Oslo Havn

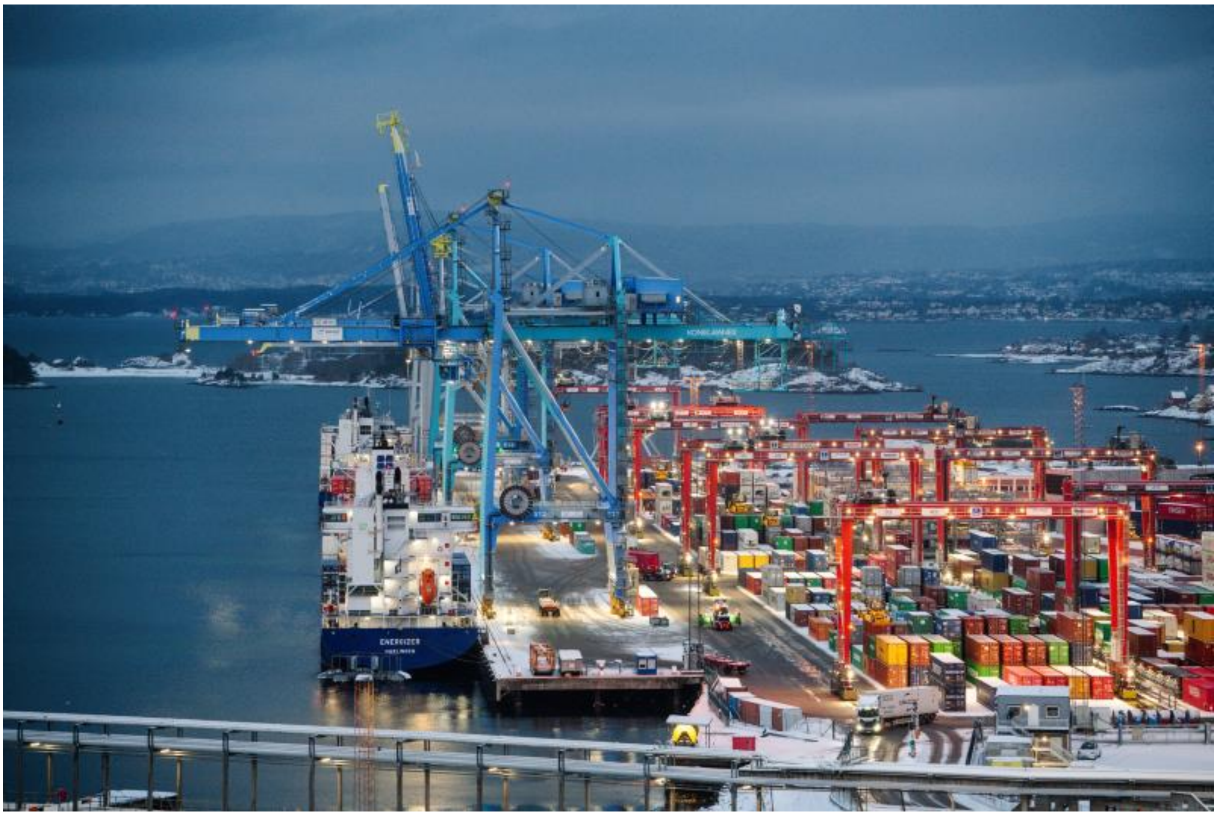
DNV

Grønt Skipsfartsprogram

Nordic Roadmap
Future Fuels for Shipping

Safe hydrogen bunkering in the Port of Oslo

Pilot study report



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Oslo Havn DNV Grønt Skipsfartsprogram Nordic Roadmap Future Fuels for Shipping

EXECUTIVE SUMMARY

The pilot study was established as part of the Nordic Roadmap for future fuels project. The main objective of the pilot study was to investigate the possibility for safe liquid hydrogen bunkering in the Port of Oslo, specifically in the container port at Sjursøya.

What we did:

In response to the objective, the pilot study work was divided into the following three tasks:

- Task 1 – exploring safe bunkering locations and concepts.
- Task 2 – a key barrier study for safe LH_2 bunkering; and
- Task 3 – assessing the port readiness level in the Port of Oslo.

What we found:

In Task 1 we assessed three different bunkering methods, truck-to-ship, port-to-ship, and ship-to-ship bunkering, where truck-to-ship was concluded to be the most mature concept to pursue. We also identified a suitable location for liquid hydrogen bunkering at Sjursøya container terminal through several inspections at the port. Lastly, this task established a baseline for the bunkering duration, frequency, and required amount from the specific pilot vessel, Samskip SeaShuttle. Different approaches for bunkering during loading and unloading containers (simultaneous operations) were investigated.

The key barriers identified in Task 2 for bunkering of liquefied hydrogen in the Port of Oslo include limited area for LH_2 bunkering, hydrogen supply, technology maturity of bunkering concept, approval and permits for LH_2 bunkering, and safe bunkering operation. The barriers were systematically assessed in a qualitative way, through stakeholders' input during a workshop. The main technical barriers identified in the workshop that could be potential showstoppers are lack of supply of LH_2 to the Port of Oslo by Q2 2026, and limited area in the port.

Task 3 summarized the Port of Oslo's current readiness level for bunkering liquified hydrogen, following the Port Readiness Level (PRL) framework developed by the International Association of Ports and Harbors. At this point, the Port of Oslo is at PRL 1, ready to progress to PRL 2.

What we recommend:

The recommendation from the pilot study is to perform a quantitative risk assessment (QRA) at the container port in Sjursøya. The QRA would be based on the identified bunker requirements, location, and bunkering concept and for hydrogen suppliers to conduct a final investment decision in liquified hydrogen capacity. Port of Oslo is to continue the work with progressing their Port Readiness Level and in addition investigate further into simultaneous operations during bunkering in close collaboration with Yilport, the operator at the container port.

The findings from this pilot study contributed with valuable insights to the Fuel Transition Roadmap for Nordic Shipping [1].

1 INTRODUCTION

DNV, together with the contributing partners Chalmers, IVL, MAN Energy Solutions, Menon Economics, and Litehauz, have been assigned the Nordic Roadmap project by the Norwegian Ministry of Climate and Environment on behalf of the Nordic Council of Ministers. The project has an overall aim "to reduce key barriers to implementation and establish a common roadmap for the whole Nordic region and logistics ecosystem towards zero-emission shipping".

The Port of Oslo's vision is to become the world's most efficient and environmentally friendly urban port, with a goal of 50% reduction of CO_2 emissions from ships by 2025, as well as 85% reduction in total CO_2 emissions by 2030 within 7 nm from the port. Europe's largest container port, Rotterdam, has fixed weekly routes to Oslo, and aims to become a green hydrogen hub. In September 2023, the cities of Oslo and Rotterdam signed a Memorandum of Understanding (MoU) that will help establish emission-free transportation between the continent and Oslo. Furthermore, Samskip plans to operate liquefied hydrogen-powered container feeder vessels on this route.

Hydrogen introduces new safety challenges. The experience with bunkering of hydrogen for ships is very limited and the regulatory approval processes are complex due to hydrogen's novel state as a maritime fuel.

On this background, the Port of Oslo together with Samskip, GreenH, Menon Economics, Norwegian Hydrogen, Statkraft, Yilport and Norwegian Maritime Authority want to explore the safety and regulatory barriers related to bunkering of hydrogen. The aim of this pilot is to investigate the feasibility of bunkering liquid hydrogen (LH_2) in Port of Oslo's container port at Sjursøya. The pilot work started in May 2024, and was finished in March 2025.

Figure 1-1: Samskip's proposed route with LH_2 powered vessels.

The two container feeder vessels chosen as basis for this pilot study are 137 meters long. The ships will operate weekly between Rotterdam and Oslo, with several stops at ports along this route, as illustrated in Figure 1-1. The vessels will be powered by 3.2 MW hydrogen fuel cells, with diesel generators as back-up. By using green liquid hydrogen as fuel, and green shore power at the port call, Samskip expects to avoid around 25,000 tonnes of CO_2 emission each year [2].

This pilot study has been divided into three main tasks to investigate the feasibility of bunkering liquid hydrogen in the Port of Oslo:

- Task 1: Bunkering locations and bunkering concepts
- Task 2: Key barrier study
- Task 3: Port readiness level

Figure 1-2 shows the overall methodology and how this pilot study is divided into the different phases and tasks. It started with a literature review to assess the status on safety standards and regulations for hydrogen bunkering, before looking at the potential bunkering locations and possible bunkering concepts. Next, a key barrier workshop was conducted, to assess the identified main barriers and investigate for any potential showstoppers. The input was used to assess the port readiness level for bunkering liquid hydrogen in the Port of Oslo. Finally, we summarized the findings and reflected on the current and future feasibility of bunkering liquid hydrogen in the Port of Oslo.

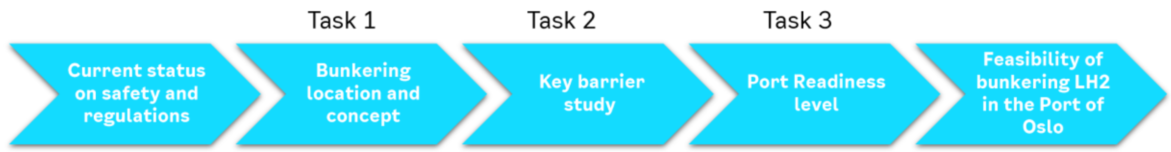

Figure 1-2: Overall methodology for the pilot study.

This report has the following structure:

- Chapter 2 – Provides high-level safety considerations for bunkering of hydrogen and presents the regulatory framework.
- Chapter 3 – Explores the potential bunkering location and bunkering concepts.
- Chapter 4 – Investigates key barriers for bunkering.
- Chapter 5 – Discusses the port readiness level.
- Chapter 6 – Presents the conclusion and the way forward.

As the pilot owner, the Port of Oslo is strongly committed to the project and aims to use the acquired knowledge on liquid hydrogen bunkering to assess both its safety and financial sustainability. The pilot offers valuable insights for strategic discussions within the organization and is expected to equip decision-makers with sufficient data to develop a well-informed strategy for implementing sustainable fuel bunkering operations in the Port of Oslo. In addition, the work carried out in this pilot has been used as input to the “Fuel Transition Roadmap for Nordic Shipping” [1] and it has been presented and discussed at several public events such as seminars and webinars and the pilot study was presented at the high level Nordic Roadmap conference in Copenhagen December 3rd 2024 and at the European Hydrogen Week in Brussel 19th of November 2024.

2 SAFETY CONSIDERATIONS AND REGULATORY FRAMEWORK FOR BUNKERING OF LIQUID HYDROGEN FUEL

Hydrogen brings new safety challenges to the maritime sector. Experience with bunkering of hydrogen for ships is very limited and the design, operation, and regulatory approval processes are complex.

2.1 Hydrogen properties

Liquefied hydrogen (LH_2) is often compared to liquefied natural gas (LNG), as both fuels are cryogenic and flammable gases. Even though many ports have experience with LNG bunkering operations today, the experiences from LNG bunkering cannot be re-used directly for bunkering of LH_2 due to the specific properties of hydrogen.

The unique properties of hydrogen, such as its wide flammability range of 4-77% in air, make it more challenging to handle safely compared to LNG, which have a flammability range of 7-20%. Hydrogen's burning velocity is significantly higher than LNG's, which raises the risk of detonation and results in quicker pressure peaks and higher explosion pressures. Additionally, hydrogen requires only a very low amount of energy to ignite, making it susceptible to ignition from weak sources like static electricity. Hydrogen gas' odourless and colourless nature also makes leaks difficult to detect.

The cryogenic nature of LH_2, with a boiling point of -253°C, presents further challenges. Materials used in the hydrogen fuel installation and bunkering systems must be able to withstand these extremely low temperatures. The solidification of oxygen and nitrogen at this temperature complicates the use of nitrogen as a purging agent, as in LNG systems. Residual nitrogen can clog filters and foul valves when LH_2 is introduced. Air condensation on external surfaces must be managed to prevent the accumulation of concentrated oxygen, which increases the risk of fire and affects equipment. The low temperature of LH_2 can cause severe frostbite and burns upon skin contact, and leaks can cause brittle fractures in structures not made of low-temperature materials.

Hydrogen's dispersion properties are both a benefit and a risk. Its buoyancy allows for rapid dispersion in air, which can mitigate explosion risk in open-air installations. However, the wide flammability range and high expansion ratio from liquid to gas can create large volumes of flammable gas, a specific characteristic of liquid hydrogen fuel. This results in larger flammable clouds compared to gaseous hydrogen or LNG. In addition, recent studies indicate hydrogen's GHG properties as a problematic aspect that requires attention. Any release, deliberate or accidental, will lead to hydrogen in the atmosphere, leading an indirect warming effect on climate, partially offsetting some of the climate benefits of the reduction in carbon dioxide [3]. Studies have indicated a global warming potential for hydrogen to be 11.6 ±2.8, indicating hydrogen to be a far worse GHG than CO_2, with a level of 1 [4].

Bunkering of LH_2 will be built on the experience and knowledge gained from LNG bunkering. However, the experience from LNG bunkering cannot be re-used directly for bunkering LH_2, due to the specific properties of hydrogen.

2.2 Regulatory framework for bunkering of hydrogen

Today, there are no international standards covering bunkering of liquefied hydrogen. The International Maritime Organization (IMO) is currently developing guidelines for the safe design of ships with hydrogen as fuel, but these guidelines are limited to the fuel installation onboard the ship. The Sub-Committee on Carriage of Cargoes and Containers (CCC) plans to further develop and finalize these interim guidelines for safety of ships using hydrogen as fuel with planned approval at Maritime Safety Committee (MSC) 111 in 2026 [5]. Meanwhile, the IMO provides a general methodology to accommodate the approval of new fuels and technologies through the IMO guidelines for the approval of alternatives and equivalents (MSC.1/Circ.1455). This approval process follows a risk-based approach, where the safety level must be demonstrated to be equivalent to that of a conventional oil-fuelled ship. The approach is commonly referred to as the Alternative Design Approval Process (ADA).

The Maritime Technologies Forum (MTF), which is a group of classification societies and flag states, has developed a guideline for bunkering of liquefied hydrogen – *"Guidelines for the development of liquefied hydrogen bunkering systems and procedures"*, aimed at supplementing the regulatory development with input on safe bunkering of liquefied hydrogen [6].

The regulatory framework for the bunkering process and the corresponding shore-side bunkering facilities is local. In Norway, the Norwegian Directorate for Civil Protection (DSB) is tasked to maintain a complete overview of various risks and vulnerability in general. Their responsibilities cover local, regional, and national preparedness and emergency planning, fire safety, electrical safety, and handling and transport of hazardous substances, among other tasks [7]. Hence, DSB approval must be obtained for bunkering of LH_2 in the Port of Oslo.

An overview of the most relevant DSB regulations and other regulations regarding bunkering of LH_2 in the Port of Oslo, as well as guidance to these regulations can be found in Table 2-1.

Table 2-1: Relevant regulations and other documents from DSB and the EU Directive.

What	Regulation	Guidance to the regulations
The handling of dangerous substances[i]	https://lovdata.no/dokument/SF/forskrift/2009-06-08-602?q=forskrift%20om%20h%C3%A5ndtering%20av%20farlig	https://www.dsb.no/lover/farlige-stoffer/farlige-stoffer/veiledning-til-forskriftene/veiledning-til-forskrift-om-handtering-av-brannfarlig-reaksjonsfarlig-og-trykksatt-stoff-samt-utstyr-og-anlegg-som-benyttes-ved-handteringen/ https://www.dsb.no/lover/farlige-stoffer/farlige-stoffer/veiledning-til-forskriftene/temaveiledning-om-innhenting-av-samtykke/
Major accidents	https://lovdata.no/dokument/SF/forskrift/2016-06-03-569?q=storulykkeforskriften https://eur-lex.europa.eu/LexUriServ/LexU	https://www.dsb.no/lover/farlige-stoffer/veiledning-til-forskrift/veiledning-til-storulykkeforskriften/

[i] It should be noted that at the time this report is written, revision of the DSB regulations on handling of dangerous substances is on hearing with deadline mid-December 2024. It contains among other things a clarification of ship-to-ship bunkering to be within the scope of the regulations.

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In relation to the obligation to consent, cf. regulation on the handling of dangerous substances § 17, DSB has issued guidance on obtaining consent as shown in Table 2-1. This contains, among other things, a list of required documentation to be submitted for assessment in respectively two steps; step I – consent to build, and step II – consent to operation/consent to take hazardous substances into the facility.

The processing time from the complete application is submitted to DSB is normally three months. However, this will depend on the quality of the submitted documentation, and whether additional information needs to be requested and possibly prepared. Projects with unknown/new technology may also require longer processing time.

Today, there are no international standards covering bunkering of LH_2. However, the IMO provides a general methodology to accommodate the approval of new fuels and technologies through the IMO guidelines for the approval of alternatives and equivalents. This approval process follows a risk-based approach, where the safety level must be demonstrated to be equivalent to that of a conventional oil-fuelled ship. The approach is commonly referred to as the Alternative Design Approval Process (ADA). Projects with unknown/new technology may require longer processing time to get the necessary approval.

2.3 Considerations regarding control zones for safe bunkering operations

The Maritime Technologies Forum (MTF) has conducted a study to facilitate information sharing on green corridor safety considerations, with a focus on shipowners and port authorities planning to establish and operate green corridors [8].

One key safety consideration that distinguishes hydrogen-fuelled vessels from conventional oil-fuelled vessels is the risk to third parties. Where a fire onboard a conventionally oil-fuelled vessel normally is contained within the ships' sides and extinguished by the onboard crew, an incident onboard a vessel with hydrogen as fuel can pose an immediate danger to people in the nearby vicinity of the vessel.

The concept of third-party risk is well known in the shipping industry and is relevant for all ships carrying dangerous goods, gases, or chemicals as cargo. Vessels carrying such dangerous cargoes are normally required to notify the harbour master prior to arrival and normally have restrictions on where they can berth. Gas carriers and chemical tankers berth at designated tank terminals to load and unload. These terminals have specific provisions, local approvals, and emergency plans for handling large quantities of these dangerous cargoes. To obtain local approval and to develop emergency plans for these tank terminals, it is commonly required to perform quantitative risk assessments (QRA) and dispersion analyses for the area. These analyses often result in risk contours that describe the frequency (e.g., 1.0×10^{-6}/year) of a pre-defined consequence (e.g., fatality) in the specific area. A difference between a ship carrying dangerous cargo and a ship with alternative fuels (e.g. hydrogen) is that the alternative fuelled vessel might be carrying cargo or performing operations that requires berthing at quays not regulated for large amount of dangerous cargo.

The same principle with risk contours for identifying control zones is applied as an industry standard for LNG bunkering. Similar detailed analysis should be made for alternative fuel bunkering operations in green corridor ports.

The Society for Gas as a Marine Fuel (SGMF) defines the following five zones for control measures [9]:

i. **Hazardous zone;** is a three-dimensional space in which a highly toxic or explosive atmosphere can be expected frequently enough to require special precautions. Generally, no persons should be within this zone when bunkering.
ii. **Safety zone;** can be defined as the three-dimensional envelope of distances inside which the majority of leak events occur and where, in exceptional circumstances, there is a recognized potential to harm life. Non-essential people should be excluded from this zone and essential staff should be protected through the use of appropriate PPE and emergency covers.
iii. **Monitoring zone;** is defined as the three-dimensional space inside which activities (including people and vehicle movements) need to be identified and monitored to ensure that they do not affect the safety of the bunkering operation. People in this zone should also be aware of the ongoing bunkering, and evacuation procedures should be clearly defined.
iv. **Marine zone;** is to protect the bunkering vessel from other marine traffic, primarily by defining minimum distances and speeds for passing vessels.
v. **External zone;** is defined by the level of risk general members of the public can be exposed to, based on local regulatory requirements. Ports cannot influence how the general public behaves outside the port area, so the risk level outside must be kept low.

DSB in Norway has developed acceptance criteria for control zones and acceptable risks for third parties. More detailed information about these can be found in DSB's theme report – "*Safety around facilities that handle flammable, reactive, pressurized and explosive substances*" [10].

A previous DNV study performed for the Port of Amsterdam, comparing safety distances for bunkering of various alternative fuels to those of bunkering of LNG, indicated safety distances for LH_2 similar to those for LNG [11].

However, it is not possible to determine any specific control and safety zones around the bunkering location without conducting a QRA for the specific operation and location. A more detailed guideline for such a QRA can be found in the "*Guidelines for quantitative risk assessments for facilities that handle dangerous substance"* [12].

Bunkering without disrupting operations for other ships and cargo operations is the norm for conventional oil-fuelled ships with short port stays. It is also being established as the default bunkering mode for LNG-fuelled ships. It is reasonable to assume that there will be a commercial and operational drive towards continuing this bunkering practice for fuels like methanol, ammonia, and hydrogen. The practice of refuelling while simultaneously performing other operations (simultaneous operations, SIMOPs) is typically reviewed on a case-by-case basis by the ship operator towards local stakeholders. The purpose is to identify potential hazardous interactions between bunkering and other activities, regarding the receiving ship and the surrounding area, and to determine if any additional safety measures need to be implemented before the activity can be performed.

Performing SIMOPs safely requires coordination between the port authority, terminal operator, fuel supplier, bunkering infrastructure owner, and receiving ship. SGMF is one organization providing guidance on how to determine which other ship and port operations may be conducted safely while an LNG-fuelled ship is being bunkered [9]. Similar guidance is relevant and needed for bunkering of methanol, ammonia, and hydrogen to evaluate the feasibility of performing other operations, such as loading and unloading cargo or having passengers onboard, while bunkering these fuels. Depending on factors like proximity to populated areas, type of fuel to be bunkered, and type of bunkering facility, the risk may be considered too high to accept bunkering in certain locations or in parallel with other operations [13].

For LNG bunkering, the establishment of control zones are a part of the bunkering operation. It is highly likely that such control zones will be required for bunkering of hydrogen as well. In order to establish such control zones, a quantitative risk assessment (QRA) and dispersion analysis for the area must be conducted. These analyses often result in risk contours that describes the frequency (e.g., 1.0 x 10-6/year) of a pre-defined consequence (e.g., fatality) in the specific area.

2.4 Stakeholder involvement

The EMSA Guidance for LNG bunkering states that one of the main challenges with LNG bunkering is managing the interfaces during LNG delivery, which also will be the case for LH_2 bunkering [14]. These challenges can be regulatory, technical, or both. Beyond specific standards and technological requirements for the safe bunkering of LH_2 as a marine fuel, harmonization is crucial. The creation of interface environments in LH_2 bunkering raises concerns about different regulatory frameworks (e.g., landside vs. shipside, road vs. port, road vs. shipside, etc.). Ideally, regulations and requirements should aim towards harmonization and compatible interfaces. The interface between the landside and the shipside can potentially lead to potential training discrepancies, equipment mismatches, and other factors that can ultimately impact safety and the environment. Minimizing risk to life and property and mitigating gas release are fundamental to making the LH_2 supply chain within the port area as efficient and straightforward as possible. Figure 2-1 illustrates the different stakeholders involved in a hydrogen bunkering operation [14].

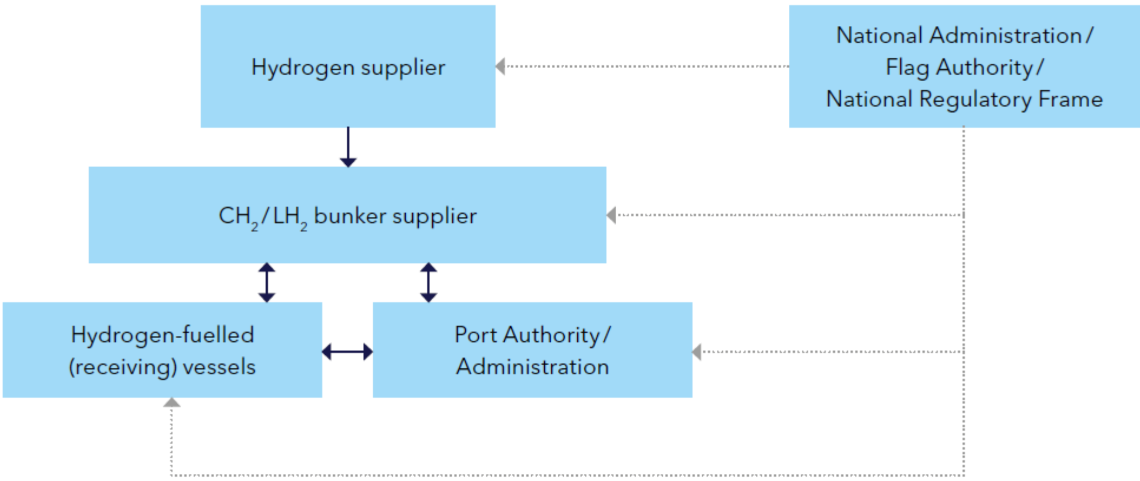


Figure 2-1: Main stakeholders and information flows involved in a hydrogen bunkering operation [15].

3 TASK 1 – EXPLORING BUNKERING LOCATIONS IN THE PORT OF OSLO

The objective of this task is to investigate potential bunkering locations in the container port at Sjursøya and how well different bunkering concepts fit the locations. The goal is to decide on the most suitable bunkering method and illustrate how the bunkering can be performed, as well as to determine the duration of the operations in the Port of Oslo.

3.1 Bunkering case description

Samskip have ordered two container feeder vessels that are to be fuelled by liquefied hydrogen. The vessels are under construction at the time this report is written. As these two vessels will operate between Rotterdam and Oslo, liquefied hydrogen must be available for them to bunker in one or both of these ports. These vessels are therefore used as basis for this pilot study, and the following considerations and assessments are highly influenced by the specific ship type, fuel demand (frequency and volume), and other requirements.

The vessels will either bunker in Rotterdam and/or in Oslo, depending on fuel availability, price, and operational circumstances. Each vessel will require 14 tonnes of LH_2 weekly to complete their journey with zero emissions. Samskip wishes to operate with reduced speed to reduce fuel consumption, but without prolonging the journey. Therefore, they wish to investigate the possibility for simultaneous loading/unloading and bunkering operations (SIMOPs), and the bunkering location in Oslo must therefore be in the container terminal area 81, see Figure 3-1.

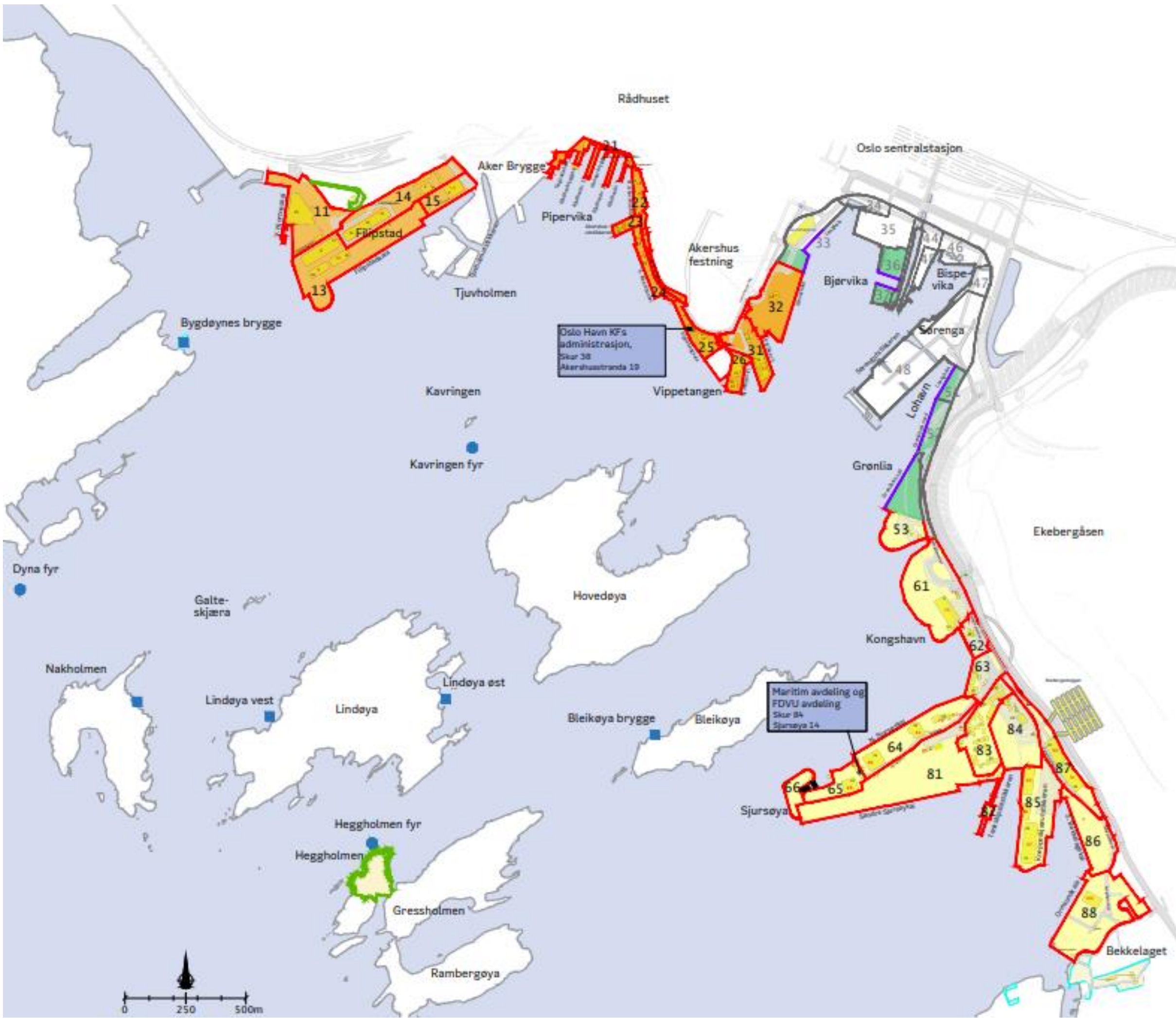


Figure 3-1: Overview of the Port of Oslo.

For the bunkering concept used as basis in this pilot study, we have assumed that the Samskip vessels will bunker half of the required fuel demand in the Port of Rotterdam, and the other half in the Port of Oslo. This means that the bunkering demand in the Port of Oslo will be 7 tonnes of hydrogen per ship (7 tonnes of LH_2, two times a week).

3.2 Bunkering method

Three bunkering methods were assessed by the pilot partners; truck-to-ship (TTS), port-to-ship (PTS), and ship-to-ship (STS). After discussing the different methods, the group concluded that truck-to-ship is the most feasible solution at this stage, and that the other bunker concepts evaluated could be relevant at a later stage in a more mature hydrogen market. Our assessments are described in Table 3-1.

Table 3-1: Overview of the different bunkering methods discussed in this pilot study, and advantages and disadvantages for each of the methods for bunkering of liquefied hydrogen in the Port of Oslo.

General		Bunkering of liquefied hydrogen in the Port of Oslo	
Bunkering method	**Description**	**Advantages**	**Disadvantages**
Truck-to-ship (TTS)	Delivering fuel directly to ships at port using trucks. Method typically used for	The only required infrastructure needed in the port is a	Limited truck capacity and fuel flow rates will require several trucks.

	small/medium-sized vessels and for vessels with a brief port stay.	bunkering tower, and a quay accessible for trucks. Proven concept for bunkering of liquefied hydrogen (MF Hydra).	Potential interference with other cargo operations in the port.
Port-to-ship (PTS)	Delivering fuel from onshore facilities to ships at port. Allows larger fuel volumes and higher delivery rates without disrupting other operations in the port.	Only one couple and decouple operation during bunkering, minimizing the safety risks during the operation.	Limited by the port's facilities and their location. Permanent location in the port, reducing flexibility for bunkering position. Liquefied hydrogen will always be present in the port, which will affect the day-to-day operations in the port. Not a proven concept for liquefied hydrogen.
Ship-to-ship (STS)	Transfer of fuel between vessels at sea, from a bunkering barge or ship to the receiving vessel.	Flexible bunkering location and timing, no port fees and berth queues. Moves the bunker operation to the seaside of the vessel.	Requires additional port infrastructure for refilling the bunker barge. Not a proven concept for liquefied hydrogen. High investment cost.

3.2.1 Truck-to-ship bunkering of liquefied hydrogen in the Port of Oslo.

As mentioned above, the most suitable bunkering method for liquefied hydrogen in the Port of Oslo in the short term will be truck-to-ship. Compared with the two other methods, PTS and STS, TTS is assessed to be the most mature concept for liquefied hydrogen, as MF Hydra has successfully bunkered liquefied hydrogen since March 2023 using this method [16]. Furthermore, the safety risks are assumed to be lower compared to the other methods.

Truck-to-ship bunkering is a well-established procedure for LNG bunkering, applied where a bunker vessel is not available or where the receiving vessel is too small to accommodate a bunker vessel [17]. During the TTS bunkering process, the tanker truck aligns itself alongside the receiving vessel. Utilizing specialized hoses, the LNG is meticulously transferred. This operation is rigorously supervised to ensure that the fuel transfer occurs at the appropriate pressure and temperature, including a predefined cooldown procedure, thereby mitigating any potential safety risks.

The same process is applied by Norled's MF Hydra liquid hydrogen-fuelled ferry. In this case, liquid hydrogen is transported to the bunkering location in liquid hydrogen tank trucks and TTS bunkered by a movable bunkering tower. The liquid hydrogen trucks can carry up to four tonnes of hydrogen and the tanks operate at pressures of two to three bar with vacuum insulation.

3.2.2 Advantages of truck-to-ship bunkering

The aim is to bunker seven tonnes of hydrogen to two ships, on two individual timeslots per week. TTS bunkering only requires a movable bunkering tower which is attached to the hydrogen tank on the truck and the tank on the ship. Since it is movable, it does not require any major changes to the port infrastructure. The bunkering tower can be placed on the quay before the bunkering procedure starts and stowed away after the procedure, to free the area for other port operations (Figure 3-2). Compared to STS and PTS, TTS has a lower investment cost. However, the drawback of this solution is that it is limited by the capacity of the trucks.

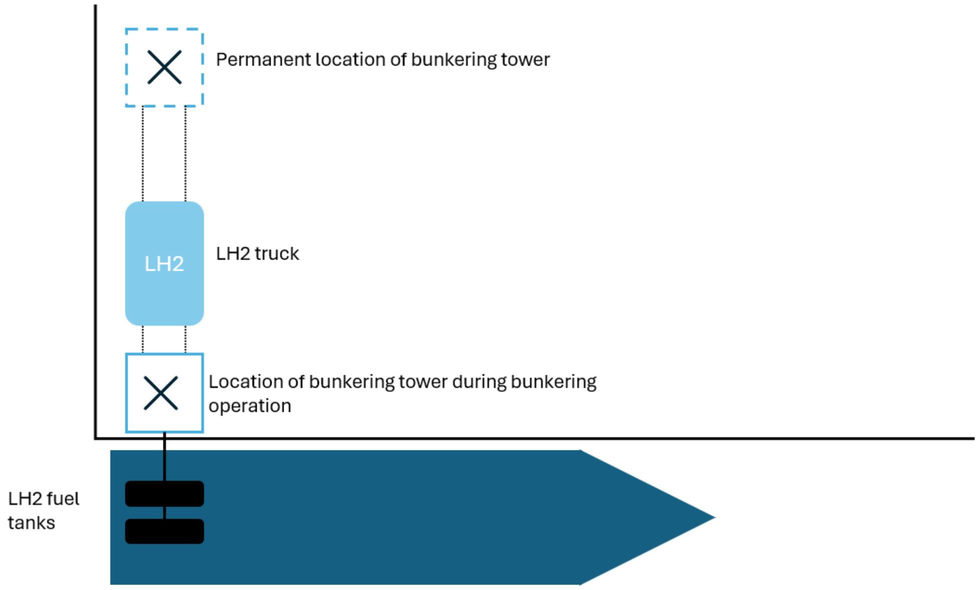


Figure 3-2: High-level drawing of truck-to-ship bunkering concept and required infrastructure.

3.3 Potential locations at Area 81, Sjursøya, Port of Oslo

Phase 1

The first step was to find potential locations with large enough areas next to the quay and close to where the vessel has the possibility to dock. A minimum area of 20x10 m was assumed for the bunkering tower installation and the LH_2-trucks. In addition, the proposed area should not intervene with the current operations in the port. The bunkering tower also requires a permanent location nearby for when not in use.

As data material, the online map provider “www.norgeibilder.no” was used initially to investigate potential locations. This service provides in-scale maps and the possibility to use a measurement tool. From the initial investigation, two possible locations on the container quay fulfilled the above-mentioned requirements, see Figure 3-3.

Figure 3-3: Overview of potential bunkering locations A and B for further investigation.

Phase 2

Two inspections were conducted on the container quay at Sjursøya. The first inspection, conducted May the 24th 2024, confirmed area A and B from phase 1 as suitable for bunkering and in close enough proximity to the quayside, without intervening with other quayside activities. During the inspection, a dialogue was held between the port authority (pilot owner) and the terminal operator (Yilport) regarding traffic on the quayside of the port, the possibility of changing the vessels' current call procedures, weather conditions, and nearby tanker pier operations. During the inspection, it was also discussed if the terminal operator deemed it possible to conduct SIMOPs. Further analysis is to be done to determine if SIMOPs are possible.

The second inspection held on June the 21st 2024 was conducted with the objective of further investigating the safety aspect of the bunkering operation at the specific locations. For that reason, safety experts from DNV conducted a visual inspection of the proposed locations in collaboration with the hydrogen supplier Norwegian Hydrogen.

Both locations were considered with the following assumptions:

- It is possible to place a bunkering tower on wheels at the location and couple an insulated tanker trailer to the tower for LH_2 transferring.
- The quayside ship-to-shore container gantry cranes could be reduced in their horizontal movement, eliminating the possibility of the cranes to collide with the bunkering tower.
- The power cable for the container gantry crane could either be moved or determined as safe in the hazardous zone.

The locations were assessed considering a step-by-step method of the bunkering operation in following order:

1) Preparation of the bunkering tower for operation, including moving into position and cooldown procedure
    a. Arrival and parking of insulated tanker trailer with LH_2
    b. Connection of tank and bunkering tower

   c. Cooldown procedure
2) Berthing of vessel
3) Connection establishment between vessel and bunkering tower
4) Bunkering operation and SIMOPs implications
5) Disconnecting and connecting more than one LH_2 tank during bunkering operation
6) Disconnecting tank from bunkering tower and terminate bunkering operation
7) Mowing the bunkering tower to its storage position

DNV emphasized the importance of safety in the choice of location, and that in their view, the best location from a safety perspective seems to be Location A, as it is placed away from the busiest areas of the port. Norwegian Hydrogen pointed out that in their view, the best location from an operational perspective is Location B. Location A was decided to investigate further, as it was the preferred location for safety and for terminal operations in general. The location minimizes impact on internal transport in the terminal and is placed in an assumed safe distance from other high-risk areas of the port. The report from the inspection can be found in Appendix A.

3.4 Proposed bunkering procedure

The concept proposed is to fuel seven tonnes of hydrogen to the ship using two trucks. Linde Group's LH_2 tanker trucks have been used for the concept and can carry up to four tonnes of hydrogen [18]. However, not all the hydrogen in the tank can be transferred to the ship, as there must be some hydrogen left in the truck to maintain the integrity of the tank and keep the chamber cryogenic cold during the return journey to the LH_2 production site. Some ullage (unfilled space) is also needed during transportation of hydrogen, to accommodate for the vaporization of hydrogen and prevent overpressure during transportation. Vaporization of hydrogen is inevitable, even with the best insulation [19]. This makes the usable volume of the tank less than 90%, thus being able to transport and deliver approximately 3.6 tonnes of hydrogen.

Since seven tonnes of hydrogen need to be bunkered, two LH_2 tanker trucks are needed. In total, both trucks can effectively bunker up to 7.2 tonnes of LH_2. An example of the truck is illustrated in Figure 3-4, showing the dimensions.

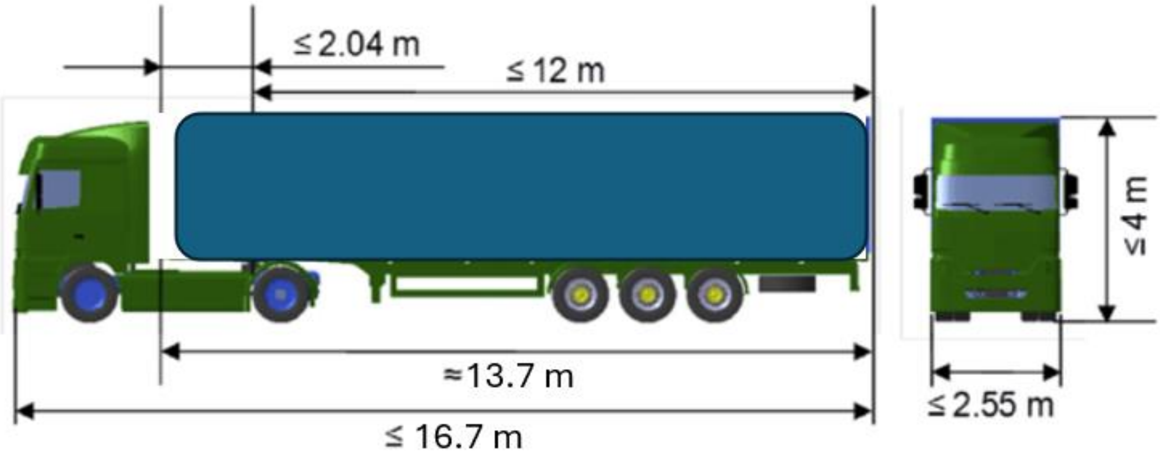


Figure 3-4: Layout and dimensions of a hydrogen tank truck.

The bunkering operator, GreenH, offers two methods for LH_2 bunkering: Either one truck at a time (bunkering in series) or both trucks simultaneously (parallel bunkering).

There are several established procedures from the LNG industry that can serve as inspiration, such as the IAPH checklist [20]. Additionally, the Maritime Technologies Forum has developed guidelines for LH_2 bunkering [6].

3.4.1 Serial bunkering and parallel bunkering

Serial bunkering connects only one tanker vehicle to the ship at a time, while the next tanker vehicle waits nearby to attach its hose as soon as the first tanker vehicle completes its bunkering process. One risk is the potential need for purging in between the hook-ups, which may result in a higher boil-off and loss of hydrogen during operations.

Parallel bunkering is when two tanker vehicles are bunkering simultaneously. It has been seen for LNG bunkering that by using a bunkering tower with two inlets, the bunkering duration will be drastically reduced, as long as the flow rate intake of the ship's storage tanks allows for it. Such systems have since the late 2010s been increasingly common in LNG bunkering, as it reduces the bunkering time by up to 50% [21], [22].

One hose extends from the top of the tower to the ship. At the bottom of the tower, the main inlet connects two hoses, which can be connected to two tanker vehicles at the same time.

To manoeuvre safely, an access way is proposed from the north-west point of the port. The entrance will ensure that arrival and departure can happen without interfering with the crane operations, and that there will be no interruption of the terminal's other activities.

Two alternatives were evaluated, where the bunkering duration, logistics, risks, and potential boil off during operation varies. Maneuvering is required by vehicles to operate safely during bunkering operation. 230 m^2 is required at the southwest corner of the quay for bunkering operations (vehicles and bunkering tower).

3.4.2 The bunkering procedure step-by-step

In Table 3-2, the serial bunkering and the parallel bunkering are explained and compared stepwise.

Table 3-2: Step-by-step comparison of the activities in the serial bunkering and the parallel bunkering operations.

#	Serial bunkering	Parallel bunkering
1	**Port call and preparations for bunkering:** Bunkering tower is moved from storage location to bunkering position. Area is prepared and locked-out according to safety procedures. (15 minutes)	
2	The first tank vehicle is parked in the designated area ready to connect to the tower. **(40 minutes)** • The vehicle is turned off, secured, and de-energized. • The vehicle connects the grounding cable to the bunkering tower. • The vehicle connects the instrument air hoses and gas hoses. • The vacuum pump in the switch box is switched on. • The vehicle connects to the main transfer hose.	Both tank vehicles are parked in the designated area ready to connect to the tower. **(60 minutes)** • The vehicles are turned off, secured, and de-energized. • The vehicles connect the grounding cable to the bunkering tower. • The vehicles connect the instrument air hoses and gas hoses. • The vacuum pump in the switch box is switched on. • The vehicles connect to the main transfer hose.
3	Flushing and cooling procedure (smaller volume compared to parallel bunkering). **(40 minutes)**	The flushing and cooling procedure commences. **(90 minutes)** • Helium which is stowed in the bunkering tower is used to purge the hose with pressure release at the exhaust pipe. • After several helium purges, gaseous hydrogen is used to cool and pressurize the hose. • Gaseous hydrogen flows through the hose for a few minutes.
4	When available, exhaust hoses are connected. The ship connects to the grounding cable to the bunkering tower. **(25 minutes)** • The ship connects the power cable to the bunkering tower. • The ship connects the transfer hose to the fuelling nozzle.	
5	After the filling hose is cold, the hose is filled with liquid hydrogen. The pressure in the tank vehicle will be higher than in the ship. If not, pressure in the tank vehicle should be built up. When the pressure in the tank vehicle is built up, the ship can open the fuelling nozzle and fuelling can commence.	
6	After the tank vehicle has transferred 3.5 tonnes of hydrogen to the ship, the tanker	After the tank vehicles has transferred **7 tonnes** of hydrogen to the ship, the tanker vehicle hose valve is turned off. (**60 minutes**)[ii]

#	Serial bunkering	Parallel bunkering
	vehicle hose valve is turned off. (**60 minutes**)[ii] • The fuelling nozzle is purged with helium and then disconnected from the vehicle. • The tank vehicle can disconnect the air and gas hoses as well as the grounding cable. • The tank vehicle can now drive away, making space for the next one to park.	
7	The next tank vehicle is parked, turned off, secured, and de-energized. (**10 minutes**) • The vehicle connects the grounding cable to the bunkering tower. • The vehicle connects the instrument air hoses and gas hoses. • The vacuum pump in the switch box is switched on. • The vehicle connects to the main transfer hose.	
8	Since the main transfer hose is already cold and filled with hydrogen, there is no need to cool it down or purge the whole hose again, only the nozzle in the connecting point shall be purged and emptied for helium. (**60 minutes**)[ii] • The refuelling from the second tank vehicle can commence.	
9	After the LH_2 is transferred to the ship, the valves are closed. **(40 minutes)** • The hose is heated up by the gas heaters. • After the hose is dry, the hose is purged with helium. • The hose is then emptied and remains in vacuum.	After the LH_2 is transferred to the ship, the valves are closed. **(40 minutes)** • The hoses are heated up by the gas heaters • After the hoses are dry, the hose is purged with helium. • The hoses are then emptied and remains in vacuum.
10	A last check is conducted both on the ship and the vehicle. **(20 minutes)**	A last check is conducted both on the ship and the vehicles. (**20 minutes**)

[ii] From the HYPER Closing Seminar in Brussels, December 11, 2019 – *Liquid Hydrogen Distribution Technology.* Link here.

#	Serial bunkering	Parallel bunkering
	The entire process of transferring **7 tonnes** of LH_2 takes 310 minutes or **5 hours and 10 minutes**.	The entire process of transferring **7 tonnes** of LH_2 takes 310 minutes or **5 hours and 10 minutes**.

While parallel bunkering has demonstrated increased efficiency for LNG bunkering and was believed to significantly impact hydrogen bunkering as well, this analysis reveals that there are no differences in duration for hydrogen. This is primarily due to the time required for connections, purging, and cooling down the system. Consequently, the selection of the bunkering method can be more influenced by the logistics of the site and port rather than solely by time considerations. Nevertheless, there are still benefits and risks associated with both bunkering methods, which should be studied further.

4 TASK 2 – KEY BARRIER STUDY

The objective of Task 2 is to investigate the key barriers for liquefied hydrogen bunkering of Samskip's container feeder vessels in the Port of Oslo and to identify potential showstoppers.

The methodology used in this task was the "traffic light" scorecard method developed in the Nordic Roadmap project to investigate key barriers for green shipping corridors. Firstly, we identified the key barriers for bunkering of liquefied hydrogen. Then, we had a workshop, where we discussed each barrier and gave each barrier a colour; green, yellow, or red, see Figure 4-1. The barriers were discussed with regards to the timeline of Samskip's hydrogen container feeder vessels' start of operation in Q2 2026 in mind.

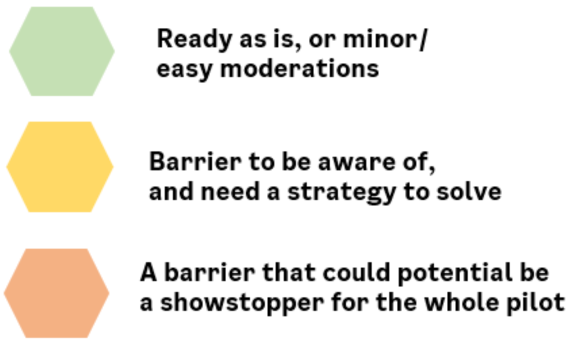


Figure 4-1: Traffic light colours and their meaning.

4.1 The key barriers and results from workshop

The key barrier types that were identified and assessed are:

1. Limited area and space for LH_2 bunkering in the Port of Oslo
2. Liquefied hydrogen supply to the Port of Oslo
3. Technology maturity for LH_2 bunkering concept
4. Approval and permits for LH_2 bunkering
5. Safe bunkering operation

The 10th of October 2024 at the Port of Oslo's headquarters, a workshop with the pilot partner group was conducted. The key barrier types (listed above) were discussed in detail, assessed, and given a colour rating.

4.1.1 Limited area and space for LH_2 bunkering

Firstly, the availability of area in the port required for the bunkering operation was discussed. This is highly dependent on the consequences of the safety zones, and what area the Port of Oslo and Yilport are willing to dedicate to liquefied hydrogen bunkering operations compared to other operations at the port, which at this point are uncertain. A detailed QRA analysis is needed to determine the size of the different safety zones described in section 2.3. In addition, the Port of Oslo will need to develop a strategy for alternative fuels and designate a specific area for the LH_2 bunkering operation.

The duration of the operation and the area required is also important for terminal operator Yilport, as they need to plan their daily operation and what they are allowed to do simultaneously with the bunkering procedure.

The barrier was evaluated as red/yellow, as this could be a potential showstopper, depending on the exact area required for bunkering liquefied hydrogen.

4.1.2 Hydrogen supply to the Port of Oslo

Two main topics were discussed for the hydrogen supply barrier: Availability of hydrogen in the Port of Oslo, and the robustness of the hydrogen supply chain to the Port of Oslo. Today, there is no hydrogen production in the Port of Oslo, nor nearby. GreenH are planning to produce compressed hydrogen at Slagentangen, approximately 100 km away, by the end of 2026. Norwegian Hydrogen currently produces compressed hydrogen at two sites, minimum 500 km away, and are planning to produce compressed hydrogen at Rjukan, approximately 180 km away. Neither of these producers are planning liquefaction plants and GreenH stated that they will only produce liquefied hydrogen if demand rises. GreenH and Norwegian Hydrogen assess that production of liquefied hydrogen in Norway will not happen by Q2 2026, and add that lead time for liquefaction plant components is up to 18 months.

Since Samskip's container feeder vessels according to the plan will need liquefied hydrogen from Q2 2026, this barrier is a potential showstopper (categorized as red), if the liquefied hydrogen should be produced in Norway. However, with a longer timeframe for the production of liquefied hydrogen, this barrier could be assessed as yellow.

4.1.3 Technology maturity for LH_2 bunkering concepts

The technology barrier was discussed in Task 1, where truck-to-ship bunkering was decided to be the most suitable option for this case with the given timeline. As truck-to-ship bunkering is already a proven concept (MF Hydra has successfully used this method for bunkering liquefied hydrogen since March 2023), this was assessed as green for truck-to-ship bunkering. Below you can see our argumentation for the different bunkering methods assessed in this pilot study.

Truck-to-ship	Truck-to-ship bunkering is ready today, mature and well-proven concept.
Port-to-ship	Liquefied hydrogen will always be present in the port, which increases safety zones, and the required area. The concept is not as mature as truck-to-ship.
Ship-to-ship	Not a proven concept, this has not been done as far as the participants in this pilot study are aware of. Liquefied hydrogen bunkering barge is a complex technology. High investment costs, but the concept could be more beneficial in a larger hydrogen market.

4.1.4 Approval and permits for LH_2 bunkering

The main concern for this regulatory barrier was the duration of an application process regarding permission and approval. In addition, the coordination between the ship and the regulatory bodies such as port authorities, DSB, and local authorities was discussed.

Today, the Port of Oslo is not a bunker port, and the port has not been involved in hydrogen bunkering operations before. Liquified Natural Gas (LNG) has been bunkered by a third party within the port's area. Therefore, the port needs to establish a methodology for approval of hydrogen bunkering operations.

DSB is responsible for the approval on the shore-side, while the Norwegian Maritime Authority has the responsibility onboard the hydrogen-fuelled vessel.

From the above discussion we have rated this barrier as a barrier to be aware of, which needs a strategy to solve (colour yellow).

4.1.5 Safe bunkering operation

The last barrier discussed in the workshop was the requirements for safe bunkering operation for liquefied hydrogen. It is crucial that the port bunker crew are properly trained and know how to handle liquified hydrogen, and that the emergency personnel on land are well informed and properly trained to handle any potential incidents that may occur.

A well-developed bunkering plan should be developed. A list of what this plan should include was identified in MTF's LH_2 bunkering guideline [8]:

- Purpose, objective, and safety policies
- Compatibility assessment
- Risk management
- Organization planning
- Communication
- Management of change
- Emergency procedure
- Training
- Operations, procedures, and checklists (include SIMOPs if applicable)

In addition, the crew training and certification may be similar to LNG, but the cryogenic temperatures, invisible flames, and flammability of hydrogen will influence the level of detail in the training program [8]. Such training program does not exist today and must be developed.

MF Hydra has conducted successful bunkering operations since March 2023, but regardless it is still a new procedure for others, and extensive training and planning is required. This barrier was rated yellow.

4.2 Overall scoring

The timeline of the pilot study challenges LH_2 bunkering operations and it was assessed that meeting the deadline of operational status in Q2 2026 is a potential showstopper. To establish a supply chain and truck-to-ship bunkering infrastructure at the port within the timeframe, seeking operational status Q2 2026, is challenging. With this factor in mind, the discussion of barriers was carried out and an assessment was conducted, based on the specific case timeline. The results from the workshop are shown in Figure 4-2.

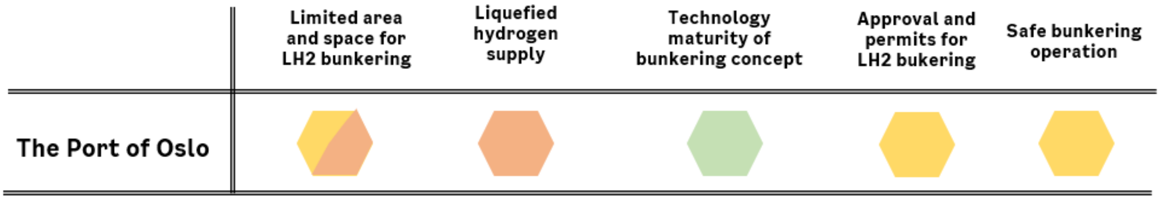


Figure 4-2: Overview of the results from Workshop II - Key barriers.

The most severe barrier identified with regards to bunkering LH_2 in the Port of Oslo within Q2 2026, was the supply of LH_2. With a longer timeframe, this could change to yellow, or even green depending on investment decisions regarding production capacity and infrastructure. The technology maturity of bunkering concept was assessed as a barrier that is ready as it is with minor/easy moderations when referring to truck-to-ship bunkering.

5 TASK 3 – PORT READINESS LEVEL

The objective of this task is to assess the current level of port readiness in the Port of Oslo regarding bunkering Liquified Hydrogen to calling vessels.

5.1 Port Readiness Level for Marine Fuels

The framework "Port Readiness Level for Marine Fuels (PRL-MF)" is jointly developed by the World Port Climate Action Programme (WPCAP), and the International Association of Ports and Harbors (IAPH) [23]. It is a self-assessment tool used to identify a port's current ability to bunker vessels, as outlined in Table 5-1. The framework can be scoped for a specific fuel and has in this case been used to assess Port of Oslo's level of readiness for liquid hydrogen.

Table 5-1: Outline of Port Readiness Level for Marine Fuels [23].

		Bunkering of target fuel
PRL-MF 9	Deployment	Market penetration and growth for bunkering of target fuel
PRL-MF 8		Full capabilities for bunkering of target fuel
PRL-MF 7		Bunkering of target fuel established on a project basis
PRL-MF 6	Development	Pilot-scale demonstration of bunkering of target fuel
PRL-MF 5		Framework for bunkering of target fuel implemented and tested
PRL-MF 4		Framework for bunkering of target fuel drafted, timeline developed
PRL-MF 3	Research	Detailed research, analysis, and conclusions
PRL-MF 2		Stakeholder interest and feasibility assessment
PRL-MF 1		Foundational background information

The framework starts at Level 1, which includes a stakeholder analysis to determine the relevance of the chosen fuel and an internal study in the port to assess the ability and interest in the bunkering fuel. The initial work in this pilot has followed the framework of the Green Shipping Programme, with identification of work tasks and conducting workshops to complete the tasks. The framework from Green Shipping Program builds on dialog between the involved stakeholders and incorporates studies of barriers, roadmaps and general analytic work, and through the pilot study providing input for the possibility of scaling the investigated subject. The Port Readiness Level framework has been utilized in Task 3 of this pilot and the checklist for level 1 was incorporated in the task work.

5.2 PRL-MF 1 domains

Level 1 consist of four domains, with the objective to gather pertinent background information as foundation for research of the requirements regarding bunkering of the target fuel.

5.2.1 Domain: Governance

The current and upcoming regulations and incentives regarding shipping decarbonization and alternative fuels have been investigated prior to and during the pilot period. International regulations and incentives from the IMO and EU have been researched and taken into consideration regarding the ongoing paradigm shift in the maritime sector. The research indicates that the upcoming regulations will push the transition of fuels used in the maritime sector towards alternative fuels and a higher amount of sustainability in the fleet. In addition, national and regional incentives have been researched, including port incentives for zero-emission ships berthing in the port. The research indicated possibilities to alter the current port fee scheme, in order to the aid the transition.

The maturity of the target fuel has also been researched, and although the current network of production, distribution, and bunkering capabilities is considered underdeveloped, there is a strong commitment from the identified stakeholders in the supply chain to establish a robust supply of the target fuel for the pilot.

The stakeholders relevant for port operations and industry development have been identified prior to the pilot startup and have all been invited to participate in the pilot tasks. During the pilot period, additional stakeholders have been identified regarding the regulatory frameworks influencing the proposed bunkering solution.

5.2.2 Domain: Safety

The requirements to serve as a port to bunker the target fuel have been identified, including the national/international safety regulations. As the target fuel is novel in the maritime sector, the only bunkering operator currently conducting operations was contacted and through the bunkering tower construction company, LH_2 Shipping, valuable information was gathered. In addition, the pilot participants GreenH, Norwegian Hydrogen and Statkraft provided detailed analysis of bunkering procedures, safety zones, and implications for surrounding port activities.

Regulatory bodies were identified and contacted regarding the pilot's proposed bunkering solution, but at this early stage only general advice could be obtained. It was informed that for the pilot project to receive specific safety considerations, the project must be at a more mature stage and the details of the bunkering procedure and bunkering transfer flow should be established.

5.2.3 Domain: Infrastructure

The research regarding infrastructure was highly focused on practical solutions already in place and operational. According to the procedures of Norled's MF Hydra, an infrastructure consisting of a bunkering tower with coupled tanker trucks was investigated.

The port infrastructure surrounding the proposed bunkering sites was investigated during multiple inspections and the port operations were considered. It was a strong preference from the pilot participant and vessel owner Samskip that the vessels should be able to load and unload their cargo simultaneously with the bunkering operation. The infrastructure of the container quay at Sjursøya was therefore in focus and no other locations in the port were considered.

5.2.4 Domain: Market, supply/demand

The basic commercial potential of the target fuel has been assessed, as well as the potential for the port to become a bunker port. As the target fuel is in a novel phase, the results are highly uncertain in the long term, but the current demand is well known, as Samskip has declared a need for 15 tonnes of liquid hydrogen weekly per vessel in order to sail with zero emissions. The supply side is more uncertain regarding local/national production, but there is a possibility to secure funding for production plants from either national or EU programmes. The sector is, however, in a development phase and, as mentioned in section 5.2.1, the maturity of the distribution network is expected to develop fast and in time for the start-up phase of Samskip's vessels.

5.3 Assessment of port readiness level

The initial 3 port readiness levels consist of research-based activities, and the Port of Oslo is assessed to be at level 1 after completing this work, well on the way to ascend to level 2 with the ongoing work in this pilot study. Future studies will enable the Port of Oslo the rise to higher levels, with more detailed research analysis and conclusions on the feasibility of hydrogen bunkering, specifically QRA and commercial factors.

A timeline for future work, see Figure 6-1, displays the projected level in Q3 2025. Dark blue is current completion status and light blues is planned work. No further work for higher levels is scheduled but awaits the decisions regarding liquified hydrogen bunkering in the Port of Oslo from Samskip.

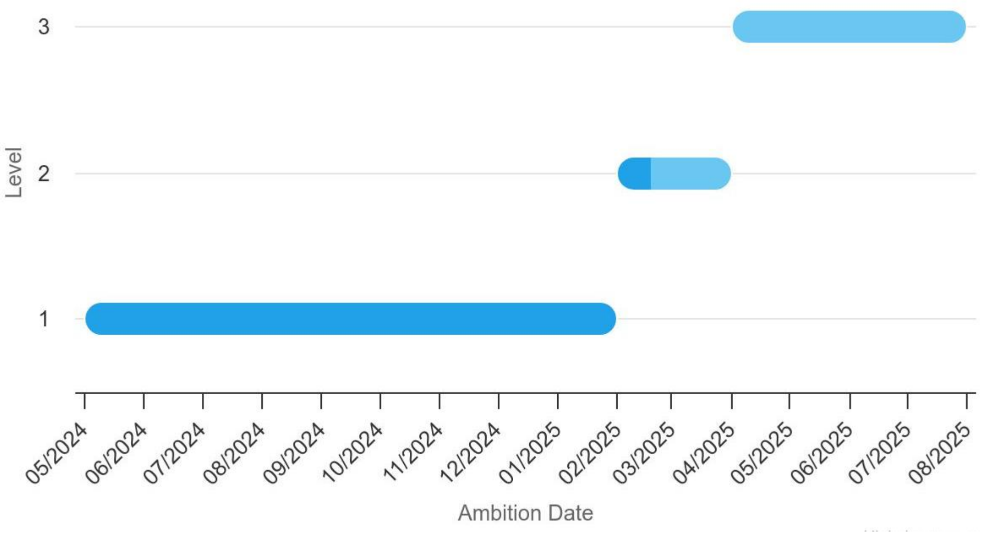


Figure 5-1: Progress of port readiness level for liquified hydrogen in the Port of Oslo.

6 CONCLUSION AND WAY FORWARD

The key learnings from this pilot study include identifying essential stakeholders such as hydrogen suppliers, bunkering operators, and regulatory bodies. Various bunkering concepts were explored, with truck-to-ship being the most mature option currently, while ship-to-ship is assessed as the optimal long-term solution as demand increases. Critical barriers and the requirements to overcome them were identified. Implementing hydrogen bunkering in a container port highlighted the complexity of regulations and stakeholder processes, as well as the challenges of simultaneous operations (SIMOPs) involving container handling, onshore logistics, and bunkering.

The Port of Oslo aims to become the world's most environmentally friendly city-close port. To do this, the port wants to receive ships using zero-emission fuels, as this is needed to achieve the goal of 85% reduction in CO_2 emissions.

The future work consists of reaching port readiness level 3 for liquified hydrogen and continuing to develop the pilot project in collaboration with relevant stakeholders (Figure 6-1). The safety work is expected to be processed in the first half of 2025, and additional research regarding the simultaneous operations is being conducted as well.

It is proposed to invite the Oslofjord collaborating ports into the work for knowledge sharing and establishment of a future network design for alternative fuels bunkering.

7 References

[1] DNV, “Fuel Transition Roadmap for Nordic Shipping,” 2024.

[2] “Offshore Energy,” 2023. [Online]. Available: https://www.offshore-energy.biz/samskips-new-hydrogen-fueled-vessels-to-feature-abbs-propulsion-system/.

[3] University of Cambridge, NCAS, University of Reading, “Atmospheric implications of increased Hydrogen use,” 2022.

[4] Maria Sand, Ragnhild Bieltvedt Skeie, Marit Sandstad, Srinath Krishnan, Gunnar Myhre, Hannah Bryant, Richard Derwent, Didier Hauglustaine, Fabien Paulot, Michael Prather, David Stevenson, “A multi-model assessment of the Global Warming Potential of hydrogen,” Communications earth & environment, 2023.

[5] IMO CCC10, September 2024. [Online]. Available: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/ccc-10th-session.aspx.

[6] MTF, “Guidelines for the development of liquefied hydrogen bunkering systems and procedures,” Maritime Technologies Forum, 2024.

[7] DSB, “The Norwegian Directorate for Civil Protection (DSB),” 2024. [Online]. Available: https://www.dsb.no/menyartikler/om-dsb/about-dsb/.

[8] MTF, “Safety considerations for establishing green shipping corridors. Maritime Technologies Forum (MTF) March 2024.,” 2024.

[9] SGMF, FP01-01 Reccomendation of Controlled Zones during LNG bunkering, 2018.

[10] DSB, “Sikkerhet rundt anlegg som håndterer brannfarlige, reaksjonsfarlige, trykksatte og eksplosjonsfarlige stoffer,” 2012.

[11] DNV, “External Safety Study - bunkering of alternative marine fuel for seagoing vessels,” 2021.

[12] Vysus, “Retningslinjer for kvantitative risikovurderinger for anlegg som håndterer farlige stoff,” DSB, 2021.

[13] DNV, Maritime Forecast to 2050 - Energy Transition Outlook, 2023.

[14] EMSA, “Guidance on LNG Bunkering to Port Authorities and Administrations,” 2018.

[15] MarHySafe, “Handbook for hydrogen-fueled vessels,” 2021.

[16] Ballard, “Norled's MF Hydra achieves significant operational milestones,” September 2024. [Online]. Available: https://blog.ballard.com/marine/norled-hydra-operational-milestones-ballard-fcwave.

[17] M. Page, “LNG Bunkering: An Overview of the Growing Industry,” October 2024. [Online]. Available: https://maritimepage.com/lng-bunkering/.

[18] L. Decker, “Liquid Hydrogen Distribution Technology,” Hyper Closing Seminar, 2019.

[19] Konstantin I. Matveev, Jacob W. Leachman, “Modeling of Liquid Hydrogen Tank Cooled with Para-Orthohydrogen Conversion,” Hydrogen Energy Technologies, 2023.

[20] IAPH, “LNG Bunker Checklist - Truck to Ship,” International Association of Ports and Harbors, 2015.

[21] SOFREGAZ, “Project: Multi-Trucks to Shp LNG Transfer,” March 2019. [Online]. Available: https://sofregaz.fr/projects-archive/multi-trucks-to-ship-lng-transfer/.

[22] LNG Journal, “Spain's Repsol successfully completes first multi truck-to-ship LNG bunkering operation at port of Malaga,” 2023. [Online]. Available: https://lngjournal.com/index.php/latest-news-mainmenu-47/item/109867-spain-s-repsol-successfully-completes-first-multi-truck-to-ship-lng-bunkering-operation-at-port-of-malaga.

[23] WPCAP, “Port Readiness Level For Marine Fuels (PRL-MF) - Assessment tool for bunkering ports,” 2024. [Online]. Available: https://sustainableworldports.org/wp-content/uploads/Port-Readiness-Level-for-Marine-Fuels-assessment-tool-July-2024.pdf.

[24] EMSA, DNV, “Mapping Safety risk for hydrogen-fuelled ships,” EMSA, 2024.

Appendix A – Inspection of potential hydrogen bunkering locations in the Port of Oslo

Inspection of potential hydrogen bunkering locations in the Port of Oslo

Friday June 21 2024, the Port of Oslo, DNV, Norwegian Hydrogen, and Yilport inspected two potential locations for bunkering of hydrogen, Location A and Location B.

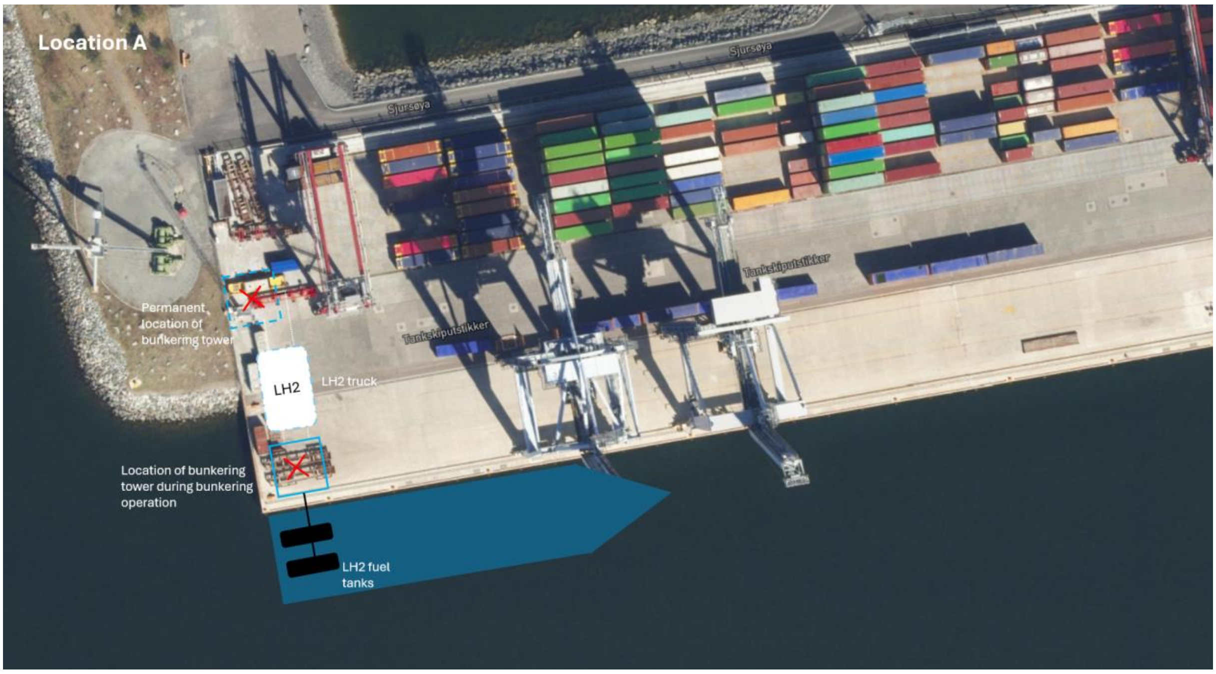
Location A

The dock area has concrete base and is today used for storing semi-trailers and various equipment. The area is located on the western part of the container terminal. The area is adjacent to the rest of the terminal without fencing or other limiting conditions. The area is approximately 40 meters in width and 50 meters in length.

- **South:** the area borders to rails where the rail mounted gantry crane operates.
- **West:** the area borders to a fenced buffer area with grass and then the water.
- **East:** the area borders to the container terminal's apron, containing containers and rubber-mounted gantry cranes.
- **North:** the area borders to a fenced area for other harbour activities.

Access to the potential bunkering area is from the east side via the main entrance to the container port. A secondary entrance is proposed from the north, minimizing tanker vehicle movements in the terminal area. The proposed location assumes that the ships dock at the west end of the quay.

Note: A wish from Yilport is that the bunkering operation should not have an impact on the port operations.



Discussion:

- For this case, the ships need to dock pointing east (aft in the west). The ships will then require help from tugboats when leaving port during specific wind directions.

- The area is mainly used for container operations. The bunkering operation can impact the port operations, as the area needs to be designated to bunkering during bunkering operations. A further analysis of required area for port operations must be carried out.
- The rails for the crane go alongside the dock and has an electric cable following the rails – this is a potential ignition source.
    - There is a possibility to move the rails (including the electric cable) away from the bunkering area, but this will decrease the operation area for the crane.

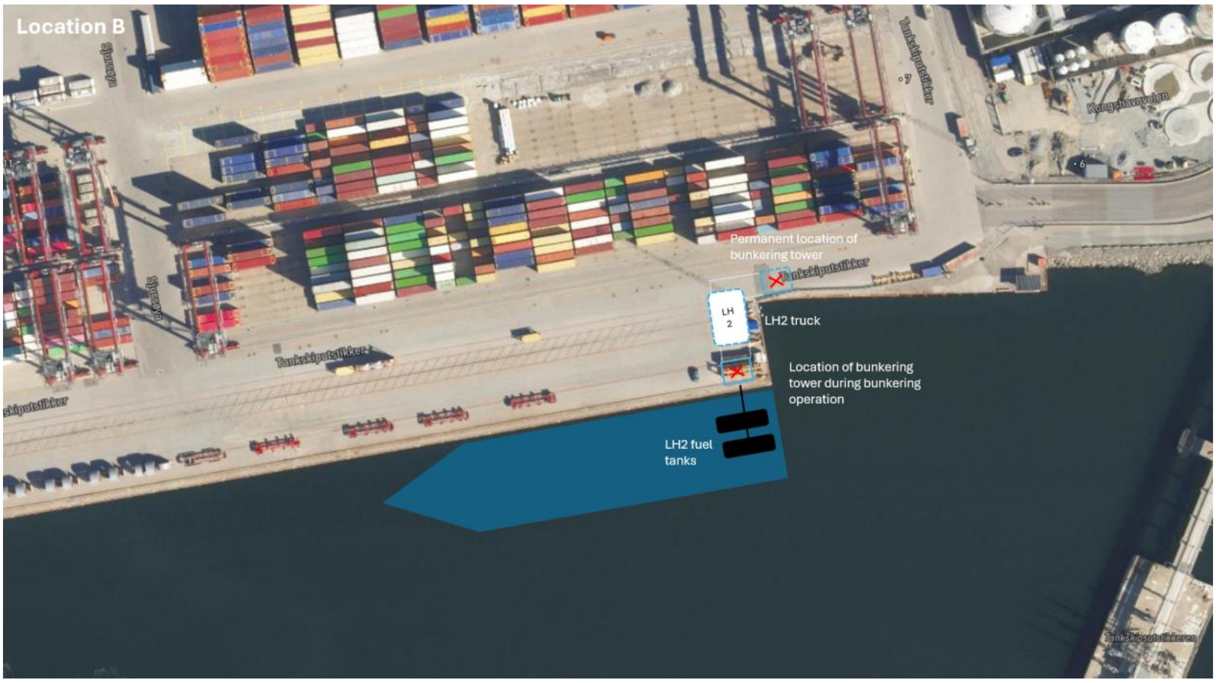
Location B

Location B is on the eastern side of the docking area, in close vicinity to Yilport's operational area, and has a concrete base. The area is closely connected to the rest of the port without any physical restriction. The area is about 45 meter wide, and 27 meter long.

- **South:** the area borders to the water.
- **East:** the area borders to the water and a docking area for oil tankers.
- **West:** the area borders to the container terminal, e.g., where the rail-mounted gantry crane operates.
- **North:** The area borders to the area where terminal tractors and top-loaded container handlers operate.

The access to this area is from the north side trough the main entrance. The vessels need to dock at the east end of the quay, and the bunkering needs to happen in the immediate vicinity. The area borders to the operational area for off- and onloading of containers to and from temporary storage.

Note: A wish from Yilport is that the bunkering operation should not have an impact on the port operations.



Discussion:

- Close to many simultaneous operations.
- Only about 140 meters to the oil terminal (bottom right corner in the picture above)
    - Busy terminal, hard to plan for when ships are docking.

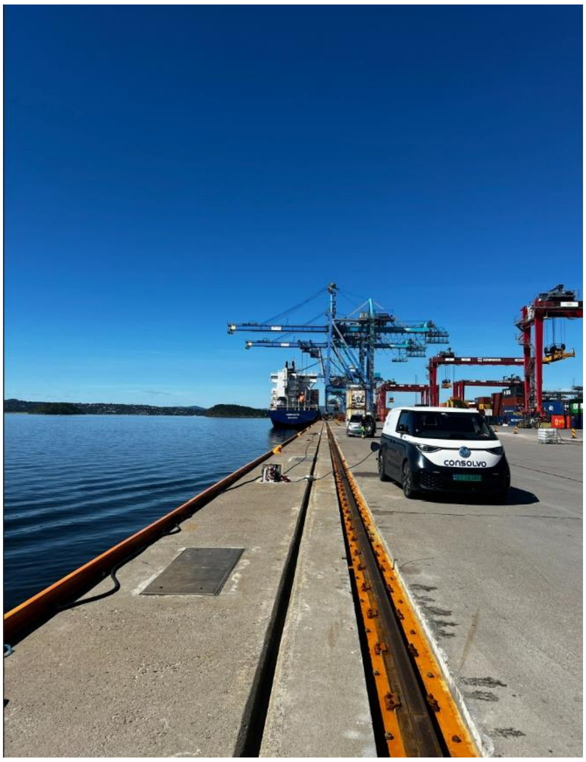
- Shore power connection point is being installed close to the potential bunkering area in Q1 2025.
- Planned CO_2-tanks to the north of the location.
- Several potential ignition sources nearby due to the many simultaneous operations.

Summary

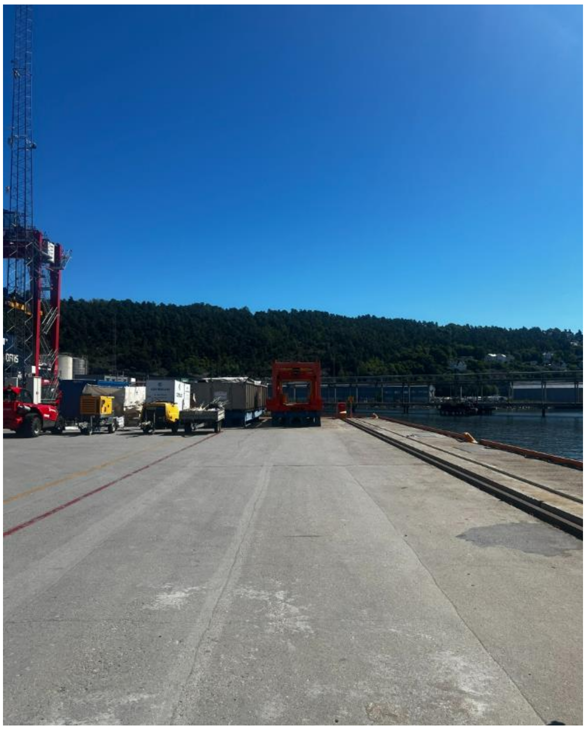
DNV emphasized the importance of safety in the choice of location. In their view, the best location from a safety perspective is Location A, as it is placed away from the busiest areas of the port. Norwegian Hydrogen pointed out that in their view, the best location from an operational perspective is Location B. The next steps will be to identify the bunkering concept in more detail, including duration of bunkering operation (flow rates), and control zones.

Additional photos from the inspection

This section presents some photos taken during the inspection, to give an impression of the activities at the docking area.



From Location B



Location B – with the oil terminal in the background

High voltage cable along the dock (both locations)


Crane rails, from location A


Location A (including the crane)

Appendix B – Safety checklist concerning the port in a green shipping corridor

The Maritime Technologies Forum has written a report highlighting the safety concerns and considerations for the operation of ships using alternative fuels in green corridors. In this report, they presented several recommendations in the form of a checklist for the adoption of alternative fuels when establishing green corridors, relevant for both ship owners and port authorities. The below list presents the recommendations relevant for the port authorities, extracted from *"Safety Considerations for Establishing Green Shipping Corridor" – March 2024, MTF.*

Port-specific considerations:

9. Port Bylaws and local regulations are updated to accommodate vessels with alternative fuels.

10. Restrictions and limitations on bunkering (pressure, flow rate, hose diameter), weather, or local traffic are identified.

11. Emergency personnel on land are trained and familiar with the relevant fuel.

12. Port bunker crew are trained for responding to and limiting potential releases.

13. Bunker crew have available suitable PPE for handling, responding, and escaping from a release of fuel.

14. A designated escape plan is developed, and safe havens established if identified necessary.

Collaborative considerations:

15. Tabletop exercise conducted between ship owner and port to identify and understand potential hazards.

16. Ship's crew and bunker personnel are invited in the tabletop exercise to familiarize them with the fuel and bunker system and related hazards.

17. Safety zones and control measures for bunkering is analysed and specified.

18. Specific emergency plans are developed and agreed for when vessel is in port.

19. SIMOP review is conducted to analyse acceptable simultaneous port activities.

20. Safety critical task analysis (SCTA) and working environment health risk assessment (WEHRA) is performed.

Technical considerations:

21. Sensors for lead detection installed in port, e.g., gas detection, thermal camera, or ultrasonic monitors.

22. Bunker hoses, fixed piping, valves, and manifolds are certified for relevant fuel.

23. The bunker system is equipped with a safety break away dry-disconnect coupling.

24. The ship shore link (SSL) and emergency shutdown (ESD) communication is compatible between port and ship.