GREENING THE DUTCH STATE FLEET

On 25 June 2019, the Dutch government and the maritime industry signed a Green Deal on Maritime and Inland Shipping and Ports. The agreement aims for measures to meet the climate objectives of the government fleet: 'twenty per cent reduction in carbon emissions by 2020, carbon neutral by 2030 and fully climate-neutral and climate-resilient by 2050'.

The first step is to launch at least one zero-emission seagoing vessel by 2030. To verify the feasibility of the objectives, the Ministry of Infrastructure and Water Management initiated various actions, including a study on the use of methanol and hydrogen as a source of energy for the design of a typical seagoing vessel. This study aimed to prove the feasibility of these technologies, leading to timely introduction on the first carbon neutral newbuilds.

Impact and goal of the project

The transition of shipping to alternative fuels, in particular methanol and hydrogen, will only materialise in ships if the technology pertaining to these fuels is proven safe and robust. A first step in proving these characteristics is to perform ship design and engineering studies with a focus on energy and propulsion systems on board, and to assess the safety and robustness of these systems. These studies are also needed to guide government policy and rule development.

In 2021, the Ministry of Infrastructure and Water Management proposed a specification of a study on greening the Dutch state fleet to DG REFORM. DG REFORM responded by launching a Request for Service under the "Multiple Framework Contract for the Support to Structural Reforms in EU Member States", for the provision of the following main deliverables:

- Basic customer requirements for a typical seagoing vessel of the government fleet.
- Two concept designs for the vessel, one for hydrogen and one for methanol.
- Two basic engineering packages, one for hydrogen and one for methanol.
- An action plan for promoting zero-emission vessels and achieving a carbon-neutral state shipping fleet.

The study was granted to a Dutch consortium led by the Netherlands Maritime Technology Foundation (NMTF). The consortium consisted of Maritime Research Institute Netherlands (MARIN), the ship design office C-Job, Bureau Veritas and the engineering company Marine Service Noord (MSN). The main aim of the study titled "Green shipping in the Dutch state fleet" was to provide the Dutch government with advice on setting specifications for the application of methanol and hydrogen technology on a seagoing vessel for the future Dutch state fleet. The results were also to guide the Dutch government in replicating and scaling the methanol and hydrogen technology to the full range of the Dutch state fleet replacement programme.

Initial vessel concepts

To assess the application of the two power, propulsion and energy (PPE) options, namely methanol and hydrogen, design studies were conducted up to the level of basic engineering. To obtain a first estimate of required power supply as well as volume and weight of the two PPE systems, an initial vessel concept for this project was determined. This concept was inspired by existing seagoing vessels of the Dutch state fleet, adjusted and complemented with current ideas about future missions and operations, and further based on educated guessing.

Assumed main particulars, propulsion arrangement and appendages of the initial vessel concept are stated in the following table.

Length	65 m
Breadth moulded	14 m
Design draught moulded	3.50 m
Displacement volume moulded	2390 m^3
Number and type of propulsors	2 thrusters
Propeller diameter	1.7 m

Table 1. Assumed dimensions and characteristics of the initial vessel concept.

As the focus of the study was on greening the ships in the Dutch state fleet, the requirements were determined on two levels. The first level was the overall ship design, and the second the configuration of the PPE systems. The requirements for the PPE level were formulated in terms of propulsion shaft power based on the prevailing conditions, the speed profile, the endurance and the auxiliary

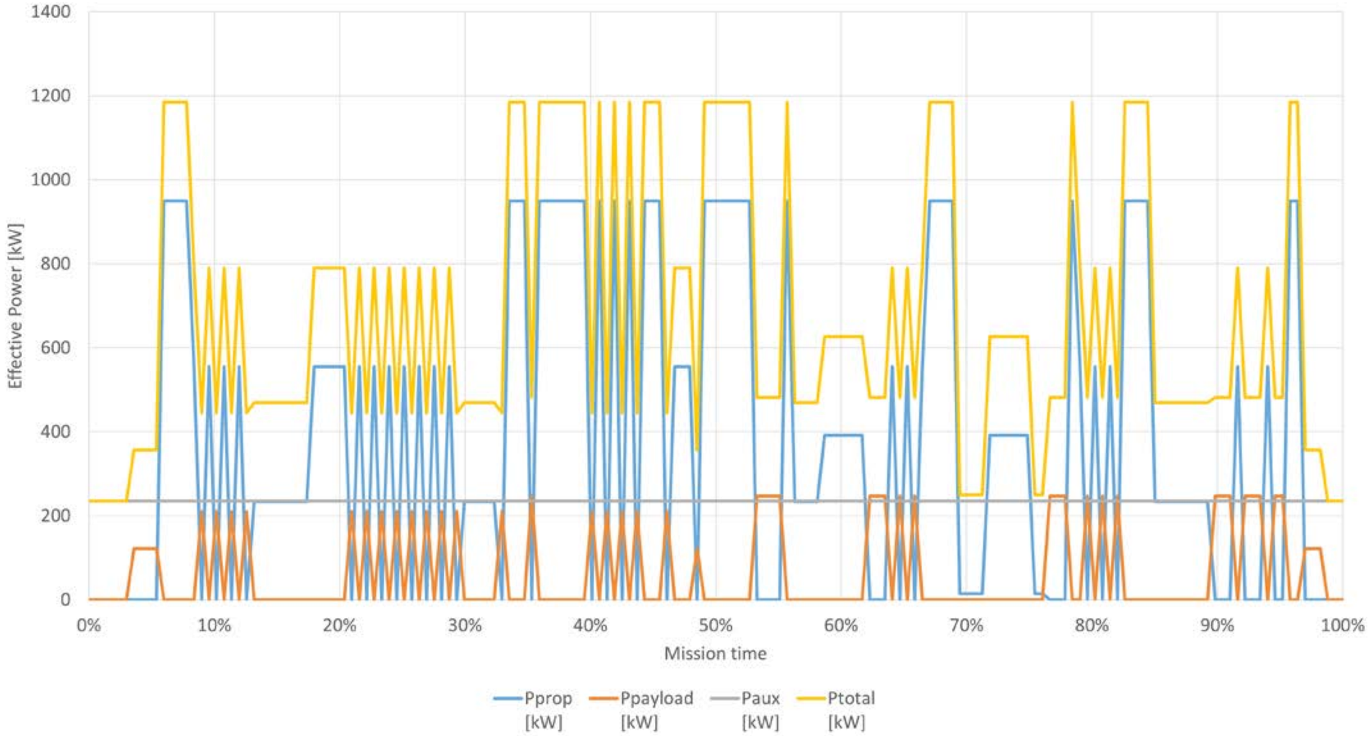

Figure 1. Power-time chart for scenario six days at sea, waterway marking and water quality survey.

power consumed by auxiliary services. These requirements were determined by MARIN using the Arcadia system analysis method. The Arcadia method for Exploration and Conceptual Design was applied using its associated software Capella.

The results should help the government in replicating and scaling methanol and hydrogen technology

Operational context

The operational analysis defined the operational context by identifying objectives and mission scenarios. These were analysed to identify actors, their activities, interactions, necessary operational capabilities and other requirements. This was done to capture the real needs of the stakeholders. The two core missions of the clients of the Rijksrederij (the government shipping company) for this particular ship are to maintain waterway markings and to perform ecological surveys. These missions include a time interval for independent operation at sea in the Netherlands' Exclusive Economic Zone between port calls. The initial mission portfolio included a fourteen-day mission. However, according to initial estimations, this would result in extremely large storage systems, at the cost of payload within limited hull dimensions. Therefore, the fourteen-day mission was converted into an eleven-day mission, including two days in port. This allowed for a more feasible ship concept.

Each mission scenario consisted of a series of events. Events are operational situations during which the operational conditions remain constant. That implicates that the load on the systems also remains constant, so the consumed power can be determined for the event. An event can occur in several mission scenarios and can occur multiple times. Examples of events for the analysis of power and energy requirements were: cruising at 10 knots in sea state 3, and cruising at 8 knots measuring water quality and manoeuvring in dynamic positioning condition to investigate the sea bottom.

The payload equipment was defined as the power consuming equipment of the systems that are directly used to perform the tasks in the missions. Together with the propulsion system and the ship's auxiliary power system, they determine the amount of consumed power that the power generating systems will have to supply. During an event, specific equipment is used, but not always on the estimated nominal power. This is expressed in a load factor, indicating the relative load on the system. With these load factors, the consumed power used by the payload systems during a specific event can be calculated.

Power-time charts

Once mission scenarios, events and load factors were specified, the power-time profiles for several situations were analysed and

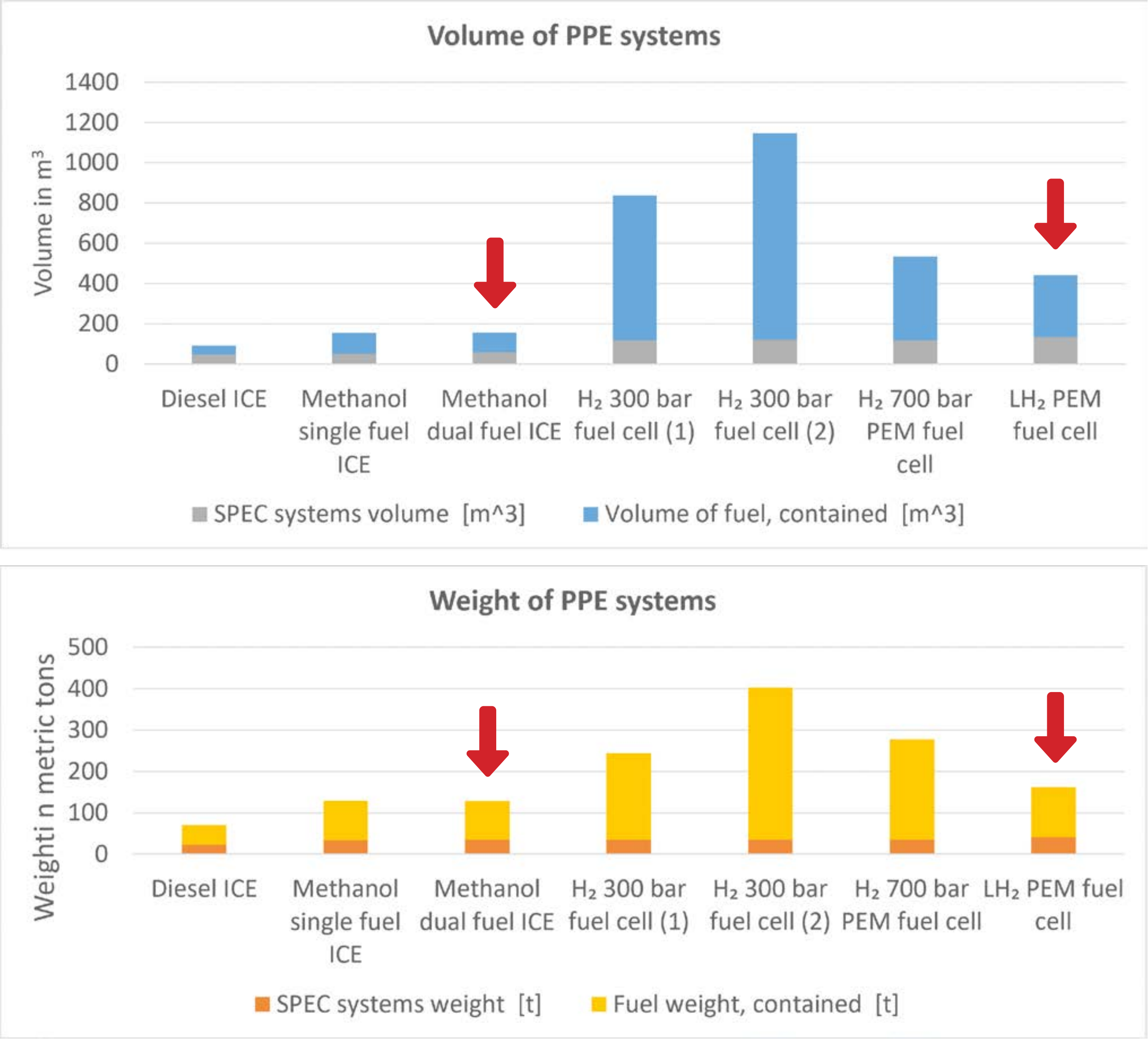

Figure 2. Volume and weight comparison of various PPE technologies.

visualised in power-time charts. A mission power-time chart (MPTC) shows the power consumption of a full mission with time steps of minutes up to one hour. It can be based on reference ships, interviews, AIS data, or a combination of these.

The power-time charts gave insight in the maximum and average power that is consumed by payload systems and propulsion during the mission. Integrated over time, it resulted in the amount of energy consumed. Furthermore, the power consumption pattern became visible. This gave information about peak loads and the potential use of peak shaving systems.

In the system analysis, the systems that have to perform the activities were defined. Further, the boundary around the PPE system was set and the external interfaces were defined. The transformation from the operational analysis to the system analysis was supported by Capella ensuring traceability of all requirements and specifications.

The maximum power is consumed when sailing at maximum cruising speed and is identical for all considered scenarios. The average power is also close at approximately fifty per cent of the maximum power, with exception of the eleven-day scenario to the Doggersbank, in which the average power is significantly lower, due to a high percentage of the time at slow speed and DP operations. Also, the effective total energy consumption per mission is very similar.

Preliminary PPE system design

In this project, the choice of the PPE technologies was pre-defined, since it is the project's objective to assess methanol and hydrogen technologies. Several alternatives were available for application of these technologies. In figure 2 the volume and weight of both PPE technologies are compared. This made it possible to select the most favourable solutions for the defined missions and to compare those with their alternatives. In the preliminary design, the focus was on weight and volume of the equipment and the contained energy storage. Of the seven solutions that were analysed, two technologies, indicated by red arrows in figure 2, are clearly favourable:

1. A compression ignited internal combustion engine (ICE), running on dual-fuel methanol/diesel. An advantage is its capability to run on diesel only, in situations where methanol is not available.
2. Polymer electrolyte membrane (PEM) fuel cell running on liquefied H_2. Although still substantial in volume, it has a smaller volume than compressed hydrogen alternatives.

Operational data from the current fleet is input for the design of new vessels

The first impression of the PPE based on the methanol ICE solution was that its requirements with regard to weight and volume can result in a feasible ship concept. Not surprisingly, the PPE based on the hydrogen fuel cell solution created a challenge with regard to weight and volume. This will result in a larger ship volume compared to the baseline concept, possibly necessitating a significant overrun of the current ship length requirement. These consequences were further explored and discussed in the next stage of the project.

Design requirements for the vessel

The design requirements for the vessel were derived from requirements for previous vessels and discussions with representatives of the Rijksrederij. Some of these requirements are conflicting, in which case the prevailing one was chosen by the representatives of the Rijksrederij. Where possible, ranges of parameters were provided to enable designers to achieve optimal designs. In this stage, Bureau Veritas set out the notations and applicable rules, as well as the requirements to obtain an approval in principle in the next phase.

The next phase: integration into the vessel design

In the previous phase of the project, the design requirements for the ship as well as the PPE systems for methanol and hydrogen were determined using a systems engineering methodology. In the second phase, the PPE system design as well as the hull and overall layout of the vessel were created. This is an iterative process, with multiple optimisation and validation cycles. Since this project focused on the PPE system, the number of cycles was limited to the minimum amount required to create a realistic, feasible hull design and layout. For this project, the Accelerated Concept Design (ACD) framework, developed by C-Job, was used. This framework was utilised to optimise the vessel with regard to power utilisation while maintaining the overall feasibility with regard to displacement and vessel stability.

Methanol design

According to expectations, it was possible to make a balanced design for the methanol PPE option within the set requirements. The feasibility of the proposed vessel concept based on methanol fuel was therewith confirmed. The presented design was taken as starting point for the next engineering phase where the main systems

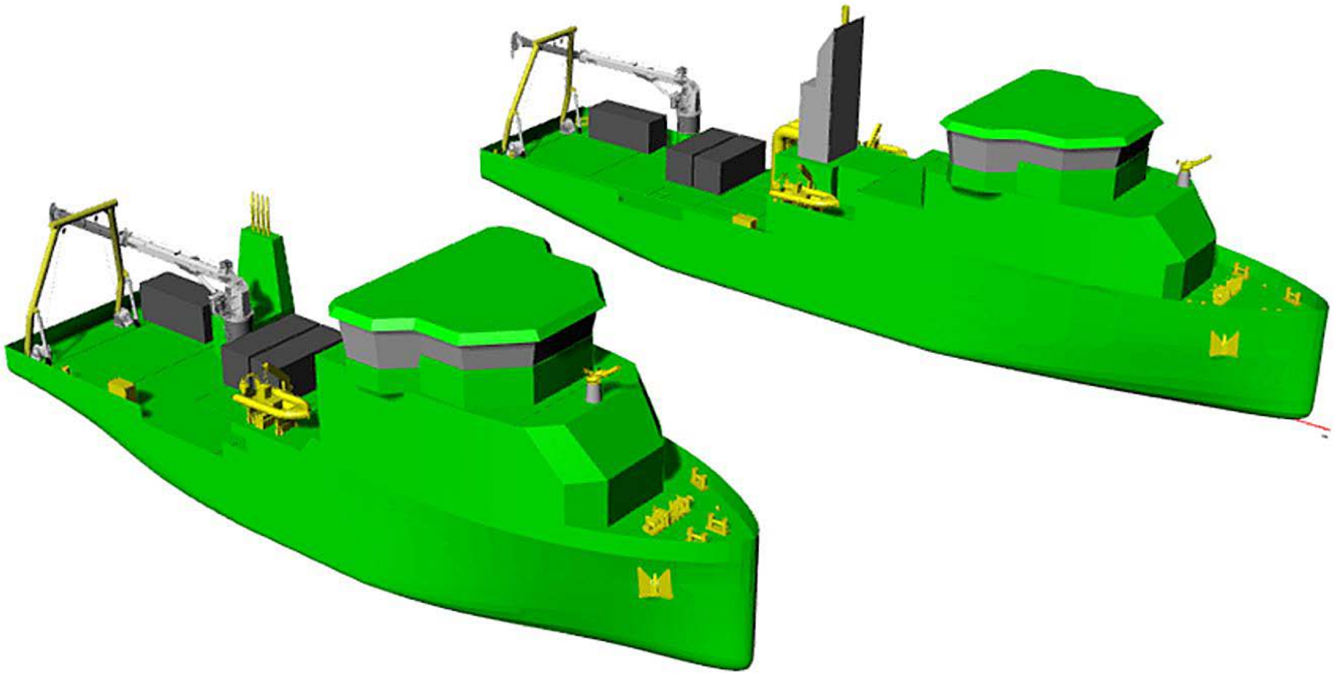

Figure 3. Impression of the methanol (left) and hydrogen (right) vessel designs.

and vessel structure were analysed in more detail on geometry/system level of detail. The impression of the vessel design is shown in figure 3. The main particulars are given in table 2.

Description	Quantity
Displacement bare hull @ design draught @ rho=1.025 t/m^3	1509 t
Length on the waterline	52.65 m
Width on the waterline	13.10 m
Design draught	3.20 m
Wetted surface area	820 m^2
Methanol tank volume total	92 m^3
Ballast water volume total	68 m^3

Table 2. Main particulars of the methanol ship design.

Hydrogen design

It proved to be impossible to achieve a balanced hydrogen powered design within the set requirements. Within the ship's maximum length requirement, insufficient space can be made available for the hydrogen tanks. From the fuel capacity evaluation, it was concluded that the design lacks roughly 45 per cent of energy storage capacity and, therefore, is not capable of executing all specified missions. The required fuel capacity can only be attained by altering the design to such extent that other core design requirements would be violated.

> It was possible to make a balanced design for the methanol PPE option

The impression of the vessel design is shown in figure 3. The main particulars are given in table 3.

Description	Quantity
Displacement bare hull @ design draught @ rho=1.025 t/m^3	2004.7 t
Length on the waterline	65.00 m
Width on the waterline	12.90 m
Design draught	3.0 m
Wetted surface area	1044.14 m^2
Hydrogen tank volume	170 m^3
Ballast water volume total	450 m^3

Table 3. Main particulars of the hydrogen ship design.

Detailed design

In the third phase, two distinctive detailed designs were made, one for methanol and one for hydrogen, with sufficient engineering detail to enable an approval in principle (AiP) assessment. The results of the detailed designs were utilised for an AiP review by Bureau Veritas. The AiPs that were issued by Bureau Veritas include a preliminary HAZID study and a number of comments that should be accounted for when applying the methanol or hydrogen PPE technology in the Rijksrederij's fleet renewal programme. The comments with most impact were related to the fuel bunkering process and involved systems. These outcomes and the initial budget estimation for the differences between both configurations will form the basis in evaluating the most feasible solution for the Rijksrederij.

Guidelines for up- and downscaling

The designs made within this project for the hydrogen and methanol solutions are scalable to the future ships of the Rijksrederij fleet. Two dominating factors were: The application of the systems engineering approach in the operational analysis, translation of requirements into a ship and system design, and the identification of critical factors in technical solutions. An advantage of choosing the seagoing multi-purpose vessel as benchmark ship was that the size is in the mid-range of the range of ship dimensions that are expected for the fleet renewal programme. During the project, some consortium partners contributed to the development of the "Maritime Master Plan" programme. In that programme, it is described how scaling of technology can be realised. The projects within the Maritime Master Plan will set out the course on implementing robust, safe and cost effective hydrogen and methanol systems for a large range of ship types.

A first guideline for scaling the technologies to the entire fleet is to make use of the cyclical process as defined in the Maritime Master Plan. This process is set up in such a way that climate-neutral ships can be efficiently developed, built, operated and improved during their lifetime. In this cyclical approach, operational data from the current fleet is input for the design of new vessels, while continuous feedback and optimisation takes place during operation.

A second guideline is that a thorough process of developing, testing and derisking innovative components and systems provides a good basis for scaling up to various ships and capabilities. Examples are fuel cells, fuel tanks and fuel pipes.

A third guideline is to set up energy systems on board in a modular way. The various power ranges can therefore be achieved by application of a multitude of well-tested modules. This prevents unnecessary and risky development of systems for each design separately. The class societies can issue a one-time approval for each of these modules. In this approach, it is essential that the supply chain partners are included early in the specification and design phases and systems engineering methodologies and standards are applied.

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