Hydrogen Refuelling Solutions for the H2 Barge 1 and FPS Waal

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Figure 1. *H2 Barge 1 (formerly the FPS Maas) sailing on Green H2.*

Abstract

The paper discusses the key lessons learned from designing and operating the hydrogen fuel system for the H2 Barge 1 (formerly FPS Maas) and the FPS Waal. This includes the challenges of operating hydrogen-powered vessels, such as the limited availability of refuelling infrastructure, and the need for close collaboration between vessel owners, regulators, and hydrogen infrastructure providers. This paper then explores the novel set of operations conducted by the crew of H2 container refuelling and the design considerations to ensure that the safety of the system is independent of operations. It also discusses the future outlook for inland vessels, and identifies two promising types of hydrogen storage: Type IV gaseous hydrogen containers and liquid hydrogen tanks. Type IV containers offer two key advantages over Type II storage: lower tank weight and higher storage capacity. This allows for the design of zero-emission inland vessels that can travel much longer distances on a single refuel without compromising additional cargo hold space.

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1. Selecting appropriate infrastructure

The use of hydrogen as a fuel in the inland shipping industry has the potential to decarbonize a significant part of the sector. Hydrogen is, however, still largely in its infancy. As a result, many key components in hydrogen storage and refueling solutions for novel hydrogen powered vessels such as the H2 Barge 1 (previously known as FPS Maas) and FPS Waal are not readily available in the market. In order to determine the most appropriate form of hydrogen storage for the FPS Maas and FPS Waal, factors such as the availability of refuelling infrastructure along operational routes, technological readiness, and green H2 molecule supply were considered.

Hydrogen refuelling infrastructure was the most significant factor to consider when determining the refuelling solution for the H2 Barge 1 and FPS Waal. This was because refuelling infrastructure could not be 'designed' out of the vessel. In the context of the H2 Barge 1 and FPS Waal, we define refuelling as the combination of hydrogen storage and filling of hydrogen into the storage solution. The most common forms of refuelling for traditional diesel inland vessels is shore-to-ship or ship-to-ship refuelling. Neither form of refuelling exists commercially at the capacity required for hydrogen powered inland vessels (ie. >= 1000 kg H2 filling capacity), thus the solution employed onboard the H2 Barge 1 and FPS Waal would have to be a novel one.

Hydrogen storage technologies are evolving rapidly and hydrogen vessel retrofits should consider the possibility of including future-readiness into the design of the vessel power system. The most cost effective route for this is to opt for a standalone hydrogen storage system that can be easily replaced with one of a higher capacity in the future without further hull modification. Containerized hydrogen storage overcomes this issue by allowing for flexibility in refuelling and the placement of the containers in the cargo hold of the vessel without additional hull modifications (see below).

Inland containers vessels are on average filled to 80 – 85% capacity. This means that up to 15 % of the cargo hold space can be occupied by the fuel cell and hydrogen container without adversely impacting cargo carrying capacity during operations. The fuel cell system and hydrogen storage containers onboard the FPS Maas will occupy 8 TEU spaces in total. Each Type II hydrogen container on the H2 Barge 1 can carry roughly 500kg of usable hydrogen, allowing for up to 1000 kg of usable hydrogen to be stored onboard the vessel. Additionally, storing hydrogen in the open-air cargo hold of the vessel provides improved safety performance in case of a hydrogen leak, as the hydrogen gas quickly ventilates into the atmosphere without a major build up within the hull. Taking all the factors described above, FPS determined that containerized hydrogen storage (Type II) would be the most suitable storage solution for the H2 Barge 1 and FPS Waal.

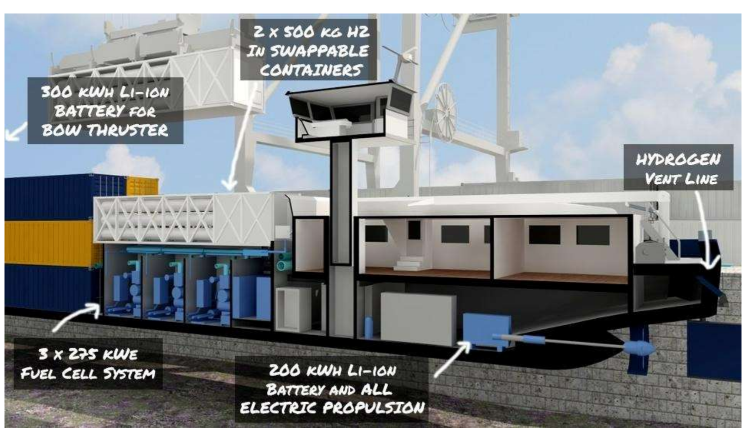

Figure 2 : Side cutaway illustration of H2 Barge 1 Hydrogen system

2. Containerized Hydrogen Storage in use

The H2 Barge 1 employs containerized Type 2 hydrogen storage when operations using the hydrogen propulsion system commence. FPS Waal will employ an identical system. The hydrogen containers are made up of several Type II hydrogen cylinders that will hold compressed gaseous hydrogen at 300 bar. For an extensive explanation of what a Type II hydrogen pressure vessel is please consult the plethora of extensive researched and well-written resources and articles on this topic that have been published.[4][5][6][7]

Once empty, these containers will be swapped when 'refueling' with filled containers placed onboard. The empty containers are passed on to our H2 container provider, who will handle the filling and transport of these containers to and from the designated swapping locations. Figure 3 illustrates the hydrogen container onboard the FPS Maas with 2 swappable hydrogen containers.

Figure 3 : Containerized Hydrogen Storage for the FPS Maas

The PEM fuel cell systems installed onboard the H2 Barge 1 operate at significantly lower pressures than the H2 stored in the containers. The H2 containers contain pressure reduction systems that reduce the pressure from 300 bar in the pressure vessels and release hydrogen into the fuel supply systems at 10 bar. This pressure reduction systems uses only pneumatic controls and do not contain any electrical control systems, thereby reducing the likelihood of potential failures. In case of a system failure or emergency where venting of hydrogen is required, all venting is performed in a controlled manner using a venting line present onboard the H2 Barge 1. The H2 containers themselves do not have pressure relief valves.

3. Why containerized storage?

3.1 Flexibility of refuelling

As discussed above, hydrogen fueling and refueling infrastructure is currently limited. Swappable hydrogen storage containers allow the vessel operator to 'refuel' the vessel by swapping out empty containers for filled containers at any terminal that is certified to handle dangerous goods alongside regular loading and unloading operations. Similarly, the operating range of the vessel can be altered by increasing or reducing the number of hydrogen containers placed on board the vessel allowing for operations in different locations that the power capacity of the fuel cell allows. These factors enable a level of flexibility in operations that otherwise would not be possible given the current infrastructure.

3.2 Reduced on-board modifications

Additionally, containerized hydrogen storage allows for the placement of the containers in the cargo hold without the need for further significant modifications to the hull of the ship. In hull hydrogen storage solutions such as a liquid hydrogen fuel tank or a compressed hydrogen tank would require additional hull modification to shield and insulate the storage unit where the diesel tank previously stood. Containerized storage in the cargo hold allows for the rapid adoption of higher capacity containerized storage in the future as the storage container can easily be replaced without any additional modifications to the hull.

Type II hydrogen containers were identified as a candidate for the H2 Barge 1 and FPS Waal as they were technologically ready for deployment and commercially available for purchase. As shown in Figure 2, Type II hydrogen containers are stored in the cargo hold of the vessel above the hydrogen fuel cells. Here, three other factors; physical footprint, safety, and carrying capacity, become important.

4. Refuelling Operations

Refuelling operations for traditional inland vessels are standard and well known in the industry. However, one of the key lessons learnt from our experience on the H2 Barge 1 is that this is not the case for a hydrogen powered vessel. While tradition refuelling means using a hose type connection to fill the diesel tank on board, refuelling using a swappable hydrogen container system involves a significant number of actions carried out by the crew, and these may differ from one container supplier to another. Depending on the solution there will be a varying number of valves and hydrogen connections to be made and inspections to be carried out during every refuelling operation. Therefore, it is necessary to make the design safe enough so that its safety is independent of operations. The goal of this section is to provide an overview of these operations and design considerations that need to be taken into account when designing a H2 powered vessel and its fuel systems.

4.1 Loading and Unloading of hydrogen containers (At Port Terminal)

Refueling operations for the hydrogen systems onboard the H2 Barge 1 and the FPS Waal differ significantly from traditional diesel refueling. Here, the filling of diesel (MGO) is replaced by the swapping of empty H2 containers for filled ones. During this process several checks and operations need to be executed by the crew performing the swap.

Each container has eight pressure vessels and fifteen valves, of which twelve are manual and three are pneumatic. During an unloading all fifteen valves need to be closed before the pressure vessels are disconnected and visual and sound checks are performed to ensure no leakage is present. This ensures that the empty hydrogen container is ready for lifting and replacement with a filled container. Similarly, visual and sound checks are performed on the filled container to ensure that no leakage is present before the eight pressure vessels are connected and the valves are opened. In addition to the manual checks performed by the crew during loading and unloading operations, automated H2 and leakage sensors are constantly monitoring all hydrogen related systems and pipes.

4.2 Container inspections

As a further check on safety, a process has been put in place to ensure maintenance requirements of H2 containers is observed during the 15 years of their lifecycle. The process is in alignment with both land-based (transportation) and maritime (onboard operation) notifying/inspection authorities. In order to retain the required certification for use, annual checks must be performed to ensure the containers meet the required performance criteria. The H2 containers aboard H2 Barge 1 undergo six-monthly inspections by our H2 container suppliers. These inspections include a pressure check and leak testing conducted by a third party assessor and are witnessed by the relevant land and maritime notifying/inspection bodies.

Additionally, extensive inspections are carried out at 5-yearly intervals. During the five-yearly inspection, hydro tests of the pressure vessels, and checks for corrosion are carried out, under the observation of the relevant notifying/inspection bodies.

5. Refuelling for future vessels

5.1 Key lessons learned from the FPS Maas and the FPS Waal

In the process of setting up a refueling solution for the Maas and Waal, several key lessons were learnt that can guide the decision making processes for inland vessel owners looking to decarbonize through hydrogen propulsion technologies. These lessons are in the area of legislation, infrastructure, standardization, and hydrogen production.

Legislation on hydrogen propelled vessel design, operations, the use of hydrogen as fuel, hydrogen production, and refueling infrastructure are in very early stages of development. As a result, these regulations are often subject to change or are difficult to navigate as a clear policy framework has not been fully developed. Vessel owners looking to retrofit hydrogen propulsion should keep in mind that regulatory hurdles and approvals do take a significant amount of time and require working in close cooperation with authorities, and class for approvals.

Similarly, hydrogen infrastructure for production, distribution, and refueling are all limited in availability. Although several major projects are planned or underway to improve the situation, it remains a significant challenge for operating hydrogen propelled vessels in the short-term. These limitations become clear in the context of refueling as illustrated in [8]. Current refueling protocols dictate that the flow rate for gaseous hydrogen refueling cannot exceed 60 grams/second. Taking a 1 ton storage system as reference, this flow rate would mean that refueling would take roughly 4.6 – 5 hours, not including the time it takes to prepare (e.g. Inspection, connection, disconnection) the storage system to be filled. Scaling up such a system to service ten ships concurrently would require substantial investments in infrastructure, as this would require a ten ton station with multiple receptacles to allow for simultaneous filling.

The use of swappable containers is a workaround to avoid long periods of refueling using a shore-to-ship or ship-to-ship hydrogen refueling system. However, enabling the effective use of a swappable container system requires a logistics network to transport to and from filling stations to the vessels, thereby increasing the cost of filling. One way to reduce the overall cost of a pool of containers is to have a large pool of widely usable containers that can be optimized to a large fleet of ships (e.g. four ships share six containers). The key challenge here would be to reach a certain level of standardization of the connections, safety, support systems, container size, and onboard integration of hydrogen containers within the fleet to allow for wide usage of the containers. In summary, legislation and infrastructure for hydrogen refueling for a fleet of hydrogen propelled IWW vessels are limited and while temporary workarounds exists, optimally tackling these issues in the long term requires substantial investments in infrastructure and close collaboration between vessel owners, regulators, and hydrogen infrastructure providers.

5.2 Future outlook for inland vessels – fuel types and possibilities

Within the context of future zero emissions inland waterway vessels two key types of hydrogen storage are promising. Type IV gaseous hydrogen containers, liquid hydrogen tanks installed in the hull, or as a containerized solution.

Type IV hydrogen containers offer two key advantages over Type II storage: Lower tank weight, and higher storage capacity. One of the key limiting factors for maximizing the H2 storage capacity of standard ISO 40ft containers is the ton weight limit for cargo operations. Type IV containers would allow manufacturers to fit a greater number of tanks within a single 40ft container while simultaneously allowing each tank to hold more usable hydrogen. This allows for the design of ZE inland vessels that can travel much longer distances on a single 'refuel' without compromising additional cargo hold space.

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