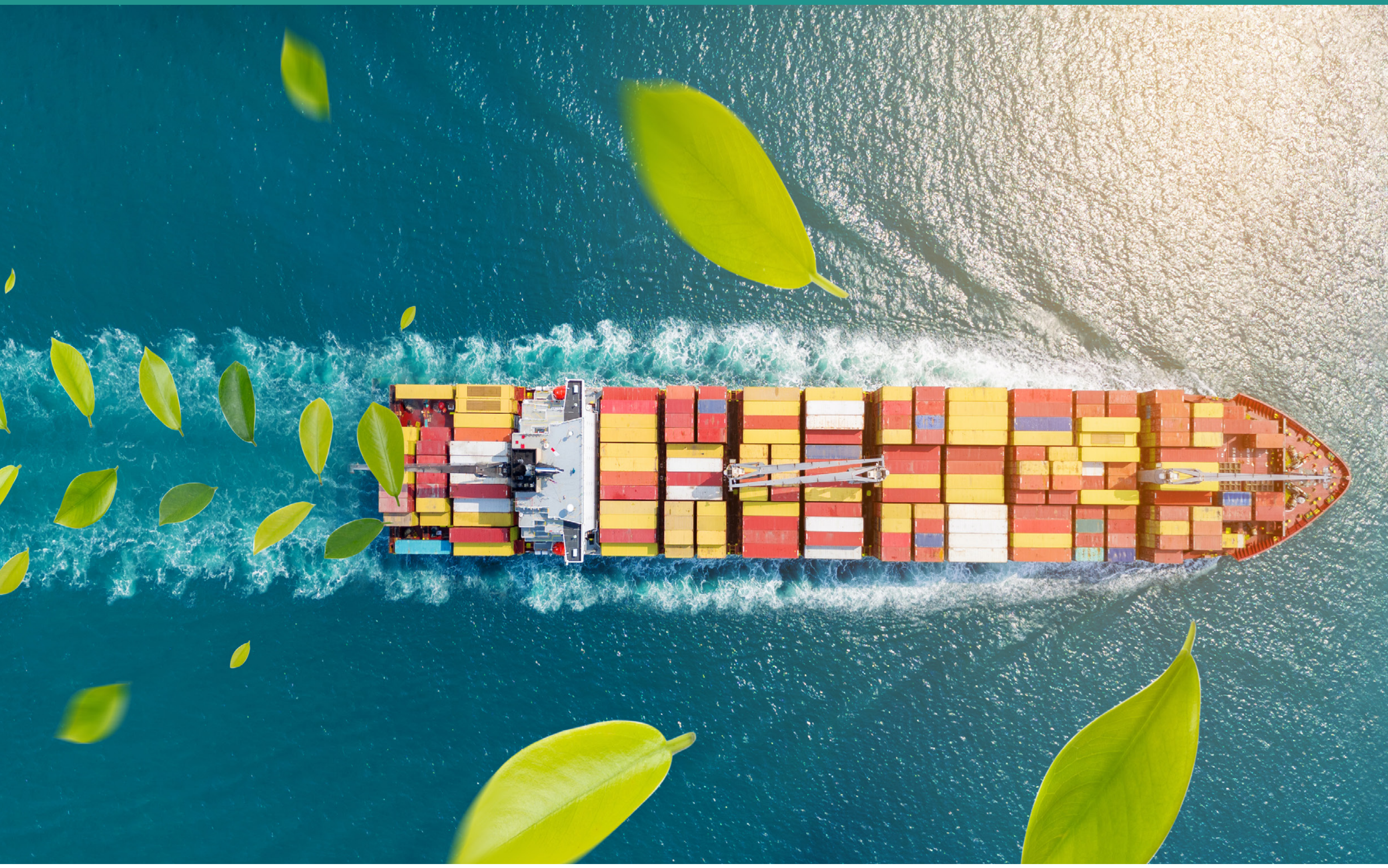
# Green Shipping in the Dutch State Fleet

Final Report & D5

Technical Support Instrument

*Supporting reforms in 27 Member States*



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# 1. Project Overview

**Project Context**

Despite continuous efforts to reduce the emissions of individual ships, the contribution of shipping to the greenhouse gas (GHG) emissions has increased during the last decade. The fourth GHG study of the International Maritime Organisation (IMO) showed that the share of shipping emissions in global anthropogenic emissions is projected to increase from about 90% of 2008 emissions in 2018 to 90-130% of 2008 emissions by 2050 for a range of plausible long-term economic and energy scenarios. This is not even close to the IMO goal of reducing GHG emissions with 50% in 2050. Urgent action is needed and implementation of green technology in government fleet renewal should stimulate the uptake of technology in commercial shipping. In this context the theme ‘'New technologies for greener shipping' has been chosen by the IMO Council in its 125th session as the World Maritime theme for 2022, reflecting the need to support a green transition of the maritime sector into a sustainable future, while leaving no one behind. The theme would provide an opportunity to focus on the importance of a sustainable maritime sector and the need to build back better and greener in a post pandemic world. The project may provide a valuable contribution on this theme.

The European Green Deal, adopted by the European Commission in December 2019, contains a roadmap to make Europe the first climate neutral continent by 2050. The EC requires that all sectors play their part, including the waterborne sector. As a follow-up, the Commission adopted a Sustainable and Smart Mobility Strategy in December 2020. The strategy highlights that waterborne transport faces important decarbonisation challenges in the next decades. This is due to the current lack of market-ready zero-emission technologies, the long development and life cycles of vessels, the required significant investments in refuelling equipment and infrastructure, and international competition in this sector. The project will contribute to prove that hydrogen and methanol technologies can be implemented in a safe and robust manner and may help to achieve the milestone of zero-emission ocean-going vessels becoming market ready by 2030. On 14 July 2021 the European Commission decided to step up the greening efforts and adopted a package of proposals to make the EU's climate, energy, land use, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. Achieving these emission reductions in the next decade is crucial to Europe becoming the world's first climate-neutral continent by 2050 and making the European Green Deal a reality. The proposals will have a profound effect on all economic sectors and policies, including shipping and shipbuilding. One example of a proposed measure relevant to this study is the Fuel EU Maritime Initiative, stimulating the uptake of sustainable maritime fuels and zero-emission technologies by setting a maximum limit on the greenhouse gas content of energy used by ships calling at European ports.

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, among other things, for a 70% reduction of CO2 in shipping by 2050 (compared to 2008) and for the launch of at least one zero-emission seagoing vessel by 2030. The climate objectives of the government fleet are: ‘20% reduction in carbon emissions by 2020, carbon neutral by 2030 and fully climate-neutral and climate-resilient by 2050’. To verify the feasibility of these objectives, the Dutch State Government Shipping Company (in Dutch: Rijksrederij) promised to study alternative means of propulsion technology, like the use of methanol and hydrogen. The project fits in with these promises and its results will prove the feasibility of these technologies, leading to timely introduction on the first newbuilds.

**Project Summary**

| Project title | Green Shipping in the Dutch State Fleet |
|---|---|
| Overall objectives | The transition of shipping to alternative fuels, in particular methanol and hydrogen, will only materialize in ships if the technology pertaining to these fuels is proven as safe and robust. An effective way to prove these characteristics is to perform ship design and engineering studies with a focus on energy and propulsion systems on board and assess the safety and robustness of these systems. These studies are also needed to guide government policy and rule development. The main aims of the study are therefore:<br>• 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;<br>• 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;<br>• to support authorities and rule setting organisations with best practices and lessons learned, related to application of green fuels;<br>• to guide the process of introducing the applications of methanol and hydrogen technology within the European shipping sector. |
| Main Tasks | Task 1: Preparation and Inception<br>Task 2: Identify basic customer requirements for the vessel<br>Task 3: Produce two concept designs for the vessel, one for hydrogen and one for methanol<br>Task 4: Produce two basic engineering packages, one for hydrogen and one for methanol<br>Task 5: Define an action plan for promoting zero-emission vessels and achieving a carbon-neutral state shipping fleet |
| Deliverables | Deliverable 1: Preparation and Inception report<br>Deliverable 2: Basic customer requirements for the vessel report<br>Deliverable 3:Two concept designs for the vessel, one for hydrogen and one for methanol<br>Deliverable 4: Two basic engineering packages, one for hydrogen and one for methanol<br>Deliverable 5: Action plan for promoting zero-emission vessels and achieving a carbon-neutral state shipping fleet |
| Project starting date | 1 March 2022 |
| Project duration | 14 months |

## 2. Summary of the Project Activities

**Work Package (WP) 1: Inception Phase and Inception Report**

To support the project activities and ensure effective coordination and engagement, a Steering Committee (SC) was established. The role of the SC during the project was to review and provide feedback and suggestions on project activities, workplans, and draft reports. The core members of the SC were composed of representatives of the consortium, the main beneficiary, and the European Commission (DG REFORM).

The inception report provided a common understanding among the key project stakeholders (the beneficiary authorities, the contractor, and the European Commission) on the implementation approach of the project. The report includes a detailed description of the methodology to be followed, the project's timeline, the composition and working modalities of the project Steering Committee as well as other relevant working arrangements followed during the project (for example regarding the involvement of a classification society), data and information needs and availability, the minutes of the kick-off meeting, and follow-up of activities agreed at the kick-off meeting. The report also includes a proposal by the contractor of indicators to monitor the project during and after its implementation.

**WP 2: Basic customer requirements for the vessel**

As the focus of the study is on the greening of the ships of the Dutch state fleet, the requirements (WP2) were determined on two levels. The first level is on the overall ship design, and the second level on the configuration of the power, propulsion and energy (PPE) system. The requirements for the PPE level will be formulated in terms of the propulsion shaft power based on the sailing speed and the prevailing conditions, the speed profile, the endurance and the auxiliary power consumed by the auxiliary services.

The initial mission portfolio included a 14-day mission. However, this resulted in large energy storage systems, at the cost of payload within limited hull dimensions. Therefore the 14-day mission was converted into a 11-day mission, including 2 days in port. This allowed for a more feasible ship concept.

**WP 3: Two concept designs for the vessel, one for hydrogen and one for methanol**

The goal of WP 3 was to develop a vessel design based on the PPE system requirements and Vessel and hull requirements as per WP2 report. The steps performed during WP 3 are illustrated by the project methodology as presented in the inception report.

A first study with regard to the main specificities of a feasible vessel was done utilising C-Job's ACD framework. Based on the gross properties of the developed logical architecture for the power and propulsion element (PPE) systems and vessel requirements, the main specificities are determined. This process and results are reported in the ACD study report. During the design process the logical and physical architecture of the PPE system were implemented in the (naval architectural) design. The resulting naval architecture design is reviewed and verified by performing preliminary calculations on critical items regarding the design requirement, weight, stability and scantlings in order to verify the feasibility of the designs. This included two concept design reports, one for the methanol design and one for the hydrogen design. Initially the design requirements were set equal for both concept designs. During the design process slight alteration to the design requirements were made based on physical limitations of the design.

**WP4: Two basic engineering packages, one for hydrogen and one for methanol**

For work package 4, the goal was to develop the conceptual design from work package 3 into a higher level of detail which will ultimately lead to an engineering package fit for Approval in Principle (AiP). As such, all documents identified as requirement for the AiP, see Figure 1, are updated or created.

Since the design is more detailed, more information is gained on component level. However, at this stage of the design make and type per component is not yet included. This will be up to the shipowner and shipyard to decide in a later design stage. However, based on commonly available component data it is verified that the assumed system configurations can be realised within the ship internal layout. The work included an evaluation of the basic design for both vessel configurations, methanol and hydrogen. Designs for the Methanol and Hydrogen fuelled vessels were presented and supported with checks and calculations on the general layout and verification of fitting components within this layout. This is to ensure that the main specificities and vessel layout meet the requirements and are sufficiently validated to continue in the detailed engineering phase of the vessels.

To obtain the dependencies of the fuel system onto the structural design setup and to get more detailed input into the light ship weight analysis, the main cross section was setup and analysed from a structural perspective. The latter forms an update to the input for the initial stability check of the vessels. The main cross sections are also part of the requirements to obtain the AiP. As part of the naval architectural calculations, an update was made regarding the light ship weight and consequently the initial stability of the vessels. It was verified that the current vessel designs comply with Class regulations.

Mechanical calculations were performed, and diagrams were created. Outcomes were used to verify the layout and space reservation on component level which can be found in the Engine room on the General Arrangement Plans. Based on the engineering package from WP4 an estimate of the differences with respect to CAPEX and OPEX for both vessel designs were presented.

**WP 5: Action plan for promoting zero-emission vessels and achieving a carbon-neutral state shipping fleet**

The goal of the report (see Annex) was to enable the Rijksrederij to use the learnings and results of the project for the future greening of the fleet, and to satisfy the second expected outcome of the project[3]:

*The designs and the design process guide other new build vessels, such as scaled-up, scaled-down or spin-off versions of the design developed under this project.*

The project should help toward long-term goals of a carbon neutral Dutch state fleet by 2030 and the development of reliable sustainable vessel designs that reduce the GHG emissions of the maritime sector. Based on the results of WP3 and WP4, the knowledge gained in other alternative fuel projects, and taking account of the ranges in propulsion power and expected operational profiles of the replacement fleet, the design and safety critical configuration and system aspects were identified, and a plan was be developed to guide the Rijksrederij in determining the critical aspects of implementation of new technology across the fleet.

Throughout the project, and during this phase, existing and potential barriers to implementation and replication of the solution were identified. These barriers can either be technical, financial, regulatory or process-related. These technical and non-technical barriers of scaling up the implementation of methanol and hydrogen were identified and discussed during a series of workshops between the project team and representatives of the Rijksrederij.

Additionally, with the solutions developed for a basic engineering level in Deliverable 4, the market has been assessed to understand to what extent the required technology is readily available. A check has been done of the opinion of stakeholders on the level of safety and robustness of the green technology.

Based on this information, a set of recommendations were developed to guide the Rijksrederij in determining the critical aspects of implementation of new technology across the fleet. The recommendations include not only guidelines developing the technical solution within the project, but also recommendations on the processes and workflow followed within the project.

# 3. Technical recommendations for next design phase of the pilot vessel

Based on the presented initial design, the feasibility of the proposed vessel concept based on Methanol fuel is confirmed. The presented design is taken as starting point for the next engineering phase, where the main systems and vessel structure will be analyzed into more detail on room/system level of detail. The following recommendations are made for the design to be taken care of in the next design phase:

- Design shows a list in all conditions. Placement of consumable tanks to be optimized to reduce heel and trim, focusing on minimizing the use of water ballast in the loaded conditions.
- Lifting at shallow draft shows large heeling angles. Provisions for water ballast in the design to be investigated to allow for lifting over the complete draft range without the active use of the ballast system during operations.
- Methanol day tanks might be moved in the double bottom, avoiding additional cofferdam structures around the tanks currently placed in the ER.
- For the hydrogen concept, from the fuel capacity evaluation can be concluded that the design has a reduced fuel capacity of roughly 45% of the energy storage capacity required and is therefore not capable of completing all specified missions and therewith cannot fully comply with set requirement by the Rijksrederij without exceeding the design length of 65m or extending the vessel significantly in other ways. The situation where the requirement to have a moonpool is omitted has been investigated and the resulting capacity in such design the capacity is 95% of the required capacity which might be gained by some other minor alteration to the design.
- These results have been discussed with the Rijksrederij and it was concluded that the required fuel capacity cannot be met without altering the design to such an extent that other design requirements would be violated. The presented design is taken as starting point for the next engineering phase where the main systems and vessel structure will be analyzed into more detail on room/system level of detail.
- The combination of having a hydrogen system and a moonpool in the vessel put a large strain on the design. Both systems need to be allocated at the middle in the vessel: The LH2 systems due to safety regulations, and the moonpool due to operational limitations. Recommended to the Rijksrederij is to reconsider this combination of requirements for further designs.
- The following recommendations are made to the design to be taken care of in the next design phase:
  - Design shows a list of all stability loading conditions. Placement of consumable tanks to be optimized to reduce heel for the complete operating range.
  - A significant amount of water ballast is required to attain sufficient draft to meet the freeboard between 1.0m - 1.3m criteria. The current design shows sufficient overall capacity, but the actual tank arrangement needs to be further refined.

# 4. Annex – Deliverable 5: Action Plan for promoting zero-emission vessels and achieving a carbon-neutral shipping fleet

# Deliverable 5:

# Action plan for promoting zero- emission vessels and achieving a carbon-neutral state shipping fleet

Green Shipping in the Dutch State Fleet

REFORM/SC2022/020

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AIP | Approval in Principle |
| BV | Bureau Veritas (project partner) |
| D1-D5 | Deliverable 1 … 5 |
| EC | European Commission |
| ECSA | European Community Shipowners' Association |
| EU | European Union |
| GHG | Green House Gases |
| HAZID | Hazard Identification |
| IMO | International Maritime Organisation |
| JIP | Joint Industry Project |
| KVNR | Koninklijke Vereniging van Nederlandse Reders (Royal Association of Netherlands Shipowners) |
| MARIN | Maritime Research Institute Netherlands (project partner) |
| MEPC | Marine Environment Protection Committee |
| MPV | Multi-Purpose Vessel |
| MSN | Marine Service Noord (project partner) |
| NMT(F) | Netherlands Maritime Technology (Foundation) (project partner) |

# 1. INTRODUCTION

## Project Context

Despite continuous efforts to reduce the emissions of individual ships, the contribution of shipping to greenhouse gas (GHG) emissions has increased during the last decade. The fourth GHG study of the International Maritime Organisation (IMO) showed that the share of shipping emissions in global anthropogenic emissions is projected to increase from about 90% of 2008 emissions in 2018, to 90-130% of 2008 emissions by 2050, for a range of plausible long-term economic and energy scenarios. This is not even close to the IMO goal of reducing GHG emissions with 50% in 2050. Urgent action is needed, and implementation of green technology in government fleet renewal should stimulate the uptake of the technology in commercial shipping.

In this context, the theme ‘'New technologies for greener shipping' has been chosen by the IMO Council in its 125th session as the World Maritime theme for 2022, reflecting the need to support a green transition of the maritime sector into a sustainable future, while leaving no one behind. The theme provides an opportunity to focus on the importance of a sustainable maritime sector and the need to build back better and greener in a post pandemic world. The current project may provide a valuable contribution on this theme.

The European Green Deal, adopted by the European Commission in December 2019, contains a roadmap to make Europe the first climate neutral continent by 2050. The EC requires that all sectors play their part, including the waterborne sector. As a follow-up, the Commission adopted a Sustainable and Smart Mobility Strategy in December 2020. The strategy highlights that waterborne transport faces important decarbonisation challenges in the next decades. This is due to the current lack of market-ready zero-emission technologies, the long development and life cycles of vessels, the required significant investments in refuelling equipment and infrastructure, and international competition in this sector. The project will contribute to prove that hydrogen and methanol technologies can be implemented in a safe and robust manner and may help to achieve the milestone of zero-emission ocean-going vessels becoming market-ready by 2030.

On 14 July 2021 the European Commission decided to step up the greening efforts and adopted a package of proposals to make the EU's climate, energy, land use, transport and taxation policies fit for reducing net GHG emissions by at least 55% by 2030, compared to 1990 levels. Achieving these emission reductions in the next decade is crucial to Europe becoming the world's first climate-neutral continent by 2050 and making the European Green Deal a reality. The proposals will have a profound effect on all economic sectors and policies, including shipping and shipbuilding. One example of a proposed measure relevant to this study is the FuelEU Maritime Initiative, stimulating the uptake of sustainable maritime fuels and zero-emission technologies by setting a maximum limit on the greenhouse gas content of energy used by ships calling at European ports.

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, among other things, for a 70% reduction of CO2 in shipping by 2050 (compared to 2008) and for the launch of at least one zero-emission seagoing vessel by 2030. The climate objectives of the government fleet are: ‘20% reduction in carbon emissions by 2020, carbon neutral by 2030 and fully climate-neutral and climate-resilient by 2050’. To verify the feasibility of these objectives, the Dutch State Government Shipping Company promised to study alternative means of propulsion technology, like the use of methanol and hydrogen. The current project fits in with these promises and its results will prove the feasibility of these technologies, leading to timely introduction on the first newbuilds.

## The Rijksrederij’s Fleet Replacement Program

The main beneficiaries of the current project are the Ministry of Infrastructure and Water Management (IenW), its executive agency (the Rijkswaterstaat) and the Dutch State Government Shipping Company (the Rijksrederij).

The Rijksrederij was founded in 2009 and operates as an independent organization within Rijkswaterstaat. The Rijksrederij has a fleet of approximately 100 vessels that are made available with crew, appropriate for tasks such as waterway marking, patrol, surveying, fishery management, and research. Additionally, the Rijksrederij has the goal to provide knowledge and advise in the areas of crew requirements, safety management, equipment and optimal ship deployment. [1]

Wider stakeholders of the project include other public bodies acting as clients of the Rijksrederij such as the coast guard and customs, as well as the private shipping sector that could benefit from the results of the project.

A key challenge towards a sustainable and eventually carbon neutral shipping sector is the transition to alternative sustainable fuels. To guarantee the availability and uptake of alternative fuels for shipping, more research on how to propel different ship types with these new fuels is needed. The COVID-19 crisis has made the financial position of shipping companies more unstable, risking a setback in their ambitions to invest in a greener fleet. It is therefore of importance that governments lead by example and facilitate, where possible, the greening of the shipping industry. Therefore, the Dutch government has decided to start with its own fleet, under the management of the Dutch State Government Shipping Company (in Dutch: the Rijksrederij).

The Rijksrederij replaces several ships that have reached the end of their economic and technical life with new multifunctional ships. These so-called Multi-Purpose Vessels (MPVs) are vessels that can be deployed for multiple tasks and clients. Functions that were previously performed by several ships, such as waterway marking and measuring water quality, are now combined on 1 ship.

The first 3 ships have been delivered within the fleet replacement program[2]. The *Merwestroom*, the *Waddenstroom* and the *Scheldestroom* sail on the large inland waterways, the estuaries, the Waddenzee and the North Sea up to 30 miles from the Dutch coast. After the MPV-30 ships, more MPV ships are being built that (partly) have different tasks and sailing areas.

Sustainability is an important theme within the fleet replacement program. The new vessels feature hybrid propulsion systems, low fuel consumption, low emissions and are capable of performing a daily operation solely on their battery pack. In addition, the ships have solar panels for the energy supply of the crew's accommodation.

Support is needed to facilitate a transition to alternative sustainable fuels for the state fleet, including on further studies regarding the application of hydrogen based fuel cell technologies and methanol-based propulsion on board of new and existing seagoing vessels.

## Impact and Goal of the Project

The transition of shipping to alternative fuels, in particular methanol and hydrogen, will only materialize in ships if the technology pertaining to these fuels is proven as safe and robust. An effective way to prove these characteristics is to perform ship design and engineering studies with a focus on energy and propulsion systems on board, and assess the safety and robustness of these systems. These studies are also needed to guide government [policy and rule development. The main aims of the project ***'Green Shipping in the Dutch State Fleet'*** are therefore:

- 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;
- To guide the Dutch government in replicating and scaling the methanol and hydrogen technology to the full range of the Dutch state fleet replacement program;
- To support authorities and rule setting organisations with best practices and lessons learned, related to application of green fuels;
- To support the beneficiary and the industry as a whole in gaining knowledge of the technical aspects, the regulatory aspects, and the feasibility of the use of alternative fuels;

[1] https://www.rijkswaterstaat.nl/water/waterbeheer/beheer-en-ontwikkeling-rijkswateren/rijksrederij/vloot-en-diensten
[2] https://www.rijkswaterstaat.nl/water/waterbeheer/beheer-en-ontwikkeling-rijkswateren/rijksrederij/vlootvervanging

- To guide the process of introducing and upscaling the applications of methanol and hydrogen technology within the European shipping sector.

The study will contribute to the implementation phase of the reform cycle in the often conservative shipping sector, by producing evidence that methanol and hydrogen technologies are ready for uptake in newbuilt ships. Our approach aims at nothing short of lowering thresholds in achieving the greening and net- zero emission of shipping by sharing the results with national stakeholders via trade associations like NMTF and KVNR, by European stakeholders via Sea Europe and ECSA and worldwide stakeholders via IMO.

## Goal of the Current Deliverable

The goal of the current report is to enable the Rijksrederij to use the learnings and results of the project for the future greening of the fleet, and to satisfy the second required outcome of the project[3]:

> *The designs and the design process guide other new build vessels, such as scaled-up, scaled-down or spin-off versions of the design developed under this project.*

The project should help toward long-term goals of a carbon neutral Dutch state fleet by 2030 and the development of reliable sustainable vessel designs that reduce the GHG emissions of the maritime sector. Achieving those goals could depend on the adoption and implementation of the recommendations of this report.

[3] Request for Service "*Green Shipping in the Dutch State Fleet*" (ID REFORM/SC2021/119)

# 2. METHODOLOGY

The results of Deliverable 3 and Deliverable 4 provide insight in the configuration and system details and give proof of the feasibility and safety of implementing methanol and hydrogen solutions for the selected vessel. The next step, the replication and upscaling to the entire state shipping fleet requires a range of design studies that is beyond scope of this study. Therefore, based on the results of WP3 and WP4, the knowledge gained in other alternative fuel projects, and taking account of the ranges in propulsion power and expected operational profiles of the replacement fleet, the design and safety critical configuration and system aspects will be identified and a plan will be developed to guide the Rijksrederij in determining the critical aspects of implementation of new technology across the fleet.

Throughout the project, and during this phase in particular, existing and potential barriers to implementation and replication of the solution will be identified. These barriers can either be technical, financial, regulatory or process-related. These technical and non-technical barriers of scaling up the implementation of methanol and hydrogen will be identified discussed during a limited series of workshops between the project team and representatives of the Rijksrederij.

Additionally, with the solutions developed to a basic engineering level in Deliverable 4, the market will be assessed to understand to what extent the required technology is readily available. A check will be done of the opinion of stakeholders on the level of safety and robustness of the green technology.

Based on this information, a set of recommendations will be developed to guide the Rijksrederij in determining the critical aspects of implementation of new technology across the fleet. The recommendations include not only guidelines developing the technical solution within the project, but also recommendations on the processes and workflow followed within the project.

Finally, to disseminate the project findings, dissemination material (the current reports and presentations) will be developed and distributed to the main beneficiary.

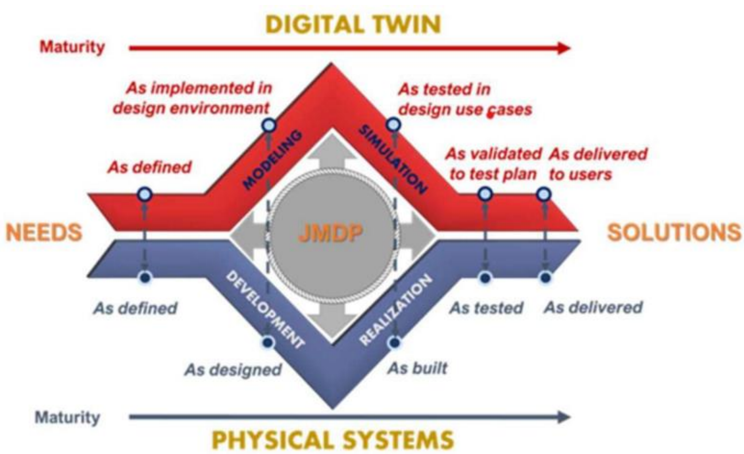
# 3. GUIDELINES FOR UP- AND DOWNSCALING OF DESIGNS

The designs made within this project for the hydrogen and methanol solutions are scalable to the future ships of the fleet of the Rijksrederij. There are two factors behind this: The application of the system engineering approach in the translation of requirements into solutions and identification of critical factors in technical solutions. . An important advantage of choosing the MPV 50 as benchmark ship is that the size is in the mid-range of the range of ship dimensions that are expected for the fleet renewal program. During the project, some consortium partners contributed to the development of the "Maritime Masterplan", in which insights gained in this project are included. In that plan, for work vessels and coastal shipping vessels, it is described on how the upscaling of technology can be realized. The Maritime Master Plan indicates how the reliability and operation of hydrogen and methanol systems can be demonstrated for a large range ship types. The following guidelines are therefore given for upscaling and downscaling, based on the results of this project and the development of the Maritime Masterplan.

## Model Based System Engineeering

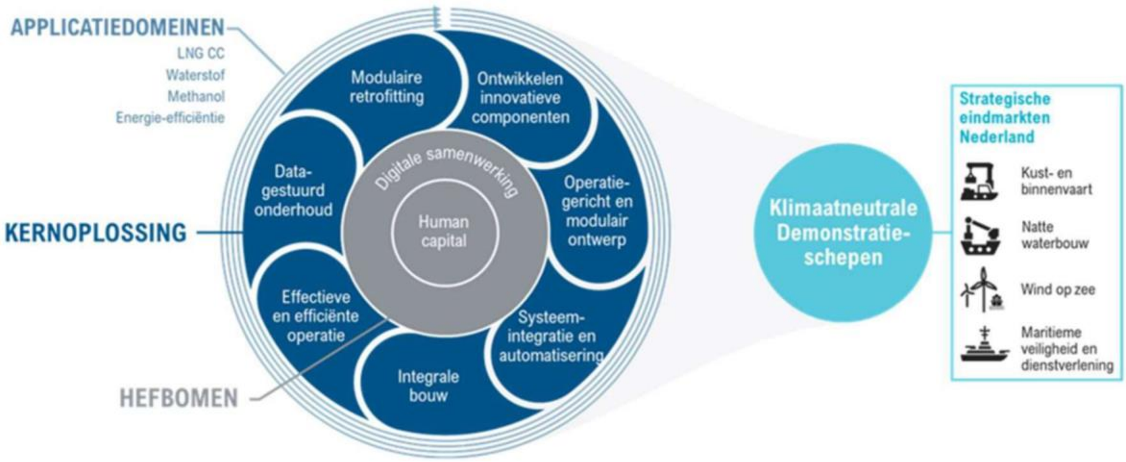
Scaling up or down hydrogen and methanol technology requires a systematic translation of customer requirements to requirements and preconditions for the designs essential. In Deliverable 2, it has been demonstrated that a thorough analysis of the requirements that affect the energy management on board is necessary to optimize solutions. In this project it has been demonstrated that an available system engineering method forces the client and the supplier of the vessels and systems to traceable and substantiated choose starting points for the design. By opting for a model-based system engineering approach, parts of the technology development and demonstration thereof can be incorporated on vessels for various applications, sailing areas and dimensions.

It is recommended to choose a method that connects to Boeing's "Model-Based Engineering Diamond". The core of this diamond model is that the digital development in the form of digital twins runs parallel to the development of the physical product, and supports that development much better. After all, in the digital, model-based environment, many interim tests and analyses can be performed, of which the results are used directly to guide the development of the product. A major efficiency boost will be thus achieved.



## Development and demonstartion of technical solutions

A first guideline for scaling up to the entire fleet is to make use of the cyclical innovation and user process as developed 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 optimization takes place during operation. Ships designs are thus continuously improved. Successful cooperation along the value chain is considered the best practice that is built on. By developing and implementing operations-oriented, modular and digitally construction saves up to 80% in engineering hours and 25% in production hours (costs) and can reduce the with 50%.




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

A third directive is to set up energy systems on board in a modular way. A well-known form of modular approach is the 20 and 40 foot container in which a complete hydrogen-driven energy system is included. The different power ranges can therefore be operated by a multitude of these modules to take. This prevents unnecessary and risky development of systems for each design separately. The class societies can issue a one-time approval for these modules.

In this approach, it is essential that the supply chain partners are included in the processes and mandatory to follow the prescribed model based system engineering methodologies and standards.

# 4. BARRIERS

To define the barriers towards further greening of the Dutch state fleet using alternative fuel solutions, a total of three workshops were held between the project team and the Rijksrederij. During these workshops, the following questions formed guidelines through the discussions:

- Which regulatory, technical, operational requirements were limiting the design / would influence the choice for methanol or hydrogen?
- What barriers still exist for the next phases for the current design, if any?
- What barriers exist within the Rijksrederij towards further implementation of methanol/hydrogen technologies?
- What technical *and* non-technical barriers exist towards further implementation of the technologies in the rest of the Rijksrederij fleet?
- Is the Dutch or the European industry ready?
- What can we learn from the project process?

It needs to be noted that some of these questions (e.g., the readiness of the market) are broad questions that would be too time-consuming to answer within the context of the current project. Only the surface will be scratched, and only the main considerations will be discussed below.

The barriers are organized in five subsets:

- **Technical and operational requirements**: these are the more specific challenges encountered within the current project, and may or may not be applicable to other projects as well.
- **Class and statutory requirements**: these will be applicable to other projects as well, although which requirements are relevant depends on e.g. the size and operational scope (inland or seagoing) of the ship.
- **Infrastructure**: these will be applicable to other projects as well, although the severity of the issues is highly dependent on the location.
- **Barriers within the Rijksrederij**: these are barriers that are Rijksrederij specific, although they are often also applicable within other organizations.
- **Market readiness**: Are the technologies in the market mature enough for adoption?

## Technical and Operational Requirements

Below is an overview of the main challenges encountered during the project. They may be quite specific and may or may not be applicable to other projects as well. There is a focus on the technical or operational requirements that have in some way limited the design, or would have an impact on the choice between methanol and hydrogen.

Overall it is clear that the main impact on the choice between the different (alternative) fuel systems is the **operational profile** of the vessel. For instance, the hydrogen concept design of the vessel within this project does not comply with the operational requirements set out in Deliverable 2. The concept design has been increased beyond the maximum length of 60 meter to 65 meter, yet it still cannot store enough hydrogen onboard to successfully complete *any* of the 6-day or 11 -day missions.

The **optional, shorter missions** that were originally included in the operational profile analysis of the vessel do not influence the choice for hydrogen or methanol – they were purged from the analysis because they were not critical in terms of energy usage, but equipment used during these missions has been taken into account.

To increase the energy storage onboard, the project team looked into an alternative design of the vessel, omitting the **moonpool** from the design. The moonpool has a required minimum size of 4 by 4 meter, and its required location is on the centreline. This interferes with the location of the energy carrier storage on the hydrogen version of the vessel. In D3, it was estimated that the tank capacity with the moonpool included in the design was 6.9 ton, while in a hypothetical design without moonpool the capacity was 11.2 ton – which is significantly more, but still short off the required 12.6 ton. In case of the increased bunker space, the vessel would be able to perform most of the 6-day missions, but not the 11-day mission.

The low **freeboard** requirement also proved to be a challenge for the hydrogen version. Due to the lower energy density of hydrogen there was a larger volume required on board for energy storage, and the required low freeboard resulted in a more slender ship. The hydrogen tank currently is higher than the deck height, causing it to protrude the deck. Due to the slenderness of the vessel the tank is also limited in breadth. Additionally, the onboard crane and its effect during hoisting operations causes stability issues, and therefore ballast needed to be added.

One of the areas to do take into account in a further design optimisation are the **lines of sight** from the bridgehouse. On the hydrogen version, the wheelhouse is more slender than on the methanol version (due to the vessel being more slender overall), causing the requirements regarding lines of sight to become more critical/complicated to implement.

Another item to keep in mind when designing the hydrogen version is the **ventilation mast**. In the current study the ventilation mast is included as a placeholder. The mast requires relatively a lot of space. If it is placed more forward, it could be in the way of navigation equipment, and if it were to move more aft it could be in the way of crane operation or other operations on deck.

It also needs to be noted that hydrogen does not create **CO2**, while methanol does. And for a full scope emission-analysis, the method of creation of hydrogen and methanol also needs to be taken into account (well-to-wake). Future emission requirements may therefore influence the choice between alternative fuel solutions.

The **required deck space** was not a limiting factor in both designs. However, if the end user would like to get a few extra square meters, the easiest way to do that is to simply lengthen the ship by a few meters, provided that the maximum length requirements do not limit that.

## Class and Statutory Requirements

The concept designs within the project fall under the Dutch flag, are between the thresholds of 500 GT and 1000 GT, and their area of operation is seagoing. During the development of the two concepts, relevant class and statutory requirements have been taken into account. However, for extrapolation of the concept to the rest of the fleet, it's worthwhile to mention which class and statutory requirements are applicable when the vessels become smaller or larger, or when their area of operation changes.

- For inland shipping, the following rules are applicable:
  - ES-TRIN (regulations regarding alternative fuel systems are partly still under development. For these areas, the regulations require supplementing with class rules for seagoing vessels)
  - Limited ADN for transport of dangerous goods (at the request of the owner, approval in principle from flag state required)
- For seagoing vessels under 500 GT SOLAS is not applicable. However, the following rules and regulations are applicable:
  - *Regeling veiligheid zeeschepen*
  - MARPOL, LL, MLC, ILO152, IS code, BWM convention, and more.
  - MSC1621 for methanol vessels
  - IGF code and MSC1647 for hydrogen vessels with fuel cells on board
- Over 500 GT, the following rules and regulations come into play:
  - SOLAS
  - MARPOL, LL, MLC, IS code, ILO152, BWM convention, and more.
  - MSC1621 for methanol vessels
  - IGF code and MSC1647 for hydrogen vessels with fuel cells on board

The current Rijksrederij project *RWS-88* will provide the Rijksrederij with knowledge and experience with the use of rules and regulations for inland shipping.

For inland shipping, it needs to be noted that certification of engines is currently still complex, albeit slightly easier for fuel cells than for methanol engines.

Especially for inland shipping, it is important to always use the latest version of the available rules and regulations. These rules (especially the statutory regulations) are constantly in development. During the development of a vessel it may also be unclear which part of the regulations is still under development. Often, rules and regulations are used that are still under development in an attempt to be ahead of upcoming changes to the rules and regulations.

For seagoing vessels, regulations for methanol are more developed, and more strict. Regulations for hydrogen are less available, and often refers to the MSC code.

## Infrastructure

The availability of (refuelling options for) green hydrogen and green methanol is considered to be the main risk for the success of hydrogen and methanol-based shipping. Currently, the refuelling options for hydrogen and methanol are very limited, especially for green hydrogen and green methanol. This has led to challenges for similar projects as well. For instance, the hydrogen concept for Lovers Canal Cruises was unsuccessful due to issues with the possibilities for hydrogen distribution. Additionally, the (also hydrogen) Watertaxi Rotterdam currently has issues with possibilities for refuelling, leading to high fuel costs (approx. 50 €/kg instead of 9 €/kg). Obviously, these kinds of price hikes have a major impact on the business case for alternative fuels.

Although from a technical perspective it is easier to create methanol distribution stations, the Dutch government is more ambitious when it comes to hydrogen. The complexity of hydrogen refuelling stations is dependent on its form (i.e. liquid or gas). There are many plans for refuelling stations, especially for multimodal transport (road and maritime). However, although there is a lot of political will at the higher level, the progress often stalls at a lower governmental level, when permits need to be attained for new refuelling stations.

In terms of suppliers, there are currently only a few (2-4) producers of green methanol, and the same amount of green hydrogen producers.

To work around the limited availability of green fuels, an intermediate solutions would be to bring the fuel by road truck to the vessels. However, the required volumes are not very large, but they need to be distributed to many different locations, given the area of operation of the 100+ vessels of the Rijksrederij.

Another workaround which is applied in many other projects is to design the vessels dual-fuel, which enables the vessel to be operational on the basis of conventional fuels, until alternative fuels are available and affordable.

## Barriers within the Rijksrederij

A number of barriers can be defined within the sphere of influence of the Rijksrederij itself. They can be organized in the following categories: organisational, financial, operational considerations, and safety (or perception thereof by crew).

### Organisational

The Rijksrederij has a broad scope of activities, for which the requirements are reliability and safety, next to sustainability. Support within the Rijksrederij for making the organisation more sustainable is growing. The topic is very much on top of mind for many within the organisation. The greening of the fleet of the Rijksrederij is an important topic, and the goal of having a emission neutral fleet by 2030 is ambitious.

The Rijksrederij does not fall under the new emission regulations, which is applicable only for >5000 GT vessels. Also, the Rijksrederij is a governmental organization, and is therefore often excluded from regulations. However, the Rijksrederij does have an exemplary role, and is aware of that role. In the Netherlands, there is a big societal discussion regarding (especially nitrogen) emission going on, and the Rijksrederij vessels often sail in the Natura 2000 natural areas. However, currently the rules and regulations don’t limit the use of conventional propulsion systems or fuels in the fleet.

It can therefore be said that the motivation to go more sustainable as the Rijksrederij is currently mainly on a moral and ethical level: The Rijksrederij is aware of its exemplary role and societal role. For instance, fishing vessels *will* have to comply with the new emission requirements, and it is the Rijksrederij's role to monitor the compliance to these rules. Of course, the ships of the Rijksrederij will also have to meet the stricter emission requirements.

Despite the ambition in the Green Deal, it is challenging in practice to secure funding for far-reaching sustainability options. For example, when setting up a new project, the costs of applying sustainable technology always tested against the costs of conventional propulsion systems.

The organization's focus on sustainability and its exemplary role in the field of emission-free shipping can be further strengthened by focusing more intensively on making the sustainability ambition concrete as expressed in the strategic goals and mission of the organization. This should contribute to solving of internal barriers, because it puts sustainability further on the map within the organization.

### Financial

The second consideration for the Rijksrederij is the cost of alternative fuel (systems). Even though prices for conventional fuel have hiked in recent times, alternative fuel (systems) are generally more expensive than conventional ones in terms of investment costs, fuel costs and maintenance costs. These high costs cause a number of the Rijksrederij projects to stall and remain in a preliminary study-phase.

Potential regulations around penalties for CO2 emissions would help countering these financial barriers. It is also expected that costs for alternative fuels will go down once the supply scales up, although it is obviously complex if not impossible to predict future prices.

### Operational

Additionally to the organisational and financial barriers within the Rijksrederij, there are also operational considerations to mention. Examples of potential required operational changes would be more regular refuelling, a change of operational capabilities, and/or a different maintenance schedule.

The maintenance, and the maintenance schedule of the alternative fuel systems is different than that of conventional systems. It requires more regular check-ups (e.g. every (half) year), which has an influence on the operational planning and availability of the vessel. Tanker vessels operators such as Anthony Veder are already used to these maintenance schedules, so this market segment may perhaps provide inspiration for future projects.

Because the choice for those systems could mean a change in operations , there is some resistance within the Rijksrederij against the implementation of innovative alternative fuel systems. Although a part of the organization is open to work with (the limits of) alternative fuel systems, another part (on all levels of the organisation) is hesitant to change the operational requirements of the fleet to accommodate for alternative fuel systems. A typical example of a change of operational requirements within the current project would be to split the 11-day mission into two parts to allow for hydrogen energy system. This could be a feasible solution for many, but currently not everyone is aligned on such sacrifices, which severely stalls progress on some projects.

Resolving these operational barriers requires a clear distinction between the operational requirements that are 'need-to-have' and the ones that are 'nice-to-have'.

### Safety

For crew, the main considerations are safety and operations. The *perceived* safety of methanol and hydrogen systems are still inferior to that of conventional systems.

For example, the new RWS88 project will be fitted with a methanol fuel system. The crew will be doing the bunkering themselves, but they do have questions regarding the fire safety and explosion safety while bunkering and normal operation. At the moment, these issues are not showstoppers, but they are definitely considerations to take into account if you want the crew onboard with innovation. The operational limitations mentioned above can be 'annoying', and the crew might be of the opinion of not being able to do their work properly or as efficient as before.

However, the rules and regulations regarding alternative fuel systems are set up in such way that the alternative fuel systems are of an equivalent safety level as conventional systems. But still, the crew's *perceived* safety may still not be equivalent. Crew training is therefore critical to a successful implementation of alternative fuel systems.

## Market Readiness

Both methanol and hydrogen systems are currently not available 'off-the-shelf', but technology providers are ready and excited for rollout of their products.

Although hydrogen components are available off the shelf, there are still only a small number of systems up and running. The components can therefore be considered proven technology, but hydrogen systems as a whole are not. Small scale systems are being built and tested, but the large scale ones are still under development. A typical example of the state of the use of hydrogen systems are the recently announced Norwegian hydrogen ferries, which are expected to enter the market by the end of 2025.

The development of mainly larger methanol systems is picking up. However, the number of different makes and sizes of methanol engines is still very limited (with most engine suppliers promising availability from 2025 onwards). For the medium speed range, and for smaller engines only one manufacturer can deliver engines, although certification is still in progress. For inland shipping, there are currently zero methanol engines available with stage V certification.

Although systems are becoming more and more available, it remains to be seen when they will be class approved. The technologies still need to prove themselves in terms of robustness, safety, and long term performance. There is therefore still a lot of work to be done before the technology is mature, and in the near future the Maritime Masterplan will provide a significant role in this as well.

# 5. RECOMMENDATIONS

## Recommendations towards a Carbon-Neutral State Shipping Fleet

Although possible to overcome, many barriers still stand between the Rijksrederij and a carbon-neutral state fleet.

The first ones to tackle would probably be the organisational barriers. There is a growing enthusiasm for sustainability within the Rijksrederij, and the organisation needs to capture that momentum to achieve great things. The Rijksrederij is aware of the exemplary role that a governmental organization has. Sustainability should therefore be a part of the organization's strategic goals and missions. Perhaps this may help with securing additional funding to achieve these goals as well.

The second main recommendation is to rethink the operational and technical requirements of the vessels. This is partly already done by replacing specialized ships with multi-purpose vessels. Need to go beyond that, and change the scope of the vessels to accommodate for alternative fuel systems. Technical examples that were run into during this particular projects were the moonpool and minimum freeboard, operational examples are the 11-day mission, which could perhaps be split up into two shorter missions. For future projects, it is therefore recommended to be very critical of which requirements are really *need-to-have* rather than *nice-to-have*.

For future projects, it is important to understand that a methanol fuel system still emits CO2, albeit less than for a conventional fuel system. A hydrogen fuel system does not emit any CO2.

Regarding the rules and regulations for inland shipping, many have been discussed above. However, it is recommended that the Rijksrederij keeps good track of the learnings from the RWS-88 project, which is currently ongoing. In any case, as the rules and regulations are often still under development, it is recommended that the last version is always used, and/or rules that are still in development under the assumption that they will be approved by the time of ship build and launch.

The availability of green methanol and green hydrogen remains an issue for further rollout of these technologies. It is therefore recommended to the Rijksrederij to work closely with the industry on the development of new refuelling stations. The national government is trying to push this agenda, but the processes often stall at lower levels of the decision-making process. Having the Rijksrederij back a project is likely to help streamline the process.

In the meantime, it is recommended to look into adjusting the operational scope of vessels temporarily to accommodate for refuelling by road truck, if viable. Central locations could be designated as refuelling stations, limiting the amount of logistics when it comes to refuelling.

Another barrier that could be resolved by working closely with the industry is that of market readiness. Many suppliers are eager to deliver their new hydrogen or methanol products. However, most of these systems still need to prove their worth when it comes to robustness, safety, and long term performance. Early adopters have an opportunity to work closely with the developers and the regulatory instances in accelerating the development of these new technologies, and the Rijksrederij is recommended to capture that opportunity, and to show that they fit their exemplary role.

Last but not least, before any of the alternative fuel systems become operational, it is recommended to implement a solid portfolio of crew training regarding these systems. The crew have to feel comfortable and safe with these new technologies before they will be excited to work with them. The whole organization will need to be on board with the changes and the operational sacrifices that they may need to make, before the carbon-neutral state fleet can become a reality.

## Recommendations for Further Development of the Concepts

Two items that require attention in a next iteration of the vessel designs developed within this project, are the lines of sight from the bridge (for both designs), and the location of the ventilation shaft (for the hydrogen version). These are currently acceptable, but critical, and could be improved in a next iteration.

What still is missing from the current design is a discussion on the automation of the two concepts, and how that would influence the choice between the two alternative fuel systems. How much could be automated for these systems? If more can be automated, it would require less personnel with highly specialised knowledge. Currently it all seems very complex, but that's mostly due to the fact that these are new technologies.

## Recommendations regarding Project Process

Although all involved parties have been really happy with the project processes, there are still some recommendations that can be made regarding these processes based on both positive and learning experiences from this project, to make future projects successful as well.

Something that has been a positive experience for everyone involved in this project is that there are no parties that are affiliated with any of the proposed solutions, ensuring an objective set of recommendations to the customer.

Even before the start of the project, it is important to involve all project partners, even though their scope of work may be later in the project, to align on the project goals and approach.

For future projects of similar scope, to test the feasibility of alternative fuel systems, it is recommended to spend more time and energy on the early stages of the project, like the definition of the requirements by the customer, rather than on the detailed design phase. Often, this level of detail is not required to make a comparison of feasibility between concepts, and it is a time-consuming activity.

Setting up the set of requirements together with the customer is very important. Although this project has been relatively successful in achieving a complete set of requirements, it remains critical that the set of requirements is complete before the design phase commences, as design changes due to change of requirements are time-consuming to make. It is important to make a clear distinction between the need-to-have's and the nice-to-have's, as they may have a huge impact on the final design. During the design, concessions may need to be done to accommodate for alternative fuel systems and their requirements.

During this project, the Rijksrederij has been involved in a couple of similar projects with different requirements, which has not helped to streamline setting the requirements for this project.

During the design, it is recommended to work with short iterative loops between the different project partners and the customer, to be able to steer the design as early as possible.

Because the proposed technologies are new, the classification societies often require more time for reviewing drawings and documents. This needs to be taken into account when planning future projects.

For the Approval in Principle, it is important to note that the scope of an AiP is set by the customer. It is recommended that the designer and the classification society sit together early in the project to discuss the expectations of the AiP. For the HAZID a similar workshop would be recommended. This also limits the risk of overdetailing parts of the design while not required for assessing the feasibility of the solution.

# 6. CONCLUSION

There is a growing enthusiasm for sustainability within the Rijksrederij, and the organization needs to capitalize on that momentum.

In this project, it has been shown that a carbon-neutral state shipping fleet is achievable, if the organization and the people within the organization are willing to sacrifice on the operational requirements. A mentality shift may be required for that, but the Rijksrederij's exemplary role towards society requires the Rijksrederij to be an early adopter of these new, sustainable solutions. The Rijksrederij needs to work together with the industry to tackle the last remaining barriers such as infrastructure and the technology's proof of robustness, safety and long-term performance towards a major rollout of these new technologies. The technology suppliers are eager to supply their new products, and to work together with the customers in further development of the technology.

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