REPORT 2021:04

# Hydrogen for shipping – Opportunities for Norway

CICERO
Center for International
Climate Research

# Hydrogen for shipping

## Opportunities for Norway

20. mai 2021

Asbjørn Torvanger

**CICERO** Senter for klimaforskning
P.B. 1129 Blindern, 0318 Oslo
Telefon: 22 00 47 00
E-post: post@cicero.oslo.no
Nett: www.cicero.oslo.no

**CICERO** Center for International Climate Research
P.O. Box 1129 Blindern
N-0318 Oslo, Norway
Phone: +47 22 00 47 00
E-mail: post@cicero.oslo.no
Web: www.cicero.oslo.no

**Title:** Hydrogen for shipping – Opportunities for Norway

**Authors:** Asbjørn Torvanger

**Financed by:** The Norwegian Ministry of Climate and Environment; ‘ekstraordinær grunnbevilgning’ to CICERO autumn 2020.

Project: CICERO's strategic initiatives - Hydrogen

**Project Manager:** Steffen Kallbekken

**Quality Manager:** Fay Madeleine Farstad

**Keywords:** Shipping; Norway; Hydrogen; Low emission fuels.

**Abstract:**
Physical and economic properties of hydrogen mean that its potential as shipping fuel with current technologies is limited to some shipping segments, since alternative fuels are better suited for other applications. An additional challenge for hydrogen is the large investments needed in infrastructure for production, transport, and bunker, as well as improved engine systems for ships. The most promising potential for hydrogen is for short to medium shipping distances, where the capacity of batteries is insufficient, whereas natural gas and biofuels could be more competitive for longer distance operations due to higher energy density by volume.
Due to energy losses at each step along the hydrogen chain (from production, through processing, transportation and using hydrogen) as compared to using natural gas or electricity/batteries directly for running ships, hydrogen will be relatively more competitive than alternative fuels when:
a) Batteries have insufficient power storage capacity, and with infrequent possibilities to re-charge;
b) A sufficient tax on CO2 emissions makes the value of capturing CO2 from blue hydrogen production high enough to cover the CCS cost. With a high cost on CO2 emissions, natural gas (LPG or LNG) for shipping becomes less competitive;
c) Biofuels (HVO or LBG) are less competitive due to higher cost or technical challenges for a specific ship application; or
d) Using hydrogen production as a battery to store surplus production of renewable power is the best value, due to grid limitations, etc. Due to multiple hydro reservoirs in Norway such storage flexibility is of less importance for Norway than e. g. Germany.
Hydrogen is currently not competitive with traditional maritime fuels and likely also not competitive with some of the alternative fuels for shipping. This means that there is need for stronger incentives through a supportive policy-economic framework, e. g. through public funding of infrastructure, public procurement, or supportive funds. There are good opportunities for Norway-EU collaboration on improving green hydrogen technologies, not the least on hydrogen-fueled shipping. Hydrogen-based shipping means opportunities for a new and internationally competitive industry in Norway given our high competence in marine-related technologies, in particular designing and building advanced ships.

**Language of Report:** English

**Bildet på omslaget:** Brødrene Aa

# Contents

# 1 Introduction

In light of society's need to decarbonize to meet the climate goal of the Paris Agreement of less than 2 degrees warming by 2100, hydrogen is often advocated as an important energy carrier in the transportation sector, as well as for the shipping segment (DNV GL 2019a). Shipping is currently responsible for around 2.7% of global $CO_2$ emissions, and this share is expected to increase (Shell 2020). The share of greenhouse gas emissions from shipping in Norway in national waters was 6% in 2019 (Statistics Norway 2019). Figure 1 depicts the number of ships in various shipping segments in Norway, and $CO_2$ emissions (in 1000 tonnes) within territorial waters and Norway's economic zone.

Hydrogen can be produced from electrolysis of water ('green') or from reforming natural gas ('blue') in combination with Carbon Capture and Storage (CCS). In terms of CCS some 90% of the associated $CO_2$ emissions can be captured and thereafter stored underground. A benefit of the 'green' hydrogen is that surplus power production from wind and solar photovoltaics can be stored as hydrogen, thus functioning as a battery. In addition, the possibility of decentralized production of green hydrogen simplifies construction of an infrastructure. The blue hydrogen version must be produced at large facilities equipped with CCS, which implies big investments and more transportation, although cost estimates per kg of blue hydrogen is lower than for green hydrogen (DNV GL 2018). Hydrogen for fuel can be pressurized or cooled down to become liquid, where the latter option saves space but is energy-intensive and expensive. Hydrogen can either be used in fuel cells to produce power for electric engines or directly in internal combustion engines.

The first attempts to use hydrogen for ships goes back to the early years after 2000, when small passenger boats were equipped with fuels cells (Butler 2019). There are several initiatives to develop hydrogen fueled ships in Norway. In 2017 the Fiskerstrand ship builder initiated the HYBRIDskip project, where a ferry is being refurbished to be fueled by hydrogen, supported by the Norwegian PILOT-E program for environmentally friendly energy technologies (DNV GL 2019a). The world's first cruise ship powered by fuel cells and fueled by liquid hydrogen is planned by a group of Norwegian companies (Radowitz 2020). The European innovation project 'FLAGSHIPS' aims at constructing one commercially operated hydrogen fuel cell vessel for France and one for Norway, to be operational during 2021 (The Maritime Executive 2019). The hydrogen will be produced from renewable electricity. The Norwegian vessel is a passenger and car ferry, with a capacity of 299 passengers and 80 cars, to be operated in Rogaland by the Norled ferry company. The Brødrene Aa. shipyard in Western Norway has developed a hydrogen-powered fast passenger boat.[1] The Ulstein ship designer and shipyard is prospecting a supply ship for offshore oil and gas

[1] The first design is named 'Aero 42 Hydrogen' and can carry 275 passengers at a distance up to 150 nautical miles. Two boats are commissioned to service the Trondheim – Kristiansund route, which is 95 nautical miles long.

production powered by hydrogen and fuel cells, which is expected to be in operation from 2022 (Ulstein 2020). The Norwegian Wilhelmsen shipping company has received EU Horizon 2020 innovation support to construct a ro-ro demonstration vessel 'HyShip' powered by liquid hydrogen produced from renewable electricity, which is expected to become operational from 2024 (Jiang 2020).[2] Through the Pilot-E innovation program the Research Council of Norway, Enova, and Innovation Norway are supporting projects to design an ammonia-fueled cargo ship for ammonia transport, a hydrogen-fueled catamaran boat for passenger and car transport, and a zero-emission cargo ship for transportation between Eastern and Western Norway (Research Council of Norway 2020).

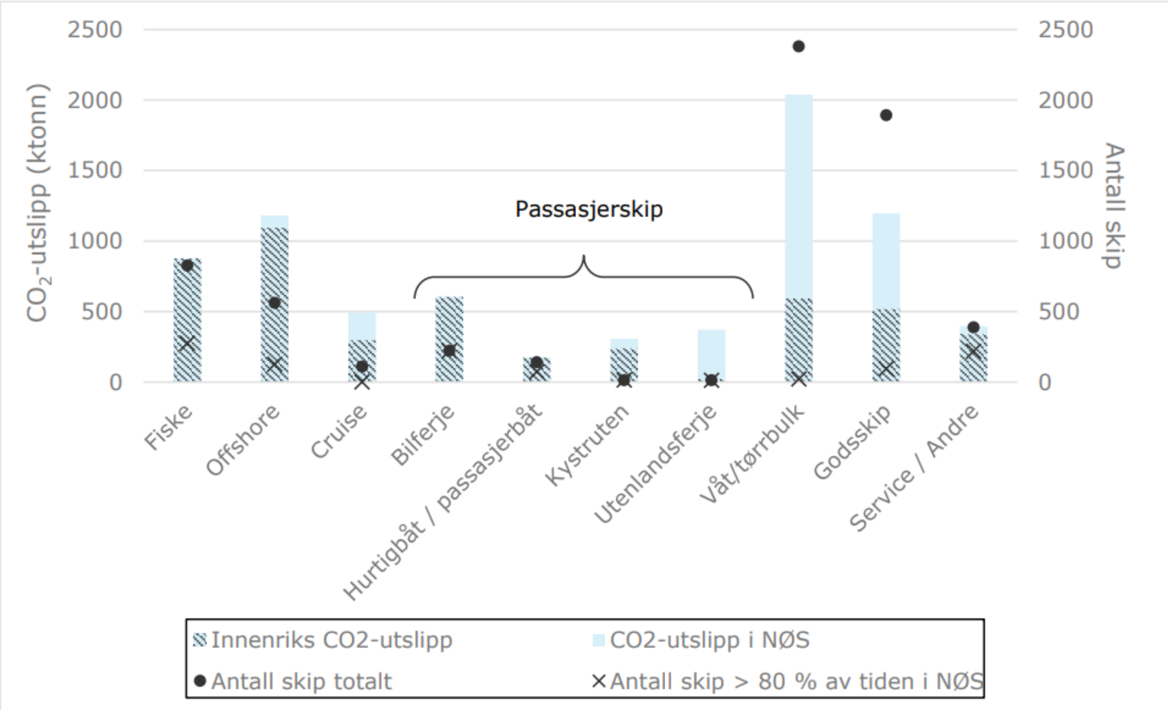


**Figure 1**. Number of ships in different segments and associated $CO_2$ emissions in Norway's economic zone and territorial waters (DNV GL 2019a).

The aim of this report is to provide a brief review of major challenges and opportunities for a new green and hydrogen-based shipping industry in Norway. For this purpose, I review crucial themes for assessing the viability of hydrogen-based shipping. In the first section I check the status of hydrogen infrastructure and hydrogen-based shipping in Norway. If a large-scale hydrogen infrastructure is built in Norway, shipping is likely only going to be one among many applications, and blue hydrogen production will likely dominate green. On this background it is interesting to check EU's strategy on hydrogen, since EU countries are often seen as the major markets for hydrogen export. There are alternatives to hydrogen as a fuel for shipping, so next I review the suitability of hydrogen as an energy carrier in shipping. Assuming that hydrogen is a viable choice for at least some shipping niches, I thereafter review some policies and measures that can stimulate use of hydrogen. In the final section I discuss opportunities for developing a new low-carbon shipping industry in Norway.

[2] At a ro-ro ship cargo can be rolled on and off the ship with the help of cars, trucks, or railroad cars.

# 2 Hydrogen production and infrastructure in Norway

Currently very little hydrogen infrastructure exists in Norway, similar to other countries. Since transportation has been mainly based on fossil fuels for a century there has been little demand for hydrogen-based technologies. In addition, many processes in energy-intensive industries have been carbon-based, even though hydrogen can be an alternative to carbon for some applications. A renewed interest for hydrogen in Norway is foremost based on the expectation that blue hydrogen from natural gas with CCS may become a big and profitable export commodity. Currently, hydrogen stations for cars are only situated in Oslo, Bergen, and Trondheim, but some new locations are planned. Ruter started testing of hydrogen fueled buses in 2012, with economic support from Enova and the EU, and currently operates around 15 hydrogen fueled buses.[3] The hydrogen station in Trondheim services cars, trucks, and forklifts. At all these stations hydrogen is produced locally from electrolysis of water. Currently there is no facility for producing liquid hydrogen in Norway. Regarding hydrogen for shipping, marine hydrogen stations may become operational from 2021 (Hydrogen.no 2020a).

In terms of shipping, hydrogen fuel will require more frequent bunkering than for conventional fuels due to much lower energy density by volume and a higher storage cost. Sizeable infrastructure investments are necessary to make hydrogen available at relevant ports in Norway. Based on data on ship visits from the ship segments where hydrogen is most competitive with other fuels, the ports with the largest potential for hydrogen bunkers in Norway are considered to be Bergen, Ålesund, Tromsø, Kristiansund, and Stavanger (DNV GL 2019a).

[3] Ruter plans and coordinates public transport in Oslo and part of Viken county (former Akershus), as well as procures transport services from various transport companies.

# 3 EU's hydrogen strategy

The European Green Deal will undoubtedly influence the future room for hydrogen inn Europe, especially regarding the scope for blue hydrogen exports from Norway. The EU has ambitious plans to expand production and use of hydrogen as part of its European Green Deal and associated 'Hydrogen strategy for a climate-neutral Europe' (European Commission 2020). EU's accentuation of hydrogen will influence the development of hydrogen technologies, collaboration between countries, and competition among hydrogen producers. Currently fossil fuels and power converted to hydrogen represents less than 2% of the EU's energy mix, and 96% of hydrogen production is based on fossil fuels (mainly from the reforming of natural gas and gasification of coal). The share of hydrogen is projected to increase to 13-14% by 2050. The vision is to install at least 6 GW of hydrogen electrolysis capacity by 2024 and 40 GW by 2030, of which 1.5 – 2.3 GW are under construction or announced. This would require significantly more power production from wind and photovoltaics. Elements of the existing gas infrastructure can be used for hydrogen, including cross-border pipelines. Some hydrogen could be blended with natural gas in pipelines, but this reduces the value of the hydrogen as a carbon-free fuel. Furthermore, a change of gas quality may require changes to infrastructure design and end-user applications, and risk fragmenting the gas market because gas quality standards vary between member states. For fossil-based hydrogen production the role of CCS to reduce $CO_2$ emissions is recognized. Hydrogen can replace fossil fuels in some industrial processes and transportation, including shipping, particularly where electrification and batteries are deemed too difficult or expensive. EU recognizes, however, that hydrogen based on renewable energy or fossil-based hydrogen with CCS are currently not competitive with fossil-based hydrogen (without CCS). Green hydrogen production is considered compatible with EU's proposal for a taxonomy on sustainable finance, as opposed to blue hydrogen production (TEG 2020). There is no discussion in EU's strategy of the low energy efficiency of using hydrogen for transport as compared to electricity and batteries (see section 4 below).

Fossil-based hydrogen costs about 1.5 EUR/kg, whereas adding CCS would mean a price of around 2 EUR/kg. Hydrogen based on renewable energy gives a price of 2.5 – 5.5 EUR/kg. This means that the $CO_2$ price would need to be in the range of 55-90 EUR/tonne to make fossil-based hydrogen with CCS competitive with hydrogen without CCS, whereas the allowance price in EU's Emissions Trading System (EU ETS) in December 2020 was at around 25 EUR/tonne $CO_2$. Thus the EU recognizes that support policies are required to expand hydrogen, and is considering a host of measures, such as introducing a standard for hydrogen production facilities based on full life-cycle greenhouse gas performance, European-wide criteria for certification of renewable and low-carbon hydrogen, minimum shares of renewable hydrogen for specific end-use sectors, and carbon contracts for difference.[4] EU emphasizes that the hydrogen infrastructure should be accessible to everybody on a non-discriminatory basis. Supportive policy frameworks exist, for example through the Renewable Energy Directive and the EU Emissions Trading Scheme (ETS). These frameworks contribute to making hydrogen a more cost-competitive fuel through penalizing fossil fuels and $CO_2$ emissions, and stimulating renewable energy production. The EU ETS Innovation Fund can also facilitate hydrogen-based innovations. On hydrogen, Norway recently joined EU's 'Important Projects of Common European Interest' (IPCEI) collaboration on innovation and industrial collaboration, which will be managed by Enova (Regjeringen 2020). The European Commission (2020) emphasizes collaboration with Southern and Eastern partners in Europe and the African Union, whereas import of blue hydrogen from Norway is not mentioned.

[4] A carbon contract of difference pays the difference between the required $CO_2$ price to make hydrogen competitive and the $CO_2$ price in the EU ETS.

Thus, Norway is facing substantial challenges regarding export of blue hydrogen to European countries due to skepticism to hydrogen produced from natural gas and EU's preference of hydrogen collaboration with Southern and Eastern Europe and Africa. An additional challenge for blue hydrogen is the changing perceptions on the role of natural gas, where the face-out of natural gas should be accelerated, as well as skepticism towards CCS in some European countries. A more promising avenue for Norwegian collaboration with EU is on improving green hydrogen technologies, and especially hydrogen applications for transportation, including shipping, as well as using hydrogen to reduce dependency on fossil inputs in industry.

# 4 Suitability of hydrogen for shipping

Hydrogen is one out of many alternative fuels for shipping. Other alternatives are liquid natural gas (LNG), liquid petroleum gas (LPG), bio diesel (HVO), biogas (LBG), ammonia, electric (batteries), ethanol, and methanol (DNV GL 2019a, 2019b). Hydrogen can be transported in liquid form as ammonia or liquid organic hydrogen carrier (LOHC). Some amount of hydrogen can be mixed with convention fuels for conventional combustion engines. Hydrogen can be part of hybrid solutions, in combination with battery solutions or other fuels. Since shipping consists of very different segments that operate under different conditions using hydrogen as a fuel for ships will require different adaptations. The energy content of hydrogen is best utilized by fuel cells, but so far only small fuel cell systems have been developed, so up-scaling will be required for larger ships (DNV GL 2019a). Hydrogen requires additional costs and space for storage on ships, fuel cells, and parallel bunker systems or integration with bunkers for other fuels.

Electrolysis of water for hydrogen production has an energy efficiency of around 70%, and fuel cells have an energy efficiency of 60-80% (DNV GL 2019a). Additionally, compression or synthesizing the gas to liquid require sizeable energy use. Reforming natural gas to produce hydrogen has a slightly higher energy efficiency at 70-85%. Due to several steps from producing hydrogen through processing, transportation, and use, as well as the CCS stage for production of blue hydrogen, the whole chain must be assessed to compare climate friendliness, energy use, and cost compared to other fuels. In some cases, transportation of power or natural gas can be more efficient than transporting hydrogen (DNV GL 2019a). Combining the energy losses at the different steps of the energy chain from electricity or gas production to running a ship propeller from these DNV GL reports, we get an illustrative total energy efficiency as shown in Figure 2. The figure shows the effects of medium, low, and high assumptions on energy efficiency at critical steps of the energy chains. The figure also shows that a battery-operated ship can utilize around 80% of the initial energy, whereas a ship using green or blue hydrogen can utilize around 40%. However, the efficiency of hydrogen can be less than 30% for blue hydrogen with low efficiency, or above 50% for blue hydrogen with high efficiency. For comparison, an electric car can utilize 70-90% of the energy contained in the power, whereas a hydrogen-fueled car can only use 30-40% of the energy content of the gas. Thus, the relative energy efficiency of different fuels is similar for ships and cars. Battery-operation has about the double energy efficiency of hydrogen operation.

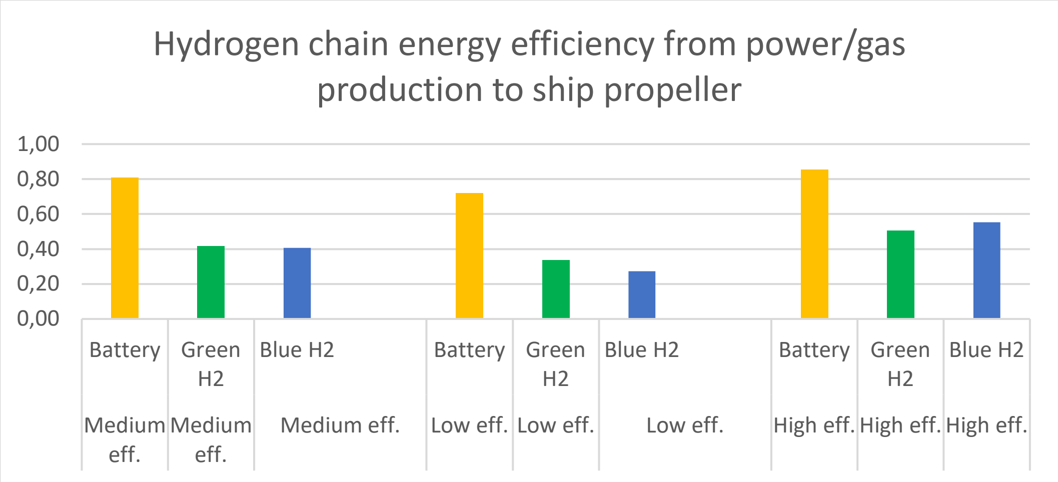


**Figure 2**. Energy efficiency along the hydrogen chain from production of electricity or natural gas, via hydrogen to running a ship propeller, dependent on efficiency at different steps of the chain (1,00 = 100 % energy efficiency).

The ship segments with largest potential for using hydrogen are ferries, fast passenger boats, fishing vessels, and offshore vessels (DNV GL 2019a). Hydrogen for ferries is mostly of interest for longer and energy-demanding connections that are part of Norwegian highways ('Riksveg'), such as some connections in Hordaland and Nordland. Around 80 fast boats service the Norwegian coast, and they have high emissions per passenger-km. Only a few of these can use batteries, whereas hydrogen could be an interesting fuel alternative. Out of the 5000 fishing vessels in Norway most are small and operate close to the coastline. Hybrid electric-fuel boats are being developed by the Selfa Artic shipyard, but for boats that have a longer operation radius hydrogen can be an interesting option (Kvile and Svendsen 2020). The main fishing boat ports are Bergen, Ålesund and Tromsø, so these are the ports that are most in need of a hydrogen bunker infrastructure for this shipping segment. Hydrogen is also an interesting option for oil and gas offshore support vessels (DNV GL 2019a).

A key challenge for hydrogen is that this technology must be adapted to a ship segment and operation and would only be competitive with alternative fuels for some applications. In addition, the energy efficiency of the chain is low, the cost is high, infrastructure must be developed, and in the case of blue hydrogen big investments in CCS are required. A different challenge is insufficient competence and regulations on hydrogen fueled transportation and related safety precautions, e.g. storage of hydrogen on ships (DNV GL 2019a). These challenges mean that hydrogen as a ship fuel is mostly of interest to some shipping niches, such a short to medium distance operations with infrequent refueling possibilities, where batteries have insufficient capacity. Hydrogen can also be attractive when biofuels are less applicable or more expensive, and the tax on $CO_2$ emissions is sufficient to make operation with traditional marine fuels and natural gas less competitive compared to hydrogen.

# 5 Stimulation of hydrogen-based shipping

A major bottleneck for hydrogen fueled shipping is the large investments required in the associated infrastructure for production, transportation, and distribution to make hydrogen available. A second stumbling block is a higher cost per kilometer transport compared to traditional fuels. In this context, technical maturity, and suitability in terms of energy density are smaller challenges. For an overview of challenges to investments in hydrogen-based shipping, confer Figure 3. To compete with the price of marine diesel, hydrogen would need to cost around 20 NOK/kg $H_2$. In the absence of marine hydrogen stations and associated pricing of hydrogen, we can compare the hydrogen price with the gasoline price for cars. The current cost of hydrogen at car filling stations is around 90 NOK/kg $H_2$, which is comparable to the fuel cost per km for a gasoline car (although gasoline is taxed much higher than hydrogen).[5] Electrolysis production of hydrogen would cost 20-50 NOK/kg $H_2$, whereas hydrogen produced from natural gas with CCS would cost 10-20 NOK/kg $H_2$ (DNV GL 2018). In addition, a hydrogen energy chain would involve sizeable additional costs for compression of hydrogen (or making the gas liquid), transportation, storage, and bunkers. Taken together this means that hydrogen is not competitive with traditional fuels in shipping, and thus dependent on favorable government regulations, support, and incentives. Demand for hydrogen might actually require stronger government stimulus than battery solutions since the latter have a much higher energy efficiency (DNV GL 2019a).

## 5.1 Measures to support hydrogen-fueled shipping

Given the barriers to develop a hydrogen fuel chain for shipping, I assess the most promising measures that can facilitate investments in and deployment of a hydrogen fuel system for shipping, divided into research and development, government funding and coordination, public procurement, and investment funds.

[5] Since one kg hydrogen can fuel a car for 100-140 km, a hydrogen price of 90 NOK/kg$H_2$ translates to 6-9 NOK per 10 km (Hydrogen.no 2020b). The average gasoline price in 2020 was around 14 NOK/l, which for an average car translates to around 8 NOK per 10 km. About 60% of the gasoline price is taxes (road use tax, $CO_2$ tax, and VAT), whereas the only tax on hydrogen is 20% VAT.

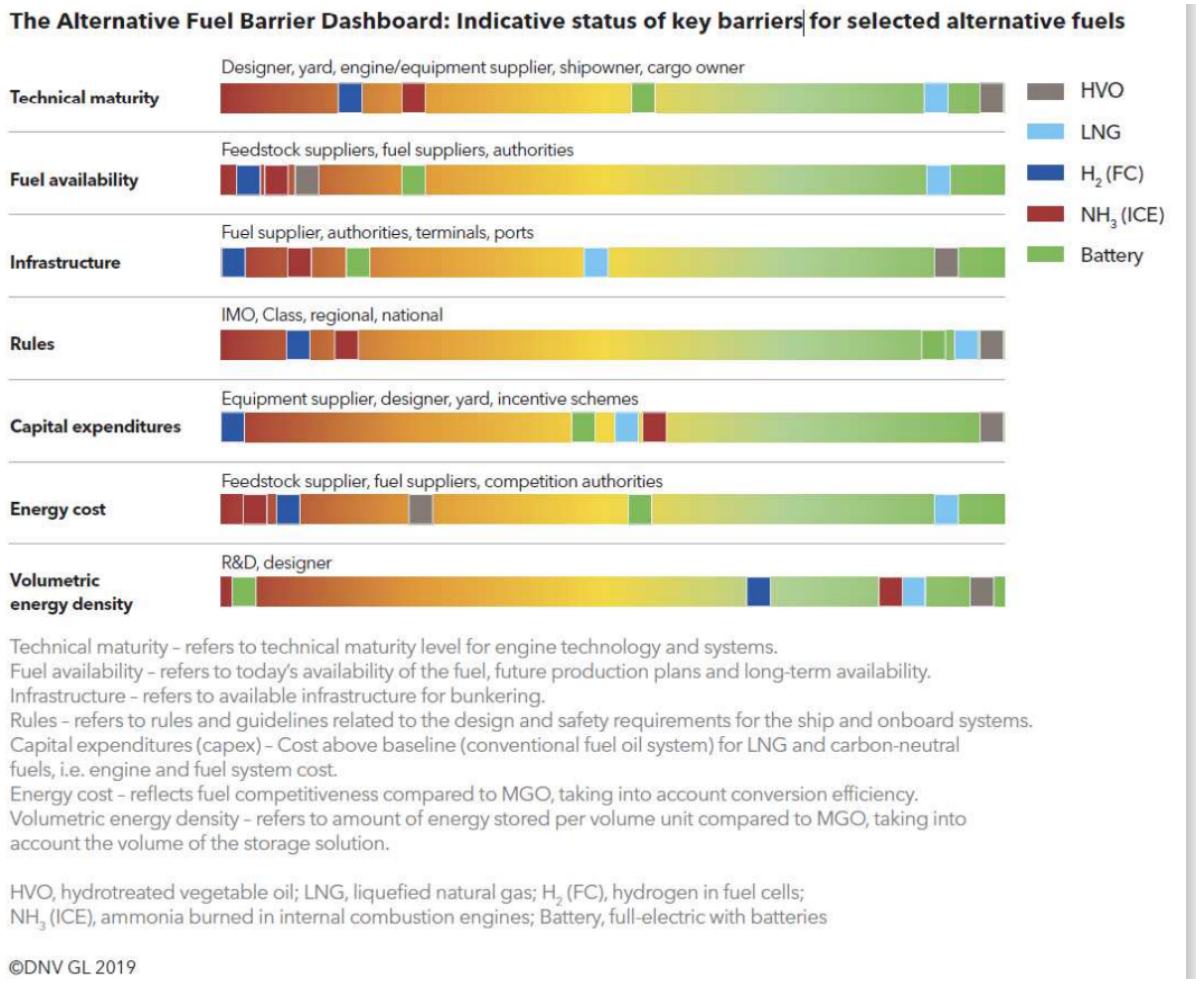


**Figure 3**. Status of key barriers at a global level for a selection of ship fuels (DNV GL 2019b).

## Research and development

Even if hydrogen technologies have reached some level of maturity, a lot remains to be developed in terms of applications to specific shipping segments and operational conditions. Furthermore, an efficient and robust infrastructure, efficient facilitation through policies and instruments, and security systems and regulation are needed. Therefore, more research, development and deployment programs are required. Innovation Norway and Enova are already supporting some hydrogen development, demonstration, and pilot projects, but more is needed.[6]

## Government funding and coordination of infrastructure

Investments in infrastructure are required to supply hydrogen for shipping. This infrastructure may be local, flexible, and modular, based on local plants to produce green hydrogen from electrolysis of water close to ports. At some scale green hydrogen production necessitates sufficient availability of power grid capacity at regional and local levels. The alternative is large-scale production of blue hydrogen from natural gas at a few central plants in combination with CCS, which requires

[6] Innovation Norway is an organization established by the Norwegian Government, tasked with contributing to sustainable growth and exports for Norwegian business through capital and expertise. Enova SF is an agency owned by the Ministry of Climate and Environment in Norway that contributes to reduced greenhouse gas emissions, development of energy and climate technology, and strengthened security of energy supply.

infrastructure for pipelines and/or rail, truck, or ship transport of the hydrogen to the relevant ports. A large-scale infrastructure construction could reduce cost due to the benefits of economies of scale and could also contribute to lower costs associated with CCS per unit of hydrogen. Over time, learning effects for both green and blue hydrogen will increase efficiency and reduce costs.

For large-scale investments in both the green and blue alternatives, hydrogen infrastructure could be considered as a critical infrastructure, like the power grid. A hydrogen infrastructure can lead to local supply monopolies, confer local power grid monopolies. Companies and their investments at different locations in a hydrogen value chain are often inter-dependent upon one another. Hence, it will be important to ensure that the development of such value chains avoids wasteful parallel systems or favors one company at the cost of another. A competitive access to the infrastructure and fair prices for users should be assured. For these reasons, ownership of the infrastructure could be private but combined with public regulation of operational terms. Or the infrastructure could be owned and operated by a public agency to ascertain open access and assure competitive pricing.

## Public procurement

Some segments of shipping are based on public licenses that allow them to operate in Norway. Examples are stretches of ferry connections that are important elements of national highways ('riksvei'), fast passenger boats servicing the coast of Norway, and the costal express route ('Hurtigruten'). The Norwegian Public Roads Administration has cooperated with counties responsible for operating ferry connections to make several of the licenses for ferry connections conditional on the choice of low-carbon solutions.[7] This has effectively stimulated the introduction of battery-operated ferry connections in Norway, and the number is fast increasing. Since oil and gas extraction in the North Sea, fishing, and aquaculture production all depend on government licenses to operate, such licenses could in principle be made conditional on the choice of technology for the ships serving these activities. Government has an additional tool that may be efficient, namely the annual purchase of ship transport services for ferries at national highways and the costal express route. Again, purchase of these shipping services could be made conditional on giving preference to green technologies and fuels.

## Funds for investments in climate-friendly shipping and hydrogen

The $NO_x$ Fund for industrial enterprises in Norway was operational from 2008 till 2019. Enterprises paid a levy on their $NO_x$ emissions. Later, enterprises could apply for support for measures to reduce $NO_x$ emissions from the $NO_x$ Fund and thereby finance investments in environmentally friendly technologies. Altogether the $NO_x$ Fund paid over 4.4 billion NOK for $NO_x$ reducing measures (NHO 2020). A similar policy instrument could be introduced to incentivize investments in climate friendly shipping and hydrogen fueled ships. Norway is taxing maritime fuels for shipping in its national waters (mineral oil, natural gas, and LNG) to reduce $CO_2$, $NO_x$, and sulfur emissions. Like the $NO_x$ fund, some of the revenue from the ordinary tax or a new tax could be used to finance a fund for climate-friendly shipping, where shipping companies could apply for investment support for climate-friendly technologies, such as engines and infrastructure for hydrogen operation.

Through the 'Klimasats' fund operated by the Norwegian Environment Agency ('Miljødirektoratet') counties and municipalities can get support for developing zero- and low-emission fast boats, fueled by electricity, ammonia, hydrogen, or biogas (Miljødirektoratet 2020).[8]

[7] The Norwegian name is 'Statens Vegvesen', which is the government agency responsible for national highways.
[8] Funding of some of the admissible activities under this fund is handled by Enova.

# 6 Opportunities for Norway

With current technologies and envisioned advances there will be a niche for hydrogen-fueled ships given that other fuels will be less competitive in some shipping segments and operations. Hydrogen-based shipping means opportunities for a new and internationally competitive industry in Norway given our high competence in marine-related technologies, in particular designing and building advanced ships. Norway is an international leader on CCS technologies and applications, which is of importance for blue hydrogen production. As noted, Norwegian ship designers, shipyards and shipowners are already involved in several projects to develop and build hydrogen-fueled fast passenger boats, ferries, supply ships for offshore oil and gas production, ro-ro ships, and cruise ships. Currently some small hybrid and battery-operated fishing vessels are in production, but there is also scope for hydrogen-fueled fishing vessels. Like other areas of rapid technology development there are uncertainties related to the direction and speed of technology advancements and maturity, and costs of different fuel alternatives. In addition, there is the political uncertainty related to the future cost levied on $CO_2$ emissions, which first and foremost depends on how climate policies in Norway and elsewhere develop over the next decades.

Although EU is encouraging hydrogen as part of its European Green Deal, Norway is facing substantial challenges to export blue hydrogen to EU, due to the priority of fossil-free green hydrogen and a perceived need for faster decarbonization away from natural gas, as well as skepticism towards CCS. There are, however, good opportunities for Norway to collaborate with EU on improving green hydrogen technologies, not the least applied to shipping.

# 7 Summary

Physical and economic properties of hydrogen mean that its potential as shipping fuel with current technologies is limited to some shipping segments, since alternative fuels are better suited for other applications. An additional challenge for hydrogen is the large investments needed in infrastructure for production, transport, and bunker, as well as improved engine systems for ships. The most promising potential for hydrogen is for short to medium shipping distances, where the capacity of batteries is insufficient, whereas natural gas and biofuels could be more competitive for longer distance operations due to higher energy density by volume.

Due to energy losses at each step along the hydrogen chain (from production, through processing, transportation and using hydrogen) as compared to using natural gas or electricity/batteries directly for running ships, hydrogen will be relatively more competitive than alternative fuels when:

a) Batteries have insufficient power storage capacity, and with infrequent possibilities to re-charge;
b) A sufficient tax on $CO_2$ emissions makes the value of capturing $CO_2$ from blue hydrogen production high enough to cover the CCS cost. With a high cost on $CO_2$ emissions, natural gas (LPG or LNG) for shipping becomes less competitive;
c) Biofuels (HVO or LBG) are less competitive due to higher cost or technical challenges for a specific ship application; or
d) Using hydrogen production as a battery to store surplus production of renewable power is the best value, due to grid limitations, etc. Due to multiple hydro reservoirs in Norway such storage flexibility is of less importance for Norway than e.g. Germany.

Hydrogen is currently not competitive with traditional maritime fuels and likely also not competitive with some of the alternative fuels for shipping. This means that there is need for stronger incentives through a supportive policy-economic framework, e.g. through public funding of infrastructure, public procurement, or supportive funds.

There are good opportunities for Norway-EU collaboration on improving green hydrogen technologies, not the least on hydrogen-fueled shipping.

Hydrogen-based shipping means opportunities for a new and internationally competitive industry in Norway given our high competence in marine-related technologies, in particular designing and building advanced ships.

# References


Butler, Jeff (2019), Throwback Thursday: World's 1st hydrogen boats.
https://plugboats.com/throwback-thursday-worlds-1st-hydrogen-boats/ (Accessed 1.12.2020).

DNV GL (2019a), Synteserapport om produksjon og bruk av hydrogen i Norge, Klima- og miljødepartementet og Olje- og energidepartementet, Rapport nr. 39, rev. 1.
https://www.regjeringen.no/contentassets/0762c0682ad04e6abd66a9555e7468df/hydrogen-i-norge---synteserapport.pdf

DNV GL (2019b), Tiltaksanalyse – Reduksjon av klimagassutslipp fra innenriks skipstrafikk, Miljødirektoratet, Rapport nr. 0939, DNV-GL.
https://www.miljodirektoratet.no/globalassets/publikasjoner/m1626/m1626.pdf

DNV GL (2018), Kartlegging av utslippskutt i maritim næring. Analyse av tiltak for reduksjon av klimagassutslipp fra innenriks skipstrafikk, Miljødirektoratet, Rapport M-1027.
https://www.miljodirektoratet.no/globalassets/publikasjoner/M1027/M1027.pdf

European Commission (2020), A hydrogen strategy for a climate-neutral Europe. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2020) 301 final.
https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

EU Technical Expert Group on Sustainable Finance (TEG) (2020), Financing a sustainable European economy, Taxonomy Report: Technical Annex.
https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy-annexes_en.pdf

Hydrogen.no (2020a), Her finner du hydrogenstasjonene i Norge.
https://www.hydrogen.no/stasjoner/kart-over-stasjoner (Accessed 3.12.2020).

Hydrogen.no (2020b), Hva koster hydrogen?
https://www.hydrogen.no/ressurser/ofte-stilte-sporsmal (Accessed 3.12.2020).

Jiang, Jason (2020), Hydrogen-fueled ship project secures EU funding, Splash247.com, 23 October.
https://splash247.com/hydrogen-fuelled-ship-project-secures-eu-funding/

Kvile, Kjersti, Ketil Svendsen (2020), Heretter skal Selfa Arctic kun bygge hybride fartøy.
https://www.tekfisk.no/fiskeri/heretter-skal-selfa-arctic-kun-bygge-hybride-fartoy/2-1-858703

The Maritime Excecutive (2019), Hydrogen fuel cell vessels destined for France and Norway, 13 May.
https://www.maritime-executive.com/article/hydrogen-fuel-cell-vessels-destined-for-france-and-norway

Miljødirektoraet (2020), Søk støtte til utslippsfrie hurtigbåter.
https://www.miljodirektoratet.no/myndigheter/klimaarbeid/kutte-utslipp-av-klimagasser/klimasats/sok-stotte-til-utslippsfrie-hurtigbater/ (Accessed 18.12.2020).

Miljødirektoratet (2019), Klimakur 2030, Kapittel 5: Sjøfart, fiske og havbruk.
https://www.miljodirektoratet.no/globalassets/publikasjoner/m1625/m1625.pdf

NHO (2020), $NO_x$-fondet.
https://www.nho.no/samarbeid/nox-fondet/the-nox-fund/ (Accessed 8.12.2020).

Regjeringen (2020), Slutter seg til europeisk satsing på hydrogen, 9 December.
https://www.regjeringen.no/no/aktuelt/slutter-seg-til-europeisk-satsing-pa-hydrogen/id2790732/

Research Council of Norway (2020), Millionstøtte til utslippsfri havgående transport.
https://www.forskningsradet.no/nyheter/2020/millionstotte-til-utslippsfri-havgaende-transport/

Radowitz, Bernd (2020), World's first liquid hydrogen fuel cell cruise ship planned for Norway's fjords, Recharge News, 3 February.
https://www.rechargenews.com/transition/world-s-first-liquid-hydrogen-fuel-cell-cruise-ship-planned-for-norway-s-fjords/2-1-749070

Shell (2020), Greenhouse gas emissions in shipping.
https://www.shell.com/energy-and-innovation/the-energy-future/greenhouse-gas-emissions-in-shipping.html (Accessed 1.12.2020)

Statistics Norway (2019), $CO_2$ og andre klimagasser, etter utslippskilde.
https://www.ssb.no/natur-og-miljo/statistikker/klimagassn/aar (Accessed 1.12.2020).

Ulstein (2020), Zero-emission operations in offshore construction market, 26 October.
https://ulstein.com/news/2019/zero-emission-operations-in-offshore-construction-market

Øystese, Kirsten Ånestad (2020), Grønn skipsfart: Utslippene må i null i 2050, Norsk Klimastiftelse, Rapport nr. 1.
https://klimastiftelsen.no/wp-content/uploads/2020/01/NK1_2020_gronn_skipsfart.pdf

**CICERO** is Norway's foremost institute for interdisciplinary climate research. We help to solve the climate problem and strengthen international climate cooperation by predicting and responding to society's climate challenges through research and dissemination of a high international standard.

CICERO has garnered attention for its research on the effects of manmade emissions on the climate, society's response to climate change, and the formulation of international agreements. We have played an active role in the IPCC since 1995 and eleven of our scientists contributed the IPCC's Fifth Assessment Report.

- We deliver important contributions to the design of international agreements, most notably under the UNFCCC, on topics such as burden sharing, and on how different climate gases affect the climate and emissions trading.
- We help design effective climate policies and study how different measures should be designed to reach climate goals.
- We house some of the world's foremost researchers in atmospheric chemistry and we are at the forefront in understanding how greenhouse gas emissions alter Earth's temperature.
- We help local communities and municipalities in Norway and abroad adapt to climate change and in making the green transition to a low carbon society.
- We help key stakeholders understand how they can reduce the climate footprint of food production and food waste, and the socioeconomic benefits of reducing deforestation and forest degradation.
- We have long experience in studying effective measures and strategies for sustainable energy production, feasible renewable policies and the power sector in Europe, and how a changing climate affects global energy production.
- We are the world's largest provider of second opinions on green bonds, and help international development banks, municipalities, export organisations and private companies throughout the world make green investments.
- We are an internationally recognised driving force for innovative climate communication, and are in constant dialogue about the responses to climate change with governments, civil society and private companies.

CICERO was founded by Prime Minister Syse in 1990 after initiative from his predecessor, Gro Harlem Brundtland. CICERO's Director is Kristin Halvorsen, former Finance Minister (2005-2009) and Education Minister (2009-2013). Jens Ulltveit-Moe, CEO of the industrial investment company UMOE is the chair of CICERO's Board of Directors. We are located in the Oslo Science Park, adjacent to the campus of the University of Oslo.

**CICERO** Center for International Climate Research
P.O. Box 1129 Blindern
N-0318 Oslo, Norway

Phone: +47 22 00 47 00
E-mail: post@cicero.oslo.no
Web: www.cicero.oslo.no