NTRANS
Norwegian Centre for Energy Transition Strategies

FME Forsknings-senter for miljøvennlig energi
Norges forskningsråd

Solving the chicken and egg problem in maritime hydrogen value chains in Western Norway

Research note from User Case 3 in FME NTRANS

Tuukka Mäkitie, Janis Danebergs, Jens Hanson, Eirik Gjelsvik Medbø

FME NTRANS report 3/21

ISBN: 978-82-93863-07-6

Summary

This research note summarizes the User Case 3 in FME NTRANS which has explored solutions to the so-called 'chicken and egg' problem in maritime hydrogen value chains, focusing on Western Norway. Based on three workshops and review of documents, the user case proposes six solutions to this problem: stronger support for both early-movers and hydrogen infrastructure, simultaneous development of supply and demand of hydrogen in local projects, establishment of hydrogen hubs, strong state leadership, and the acknowledgement of hydrogen innovation's complexity in policymaking. These perspectives complement the Norwegian government's hydrogen roadmap by highlighting especially the systemic and uncertain nature of hydrogen innovation, and the importance of state leadership.

The supply chain for hydrogen to maritime end users (figure by Big Fish for Ocean Hyway Cluster)

Front page photo: Florø, Fjordbase (Photo by INC Gruppen)

1.Introduction

The Norwegian Government's Hydrogen Strategy outlines that hydrogen has the potential to contribute to the decarbonization of "hard-to-abate" sectors such as processing industries, heavy goods transport and shipping (Regjeringen, 2020). However, hydrogen innovation is yet in an early phase. In the shipping sector, the first ferry in Norway using hydrogen as an energy carrier, MF Hydra, is coming into operation in 2021. Importantly, as hydrogen is not yet widely used as a zero-carbon energy carrier, further deployment of hydrogen-powered vessels is interdependent with the build-up of a whole hydrogen value chain, meaning adequate (and emissions-free) production, distribution, and bunkering of hydrogen.

A key problem in hydrogen innovation is thus the "chicken and egg" problem between supply and demand of hydrogen (Damman, Sandberg, Rosenberg, Pisciella, & Johansen, 2020; DNV GL, 2018). Hydrogen production is yet very limited and expensive, and hydrogen bunkering is not available in ports. This creates uncertainty regarding the availability of hydrogen and discourages shipowners to invest in hydrogen-powered vessels. Around the year 2020, hydrogen-powered vessels have thus not widely been seen as a feasible technology by Norwegian shipowners in the short term (Mäkitie, Steen, Sæther, Bjørgum, & Poulsen, 2021). Conversely, this means that there is yet limited demand for zero-carbon hydrogen, creating uncertainty for hydrogen suppliers regarding market opportunities, thus discouraging investments in hydrogen production and distribution. These uncertainties in both the supply and demand of hydrogen for maritime use create negative feedback loops, forming a key obstacle for the hydrogen innovation.

In User Case 3 of FME NTRANS, taking place during Q2 2020 – Q2 2021, we focused on producing more knowledge regarding this problem. Our case study context was maritime hydrogen value chains in Western Norway (Vestland). This region has an advanced maritime cluster, several vessel routes suitable for hydrogen use (e.g. high-speed passenger ferries), and suitable conditions for hydrogen production, making it an interesting site for maritime hydrogen experimentations. Hydrogen value chains may allow cutting emissions in maritime transport in the region and create economic opportunities for local actors. We asked: *what are the key challenges in forming maritime hydrogen value chains in Western Norway, and how these challenges may be alleviated?*

We sought answers to these questions through a so-called 'research sprint' which constituted of three case study workshops with partners of FME NTRANS, including both practitioners and researchers from public, private and research organizations. Due to the COVID-19 restrictions, the workshops were performed through the Teams platform. In addition, review of policy documents (e.g. governmental white papers), reports, existing scientific literature and other documents was performed.

This research note presents the results of this research sprint. The purpose of this research note is to provide practice-oriented insights on the chicken and egg problem in maritime hydrogen value chains, and how these may be solved. The results are deemed relevant for public and private actors in Western Norway, but also in other regions with similar ambitions to develop and deploy hydrogen-powered vessels.

The research note is structured as follows. Section 2 briefly presents hydrogen value chains and the key policies affecting the build-up of hydrogen value chains in Norway. Section 3 presents insights from our research sprint by identifying important features of the chicken and egg problem. Section 3 also proposes key factors that may help alleviating the problem. Section 4 concludes by highlighting some of the key points made in this research note.

Aero 40 H2 fast ferry concept design by Brødrene Aa. Capacity for 277 passengers. Storage 4x154kg compressed hydrogen (figure: Brødrene Aa)

2. Maritime hydrogen value chains in Norway

2.1. Briefly on hydrogen value chains

The accelerated deployment and development of hydrogen-powered vessels is dependent on complementary developments in the production and distribution of hydrogen (Mäkitie, Hanson, Steen, Hansen, & Andersen, 2020). Two ways of producing low-carbon hydrogen are relevant for the Norwegian context: electrolysis by using electricity to split water into hydrogen and oxygen ("green hydrogen"), and natural gas reformation where carbon emissions to atmosphere are capture and stored ("blue hydrogen") (Damman et al., 2020). Blue hydrogen production is centralized and considered commercially viable only in large volumes of production (DNV GL, 2019; Menon & AFRY, 2020). Centralized hydrogen production also requires distribution infrastructure, such as pipelines, hydrogen tankers or trucks. Use of pipelines and vessels is currently neither available nor feasible in small volumes (NCE Maritime CleanTech, 2019; PwC, 2019). While the transport of compressed hydrogen by trucks is a well-established technology, but is inefficient for large distances (Danebergs & Aarskog, 2020). The best-established method for long-distance hydrogen transport by both ships and trucks is through hydrogen liquefaction at -253°C, which notably increases its volumetric density. The trade-offs are decreased energy-efficiency due to the energy intensive liquification and capital costs of both the liquification equipment and for the very low temperature storage solutions. In addition, the supply chain of liquid hydrogen becomes more complicated due to management of extreme temperatures, boil-off, etc. (Dagdougui, Sacile, Bersani, & Ouammi, 2018; Petitpas, 2018).

Green hydrogen, however, is more suitable for small-scale and distributed production. As it is based on renewable energy, it is a more long-term solution than blue hydrogen, which is based on limited natural gas resources. If green hydrogen is produced at the harbour, there is no need for distribution for maritime use, reducing cost (DNV GL, 2019; NCE Maritime CleanTech, 2019; PwC, 2019). Locally produced green hydrogen is therefore perhaps the most feasible mean of hydrogen production for maritime use in the early phase. For instance, Western Norway has surplus renewable electricity production which could allow for hydrogen production (NCE Maritime CleanTech, 2019). Moreover, several passenger vessel routes in the region could be well suited for use of hydrogen as an energy carrier (Menon & AFRY, 2020). Aarskog and colleagues (2020) note that vessels with large energy needs and regular routes (such as high-speed passenger vessels) are optimal for initiating hydrogen supply infrastructure (Aarskog & Danebergs, 2020). While hydrogen solutions for high-speed ferries in Western Norway currently have higher capital and operational expenditures than conventional fuel vessels, price-parity may be reached by 2025-2030, assuming continued development in e.g. hull efficiency and fuel cell lifetime, introduction of a moderate carbon price, and learning through demonstration projects (Aarskog et al., 2020).

The use of hydrogen as an energy carrier in vessels has rather low energy-efficiency, with about 25% energy-efficiency when considering both production of hydrogen (either green and blue hydrogen) and its use in fuel cells (Menon & AFRY, 2020; NCE Maritime CleanTech, 2019). Hydrogen currently has also higher capital and operational expenditures than battery-electric solutions (PwC, 2019). However, hydrogen has higher energy-density than batteries, making it more suitable for longer and more energy-requiring voyages. Therefore, hydrogen also does not need to be bunkered in every quay-side, but only needs to be available regionally in hydrogen hubs (Danebergs & Aarskog, 2020; Menon & AFRY, 2020). However, the maritime hydrogen innovation in Norway has until now lagged behind the battery-electric vessels (Steen, Bach, Bjørgum, Hansen, & Kenzhegaliyeva, 2019).

Also regulatory issues hinder hydrogen innovation in the maritime use, and throughout the value chain the regulations, standards and codes need to be further developed and adapted. For instance, hydrogen is considered as a dangerous substance in legislature, and storage of more than 5 tons of hydrogen falls under the regulation regarding large accidents (storulykkeforskriften) (NCE Maritime CleanTech, 2019; PwC, 2019). Moreover, ports may lack the appropriate knowledge regarding creating hydrogen supply systems (Menon & AFRY, 2020), as well as the space for hydrogen bunkering, as hydrogen has lower energy-density than e.g. marine gas oil (NCE Maritime CleanTech, 2019). Finally, hydrogen can be used as an energy carrier in different forms, such as in gaseous or liquefied form, or as ammonia. This creates additional complexity to the chicken and egg problem, as each of these forms of hydrogen require differing production and storage processes and facilities.

2.2. Norway's hydrogen strategy and roadmap

The Norwegian government's hydrogen strategy from 2020 outlines that hydrogen infrastructure development should be largely driven by the market. But the state plans to invest in hydrogen R&D programs and supports demonstration and pilot projects (Regjeringen, 2020). Indeed, the Pilot-E program has financed research projects across the hydrogen value chain. Moreover, hydrogen vehicles are set for various tax breaks, and the government seeks to develop regulations to be more conducive for hydrogen innovation. Increasing carbon fee (CO2-avgift), already existing for fossil fuels in Norway, is seen as a key instrument to induce low-carbon innovation in transport sector, and has been announced to more than triple by 2030 from the 2021 level (Regjeringen, 2020). Seen overall however, this hydrogen strategy can be seen as rather unspecific and unclear in terms of concrete policy measures.

The hydrogen strategy was followed up in June 2021 by the Norwegian government's hydrogen roadmap, published in the context of a white paper on energy, "Energi til Arbeid" (Meld.St. 36) (Regjeringen, 2021b). The hydrogen roadmap is connected to the climate plan of the government (Meld.St. 13) (Regjeringen, 2021a). The hydrogen roadmap has more concrete targets than the strategy, and also pledges the state to contribute to the building of a domestic hydrogen value chain. The roadmap sets a target that in cooperation with private actors the state seeks to develop five hydrogen hubs for maritime transport with opportunities to connect these hubs with land-based transport needs. By 2030 the aim is to develop a network of geographically diffused hydrogen hubs which match with the demand for such infrastructure. Moreover, the roadmap aims to develop a number of pilot projects by 2025, and contribute to that hydrogen-powered vessels are a competitive and safe alternative in domestic shipping by 2030. The government also wants to increasingly use public procurement to induce green innovation, and support counties in advancing zero- and low-carbon high-speed ferries (Regjeringen, 2021b). The government has also earlier announced that the new tendering for ferry crossing Bodø-Værøy-Røst-Moskenes shall demand the use of hydrogen.[1] The Norwegian government has reserved NOK 80 Million in infrastructure and a total of NOK 200 Million in hydrogen in 2021, largely focusing on R&D.[2] For comparison, Germany recently announced an investment plan of EUR 8 Billion (about NOK 80 Billion, spreading over several years) in large-scale hydrogen projects.[3]

At the regional level, the county of Vestland has also published its own hydrogen strategy (Vestland fylkeskommune, 2019). This highlights the opportunities of the county and its municipalities to use public procurement in developing and deploying zero-emission technologies, and recognizes the importance of infrastructure in the early phase of innovation to induce the hydrogen innovation. Vestland's strategy also recognizes that users from multiple sectors would create valuable synergies for building of hydrogen hubs.

Havila Kystruten – 4 LNG vessels have been designed "ready for liquid hydrogen". The first sailing is planned 1. December 2021. Storage of 3500kg LH2, 640 passengers 640 (figure: Havila)

[1] https://www.regjeringen.no/no/aktuelt/regjeringen-innforer-stiller-krav-til-hydrogenferjer-pa-strekningen-bodo-moskenes/id2782423/
[2] https://e24.no/det-groenne-skiftet/i/jB4p7A/regjeringen-dobler-hydrogensatsingen-lover-100-nye-millioner
[3] https://www.euractiv.com/section/energy-environment/news/germany-to-invest-e8-bn-in-large-scale-hydrogen-projects/

3. Suggestions for solving the chicken and egg problem in maritime hydrogen value chains

While technology development remains important, challenges beyond the technological realm provide important barriers for the further development and use of hydrogen. The chicken and egg problem is one such challenge, which we explored in User Case 3 of FME NTRANS. This section outlines some suggestions that emerged in the User Case regarding how issues related to the chicken and egg problem can be alleviated.

1. Support for early-movers

As hydrogen is yet an immature technology, the price of building and operating a hydrogen-powered vessel is higher, and the performance is somewhat uncertain. Such factors hinder the attractiveness of a novel technology among adopters (Mäkitie et al., 2021). However, the deployment and use of hydrogen-powered vessels is exactly what enables price reductions (through e.g. further development of technologies and economies of scale in hydrogen production) and learning, which in turn is critical to improve the performance and attractiveness of hydrogen-powered vessels. The literature on technological change has shown that substantial changes in the applicability and costs of a technology occur after it is taken into use (Kline & Rosenberg, 1986). It is therefore **crucial that there are early-mover adopters** who despite higher prices and uncertainty decide to invest in hydrogen-powered vessels, and thus create demand for the whole hydrogen value chain. Here **public procurement** is a key instrument in public policy, and it has already been successfully used to induce zero-emission solutions in the maritime sector. Regional actors such as **counties and municipalities** have an important role to play implementing such tenders. However, they have struggled to carry the extra costs and risks inevitably related to the adoption of radically new technologies, and thus may need **sufficient state funding** for such initiatives. Also **private actors** have an important role to play, and e.g. HeidelbergCement and Felleskjøpet have ordered the world's first bulk vessel running on hydrogen. Public inducement and support mechanisms (e.g. **financing schemes, contracts for difference**, etc.) can thus be important in reducing early-mover risk, and thus help creating early markets of hydrogen-powered vessels, which then contributes to the reduction of market uncertainty and learning in the whole maritime hydrogen value chain.

2. Public support for hydrogen infrastructure

Solving the chicken and egg problem requires that all parts of the value chain are developed simultaneously. A key interface between hydrogen supply and hydrogen-powered vessels is the storage and bunkering infrastructure at ports. It is however unclear whether actors in an early phase of hydrogen innovation are willing to take the full risk of investing in such infrastructure when there are yet few or no vessels to use them. However, scientific literature suggests that infrastructure usually precedes the adoption of novel transport technologies (Leibowicz, 2018). Ports, often publicly owned in Norway, play a key part in this, but may lack the resources to carry the risk of building a hydrogen infrastructure without guaranteed users. It therefore seems that **public support for the build-up of infrastructure** is necessary to enable the deployment of hydrogen-powered vessels. Such support mechanisms would need to address the risk of achieving minimum sales volumes (**volume risk**), the risk of achieving a certain sales price (**price risk**), and the risk of making sub-optimal investments in immature (inefficient or sub-optimal) technologies (**technology risk**) (Tomasgard et.al, 2016). Examples of state support mechanisms at early stages could be **operation support**, where the state covers losses in a project for a limited time. This would alleviate both price and volume risk, and the time limitation would incentivize a focus on efficiency improvement. **Investment support** is another early-stage mechanism, where the state supports infrastructure investments to reduce the technology risk. This mechanism should be combined with demand-side mechanisms or operation-phase mechanisms, such as a feed-in tariff. A **feed-in tariff** is a mechanism where price risk is removed through the guarantee of a certain sales price for the producer. The state would pay the difference between a "norm price" where the price of hydrogen can compete with fossil fuels, and the guaranteed sales price. Other support mechanisms for infrastructure build-up at later stages include **hydrogen certificates**, **green taxation** and **performance-based loans** (Tomasgard et.al, 2016).

3. Development of supply and demand within local projects

As the hydrogen value chain is yet in an early phase, one way to circumvent the chicken and egg problem is to develop the whole supply chain of hydrogen (production of e.g. green hydrogen, storage, bunkering and use) in **a joint consortium in a local scale** within a single project. Such local joint initiatives and collaboration also facilitate the building of **trust and communication between actors** of a value chain. This is necessary to diminish the uncertainty and risk for both suppliers and users of hydrogen (cf. Hellsmark, Frishammar, Söderholm, & Ylinenpää, 2016). To overcome price constraints, local joint projects may seek to target **premium market segments** with higher willingness to pay for zero-carbon shipping, such as the tourism segment. An example of such an initiative is Hellesylt Hydrogen Hub. Ideally such projects would be based in locations which also have other potential demand for hydrogen solutions (see next point).

4. Hydrogen hubs combining the hydrogen needs of different sectors

Key factors for driving down the cost of hydrogen supply are economies of scale and scope. Higher aggregate demand for hydrogen allows the reduction of hydrogen production cost. Higher aggregate demand by building **hydrogen hubs** in locations with large enough potential demand, thus **combining the hydrogen use from several sectors** (such as shipping, land-based transport and process industry) in the same location. Hence, hydrogen hubs serving multiple hydrogen using sectors can be an important initial step for building a network of hydrogen bunkering. To realize hydrogen hubs, collaboration between actors from different, perhaps earlier unrelated, sectors is necessary. Public (e.g. transport authorities or public financiers) and private actors (e.g. cluster organizations) can thus play a key role in **intermediating such collaboration**, for instance by encouraging collaboration through public financing schemes, or knowledge and personal network building through cross-industry events. Moreover, opportunities to **use the bi-products of**

electrolysis (e.g. oxygen in aquaculture, heat in district heating) may contribute to economies of scope benefits. Abilities to recognize synergies across sectors and capabilities to arrange collaboration between different actors are therefore important. Forums for such collaboration, e.g. **R&D projects, pilot and demonstrations projects, and cluster organizations**, can thus be key for formation of hydrogen hubs.

5. Strong state leadership

Because of the overwhelming uncertainty emanating from the non-existence of a hydrogen value chain, few private or regional actors have yet been willing to commit in absorbing the early-mover risks related to investments in hydrogen solutions, causing delays in the adoption of hydrogen technologies. In order to meet the government's target of cutting 50% of carbon emissions in Norwegian shipping by 2030 (Regjeringen, 2021a), such delays are no longer possible. **Stronger state leadership** thus seems necessary to reduce the uncertainty by setting a clear direction for the government's intention to deploy hydrogen solutions. This leadership should have a **holistic perspective on hydrogen innovation**, meaning approaching the hydrogen innovation as a task of building a whole hydrogen value chain. This would also require **concrete goals** for implementation with **milestones** for deployment of hydrogen technologies, and a **credible budget** for the realization of such goals. This also means a mutually **coherent and coordinated mix of policies**, potentially a mix of both technology-specific and technology-neutral instruments. For instance, support for both the **R&D and the full-scale deployment and up-scaling** of hydrogen value chains is needed, while general mechanisms such as increasing **carbon fee** can be an important part of generally improving the competitive position of zero-emission technologies.

6. Acknowledge the complexity of hydrogen innovation

Hydrogen innovation in shipping is a highly complex task. Shipping is very heterogenous, ranging from short ferry crossings to deep-sea shipping, where different shipping segments have differing energy and infrastructure needs. Moreover, hydrogen can be used in several forms, for instance in gaseous or liquefied form, or as ammonia. Each of these hydrogen forms require their own value chains. There are also other notable low- and zero-emission solutions in the market, such as battery-electric and liquefied biogas, partly competing against hydrogen solutions. Finally, hydrogen can be produced in multiple ways: through centralized blue hydrogen, or more decentralized green hydrogen. In sum, it is thus yet unclear which shipping segments are most suited for which type of hydrogen, and how shall this hydrogen be produced. This vast **complexity** regarding the hydrogen innovation **must be acknowledged**. In other words, policymaking must accept that some answers regarding the future of hydrogen are yet unknown, and **missteps and failures are possible**. This should however not postpone the responses to tackling the chicken and egg problem in hydrogen innovation. Rather, governance strategy should **pursue experimentation and learning in different hydrogen solutions**, and continue investments in R&D.

4. Conclusion

This research note has identified several perspectives to the chicken and egg problem in hydrogen innovation, and has proposed approaches that may help to solve this problem. These perspectives are deemed relevant for both public and private actors.

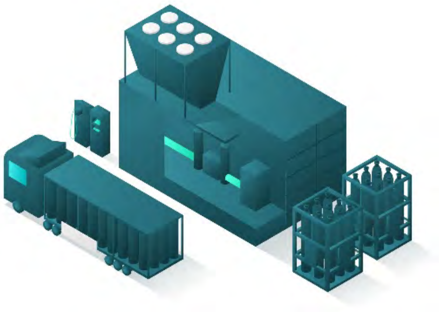
The research sprint that produced these insights took place before the government's hydrogen roadmap was published in June 2021. This latest roadmap outlines some similar steps as in this research note. However, this research note also proposes also complementing perspectives.

First, this research note argues for a holistic perspective on hydrogen innovation. The whole value chain must be considered in order to support the deployment of hydrogen-powered vessels. Innovation activities must therefore address both the supply and demand of hydrogen. Collaboration and intermediation between different segments within the hydrogen value chain, and across the different sectors that may use hydrogen solutions (e.g. land-based transport, process industry, shipping) is necessary. Moreover, infrastructure building may have to precede the deployment of hydrogen-powered vessels.

Second, because of the overwhelming uncertainty causing the chicken and egg problem, strong leadership and direction from a powerful actor such as the state is likely needed to accelerate the hydrogen innovation. This requires both concrete objectives and credible means by the state to reach them.

Third, hydrogen is in many ways more complex than e.g. battery-electric vessels because of the complete lack of value chain, and the presence of several forms that hydrogen can be used as an energy carrier. Thus, also the governance approaches have to reflect this complexity, and pursue experimentation and learning, and tolerate possible setbacks.

In conclusion, the chicken and egg problem in the maritime sector remains as a vast challenge for public and private actors who wish to promote the development and deployment of hydrogen-powered vessels. However, due to e.g. hydrogen's potential to mitigate carbon emissions and contribute to creation of business and export opportunities for Norwegian firms, such challenges may well be worth the effort.



Representation of an electrolyser, compressed hydrogen storage bottles and distribution truck (figure by Big Fish for Ocean Hyway Cluster)

References

Aarskog, F. G., & Danebergs, J. (2020). *Estimation of Energy Demand in the Norwegian high-speed Passenger Ferry Sector Towards 2030*. Retrieved from https://ife.brage.unit.no/ife-xmlui/handle/11250/2653026

Aarskog, F. G., Danebergs, J., Strømgren, T., & Ulleberg, Ø. (2020). Energy and cost analysis of a hydrogen driven high speed passenger ferry. *International Shipbuilding Progress, 67*, 97-123. doi:10.3233/ISP-190273

Dagdougui, H., Sacile, R., Bersani, C., & Ouammi, A. (2018). *Hydrogen Infrastructure for Energy Applications. Production, Storage, Distribution and Safety.*: Academic Press.

Damman, S., Sandberg, E., Rosenberg, E., Pisciella, P., & Johansen, U. (2020). *Largescale hydrogen production in Norway - possible transition pathways towards 2050*. Retrieved from https://ife.brage.unit.no/ife-xmlui/handle/11250/2650236

Danebergs, J., & Aarskog, F. G. (2020). *Future compressed hydrogen infrastructure for the domestic maritime sector*. Retrieved from https://ife.brage.unit.no/ife-xmlui/handle/11250/2719412

DNV GL. (2018). *Grønt kystfartsprogram barrierestudie. Barrierer for lav- og nullutslippsløsninger for transport av tørrlast med skip*. Retrieved from Høvik, Norway: https://grontskipsfartsprogram.no/wp-content/uploads/2021/02/GKP_barrierestudie_torrlast__final_rev1.pdf

DNV GL. (2019). *Produksjon og bruk av hydrogen i Norge*. Retrieved from https://www.regjeringen.no/contentassets/0762c0682ad04e6abd66a9555e7468df/hydrogen-i-norge---synteserapport.pdf

Hellsmark, H., Frishammar, J., Söderholm, P., & Ylinenpää, H. (2016). The role of pilot and demonstration plants in technology development and innovation policy. *Research Policy, 45*(9), 1743-1761. doi:https://doi.org/10.1016/j.respol.2016.05.005

Kline, S. J., & Rosenberg, N. (1986). An overview of innovation. In N. R. Council (Ed.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth*. Washington, DC: The National Academies Press.

Leibowicz, B. D. (2018). Policy recommendations for a transition to sustainable mobility based on historical diffusion dynamics of transport systems. *Energy Policy, 119*, 357-366. doi:https://doi.org/10.1016/j.enpol.2018.04.066

Menon, & AFRY. (2020). *Scenarioanalyse av infrastrukturbehov for alternative drivstoff til fartøy i maritime sektor*. Retrieved from https://www.menon.no/wp-content/uploads/2020-0-Alternative-drivstoff-for-skipsfart-m-P%C3%B5yry-m-fl.pdf

Mäkitie, T., Hanson, J., Steen, M., Hansen, T., & Andersen, A. D. (2020). The sectoral interdependencies of low-carbon innovations in sustainability transitions. *FME NTRANS Working papers, 01/20*. Retrieved from https://www.ntnu.no/documents/1284688443/1285504199/NTRANS_Working_paper+01_20.pdf/9f86b986-91b1-5ce1-114b-af18484bf587?t=1604060267764

Mäkitie, T., Steen, M., Sæther, E. A., Bjørgum, Ø., & Poulsen, R. T. (2021). Norwegian ship-owners' adoption of green fuels. *FME NTRANS Working papers, 01/21*. Retrieved from https://www.sintef.no/en/publications/publication/1920824/

NCE Maritime CleanTech. (2019). *Norwegian future value chains for liquid hydrogen*. Retrieved from https://maritimecleantech.no/wp-content/uploads/2016/11/Report-liquid-hydrogen.pdf

Petitpas, G. (2018). *Boil-off losses along LH2 pathway* (LLNL-TR-750685; Other: 936219 United States 10.2172/1466121 Other: 936219 External Audience (Unlimited) LLNL English). Retrieved from https://www.osti.gov/servlets/purl/1466121

PwC. (2019). *Status H2 som energibærer i maritim næring*. Retrieved from https://www.bluemaritimecluster.no/download?objectPath=/upload_images/CCCEB48BF3354E519C4EAF01D71443E0.pdf

Regjeringen. (2020). *The Norwegian Government's hydrogen strategy towards a low emission society*.

Regjeringen. (2021a). *Klimaplan for 2021-2030*.

Regjeringen. (2021b). *Meld. St. 36. Energi til arbeid – langsiktig verdiskaping fra norske energiressurser*.

Steen, M., Bach, H., Bjørgum, Ø., Hansen, T., & Kenzhegaliyeva, A. (2019). *Greening the fleet: A technological innovation system (TIS) analysis of hydrogen, battery electric, liquefied biogas, and biodiesel in the maritime sector*. Retrieved from https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2613837

Tomasgard, A., Møller-Holst, S., Thomassen, M., Bull-Berg, H., Damman, S., Bjørkvoll, T. (2016) *Nasjonale rammebetingelser og potensial for hydrogensatsingen i Norge.* Report for Oslo Kommune. Retrieved from https://www.oslo.kommune.no/getfile.php/13113018-1457454555/Tjenester%20og%20tilbud/Politikk%20og%20administrasjon/Prosjekter/Program%20for%20storbyforskning/Nasjonale%20rammebetingelser%20og%20potensial%20for%20hydrogensatsingen%20i%20Norge%20-%20SINTEF-rapport%20A27350.pdf

Vestland fylkeskommune. (2019). *Hydrogen Region Vestlandet - Strategi og handlingsprogram 2019-2020*. Retrieved from https://www.vestlandfylke.no/globalassets/gron-vekst-og-klima/hydrogen/hydrogenregionvestlandet_strategi.pdf

Research sprint participants of User Case 3, FME NTRANS (in alphabetic order)

Asgeir Tomasgard	Norwegian University of Science and Technology
Audun Gisle Sunde	Vestland County Council
Bente Johnsen Rygg	Western Norway University of Applied Sciences
Bjørn Sundland	BKK
Camilla Røhme	Norwegian Public Roads Administration
Christian Klöckner	Norwegian University of Science and Technology
Cyriac George	University of Oslo
Einar Bjørshol	Norwegian Coastal Administration
Frode Rømo	SINTEF Industry
Geoffrey Sean Gilpin	Western Norway University of Applied Sciences
Janis Danebergs	Institute for Energy Technology
Jens Hanson	SINTEF Digital
Kari Aamodt Espegren	Institute for Energy Technology
Kjell Løvold	Hydrogen Storage AS
Kristin Gulbrandsen Frøysa	University of Bergen
Kristin Linnerud	Western Norway University of Applied Sciences
Kristin Maurstad	Kinn Kommune
Marius Korsnes	Norwegian University of Science and Technology
Mark Purkis	Ocean Hyway Cluster
Markus Steen	SINTEF Digital
Negar Safara Nosar	Western Norway University of Applied Sciences
Ola Teigen	Kinn Kommune
Øystein Ulleberg	Institute for Energy Technology
Paolo Pisciella	Norwegian University of Science and Technology
Rune Njøs	Western Norway University of Applied Sciences
Sigrid Damman	SINTEF Digital
Steffen Møller-Holst	SINTEF Industry
Steinar Kostøl	Ocean Hyway Cluster
Tore Olderkjær Solheimslid	Vestland County Council
Trond Moengen	Research Council of Norway
Tuukka Mäkitie	SINTEF Digital
Velaug Myrseth Oltedal	Western Norway University of Applied Sciences

NTRANS

We study the role of the energy system in the transition to the zero-emission society.