



Can a hydrogen fuelled vessel be financially competitive and technically feasible?

A Green Shipping Programme pilot study managed by Hydro



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1.0 Executive Summary

This Green Shipping Program pilot study has analysed the following question:

“Can a hydrogen fuelled vessel be financially competitive and technically feasible?”

Hydrogen is an almost emission free fuel not commonly used as a fuel in the maritime industry today. Commercial use of hydrogen as a maritime fuel would be a leap step towards IMO (International Maritime Organization) and Norway’s target of reducing emission from shipping substantially.

Important assumptions have been unique for this study making it a highly realistic business case. The pilot study has compared four theoretical vessel types running on hydrogen or Marine Gas Oil (MGO). The considered sailing route was weekly roundtrips between Årdalstangen (Norway) and Amsterdam (the Netherlands) and the vessel would carry only Hydro-cargo. To ensure stable framework conditions, Hydro would guarantee a 15-year freight agreement combined with a hydrogen supply agreement with the same length where Hydro’s Energy department would be responsible for producing and supplying hydrogen in the theoretical scenario.

Conclusions from the study show that a hydrogen fuelled ship is not cost competitive against a MGO fuelled ship without public support. Given a hydrogen fuelled ship receives the same public financial support as the smaller electric container vessel, Yara Birkeland, then compressed hydrogen and MGO would offer similar financial returns regardless of type of vessel.

However, a hydrogen fuelled ship is not unprofitable, even without public financial support. All vessel types simulated offer positive internal rates of return. If a vessel owner/operator could accept a lower, but long-term, rate of return the business case is still profitable. In addition, there are potential upsides to the business case as the experience curve could reduce operating expenses and residual value of the vessel is relatively low after the 15 years has passed.

Key points to making this pilot study become reality would be:

- Stable framework conditions
 - Long-term freight agreement
 - Long-term hydrogen supply agreement
- Accept lower rate of return to reduce emissions
 - If not, substantial public financial support is needed

2.0 Introduction to the pilot

2.1 Hydro(gen)ship – GSP pilot

The Hydro(gen)ship pilot has been managed by Hydro Aluminium and is a part of the Green Shipping Programme (hereafter abbreviated as GSP). GSP is a public-private partnership and aims to find scalable solutions for efficient and environmentally friendly shipping. The Hydro(gen)ship pilot’s primary objective was to analyse drivers and barriers of costs affecting a transition from today’s fossil-based general cargo vessel to a hydrogen electric hybrid vessel technology with low- or zero carbon emission. This pilot was established in March 2019 and is a contribution to engage in a more sustainable and efficient shipping sector, with a rapid reduction in CO₂-emission through the next years.

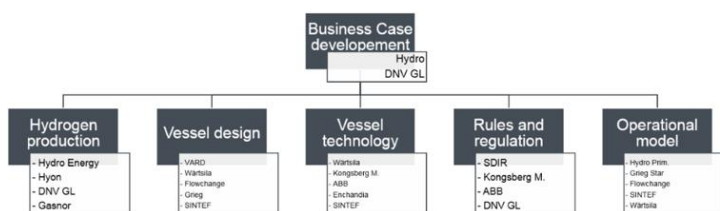
Hydro Aluminium is a Norwegian aluminium and renewable energy company with operations in some 50 countries around the world. For this pilot, focus has been on Hydro’s aluminium production in Årdal where about 5000 mt of aluminium is produced on a weekly basis, equal to 260 000 mt annually. The aluminium, produced in Årdal, is trucked down to Årdalstangen where it is shipped to Amsterdam. Simultaneously, about 40 000 mt of goods is annually shipped in the opposite direction. The pilot has assessed the opportunity to transport the cargo on this route emission free by utilizing a hydrogen fuelled vessel through the hypothesis “Can a hydrogen fuelled vessel be financially competitive and technically feasible?”.

This report will describe how a newbuild hydrogen vessel compares to the baseline, a newbuild MGO vessel, from a financial perspective. In addition, it will also elaborate on technical aspects, security and governmental regulations and laws related to a hydrogen electric hybrid vessel.

The competitive advantage in the pilot lies in the collaboration between two of Hydro’s business areas, Hydro Energy and Hydro Primary Metal. Primary Metal controls the supply chain, while Energy has the knowledge and capacity to produce hydrogen in Årdal at a competitive price. This pilot contains input on hydrogen prices from Hydro Energy, but the costs related to a production plant of hydrogen will not be considered in this report.

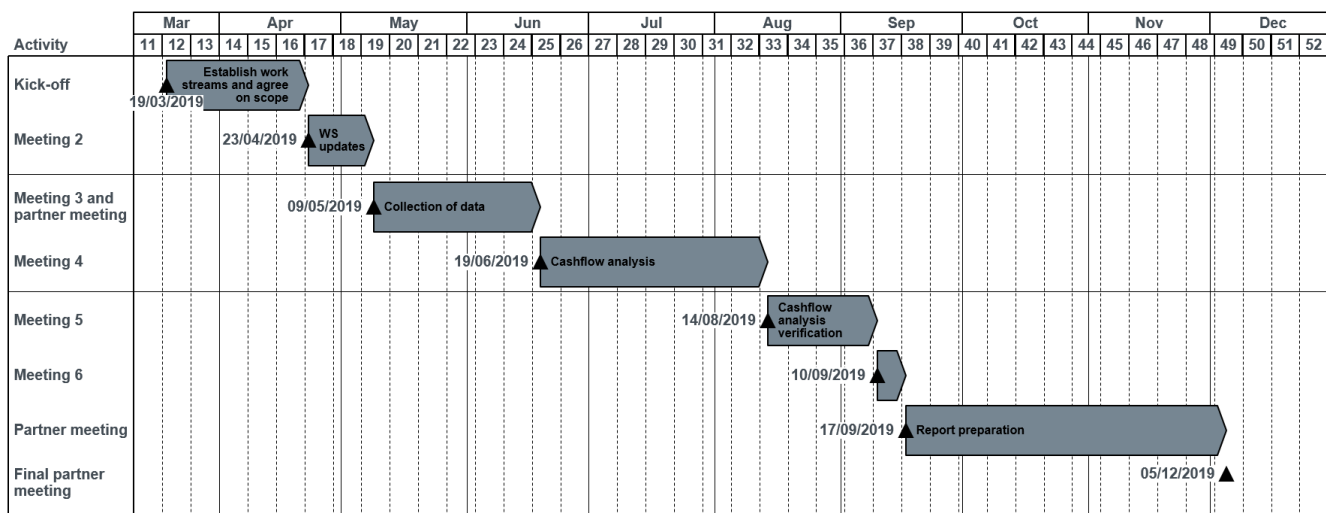
2.2 Collaboration – 15 pilot partners

This report is an output from a pilot study which is a part of GSP, with Hydro as pilot owner, where the scope of the analysis lays in different technical knowledge and costs related to a newbuild vessel. It was therefore a decisive factor to have 15 participants with different knowledge and expertise. The main communication has occurred through skype and mail, with a crucial participation and flow of information. Here is an overview of the participants and their role during the pilot:



2.3 Timeline

The Pilot has taken more time than expected, however it has given a thorough understanding of hydrogen as a fuel, as well as given a definite answer to the hypothesis.



2.4 Methods and data

The main part of the report is based on a discounted cashflow analysis, which is a method to value a project, company or asset using the time value of money. All data used as input into the analysis has been collected from pilot participants and other Hydro projects and reports.

3.0 Maritime transport

3.1 Greenhouse gases in maritime transport

International shipping traffic accounts for a large part of the world's emissions of greenhouse gases. About 90% of world trade is carried by the international shipping industry, and the industry accounts for around 2.5 percent of the world's CO2 emissions according to International Maritime Organisation's (IMO) 3rd GHG study. In accordance with EU strategies and the Paris Agreement, Norway has committed to reducing greenhouse gasses by 30% by 2020 and 80-90% by 2050, compared to 1990. Also, the shipping industry has for the last couple of years been subject to a stricter regime with rules that limit emissions to air of pollutants. For instance, IMO has ambitions to at least reduce the total greenhouse gas emission from international maritime traffic by 50% by 2050, compared to emission levels in 2008.

The Norwegian government seeks to become more sustainable within the shipping industry and decided that 40% of all ships in the short sea shipping should be using biofuel, or other low-zero emission fuels, for vessels by 2030. Both nationally and internationally, there is an increased focus on measures to reduce pollution and greenhouse gas emissions in the maritime sector. In Norway, coastal shipping accounts for almost 10% of our CO2 emission, so a transition to more environmentally friendly fuels will be an important contribution to a climate fight.

3.2 Vessel types

Maritime transport consists of very different vessels which operates in different markets and segments; local, regional and global. The shipping industry makes it possible to move cargo around the world and have been a part of the compression of the global economic system since they carry 90 % of the global trade volume. “If seaborne trade volume is a proxy for the well-being of the global economy, the world fleet and the industry that provides the necessary vessels and services are the backbones of that economy.” (United Nations, 2018).

There’s a huge difference between ship segments and ship types due to different applications and operating patterns. This has a large influence on the selection and implementation of emission-reducing measures, including possible use of hydrogen. Based on future outlooks, development of ship types over the last years and what types of cargo Hydro want to carry from Årdal to Amsterdam, this study looks at two potential vessel types, with three sub-categories within one of the vessel types; RORO or general cargo vessels (aka. multi-purpose vessel). The three sub-categories of general cargo vessels considered are gearless vessels and vessels with either swing cranes or gantry cranes.

Roll-on/Roll-off (roro) vessels are used to carry wheeled cargo, on cassettes or roll-trailers. Loading and discharging with a roro-vessel is more cost efficient and time saving compared to the other vessel types considered. The vessel type demands less capital investment on onshore extra equipment and the loading/discharging process requires less manpower. Despite roro-vessels having a higher utilisation grade than general cargo vessels, the main disadvantage with roro-vessels are the higher newbuild cost compared to general cargo vessels. Regarding HSEQ, it is also considered to be a safer loading/discharging method compared to crane operations. There are also other supply chain benefits related to utilising a roro-vessel since cassettes/roll trailers make it easier to move cargo internally at the plant, however these benefits are difficult to quantify and are thus not quantified in the analysis.

A **general cargo vessel** is a merchant ship specially designed to transport any kind of non-containerized general cargo. **Gearless general cargo ships** are vessels without cranes or conveyors. These ships depend on shore-based equipment at their ports of call for load/discharge, and for that reason they avoid the costs of installing, operating and maintaining cranes. Compared with roro-vessels, this vessel type needs more manpower for its onshore-operations and is more exposed to HSEQ-risk (i.e. dropping cargo). The loading/discharging process is more time-consuming, but this vessel has a lower newbuild cost compared to roro-vessels. A **general cargo ship with swing crane** is equipped with a swing crane which require costs related to instalment, operations and maintenance. This is not as efficient as a roro-vessel due to the increased time used for loading/discharging with cranes. A **general cargo ship with gantry crane** is fitted with gantry cranes for self-loading and discharging and are in general more efficient than vessels with swing cranes (for aluminium), while not as efficient as roro. Note that these descriptions are highly generalized, and efficiency, HSEQ-risk and vessel price will vary from ship to ship and cargo to cargo.



Swing crane example

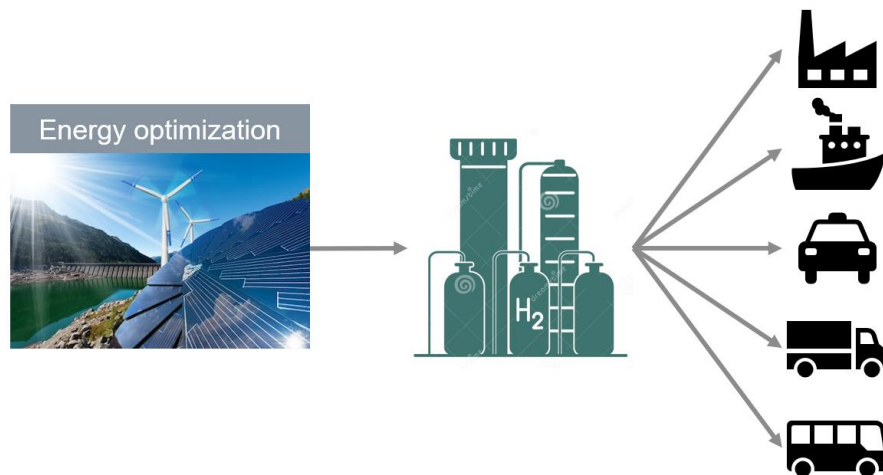


Gantry crane example

4.0 Hydrogen

4.1 Hydrogen as a fuel in shipping

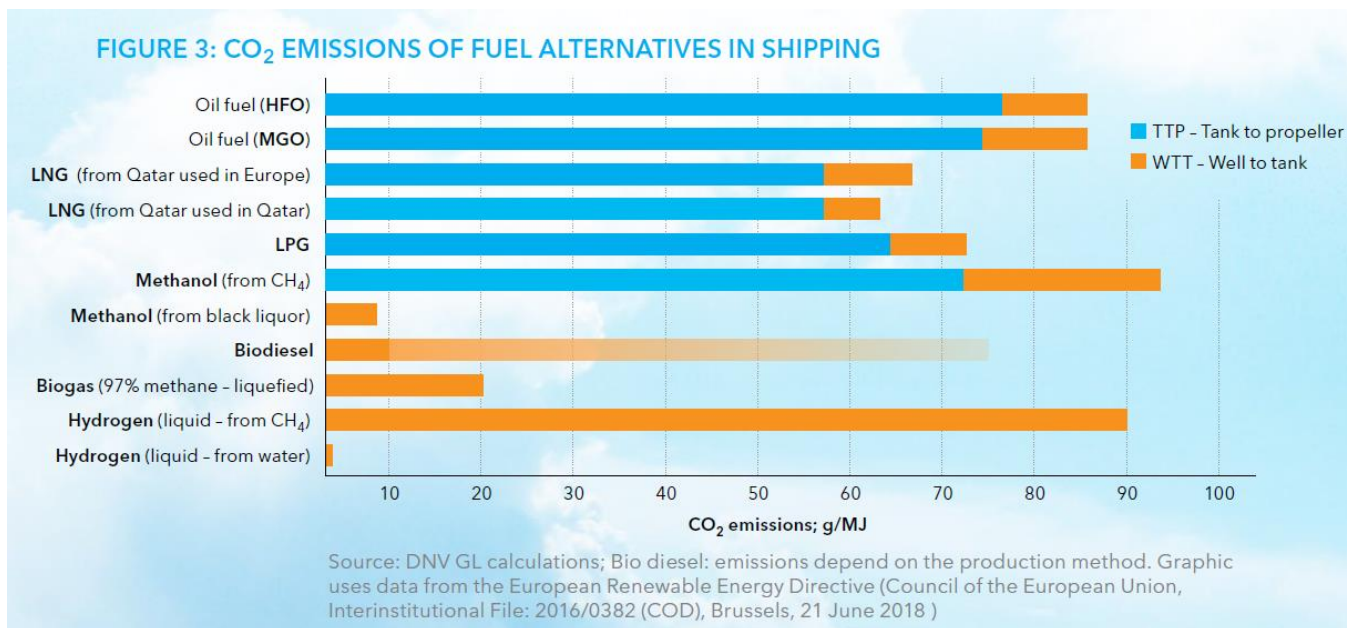
Hydrogen is expected to be significant part of the future energy mix, as a provider for unregulated, renewable energy. Besides battery charging, hydrogen is the only zero emission fuel. Together with fuel cells as energy converters, the only discharge is pure water. Renewable power from solar, wind or hydropower production can be used in the production of hydrogen by electrolysis.



Hydrogen is more suited for long term storage and for transport of large amounts of energy than electrochemical batteries. Thus, hydrogen has a high potential for energy storage in areas that are not connected to a national grid, and when there is a demand for zero emission transport. It could therefore play an important role in the heavy transport sector such as bigger vehicles and maritime short sea, for achieving an emission-free transport. The weight of hydrogen is 14 times lower than air and it is three to four times more energy efficient than MGO per kilo. As a fuel, this study will compare cost related to both liquid and compressed hydrogen as well as conventional fuel, MGO.

4.2 Production and storage of hydrogen

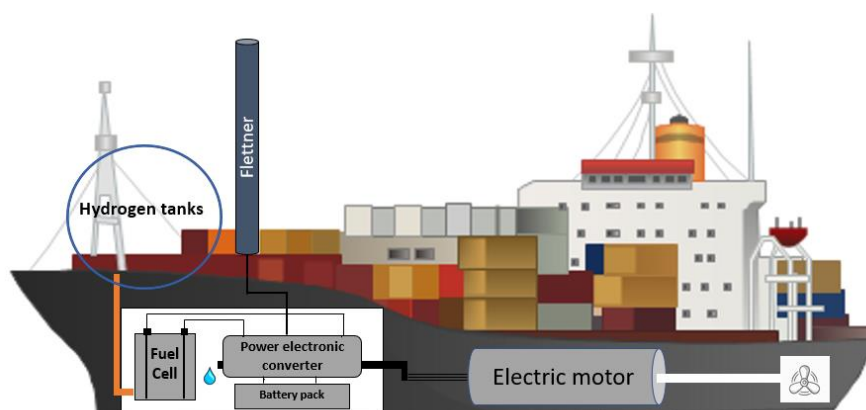
Hydrogen can be produced in several ways and its environmentally friendliness will depend on the production method. **Green hydrogen** is a term used for CO₂-emission free production, based on a renewable power source such as wind, solar or hydropower. Electrolysis is the most common method used to produce green hydrogen, which is a process where electricity is used to split water molecules into hydrogen and oxygen gas. Most of the hydrogen in today's market is produced from natural gas or electrolytic process with coal, which will not be environmentally friendly and have a high CO₂-emissions. Hydrogen produced in this way is often referred to as **grey hydrogen**. Correspondingly, **blue hydrogen** is the term used if the CO₂ from the process is captured and stored (today's technology can potentially filter away 90 % of the CO₂). The two bottom bars in the figure below, from DNV GL's "Maritime Assessment of Selected Alternative Fuels and Technologies" from June 2019, depicts the difference between green and grey hydrogen:



Safe and cost-efficient storage of large quantities of pressurised (compressed) hydrogen gas is a challenge with today's technology, especially to a widespread commercialization of fuel cell vessels. A disadvantage with compressed hydrogen stored on vessels is the physical volume and physical containment required, as the energy by volume is less than gasoline or other liquid fuels. One kg hydrogen contains approximately 33 kWh, while MGO only holds 1/3 of the calorific value, but since compressed hydrogen has a much lower energy density (33 vs 890 kg/m³) it typically demands 10 times the space together with a more complex storage system. Liquefied hydrogen has a higher energy density, 71 kg/m³, and demands less space than compressed hydrogen.

4.3 Advantages and opportunities with hydrogen as a fuel

Hydrogen is a flexible energy carrier and has the possibility to deliver clean energy to a multitude of sectors if infrastructure is developed. Primarily, it has a good environmental impact with only water and heat as a by-product. If green hydrogen is used to power fuel cells, the emission is almost zero in the whole supply chain of hydrogen as a fuel. Hydrogen stored as a compressed gas in pressure vessels or as a liquid in cryogenic tanks can offer wider range compared to electricity batteries. It could therefore be used in the short sea market and be a game changer regarding to CO₂-emission reduction.



4.4 Challenges with hydrogen as fuel

The most common use of hydrogen today is in oil refining and to produce fertilizers. To make a significant contribution to clean and green energy transitions, hydrogen should also be adopted in transport and shipping, where it is currently almost absent. However, widespread use of hydrogen as a fuel in the global energy transitions faces several challenges, especially if the production should be clean and green.

It is costly to establish value chains for production and use of green hydrogen today, but mass manufacturing of fuel cells, refuelling equipment and electrolyzers can reduce the cost rapidly during the next years. Also, introduction of hydrogen as a fuel, needs higher focus on development of hydrogen infrastructure and value chains. According to IEA's report about hydrogen "The Future of Hydrogen" from 2019, the demand for hydrogen is increasing yearly and there is a need of further infrastructure development . Hopefully, it could also repeal regulations and knowledge gaps that limit the development and investments of a green hydrogen industry. Further on, the low energy density in compressed hydrogen gives a challenge in storage and transport compared to liquid fossil fuel.

5.0 Law, regulation and safety

Maritime applications of fuel cell systems must satisfy requirements for on-board energy generation systems and fuel-specific requirements regarding the arrangement and design of the fuel handling components, the piping, materials and the storage. In current regulations, these aspects are handled separately.

The International Code of Safety for Ships using Gases or other Low-Flash-Point Fuels, better known as the IGF Code, provides specific requirements for ships using such fuels. Having entered into force on 1 January 2017, the IGF Code is a mandatory instrument applicable to all ships using gases and other low flashpoint fuels, built or converted after the entry into force of the Code. However, presently, it only contains detail requirements for natural gas (LNG or CNG) as fuel, and only for use in internal combustion engines, boilers and gas turbines.

A phase 2 development of the IGF Code initiated by IMO and its CCC sub-committee is currently allowing the development of technical provisions for fuel cells. Requirements for fuel cells will be developed as an Interim Guideline and the work is scheduled to be finished in September 2020, with approval by IMO during MSC 104 in 2021. However, this only covers the fuel cell installation itself, as an on-board energy generation system, and it does not provide fuel-specific requirements regarding the arrangement and design of the fuel handling components, the piping, materials and the storage.

Until these additions and amendments are finally approved and entered into force, applications making use of other gases and low flashpoint fuels, including use of fuel cells, within the frame of the IGF Code Part A, are required to follow the alternative design method in accordance with SOLAS Regulation II-1/55 to be used for demonstration of an equivalent level of safety. Even after the Interim Guideline for Fuel Cell is approved, the fuel-specific requirements regarding the arrangement and design of the fuel handling components, the piping, materials and the storage needs to be covered by the alternative design as describe above.

6.0 Assumptions and input factors

6.1 General Assumptions

Realistic assumptions are critical to enable rational decisions regarding new investments. The assumption forming the basis for the calculations are available in the spreadsheet while the critical assumptions are explained in this chapter. The pilot study has performed estimates and calculations in a separate Excel spreadsheet which this report will refer to in both chapter 6 and 7. The spreadsheets contains all estimations in the pilot study and has been available to all pilot partners involved in the pilot study.

The cash flow model in the spreadsheet is based on experience, research and current cost received from the pilot participants, but it also contains some assumptions. The CAPEX for all vessel types lies in a range between 52% - 70% of the overall cost. The newbuild price of a vessel is based on price estimates from a European shipyard, not a cheaper Asian option. OPEX cost is based on approximately daily cost from Grieg Star fitted to relevant vessel size. Port facilities and equipment needed differs from vessel type, where roro-vessels needs investments in cassettes, translifters and roro ramp. These costs could be disregarded should Hydro decide to roro-transport on a regular basis. General cargo vessels with gantry cranes also need an investment in cassettes, where both cases with cassettes is based on 240 units, which equals to three sets. Further on, a maintenance cost on shore-based cranes are added for a gearless general cargo vessel.

The most complex calculations is the fuel cost, where it is a difference between vessel type and fuel type. Hydro's Energy department provide present hydrogen prices in the range of 3,5 EUR/kg for compressed hydrogen, and 4,8 EUR/kg for liquid hydrogen, based on delivery from Årdalstangen. The fuel consumption depends on many variables, such as total load of fuel, which depends on needed thrust, final break, hotel load and vessel speed(s). Vessel speed depends on load/discharge time, meaning less time at the ports gives a slower average speed in knots. Also, the Flettner rotor gives more effect if your speed is slower, but in this case, it is assumed that the rotor will reduce fuel consumption with 10 % for all speeds.

Accumulated savings and revenue in the cash flow is mainly based on an approximately freight rate from Hydro on the current stretch, which is 20 EUR/mt with a sailing cargo on 5500 mt per week, 50 weeks during a year. It also contains "other savings" which varies between different vessel types. A roro-vessel has the biggest saving since the efficiency is higher, no maintenance of cranes and a lower man-power demand. Weighted average cost of capital (WACC) is 10%, and calculated inflation is 1,5 % in this case. The interest rate is 2 % based on information from pilot participants, and the vessel depreciation is 14 % on ships according to the Norwegian Tax Administration.

6.2 Capital Expenditures

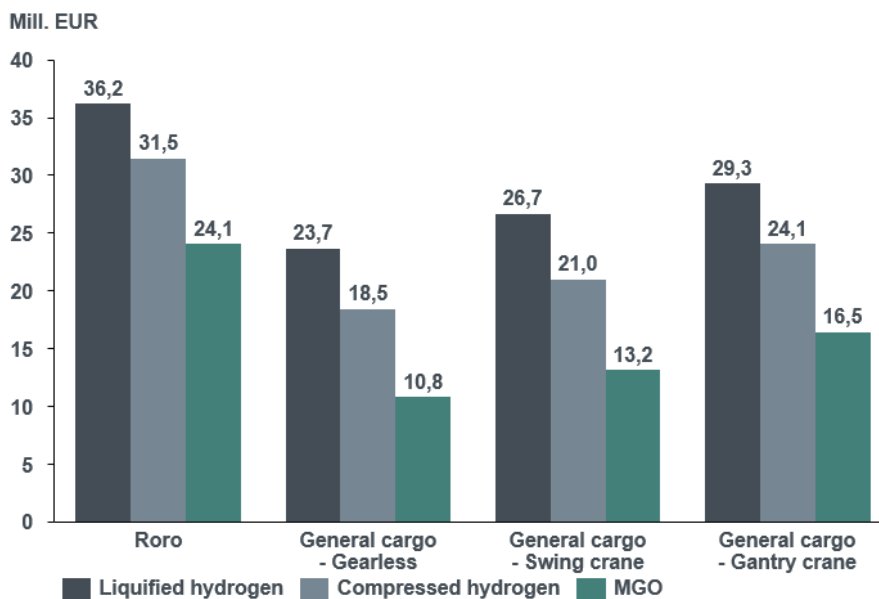
To undertake realistic cost calculations of the capital expenditures, it was necessary to take a deep dive into the technical approach including hydrogen components which are essential compared to a general cargo ship running on MGO. A hybrid vessel primarily driven by hydrogen gives more complex system and can potentially increase the investment cost significantly. With that in mind, this report provides guidance through the investments needed to get a newbuild hydrogen ship, compared to the base case.

A newbuild vessel in Europe is estimated to have higher capital expenditure compared to a Chinese-built vessel, but commonly have a lower operational expense. A roro-vessel has a newbuild cost which is 55 % higher than a gearless general cargo vessel based on a market analysis for newbuild vessels in Europe.

From a technical perspective, the hydrogen vessel needs to add several elements like specialized fuel tanks, motors and catalysators to generate electrical power. In this pilot study, a Flettner rotor is also added. A Flettner rotor uses wind to create additional thrust for ship propulsion and is a high cylinder that stands vertically on a

ship and rotates on its own axis. The average effect of the rotor sail is assumed to reduce fuel consumption with about 10%. Since this study considers a hybrid vessel with fuel cells and wind power from a Flettner rotor, with gas oil/bio-fuel as a backup supplement, the study becomes slightly more complex. Since a newbuild vessel includes a diesel motor and it is used both in the hydrogen vessel and base case, it will not be taken to account in the cash flow.

The necessary investments which is included in the capital expenditures are as already mentioned newbuild cost and Flettner rotors, but also fuel tanks for hydrogen, 1500 kW fuel cell generator, battery 452 kWh and PM motor take a big part in the cost. The figure below compares the estimated newbuild investments cost for ro-ro and the three general cargo vessels. As seen from the chart, ro-ro is the most expensive vessel type, and liquid hydrogen is the most expensive fuel.



6.3 Operational expenses

The operational cost is based on an approximate calculation from Greig Star, where ro-ro and general cargo with swing crane and gantry crane has a daily cost of NOK 17 000, and gearless general cargo has a daily cost of NOK 16 500. This includes crew costs, repair and maintenance costs, marine insurance and P&I, stores, spares and lubrication oil costs, and sundry costs. It also includes a yearly maintenance of the Flettner rotor. This also includes estimated port costs for calling Amsterdam on a weekly basis 50 times a year, while port costs related to calling Årdalstangen is not included as this anyhow would indirectly add to the freight rate. However, what is not included are costs related to commercial operation of the ship.

6.4 Fuel cost

Electrolysers are currently being produced in small quantities, so prices are expected to fall drastically if demand for green hydrogen is to increase and economies of scale are obtained in the production of electrolysers. According to a Norwegian Water Resources and Energy Directorate (NWRED) analysis from 2019, simulated cost trends for the different production methods of hydrogen illustrate that price of natural gas (used for producing grey hydrogen) is expected to increase in the future, while the electricity cost for green hydrogen production will fall as a result of cheaper solar, wind and hydro power. The analysis forecasts the cost of green hydrogen to decline rapidly in the coming years, and this forecast assumes that demand for pure hydrogen is increasing and the price of electrolysers is falling sharply.

Hydro's Energy department has, as mention earlier, estimated that the fuel cost of green hydrogen produced from wind- and hydropower from Hydro's own hydropower plants and contracts, to be around 3,5 EUR/kg for

compressed hydrogen gas and 4,8 EUR/kg for liquid hydrogen. This is used in the fuel cost calculations in the abovementioned spreadsheet. For MGO, an average cost of 571 USD/mt is used. Hydro's estimated fuel price (sales price) of hydrogen looks reasonable compared to Statkraft's statement, from NWRED's analysis, that the production cost of hydrogen in 2025 is expected to be 18,5 NOK/kg (1,8 EUR/kg).

For all vessel types considered, sailing weeks is 50 per year and the contract span of a vessel is intended to be 15 years. Based on this information and expected energy demand per roundtrip, it is possible to calculate the potential fuel cost for the contract time, and the fuel consumption.

6.5 Port facilities and equipment's

This section is divided into two parts in the cash flow analysis, where roro- and general cargo vessels have costs related to extension or maintenance. Roro vessels need a ramp to discharge the cargo, which could be arranged in cooperation with Kristiansund Municipality. For a gearless general cargo vessel the maintenance cost for the cranes at the port in Årdal is estimated to EUR 2.9 million during a potential 15-year contract span. Both roro- and general cargo vessel with gantry crane need cassettes, which is mention in the assumption chapter.

6.6 Hydrogen sales

Hydro is the third biggest energy producer in Norway, and 100% of the energy is produced or bought from renewable energy sources. The total Norwegian power consumption annually is approximately 130 TWh, where Hydro use 17 TWh. In other words, Hydro consumes 13 % of Norwegian power in its aluminium production.

The production of hydrogen will be based on renewable power acquired by Hydro's Energy department, so consumption and production can be balanced on demand. With one shipment using hydrogen as fuel, the power needed for Hydro will increase from 17 TWh to 17,05 TWh during a year.. Should this pilot become reality, it would open doors and increase the likelihood of more hydrogen powered ships along the Norwegian coast. In addition, it could facilitate the usage of hydrogen in other value chains as public transport and industrial production.

6.7 Potential public financial support

Financial support from public Norwegian sources are related to either Enova or the NOx-fund. Since support from one source excludes the other, the project has mainly focused on potential support from Enova.

Enova has an opportunity to subsidise companies who want to realize innovative projects in energy and climate technology. The technology or solution that could be supported must be new and significantly improved compared to the best technology used in the market, as well as involve risks that are higher than in a similar but less innovative investment. Since this pilot study is focused on the first cargo carrier using hydrogen as a fuel, it will be innovative and new to the market. It would also directly reduce greenhouse gas emission as a result of switching from fossil to renewable input factors, by utilization of renewable power sourced by Hydro to produce hydrogen. It would be a pilot to develop and use new hydrogen technologies and solutions, which also have possibilities to expand and further dissemination to other parts of Hydro's production, and other hydrogen ships in the future.

7.0 Analysis results

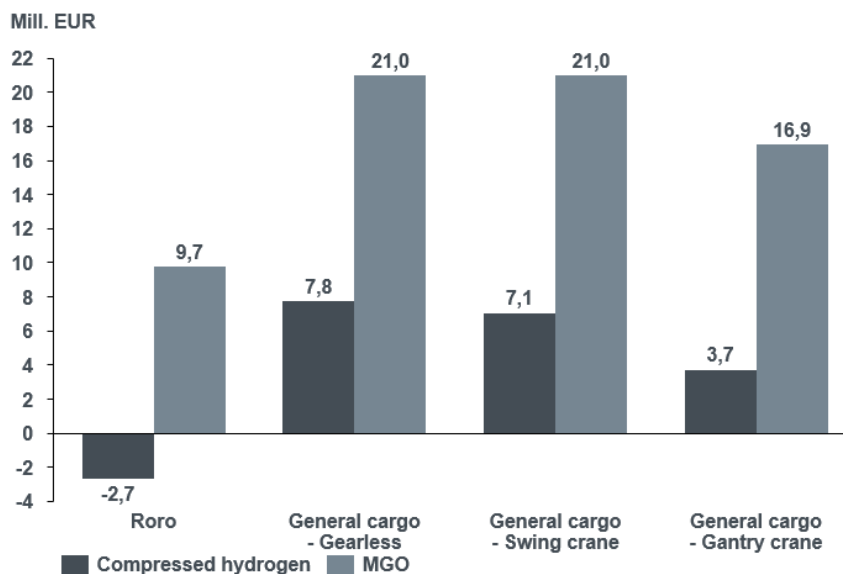
7.1 Analysis results

The results can be interpreted in many ways, but firstly to answer the initial hypothesis:

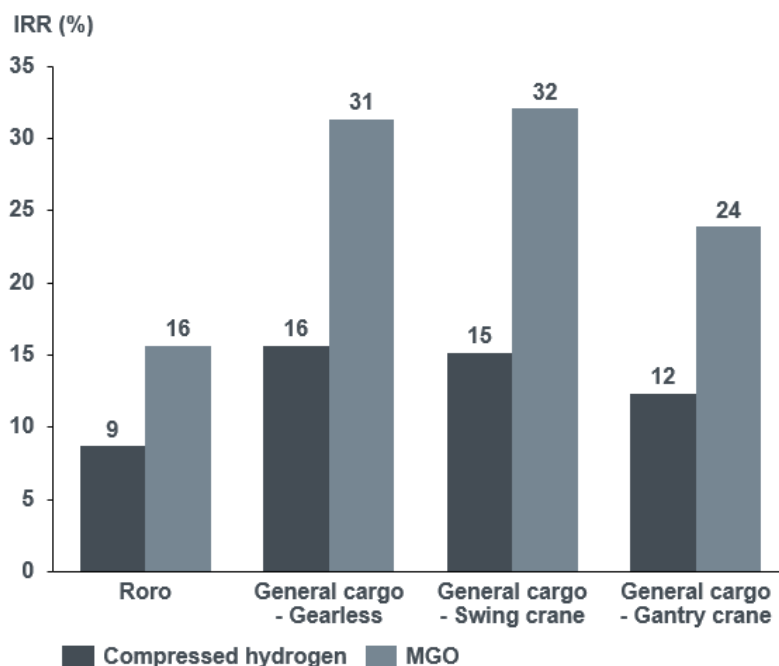
“Can a hydrogen fuelled vessel be financially competitive and technically feasible?”

The short answer to this is: No, a hydrogen fuelled vessel is not financially competitive, but it is in theory technically feasible.

The short answer to the hypothesis is however not very nuanced. A MGO fuelled vessel, of any vessel type, has a better return on investment than a hydrogen fuelled vessel, but a hydrogen fuelled vessel can still have a positive return on investment. Out of the two hydrogen fuel options, liquefied (cryogenic) hydrogen proved to be unrealistic due to the higher capex for this option and the higher fuel cost. Based on this, the findings are presented only for compressed hydrogen. As seen from the figure below, without any public support/funding and based on assumptions described in chapter 6, the Net Present Value (NPV) of the total cash flow is positive for all MGO-fuelled vessels and hydrogen fuelled general cargo carriers. The only vessel type without a positive NPV is the hydrogen fuelled ro-ro-vessel, but as the conclusion above states, MGO gives a better return on investment than the more environmentally friendly option.



Even though MGO is the better investment option without public support, it still doesn't mean hydrogen is a bad investment. In this pilot study, a Weighted Average Cost of Capital (WACC) of 10% has been used to assess the profitability of the project. If the pilot study had used a smaller WACC, the hydrogen ro-ro-vessel could have become positive as well. The metric Internal Rate of Return (IRR) shows a different picture. Based on all the assumption mentioned, all four vessel types and fuels have a positive IRR as seen below:



The break-even point, when the business case becomes profitable, will naturally depend on the WACC. The break-even point in number of years (given the contract length would be expanded) is given in the table below:

	Compressed hydrogen	MGO
Roro	16 years	10 years
General cargo – Gearless	10 years	5 years
General cargo – Swing crane	10 years	4 years
General cargo – Gantry crane	13 years	6 years

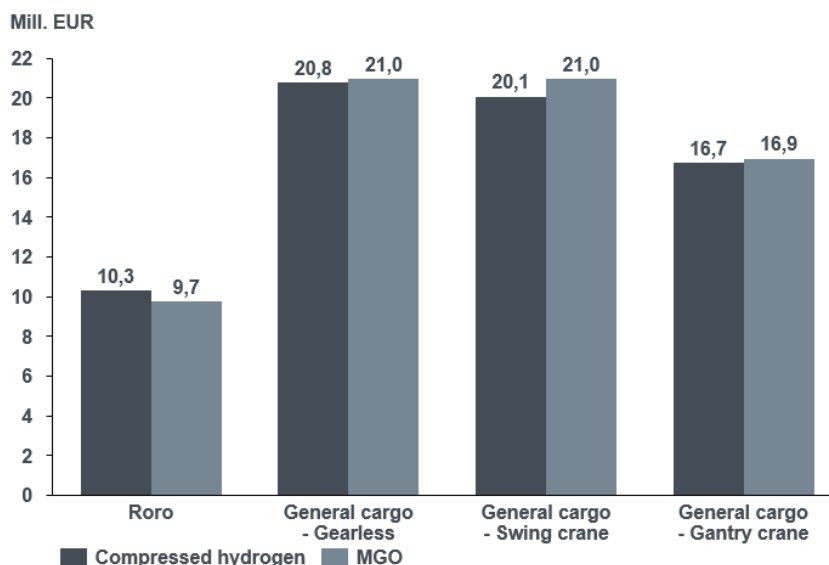
The table above gives an indication on when the vessel becomes financially attractive as an investment, but it must be noted that there are several cost aspects not included in the study, like commercial operation, long-term maintenance cost and other unexpected costs. Based on this it is highly unlikely that a ship owner, or any other investor, would invest in the case at a 10% WACC. Should the business case continue to return a positive after the above-mentioned costs are added the business case would suddenly become more attractive.

In the study, 15 years has been used in the cashflow with a vessel sales value included in the last year. From a market perspective 15 years is long to be a commercial freight agreement, but short to be the lifetime of a vessel. According to BIMCO, smaller ships live longer lives and average demolition age for a Handysize vessel (larger than example in pilot study) was in 2018 about 32 years. The value of the ship is then expected to be around 10% of the newbuild price after 15 years which is a very conservative number. Most likely a vessel will be worth a lot more after 15 years adding a substantial potential upside to the business case.

7.2 Analysis results with public support

A hydrogen fuelled cargo carrier would be one of the first of its kind and should most likely be eligible for public support. As an example, should the project expect similar support from Enova as Yara Birkeland received

(electric container vessel), the net present value with a hydrogen ship becomes more profitable. Yara Birkeland received NOK 133 million from Enova, which is equivalent to about EUR 13 million. If “Hydro(gen)ship” became a reality, and received the equivalent support, then interestingly enough a hydrogen fuelled roro-vessel becomes the relatively most cost competitive option compared to MGO fuelled vessels:



The internal rate of return will on the other hand higher be higher for the general cargo vessels. Depending on what the deciding factors for such a business case would be, the internal benefits of rolling cargo needs to be further assessed if a roro-vessel should be the preferred vessel type. Health, safety and environmental considerations could anyhow outweigh the financial considerations.

7.3 Potential extensions of pilot study

The extension possibilities related to a project with a hydrogen fuelled vessel are huge. Hydrogen produced locally at Årdalstangen can have significant synergies with other usages, i.e. local transport and industry. Concrete examples are trucks used at the port, road transport of cargo between Årdal and Årdalstangen and local buses. In addition, there is an opportunity to expand the hydrogen usage to the aluminium plant where hydrogen could be used for aluminium casting, as well as a safety battery for electricity production.

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