NEXT NORDIC GREEN TRANSPORT WAVE - LARGE VEHICLES

Hydrogen transport from large-scale production points to Nordic consumers

Overview - hydrogen transport from large-scale production points to consumers in all Nordic countries

Deliverable 2.4
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Nordic Innovation

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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.

Partners in Next Wave:

KUNNSKAPSBYEN LILLESTRØM

VTT

Brintbranchen Hydrogen Denmark

ÍSLENSK NÝORKA ehf ICELANDIC NEW ENERGY Ltd.

VÄTGAS SVERIGE

NORSK HYDROGENFORUM hydrogen.no

Authors:
Name of author, contributors company/ organization
VTT: Jari Ihonen
Hydrogen Sweden: Anna Grzelec, Erik Wiberg, Björn Aronsson
Icelandic New Energy: Jón Björn Skúlason
Hydrogen Denmark: Tejs Laustsen Jensen
Norwegian Hydrogen Forum: Ingebjørg Telnes Wilhelmsen
Kunnskapsbyen Lillestrøm Norway: Jon Eriksen

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Summary

The availability of hydrogen transport containers is studied by using data from three manufacturers of hydrogen transport containers (Umoe Advanced Composites (UAC), Wystrach, and Hexagon). One container type from UAC is glass fibre based low CAPEX alternative, while the two others are more costly carbon fibre alternatives. The container data has been combined here with the traffic regulations reported in Deliverable 2.3.

The main outcome is the maximum amounts of hydrogen that could be transported on Nordic roads using hydrogen transport containers. The focus is on the maximum amounts of hydrogen only; not on the operation efficiency nor overall economics (e.g., accounting for things like number of fillings, or container/compressor/other equipment utilisation rate).

The operation time of loading or unloading containers may have significant importance on total cost of ownership (TCO). Therefore, especially for short distance transport this is an important parameter and may favour some configurations. This is also omitted in this study.

If hydrogen is transported to the hydrogen refuelling station (HRS), the selected pressure level should be optimised as a part of overall hydrogen supply chain optimisation. It seems that higher pressure levels are preferred in the future, as this will lower cost of compression onsite the HRS as well as improving the HRS reliability.

The focus in this study is large scale hydrogen gas transport. Therefore, 40 ft and 45 ft containers are the most interesting container sizes. However, in many cases, also 20 ft containers (including hook load model) may be of interest for lower loading and unloading times, especially for HRS with lower hydrogen dispensing amounts.

This outcome can be used for building hydrogen supply chains based on centralised or semi-centralised hydrogen production and transport to single hydrogen refuelling stations or "hydrogen hubs" that can refuel heavy-duty vehicles as well as other transportation equipment (maritime, trains etc).

The summary of results for Nordic countries is shown in *Table 1*. The results are dependent on available container solutions. Especially for new pressure levels (due to new EN 17339 standard) results should be taken as illustrative.

Table 1. Maximum amounts of hydrogen that could be transported on Nordic roads using hydrogen transport containers available in the market

Country	Low CAPEX solution	High CAPEX solution	High CAPEX solution, new EN 17339 standard
Denmark	894 kg UAC container (450 bar)	1,065-1,115 kg 40 ft container at pressure level 500 bar from Wystrach or Hexagon	1,300-1,350 kg 40 ft container at pressure level 635 bar from Wystrach or Hexagon
Finland	1,118 kg with B-link and two 40 ft UAC high cube containers (200 bar)	1,670 kg with B-link and two 40 ft containers (300 bar)	2,200-2,300 kg with B-link and two 40 ft containers at 500 bar
Iceland	734 kg UAC container (350 bar)	1,065-1,115 kg 40 ft container at pressure level 500 bar from Wystrach or Hexagon	1,300-1,350 kg 40 ft container at pressure level 635 bar from Wystrach or Hexagon
Norway	894 kg UAC container (450 bar)	1,065-1,115 kg 40 ft container at pressure level 500 bar from Wystrach or Hexagon	1,300-1,350 kg 40 ft container at pressure level 635 bar from Wystrach or Hexagon
Sweden BK1	1,008 kg with three 20 ft UAC containers (250 bar)	1,505 kg with three 20 ft containers from Wystrach (500 bar)	1,800-1,900 kg with three 20 ft containers
Sweden BK4	1,305 kg with three 20 ft UAC containers (350 bar)	1,505 kg with three 20 ft containers from Wystrach (500 bar)	1,800-1,900 kg with three 20 ft containers

Dedicated hydrogen transport solutions optimized for the Nordic market does not exist. This may change in the future and biogas transport may help in this, especially in Finland and Sweden.

From a Nordic perspective, the development towards higher pressure levels in transport containers is important to follow as in most of the countries (Norway, Sweden (BK4), and Denmark) the volume is the limiting factor, not the weight. As a comparison, the volume restrictions of Norway (weight restriction 50 tonnes) and Denmark (weight restriction 56 tonnes), actually makes the amount of transported hydrogen the same as for Iceland having a weight restriction of only 44 tonnes (except for the Low CAPEX solution, where the selection of commercial containers is limited).

Furthermore, if the maximum vehicle length allowed at the Sweden BK4 roads (BK4 weight restriction 74 tonnes) is increased from 25.25 m (as of today) to 34.5 m (as investigated by the Swedish Transport Administration), the amount of transported hydrogen would be the same (or more) than in Finland as the maximum weight of Sweden (BK4) is 74 tonnes, while in Finland the limit is 68 tonnes.

It is expected that the further development of container- and semi-trailer-based hydrogen road transport solutions will increase the amount of hydrogen that can be transported on Nordic roads in the future. This will take place, especially, if the gas pressure in transport is further increased from 500 bar upwards, even up to 1,000 bar as studied in the German H_2-HD project.

Background

Overview of hydrogen supply chain (HSC) options

In general, transport of hydrogen is possible by tube trailers, by pipeline, and using cryogenic liquid hydrogen (Reuß et al. 2017). Hydrogen supply chain (HSC) using these options has been a topic of numerous studies (Li, Manier, and Manier 2019; Maryam 2017; Reddi et al. 2018; Reuß et al. 2017). In these studies, however, nor the Nordic regulation limits, or the current available transport solutions are accounted for. Hence, these results are not directly comparable with current technology especially when Nordic weight limits are applied.

Liquid hydrogen

The transport of cryogenic liquid hydrogen is a special case, as liquid hydrogen is not yet commonly available. Liquefaction would enable hydrogen to be trucked more efficiently over long distances due to significantly higher truck payloads. The latest solutions from Linde enable payloads of 3,000 and 4,000 kg for ISO container and for LH2 trailer, respectively[1]. In the literature even higher payloads are used, e.g., 4,300 kg (Reuß et al. 2017). The weight limits would allow higher payloads with longer vehicles, as due to the low density of liquid hydrogen systems, volume is always the limiting factor, not the weight. For example, in Finland the transport of two 40 ft ISO containers (2x 3,000 kg) from Linde would be possible. The maximum length of semi-trailers in Finland (23 m) and Sweden (24 m) would also allow transport of very long semi-trailer.

Liquefaction is cost and energy efficient only in large scale production. In small or medium scale production the energy usage and capital expenses are significantly larger than in large-scale production. Therefore, liquid hydrogen will be significantly more expensive than gaseous hydrogen until large-scale liquefaction plants are commonly available.

Liquefaction is especially well motivated when liquid hydrogen has a high value for end user. This is the situation, when hydrogen is stored as liquid in end user application, for instance, in maritime applications. In addition, if cryo-pump technology from e.g., Linde is used at hydrogen refuelling station (HRS), the use of liquid hydrogen would enable lower compression energy consumption[2]. In addition, hydrogen cooling by a separate cooler is not needed. These benefits may accelerate the production and use of liquid hydrogen for transportation applications.

Liquid organic hydrogen carriers (LOHC)

In addition to the hydrogen supply options mentioned above, it is possible to use liquid organic hydrogen carries (LOHC) such as dibenzyl toluene or toluene. Using LOHC, hydrogen payloads of 1,500-2,000 kg would be possible with 40 tonne trucks. Different LOHCs are currently in advanced research state or

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1 https://www.sintef.no/globalassets/project/hyper/presentations-day-2/day2_1105_decker_liquid-hydrogen-distribution-technology_linde.pdf

2 https://www.linde-engineering.com/en/plant-components/hydrogen-fueling-technologies/index.html

early commercial stage (Aakko-Saksa et al. 2018). However, the cost efficiency of hydrogen transport be LOHC is difficult to estimate as there are no reliable cost data available for hydrogenation and dehydrogenation reactors (Hurskainen and Ihonen 2020).

Hydrogen transport by compressed gas

The main logistic option for hydrogen transport today is truck delivery in the form of compressed gas. Amongst others, according to (Lahnaoui et al. 2019; Yang and Ogden 2007), this means of transport has been considered the most suitable for delivering relatively small amounts of hydrogen for short or moderate distances (<200–300 km). In many of older studies the input data for tube trailers is already outdated, as heavy steel-based cylinders were assumed. Therefore, the conclusions of these studies are not any more valid. Currently, tube trailers are lighter and cheaper. Therefore the hydrogen transport by tube trailers is much more cost efficient than 5-15 years ago.

Due to development of fiberglass and carbon fibre composite cylinders, there has been increase of hydrogen payloads from 200-300 kg up to 1,000 kg with 40 tonne trucks (Lahnaoui et al. 2019). At the same time, the pressure level has increased from the traditional 200 bar up to 500 bar enabling more compact storage. Even 1,000 bar transport solutions are studied in German national project H_2-HD[3]. The use of 1,000 bar in transport would almost completely eliminate the need of compressor at HRS dispensing hydrogen at 700 bar, while the use of 450-500 bar in transport would do the same for hydrogen dispensed at 350 bar.

When these new tube trailer options has been used in the latest HSC analyses, it has been noticed that the cost-efficiency of hydrogen transport by tube trailers has increased significantly (Andresen, Bode, and Schmitz 2018; Lahnaoui et al. 2019; Reuß et al. 2017; Ulleberg and Hancke 2020).

The use of tube trailers may be the first step in building the hydrogen infrastructure. Then, when the demand has increased, they can be partially replaced by pipelines, on-site electrolysers, or with liquid hydrogen supply options. Tube trailers can also complement on-site production of hydrogen in hydrogen refuelling stations, increasing security of hydrogen supply. The hydrogen tube trailers or gas containers are flexible and may first serve one location before being moved to serve another location later on.

Hydrogen transport by pipeline

When the amount of hydrogen transported is increasing, pipelines are becoming the most cost-efficient transport method (Yang and Ogden 2007). For very large amounts of hydrogen, the pipeline becomes superior option in terms of cost and energy efficiency. Therefore, in long run, dedicated hydrogen pipeline infrastructure should be created to support wider use of hydrogen. European gas companies has drafted a plan for such an infrastructure for Europe (Enagás et al. 2020).

[3] https://fuelcellsworks.com/news/hypos-partners-work-on-safe-and-lightweight-high-pressure-tanks-for-storing-and-transporting-green-hydrogen/

Semi-central hydrogen supply chain

The most cost-efficient hydrogen production by electrolysis can take place in large industrial units far from hydrogen refuelling stations. This is due to the fact that electricity bought at higher voltage level usually is cheaper and specific capital cost of the electrolyser and storage are lower. In addition, when hydrogen is also used for industrial purposes. On top of that, by-products (oxygen, heat) may be easier to use, generating extra revenues, thereby reducing hydrogen production cost.

In addition to large centralised / industrial hydrogen production units, hydrogen production could take place in very large hydrogen refuelling stations, which are dispensing large amounts (several tonnes per day) of hydrogen for fleet applications (bus fleets, truck fleets).

For smaller hydrogen refuelling stations and in densely populated areas, however, on-site hydrogen production normally is not the best option. In this case, the hydrogen typically will be delivered by tube trailers, if a large hydrogen production point is within reasonable distance. This so-called semi-central hydrogen supply chain (HSC) is illustrated in *Figure 1*.

The cost for compressing and transporting hydrogen is highly pressure dependent. Therefore, the pressure level of such a semi-central HSC should be carefully selected evaluating the pros of high volumetric density (at high pressure) versus the cons of more expensive components and higher operational costs.

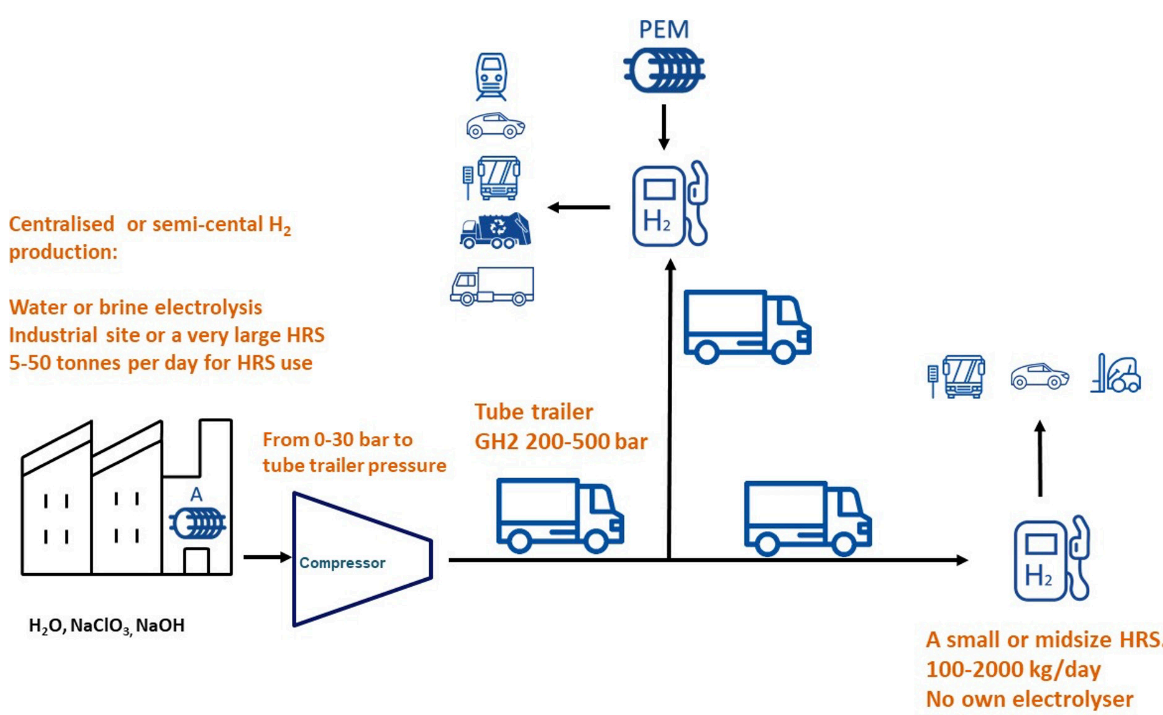

Figure 1. Semi-central hydrogen supply chain.

Available compressed gas containers applicable in the Nordic market

The number of available containers for compressed gas transport is increasing, as the use of hydrogen and biogas in traffic is expanding. Here, a brief overview of the container availability ultimo 2020 is given, also including known changes to take effect in 2021.

Technical information has been obtained from Umoe Advanced Composites, Hexagon Raufoss, and from Wystrach GmbH. Indicative pricing information has been received from Umoe Advanced Composites as well as some of their customers.

An exhausting analysis is not part of this study. However, the provided container information gives a good bases for estimating maximum amounts of hydrogen that can be transported. Furthermore, the collected data will be used for calculations in other Next Wave deliverables, especially Deliverable 2.5 on detailed analysis for large-scale hydrogen transport in Finland.

The main change to take effect in 2021 is that there will be changes in carbon fibre container weights due to new design guideline in EN standard 17339[4]. Currently, this can only be estimated but in principle, the new design guideline will allow >20 wt-% more hydrogen in each vessel, thus, reducing the hydrogen transportation cost by more than 20%.

The cost of compressed gas containers

Based on the experience of VTT, the cost of gas containers should be between 400-800 €/kg depending on size, material, and pressure level. Umoe Advanced Composites has been open about an indicative price for their containers (350-450 €/kg), which has been confirmed to VTT by their customers.

Latest information from 2020 and from thesis of Amanda Grannas (Grannas 2019) in *Table 2* indicate that the cost for Type IV containers using carbon fibre cylinders is just under 700 €/kg for pressure levels 350-500 bar. However, when higher pressure levels can be applied, due to EN 17339, the cost per kg should decrease by 20%, i.e., 550 €/kg. A lower cost of carbon-based composite cylinders probably will affect future pricing of fiberglass-based solutions as well.

Table 2. Price data for containers from year 2019 (Grannas 2019)

	Supplier A	Supplier B	Supplier C
Model	Magnum 2 Type IV	10" 500 bar	40" ISO Standard Type IV
Pressure [bar]	250	500	350
wt-% hydrogen	5.54	3.82	3.58
Material	Full carbon polyethylene	Composite Type 4	Fiberglass
CAPEX / kg H_2	600 €	729 €	400 €

4 17339:2020 Transportable gas cylinders - Fully wrapped carbon composite cylinders and tubes for hydrogen.

The weight and dimensions of compressed gas containers

Information about weight and dimensions for containers were obtained from three suppliers: Hexagon Raufoss AS (HR or Hexagon), Wystrach GmbH (WYS or Wystrach), and Umoe Advanced Composites AS (UAC). Weight figures are based on publicly available datasheets (HR, WYS) or preliminary data for coming products in 2021 (UAC). Container and hydrogen weights (in kg) for regular 40 ft and 45 ft containers, as well as 40 ft and 45 ft high cube containers are shown in *Table 3*, *Table 4*, and *Table 5*, respectively. Additional information about 20 ft containers from UAC and WYS was used for Sweden.

When the new design code (EN 17339) is applied, increased pressure levels should be possible for carbon fibre-based solutions. According to new data from Hexagon, shown in *Table 6*, the effect is about 22-23%.

Thus, when the new carbon fibre composite cylinders are available, the amount of stored hydrogen should increase about 20%, when "the old" pressure levels are applied. New hydrogen transport container weights for HR and WYS are estimated based on that 20% and shown in *Table 7*.

Table 3. Container weight and hydrogen capacity (both in kg) of standard 40 ft hydrogen transport containers

Pressure level (bar)	200	250	300	350	450	500
HR	NA	18035 / 720	20200 / 835	NA	NA	31485 / 1115
WYS	NA	NA	19734 / 784	NA	NA	29565 / 1065
UAC	17487 / 457	21859 / 566	24461 / 658	27951 / 734	35938 / 894	NA

Table 4. Container weight and hydrogen capacity (both in kg) of standard 45 ft hydrogen transport containers

Pressure level (bar)	200	250	300	350	450	500
HR	NA	20295 / 815	22750 / 950	NA	NA	NA
WYS	NA	NA	22187 / 887	NA	NA	33198 / 1198
UAC	19204 / 518	24005 / 641	27000 / 745	31053 / 831	39925 / 1013	NA

Table 5. Container weight and hydrogen capacity (both in kg) of 40 ft and 45 ft high cube hydrogen transport containers

Pressure level (bar)	200	250	300	350	450	500
UAC (40 ft)	20925 / 559	26156 / 692	29337 / 804	33 436/ 897	NA	NA
UAC (45 ft)	23224 / 633	29030 / 783	32691 / 911	37456 / 1016	NA	NA

Table 6. New data on container weight and hydrogen capacity (both in kg) from Hexagon on their 40 ft and 45 ft hydrogen transport containers when new pressure levels are applied

Pressure level (bar)	318	381
HR (40 ft)	18035 / 889	20200 / 1029
HR (45 ft)	20295 / 1005	22750 / 1165

Table 7. Estimated container weight and hydrogen capacity (both in kg) of 40 ft and 45 ft hydrogen transport containers based on new composite cylinders made in compliance with the new design code (EN 17339)

Pressure level (bar)	250	300	500
HR (40 ft)	14428 / 720	16160 / 835	25188 / 1115
WYS (40 ft)	NA	15787 / 784	23652 / 1065
HR (45 ft)	16236 / 815	18200 / 950	NA
WYS (45 ft)	NA	17750 / 887	26558 / 1198

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Denmark

With 56 tonnes total weight limit for the articulated vehicle, transport of 40 ft container at pressure level 500 bar from Wystrach (29.6 tonnes) or Hexagon (31.5 tonnes) should be possible, with 5 or 6 axle truck-trailers.

These solutions give a hydrogen transport capacity of 1,065 kg and 1,115 kg, respectively. When the new design guideline (EN 17339) is applied, it should be possible to transport some 1,300-1,350 kg of hydrogen in a single load (at 635 bar).

For the 40 ft UAC solutions, transport of the heaviest container (450 bar) should be possible as the container weight is 35.9 tonnes (of which 894 kg is H_2). This transport requires a 6 or 7 axle truck-trailer.

On the other hand, if 300 bar infrastructure is used, then container weights from Wystrach and Hexagon are 19.7 tonnes and 20.2 tonnes and hydrogen payload 784 kg and 835 kg, respectively. This would allow the use of 4 axle truck-trailer.

With 5 axle truck-trailer the use of UAC container (24.5 tonnes, 658 kg H_2) is possible if 300 bar infrastructure is used. It may also be possible to use 4 axle truck-trailer, but then the weight limit will be very tight.

In Danish law, there is an exemption for 45 ft containers in intermodal transport[5]. In intermodal transport the length of the vehicle can be 16.65 m, but weight is limited to 44 tonnes. This indicates that use of 45 ft container could be possible for hydrogen transport. With 300 bar pressure level it would be beneficial to use 45 ft containers, as with these containers up to 950 kg hydrogen could be transported with Hexagon container.

When the new design code (EN 17339) is applied, transport of a single 45 ft container with about 1,200 kg hydrogen at 500 bar may also become possible.

5 https://www.retsinformation.dk/eli/lta/2016/1497

Current operating vehicles for natural gas / biogas and hydrogen

Hydrogen refuelling stations

Denmark currently has six public hydrogen refuelling stations (HRS)[6] in operation. They are spread around the country and serve to refuel regular fuel cell cars. None of these stations produce their hydrogen on-site. The hydrogen is delivered by trucks with a specially designed trailer that contains the hydrogen, with a weight limit of 44 tonnes.

Specifications of the trailers are classified – however they are to comply with *ISO 19880-1:2020, Gaseous hydrogen — Fuelling stations — Part 1: General requirements*, which the Danish Safety Technology Authority (Sikkerhedsstyrelsen) has stipulated[7]. ISO 19880-1:2020 provides, amongst others, requirements for and guidance on the hydrogen production/delivery system of an HRS, including:

- delivery of hydrogen by pipeline, trucked in gaseous and/or liquid hydrogen, or metal hydride storage trailers[8]

Furthermore, the trailers need to comply with the rules and regulations as stipulated in the *Bekendtgørelse om indretning m.v. af trykbærende udstyr* (design of pressure-bearing equipment), while filling the trailer and while emptying it at the HRS.

In the city of Aalborg, the first three hydrogen buses are deployed as part of the regular bus service[9]. The buses refuel at a local HRS, especially built to refuel the buses, which has an alkaline electrolyser on-site and a cascade hydrogen storage system storing hydrogen at 35, 350, and 450 bar[10].

Announced projects of relevance

The H2Bus consortium aims to deploy 1,000 hydrogen fuel cell buses in three European countries, Denmark being one of them. The H2Bus consortium plans on deploying 200 buses in Denmark in the first phase of the project. The project partners are Everfuel, Wrightbus, Ballard Power Systems, Hexagon Composites, Nel Hydrogen, and Ryse Hydrogen.

The consortium has announced that the hydrogen for the buses will produce from renewable and low-cost electricity at centralized hydrogen logistic centres and transported to the bus operator's depot via high-capacity hydrogen trailers[11]. Currently, the specifications of the high-capacity hydrogen trailers are not disclosed.

6 www.brintbiler.dk
7 https://www.sik.dk/erhverv/gasinstallationer-og-gasanlaeg/vejledninger/gasanlaeg/fyldestationer-tankning-koeretoejer-cng-lng-eller-gasformig-brint#
8 https://www.iso.org/standard/71940.html
9 https://3emotion.eu/about-project
10 https://greenhydrogen.dk/GHS/ghs-helps-danish-city-put-hydrogen-busses-in-service/
11 H2BUS, October 2020, https://h2bus.eu/offering

The 1.3 GW installed electrolyser capacity project that is scheduled for the Copenhagen area is a consortium of the partners: Copenhagen Airports, A.P. Møller-Mærsk, DSV Panalpina, DFDS, SAS, Ørsted, Nel Hydrogen, Everfuel, and Haldor Topsøe [12,13] .

The project partners are keen on testing electro-fuels for heavy duty road transport (DSV Panalpina), aviation (SAS and Copenhagen Airports) and the maritime sector (A.P. Møller-Mærsk and DFDS). There are no specifications given as on how the hydrogen and/or electro-fuels will be transported to for example the airport or ships. However, there is an ambition that there will be an on-site electrolyser. Project partner Everfuel's role in the project is to produce the trailers that will transport the hydrogen to the nearest refuelling station. Also, no specifications are known about the trailers.

Biogas

CBG (compressed biogas) is the only biogas used in the Danish transport sector. There are several Danish cities where public transport buses running on biogas, the total amount of gas buses as of September 2017 was 117[14]. There are 16 gas refilling stations in Denmark, which are connected directly to the natural gas grid. Therefore, in Denmark there are no synergies between hydrogen and biogas logistics.

Summary for maximising the hydrogen transport capacity

Taken the ambition of deploying 200 hydrogen fuel cell buses in Denmark and possibly the incorporation of e-fuels in heavy-duty road transport, the maritime sector, and in aviation fleets, there will be an extended need for transport of hydrogen by trucks and trailers in the near future to secure the supply of hydrogen to the to-be-established HRS's.

It is therefore of high interest, that rules and regulations are adequate and can accommodate this new type of infrastructure.

In Denmark, the hydrogen transport is already more effective than elsewhere in Europe as 56 tonnes total weight is applied. However, 16.50 m length for articulated vehicle limits the weight of the hydrogen to about 1,065-1,115 kg per truck.

[12] https://orsted.com/en/media/newsroom/news/2020/05/485023045545315

[13] https://transporttidende.com/artikler/navne-and-uddannelse-c58/braendstofprojekt-udvider-partnerkredsen-p51495

[14] Fremsyn (September 2017) Biogas til transport i 2020 – potentiale for udrulning af biogas for ting transport. Report ordered by E.ON, HMN Naturgas, NGF Nature Energy and DGD , p.4 & 8.

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Photo: Mike, Pexels

Finland

Transport in A-double, B-link, and semi-trailer configurations

In Finland, the use of high cube containers would be possible, as the height limit is 4.4 m. However, these are not available from all suppliers. The maximum semi-trailer length (23 m) would allow container length of 19.3 m (about 63 ft). However, such containers are not available.

Therefore, here, the analysis for Finland is limited for existing supply of 40 ft and 45 ft containers. The main transportation options would be using either A-double or B-link configurations with 40 ft and 45 ft containers.

In A-double (max length 34.5 m), a two 45 ft container configuration (also high cube) is possible, but the maximum weight for ADR vehicles is 60 tonnes. The available payload for two containers would then be about 40 tonnes, as empty-vehicle-weight including trailers typically is about 20 tonnes. In B-link (B-train), the maximum weight is 68 tonnes. However, in a B-link configuration there is room only for two 40 ft containers.

If maximum amount of hydrogen is the main goal, then 500 bar pressure level and 40 ft containers would be the choice. When new design code (EN 17339) is applied, the weight of 40 ft containers should be 23-24 tonnes at pressure level 500 bar, as seen in *Table 7*. This would enable transport of up to 2,200-2,300 kg with B-link and two 40 ft containers. The final container weights of this type are yet to be confirmed.

However, as long as there is no need to transport hydrogen to the HRS, 500 bar pressure level may not be economically motivated in Finland due to the energy needed for compression and high capital cost for 500 bar infrastructure. The existing hydrogen infrastructure in Finland is based on 200 bar or 300 bar pressure levels, and this would be the easiest to apply in the beginning. On the other hand, if hydrogen is used in HRS, then 500 bar pressure level is well motivated as it also reduces the need of compression at the HRS. Due to this, also other pressure levels are discussed.

As 200 bar is the most common pressure level for hydrogen transport, transportation by means of 40 ft high cube containers at 200 bar in an A-double configuration could be an option (for biogas transport, 250 bar pressure level seems to be the most common). In this configuration two 200 bar high cube containers (UAC) should be possible, as total weight of containers is 41,850 kg. Corresponding hydrogen amount is (2x 559 kg = 1,118 kg). The issue with 200 bar pressure level is that it is not considered a pressure level of the future gas transport chain, and, thus, carbon fibre-based solutions are not developed for this pressure level.

With 300 bar pressure level, both carbon fibre- and fiberglass-based solution are available. Since two 40 ft containers can be transported with B-link, two existing X-STORE 40 ft containers with pressure level 300 bar from Hexagon could be transported with total hydrogen capacity of 1,670 kg and total vehicle weight about 60 tonnes (maximum 68 tonnes). With Wystrach, 40 ft container at 300 bar, 1,568 kg hydrogen could be transported with vehicle weight of about 60 tonnes, which would enable the use of A-double.

If it is assumed that two 45 ft container can be transported with A-double, two 45 ft containers with pressure level 250 bar from Wystrach can be transported with a total hydrogen capacity of 1,774 kg and total vehicle weight about 59 tonnes (maximum 60 tonnes). The problem is that 250 bar is not a common pressure level.

With 300 bar pressure level, the current 45 ft containers are too heavy for A-double. Therefore, with existing containers and pressure levels, 1,670 kg seems to be the maximum that can be transported in Finland before containers based on the new design code (EN 17339) are available.

When the new design code (EN 17339) is applied in new products, 300 bar containers should be about 20% lighter and two 45 ft containers from Hexagon could be transported with A-double with total load of 1,900 kg. This seems to be a very attractive solution in Finland, while the total weight of the containers is still only about 36.2 tonnes. If existing 45 ft containers (250 bar) could be used at 300 bar (due to EN 17339), some 2,010 kg of hydrogen could be transported with total container weight 40,590 kg while the total weight of the A-double would still be just under 60 tonnes.

Containers for the EU market are not optimised for Finland where high cube containers can be used, and containers can be longer. Therefore, maximum weight and volume limits cannot be fully utilised, especially when the lowest pressure (200 bar) level is used.

Current operating vehicles for natural gas / biogas and hydrogen

Gasum

Gasum is using 20 ft biogas containers from UAC and the vehicle combination is shown in *Figure 2*. This combination most probably fulfils the weight limit (60 tonnes) and length limit (25.25 m), which were allowed before January 2019.

Therefore, this combination is not anymore the most cost-effective way to transport gas in Finland. On the other hand, weight limit (60-68 tonnes) would probably not allow four 20 ft biogas containers in the same truck.

Figure 2. On left: Gasum biogas transport by Speed Group Oy. On right: 20 ft container used by Gasum[15].

A single container can have 14.85 m^3 biogas divided in sections of 4.95 m^3. The weight is for 3.4 tonnes per container at 250 bar. There are some differences in the safety solutions compared to hydrogen transport, but the main design is the same.

Woikoski

Woikoski has been using containers based on steel cylinders[16]. However, also they are starting to use 20 ft hydrogen containers from UAC, but for the pressure level 300 bar. The logistic system is expected to be very similar for the concept of Gasum for biogas. However, no public details are available.

Possible future vehicle configurations

The current weight limit (68 tonnes vs. regular 76 tonnes) for ADR traffic is based on risk analysis. The limit was chosen as in accidents the amount of burning liquid can destroy e.g., road and tunnel structures[17].

When current limits for truck dimensions were decided, there was a discussion of changing to the weight limit for limited network of roads. However, this may not apply to ADR transport due to reasons explained in previous paragraph.

Due to the limitation for ADR traffic, it is not probable that there will be new vehicle configurations in the near future.

15 Raul Kade, Onnettomuusharjoitus Kuopio Kaasun kuljetukset konteissa ja kontit (Kuopio 11.10.2018) https://www.pelastusopisto.fi/wp-content/uploads/Kuopio_11.10.2018RaulKade.pdf

16 Page: https://www.vttresearch.com/sites/default/files/julkaisut/muut/2013/VTT-R-02257-13.pdf

17 https://www.kuntaliitto.fi/sites/default/files/media/file/2130327%20M%20ja%20M%20VNa%20perustelumuistio%20Laus%20muutokset%20%282%29_9.pdf

Possible exceptional limits for hydrogen transport

There is a possibility to apply a special permit from Traficom for operation of trucks heavier than 68 tonnes, also for ADR[18]. However, the reason for these permits must be a study of new transportation configurations.

Since in the previous high-capacity transport (HCT) experiments the maximum weights were above 100 tonnes, it can be assumed that this is possible for gas transport, assuming that the safety requirements in the selected route can be fulfilled. In this case, very heavy 40 ft containers (close to 40 tonnes) could be transported with B-link, assuming that other weight limits can be fulfilled.

However, it can be that the permission is easier to achieve for lower exceptional weights, such as 76 tonnes for the B-link. This would already allow some additional transportation options.

18 Traffic law: https://www.finlex.fi/fi/laki/ajantasa/2018/20180729#L7P192

Photo: Tomáš Malík, Unsplash

Iceland

It is possible that 500 bar container (40 ft) from Hexagon (H_2 weight 1,115 kg, total weight 31,485 kg) or from Wystrach (H_2 weight 1,065 kg, total weight 29,565 kg) could be transported with 5 axle truck-trailers. However, the weight limit is very close especially for 31.5 tonne container.

If less expensive class fibre containers from UAC are used, about 70% of the hydrogen amount can be transported with pressure level 350 bar (H_2 weight 734 kg, total weight 27,951 kg).

If new design code (EN 17339) for carbon fibre cylinders is applied, pressure level could be increased to 635 bar and correspondingly 20% more hydrogen could be transported. Up to about 1,300 kg could be possible with a single vehicle. This can also be considered as maximum for other European countries with 44 tonnes maximum weight limit.

The existing containers using carbon fibre cylinders could contain about 20% more hydrogen, if used for higher pressure level. However, these container weights are already approaching or exceeding typical maximum gross weight limits for Iceland. In addition, the availability of compressors for pressure level 635 bar is uncertain. Thus, it is more probable that when new design code (EN 17339) for carbon fibre cylinders is applied, 500 bar is kept as pressure level and weight of the container is reduced by about 20%.

As a conclusion, transport regulations in Iceland favour 500 bar pressure level and 40 ft or 45 ft containers. The expected hydrogen amount is 1,100-1,250 kg, when new design code (EN 17339) is applied and carbon fibre cylinders are used in containers.

If 500 pressure level is not needed nor economically motivated, 350 bar pressure level and fiberglass-based containers from UAC are an interesting alternative. In addition, when new design code (EN 17339) is applied and the current 300 bar containers with carbon fibre cylinders can be operated at 381 bar, a single 40 ft container can contain 950-1,000 kg hydrogen, while a single 45 ft container can contain 1,100-1,150 kg of hydrogen.

Current operating vehicles for natural gas / biogas and hydrogen

There has been no transport of biogas or hydrogen by gas containers in Iceland so far.

Photo: Ben Garratt, Unsplash

Norway

Current operating vehicles for natural gas / biogas and hydrogen

Until the recent development within hydrogen mobility, there has been little transport of hydrogen in larger quantities on Norwegian roads. Even if some industries (like the fertiliser industry and refineries) use large amounts of hydrogen, these consumers prefer to produce their hydrogen on-site. As a result, traditionally, there has been no tailored transport modules available for those that eventually needed larger quantities of hydrogen and, typically, hydrogen was supplied to the customers in multi cylinder packs (MCPs) being an inefficient and expensive solution.

By replacing the MCPs usually made up of regular steel gas bottles with large type IV low-weight composite or fiberglass pressure vessels, the payload efficiency – and thus, also the cost-efficiency – increases radically. For one of the solutions listed below, the *Energy Hotel* by Hynion, replacing steel bottles by composite vessels – the weight load was said to be reduced by at least 20 tonnes for a 250 kg hydrogen transport solution (Hyop, 2018).

Two types of containerised hydrogen transport solutions are used for transport of larger hydrogen quantities in Norway:

- The *Energy Hotel* by Hynion
- The hydrogen transport and storage modules by UAC

The current version of the *Energy Hotel* used by Hynion is a 250 kg, 250 bar hydrogen transport and storage solution developed by Hyop AS – a predecessor company of Hynion AS (Hynion, 2020). The 25 ft swap-container with a width of 2.44 m is resting on four folding legs for easy handling by vehicles with a platform truck body, *Figure 3*. The total weight of the swap-container based on composite pressure vessels from Hexagon Composites is 14 tonnes.

Figure 3. The Energy Hotel hydrogen transport and storage solution. The Energy Hotel technology is the IPR of Hynion AS. Source: Hynion AS.

The UAC hydrogen transport and storage module used in Norway is equipped with type IV fiberglass pressure vessels, Figure 4. The swappable module is handled by a hook or crane. UAC offers a wide range of 20 ft, 40 ft and 45 ft containerised transport modules for hydrogen (UAC, 2020) carrying from 222 kg H_2 at 200 bar, up to 1,016 kg H_2 at 350 bar. For the 20 ft container solution being deployed in Norway, a maximum capacity of 356 kg H_2 at 350 bar is possible according to the UAC *Hydrogen storage and transportation solutions datasheet* (UAC, 2020).

Figure 4. Hook-loaded hydrogen transport and storage module by UAC (UAC, 2018).

Biogas is a growing energy carrier in Norway. According to Gasum, most of the biogas being transported on Norwegian roads is in the liquid phase (LBG) (Gasum, 2020). However, for shorter distances gas phase biogas is transported by means of hook-loaded transport and storage modules, *Figure 5*, each module having a capacity to carry 4,000 m^3 of biogas at 250 bar.

According to Gasum, in Norway, it is possible to combine two such hook-loaded biogas modules in the same transport operation while for instance in Sweden a configuration of three modules would be allowed in a single transport operation.

Figure 5. Hook-loaded biogas transport and storage module by AGA (a predecessor company of Gasum) (AGA, 2012).

Summary for maximising the hydrogen transport capacity

A single 4o ft container from Hexagon would contain 1,115 kg hydrogen at pressure level 500 bar and container weight would be 31,485 tonnes, which is within the weight limits of Norwegian roads (tonnes) when 50 tonnes is the weight limit.

When EN 17339 is applied, the maximum amount of hydrogen is not increasing, since the vehicle length is the restricting factor, as for Denmark. However, the amount of hydrogen could be increased up to 1,450 kg, assuming that compressors are available for higher pressure level (635 bar).

As for Denmark, transport of the heaviest UAC 40 ft container (450 bar) should be possible, and attractive, as the weight of the container is 35.9 tonnes (of which 894 kg is hydrogen).

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Photo: Roberto Hanas, Unsplash

Sweden

Hydrogen transport in BK1 roads (max weight 64 tonnes)

For BK1 roads and for a 64-tonne vehicle, the distance between the first and last axel of the vehicle or combined vehicle must be at least 20.2 m[19].

On 64-tonne roads, a payload of 43-44 tonnes is possible for vehicles with length of 24 m or 25.25 m. In this case, also weight is limiting the choice of containers. One 20 ft and one 40 ft container with 500 bar (635 bar with EN 17339) from Wystrach (total 43.57 tonnes) is possible, as for 74-tonne roads as well as three 20 ft containers (42 tonnes). In the first case, the hydrogen transport capacity is 1,567 kg, while in the latter case it is 1,506 kg. As with 74-tonne limit, applying EN 17339 would allow a payload of 1,800-1,900 kg of hydrogen.

A low-cost flexible solution can be reached with three 20 ft containers from UAC at pressure level 250 bar. The total weight of three such transport containers is 39 tonnes, and the hydrogen capacity of a single transport operation will be 1,008 kg.

Hydrogen transport in BK4 roads (max weight 74 tonnes)

For 74 tonnes, the distance between the first and last axel of the vehicle or combined vehicle must be at least 20.2 m. On 74-tonne roads, a payload slightly above 50 tonnes is possible for vehicles with length of 24 m or 25.25 m, see Deliverable 2.3.

When 74 tonnes can be used on BK4 roads, the length of the vehicle is the limiting factor, not the weight. Therefore, a fiberglass high cube containers from UAC at 350 bar may be an attractive solution. Here, a configuration of three

[19] https://www.transportstyrelsen.se/sv/vagtrafik/Yrkestrafik/Gods-och-buss/Matt-och-vikt/Bruttoviktstabeller/

20 ft high cube containers, or a configuration of one 20 ft high cube container and one 40 ft high cube container both have a total weight of 50.2 tonnes. In the first case the hydrogen capacity is 1,305 kg, while in the latter case it is 1,332 kg. Since this is achievable at pressure levels already at 350 bar, the compressor cost and energy cost would be lower than with 500 bar pressure level.

When EN 17339 is applied, the hydrogen cylinders, and thus, the transport containers, can be made lighter. Therefore, if the total vehicle weight becomes the limiting factor, the 500 bar pressure level can be kept reducing the container weight by 20% compared to today's standard.

Current operating vehicles for natural gas / biogas and hydrogen

In Sweden, Linde transports hydrogen on swap bodies, where a single truck carries three 20 ft containers. There are both swap bodies with steel tubes and composite tubes. Each swap body contains 120 kg hydrogen in the steel version and 330-350 kg in composite version, due to lower weight of the vessels. This is calculated with a residual pressure amount of 5-6 %. Linde Sweden are also looking into and can make available other types of transportation used for instance in Germany, if required by the Swedish demand[20].

Possible future vehicle configurations

The Swedish Transport Administration has investigated the possibility to increase the combined vehicle length to 34.5 m by assignment of the government. The report describes that a total of 9,000 km, where of 4,500 km of continuous road, could be opened to 34.5 m combinations. These are illustrated in Deliverable 2.3. The Swedish Transport Administration's recommendations require the vehicles to follow the EU module system[21].

Hydrogen transport in BK1 roads when 34.5 m is allowed

If vehicle length of 34.5 m is allowed, some 41-43 tonne payload should be possible for 64-tonne vehicles.

The longer length of the vehicle opens for the 300 bar pressure level option. Total weight of two 40 ft containers from Hexagon is 40.4 tonnes with 1,670 kg hydrogen payload. Total weight of two 40 ft containers from Wystrach is 39.5 tonnes with 1,568 kg hydrogen payload.

Lengthwise, with 34.5 m vehicles, the use of two 45 ft containers could be possible, but then both the Wystrach and the Hexagon container solution will exceed 44 tonnes. Therefore, it seems that two 40 ft containers is the preferred configuration. With increase of pressure level from 300 bar to 381 bar (due to EN 17339) the hydrogen payload increases to 1,900-2,000 kg.

20 Linde telephone interview 2020-11-06

21 https://www.trafikverket.se/contentassets/1160ae4fe6504bba8e3629eee4b60d7c/langre_lastbilar_pa_det_svenska_vagnatet_for_mer_hallbara_transporter.pdf

Hydrogen transport in BK4 roads when 34.5 m is allowed

If vehicle length of 34.5 m is allowed, a payload slightly above 50 tonnes should be possible for 74-tonne vehicles.

With 34.5 m limit for the 74-tonne roads, the situation is the same as for Finland, except the weight limit is 6 tonnes more. With two 500 bar, 40 ft containers from Wystrach the total weight with today's transport containers is 59 tonnes, which is too much. Taking into account the expected 20% weight reduction (due to EN 17339), the weight should be clearly under 50 tonnes enabling a hydrogen capacity of 2,130 kg in single transportation.

Even two 40 ft containers from Hexagon (currently 63 tonnes) could be just under 50 tonnes when EN 17339 applies, enabling 2,230 kg in a single truck load.

The current weight of two 45 ft containers from Wystrach is 66.4 tonnes. Assuming 20% weight reduction (due to EN 17339), the total weight will be 53 tonnes (2,400 kg hydrogen) which most probably will be too much for a 74-tonne vehicle.

Since the maximum height is 4.5 m, also in Sweden the use of high cube containers would be possible. On BK4 roads, assuming 34.5 m is allowed, the transport of two UAC 45 ft containers at pressure level 200 bar would enable a hydrogen capacity of 1,266 kg. Taking into account the low pressure level (200 bar), this may be an interesting alternative.

Summary for maximising the hydrogen transport capacity

The current extreme case (64-tonne, 24/25.25 m) allows about 1,500 kg of hydrogen to be transported in a single truck load. After EN 17339 is in force, 1,800-1,900 kg would be possible, but the total weight limit is very marginal.

The new extreme case (74-tonne, 34.5 m), which will be possible in the near future, allows for a 2,130-2,230 kg hydrogen payload within a limited road network.

Next Nordic Green Transport Wave - Large Vehicles

Deliverable 2.4

Hydrogen transport from large-scale production points to Nordic consumers

Version 1.0

2021