D3.18 Evaluation report on Power Management System

Synergetics | Synergies for Green Transformation of Inland and Coastal Shipping

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Table of Contents

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List of Figures

List of Tables

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Executive Summary

This report presents the evaluation of the Power Management System (PMS) implemented on two hydrogen-powered inland container vessels, H2B1 and H2B2, operated by Future Proof Shipping. Both vessels were retrofitted from conventional diesel propulsion to fully electric systems powered by hydrogen fuel cells, with H2B1 serving as the testbed for the initial PMS version and H2B2 benefiting from its subsequent improvements.

The first version of the PMS, installed on H2B1, revealed several challenges in integrating fuel cells with battery systems in a maritime environment. These included limitations in control software, inefficient battery charging practices, and manual operation demands that affected energy efficiency and crew workload.

In response, a second version of the PMS was developed and deployed on H2B2. Key enhancements included improved battery charging logic, optimized state of charge (SoC) management, automated fuel cell shutdown and start-up procedures, and the ability to disable non-essential systems when idle. These updates significantly reduced energy consumption, improved temperature control, and extended fuel cell life.

Lessons from the operation of both vessels underscore the importance of peak shaving algorithms and predictive control to ensure efficient energy distribution between batteries and fuel cells. Planned future upgrades aim to enhance automation, reduce crew workload, and integrate predictive AI-based algorithms for more adaptive and anticipatory energy management.

This evaluation highlights the critical role of adaptive software, iterative system refinement, and operational feedback in pioneering clean propulsion technologies for inland shipping, supporting broader decarbonization goals in the maritime sector.

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1. | Introduction

1.1 Objective

The objective of this document is to describe the Power Management System (PMS) onboard the two Future Proof Shipping (FPS) owned inland container vessels. Both vessels are equipped with the same PMS but different versions of it, with the newer version being an improvement over the previous. Challenges and experience gained from the first version of the PMS will be discussed.

1.2 Vessels

Future Proof Shipping owns and operates two inland container barges, H2B1 (former MCS Maas) and H2B2 (former FPS Waal) running exclusively on hydrogen with a fully electrical propulsion system. The vessels were built as traditional inland barges with a diesel engine approximately thirty years ago and were later retrofitted by swapping the combustion engine drivetrain with electrical propulsion system. All the auxiliary systems that could be adapted to the new propulsion system were kept and are still in operation.

1.2.1 H2B1 specification

Table 1: H2B1 specification

Vessel			
ENI	2323207	Build Place	Begej Te Zrenjanin, Yugoslavia
Flag	Netherlands	Converted to ZE	May 2023
Build year	1997	Trading Area	Rhine between open sea and Basel, European inland water zones 3 & 4, Dutch inland water zone 2
Dimensions			
LOA	109.95 m	Max Draught	3.21 m
Beam	11.44 m	at 75% load	2.87 m
Min. Air Draught	7.0 m	at 50% load	2.23 m
Deadweight	3041 mt	at 25% load	1.62 m
Container capacity	192 TEU	at 0% load	0.89 m
Number & type of Holds	Single open hatchless hold	Barge	Vessel can sail with a pusher barge Please see separate specification sheet
Power & Propulsion			
Power	Hydrogen PEM Fuel Cells	Rudders	3 double free-hanging balance rudders
Battery capacity	500 kWh	Bow Thruster	360° Rooster type, 403kW, Van Tiem
Fuel Cell power	825 kW	Propulsion	Single propeller
Hydrogen equipment			
Hydrogen storage	2x 40ft units	Pressure of storage unit	300 Bar
Type	Compressed Hydrogen	Capacity of 1 unit	500 kg
Pressure vessel	Type 2, Steel	Total Capacity	1 000 kg
Crew & accomodation			
Crewing	A1, A2 and B Class certified	Cabins	6 cabins, 7 beds

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1.2.2 H2B2 specification

Table 2: H2B2 specification

Vessel			
ENI	02326484	Build Place	Santierul Naval Orsava, Romania
Flag	Netherlands	Converted to ZE	4Q '23
Build year	1993	Trading Area	Rhine between open sea and Basel, European inland water zones 3 & 4, Dutch inland water zone 2
Dimensions			
LOA	109.80 m	Max Draught	3.30 m
Beam	11.39 m	at 75% load	2.72 m
Min. Air Draught	6.30 m	at 50% load	2.12 m
Deadweight	2 766.40 mt	at 25% load	1.51 m
Container capacity	190 TEU	at 0% load	0.86 m
Number & type of Holds	Single open hatchless hold		
Power & Propulsion			
Power	Hydrogen PEM Fuel Cells	Rudders	Dual profile rudders, Van de Velde
Propulsion	Single Screw	Bow Thruster	1 x 4 channel / 360° rotation
Fuel Cell power	1 028 kW		
Hydrogen equipment			
Hydrogen storage	2x 40ft units	Pressure of storage unit	Type 2, 300 Bar
Type	Compressed Hydrogen	Capacity of 1 unit	500 kg
Internal canister material	Steel	Total Capacity	1 000 kg
Crew & accomodation			
Crewing	A1, A2 and B Class certified	Cabins	5 cabins, 8 beds

1.3 Power Management System

Vessels that run on hydrogen, can either utilize an internal combustion engine (ICE) that runs on hydrogen, or fuel cells (FC) that are devices transforming hydrogen to water while providing an electrical current/voltage differential. Both FPS vessels are utilizing the fuel cell technology and consequently are equipped with an electric motor as the main means of propulsion as well as an electric bow thruster as a manoeuvring and emergency means of propulsion. The PMS allows for precise and safe control of the operation and output of the fuel cells, the input of either motor, and all residual electrical systems.

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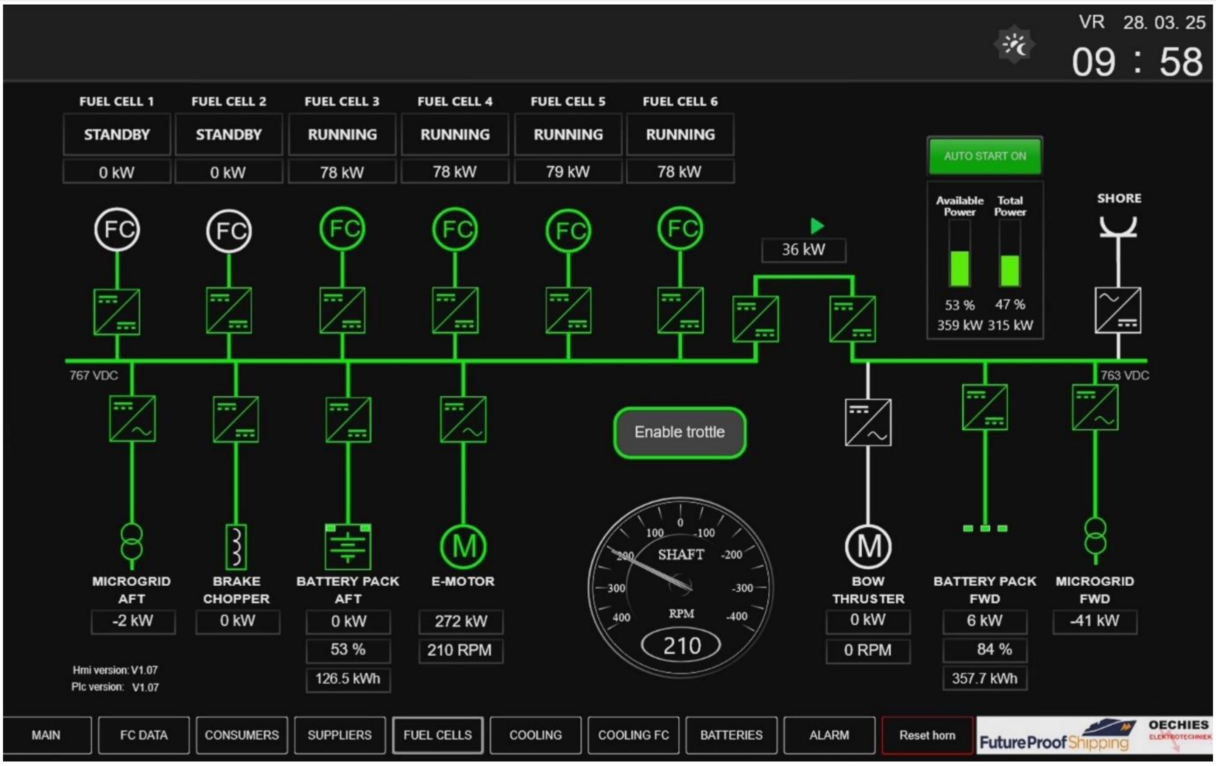
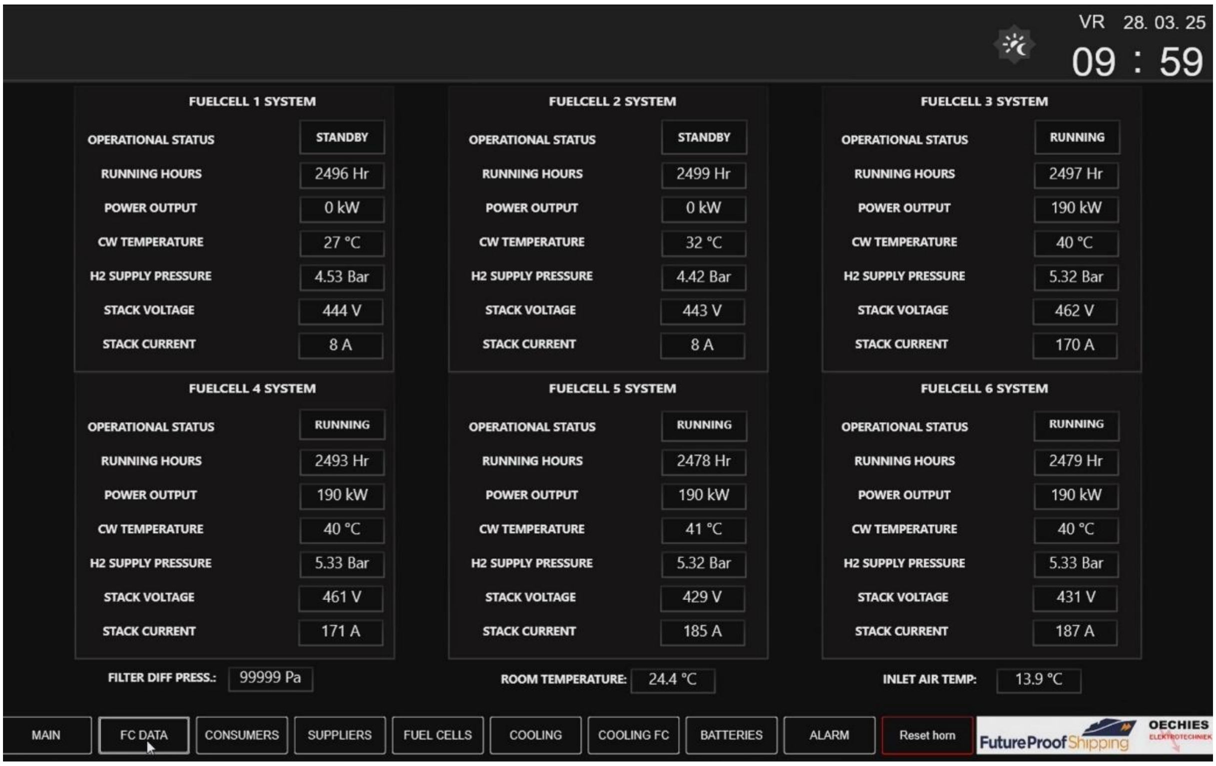


1 | Main page of the PMS human machine interface (HMI) onboard



2 | Fuel Cell page of the PMS HMI onboard

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1.4 Succession of two versions of the PMS

The PMS was developed by Oechies. The first version was installed on H2B1 which was the first FPS vessel to be retrofitted with a hydrogen system. After an operating and testing period of 4 months the experience gained from the first vessel led to the development of the second version of the that was installed on the second vessel that was retrofitted: H2B2.

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2. | Challenges with PMS v1

2.1 Challenge 1: PMS design

The retrofit of H2B1 from diesel to electrical propulsion using fuel cells is the first of its kind in the inland marine industry. The control software must be completely reshaped to balance the use of the batteries onboard together with the output of the fuel cells and to maintain similar ship control capability for the crew while optimizing the size of the battery packs and the number of fuel cells. Additionally, the PMS needs to comply with safety standards provided by the classification societies; in this case Lloyds Register.

2.2 Challenge 2: Continuous upgrade

During the commissioning and the first month of testing in operation, most of the control was kept to manual mode to gain experience in the system and assess what parts of control and the PMS can be safely automated. Moreover, the control software needs to continuously log data to provide a solid and consistent basis to improve the control ergonomics and the PMS efficiency.

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3. | Upgrades on v2

While FPS and Oechies are in constant communication and the PMS is continuously being updated there were two distinct versions of it.

3.1 Similarities between H2B1 and H2B2

The two hydrogen powered vessels, H2B1 and H2B2, are very similar in form, power, and size. They were retrofitted with hydrogen systems at different times, and even though Holland Shipyards managed the retrofit, the two vessels were installed with hydrogen systems provided by different manufacturers. The layout of the systems is very similar, something that aids in the use of the same PMS on both vessels. For example, H2B2 was fitted with six fuel cells, that were joined in groups of two, resulting in a virtual system of three fuel cells and providing the same layout of the PMS control screen.

The retrofit of H2B2 vessel benefitted from the lessons learned from the first retrofitting work on H2B1. For H2B2, the PMS was adapted to the different configuration with six fuel cells and with a better peak shaving[1] algorithm. Temperature control and power demands were updated and adapted to the different type of fuel cells. The improvement of the peak shaving algorithm and other transposable improvement were applied to H2B1 afterward.

3.2 Improvements over v1

Generally, the PMS was updated to better monitor and control the temperature of the batteries and to maintain their state of charge at the desired level. This was achieved by controlling the fuel cell power output when the batteries were over- or under-charged.

3.2.1 Disable foreship system

During the initial testing period, it was observed that there were several systems on stand-by in the foreship. When the vessel is moored or idle in general there is no need for these systems to be on stand-by (such as the bow thruster). So, one of the improvements was to de-activate these systems when the throttle was in the neutral position and the cooling water was <50°C. This change resulted in the consumption dropping from ~20kWe to ~10kWe.

3.2.2 Batteries charging current while throttle is deactivated

In the first version of the PMS the batteries were being charged at maximum current, something that resulted in higher fuel cell cooling water and battery temperatures, as well as a more frequent start-stop cycle of the fuel cells. In the new version of the PMS the batteries are being charged at 60 kW which is the minimum net available power produced by a fuel cell.

3.2.3 Batteries charging current while sailing

Similar to point 3.2.2, the batteries were being charged at maximum allowable current while the throttle was active. In the new PMS version, the batteries are being charged as follows, depending on their state of charge (SoC):

- SoC < 45 %: 200 kW
- 45 % < SoC < 55 %: linear power between 100-200 kW
- SoC > 55 %: 100 kW

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[1] Peak shaving is the process of storing or utilizing the excess power produced by the fuel cell, during powering up or shutting down.

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3.2.4 SoC limit on main batteries

The initial set-up of the system had the batteries being charged every time there was excess power on the system, something that usually happened during the shut-down procedure of a fuel cell. When the batteries were full, this excess power would be consumed by the brake chopper (a device that acts as a consumer, but with no useable work) and be wasted in the form of heat.

The updated PMS now keeps the main batteries at a stage of charge around 55 % providing enough capacity to absorb any excess power, and also enough power to feed the vessel during the powering-up procedure of a fuel cell. The 55 % SoC of the batteries is acting as a buffer for the few seconds that the fuel cells need to start up or shut down, or even in the case that a fuel cell takes longer to start up due to a fault.

3.2.5 Fuel cell shutdown

The fuel cell operational range is 100-300 kWe. To maintain the life and efficiency of the fuel cells, the PMS will shut them down when there is a demand of less than 100 kWe. During the shut off procedure the fuel cells do not immediately stop, but they ramp down gradually. During the shut down process the power generated needs to be absorbed by either the batteries -that are getting recharged- or the brake chopper. It is therefore important for the conservation of energy onboard to carefully monitor the state of charge (SoC) of the batteries and shut down the fuel cells when the batteries can still receive this extra energy. Usually, the fuel cells will shut down at the following scenarios:

Scenario 1

- 1 fuel cell operating,
- battery SoC>83 %,
- battery can absorb less than 69 kWe

Scenario 2

- 2 fuel cells operating,
- Battery pack SoC>80 %,
- batteries can absorb less than 135 kWe

Scenario 3

- 3 fuel cells operating,
- Battery pack SoC>75 %,
- batteries can absorb less than 210 kWe

3.2.6 Automatic charging of the batteries

To avoid the batteries falling to a very low voltage, the system was set up so that the fuel cells will automatically start up in order to charge the batteries when the state of charge was below 30 %. This is more common during the rest hours when the crew is not on duty but there is increased hotel load.

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4. | Future changes

4.1 Lessons learned

The combination of a battery system and multiple fuel cells represents a first-of-its-kind setup in vessel propulsion, resulting in several unexpected behaviors during testing and operation. Both the fuel cell control software and the overall PMS have been progressively refined based on these operational insights.

The efficiency of the peak shaving mechanism is proven to be essential to the durability of the fuel cell performance. The first iteration of the PMS was prioritizing the use of the battery to handle abrupt changes in the power demands, for example when the vessel was maneuvering, and the fuel cells were compensating the lack of response from the battery pack to match the propulsion power demand.

Start-up and shutdown sequences of the fuel cells were originally kept manual, i.e. the captain had to do it via the PMS screens, to allow for feedback on the different vessel use and response when sailing, compared to a traditional engine. One of the PMS improvements was to automatize this sequence in idle mode, for charging the battery, but warnings were still triggered to inform the crew that they should start or stop a fuel cell soon. However, the crew still must anticipate the use of fuel cells depending on what is coming up on the way when sailing. For example, when approaching a lock, at least one fuel cell is kept active to be able to maneuver while keeping an eye on the battery state of charge to not reach the maximum charge and hit an alarm level. This operation increases not only the workload of crew but make the specific training to the fuel cell system more difficult to integrate.

4.2 Planned upgrades

The battery’s capacity and charge range were selected in coordination with the fuel cells to strike a balance between optimal power management and cost-effective retrofitting. While this configuration cannot handle every power demand scenario, there is room for further refinement—particularly in the peak shaving algorithm.

The next planned upgrade aims to give higher priority to the battery when responding to changes in power demand. This will be achieved by intentionally delaying the fuel cells' response based on the number of active fuel cells, the current state of charge of the battery, and the actual power demand.

The robustness of the automatic start-up and shutdown sequences has been validated in idle mode. To further reduce the captain's workload related to fuel cell management, warnings for charging and discharging will only appear if a sequence fails and requires crew intervention. A similar automation approach will be explored for sailing mode, although the crew will still retain manual control over starting or stopping fuel cells during navigation.

4.3 Ideal functionality

In the current configuration of the FPS barges, the most significant challenge for the PMS is peak shaving—to ensure consistent fuel cell operation and extend the life of its components.

Ideally, the battery should be oversized in terms of charging capacity, enabling it to manage sudden power demand spikes. This would allow the fuel cells to ramp up smoothly without being forced to react abruptly. In practice, a battery capable of supplying half of the vessel’s nominal propulsion power would be sufficient to cover nearly all common maneuvering scenarios.

With sufficient operational data, the PMS could integrate a predictive algorithm to anticipate power demand and manage fuel cell output accordingly, leading to a more stable load profile. However, the effectiveness of such an algorithm depends on the sailing behavior of individual captains, so it must be adaptive. Implementing this type of system would require clean, consistent datasets from onboard sensors and could rely on AI-based analytics to improve accuracy over time.

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