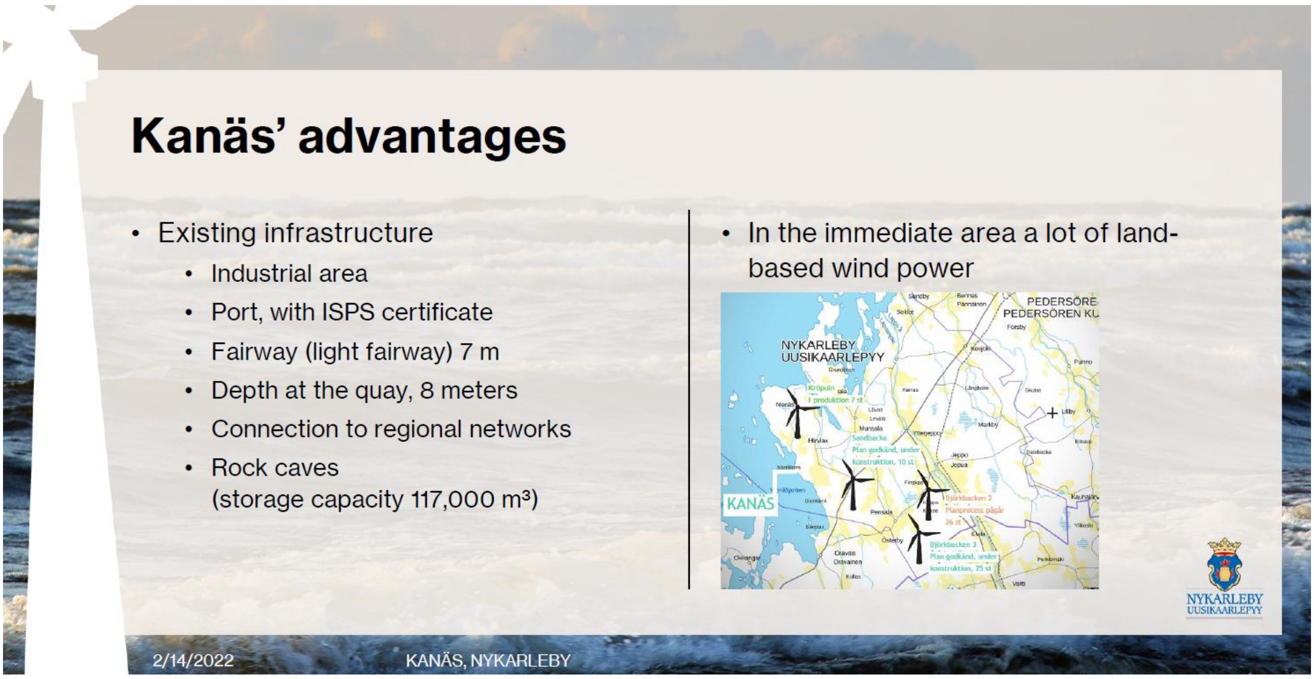


Figure 14 Case Kanäs - advantages of the site

Hydrogen storage is one of the key challenges discussed as a technological barrier preventing the scale-up of the hydrogen economy. The feasibility of large-scale storage of hydrogen has been studied in the European context for example salt caverns. For Finland, these types of geological storage options do not exist. However, old oil caverns that are no longer in use might provide an alternative. One such location is in Kanäs, in Uusikaarlepyy municipality in Ostrobothnia.

The pilot project idea is to study the feasibility of utilizing this location for hydrogen (or other green fuels) storage and how it could support the municipality in its transition toward carbon neutrality. One of the challenges is that the district heating is located rather far from the area of the oil cavern and thus poses questions for how to ensure industry synergy and a good level of sector coupling. Additionally, there could be other synergies that can be related to the industrial area as such and the nearby harbor in particular.

The focus of the project idea is in this case more technical and technological because the technological choices are not straightforward and the commercial feasibility of large-scale storage of hydrogen has not yet been determined. However, the project would also be a good case for building the model of ecosystem organizing, since the actors that need to be included are diverse (among others wind power operators, the local municipality and the local energy company, hydrogen and other e-fuels storage solution providers, harbor companies) and how their interests could be combined is a key question for determining the feasibility of the solution.

This pilot project could provide the region with an opportunity to develop flagship hydrogen or other e-fuels storage demonstration project. Since hydrogen storage on large scale is an understudied area of research, especially in Finland and there have not been any large-scale hydrogen storage demonstration projects yet, this would be a niche where the region could stand out as a pioneering region. Additionally, it would provide an interesting case for reusing and refitting fossil-based industry infrastructure for greener alternatives and enhancing municipal green transition.

3.3 Digital platform demonstration - optimizing the hydrogen market

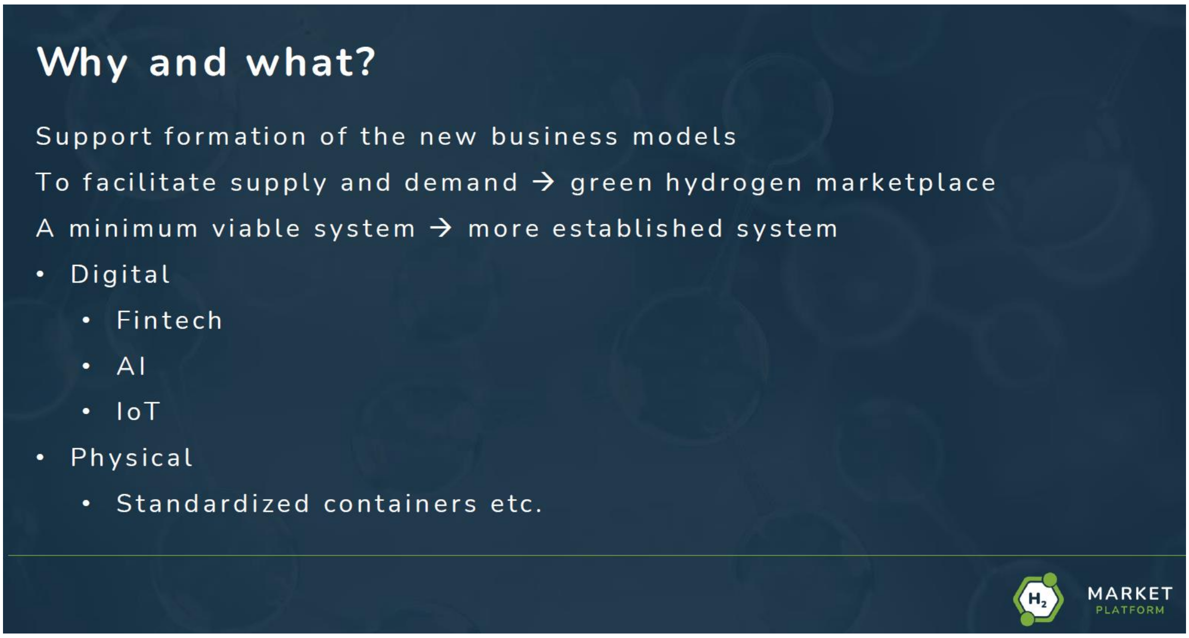
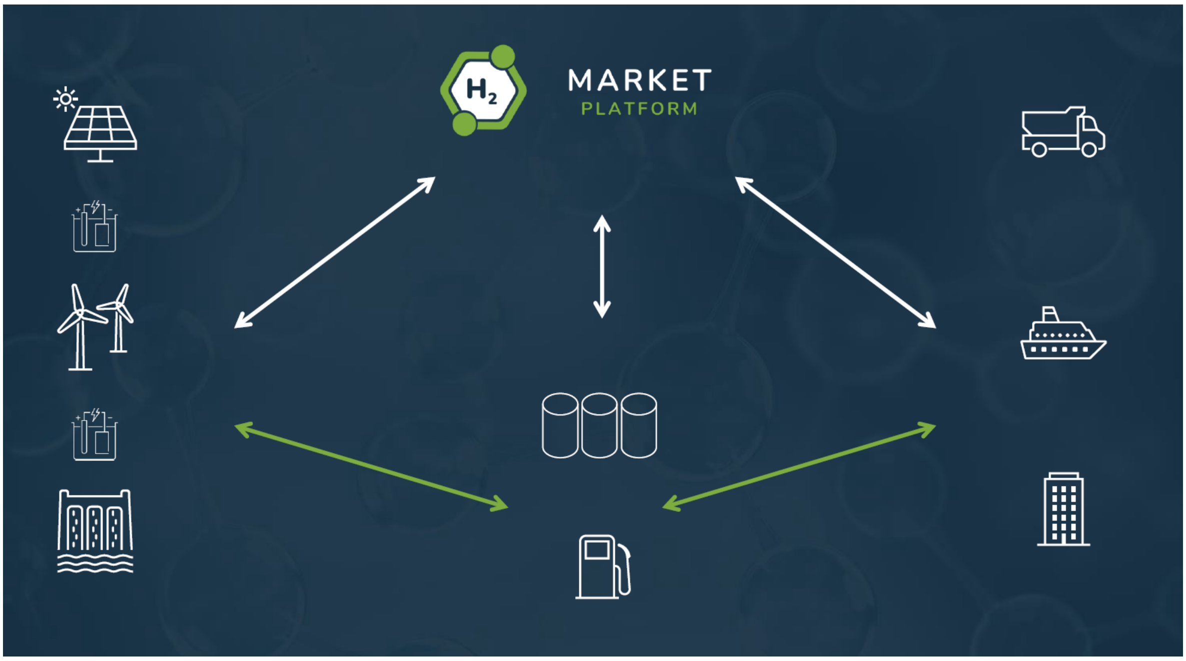


Figure 15 Digital platform demonstration background



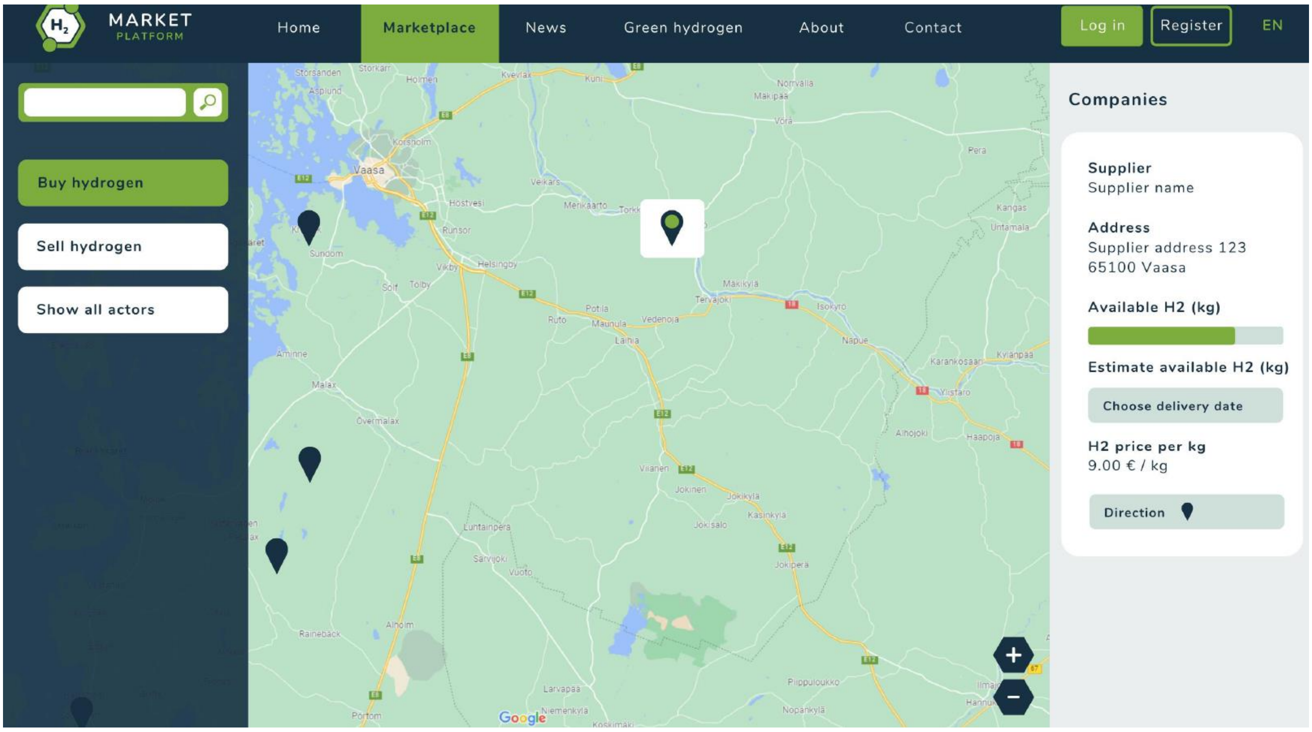


Figure 16 Digital market platform visualization

To optimize the green hydrogen production processes as well as efficiently manage supply and demand, advanced ICT solutions are needed. A good Energy Management System (EMS) and/or a market platform with AI and machine learning features could provide opportunities for supporting the profitability of future hydrogen businesses. The key challenge of building the hydrogen market is how customers and producers of hydrogen can find each other and how the demand and supply side of the market can be met. This project idea suggests developing a small-scale demonstration pilot of the type of digital system that could be provided to optimize hydrogen production and demand matching challenges and solve this need. Some regional business actors have expressed their interest in developing this type of digital solution. However, the hydrogen market is still at such an early development phase, that the pilot project would probably be more feasible as an early-stage RDI project than a project supporting the commercialization of this type of solution.

3.4 Energy System Demonstration project - developing system-level know-how

Building know-how of the technical functioning of hydrogen and its coupling with different technologies in the whole energy system is essential if there is an ambition to support the development of the hydrogen economy as a whole in the region. There is still a clear lack of detailed technical and technological and business understanding of hydrogen's role in the whole of the energy system. Therefore, the steering group of the project discussed that the development of a small-scale energy system demonstration environment would be important to build so that different actors in the region, both students and others, would get a tangible demonstration of how green hydrogen production and use work in real life.

In Technobotnia there is already a small-scale demonstration using electrolysis, but the equipment is very simple and old. Research on energy systems is on a high level at the University of Vaasa and inside the Vebic-FREESI research platform. It would be very important to build a demonstration environment that would not only demonstrate the functioning of an electrolyzer but demonstrate a whole energy system. However, this will require substantial investments, which are not readily available.

A small-scale physical hydrogen demo environment could therefore be coupled with a digital simulation environment where the integration of hydrogen into the large energy system could be modeled in more detail. Building a project together with project partners that have the skills and knowledge that are currently lacking in Vaasa would be essential (such as chemical engineering). The local companies have the resources and know-how to aid in constructing the digitally simulated environment. One possibility would be to connect with a lab internationally that already has this demonstration environment and showcase it here.

There is a clear demand both for a physical and a digital demonstration environment of the green hydrogen-based energy system solutions that can be built. A project focusing on building this type of lab in connection to the university campus area or at another suitable site in the region could thus be started.

4 H2 Ecosystem Roadmap - Presenting a vision of the hydrogen economy in Ostrobothnia

With input from Ossi Koskinen, Kjell-Owe Ahlskog and Kenneth Norrgård

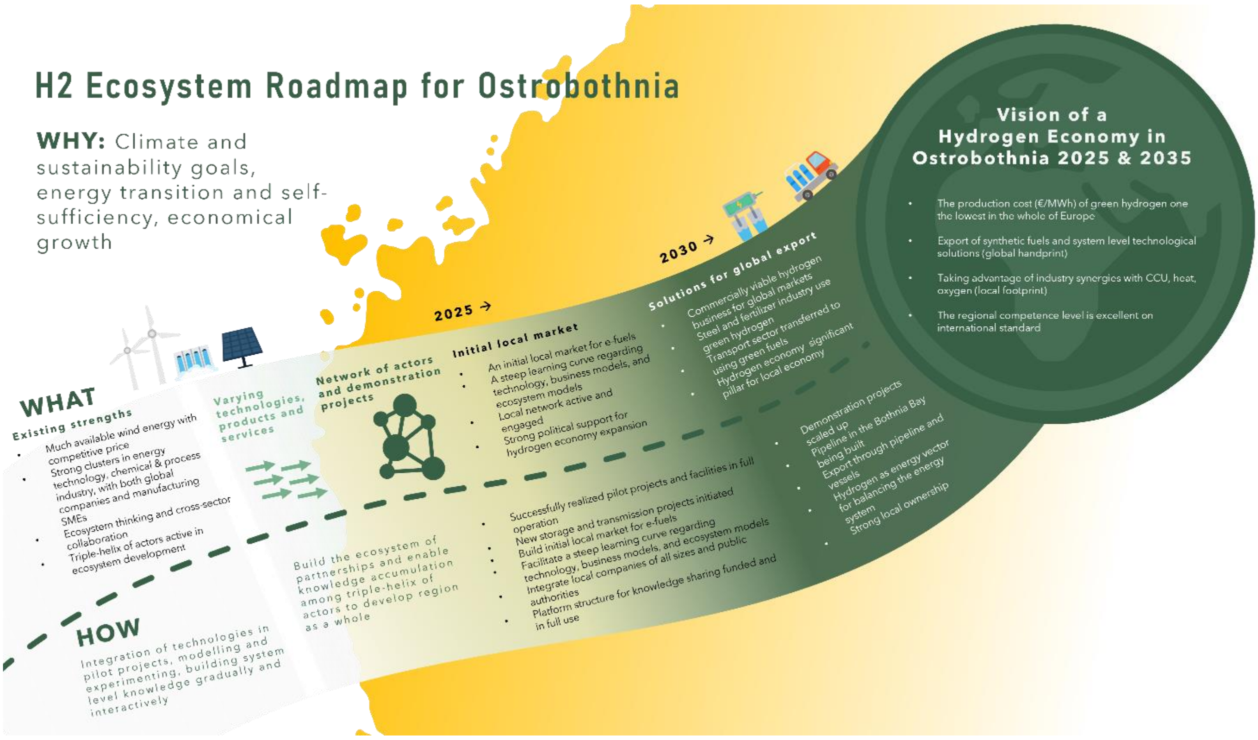


Figure 17 The H2 Ecosystem Roadmap for Ostrobothnia

The goal of work package 3 has been to create a roadmap for the development of a green hydrogen ecosystem in Ostrobothnia. The roadmap summarizes in a visual form the *why*, *what,* and *how* of developing the hydrogen economy in the region. The objective of the roadmap is to facilitate a broadened understanding of the need for preparing the region as a whole to be involved in developing the business opportunities of hydrogen as part of a CO2-neutral sustainable future. We hope that it will aid in creating a shared understanding and a common vision for the future, that can drive development forward.

Results from the visioning and scenario workshop that was arranged on the 2nd of September[1] form the main part of the content of the analysis underlying the roadmap. However, key points that have been discussed in interviews and other workshops with different stakeholders during the project are also incorporated into the analysis. The aim of the scenario and visioning workshop was to involve participants from the triple-helix of the region to give their input in the creation of a common vision for where Ostrobothnia could be heading in terms of the hydrogen economy of the future.

The next section begins with a description of the most significant factors impacting the development of the hydrogen economy in the Ostrobothnia region. This is followed by SWOT analysis and three different scenarios for the development of the hydrogen economy in Ostrobothnia. The next chapter concludes the work package 3 report with a set of recommendations for action points for different regional actors, suggesting ways of promoting the development of the hydrogen economy in practice.

4.1 The most significant factors impacting the development of the hydrogen economy in the Ostrobothnia region

The following sections describe the most significant factors that impact the development of the hydrogen economy regarding hydrogen production, transmission/storage, usage, and hydrogen knowledge and capabilities.

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[1] A general summary of the workshop content and participants was provided in tables 1 and 2 in chapter 1 of this project report.

4.1.1 Hydrogen production and optimization

Production of carbon neutral hydrogen is at the moment mostly focusing on green hydrogen, i.e. producing hydrogen through the process of water electrolysis (AEL, PEM, or SOEC), but participants in the workshop point out that also other technologies exist. At the moment the only production site of green hydrogen near the Ostrobothnia region is in Kokkola, where Woikoski Oy produces hydrogen for industrial use through electrolysis. As was presented in the previous chapters, plans for large-scale hydrogen production are on their way in the region with estimates for having plants in operation by 2026 at the latest.

For economically viable green hydrogen production, cheap electricity production and a high capacity factor (full load hours) for the electrolysis process are essential. Power Purchase Agreements (PPA) are one solution to acquire electricity at a competitive price. However, workshop participants raised the issue that there are still question marks regarding the usage of PPA (e.g. liabilities) and that a hydrogen-dedicated PPA product might be needed for the region.

Regarding production the main question is how to maximize the operating hours of the electrolysis; According to literature reviews on the project (Koskinen, 2022; Sharma, 2022), the most expensive alternative is to use only curtailed production wind/solar production (negative prices). The location of the production site is focal and the production can be centralized or decentralized. Logistical aspects that should be considered when new sites for hydrogen production are planned are access to water and electricity (including the grid), but also access to biogenic CO2 might be a critical aspect. The location of future local users of hydrogen and E-fuels should be considered already at the planning phase. Last but not least, proximity to ports will most likely also be an important success factor.

Thus, regarding the business model of the hydrogen production plants, hybrid solutions both regarding the source (grid electricity, hydrogen dedicated wind farm, biomass) and location of production should be considered in terms of the end user to optimize production. Regarding the end product that is sold, there can also be a hybrid solution: which end product is sold (pure hydrogen, methane, methanol, ammonia, or other P2X-products) can vary depending on the current market price of the product.

The lifetime of the production facility is crucial as well as how multiple income streams (heat and oxygen) of the production can be utilized. There are actors in the region interested in developing advanced ICT solutions, which can be used to optimize production processes. It has been pointed out that a good Energy Management System (EMS) with AI and machine learning features is key to a profitable business.

System efficiency of the production facility is crucial, but participants in the workshop point out that we might not locally be able to improve the "energy vector" as such or minimize the losses with new inventions. Thus, optimization can be made using commercially available technologies, but innovations can be made in the design of new operations and business models. Several actors that have participated in the project activities have expressed the need to study the business models of different hydrogen production alternatives and hydrogen use cases in deeper detail. Dedicated projects focusing on the business models of hydrogen production have been called for in several discussions with network participants.

4.1.2 Hydrogen transmission and storage

Storing and transporting hydrogen is challenging because hydrogen is a very small molecule that can pass through steel even at room temperature, and hydrogen has low energy content per volume unit, requiring large volumes for its storage. However, technologies are developing fast and new technology for storing hydrogen such as LOHC (liquid organic hydrogen carriers) can be of interest to local actors.

The hydrogen storage question will need to be resolved in all of the pilot projects that are underway. Solutions for storing hydrogen in smaller containers stacked together are used by Woikoski in Kokkola and are often the preferred alternative in decentralized hydrogen. The most significant hydrogen storage and transport project impacting the region of Ostrobothnia is the building of the Nordic Hydrogen Route hydrogen pipeline around the Bothnia Bay area presented in the previous chapter among the pioneering project in the region. This project will be especially significant in terms of land use plans and providing a large-scale hydrogen storage opportunity and connecting producers and consumers of hydrogen together.

There are many differing views on large-scale hydrogen storage and transport, and one view is also that hydrogen should not be shipped or transported as such, at least outside Finland and North Sweden, but should be first refined into green e-fuels, such as synthetic methane, green methanol, and ammonia (Sivill et al. 2022). Participants in the workshop also expressed that this development trajectory could have advantages for the regional Ostrobothnian market since biogas is already an established fuel in the regional market and the demand for biogas for example in Vaasa-Korsholm is currently higher than what Stormossen can produce. Many of the large-scale wind power projects that are now planned, will involve hydrogen production as well, but base their business case on the production and sale of different types of e-fuels instead of pure hydrogen. Industry experts have pointed out that storing these fuels in large quantities will be much easier, than storing pure hydrogen.

4.1.3 Hydrogen applications and use

Replacing the existing use of grey hydrogen in industry, especially in the process and chemical industry, which is now using fossil-based (gray) hydrogen is seen by most of the workshop participants as a priority. Some industrial users of hydrogen as a chemical product exist for example in the Pietarsaari and Kokkola area, but the biggest off-taker in the region will be SSABs steel factories in Raahe and Luleå.

The transition to using e-fuels for long-distance heavy-duty transport and in the maritime business is perceived as the second most important use of hydrogen. Green hydrogen use in this sector will be intrinsically tied together with the availability of points for carbon capture for combining these in the production of e-fuels, such as synthetic methane, green methanol, and ammonia. The development and demonstration of P2X solutions together with CCU are thus essential for the short-term use of green hydrogen in the region. The e-fuel and fertilizer markets are also perceived to have the greatest export potential in the short term. However, some of the experts discussed see that a goal should be that the local transport sector would start to use locally produced green energy. Also, local production companies (e.g. forest machines) could be encouraged to test new solutions based on hydrogen and/or locally produced e-fuels.

The use of pure hydrogen in the production of energy and energy storage, i.e. using it as a fuel and as a flexible energy vector balancing the energy mix, is perceived by some participants as a possible alternative in the long-term time horizon (2040), when the phase-out of all carbon-emitting energy use is targeted. However, round-trip efficiency is still a major obstacle to the feasibility of this alternative, and major technological advances are required. The technology for using 100% hydrogen in combustion engines is not yet market ready, thus technological progress is still needed for this consumption alternative to be realized.

The use of hydrogen as an energy carrier for transferring energy from one place to another was also considered important by the discussants, especially from the point of view of land planning. However, a common view was that this use of hydrogen will not be realized in the short term, but will be dependent on the way hydrogen production in the region and the infrastructure for storing it will develop. Thus, this use of hydrogen is considered important in the long-term perspective and will impact regional land planning more than direct business opportunities for the regional actors.

The lack of big market potential (scarcely populated country) compared to many Asian countries for example as well as the lack of financing in municipalities for big infrastructure projects (tanking stations, conversion of public transportation to run on FCEV technology), are seen as the major obstacles for growing the use hydrogen in the personal vehicle sector. Although self-sufficiency in energy production and decentralized energy solutions are seen as important, hydrogen use in decentralized energy solutions still lacks actors who can take this development forward. In the long term, however, the opportunities for FCEVs and decentralized energy solutions could grow in importance.

4.1.4 Hydrogen knowledge and capabilities

An important part of supporting green hydrogen uptake is developing technological knowledge and solutions related to its use. This is one of the most significant areas impacting the hydrogen economy's development in the region of Ostrobothnia and cuts through all three themes that were considered in the scenario workshop (production, transmission and storage, and consumption). Local pioneering pilot projects, where the system solutions are developed and where local actors are involved, will have a significant role in moving the hydrogen economy forward and enabling a steep learning curve with green hydrogen production in our region. It is not only technical knowledge and business knowledge that is developed, but the pioneering projects will be the ones doing the hard work of getting the approval of local public authorities as well. Representatives from the public authorities have encouraged project leaders to be proactively in contact with the responsible agencies in an early phase and initiate an open dialogue, to make permitting processes go more smoothly.

Local hydrogen, CCU, and P2X projects will be important for the region's companies to develop and test the applicability of their existing products and services. Participants note that most likely small and medium size projects will offer better opportunities for local companies to participate than larger projects later on. Cities and municipalities in the region will have a central role in contributing to the initiation of these pilot projects and offering a platform for demonstration. The Aurora Botnia ferry is a good example of using local resources for building up a demonstration of local capabilities, and it should also be further utilized to test new technology and fuels. Participants in the workshop also pointed out that in the long term, it is possible to sell the know-how itself that is built through developing these solutions in the first place.

The hydrogen economy's development in the region also has several connection points with the Giga Vaasa project and its need for goods transport. Finding the connection points between the Giga Vaasa and the developing hydrogen economy will also provide important drivers for developing green energy system solutions in the region. The EnergyVaasa cluster and the EnergySAMPO innovation ecosystem are good platforms to be used to enhance the development of a regional hydrogen ecosystem.

Cooperation is essential for the successful development of the hydrogen economy. A triple-helix (companies, researchers/educators, public authorities, and decision-makers) are needed. There is already a good level of collaboration between the different actors, but more can be done. Especially having more focused and concrete collaboration projects that the different actors can work on is essential. Getting also small local users involved as partners in demonstration and pilot projects, where the use of green hydrogen can be tested and financed through public funding, is important.

4.1.5 SWOT -analysis of the development of the hydrogen economy in Ostrobothnia

A SWOT analysis of the development of the hydrogen economy in Ostrobothnia

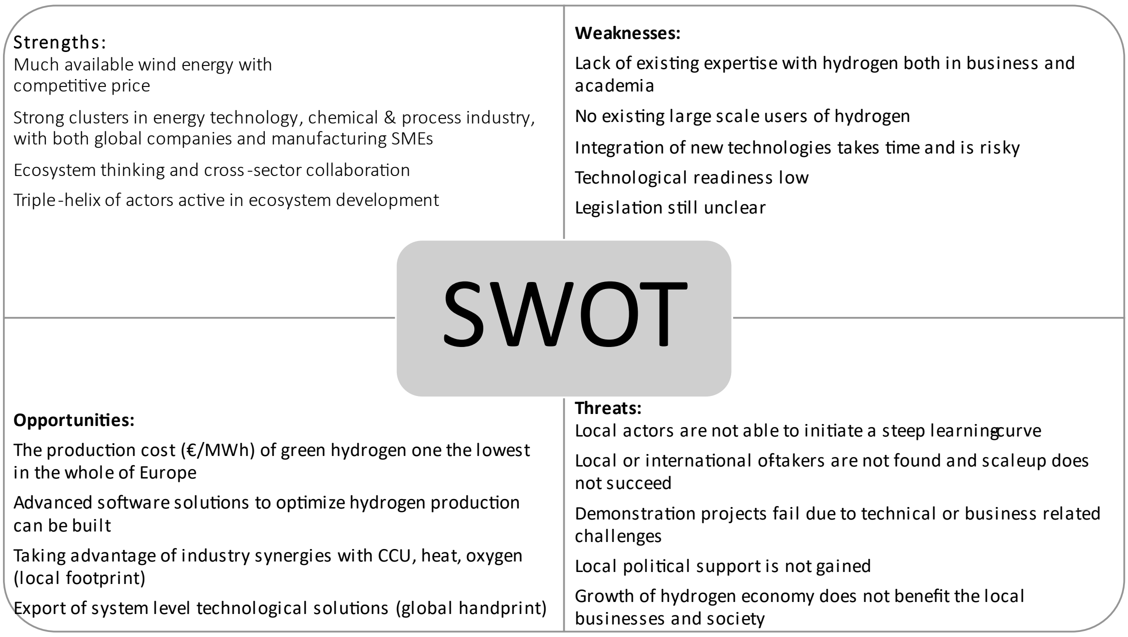

Figure 18 A SWOT -analysis of the development of the hydrogen economy in Ostrobothnia

Strengths

The amount of renewable energy produced at a comparatively low price is high in the region. There is a strong energy technology cluster, with both leading global companies, high-tech digital solution companies, and SME subcontractors with business potential in a hydrogen economy. Ecosystem thinking has been built up for a long period, and there is a tradition of cross-sector collaboration among a triple-helix of actors in business, regional development, and within research and education institutions. Also, the regional actors have proactively started building the local know-how related to hydrogen technologies, and system solutions, and developing the ecosystem in general.

Weaknesses

The low starting point of expertise with hydrogen. Neither businesses nor the research community has previously focused on hydrogen technology or hydrogen-related solutions. Thus, there is a great knowledge gap that needs to be bridged and regional actors need to catch up with the experts spearheading the hydrogen know-how. At the moment, there are no existing large-scale users of hydrogen in the region.

There are still many technological challenges that need to be resolved, for example, related to the storage and transmission of hydrogen as well as the round-trip efficiency of the solutions.

Also, because the solutions that are developed are integrating new types of technologies for the first time, the process will be time-consuming and risky. Lastly, legislation is still lagging and this weakness can prevent or postpone the successful realization of the projects. The legislative challenges include for example the use of grid electricity and guarantees of origin, as well as taxation and permitting.

Opportunities

Ostrobothnia has the opportunity to become a global exporter of hydrogen and e-fuels if the production cost (€/MWh) of green hydrogen is one the lowest in the whole of Europe. If the Nordic Hydrogen Route is built, both hydrogen and different P2X products can be exported through a pipeline to the large steel industry customers in the north. If actors in the region can scale up the initiated demonstration projects, the region can have a major role in the green transition and in facilitating the development of replacing fossil fuel-based grey hydrogen with green hydrogen. Additionally, the region's transport sector can transfer to fully using locally produced green fuels (synthetic methane, hydrogen, ammonia), thus reducing significantly the regional carbon footprint and increasing energy self-sufficiency.

There is also an opportunity for the region to start providing new innovative energy system solutions to global markets, once the functionality of these use cases has been demonstrated in the local context. These must include the demonstration of hydrogen use and its role in the local energy system, including using green hydrogen as energy vector balancing and enabling flexibility in the electricity grid, as a direct fuel used for energy production in combustion engines. If the actors in the region can truly collaborate in building new businesses together, there is an opportunity for a strong local hydrogen ecosystem to emerge. There is an opportunity for local actors to be running the hydrogen business and for the majority of the region's green electricity and green hydrogen production capacity to be locally owned. A large number of local companies could be in the future producing products and services for the global hydrogen and e-fuel markets.

Threats

Key issues that can threaten the realization of the hydrogen vision include: If local actors are not able to catch up on knowledge and capabilities related to the hydrogen technologies, and if a steep enough learning curve is not achieved in time, the region will not be able to secure its place in the emerging European hydrogen economy. If local or international of-takers are not found and if the scale-up of the first projects in the region does not succeed, the region's actors will have difficulties of carving out a share of the developing market. Furthermore, if the initiated demonstration projects fail due to technical or business-related challenges, additional investments will most likely not be supported and the business ecosystem around does not grow

A significant threat to realizing the vision is also the lack of local political support, which could be caused by a lack of knowledge among decision-makers or the civil society turning against hydrogen-related solutions. The last threat worth to be mentioned is a lack of foresight into how the growth of the hydrogen economy can benefit the local society. If for example, all projects built and operated remain in foreign ownership and local SME companies are not used as subcontractors, the benefits for the local economy remain low, which can prevent a favorable impact of the development on the region.

4.2 Hydrogen scenarios

Based on the presentation of the most significant factors impacting the development of a hydrogen economy in Ostrobothnia as well as the SWOT analysis, we present the next three different scenarios: 1. A best-case scenario, if all the existing strengths of the region are leveraged upon and all the opportunities taken advantage of, 2. A realistic scenario if some of the weaknesses of the region will hamper the development and if some of the threats are realized, and 3. Two worst case scenarios, one if none of the opportunities of the region are taken advantage of, and second if the development of the hydrogen economy does not benefit the region of Ostrobothnia as is hoped for.

4.2.1 Best case scenario 2025 and 2030

In 2025 the Ostrobothnia pilot hydrogen production facilities are fully operational and there has been a steep learning curve regarding both the local industry and universities. This has been enabled by local companies that have been willing to make the needed investments and each player in the network has found their role in the ecosystem. Local small and medium size H2 projects related to hydrogen storage and transmission have also been initiated throughout the region. We have built capabilities and know-how for handling both production and storage/transmission within our ecosystem. Also, local authorities responsible for permitting have built up the needed knowledge and permitting processes to go smoothly. The demonstration technology is available. We have the network for sharing knowledge and also the facilities to do research and development in the areas that are vital for the Ostrobothnia region. Platforms for knowledge sharing and accelerating new collaboration projects, such as BotH2nia and EnergySAMPO, are in full use. Local companies of all sizes can participate in the H2 projects and can test/develop their products and services and there is an integration of the whole value chain. An initial local market for use of green H2 and e-fuel is in place. The strategies for the region speak for an expansion of the H2 business and the decision-makers are on "our side". There is public awareness about the significance of the H2 solutions regarding the lowering of the carbon dioxide content, which leads to customers starting to demand green H2.

In 2030 in Ostrobothnia, the production cost (€/MWh) of green hydrogen is one the lowest in the whole of Europe, and both hydrogen and different P2X products are exported through the hydrogen pipeline and vessels onto international markets. The demonstration projects in the region have been scaled up. The H2 pipeline around the Gulf of Bothnia is built, which enhances the trade and further processing of our locally produced H2. The fossil fuel-based grey hydrogen has been replaced with green hydrogen in all major industries (Steel, fertilizers, etc.). The region’s transport sector has fully transferred to using locally produced green fuel (Methane, H2, Ammonia) and rules are in place for use of e-fuels both in the marine and heavy-duty transport sectors. We have demonstrated the functionality of new tangible use cases of hydrogen and its role in the local energy system, including using green hydrogen as energy vector balancing and enabling flexibility in the electricity grid, as a direct fuel used for energy production in combustion engines. There is in place a strong local network of players that are running the H2 business and the majority of the region’s green electricity and green H2 production capacity is locally owned. A large number of local companies produce products and services for the global H2 and E-fuel market.

4.2.2 Realistic scenario 2025 and 2030

In 2025 there has been some success but also drawbacks in Ostrobothnia regarding green hydrogen production. We know what we should do, but public decision-makers and company leaders need to take decisions to speed up the development. The rapid growth of wind power in Ostrobothnia has created a good starting point for hydrogen production. Some bottlenecks, e.g. EU -legislation to use grid electricity and the Origin of Guarantees, have slowed down the ability of the region to get the full potential of green hydrogen production. In the field of green hydrogen production, local universities have created a rather deep collaboration with the local industry and foreign universities. Concrete business cases are prepared for but have not yet taken off. We have some successful use cases and companies doing business, but we are struggling with building the cluster of companies needed to create an efficiently functioning local H2 ecosystem. We are having projects and fruitful discussions about the possible solutions, but strong leadership and coordination between different actors and the resources in the region should be improved to build up a successful local H2 ecosystem.

In 2030 there is some green hydrogen production in Ostrobothnia, but also other regions on the Finnish west coast are strong with this and the competition in the markets is relatively hard between regions. The change or building of the needed infrastructure for transporting and storage takes too long. We have not succeeded to export products due to technological challenges or business reasons. Longer-term incentives such as regulation and taxation, as well as support schemes for a transition period (similar to the wind energy sector development), are being planned, but have not yet been implemented.

4.2.3 Worst case scenario 2025 and 2030

In 2025 the local pilot projects have not quite succeeded in their production and there are only some minor hydrogen activities within the local universities. There have been both legislative and technical issues to success with hydrogen production. There is not enough green electricity for the production of green H2 in the Ostrobothnia region. We have not found end users for green H2 and the local Ostrobothnian market is too small to be interesting for new green H2 businesses. There is a reluctant public opinion of the hydrogen economy and there are no customers in favor of green H2 solutions that would increase the demand.

In 2030 other regions than Ostrobothnia have had many hydrogen pilot projects and they possess the technical and business knowledge of how to produce cost-competitive green hydrogen. We have not been able to develop solutions (lack of technology or lack of money or both) that are profitable enough for companies in Ostrobothnia to grow and be successful in the H2 business.

4.2.4 Alternative Worst-case scenario

Local production capacity for hydrogen and e-fuels have been built at high speed and the region is a big producer of cheap green energy. All wind farms and all hydrogen production capacity are owned by foreign investors. The production sites are built, run, and maintained by foreign experts. All locally produced green electricity is used to produce hydrogen and e-fuel that are exported to central Europe. The development has had a very limited positive impact on local companies and local employment. Local people and companies are forced to use expensive fossil fuels for their transport and heating.

5 Summary and recommendations for promoting the development of a hydrogen economy in Ostrobothnia

As stated in the introduction to this work package 3, the development of the hydrogen economy is at the moment on the first steps of a new and emerging socio-technical environment. Many of the system-level solutions that are visioned as part of the emerging hydrogen economy are now developed for the first time. For these to be realized, different technologies in the hydrogen value chain need to become connected. At the moment very few actors have a detailed system-level understanding of how all the different technologies will be combined. The pilot and demonstration projects that have already been started in our region are good examples of all the required system-level alignment that must take place for green hydrogen solutions and their business cases to be realized. Orchestrators and leaders that have the required system-level understanding are needed.

What the development of the hydrogen economy means and requires from a broader base of actors in the region, must also be understood. It has therefore been essential to forming a shared view of the current status of the hydrogen economy and a common vision for where we could be heading.

The local pilot and demonstration projects are vital for directing the development of the hydrogen economy in our region. It is through these projects that a deeper understanding of the system-level operation and business feasibility is developed. This knowledge is built up interactively with initial customers, business partners, and suppliers of different components. It is also through the pilot projects that the ecosystem of partnerships is built up, who can together develop system-level solutions for global export.

However, besides business partners, also the broader network of actors must be involved in a learning process. These include the local research and education institutions, which will educate the required workers in the future, but also local authorities, who will be in charge of land use plans, permitting, and safety standards. It is through building up knowledge within the larger triple-helix network of actors that the region as a whole will be able to develop and benefit from the hydrogen economy. This will require that actors continue to share knowledge, engage in networking activities and collaborate on projects that develop both their capabilities regarding the hydrogen economy as well as those of the whole region.

Based on the project work and the insights gathered during the process, we give several recommendations to different actors who are in a position to promote the development of the hydrogen economy in our region:

- First of all, local decision-makers should put focus on determining the role of hydrogen in municipal and regional strategies and include it as one piece in the puzzle towards climate neutrality. The strategic focus should be combined with directing public funding accordingly.
- Second business leaders in the pioneering projects are encouraged to be transparent and involve local stakeholders (suppliers, researchers, and public authorities) already in the development process, so that knowledge can accumulate in the region among a broad base of actors.
- Third, there are specific knowledge needs that research and education institutions in the region should respond to. Building a demonstration environment where hydrogen as part of the larger energy system can be studied is one of the areas that should be prioritized. Other important areas include the business models

related to the hydrogen economy and developing knowledge of hydrogen safety and standards. Overlapping activities should be avoided and instead, actors are encouraged to reserve adequate resources for collaboration and joining forces across organization boundaries.

- Fourth, an actor that coordinates the hydrogen development activities in the region and a structure that continuously supports these activities should be defined. We recommend that the regional development companies establish a Hydrogen Ostrobothnia consortia or team that can coordinate activities locally and continue to disseminate knowledge about hydrogen activities in the region.
- Fifth, the coordinating actor should provide services for focused matchmaking to put together actors with complementary resources and common interests regarding the development of hydrogen technology and business opportunities. This should have a clear goal that concrete new pilot and demonstration projects related to hydrogen are started in the region.
- Sixth and last, financing sources for different projects should be gathered on one platform so that they can be efficiently combined. The actor coordinating hydrogen activities and technology and business development in the region should maintain a real-time funding database and provide support and resources on application writing.

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Presentations at different workshops and seminars arranged by the project:

Figure 3. Hycamite Oy presentation by Laura Rahikka at H2 Ecosystem Roadmap project seminar event 19.05.2022

Figure 4. Presentation by Joakim Berg, WasaGroup Oy at the H2 Ecosystem Roadmap Hydrogen Seminar 11.11.2021

Links to videos presenting some of the pioneering projects:

Kenneth Widell's presentation of H-Flex-E at the Vasa Gas Exchange Webinar: https://www.youtube.com/watch?v=I3YY-hiOusg (time approx..12:24-27:00)

Niko Toppari's presentation of H-Flex-E for the WIC Science channel (in Finnish): https://www.youtube.com/watch?v=VgXwcxcp9aU

Juha Ripatti's presentation of EnergySAMPO CCU at Energy Week 2022: https://www.youtube.com/watch?v=SETwN-M8ky4&t=4856s (time approx. 1:21:00 - 1:37:00).

Nordic Hydrogen Route launch 22 April 2022: https://www.youtube.com/watch?v=8YBQ3jOyyxI

Decentralized production of hydrogen explained with the example of Nilsson Energy Ab:https://vimeo.com/user92740057, https://www.youtube.com/watch?v=ajucZpQ4VYU

Rasmus Hautala at Wasa Future Festival 10.8.2022 presenting large-scale hydrogen production opportunities in the Ostrobothnia region: https://www.youtube.com/watch?v=-uf25k6xhsM (time approx. 1:31:00-1:60:00)

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H2 ECOSYSTEM ROADMAP

FOR OSTROBOTHNIA