H2ALEOLUS

DELIVERABLE D3.3

Valorisation plan for hydrogen and by-products

PUBLIC

Federico Zenith (SINTEF)

Quality Assurance: Vibeke S. Nørstebø (SINTEF)

Project acronym:	HAEOLUS
Project title:	Hydrogen-Aeolic Energy with Optimised eLectrolysers Upstream of Substation
Project number:	779469
Call:	H2020-JTI-FCH-2017-1
Topic:	FCH-02-4-2017
Document date:	April 27, 2020
Due date:	June 30, 2019
Keywords:	boat, ship, aquaculture, car, bus, snowmobile, truck, plane, svalbard, steel, ammonia, oxygen, heat
Abstract:	This document summarises the valorisation activities performed during the first two years of the project. Possible applications are reviewed for their technological readiness and potential to absorb the hydrogen production expected in Berlevåg from 2020. The most promising applications are in the maritime sector and the supply of energy to Longyearbyen in the Svalbard archipelago.

Revision History

Date	Description	Author (organisation)
2018/Apr/16	Initial ideas	Federico Zenith (SINTEF)
2018/Oct/14	Restructuring with actions & potential after project meeting	Federico Zenith (SINTEF)
2019/Oct/04	Complete draft	Federico Zenith (SINTEF)
2019/Oct/09	Quality Assurance	Vibeke S. Nørstebø (SINTEF)

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement № 779469.

Table of Contents

1 The Haeolus Project

HAEOLUS is an EU co-funded project that proposes the integration of a new-generation 2.5 MW PEM electrolyser in a 45 MW wind farm. The project will demonstrate different control strategies to enhance the techno-economic performance of the system.

The Raggovidda wind farm is in a remote area of Norway, the Varanger peninsula. The wind farm is situated at an elevation of approximately 400 m above sea level and 30 km south of the town of Berlevåg. Raggovidda has a granted concession of 200 MW, but only 45 MW of capacity have been built due to limitations in the grid export capacity. Steady winds result in high capacity factors of about 50 %. Raggovidda wind farm is owned by Varanger Kraft and produced just short of 200 GWh in 2015.

The HAEOLUS project's impact is expected to be relevant for the following aspects:

- The wind farm is in a sub-grid with limited export capacity (95 MW at Varanger) compared to its full concession of 200 MW;
- Storing excess energy as hydrogen will help reduce uncertainty in wind power production, which is much larger than total consumption in the Varanger peninsula: relatively small uncertainties can destabilise the grid;
- In the long term, Varanger Kraft are strategically interested in exploiting their full wind power potential by producing and exporting hydrogen in large scale.

This report summarises the possibilities for valorisation of the hydrogen produced by the electrolyser; there are currently no hydrogen consumers in the region, and valorisation will require a market to be created.

2 Plant Location and Estimate of Hydrogen Production

The HAEOLUS consortium decided to locate Hydrogenics' 2.5 MW electrolyser in the Berlevåg harbour area, which is planned to become an industrial park in the near future. The location makes it possible to integrate the electrolyser with other future industries, and allows relatively easy export possibilities compared to a location on the Raggovidda plateau where the wind park is located.

Berlevåg harbour is accessible by sea year-round, even though its position is exposed to the Barents sea, and access may be difficult for larger ships on particularly windy days. Finnmark's county road 890 passes in front of the electrolyser site and has been recently been upgraded; it is usable year-round to access the Norwegian road network, even though convoys need to be formed in winter to pass the Hanglefjellet mountain range between Berlevåg and Tana.

The electrolyser will be able to produce 1 ton of H_2 per day, and will be connected directly to the Raggovidda wind park; if power from the wind park were momentarily insufficient to meet production targets, it is possible to use power from the grid. HAEOLUS committed to a total hydrogen production from wind power of 120 tons over 30 months.

3 Outreach to Local Authorities and Businesses

A successful deployment of the HAEOLUS electrolyser depends on the establishment of a hydrogen consumer base in the region. The project has been supported by the Berlevåg municipal and Finnmark county councils in outreach activities towards the business sector in the area. The development of a hydrogen hub in Varanger has attracted the attention of national politicians, with increased interest in hydrogen technologies and leaders of major parties calling for a national hydrogen company following the pattern of Statoil.

Finnmark county council, in particular, organised two workshops in Vadsø (March 21 and May 14, 2019) open to local businesses, municipalities and schools to explore how to exploit hydrogen production in the local context.

Figure 1: Snapshot from the first workshop in Vadsø.

In autumn 2019, a project proposal was submitted to the Pilot-E program of the Norwegian Research Council, Innovation Norway and Enova, with the objective of establishing initial logistics for hydrogen distribution in Finnmark, starting with filling stations in Berlevåg and Vadsø, with possible further developments in Kirkenes, Nordkapp, Tana and Longyearbyen. The proposal has a total budget of 3.7 million euros, and a decision is expected by the end of the year.

4 Maritime transport

4.1 Fishing Boats

A lot of the local economy in Northern Norway is based on fishing, and three fishermen in Berlevåg already expressed interest in retrofitting their boats with hydrogen fuel cells at the workshop organised by Finnmark county council.

Norway has already one *battery* fishing boat (the *Karoline*), which however uses diesel for propulsion and batteries on site, built by Selfa Arctic. Such auxiliary power units for on-board power, with a layout similar to Karoline's, are relatively easily implemented. Boats would load a hydrogen container as fuel.

Selfa Arctic was contacted for their experience in building Karoline, and confirmed interest in hydrogen; indeed, they also pointed out they would like to remove diesel propulsion altogether, rather than just replicating the Karoline with hydrogen. Selfa Arctic signalled they would like to start such a project, but were concerned about financial coverage; individual fishermen in Berlevåg are unlikely to be able to shoulder the costs of a prototype. It was suggested to seek an appropriate funding scheme, such as an EU project; however, no relevant topic was published since by the FCH JU.

One of the fishermen in Berlevåg set up a company, Ervik Kystfiske, and requested funding from the Norwegian Research Council for a feasibility study. Funding was granted and the study is now underway, with the support of Skogsøy Båt of Mandal, Global Ocean Technology Norway and SINTEF; the project is schedule to be completed in January 2020 and expected to lead to a development phase.

Ervik Havfiske[1], a company owning a fleet of fishing boats, has also expressed interest in hydrogen-powered fishing vessels.

Moen Marin, a quickly growing ship builder specialising in aquaculture support vessels, recently built a 21 m fishing boat with a setup similar to Karoline (batteries and diesel), the *Angelsen Senior*. After an initial meeting with SINTEF, they expressed interest in hydrogen technology, and may later be connected to the aquaculture sector for hydrogen-powered support vessels (section 4.4).

The hydrogen consumption potential for each fishing boat is estimated to 20–30 kg per day. Along the Norwegian coast, there is about 3000 fishing boats close to the operating age of 30 years that will need replacement in the next few years.

4.2 Fast Passenger Boats

Through the MoZEES research centre, SINTEF participates in a study on the feasibility of hydrogen-fuelled high-speed passenger ships, which are an important means of transport in Norway due to its irregular coastal geography. This study also involves the shipbuilding company Brødrene Aa of Hyen, Norway, who are strategically interested in propulsion electrification.

The Finnmark county council has been evaluating the establishment of a fast passenger ship route between the towns of Kirkenes and Vadsø (currently served by a short plane ride, about 10 minutes, across the Varangerfjord). The council's current plan explicitly assumes that the route will be realised with a hydrogen-powered boat.

The hydrogen consumption potential for one such fast passenger boat between Vadsø and Kirkenes is estimated at 2 tons hydrogen per week.

4.3 Cruise Ships

Cruise ships are very popular among tourists in Norway, and their usage of large quantities of fossil fuels has raised environmental concerns, primarily on Norway's more tourism-intensive West Coast. However, Norway's Coastal Express, also a popular cruise route, navigates all the way from Bergen to Kirkenes, and also briefly stops in Berlevåg.

[1] Unrelated to Ervik Kystfiske.

From 2021, four of the eleven ships operating on the Coastal Express route will be operated by Havila, a company that at the end of 2018 received a grant for over 10 million euros to develop hydrogen cruise ships. Participating in that consortium is also SINTEF.

Potential: A Coastal Express ship typically uses 3.6 MW motors; assuming a 50 % average load, it would correspond to about 2.6 tons a day for each ship. There are 11 such coastal cruise ships taking 12 days for the round trip between Bergen and Kirkenes, passing twice by Berlevåg in rapid succession as they turn back south at nearby Kirkenes. Assuming hydrogen tanks installed on such ships would be large enough to be sufficient for two days, the potential is about 5–6 tons of hydrogen per day.

4.4 Aquaculture

Aquaculture has had an explosive growth in Norway in the last years, driven by more effective methods for production of fish, especially salmon.

Aquaculture ponds are typically installed in fjords, and often rely on diesel generators to provide power to floating installations and propulsion to the support ships. To reduce emissions, it is often suggested to electrify these ponds by cables from land; however this reduces flexibility in positioning of the ponds, as in many well-suited areas, especially in Northern Norway, there may be no available grid capacity—or no grid at all.

Using hydrogen for power production and propulsion of support ships will allow to produce emission-free fish for export, which according to market experts can command a much higher price on the international market. The potential for a single aquaculture plant was estimated at about 40–50 kg of hydrogen a day; at least two such plants in the area, which cannot be electrified from land, were identified.

Aquaculture can make use of by-produced oxygen for pond oxygenation; see section 8.

5 Land Transport

5.1 Cars

More than half of all new cars in Norway are battery vehicles, yet very few of these are sold in Finnmark. The reasons of the low success of electric vehicles in Finnmark compared to the rest of the country is that distances between towns are much longer (e.g. about 90 km from Berlevåg to the two nearest villages, Austertana and Båtsfjord), temperatures much colder (reducing the range of battery cars), and the fast-charger network is not developed (only two CCS/ChaDeMo chargers, one in Kirkenes and one in Alta, 500 km apart).

Whereas hydrogen cars face stiff competition from battery cars elsewhere in Norway, they offer a serious value proposition for zero-emission mobility to privates and companies in Finnmark; e.g. a Hyundai Nexo can perform a return trip from any town to any other one within Varanger on a single tank. Furthermore, hydrogen cars can be used to provide power to huts and cottages with no access to the grid, which many people in the area own: e.g. the Toyota Mirai is equipped with a ChaDeMo outlet.

Several authorities and companies, such as Berlevåg municipality, Finnmark county council and Varanger Kraft have already expressed interest in hydrogen cars. Privates may also be interested as the demand for zero-emission vehicles is not covered by batteries in this part of Norway. The consumption potential is estimated at 0.2 kg of hydrogen per day per car.

5.2 Buses

Hydrogen buses are a good fit for regional transport in Varanger, as batteries cannot hope to deal with the long distances and low temperatures. However, due to scarce population, public transport from Berlevåg is limited to an on-demand minibus service, which often is actually provided by taxis: in this case, a deployment of hydrogen cars would be more likely.

Finnmark County Council was however interested in 12 m buses for public transportation in Vadsø and other towns; Nordkapp, in particular, has a significant tourist presence and a strong flow of tourists from the town of Honningsvåg to the actual North Cape.

Consumption of hydrogen will likely not be significant, though more than for private cars. Other refuelling stations may be needed elsewhere in Varanger, but not as many as for private cars. The consumption potential is estimated at about 10 kg per day per bus.

5.3 Snowmobiles

Noise and smell from snowmobiles is a source of complaints from Norwegian tourists who would like to enjoy silence in nature, whereas others rely on snowmobiles to get around during winter; snowmobiles are also popular with tourists, especially at North Cape and Svalbard.

A hydrogen snowmobile may be much more silent and emission-free, and solve some of these social tensions. Potential customers for a hydrogen snowmobile are mostly in the tourism industry in Nordkapp and Svalbard, who have expressed interest, but possibly also companies and privates; e.g., Varanger Kraft owns some snowmobiles to reach the Raggovidda plateau in winter, and may acquire a prototype for demonstration.

VTT in Finland reportedly developed such a prototype a few years back. VTT agreed to lead an initiative to develop an updated prototype, and involved Aurora Powertrains of Finland, who have experience in electric snowmobiles. The potential consumption will be small (less than 100 g per day per unit), but it would be very visible.

5.4 Waste Collection Trucks

Local company ØFAS manages waste collection in East Finnmark, based in Tana. They are interested in acquiring hydrogen-powered garbage trucks, as those are in development in several EU projects.

No commercial vehicles are available yet, but demonstrations have already been held and prototypes have been tested in operation; supplying Tana with hydrogen should be relatively easy, but a first truck could also be based directly in Berlevåg.

The consumption potential is estimated at 1 kg per day per vehicle.

5.5 Trucks and Forklifts

An industrial park is projected to be started in Vadsø, and the entrepreneurs behind it have expressed interest in giving hydrogen a role in it. The main possibilities lie in forklifts, delivery trucks and usage of hydrogen as a chemical feedstock.

Hydrogen forklifts are a commercial technology, while hydrogen trucks are very close to market (Scania, Nikola). The potential for this application is still very uncertain and depends on the successful development of the industrial park, but could range up to a few hundred kg of hydrogen a day.

5.6 Mining Dump Trucks

Close to the town of Kirkenes is a previously closed mine that is about to resume operations. They will soon have to order dump trucks and other large equipment, and are interested in exploiting hydrogen for improve diesel combustion in their engines. Hydrogen dump trucks are not yet available, but co-injection of hydrogen and diesel has reportedly good effects on their local emissions (CO, NO_x, PM, etc.), which is important to public acceptance of the mine since it is situated right beside a residential area.

6 Air Transport

There has been significant interest in battery planes in Norway recently, but no particular focus on hydrogen, even though its higher energy density should put it at a decisive advantage.

In Varanger, local flights are operated by Widerøe with turboprop planes that start from Tromsø in the west and land in Hammerfest, Berlevåg, Båtsfjord, Vardø, Vadsø and finally Kirkenes. These planes are small 39-seaters, and each of those legs is fairly short (max 200 km, min 32 km), making it an ideal testing ground.

The Norwegian air traffic authority, Avinor, was contacted and were interested in the concept and suggested they would follow up their contacts in Airbus, Widerøe and SAS. The US

company Zeroavia is aiming to produce a hydrogen-fuelled 19-seater by 2022, which could be tested in the area; SINTEF has already contacted ZeroAvia, and connected them to Norwegian financing body Enova and Widerøe.

While the potential of this option is larger, at least 100 kg per day per plane, it is also in a longer time frame than the HAEOLUS project.

7 Stationary Applications

7.1 Upgrading of Biogas to Biomethane

In 2020, a new biogas plant is foreseen to be built in Båtsfjord, the neighbour municipality of Berlevåg. This plant will mainly treat refuse from the fish industry, and can exploit hydrogen to upgrade the biogas to biomethane.

This technology is already commercially available and relatively easy to deploy. SINTEF experts in biogas calculated that the Båtsfjord biogas plant may make use of about 80 tons of hydrogen a year, which is well within the capacity of the HAEOLUS plant.

The distance between Båtsfjord and Berlevåg (90 km by road) requires a simple distribution infrastructure, which may later be expanded to cover the rest of Varanger and Finnmark.

The owners of the biogas plant signalled interest in the idea, which is being followed up by SINTEF. Given the short distance and simplicity of deployment, this alternative is one of the most promising for early valorisation of produced hydrogen.

7.2 Svalbard Power Grid

The Svalbard archipelago sustains a population of a few thousand people and is the northernmost part of Norway. It is also the location of the only non-renewable power plant on Norwegian soil, a coal power plant fuelled by the local mine.

Authorities Svalbard and on the mainland prioritise a decarbonisation of the islands, and SINTEF has already performed studies in that direction. An initial deployment of fuel cells and transport of hydrogen by container may be started before the end of HAEOLUS.

Local authorities have been contacted and are involved in several research proposals for hydrogen energy. The total potential for energy supply to Longyearbyen (Svalbard's main village) is estimated a 7 tons a day.

7.3 Hybrit Project

The Hybrit project in Luleå, Sweden, aims at producing carbon-free iron, by replacing coal with hydrogen as the reducing agent. This would create a large demand for renewable hydrogen in an area not geographically too remote from Berlevåg (about 840 km by road).

The Hybrit pilot will not operate continuously (it will be a single blast furnace), but should require a capacity of about 3 tons per day while in operation. The full-scale deployment will require electrolyser capacities in the GW scale.

Export from Berlevåg to Luleå will require:

- Pressure containers, possibly part-time rented to Luleå to provide storage;
- Compressor station at Berlevåg;
- Transport by trucks (there are already many carrying fish south from Berlevåg).

In the long run, Hybrit will probably want to have their own electrolysers and will likely outstrip the whole wind generation capacity in Varanger, but for some years they might be a good customer. However, the Hybrit project is a very long one, and they will not be ready for a pilot before the early 2020's, remaining outside the scope of HAEOLUS.

7.4 Ammonia production

It is possible to produce ammonia from hydrogen, which is easier to store (liquid at 10 bar and environmental temperature) and transport than hydrogen itself.

Ammonia can be sold as chemical feedstock, e.g. in the fertiliser industry, which is historically important in Norway (Yara). In Norway, ammonia is seen as an attractive energy vector especially by Statkraft, who suggested it to provide energy to Svalbard. Within HAEOLUS, Hydrogenics considers ammonia a very realistic valorisation option in the near future.

8 By-Products

The electrolyser produces also heat and pure oxygen, which can be valorised as well. HAEOLUS's plant can produce up to 8 t/d of oxygen and about 1 MW of heat at 60 °C during operation.

Oxygen, in particular, is an important feedstock in aquaculture, where it used in large volumes to allow higher fish densities in ponds and land-based hatcheries. Due to the large distance from production sites, oxygen can be sold at relatively high prices in Finnmark; these prices are however often confidential information. Gas companies can be involved for the transport of oxygen for Berlevåg, since oxygen storage is more challenging than hydrogen; alternatively, oxygen could be sold directly to local aquaculture companies.

Oxygen is also considered as a chemical feedstock for the production of hydrogen peroxide, which is one of the options considered by Berlevåg municipality.

Heat is generally considered a lesser-value by-product compared to oxygen, but several scenarios have been considered, including heating of greenhouses and installation of a district-heating system in Berlevåg.

9 Conclusions

The HAEOLUS project has generated a lot of interest in the local community, and municipal and county authorities have been very collaborative.

While there are no hydrogen consumers in the area at this date, many potential uses have been identified, both of commercially available technologies such as cars and buses, technologies in advanced states of development such as trucks, and more long-term targets such as the development of hydrogen planes.

The single most promising early deployment is the biogas plant recently opened in Båtsfjord. SINTEF is currently following up with the plant owners how to exploit this opportunity, which should make valorisation within the project's life span feasible.

Other very promising consumers are the maritime sector (fishing boats, aquaculture, fast passenger ferries, cruise ships) and export to Svalbard, where available technology for combined heat and power can be applied as a drop-in replacement to coal.

In general, there will be an induction period after production start during which consumers will gradually adjust to the availability of hydrogen and begin exploiting it. For some applications with easily deployed available technology (biogas, buses, etc.), the time may be quite short, e.g. about a year, while other alternatives may require longer time for development of appropriate solutions or deployment of reliable logistic supply chains.