L.W. VAN INGEN AND M. B. G. CASTRO

TOWARDS A GREEN MARITIME TECHNOLOGY

ABSTRACT

In a world with growing population, urbanisation, mechanisation and thus increased energy demands in the future, in combination with the influence of fossil energy resources on global warming, the 21st century has already brought – and will continue to bring – many different challenges. The European Maritime Industry (ICS, International Chamber of Shipping) announced recently the goal of CO_2 reduction of 50 per cent in 2050 is achievable. According to the COP21 (United Nations Climate Change Conference) Paris Agreement, the whole world must be fossil-fuel free by 2080 in order to limit global warming to +2°C.

The awareness of the need for efficient use of any kind of energy source in combination with further developments and research of renewable energy and energy sources has also reached the maritime industry. OEM type companies innovate not only in fuel efficiency and product development in their own field of industry, they also work together with other innovative companies and look after synergy effects by combining innovative applications and solutions in a creative way.

With all current and new innovations in the pipeline, the questions arises: 'Can we become 100 per cent green in the maritime industry?'

In Europe, the project Joint Operations for Ultra Low Emission Shipping (JOULES) was initiated and involved many maritime industry partners. Royal IHC and dredge cycles, simulation models and assessment tools were developed and plotted against the development of fossil and non-fossil energy sources now and in the future. The results are very promising.

This paper describes the work executed and conclusions drawn from the JOULES study. The conclusions show a statement for the possibilities and impossibilities in the coming decades and in year 2050.

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Above: An artist's impression of the TSHD concept developed for the EU Research Project JOULES: an autonomous, hybrid-electric and fuel cell-driven dredging vessel.

INTRODUCTION

Global Trends

The developments of the 21st century in terms of population growth and energy demand at a global scale require a transition to renewable resources and high efficiency systems in order to fulfil human needs in a sustainable manner. In recent years, the trends observed in air and road transport emission legislation are now reaching the maritime sector as well.

Further, the measures announced in the COP21 Paris Agreement mean that all energy users need to decrease energy consumption, capture emissions and initiate the transition to renewable fuels. By 2080, this transition should be complete in order to stabilise average world temperatures at +2° C. The Paris Agreement emission path shown in Figure 1 [1] shows two possible paths for CO_2 emissions up to 2100 and their consequence on the rise of Earth's average temperature compared to the pre-industrial era. The lowest path is the one proposed in COP21 which shows the need to decrease CO_2 emissions and even capture CO_2 after 2080 in order to stabilise climate change around the +2° C limit. While the discussion on climate change is still ongoing with often much controversy, there is consensus that at some moment in the near future, fossil fuels will not be sufficient to supply global energy

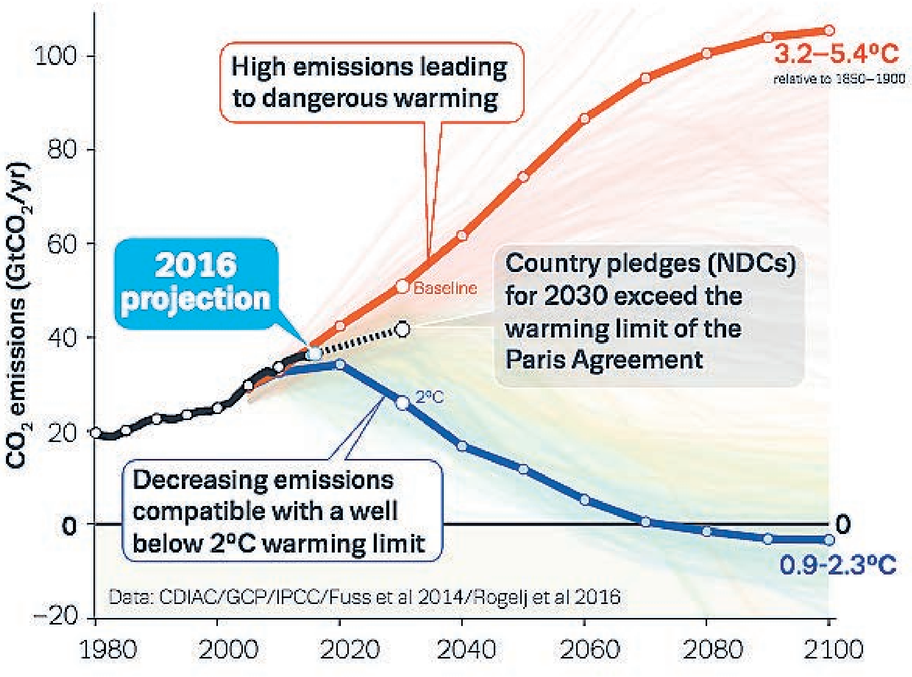

Figure 1. CO_2 emission paths up to 2100 [1].

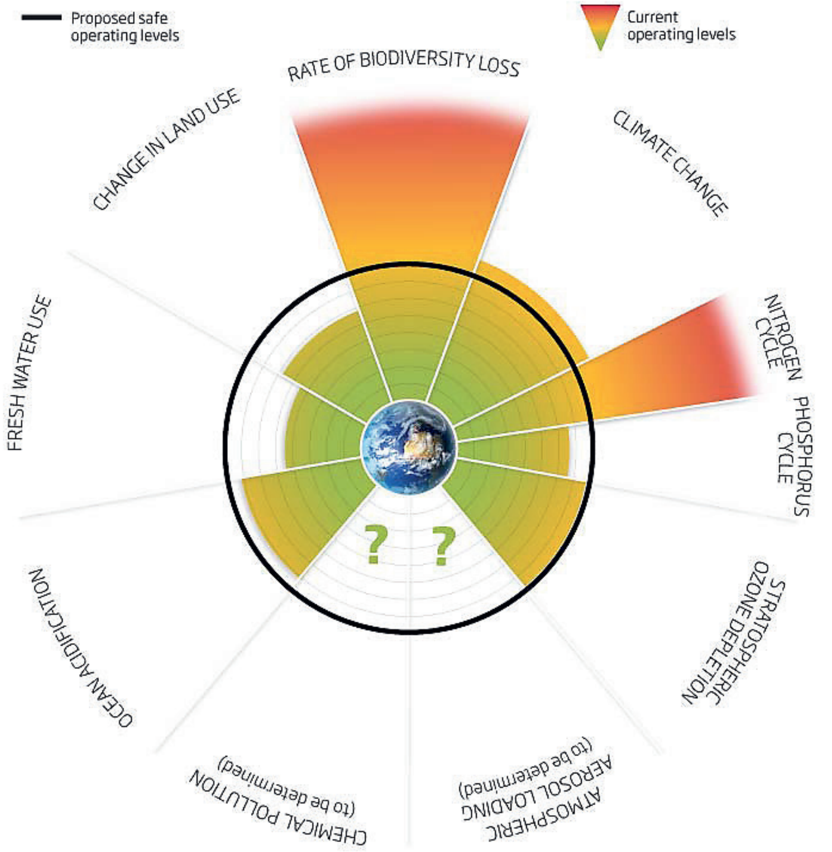

Figure 2. Beyond the boundaries: current status of nine planetary systems according to Rockström [2]. We have already overstepped three of nine planetary boundaries and are at grave risk of transgressing several others. Image © NewScientist

needs. All energy research institutes predict a mix of energy sources will be required to supply global needs by 2050 and much effort is being made to develop renewable energy alternatives that do not compete with food supply since food and water supply will be among other major challenges of the coming decades.

The ongoing climate change discussion is only focusing on climate change. According to Rockström [2], eight planetary systems are essential for maintaining life on Earth. Rockström published an article where the safe limits of the exploitation of these systems are proposed. Figure 2 shows these systems and the estimated status compared to the safe limits denoted by the inner black circle. The diagram shows humans have already exceeded or are reaching these proposed limits in most of the planetary systems, and biodiversity loss and nitrogen cycle are in fact at a further unbalance state than climate change, according to the authors. In the face of population growth and welfare increase at a world level, one realises the formidable challenges ahead of humanity in the 21st century.

DEVELOPMENTS IN THE MARITIME INDUSTRY

Efforts on Emissions and Efficiency

In line with the global trends presented above, International Maritime Organization (IMO) is introducing energy and emissions regulations which have become progressively stringent. While the emissions of NO_x and SO_x are regulated and progressively coming into force, CO_2 emissions are recently regulated in the form of the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). Steps of 10 to 30 per cent increased energy efficiency are expected for all types of commercial vessels in the coming decades. These steps are not easily achieved and recent IMO technical documents were published advising on the minimum installed power required to safeguard safety of the newly designed vessels.

Another aspect which is challenging for vessels is harbour emission regulations and regulations for the so-called ‘Special Areas’ where the emission regulation of certain contaminants is even stricter. Many harbours established very

Figure 3. The Stena Germanica was converted to Methanol under Lloyds Register classification in 2015.

Figure 4. The Viking Prince is one of many existing LNG-powered PSV vessels.

Figure 5. The hydrogen-powered catamaran built by Cheeta Marine.

Figure 6. The Power Cube from Redox Power is a SOFC fuel cell being used as a UPS system.

stringent regulations which in practice require often changes of fuel during harbour approaching and docking. Cold ironing has been suggested as a solution for harbours, but existing cold ironing infrastructure is not sufficient and the associated costs – roughly twice the cost of on-board power production – are not attractive. In the maritime sector as well, clean competitive solutions are needed for the existing typical maritime fuels. Natural gas, methanol and hydrogen, batteries and synthetic diesel are a few examples of alternative fuels that have lower emissions and can be produced using renewable resources. Figures 3, 4 and 5 show some examples of vessels exploring the use of those alternative fuels. These developments are started at a limited scale and after success, are scaled up to the maritime sector. Figure 6 shows a commercially available Solid Oxide Fuel Cell (SOFC) which can use a variety of fuels to produce electricity and has very low emissions due to the combustion-free chemical process taking place inside the fuel cell. These technologies will be more frequently considered and applied in the maritime sector after upscaling.

Dredging vessels are exempt from the IMO EEDI regulations for the time being, together with another few vessel types, but subject to the NO_x and SO_x regulation. Upon publication of the EEDI regulation draft, the European Dredging Association (EuDA) concluded the definitions used could not apply to work vessels and a differentiated method was needed. EuDA established a work group called Task Group Emission Figures (TGEF) in order to investigate how a CO_2 index would apply to dredging vessels. This group collected publicly available data and established a CO_2 index calculation method which would be acceptable for the dredging industry. The main conclusions were published in the EuDA position paper [3] which stated dredging vessels are quite particular as they do not only transport goods but they also perform specifically needed tasks which were not included in the standard EEDI definition. Further, the project specifics – soil type, depth and sailing distances – dictate the final CO_2 emissions, so even within the dredging market there is no ‘one size fits all solution’, and supporting the establishment of a GHG fund for the maritime sector as a monetary stimulant for efficiency.

Figure 7. Royal IHC's hull and bulb design which reduces wave and fuel consumption.

Figure 8. The Minerva is the first TSHD sailing on LNG in the world.

In order to prepare for the anticipated changes, Royal IHC as well as maritime suppliers worldwide have been developing technologies to reduce the fuel consumption of its vessels, as fuel saving is translated into cost savings for dredging operators. A few examples of these efforts have been going on for more than 20 years now, including the hull design with the typical IHC bulb which reduces fuel consumption by roughly 20 per cent (see Figure 3) and developments such as the high efficiency pump series to increase efficiency from 70 to above 80 per cent in the Best Efficiency Point (BEP).

Another significant development is the design and launch of the first dredging vessels working on LNG (see Figure 7), the 3,500 cubic metre Trailing Suction Hopper Dredger (TSHD) Minerva and the 7,950 cubic metre TSHD Scheldt River are both built for the DEME group (see Figure 8). After these two vessels, another two larger TSHDs are now being engineered and will be built in the coming years, with respectively 8,000 cubic metres and 15,000 cubic metres. In fact, Royal IHC has performed even small trials with fuel cells as auxiliary power supply to investigate the practical integration aspects of novel fuels (see Figure 9).

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graduated in Naval Architecture and subsequently studied Offshore Hydrodynamics and Business Administration. He worked as designer and engineer, onshore as well as offshore, and held various management positions in engineering companies and shipyards. In 2012 he returned to Royal IHC in the function of Sales Manager Northern America and Vice President of IHC America.

BERNARDETE CASTRO
graduated in Mechanical Engineering at the Technical University of Lisbon, Portugal, and obtained her PhD in Sustainable Product Design at the Delft University of Technology, the Netherlands in 2005. After a period as Lecturer at the Rotterdam University of Applied Sciences, she joined Royal IHC in 2006. There, she has been since involved in a number of Product Development and R&D projects in the areas of drive technology, materials fatigue and sustainability. She is currently project manager R&D at IHC MTI, the knowledge institute of Royal IHC.

Figure 10. Overflow in a typical dredging vessel shows the turbulent flow with air inclusion.

Other emissions being addressed by Royal IHC include the release of fines to the water during dredging – called turbidity – and the underwater sound (see Figure 10). A novel type of overflow design – the airless overflow – combined with careful positioning of the overflow installation on the ship can reduce turbidity significantly. IHC has also performed studies and measurements on underwater sound in order to investigate the principal sources and frequency ranges. Underwater sound is very important in offshore works such as dredging and pile driving and IHC developed a low underwater sound level installation that proved to be very effective (see Figure 11). A recent publication [4] indicates the growing concern regarding the acoustical effects of dredging works and makes a good overview of studies and methods to apply.

Figure 9. Test with a PEM fuel cell as auxiliary power – which uses hydrogen – during sea trail of a Beaver 40.

The developments described above show that at a global level, the maritime industry and its equipment suppliers are making significant efforts to improve the efficiency and environmental performance of vessels. However, despite the significant efforts which are ongoing, the requirements for zero CO_2 emissions by 2080 – as established at the Paris Agreement – are still far out of reach by current measures. A more radical design of the power supply systems is needed as well as the substitution of fossil fuels by alternative renewable fuels. In order to address this challenge, IHC participated in a large European Union (EU) project to research the possibilities of achieving very low emission concepts and a selection was then developed and simulated. The concepts described in the next session represents the effort being undertaken in the EU-funded Joint Operation for Ultra-Low Emission Ships (JOULES) project.

THE DREDGING VESSEL OF 2050

The JOULES Project

Initiated in 2013, the JOULES project concluded in May 2017. A large number of partners from the industry and knowledge institutes joined efforts to develop advanced ship concepts and methods to access the efficiency and environmental performance of those concepts. Goals for CO_2 emission reduction were defined for all ship types included in the project. Simulation models of the various driveline components were developed in a platform that allowed common use by most existing simulation software. The models were developed by the Equipment Suppliers in the project. These models could be coupled easily in order to simulate a driveline and estimate the fuel consumption and emissions. The involved universities had the specific task of quality control of the models supplied.

Further, an environmental-economic assessment tool has been developed to access the environmental performance of the vessel concepts and provide a rough estimation of the economic aspects involved: costs, revenues

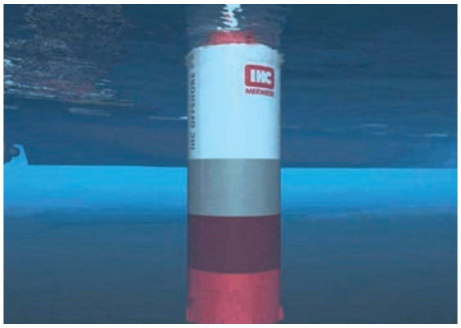

Figure 11. The 'IHC Hydrohammer' is a pile driving installation with reduced noise levels to allow for pile driving even in the more sensitive areas.

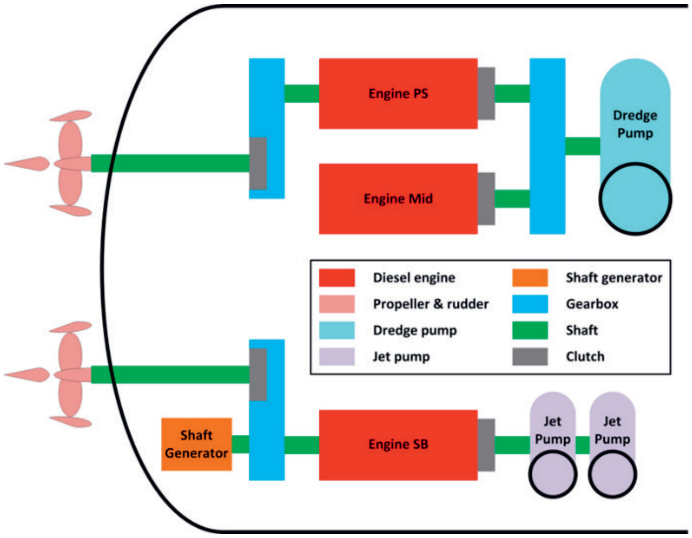

Figure 12. Layout of the driveline of the baseline TSHD.

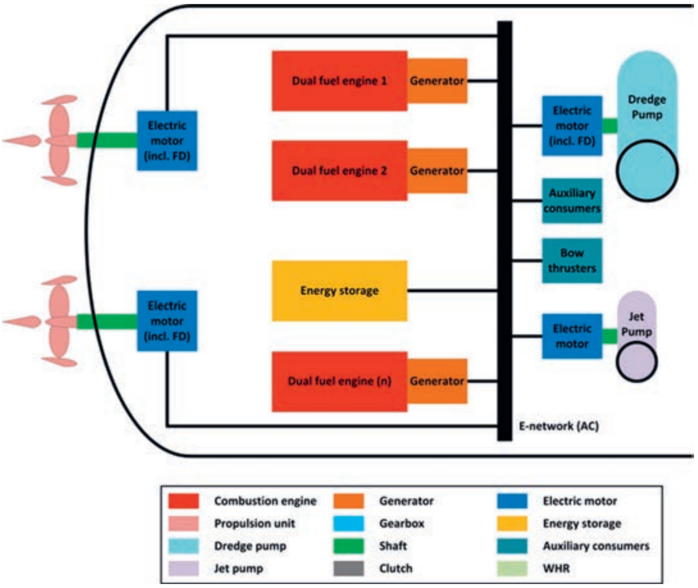

Figure 13. Layout of the driveline of the 2025 concept.

Table I. Baseline Vessel

Length (Loa)	96.50 m
Length (Lpp)	84.95 m
Breadth	21.60 m
Depth	7.60
Gross Tonnage	5100 GT
Design speed	12.3 knots
Suction pipe diameter	1000 mm
Hopper capacity	5600 m^3
Machine type/-concept	Diesel direct
Total installed power	7,926 MW
Maximum power on dredge pumps	4,05 MW
Rated generator power	1,633 MW
Maximum power on propeller	4.05 MW
Propeller type	CPP
Bow thruster power	0.45 MW
Deadweight	8106 ton
Cabins No.	15
Decks No.	3
Special Equipment	Dredge pumps, jet pumps, heavy winches, gantries

and Net Present Value (NPV). This tool, called Life Cycle Performance Assessment (LCPA) tool, included the most significant impacts caused by ship emissions to air, according to standard Life Cycle Assessment (LCA) methodology. Furthermore, a database of alternative fuels has been built, including the energy required to produce the fuels, their emissions due to utilisation and the expected fuel costs in the future, in a range from low to high as the uncertainty increases when one looks further into the future. This allowed for the exploration of the combination driveline-fuel that might be feasible in 2050 for certain vessel types.

CASE DESCRIPTION: DREDGER

Royal IHC used a TSHD as a case study, as it is a particularly difficult vessel type to achieve high CO_2 reductions due to the high installed power and intense load peaks characteristic to dredging under sea conditions. A baseline was established, choosing a vessel driveline that was state-of-the-art for diesel-direct driveline types at the time of the project initiation. Two concepts were then developed: one for 2025 (near future), and one for 2050 (far future) that would represent the most advanced practicable technologies and design that can be currently foreseen. The CO_2 emission goals established for 2025 and 2050 were respectively 20 and 40 per cent.

BASELINE

The baseline was a mid-size TSHD with diesel-direct propulsion. The specific driveline design of the baseline is already quite optimal as this vessel uses three main engines that can be switched on and off, allowing different configurations for sailing, dredging and discharge. See Table I for the main particulars of the baseline vessel.

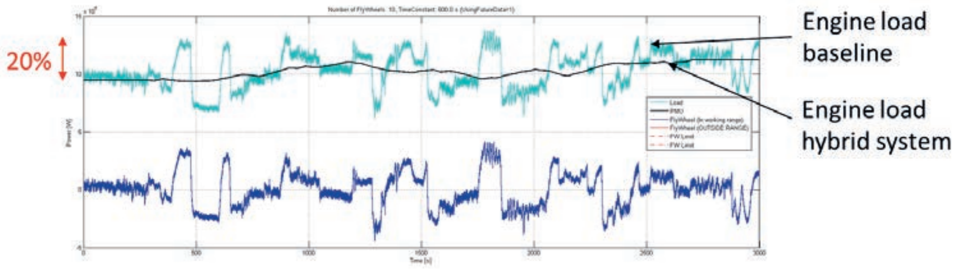

Figure 14. Dynamic simulation showing the peak shaving effect of the flywheel system: light blue: baseline engine load; black: engine load with hybrid system composed of 3 x 100 kW flywheels; dark blue: flywheel load.

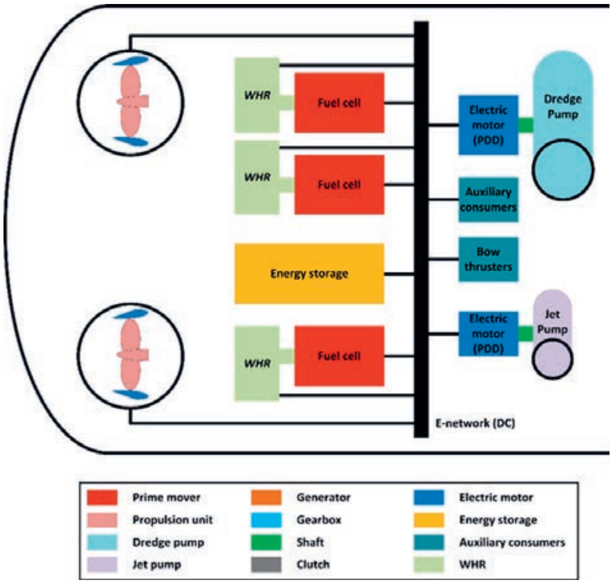

Figure 15. Layout of the driveline of the 2050 concept.

Figure 16. A 3D impression of the 2050 concept shows the unmanned vessel with fuel cell drive and hub-less propellers.

2025 CONCEPT

The 2025 concept was meant to use currently available technologies and combine those in a way to achieve the CO_2 reduction goals established in the project for 2025. The driveline was based on an hybrid dual-fuel power supply, a gas engine with diesel as pilot fuel allowing for two operation modes. Gas mode uses methane and diesel as pilot fuel and diesel mode uses only diesel, introducing energy storage and an electrical DC grid for power distribution to all users. The energy storage device chosen was a flywheel. Earlier studies showed that a flywheel is well-suited for the shape and duration of the load peaks characteristic of dredging. Additionally, this is the energy storage device which currently allows the lower investment costs per installed power. In Figure 14, the results of the dynamic simulations with a flywheel system are shown. Due to the peak shaving effect, the installed power on the engines can be 20 per cent lower compared to the baseline, for the same dredging and sailing performance, one can go as far as 30 per cent, but a large number of flywheels is required, what is not practical. Combined with the use of a cleaner fossil fuel, important fuel savings and emission reduction are achieved.

2050 CONCEPT

This concept was defined based on the most advanced power supply technology expected to be in place by 2050: the fuel cell technology. The fuel cell's main power supply added energy storage to accommodate load peaks. When using a fuel cell, a hybrid driveline is essential as the fuel cell must be protected from load peaks. Further, a hub-less propeller is used (see Figure 16), that has an estimated 20 per cent higher efficiency than conventional propellers and the vessel is unmanned, reducing the air resistance and the need for advanced human-related life support and safety infrastructure on-board. These design choices lead to a vessel with an installed power of 40 per cent lower than the baseline vessel. This reduction can go further when a fuel cell is coupled with a so-called bottom cycle such as a gas turbine, gas engine and steam cycle. In this configuration, theoretical models show a total efficiency of 70 to 80 per cent is achievable, however, this complex power supply could not be modelled so a simpler fuel cell model with 50 per cent efficiency was used. Figure 12 shows the driveline layout while Figure 13 and Figure 14 show 3D impressions of the 2025 and 2050 concepts respectively. Unmanned, the concept reduces the on-board systems to the minimum for the functional purposes of a TSHD.

OPERATIONAL PROFILE

The operational profile was modelled in the simulations with its specific duration and energy requirements. The TSHD has four main operating modes based on the average time spent on specific dredge cycle task:

• Free sailing empty (including manoeuvring empty)	30%
• Dredging	25%
• Free sailing full (including manoeuvring full)	30%
• Discharging (mix of shore pumping, dumping and rainbow)	15%

Discharging can be done in three methods: via a shore connection (most common), rainbowing (when necessary) and dumping (when possible). However since the shore pumping method is most common, this main discharge method is used in the JOULES project.

The operational profile and engine loads can vary with specific project conditions such as distance between dredging and discharge locations, resulting in a relatively larger amount of time for sailing. For the same operational profile, power demand can also vary strongly with soil characteristics and weather conditions.

In the JOULES project, several operational profiles based on real measured dredging cycles are used for the simulation and evaluation of the baseline as well as 2025 and 2050 drive systems when using energy storage. For the first simulations, the loads shown in Table II were assumed, according to a standard CO_2 index calculation method proposed by EuDA.

Table II. Operational profile of the dredging vessel and required power.

Input baseline (from measurements)						
	Time	Speed (knots)	Propulsion power (kW)	Dredge pump power (kW)	Jet pump power (kW)	Total power (kW)
Sailing empty	30%	13	3800	0	0	3800
Sailing loaded	30%	12.5	3800	0	0	3800
Dredging	25%	3	3100	2200	650	5950
Discharge	15%	0	850	1800	650	3300
Input 2025 concept						
	Time	Speed (knots)	Propulsion power (kW)	Dredge pump power (kW)	Jet pump power (kW)	Total power (kW)
Sailing empty	30%	13	3040	0	0	3040
Sailing loaded	30%	12.5	3040	0	0	3040
Dredging	25%	3	2840	1760	520	4760
Discharge	15%	0	640	1440	520	2640
Input 2050 concept						
	Time	Speed (knots)	Propulsion power (kW)	Dredge pump power (kW)	Jet pump power (kW)	Total power (kW)
Sailing empty	30%	13	2280	0	0	2280
Sailing loaded	30%	12.5	2280	0	0	2280
Dredging	25%	3	1860	1320	390	3570
Discharge	15%	0	510	1080	390	1980

Table III. Overview of the installed power of components in the driveline models.

Baseline		2025		2050	
Component	Power (kW)	Component	Power (kW)	Component	Power (kW)
Diesel engines	6075	DF Engine	5000	Fuel Cell	5000
Flywheel	-	Flywheel	300	Flywheel	1000
WHR	-	WHR	-	WHR	2000

Table IV. Comparison of the performance of the baseline and the concepts: total emission and relative.

Emissions (kg/h)	Baseline	2025	2050
CO_2	326	253	0
SOx	59	0.24	0
NOx	34	6	0
PM	0.17	0.31	0

Emissions (%)	Baseline	2025	2050
CO_2	100%	78%	0%
SOx	100%	0.4%	0%
NOx	100%	18%	0%
PM	100%	181%**	0%

** Calculation error

SIMULATION RESULTS

The installed power of major components used in the simulations is shown in Table III and the results from the models in Table IV. Though the 2025 system was 20 per cent smaller in installed power, a maximum 22 per cent CO_2 emission reduction is achieved. SO_x and NO_x emissions are also reduced and PM emissions are expected to be reduced in practice due to the use of gas as fuel in 2025. However, a

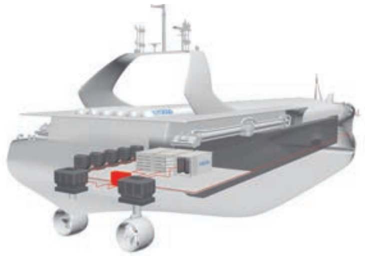

Figure 17. A 3D impression of the driveline components of the 2050 concept in the hull.

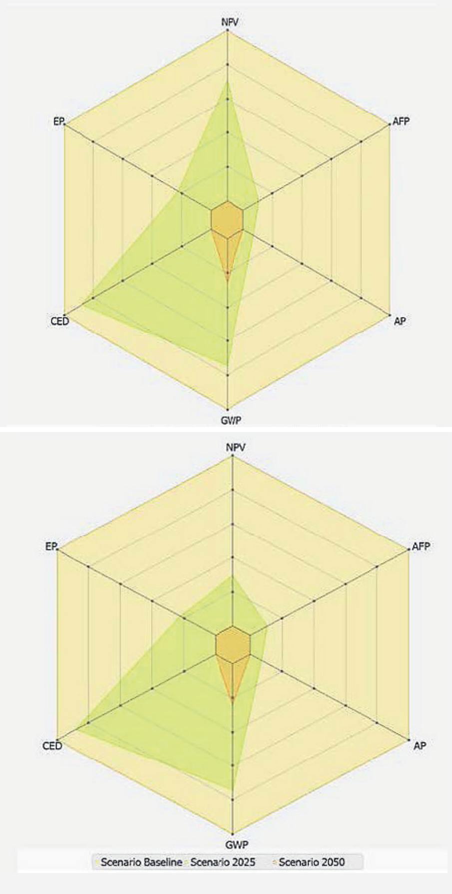

Figure 18. Spider web diagram of the KPI results for the three concepts excluding external costs (top) and including external costs (bottom).

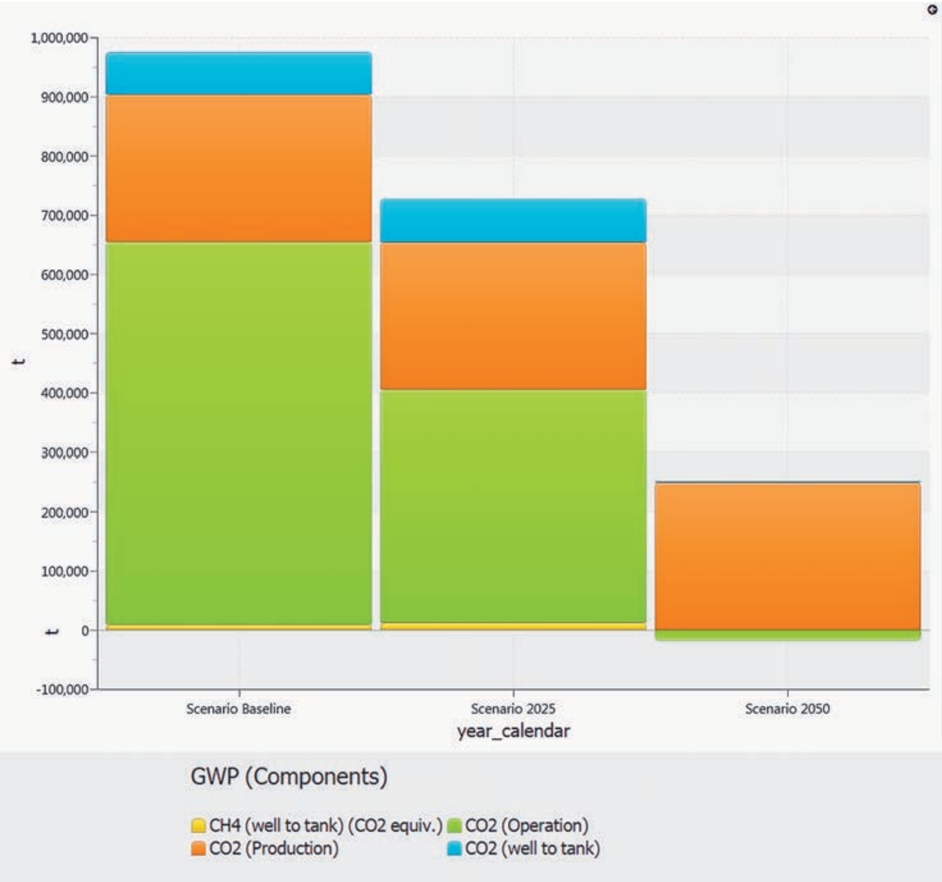

Figure 20. GWP contribution by the lifecycle components: fuel production (well to tank), vessel production (Production) and operational phase (Operation).

small problem in the simulation model led to an increase in the modelled values. In the 2050 concept, a CO_2 reduction of 100 per cent is achieved due to the use of hydrogen as a fuel (see Figure 17).

ENVIRONMENTAL ASSESSMENT

Key Performance Indicators (KPIs) show how a concept performs relative to the baseline. In the LCPA tool, six KPIs have been defined to evaluate the performance, of which five are dedicated to the environmental performance and one to the financial performance:

- Aerosol Formation Potential (AFP)
- Acidification Potential (AP)
- Global Warming Potential (GWP)
- Cumulative Energy Demand (CED)
- Eutrophication Potential (EP)
- Net Present Value (NPV)

Table V. KPI values for the baseline and concepts: absolute and relative scores.

KPI	Baseline	2025 Design		2025 Design	
	Value	Value	Relative (%)	Value	Relative (%)
AFP (t)	19.8	2.1	-89%	0	-100%
AP (t)	24.3	1.7	-93%	0	-100%
GWP (t)	974.7	727.0	-25%	246.2	-75%
CED (GW *h)	2.8	2.4	-12%	0	-100%
NPV (kEUR)	-144.5	-42.2	-71%	14.2	-110%
EP (t)	1.4	309.0	-78%	0	-100%

These indicators are commonly used for environmental assessment. The tool KPI calculation methodology report is available in the project website (http://www.joules-project.eu/Joules/results). The tables and figures show the environmental assessment results. According to these results, the concepts 2025 and 2050 have a far superior environmental performance and a spider web diagram (see Figure 18) visualises the reduced area.

According to this tool, the CO_2-eq GWP reduction was 25 per cent for the 2025 concept and 75 per cent for the 2050 concept. In fact, Figures 18 and 19 show that according to the LCPA tool, most of the GWP emissions originate in the vessel production, due to the production of the materials needed for the vessel. The simple data set is based on current energy and emissions for materials production, without consideration of possible renewable energy use for materials production. Also in the other KPIs, both concepts perform much better. The driveline concepts surpass the goals defined in the project, achieving nearly zero emissions, to show good environmental performance will be technically feasible in the future (see Figure 20).

ECONOMIC ASSESSMENT

Net Present Value and the Effect of External Costs

The economic assessment is based on the investment costs, end-of-life costs, and operational costs and revenues, which in the model are respectively the fuel costs and the dredging revenues. The fuel price projection has been taken from the JOULES fuel table which has been defined and documented as part of internal document D21.1.

For the revenues, an estimation of yearly based revenue was made, based on the typical payback time of this type of vessel, about 2 to 3 years. A discount rate of 10 per cent was used in the NPV calculation.

The economic assessment was made in two ways. First, excluding external costs and second, including external costs. External costs are costs related to several emissions and are not carried by the vessel owner but by Society. For example, CO_2 costs are costs induced by climate change due to the CO_2 emission and NO_x costs are costs induced in the local communities related to the loss of life or productive years spent with respiratory diseases of communities living in coastal areas. These costs are being implemented in the policies step by step, so it is expected they are in place by 2050 (EC 2014). The values used were the average values in the LCPA tool as in some cases, the width band of the external costs is very wide. These costs are summed up in the KPI NPV. Table VI shows the inventory of costs in the LCPA model, discounted. Cost levels of the three design alternatives are presented, and included also the external costs. The external costs implemented in the LCPA tool were calculated according to EC guidelines for external costs for the transport sector (EC 2014).

As Table IV and Figure 18 show, the external costs are very significant for the dredger case. When the external costs are included, the values shift considerably within the KPI. Figure 21 shows the NPV development in time and Figure 22 shows the costs per cost component. The external costs have the same order of magnitude of the direct costs, so they are expected to become a significant part of the

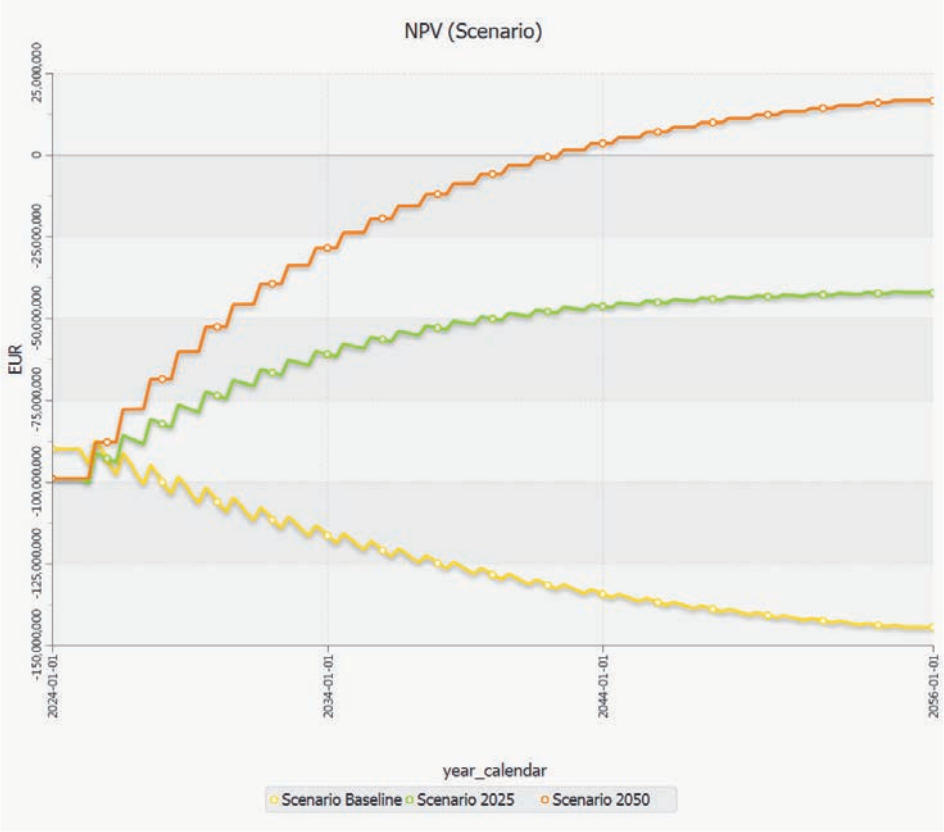

Figure 21. NPV scenario: NPV development during the lifecycle considering external costs.

Table VI. Inventory of discounted costs for all concepts.

Costs Type (Euro)	Baseline	2025 scenario	2050 scenario
	Internal costs		
Investment costs (Discounted)	-180.000.000	-198.000.000	-198.000.000
Operation costs (Discounted)	0	0	0
Operating Revenues (Discounted)	226.500.000	226.500.000	226.500.000
Operating Urea costs (Discounted)	0	0	0
Operating Fuel Costs (Discounted)	-96.400.000	-63.800.000	4.000.000
End-of-Life Costs (Discounted)	-95.000	-95.000	-95.000
End-of-Life Revenues (Discounted)	0	0	0
	External costs		
External costs CO_2 (Discounted)	-63.200.000	-38.500.000	1.100.000
External costs NO_x (Discounted)	-49.600.000	-10.400.000	1.000
External costs PM10 (Discounted)	-35.200.000	-57.000	0
External costs SO_x (Discounted)	-90.400.000	-45.000	0

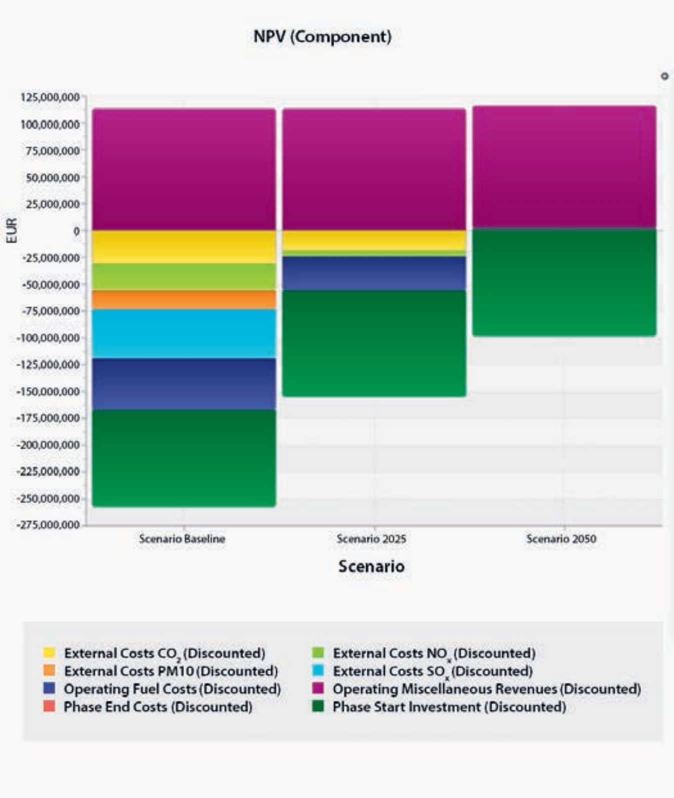

Figure 22. Total costs for the three concepts, including the external costs.

economic assessment once these are implemented and might compensate for higher fuel costs. Figure 21 shows the NPV development of the three cases over time, including the effect of external costs. In this scenario, it is visible that the concepts 2025 and 2050 have a better NPV development over the years, quickly overcoming the baseline.

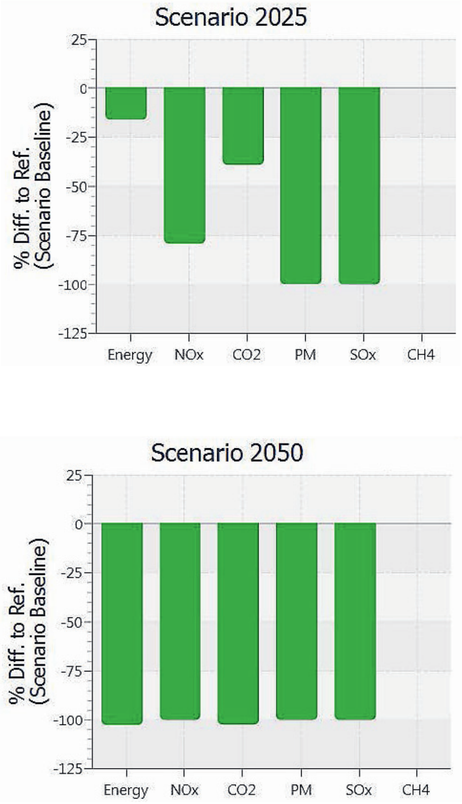

Figure 23. Emissions values compared to the baseline: operational phase.

CONCLUSIONS

This article shows the challenges for the maritime industry and the efforts this industry as well as Royal IHC has been undertaking to prepare for these changes.

Within a EU-funded R&R project, a number of alternative concepts for TSHD drivelines has been defined to address the emission goals of the future. The concepts have been evaluated and the results show that very green vessels are technically feasible in the future. The technologies used exist now at small scale and are upscaling to achieve the high installed power needed in the maritime sector. The concepts largely exceed the project GWP reduction goals, achieving at least 75 per cent reduction for the 2050 concept.

The use of renewable fuels and fuel cell technology (combined with energy storage and power management) shows large advantages in terms of emissions, and it is therefore a powerful way to address the sustainability issues of the maritime sector in the future, when combined with an efficient driveline design. These advanced drivelines are complex and often the design efforts met the applicability boundaries of simple modelling tools, leading to the need for more complex modelling and design which includes the dynamic aspects of load profiles.

The investment costs are still high for these novel technologies and fuels, and fuel cost developments are uncertain. This introduces high risks for these types of innovation. These developments should be stimulated by policy making and industrial cooperation. External costs are being discussed and are expected to be implemented in the future, an example is the GHG fund discussed at IMO. The effect of external costs is significant for the dredger case in the near future, and will influence the power supply and fuel choices.
The development of the related policies must be followed closely and these costs should be included in the design tools in order to prepare for these future aspects.

Dredging vessel concepts that are nearly 100 per cent green GWP according to the Paris Agreement and have very low emissions of other harmful components will be technically feasible in the future. In order to achieve these levels of environmental performance, technological developments must be coordinated with political efforts to guarantee economic viability of the maritime sector.

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