

A large cargo ship is docked at a port, with several cranes visible. The ship has containers from Hapag-Lloyd, LERSK, and CMA CGM. In the background, two wind turbines are visible against a sunset sky. The water is dark and calm.

NEXT NORDIC GREEN TRANSPORT WAVE - LARGE VEHICLES

Prospectus of using hydrogen in heavy-duty
equipment, including non-road mobile machinery

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Next wave - about the project

Electrification of the transport sector already began and the Nordic countries, specifically Norway and Iceland, have taken major steps resulting in battery electric vehicles (BEVs) already accounting for a substantial percentage of the total sales. The world is looking towards the Nordics as they are providing global examples for success. However, little is happening regarding larger vehicles as battery solution still are not able to provide heavy-duty users (e.g., buses, trucks, and lorries) the mobility they need.

Fuel cell electric vehicles using hydrogen as a fuel can solve this. The project focuses on providing infrastructure for a large-scale deployment of trucks, buses, and lorries. The goal is to further stimulate the global technological lead, which the Nordic countries have by stimulating the very first hydrogen infrastructure roll-out for larger vehicles while at the same time map how the infrastructure build-up needs to be done, so that the transition to hydrogen vehicles can happen smoothly. Such roll-out will also benefit the use of hydrogen for trains and the maritime sector. Furthermore, in addition of sourcing the hydrogen as a by-product from the industry, in the Nordic region we have the unique opportunity to produce the hydrogen in a green manner exploiting renewable electricity production.

Already, Nordic industries have taken international lead in the field of hydrogen and fuel cells and a unique cooperation exists between "hydrogen companies" via the Nordic Hydrogen Partnership (former Scandinavian Hydrogen Highway Partnership, SHHP) cooperation. Jointly they have marketed the Nordic platform for hydrogen and, at the same time, paved the way for vehicle manufacturers to deploy such vehicles in the Nordic countries. When it comes to hydrogen, the Nordics have globally leading companies both within the infrastructure and the fuel cell business. The project therefore sets forward four key activities in a unique project where technical innovation and deployment strategies are intertwined.

The project will deliver an analysis on large-scale transport of hydrogen with mobile pipeline, a description of the innovation and business potential for a roll-out of FC-buses in the Nordic region, as well as a coordinated action plan for stimulating the FC truck demand and a prospect for utilising hydrogen in heavy-duty equipment. Finally, the project will contribute to national and Nordic hydrogen strategy processes even providing input to a possible Nordic Hydrogen Strategy.

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Summary

A segment which has not gotten high attention is the Non-Road Mobile Machinery (NRMM) and other heavy-duty (HD) equipment. Even if several zero-emission solutions do exist (such as forklifts, cranes, etc.), still, when it comes to construction, mining, forestry, etc., zero-emission equipment solutions are rare.

With increased development within trucks and the maritime industry, zero-emission solutions are simultaneously making progress also for NRMM and HD equipment. First demos are being launched in various categories, and there are signs development might pick up speed during the next few years. However, this segment is needy for specialised infrastructure on site or a mobile refuelling solution.

Ports can be the best option for initial uptake of NRMM and HD equipment as they are serviced by trucks which soon might demand hydrogen as fuel. That could open an opportunity for hydrogen powered NRMM and HD equipment as infrastructure would most likely be built inside the ports or in the immediate neighbourhood.

NRMM and HD equipment is a segment where hydrogen solutions are raising eyebrows, and likely, the number of hydrogen powered solutions - like for mining equipment, tractors, construction equipment, material handling equipment - will be presented in the coming 3-5 years. For the Nordic countries, infrastructure preparation and planning of NRMM demo activities should be targeted, whereas funding for such activities should be increased.

Overview of Non-Road Mobile Machinery (NRMM) and hydrogen

The use of diesel for Non-Road Mobile Machinery (NRMM) is significant. As an example, in Finland the use of diesel fuel for NRMM is about 770,000 tonnes (unfortunately an accurate figure for the whole of the Nordic region could not be established), not including mining machineries.

The largest uses of NRMM machines are in:

- Agriculture (tractors, combine harvesters)
- Construction equipment (wheel loaders, articulated hauler, rigid haulers, excavators)
- Forestry equipment (forest harvesters, forest forwarders)
- Mining equipment (wheel loaders, articulated hauler, rigid haulers, excavators)
- Material handling equipment in ports and logistics centres (RTG, reach stackers, straddle carriers, forklifts, wheel loaders etc.)

Regarding the use of hydrogen in these machines, there are different aspects to be considered. Even if hydrogen powered applications such as forklifts¹ and mining locomotives² were tested already late '90s/turn of the millennium, the NRMM-segment has not been high on the hydrogen agenda. Now, this is about to change.

In addition to dedicated development routs, like the continued development of the fuel cell forklift (see the Material handling equipment section below), recently, also there has been more general/structural changes within the NRMM-segment like (just to name a handful of examples):

- Multinational diesel engine manufacturer Cummins acquiring the fuel cell systems specialist Hydrogenics Corp, starting joint development of an electrically powered mini-excavator with Hyundai Construction Equipment, and joining the Hydrogen Council³.
- The Volvo-representative to the Leverandørkonferanse - utslippsfrie bygge- og anleggsplasser at the Norwegian Environment Agency already back in 2017⁴ announcing Volvo quit developing the diesel engine. This strategical shift was followed by a binding agreement between the Volvo Group and Daimler Truck AG signed late 2020 forming a joint venture (named cellcentric) to develop, produce, and commercialize fuel cell systems for use in heavy-duty trucks, as well as other applications⁵.
- JCB has announced hydrogen and fuel cell development within their equipment and plan to provide variety of solutions with hydrogen as the key fuel⁶.

¹ https://www.engineeringnews.co.za/article/fuelcell-driven-forklifts-developed-2000-06-09/rep_id:4136.

² <https://www.osti.gov/servlets/purl/816032>.

³ <https://www.dieselprogress.com/5027641.article>.

⁴ <https://innovativeanskaffelser.no/utslippsfritt/>.

⁵ <https://www.daimler.com/company/news/fuel-cell-joint-venture-volvo.html>.

⁶ <https://www.jcb.com/en-gb/campaigns/hydrogen>

In the following some major aspects are summarised and examples of hydrogen-based NRMM are given.

Agricultural machines

In agriculture, the use of fuel is relatively distributed and concentrated on certain times of the year. The annual usage hours are low. Therefore, agriculture is not very attractive as a first-mover segment for hydrogen, excluding very large farms and locations where hydrogen has also other use (e.g., trucks). However, electrification of the agriculture segment also gives some opportunities as for instance hydrogen tractors can be made lighter than the traditional machineries based on internal combustion engines. As a result, the soil is less compacted and therefore remains healthier. Other benefits are a much more efficient and powerful powertrain, less wear, and less maintenance. Some examples of agricultural machineries are:

- Already in 2011, New Holland presented the first hydrogen tractor ready to go into service on a farm⁷, but it was never commercialised.
- In 2021, Deutz showed a tractor running on pure hydrogen in a combustion engine⁸.
- In May 2021, H2Trac announced that their first hydrogen EOX-175, developed together with seven Dutch farmers, was delivered to city farmers in Arnhem⁹.

Construction equipment

Construction equipment is a highly interesting segment for hydrogen, especially when construction takes place in urban environment and diesel pollution is a major issue. The main issue for construction equipment is hydrogen supply. There is a clear need for semi-mobile large-scale hydrogen refuelling stations (HRSs), which could use large hydrogen containers (500 bar). One potential supplier is Wystrach¹⁰, even if their current mobile solution is small-scale (discharging capacity of +300 kg/day).

- Volvo Construction Equipment (CE) announced in May 2021 their investment in a test facility for fuel cell applications. Volvo CE sees hydrogen fuel cell technology as playing a key role within its overall electromobility ambitions, together with battery electric solutions, as demonstrated by the electric compact machines¹¹.
- In March 2020, Hyundai Construction Equipment announced¹² start of Hydrogen Fuel Cell Excavator development together with Hyundai Motor Group and Hyundai Mobis aiming at mass-distribution in 2023.
- JCB announced in July 2020 their 20-tonne 220X excavator powered by a hydrogen fuel cell had been undergoing rigorous testing at JCB's quarry proving grounds for more than 12 months¹³.

⁷ <https://agriculture.newholland.com/eu/en-uk/about-us/whats-on/news-events/2011/nh2>.

⁸ www.deutz.com/en/investor-relations/investor-news/deutz-hydrogen-engine-ready-for-the-market

⁹ <https://fuelcellsworld.com/news/first-100-hydrogen-eox-electric-tractor-sold-by-h2trac/>

¹⁰ <https://www.wystrach.gmbh/en/produkt-wyrefueler.html>

¹¹ <https://www.volvoce.com/global/en/news-and-events/press-releases/2021/volvo-ce-takes-big-step-towards-a-carbon-neutral-future-with-hydrogen-fuel-cell-test-lab/>

¹² <https://www.hyundai-mh.eu/en/news/2020-03-pr-hyundai-hydrogen-fuel-excavators>

¹³ <https://www.jcb.com/en-gb/news/2020/07/jcb-leads-the-way-with-first-hydrogen-fuelled-excavator>

- In October 2021, Mourik put the first completely clean hydrogen excavator (a converted 30-tonne Liebherr R926 Generation 8 crawler excavator) into operation at the Strong Lekdijk dike reinforcement project near Schoonhoven.
- Articulated haulers and "small" rigid haulers are interesting NRMM vehicle group, as they are quite close to HD trucks.

Forestry equipment

Forestry equipment is a major fuel consumer, for example, in Finland and Sweden. However, the hydrogen fuel supply for forestry equipment is a major issue and hydrogen is not an easy option. This may change when liquid hydrogen becomes a common fuel. Fuel cells may also become an interesting option, if methanol is used as fuel.

- Some hybrid demo units exist.
- Not interesting at this point.
- In the county of Värmland in Sweden, the Swedish Institute RISE has together with stakeholders investigated the benefit of using hydrogen as a fuel for forestry equipment as well as addressed the hydrogen distribution.

Mining equipment

Mining equipment for open pit mines is highly attractive for hydrogen use since mines are semi-permanent industrial places. The equipment for open pit mines is in many ways similar to construction equipment, but also larger in scale. The HRS issue for mobile equipment (wheel loaders, articulated haulers, rigid haulers) can be solved with existing equipment. However, for refuelling of excavators a new off-road mobile HRS could solve the issue.

Heavy trucks are often needed supplying chemicals and fuel for the mines. Heavy trucks are also needed for product transport if rail transport is not possible. The cost for transport can be very important for the operation of a mine, especially for iron ore mines (e.g., Pajala/Kaunisvaara in Sweden).

During 2019-2021, there has been several announcements for mining trucks (rigid hauler), including:

- <https://im-mining.com/2020/08/20/weichais-first-production-fcev-200-ton-mining-truck-roll-factory-h2-2021/>
- <https://www.ballard.com/about-ballard/newsroom/news-releases/2019/10/29/ballard-receives-po-from-anglo-american-for-900kw-of-fuel-cell-modules-to-support-mining-truck-demonstration-project>
- <https://asia.nikkei.com/Business/Engineering-Construction/Komatsu-aims-for-lead-in-hydrogen-powered-mining-trucks>

A single large mining truck can operate 24/7 with average power of about 1 MW. Annual fuel consumption can be >1 M litres for single mine truck, which corresponds to the fuel consumption of about 1,000 passenger vehicles.

Material handling equipment in ports, logistics centres, and industry areas

Material handling equipment in ports, logistics centres as well as industry areas is a highly interesting application, since these have also very large truck traffic. Within the NRMM-segment, forklifts are dominant in numbers. As of October 2019, more than 25,000 hydrogen FC-powered forklifts were already in commercial use in the US¹⁴. In Europe, however, with the potential to replace some 70,000 new internal combustion engine (ICE) models annually, the corresponding number was only about 500. Hydrogen recently being put high on the political agenda in most European countries, hopefully, this is about to change.

Typical machines are:

- Container handling equipment
- Forklifts
- Wheel loaders

Examples of some recent announcements in this area are:

- Loop Energy Inc. and Morello Giovanni S.r.l. (Morello) announced signing of a strategic cooperation agreement¹⁵ for the development and manufacture of heavy-duty hydrogen electric material handling equipment in March 2021.
- The FCH JU study¹⁶ "Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities - FCH Port operations equip." made by Roland Berger in 2017.

Mobile hydrogen refuelling stations

Mobile hydrogen refuelling stations (HRSs) can serve several purposes including:

- Refuelling of hydrogen machinery and equipment temporarily operated at a specific location, e.g., forestry and construction equipment.
- Refuelling of hydrogen machinery and equipment not being able to travel to the regular refuelling stations, e.g., agricultural machines and material handling equipment.
- Filling in for the first stationary refuelling stations increasing the hydrogen availability in an early market stage.

Examples of first-generation mobile refuelling stations are:

- REH2 HFS from REH₂ (part of the Nilsson Energy Group) in Sweden, www.reh2.se
- WyRefueler from Wystrach GmbH in Germany, www.wystrach.gmbh/en/produkt-wyrefueler.html
- Hydrogen refuelling truck by UK based Fuel Cell Systems Ltd., www.fuelcellsystems.co.uk/hydrogen-refuelling
- The Linde refuelling truck, a mobile solution with a hydrogen storage and a dispenser built in a truck being able to be at site for demonstration and events.

¹⁴ <https://fuelcellsworld.com/news/fuel-cell-fork-lift-trucks-drive-hydrogen-into-the-future/>

¹⁵ <https://www.oemoffhighway.com/electronics/power-systems/press-release/21318917/loop-energy-formerly-powerdisc-development-corp-loop-energy-collaborating-with-morello-on-heavy-duty-hydrogen-material-handling-trucks>

¹⁶ https://www.fch.europa.eu/sites/default/files/FCH%20Docs/171121_FCH2JU_Application-Package_WG3_Port%20operations%20equipment%20%28ID%202910574%29%20%28ID%202911660%29.pdf

Further development regarding mobile hydrogen refuelling infrastructure is of high importance in general when it comes to NRMM. Already the Nordic countries have played an important pioneering role when it comes to hydrogen infrastructure (both production and dispensing). To develop the state-of-the-art mobile HRS would support in general future deployment of trucks and NRMM.

Hydrogen-powered gensets

Some heavy-duty equipment might be electrified as battery electric, cable electric, or a combination/hybrid of the two (so-called PeakShavers). In this case, e.g., containerised hydrogen-powered gensets can provide the electrons needed to charge the batteries or feed the electric cable. Such gensets are also developed to power temporary energy needs such as music festivals and emergency camps. Back-up power is also a very interesting field for deployment of hydrogen and fuel cells. This can be at hospitals, industrial locations, data centres, airports or alike. Such applications are already becoming attractive both technically and economically for customers.

Examples of hydrogen-powered genset initiatives in the Nordic region:

- FCC 1600 from TECO 2030 is a 1,600 kW containerised fuel cell based genset undergoing development and Type Approval in accordance with Maritime rules and regulations, <https://kommunikasjon.ntb.no/data/attachments/00110/aecb911c-9c2d-49f4-854d-167199481fdb.pdf>
- Mobile Pow Unit (MPU) from PowUnit AS is a series of fuel cell-based products intended to replace conventional aggregates and be equipped for integration with different electrified machines as well as providing heat at construction sites, <https://www.powunit.com>
- Everywh2ere is an EU-project under the Fuel Cells and Hydrogen 2 Joint Undertaking undertaken by RINA-C (coordinator), VTT, PowerCell et. al. developing and testing 25 kW and 100 kW fuel cell equipped transportable gensets, <https://www.everywh2ere.eu>

Scope of the work for this report

As a summary, **ports** and **large logistics centres** are potential hydrogen hotspots for all Nordic countries, as also concluded in *Deployment of hydrogen trucks and infrastructure in the Nordics - Status, ambitions, and recommended actions to stimulate the demand* (Next Wave Deliverable 5.1/5.2). Therefore, the potential for NRMM in some of the most potential ports and logistics centres is reported. Some of the ports have also potential to supply hydrogen for maritime operations.

In all the Nordic countries there are number of opportunities for deployment of heavy-duty hydrogen equipment, being it at an industrial site, construction site, mines or potentially most interestingly at ports. The following chapters will examine each of the Nordic countries in more detail in this context.





Photo: Guillaume Baviere, Flickr -
<https://www.flickr.com/photos/B4554176@N00/6133222589>

Denmark

Port and port areas

Denmark is a maritime nation, with the world's 6th largest shipping fleet. As such – the decarbonisation of this important part of the infrastructure is vital for Denmark, also as a long-term strategic position. Hence, a lot is currently being undertaken regarding this task – including production of hydrogen-based fuels. This effort is linked to the maritime strategy and the ships themselves – not the transport on the ground in ports etc. There is obvious potential with regard to the heavy truck traffic, but this will be covered in *Deliverable 5.1/5.2*. The Danish Association of Harbours considers the deployment of hydrogen/hydrogen-based fuels such as ammonia – to be essential for the decarbonisation of the port infrastructure in Denmark. Both Copenhagen-Malmö Port, ADP, Port of Hirtshals, Port of Hanstholm, Port of Ronne, Port of Aarhus, and the Port of Esbjerg are important regarding hydrogen logistics and deployment of hydrogen infrastructure.

The market

There is no mining in Denmark and in general heavy-duty machinery is limited compared to other parts of the Nordics. But obviously construction is a major sector, where zero-emission construction sites – with Nordic inspiration from Norway, is a growing factor especially concerning the urban centres of Copenhagen and Aarhus. Currently, this is mainly implemented with on-site power supply and battery electric solutions while more heavy-duty equipment is still operated with diesel engines.

As seen in the non-road equipment overview given in *Table 1*, the number of vehicles is substantial and would be a significant impact on the local environmental and air quality contribution as well as a CO₂-reduction potential, if hydrogen solutions were implemented in the construction sector.

But although the potential theoretically is substantial, the lack of available construction machinery etc. combined with the need of implementing zero-

emission technologies in the wider transport sector, will most likely mean that trucks will be prioritized over the heavy-duty equipment. As such it is probably not likely to be the first sector to benefit from the opportunities of a further deployment of hydrogen.

Tabel 1. NRMM in Denmark (copyright Danish ministry of the Environment).

Antallet af mobile ikke-vejgående maskiner, energiforbrug, NO _x - og PM _{2,5} emissioner indenfor industri og handel/service i Danmark for 2016 og 2030, detaljeret opdelt i effektklasser og emissionstrin									
Motorstørrelse	Emissionstrin	Antal maskiner	2016 Energiforbrug PJ	NO _x Tons	PM _{2,5} Tons	Antal maskiner	2030 Energiforbrug PJ	NO _x Tons	PM _{2,5} Tons
P<8	1991-Stage I	3500	0,044	42,9	7,62	-	-	-	-
P<8	Stage V (2019)	-	-	-	-	3500	0,044	23,1	1,91
	Total	3500	0,044	42,9	7,62	3500	0,044	23,1	1,91
8<=P<19	1991-Stage I	6500	0,233	230,0	41,29	-	-	-	-
8<=P<19	Stage V (2019)	-	-	-	-	6500	0,233	123,6	10,32
	Total	6500	0,233	230,0	41,29	6500	0,233	123,6	10,32
19<=P<37	1981-1990	8	0,000	0,0	0,01	-	-	-	-
19<=P<37	1991-Stage I	1909	0,093	82,1	18,15	-	-	-	-
19<=P<37	Stage II	4266	0,155	87,6	8,66	13	0,000	0,0	0,00
19<=P<37	Stage IIIA	10602	0,506	281,1	32,10	1990	0,070	38,8	4,72
19<=P<37	Stage V (2019)	-	-	-	-	13383	0,637	217,4	0,99
	Total	16785	0,754	450,9	58,91	15386	0,707	256,3	5,72
37<=P<56	1981-1990	408	0,051	36,1	11,14	-	-	-	-
37<=P<56	1991-Stage I	5267	0,450	461,0	56,00	-	-	-	-
37<=P<56	Stage I	3089	0,275	181,9	19,38	301	0,036	24,2	2,80
37<=P<56	Stage II	7221	0,765	366,9	21,69	498	0,050	23,2	1,83
37<=P<56	Stage IIIA	6040	0,624	235,7	19,17	2682	0,211	80,3	8,36
37<=P<56	Stage IIIB	2158	0,267	99,1	0,69	2881	0,251	93,7	0,81
37<=P<56	Stage V (2019)	-	-	-	-	14934	1,467	546,8	2,53
	Total	24183	2,433	1380,7	128,06	21296	2,016	768,3	16,33
56<=P<75	1991-Stage I	3	0,000	0,0	0,00	-	-	-	-
56<=P<75	Stage I	165	0,006	4,3	0,46	-	-	-	-
56<=P<75	Stage II	624	0,071	33,3	2,36	-	-	-	-
56<=P<75	Stage IIIA	444	0,073	29,0	3,05	1	0,000	0,0	0,00
56<=P<75	Stage IIIB	841	0,139	42,1	0,39	47	0,001	0,2	0,00
56<=P<75	Stage IV	643	0,082	3,3	0,22	430	0,013	0,5	0,04
56<=P<75	Stage V (2020)	-	-	-	-	2827	0,419	17,1	0,72
	Total	2720	0,372	112,0	6,48	3305	0,432	17,8	0,76
75<=P<130	1991-Stage I	523	0,034	40,2	2,67	-	-	-	-
75<=P<130	Stage I	621	0,086	61,2	3,21	-	-	-	-
75<=P<130	Stage II	1915	0,235	106,2	7,83	-	-	-	-
75<=P<130	Stage IIIA	3048	0,817	283,9	35,32	122	0,020	7,0	1,08
75<=P<130	Stage IIIB	1768	0,612	189,4	1,75	411	0,056	17,5	0,21
75<=P<130	Stage IV	1507	0,396	16,5	1,08	1402	0,127	5,3	0,44
75<=P<130	Stage V (2019)	-	-	-	-	7229	1,989	83,0	3,56
	Totalt	9382	2,180	697,4	51,86	9164	2,192	112,8	5,28
130<=P<560	1991-Stage I	4	0,000	0,2	0,02	-	-	-	-
130<=P<560	Stage I	72	0,008	5,3	0,30	-	-	-	-
130<=P<560	Stage II	450	0,106	49,2	1,78	-	-	-	-
130<=P<560	Stage IIIA	1364	0,898	319,4	20,32	-	-	-	-
130<=P<560	Stage IIIB	914	0,687	132,0	2,05	22	0,001	0,2	0,00
130<=P<560	Stage IV	1258	0,905	38,6	2,53	351	0,053	2,3	0,19
130<=P<560	Stage V (2019)	-	-	-	-	3902	2,759	117,8	5,00
	Total	4062	2,604	544,6	26,99	4275	2,814	120,3	5,19
	Grand total	67132	8,620	3458,5	321,2	63425	8,438	1422,1	45,5



Photo: Vladimir Patkachakov, Unsplash

Finland

Ports and port areas

The traffic within the ports in Finland as well as to and from the ports is reported in environmental permits for each port.

In addition, every 3-5 years, The Finnish Transport Infrastructure Agency (Väylävirasto) publishes the "Study on the hinterlands of the Finnish sea ports", where full statistics of export and import for each port is reported.

The most interesting ports in Finland are Helsinki (Vuosaari) port as well as Kotka-Hamina ports. This is due to very large truck traffic, reported in *Deliverable 5.1/5.2*. In the report of the Finnish Transport Infrastructure Agency, it can also be found that road transport to and from these two ports are the most significant in Finland. Even if Vuosaari is used as case example here, Kotka-Hamina ports would be equally attractive for hydrogen NMRR.

There are totally about 10 ports in Finland, that have sufficient amount of heavy road traffic motivating hydrogen refuelling station, which could also serve NMRR in the ports.

Case Vuosaari port

The truck traffic for Vuosaari port is 1,180 trucks per day, based on their environmental permit (ESAVI/306/04.08/2012), *Table 2*. This, together with other nearby truck traffic creates a very large potential for hydrogen trucks.

Table 2. Truck and working machine traffic in Vuosaari port area

City / site	External (visits, includes back and forth)	Internal	Reference
Helsinki, Helen Vuosaari bioheat plant	75 trucks when operating at full power		ESAVI/2015/2018
Helsinki, Vuosaari port	1,180 trucks per day	7,500-7,600 kt CO ₂ -emissions	ESAVI/306/04.08/2012

According to environmental permit (ESAVI/306/04.08/2012) the total number of working machines was 193, corresponding to a total CO₂-emission of about 5,500-5,600 tonnes. Currently, the emissions are about 7,500-7,600 tonnes. This would correspond to about 500-600 tonnes of hydrogen if all would be powered by hydrogen.

The fuel consumption of working machines at the port is not sufficient for large HRS with low hydrogen price. However, the total fuel consumption of heavy-duty transport in Vuosaari would be sufficient. The key issue would be how to locate a common HRS.

For NMRR in ports, also battery electric vehicles can be a very competitive alternative. Hydrogen fuel cells suits best those machines with a high average load and/or irregular duty-cycles. Such machines are, for example, reach stackers.

Industrial sites

In addition to the areas with ports and industry clusters, there are separate industrial locations with moderate hydrogen need for external transport (<5 tonnes H₂/day) but still significant internal operations.

In Finland, these sites include especially SSAB in Raahen and Outokumpu in Tornio. In addition to these, there are also some other industrial sites (e.g., Harjavalta area, Kokkola industry park) with significant transportation amounts. However, in these sites the transportation needs are distributed between several companies and therefore they are not so attractive as large hydrogen hotspots. In Kokkola industry park, however, there is an electrolyser, which would support a mid-size hydrogen hotspot (<2 tonnes per day).

Mines

In Finland there are three very large open pit mines, which are interesting for mine trucks or articulated haulers. These are Terrafame mine in Sodankylä, Kevitsa mine in Sodankylä, and Yara Siilinjärvi mine in Siilinjärvi.

In all these mines, the diesel consumption for the mine trucks or articulated haulers is significant and actually much larger than the diesel consumption for trucks visiting the mines. For example, the diesel consumption in Kevitsa mine (19-31.5 million kg) would correspond about 10-15 tonnes of hydrogen dispensed daily, while all trucks visiting the mine would need less than 2 tonnes per day.

The emissions from mine trucks or/and articulated haulers are listed in *Table 3*. In addition to these, there are also some other industrial sites (e.g., Harjavalta, Kokkola) with significant transportation amounts. However, in these sites the transportation needs are distributed between several companies and therefore they are not so attractive as large hydrogen hotspots. In Kokkola industry park, however, as mentioned above, there is an electrolyser, which would support a mid-size hydrogen hotspot (<2 tonnes per day).

Table 3. Overview of emissions from mine trucks or/and articulated haulers from the three very large open pit mines in Finland

City / site	External truck visits per day	Internal traffic	Environmental permit Dnro or other reference
Sotkamo, Terrafame mine and battery chemical plant	25-35 10-15	Total (external and internal) CO ₂ emissions 47-64 kt/year total 17.6-24 million dm ³ diesel use	Terrafame Oy Environmental permit application and PSAVI/3626/2019
Siilinjärvi, Yara Siilinjärvi mine	20	12 million kg diesel use	ISAVI/1194/2015
Sodankylä, Kevitsa mine	25	Between 19-31.5 million kg diesel use	PSAVI/144/04.08/2011

In addition to these major mines, there are a number of smaller mines in Finland. The mines in Table 3, however, are the most potential ones due to economics of scale for hydrogen production and dispensing. The Terrafame mine in Sotkamo has already significant hydrogen production and use, up to 6,200 tonnes per year.

Concerning potential new mines, the largest are Keliber Lithium mines close to Kokkola as well as Hannukainen mine in Kolari. Both these sites could be interesting for hydrogen-based heavy-duty transport but have not been analysed further so far.





Photo: Peter H (Tama66), Pixabay

Iceland

For Iceland, transport fuel is more important when it comes to reduction of greenhouse gases than many other countries. Historical emission data from trucks, vans, and equipment for the period 1990-2017 is depicted in *Figure 1*. Today, NRMM is responsible for 7% of total greenhouse gas emission in transport (2017). This is not a large portion but still shows the importance of decarbonising the sector and reaching Iceland 55% goal set by the Government – well beyond the 29% laid out in the Paris Agreement.

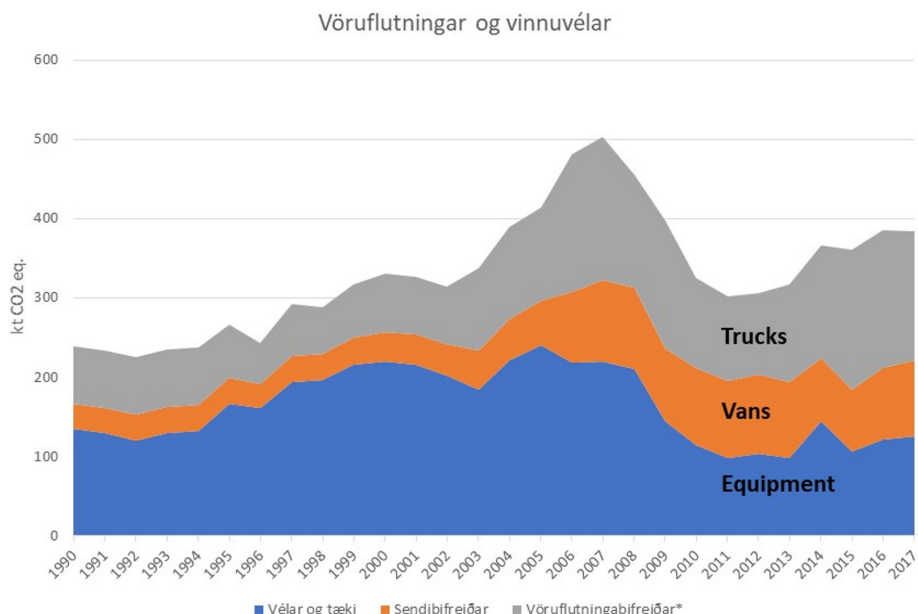


Figure 1. Emission from segments in Iceland. Heavy-duty equipment is shown as blue!

The market

Iceland has little to no forestry and/or mining industry compared to the other Nordic countries. However, ports and maritime operations are very important and within those there are both equipment and trucks operating. This provides an excellent case for hydrogen deployment as the same infrastructure could be used for both.

The total number of equipment registered in Iceland is 29,281 as of August 2021. The group consists of any type of machinery and heavy equipment which is by law registered with the Occupational Safety and Health Authority (OSHA)¹⁸ including Non-Road Mobile Machinery. Roughly half of these are powered in part or entirely by electric motors. According to current regulation, registering approximate fuel consumption and machine hours is not mandatory, but project partners have put in a formal request to OSHA to require more detailed information on equipment upon registration. This is to improve data and analysis of the fleet composition and contribution to the needed reduction in national greenhouse gas emissions. Furthermore, more comprehensive, and regular information collection on heavy equipment will enable proper and accurate forecasting of its renewal and transition to low or zero-emission fuels.

Current information relevant to this report is displayed in *Figure 2*. Fuel consumption for the Icelandic construction sector is denoted in red and shows a steady decline since its culmination in 2007, at 61,000 tonnes oil equivalent. The figure also demonstrates the relative contributions of the sectors included here to national emissions and thus opportunity for energy transition.

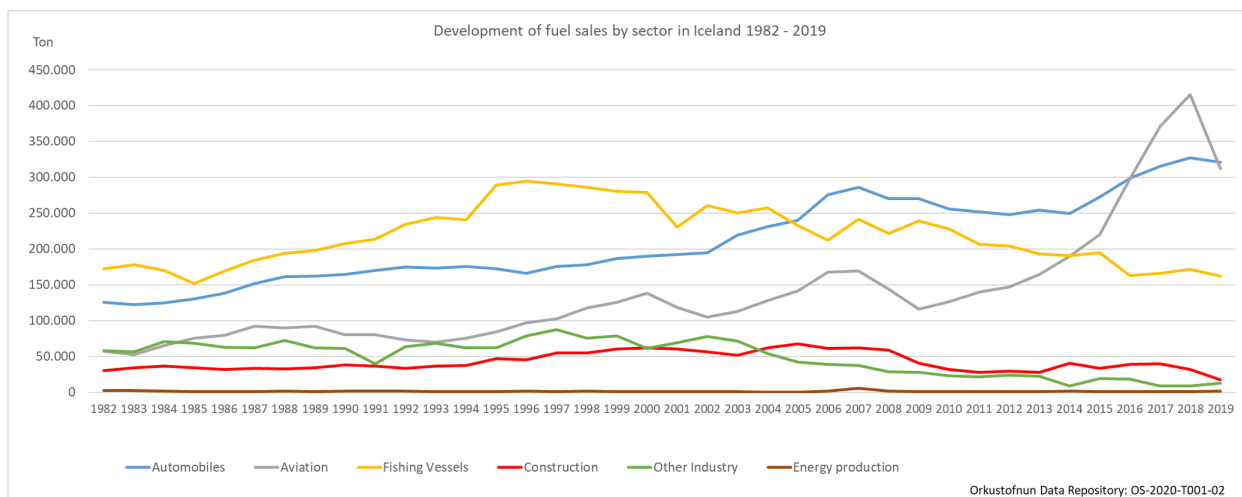


Figure 2. Development of fuel sales in the period 1982-2019 by sector in Iceland.

¹⁸ Vinnueftirlit Ríkisins <https://vinnueftirlitid.is/>



Photo: Troy Mortier, Unsplash

Norway

Ports and port areas

There is an ambition of the Norwegian Hydrogen Roadmap¹⁹ presented June 2021 to establish five hydrogen hubs for maritime transport within 2025. In addition, most likely some of the five to ten pilot projects that are to be established for the development and demonstration of new and more cost-effective hydrogen solutions and technologies will be maritime pilots. Non-road mobile machinery (NRMM) as well as land transport in such ports should have the opportunity to make use of this hydrogen infrastructure. Currently, 15 feasibility studies throughout the Norwegian coast, *Figure 3*, have been granted support from Enova to elaborate on the business case for green hydrogen at their site, with the intention to support 2-4 full-fledge project with up to 150 MNOK per project in the end²⁰.

Material handling equipment in logistics centres and industry areas

Since December 2017, at their distribution centre at Tiller in Trondheim, the Norwegian wholesaler ASKO operates one of the first examples of an on-site hydrogen production and dispensing solution²¹. The hydrogen is produced based on solar power from 9,000 m² (as of 2019) of PV-panels on the roof of the distribution centre. Part of the annual PV electricity production of about 1 million kWh is fed to the on-site hydrogen production unit with a capacity of 300 kg H₂ per day. The

¹⁹ The roadmap is part of governments report to the national assembly: *Energi til arbeid – langsiktig verdiskaping fra norske energiressurser*
<https://www.regjeringen.no/contentassets/3d9930739f9b42f2a3e65adadb53c1f4/no/pdfs/st-m202020210036000dddpdfs.pdf>

²⁰ https://presse.enova.no/pressreleases/enovastoette-til-15-hydrogenprosjekt-i-maritim-transport-3130758?_ga=2.176605985.50009048.1635604045-1318445704.1595944296&_gac=1.258540152.1632829190.CjwKCAjw-sqKBhBjEiwAVaQ9awSDXESlo4YTverOG7_Eum3WV-MgE9sTMzaYFp5QHvjBbKD61Wlz7mhoCXCwQAvD_BwE

²¹ <https://asko.no/nyhetsarkiv/i-front-med-hydrogen/>



Figure 3. Feasibility studies throughout the Norwegian coast granted support from Enova to elaborate on the business case for green hydrogen.

hydrogen is dispensed both at 350 bar and 700 bar serving both forklifts and city logistic distribution trucks (350 bar, see Table 4), as well as ASKO-employee hydrogen cars (700 bar).

Table 4. Technical data for the Scania hydrogen trucks at ASKO MIDT-NORGE AS i Trondheim

Item	Description
Manufacturer	Scania/Asko
Max. Gross Vehicle Weight	27 ton
Battery	56 kWh
Range	400-500 km
Fuel cell capacity	90 kW
Power total	290 kW
Torque	2200 Nm
H2 Storage	33 kg @ 350 bar
Fuel cell manufacturer	Hydrogenics
Status	Demonstration 4 trucks operational since 2019

Construction sites

Zero-emission construction is high on the agenda in Norway and several municipalities and public bodies have strategical targets to lower the emissions from the construction sector. In Oslo, for instance, all construction sites (including mass transport) shall be zero-emission by 2025²².

Back in 2017, nine²³ key building commissioners, property managers, and developers signed a common announcement setting requirements for the use of zero-emission technologies, processes, and solutions related to the construction and operation of building as zero-emission technology becomes available in the market. As a result, the World's first zero-emission construction site²⁴ was launched downtown Oslo in September 2019 giving Olav V's gate/Klingenberggata a real makeover²⁵. A few years later, the new fire station at rural Lystad in Lillestrøm municipality will be constructed using almost only zero-emission machinery²⁶.

Currently there are no hydrogen powered construction machineries in Norway, but both Pon Equipment in Lillestrøm and Nasta in Larvik are well into the electrification of heavy-duty machineries such as 8-38 tonnes excavators from Caterpillar and Hitachi. These days, both Pon Equipment and Nasta receives the to-be-electrified excavators without engines upon delivery in Norway and some 150-200 electric excavators are in daily operation in Norway these days. The machines are categorised as battery-only machinery, hybrid "PeakShavers" combining battery and cable connection, and cable connected machines. A main challenge with the battery-electric construction machinery is the energy consumption versus the onboard energy storage leading to downtime due to charging during the working day. Regarding the cable-connected machines the operating range is limited, and obviously, at all times, it is crucial to keep an eye on the cable avoiding damages. Nevertheless, in both cases, the availability of high electric capacity onsite the construction area often is a main challenge as the energy capacity during the construction period in most cases surpasses the energy capacity needed when the construction time is up. The use of hydrogen powered machinery can solve this.

Two main challenges for the further development and deployment of zero-emission construction sites in Norway is the lack of machinery and the lack of infrastructure. This goes for both battery/cable electric machinery as well as hydrogen electric machinery. To generate a first demand for hydrogen infrastructure, Nasta investigates hybrid diesel/hydrogen excavators²⁷ together with their Belgian partner CMB. Even if the goal is pure hydrogen machinery in

²² <https://www.oslo.kommune.no/for-vare-leverandorer/krav-til-leverandorer/klima-og-miljokrav/>
²³ Including Statsbygg (the Norwegian government's building commissioner, property manager and developer), Omsorgsbygg Oslo and Kultur- og idrettsbygg Oslo (the municipal enterprises that builds, maintains, and manages municipal purpose buildings as well as culture and sports arenas in Oslo), Bane NOR (state-owned company responsible for the Norwegian national railway infrastructure), Statens vegvesen (The Norwegian Public Roads Administration), AFK eiendom (property manager of Akershus county council), as well as counties and county councils in the Oslo area.

²⁴ <https://doffin.no/Notice/Details/2019-336966>.

²⁵ <https://magasin.oslo.kommune.no/byplan/ny-gagate-gir-nytt-liv-til-sentrum#gref>

²⁶ <https://www.bygg.no/handverkskompaniet-bygger-ny-brannstasjon-i-sorumsand/1469318/>

²⁷ <https://www.luyckx.be/en/product/cleantech-construction-solution?category=hitachi-1>



Photo: Shane McLendon, Unsplash

the end, their current philosophy is to stimulate the first hydrogen demand within this sector. Thus, by offering relatively inexpensive hydrogen-based excavators such as the hybrid diesel/hydrogen excavators, Nasta/Hitachi with partners aim to contribute to this very first hydrogen infrastructure demand.



Photo: Markus Distelrath, Pixabay

Sweden

Ports and port areas

The ports of Trelleborg, Gothenburg, and Gävle have announced that they will establish hydrogen production in connection to the ports. With the very high frequency of transportation within the port areas the current fuels create very concentrated and high emission levels, which makes it very hard for these cities to fulfil their climate targets. The motivation is then high to find alternative fuels with low or no harmful emissions. The hydrogen at these ports is aimed to be green hydrogen and the initial use is for the transportation around and within the port area for both incoming vehicles from land and with ships from the seaside, as well as transportation of goods within the port area with different vehicles such as forklift trucks of different sizes. In a longer perspective also incoming trains, boats, and ships could be using hydrogen as a fuel.

In Gävle port, they have signed an agreement for hydrogen production from wind power and they run a ten-year programme to energy optimize the port cluster until 2030 with the target to reduce GHG-emissions in line with the Paris agreement. Gävle University calculate a 70% emission reduction by swapping from current fuels to hydrogen.

In Trelleborg, there is a ten-year plan for the city development including hydrogen. The port is one of the main areas for a big development because it will be moved partly towards east to release areas for new buildings close to the sea. In the port there are today annually 750,000 trucks passing, due to the frequent lines to Germany and Poland. This number can be doubled according to some investigations, and by that, become one of the country's most used ports.

Gothenburg port and the fuel retail company Circle K announced in May 2021 that they will establish a hydrogen refuelling station close to the port area mainly for hydrogen trucks. In November 2021, the energy company Statkraft and the Gothenburg port announced that they will aim for a hydrogen production unit within the port area. This is an initiative financed by the CEF-programme in the EU-project Nordic Hydrogen Corridor.

Material handling equipment in logistics centres and industry areas

In October 2021, myFC sign an agreement with Porsche for evaluation of fuel cell solutions for automated warehouse robots.

Mines

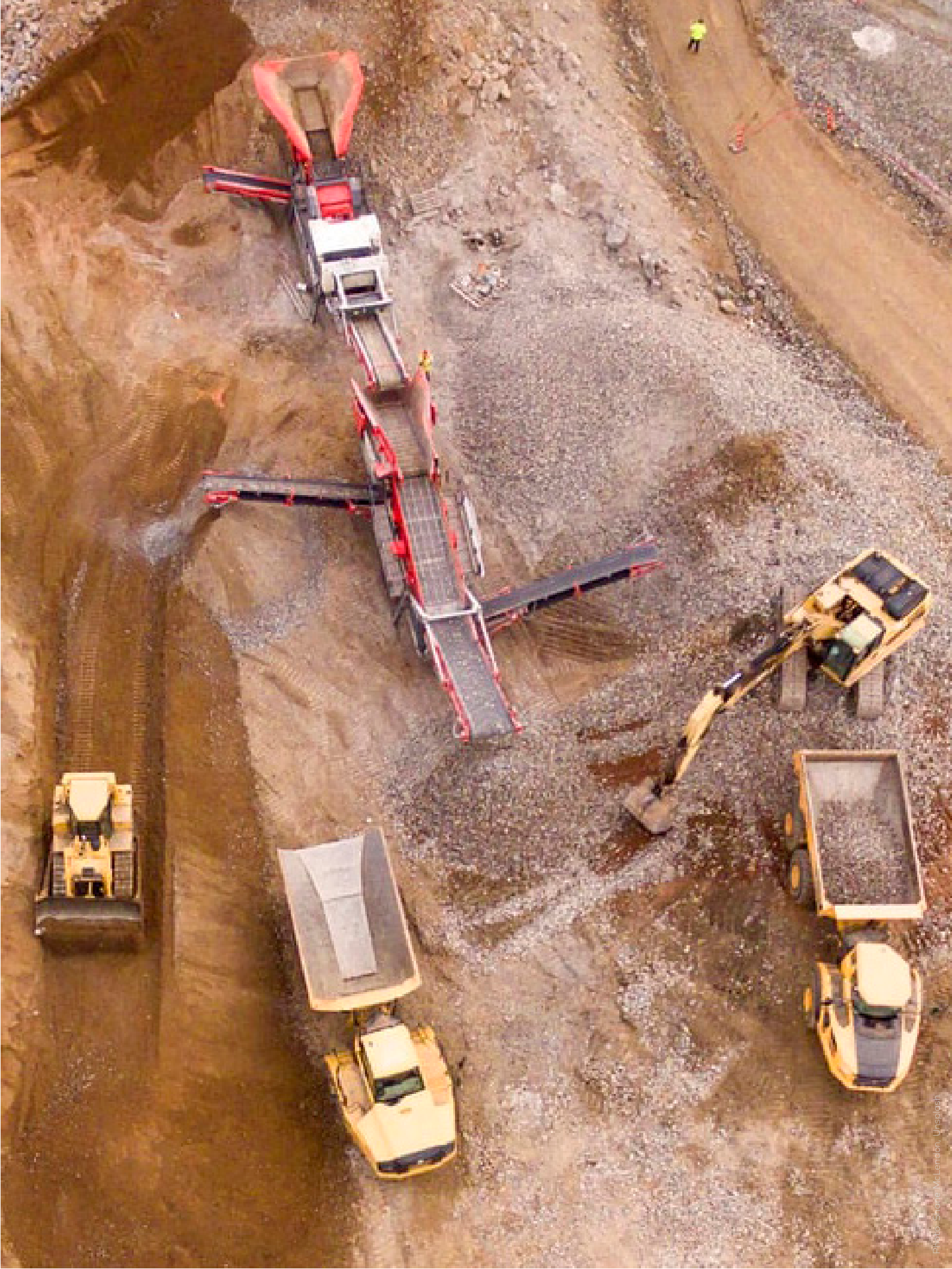
During the last ten years, a number of investigations about using hydrogen for different vehicles within the mining area has been performed, but so far no demonstration or implementation has been seen.

Industrial sites

In 2016 SSAB, PowerCell, and Kalmartruck (part of Cargotec) showed a 14-tonnes hydrogen forklift truck at the SSAB site in Oxelösund. The demo project was successful and SSAB had plans to continue the use if the hydrogen truck at another site in Sweden.

Photo: Jake Nebov, Unsplash





Conclusion

The development state of heavy-duty equipment is not at the same level as for hydrogen passenger cars, or even larger vehicles, such as hydrogen trucks. Some Non-Road Mobile Machineries (NRMMs) also often creates a new demand for refuelling, i.e., a mobile hydrogen refuelling station (HRS). Still, development has started and in the Nordic countries there can be very good synergies between the use of NRMM and infrastructure for trucks, specifically in ports, mining, and forestry. All extremely important industries for the Nordic countries.

Nordic stakeholders are following the development of such equipment closely and some companies within the Nordics might become important providers of the technologies, i.e., like Volvo. With deployment of trucks within the Nordic countries, an opportunity will be created, most likely at ports, for deployment of hydrogen powered NRMMs. But importantly also is to stimulate the development of a mobile hydrogen refuelling infrastructure which can fulfil the needs of NRMM. In the US, hydrogen forklifts are already in commercial use in thousands. There's not a simple answer to why such solutions have not picked up the same traction in Europe – but there are for sure commercial opportunities for such solutions.

However, it is likely that increased hydrogen infrastructure deployment, and, in addition, potential availability of mobile HRSs, will be key success criteria for the first deployment stage of NRMM. Industrial stakeholders are very interested, and with current technical development potential, the hydrogen powered NRMM deployment is likely soon to come.

Next Nordic Green Transport Wave - Large Vehicles

Deliverable 3.1

**Prospectus of using hydrogen in heavy-duty equipment,
including non-road mobile machinery**

Version 1.0

2021

