Green Shipping Programme

A GREENER WORKHORSE

PILOT REPORT - FEASIBILITY STUDY

Abstract

Growing recognition of the threat posed by man-made climate change has spurred government institutions, industry, and science to find clean fuels to power economic activity. Deep-sea container vessels consume large amounts of fuel and is a considerable contributor to global maritime emissions. There are around 700 vessels in the container segment 2000-3000 TEU, each consuming around 110 tonnes of fuel everyday! The intention of this pilot project is to investigate the technical and economic feasibility of retrofitting a 2,500 TEU deep-sea container ship to run on methanol as the current maturity level of methanol fuel technology is higher than those of other renewable fuels. Due to high cost of renewable fuels, the study will also consider energy efficiency measures such as battery hybridisation to reduce fuel consumption as much as possible. The aim of the study is to execute a thorough techno/economical and safety pre-study of emission reduction, including products to choose and activities needed as a first step towards realisation.

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Green Shipping Programme

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Executive Summary

Is it technically possible and economically feasible to convert a midlife container vessel to operate on green methanol? Alternatively, what other fuel-saving investments could solve the same task, reducing CO2 emissions sufficiently to meet existing and future CII requirement?

The study concluded that conversion of main and auxiliary engines, including installation of methanol fuel tanks and methanol fuel supply system is possible today. Rules and regulations are also in place for such conversion.

In Sealand Philadelphia's present trade, the availability of green methanol is not yet developed. High cost of conversion and present significant cost of bio and e-methanol makes conversion of a midlife vessel less attractive.

The alternative path – fuel-saving initiatives—appears to be more sustainable for a midlife container vessel having large power demand for reefer containers. An extensive fuel saving conversion offers less fuel cost and extended CII compliance. At end of life, biofuels can be introduced for additional lifetime extension.

Pilot Project Introduction

According to IEA, the global CO2 emissions was at a level of 36.3 GT in 2021. Out of this, 7.65 GT came from transport. Emissions from shipping was 0.84 GT, or 840.000.000 tonnes CO2 (2.3%) of total emissions, making maritime transport very efficient as 90% of goods are transported by sea. With that said, the maritime sector has to do its part to save the planet, hence the increased focus on emission reduction throughout the industry. In maritime, 85.5% of the GHG emissions come from container vessels, bulkers, and tankers in international trade.

WHY CONSIDER RENEWABLE METHANOL?

Growing recognition of the threat posed by man-made climate change has spurred government institutions, industry, and science to find clean fuels to power economic activity. In this context, renewable methanol has risen as a clean alternative to fossil fuels, offering a clear pathway to drastically cutting emissions in power generation, overland transportation, shipping, and industry.

Compared to fossil fuels, renewable methanol reduces carbon emissions by 65 to 95%, depending on the feedstock and conversion process. That's one of the highest potential reductions of any fuel currently being developed to displace gasoline, diesel, coal, and methane. Additionally, the combustion of pure methanol produces no sulphur oxides (SOx), low nitrogen oxides (NOx), and no particulate matter emissions.

Tankers carrying methanol as cargoes have been successfully using dual-fuel 2-stroke methanol engines for propulsion since 2017 and Thome Group has managed such vessels with great success for the past seven years. In other words, methanol has been used as main fuel onboard deep-sea ships for some years and the maturity level is quite advanced compared to other fuel technologies. In DNV's Maritime Forecast to 2050, it clearly shows that the current maturity level of methanol fuel technology is higher than those of ammonia and hydrogen. For ammonia, we see developments of 2-stroke and 4-stroke engine technologies on parallel paths enabling uptake in deep-sea and regional short-sea shipping. For hydrogen, the timeline reflects that short-sea shipping is expected to be instrumental in maturing the technology. Consequently, the development of fuel cells and 4-stroke engines are ahead of other hydrogen energy converters. The new fuels have reached different level of regulatory maturity – with methanol regulations for onboard use being the most mature and hydrogen being the least mature of the three fuels assessed (fig. 1).

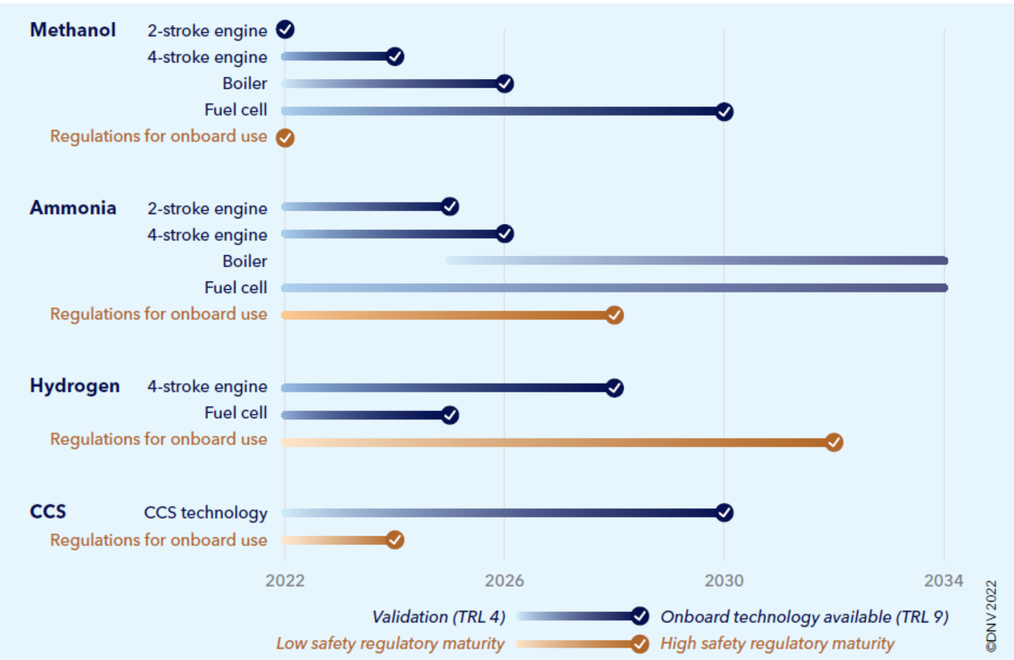


Fig 1. Estimated maturation timelines for energy converters, onboard CCS technologies, and corresponding safety regulations for onboard use (Source: DNV Maritime Forecast to 2050)

With increased interest in methanol as fuel for other deep-sea ship applications as well, the commercially available product range is expected to increase. Retrofit options for 2-stroke engines are also available, being one of the reasons for this study.

In addition to this, there is an increased interest in methanol as fuel from shipowners operating in segments where 4-stroke engines are the preferred choice. This has triggered a technology development from manufacturers aiming to serve both the newbuilding market and potential retrofits, also for 4-stroke engines, and in the case of this project being considered for the auxiliary engines.

LEGISLATION DRIVES CHANGE

Government legislation on emissions has created challenges for those who need to comply, opening new markets and opportunities for alternative fuels, including renewable methanol. Europe's first biofuel policy was introduced in 2003, setting blending targets for 2010. This policy was integrated in the Renewable Energy Directive (RED) in 2009, which set an obligation of 10% renewable energy in transport for 2020. In 2018, the European Parliament, Council and Commission agreed on the Renewable Energy Directive II (RED II), requiring 14% renewable energy to be used in transport by 2030. RED II has created new markets for conventional biofuels like ethanol and biodiesel and for alternative biofuels such as renewable methanol, especially when made from wastes, residues, or renewable electricity (Renewable Energy Directive II, Annex IX Part A). Please see Annex 1 for more information.

Other European policies also impact the potential uptake of renewable methanol:
the Fuel Quality Directive, Alternative Fuel Infrastructure Directive, and Air Quality Directive, among others.

The USA introduced the first biofuel policy in the form of the Energy Policy Act in 1992 (Annex 2). Its objective was reducing dependence on oil imports, increasing energy security, and improving sustainability.

In 2007, the United States introduced the Renewable Fuel Standard (RFS), requiring a minimum volume of biofuels to be used in the national transportation fuel supply each year. The total renewable fuel requirement is divided into four separate, but nested categories. These are: total renewable fuels, advanced biofuels, biomass-based diesel, and cellulosic ethanol. Each has its own volume requirement. To qualify for the advanced biofuels category, a fuel must reduce lifecycle greenhouse gas emissions by 50%. To qualify for the cellulosic and agricultural waste-based biofuel subcategory, fuels must reduce lifecycle greenhouse gas emissions by at least 60%.

Beyond national policies, some industries, such as the marine sector, have also introduced their own mandates. The International Maritime Organization (IMO) introduced Emission Control Areas to significantly reduce SOx and NOx emissions. In 2018, the IMO also announced its aim to reduce CO2 emissions from the sector by 50% by 2050.

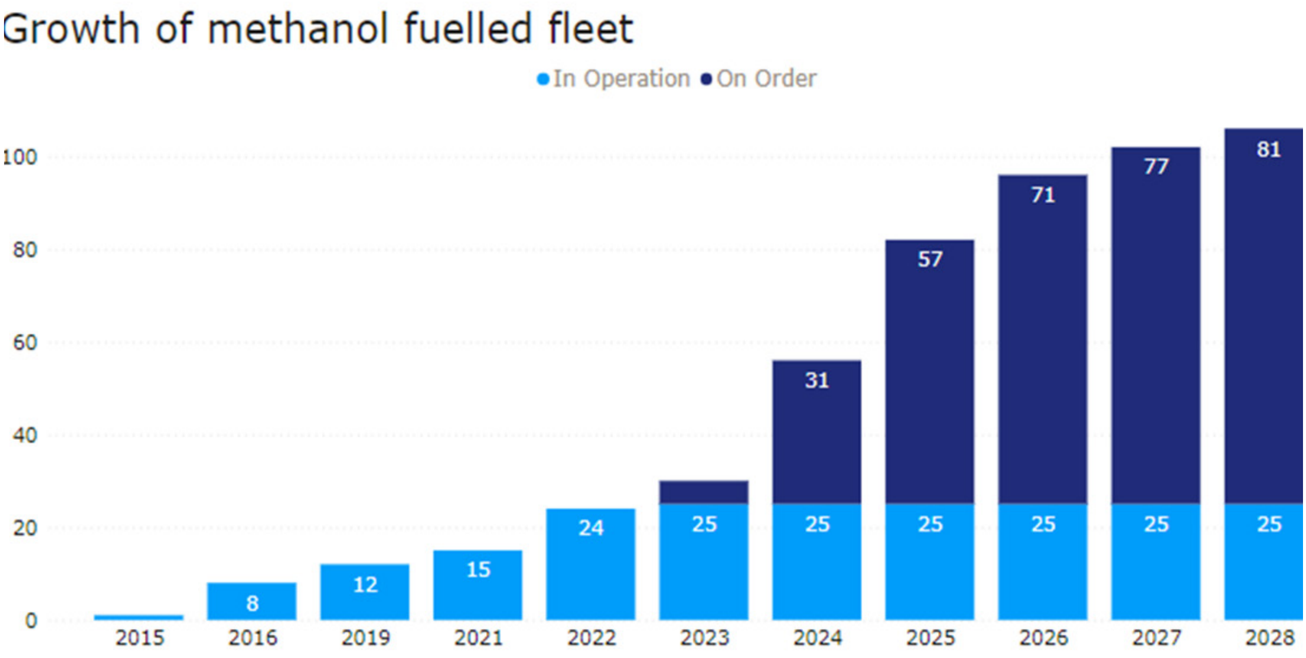


Fig 2.
Growth in methanol fuelled vessels since 2015 – Source: Alternative fuels Insight, DNV

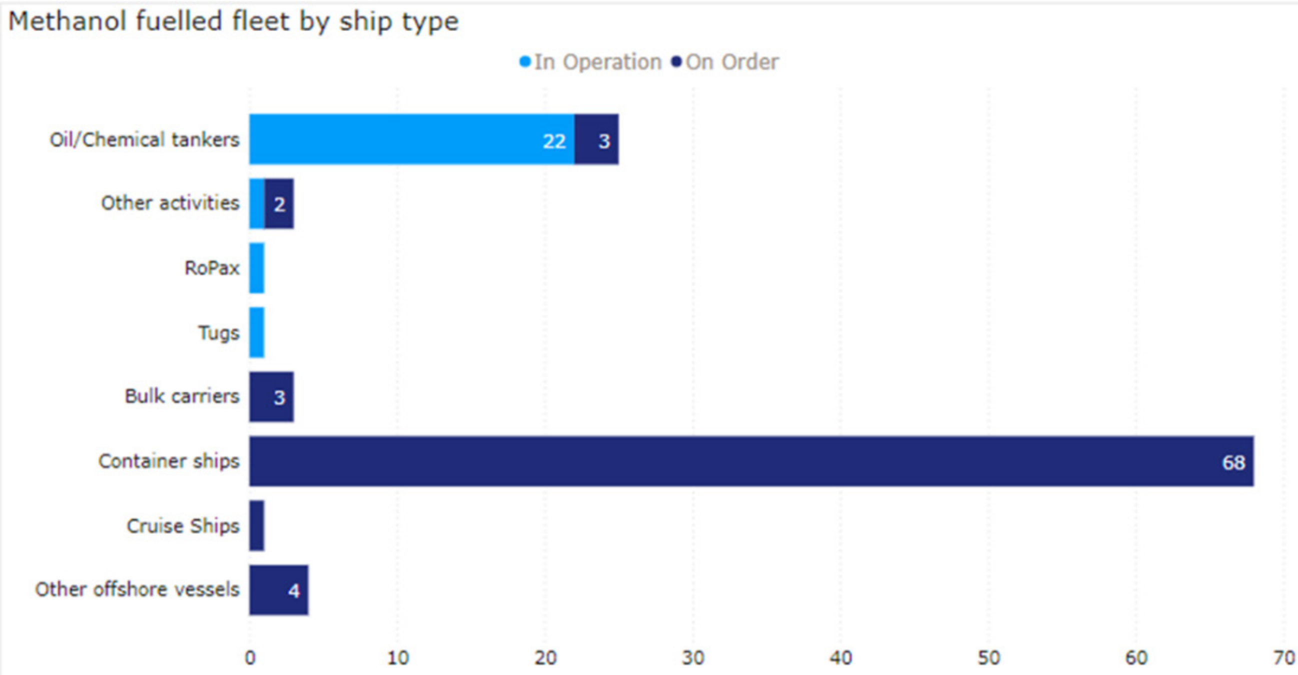


Fig 3.
Growth in order of methanol fuelled vessels by vessel type (Source: Alternative fuels Insight, DNV)

Deep-sea container vessels consume large amounts of fuel and is a considerable contributor to global maritime emissions. There are around 500 vessels in the container segment 2.000 - 3.000 TEU, each consuming around 110 tonnes of fuel everyday. Thus, identifying effective ways to curb these emissions is a priority. Methanol has been pointed to by key stakeholders and analyst as a potentially viable fuel for decarbonizing shipping. The intention of this pilot project is to investigate the technical and economic feasibility of retrofitting a 2,500 TEU deep-sea container ship to run on methanol, in combination with energy-efficiency measures such as battery hybridisation. The aim of the study is to execute a thorough techno/economical and safety pre-study of emission reduction, including products to choose and activities needed as a first step towards realisation.
Thome Group, together with their principal SinOceanic Shipping, selected MV “Sealand Philadelphia” for this study. The main reasons behind the selection are:

1. The vessel is built in 2008 – the year used as benchmark for reduction of maritime carbon emissions.
2. Under normal circumstances, this vessel is now around mid-life. What changes can be done to reduce emissions in economical responsible way? Can the lifetime be extended based on investments done?

3. Variable operational profile; hence suboptimal operational speed vs. design speed
4. MV "Sealand Philadelphia" represents most of the deep-sea vessels, 2-stroke main engine for propulsion and 4-stroke engines for power generation, consuming traditional fuel.
5. The onboard power demand is variable due to varying number of reefer containers; scrutinize opportunities for hybridisation.
6. Project findings can be considered for most larger vessel segments.
7. A good showcase/benchmark for the maritime industry (technical, economic, and political)

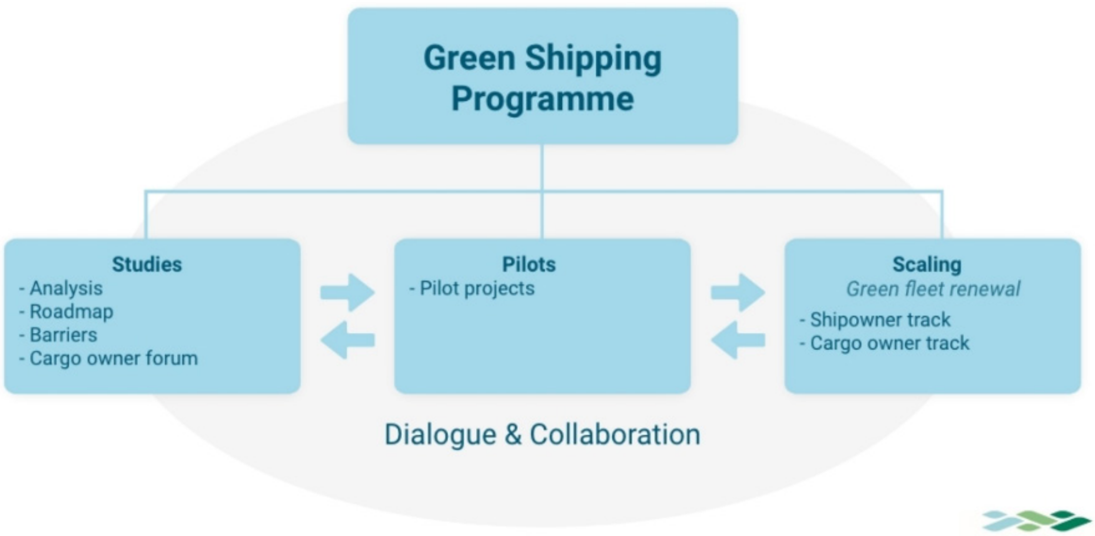
WIDE COLLABORATION

This report is a product of collaboration in its true sense. Thome Group and SinOceanic Shipping are the project owners and the feasibility study is carried out under the umbrella of the Green Shipping Programme.

Thome Group is recognized as one of the world's leading independent international ship managers with offices and agents worldwide and offers a wide range of services that are comprehensive, innovative, and delivered in excellence. Main services include Ship Management, Offshore Management, Oil & Gas, Marine Services, and Crewing.
SinOceanic Shipping is a shipping and ship finance company with established business relation with major charterers like Maersk, MSC, HL, etc. The management team have extensive network and industry experience. "Manage the Manager", effective control of the outsourced activities with high degree of shipping knowledge within all segments (Chartering, Operations, Ship Management, NB Projects, and Conversions). Their strategy is to have sustainable green shipping projects with low emissions, and exceeding future known rules and regulations.

The Green Shipping Programme (GSP), a public-private partnership, aims to advance the Norwegian government's maritime strategies and plans. The programme's vision is to develop and strengthen Norway's goal to establish the world's most efficient and environmentally friendly shipping. GSP was first established in January 2015 under the name "the Green Coastal Shipping Program", consisting of 16 private companies and organisations, as well as two government ministries. In the spring of 2019, the program changed its name to the Green Shipping Program to state its international ambitions.

As of 2022, the program includes 114 private companies and organizations as well as 14 public observers. The Green Shipping Program is financed partly by public allocations from the State budget of Norway and partly by the members themselves.

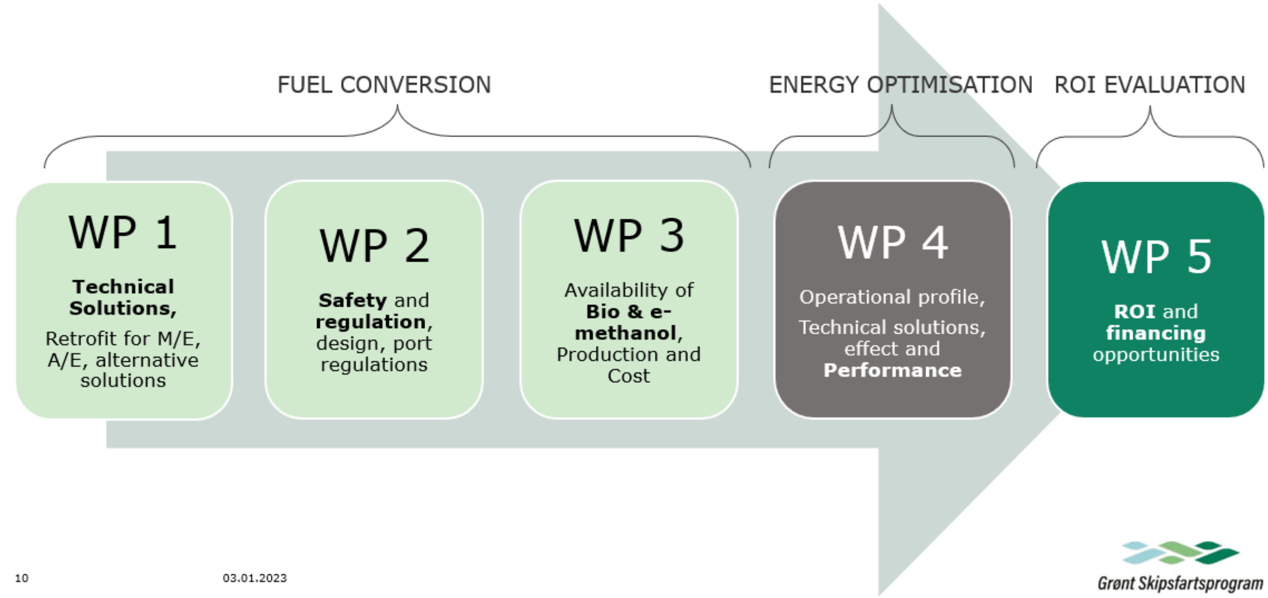


Grønt Skipsfartsprogram

PROJECT PARTNERS AND CONTRIBUTORS

Following partners from GSP have participated in the project, together with companies from the maritime supply industry that have put in many hours and significantly contributed to the findings

Work Processes



CONTRIBUTORS TO INDIVIDUAL WORK PACKAGES

WP 1) Technical conversions of main engine, auxiliary engines, boiler, fuel cells, tank arrangement and fuel systems - Win GD, Eiken Maritime, MAN Energy Systems, Alfa Laval, Alma, and Breeze Sip Design

WP 2) Safety/regulation (individual technical systems and products) – DNV, Norwegian Maritime Authority (NMD), Methanol Institute

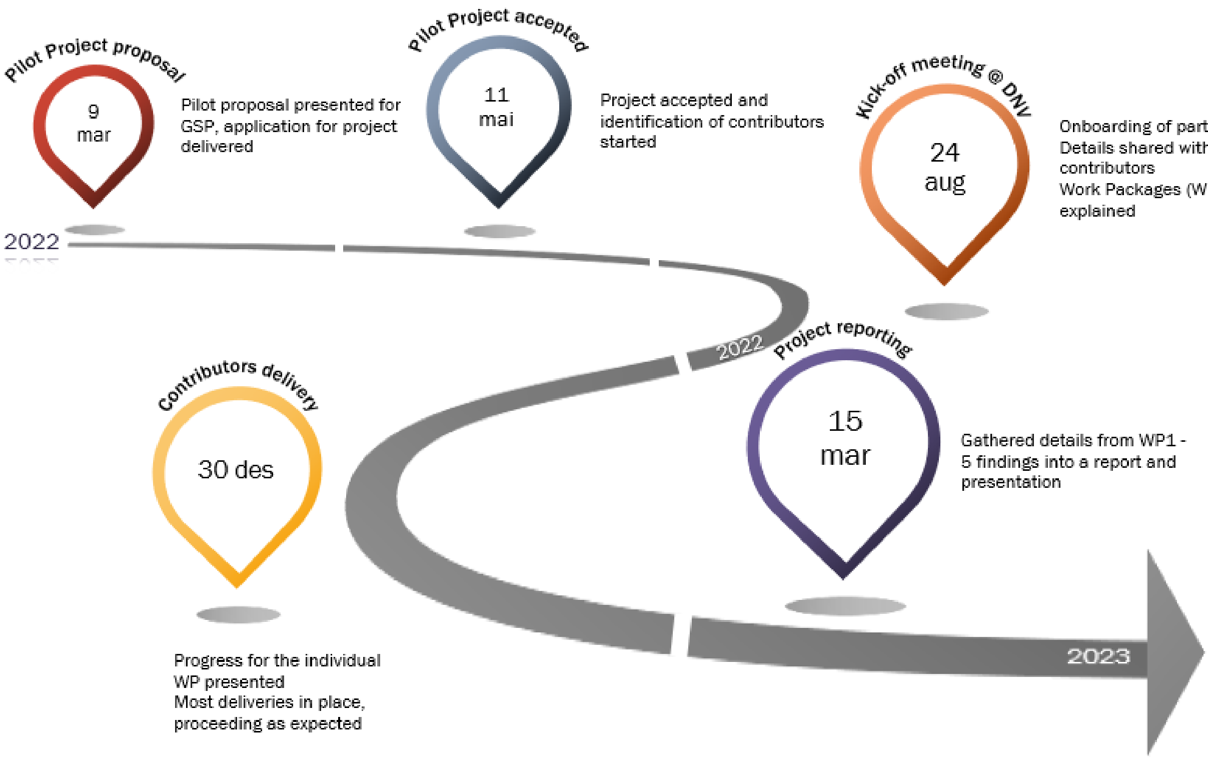
WP 3) Availability and cost of bio and e-methanol – DNV, Methanol Institute, Statkraft, Methanex, and Sintef

WP 4) Technical solutions, energy efficiency – Kongsberg, WE Tech, Berg Propulsion, WinGD, Jotun, Breeze Ship Design, Norsepower, Alfa Laval, DNV, and Sintef

WP 5) ROI and financing opportunities – DNV, DNB, Methanol Institute, Sintef, and VesselsValue

TIMELINE

The pilot project proposal was presented to GSP on 9th March 2022 and presented for acceptance of partners in May. The project was formally accepted by GSP at the same date. The work to identify potential partners then started and many showed interest from the very beginning. The formal kick-off meeting was held at DNV on 24th August, where work tasks were discussed, and the individual contributors agreed on what work to carry out.



Partners and contributors delivered their input in timely fashion so that the analysis work and preliminary conclusions could be made. The work with reporting could start as planned on 2nd January 2023 and will be presented for GSP early February. The intention is to present the outcome of the study on the GSP partner meeting at DNV on 15th March. This will be followed by a webinar where all partners in GSP are invited.

Work Process 1, Technical solutions - methanol conversion

WP 1.1) MAIN ENGINE 2-STROKE, METHANOL CONVERSION

According to the engine maker, a conversion of the Wartsila 7 RT-flex68-B to methanol would imply a retrofit-optimised solution where the methanol is supplied directly to the engine at low pressure. Fuel pressure amplification then takes place on the engine, using existing energy from the servo oil system, and the methanol is injected into the cylinder at medium pressure.

Supplying methanol directly to the engine at low pressure eliminates the need for costly and energy demanding high-pressure equipment in the fuel supply system, which reduces the footprint for the fuel supply system and maximises retrofit installation flexibility (see fig. 4). On-engine pressure amplification using an existing energy source means lower energy costs and associated emissions (fig 5).

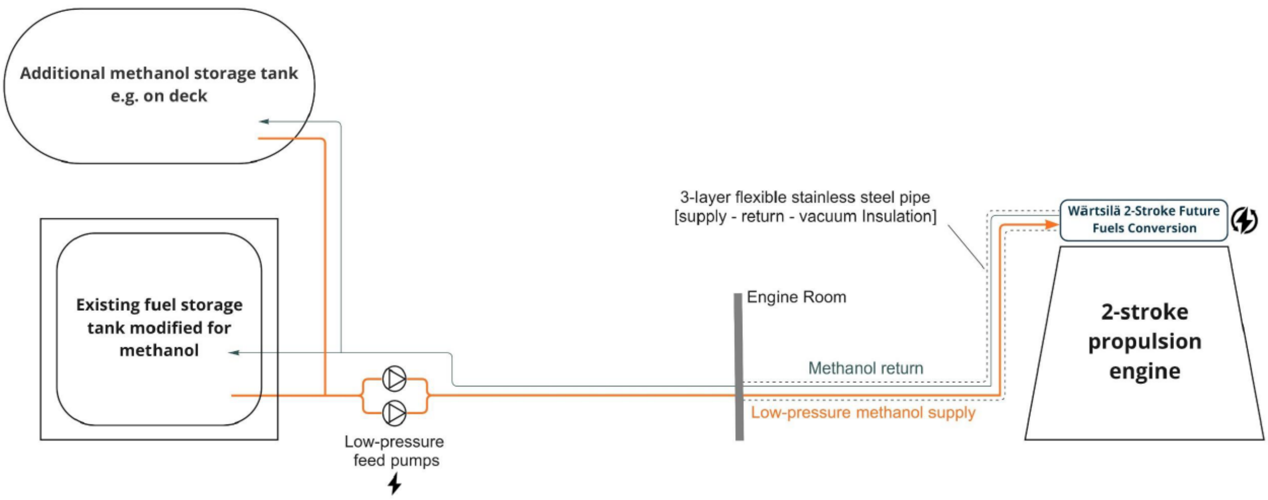


Fig 4.
Sketch of typical low pressure methanol fuel system

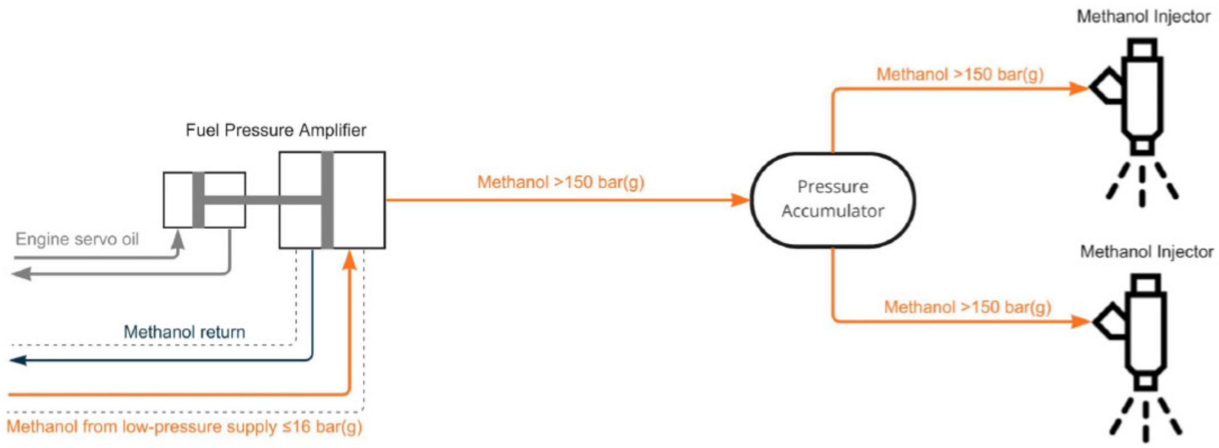


Fig 5.
Sketch of typical arrangement per cylinder for methanol

The 2-stroke engine fuel conversion scope would then include:

INSTALLATION PER ENGINE

- Rail enclosure with ventilation system
- Instrumentation, sensors, cabinets & cables
- On-engine piping
- Fuel injection control system upgrade
- Safety & monitoring system extension
- On-engine platform modifications

INSTALLATION PER CYLINDER

- Cylinder cover with fuel/gas injectors
- Gas expander (LNG only)
- Pressure accumulator
- Fuel pressure amplifier

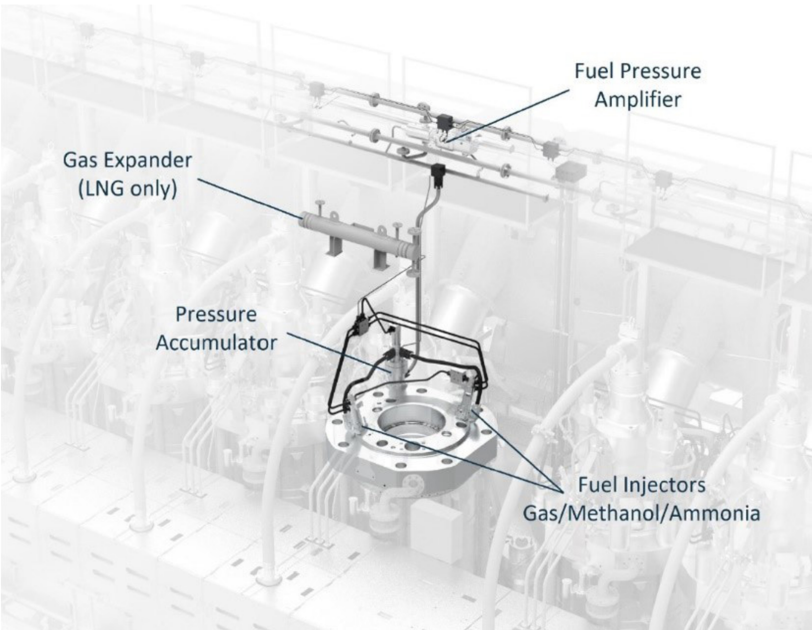


Fig 6.
Sketch of typical installation per cylinder

PROJECT SCOPE

When the commercial decision is made and the project can start, the tasks as described below (fig. 7) will have to be carried out. According to the vendor, this process could take 10 to 18 months and the earliest expected possibility for conversion would be 2024.

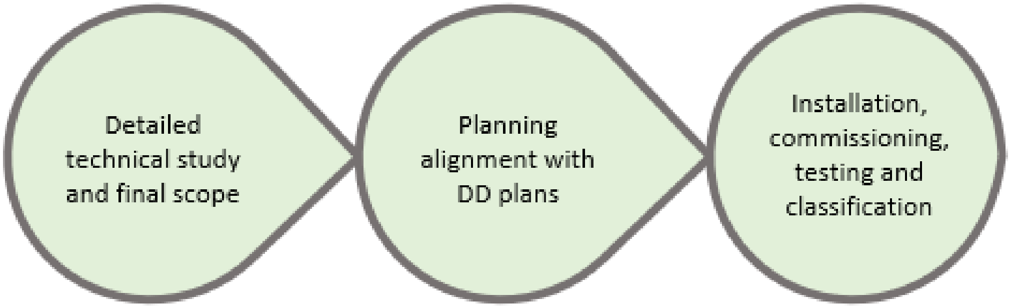


Fig 7. Project Outline

Cylinder Lubrication - Methanol has basically no sulphur, hence grade/detergency of cylinder lubricant is fed to the cylinders in the same way as for VLSFO/ULSD. Normal practise from 2020 has been to use a cylinder lubricant with base number (BN) 40 by default, and switch to BN100 every several days, depending on inspection findings through scrape down analysis. This is basically done to clean the cylinders as required.

It is very important to carry out scrape down analysis to monitor engine corrosiveness upon start of DF operation and adjust cylinder oil feed rate accordingly. Special focus is needed on controlling the residual BN as to much detergency will polish the liner.

A higher rate of system oil consumption should be expected – an increase of about 20% might be realistic due to sealing/cooling oil arrangement for the fuel booster injection valves.
Indicated pricing for such conversion would be around 3 MEUR or 140 EUR/kW. For such price, on-engine parts, labour, commissioning, tuning, updating the NOx Technical File, and Classification are included.

WP 1.2) AUXILIARY ENGINES 4-STROKE, METHANOL CONVERSION

MAN Energy Solutions is working on a development plan for a methanol solution for four-stroke engines and expect availability around 2024. The first four-stroke engine type to be prepared for methanol operation is the 21/31. MAN Energy Solutions plans to have one 6L21/31DF-M up and running at their test facility by Q1 of 2023 and will start testing, including performance and emission measurements.

MV "Sealand Philadelphia" is equipped with this type of auxiliary engines with the following specification:

- 2 x Zhenjiang Marine Diesel Works MAN B&W - 8L 21/31 (1 600 kW @ 900 rpm)
- 2 x Zhenjiang Marine Diesel Works MAN B&W - 9L 21/31 (1 800 kW @ 900 rpm)

The scope of conversion for these engines are installation of methanol injectors, double wall methanol pipe, methanol valve unit for nitrogen purging and control system for methanol injection. At the moment the add-on equipment scope is not finalized, so no accurate price estimates can be given. Indication for this technology can be in the range of 400 USD/kW, but MAN is considering an alternative concept which would bring retrofit costs at a lower level and shorten the time to market. A total price for converting the 4 auxiliary engines would currently be at 2.72 MUSD (2.57 MEUR), however this price might come down. Regarding system oil it is expected that similar oils as for VLSFO/ULSD will be used. Engine makers and lubricant suppliers should be consulted for their recommendation.

WP 1.3) BOILER, METHANOL CONVERSION

To convert from the installed Kang Rim Co. Oil fired composite boiler into a methanol Dual Fuel (DF) boiler system would incur significant changes. In addition to the upgrade of the Marine Gas Oil (MGO) system, a new methanol system must be fitted. Components here include a methanol DF composite boiler, methanol burner, pumps, flow meter, extraction fan, and nitrogen supply (yard delivery). In addition to this comes piping and cabling, which is in the yard supply. Commissioning is estimated to be maximum of 25 days, spread over 2-3 trips and included in the price calculation. However, the duration/pattern of travel will be subject to the location of shipyard and class requirements for retrofit.

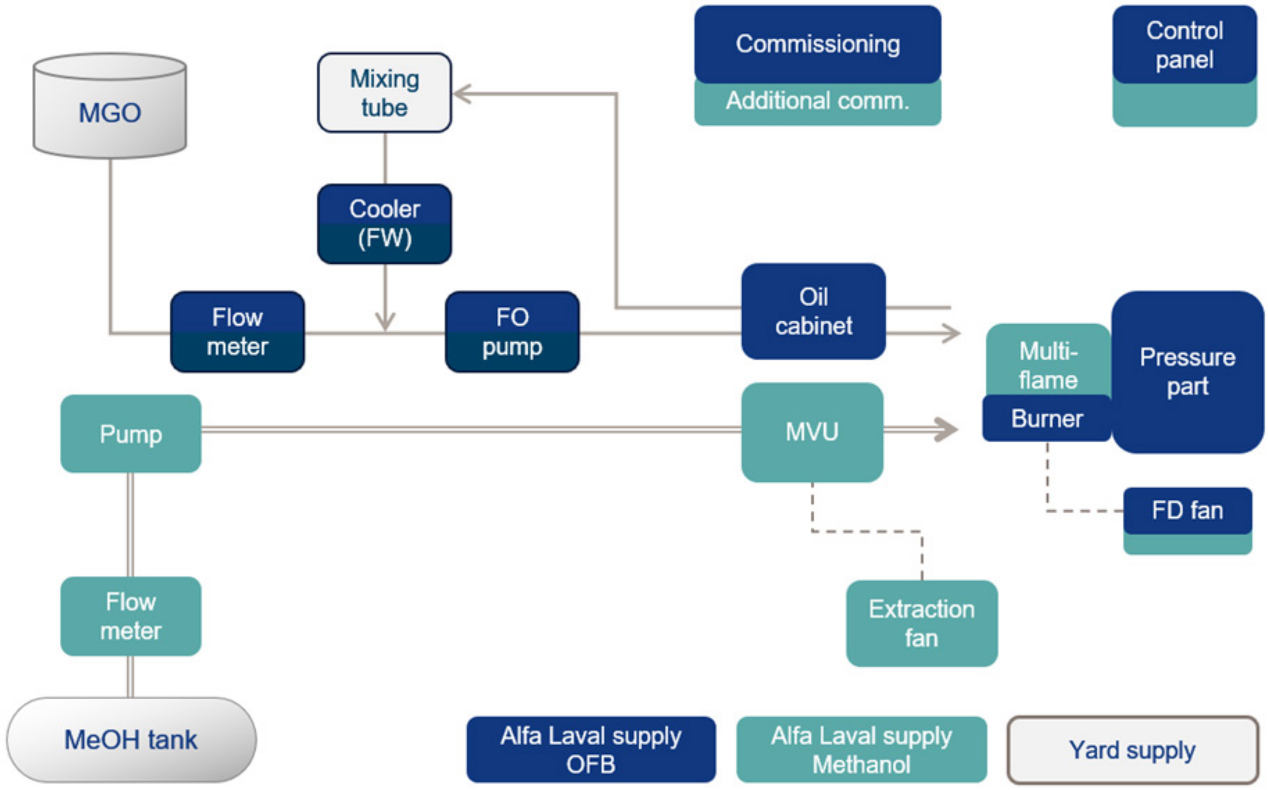


Fig 8.
Sketch of typical arrangement and components needed for conversion to methanol DF boiler system

A price estimation for such system would be in the range of 500 kEUR (+/- 20%), net of installation costs to be incurred by shipyard.

In addition to above, an economiser system for improved steam balance from the auxiliary engines could be considered.

WP 1.4) ALTERNATIVE SOLUTION, HIGH TEMPERATURE SOLID OXIDE FUEL CELL

A solid oxide fuel cell (SOFC) is an electrochemical sconversion device that produces electricity directly from oxidizing a fuel. Fuel cells are characterized by their electrolyte material; the SOFC has a solid oxide or ceramic electrolyte. Advantages of this class of fuel cells include high combined heat and power efficiency, long-term stability, fuel flexibility, low emissions, and relatively low cost. The largest disadvantage is the high operating temperature which results in longer start-up times and mechanical and chemical compatibility issues.

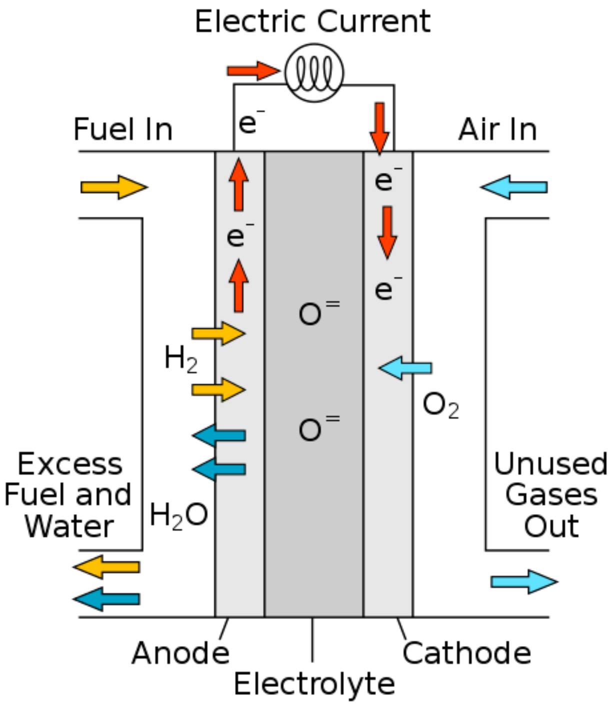


Fig 9.
Scheme of a solid-oxide fuel cell

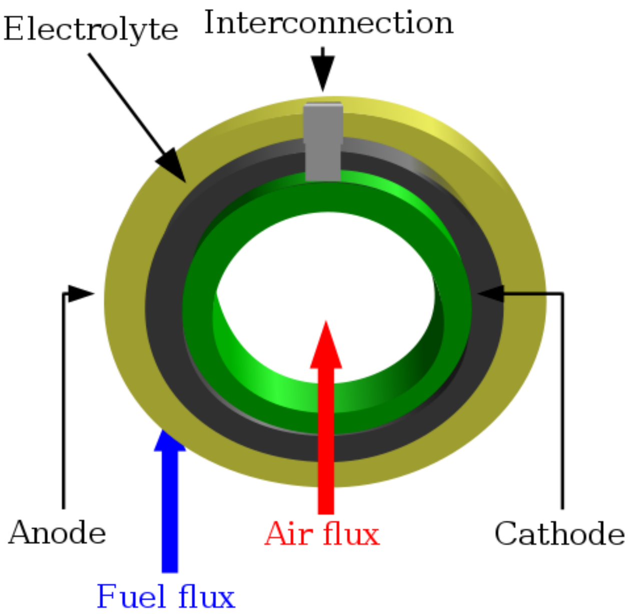


Fig 10.
Cross section of three ceramic layers of a tubular SOFC.

A solid oxide fuel cell is made up of four layers, three of which are ceramics (hence the name). A single cell consisting of these four layers stacked together is typically only a few millimetres thick. Hundreds of these cells are then connected in series to form what most people refer to as an "SOFC stack". The ceramics used in SOFCs do not become electrically and ionically active until they reach very high temperature and as a consequence, the stacks have to run at temperatures ranging from

500 to 1.000 °C. Reduction of oxygen into oxygen ions occurs at the cathode. These ions can then diffuse through the solid oxide electrolyte to the anode where they can electrochemically oxidize the fuel. In this reaction, a water by-product is given off as well as two electrons. These electrons then flow through an external circuit where they can do work. The cycle then repeats as those electrons enter the cathode material again.

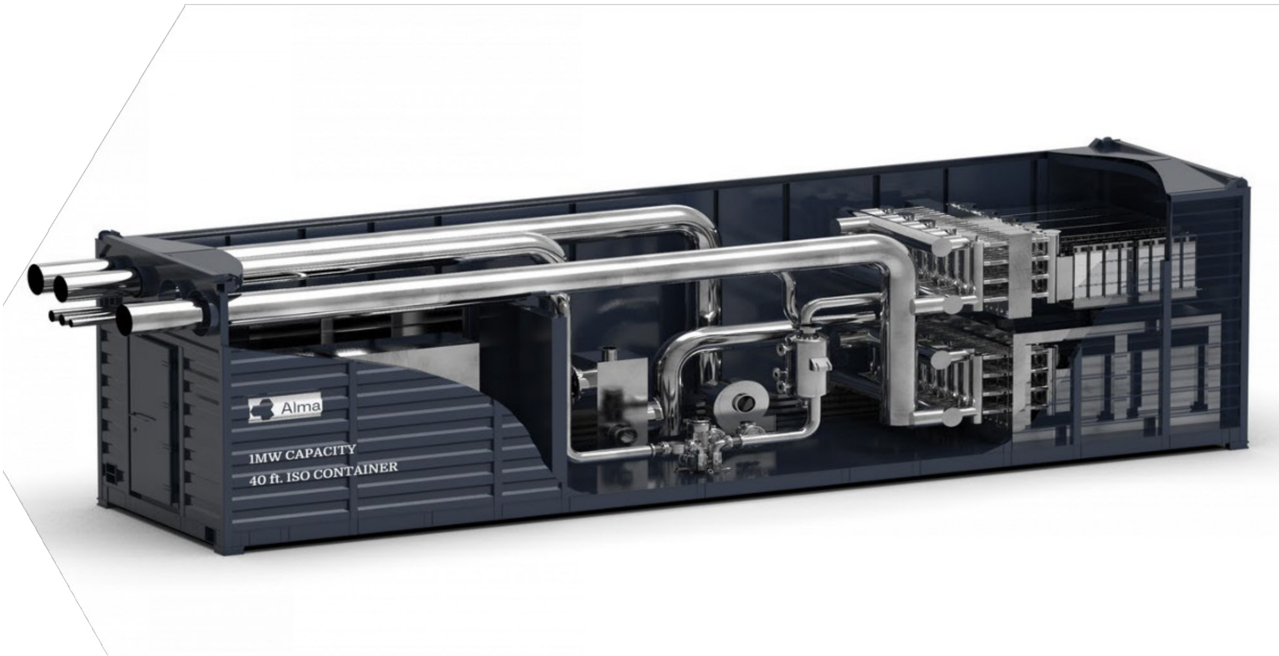


Fig 11.
Rendering of a 1MW fuel cell (pilot installation)

Alma Clean Power offers clean power systems for maritime industries. The power systems are based on high-temperature Solid Oxide Fuel Cells (SOFC) which offer the following key advantages.

FUEL FLEXIBILITY

o High-temperature SOFC can produce power from a variety of fuels, such as hydrogen, ammonia, methanol, ethanol, and natural gas.

o The high temperature facilitates internal reforming, hence external reforming can be removed or simplified.

HIGH EFFICIENCY

o Leading tank to wake efficiency across a wide range of fuels

o Electrical efficiency depends on fuel type, and can be more than 60%

ENABLES ZERO-EMISSIONS

o Depending on the fuel, SOFC gives zero emissions or concentrated CO2 for storage

o Combustion free process, hence negligible NOx or Sox

The SOFC power systems are engineered to suit the needs of complex sectors such as maritime shipping and offshore oil and gas.

SAFE AND COMPLIANT

o Developed to comply with maritime safety rules & regulations for operation in maritime environments.

COMPACT AND MODULAR

o Compact design essential for remote maritime and offshore sectors

o Compact and modularized systems offer new ways to consider location and redundancy of power systems.

LOW NOISE AND VIBRATIONS

o Since the fuel cell system comprise very few moving parts, the system is practically noise and vibration free.

LESS SERVICE AND MAINTENANCE

o Regular maintenance lower than for conventional power systems, as there are few moving parts.

o Replacement of degraded parts aligned with main service intervals.

OPEX REDUCTION

o End-user cost savings compared with conventional power systems, due to lower fuel consumption, low or no CO2 taxes, and less regular maintenance.

Alma Clean Power **cost roadmap** is divided into three phases. In the pilot and demonstration phase, key focus areas are technical development and development of supply chain and production capacities. Cost drivers in this phase are primarily related to scaling internal and external production capabilities and a substantial amount of engineering, design, and test hours. Significant efforts which will benefit future projects have already been put into this phase.

In commercialization phase, the technical foundation has been established and we expect a limited number of pre-commercial and early commercial projects to be delivered. In this phase, the key focus areas are product improvements and production scaling.

Approaching the end of this decade, a full rollout is planned. Our target is to produce 400 MW SOFC systems per year by 2030. This involves a high degree of standardized building blocks and streamlined automated processes.

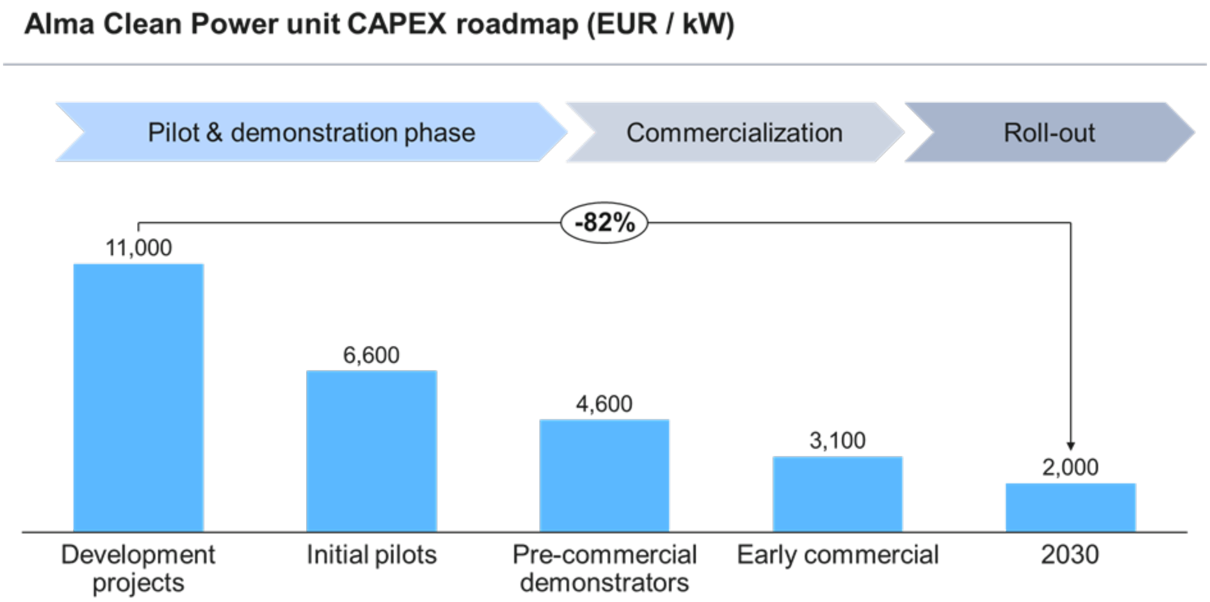


Fig 12.
ALMA cost road map

Please see Fig. 13 for an example of total cost of ownership results from an investigation in a typical installation, as first indication on the relevance of the technology, not only as a zero-emission enabler. This proves to be financially viable as well.

Interesting to see the strong case in auxiliary engine installations. Clearly, large 2-stroke engines direct coupled to propeller shaft is quite efficient, but in the longer picture, total SOFC installations in vessel might make sense.

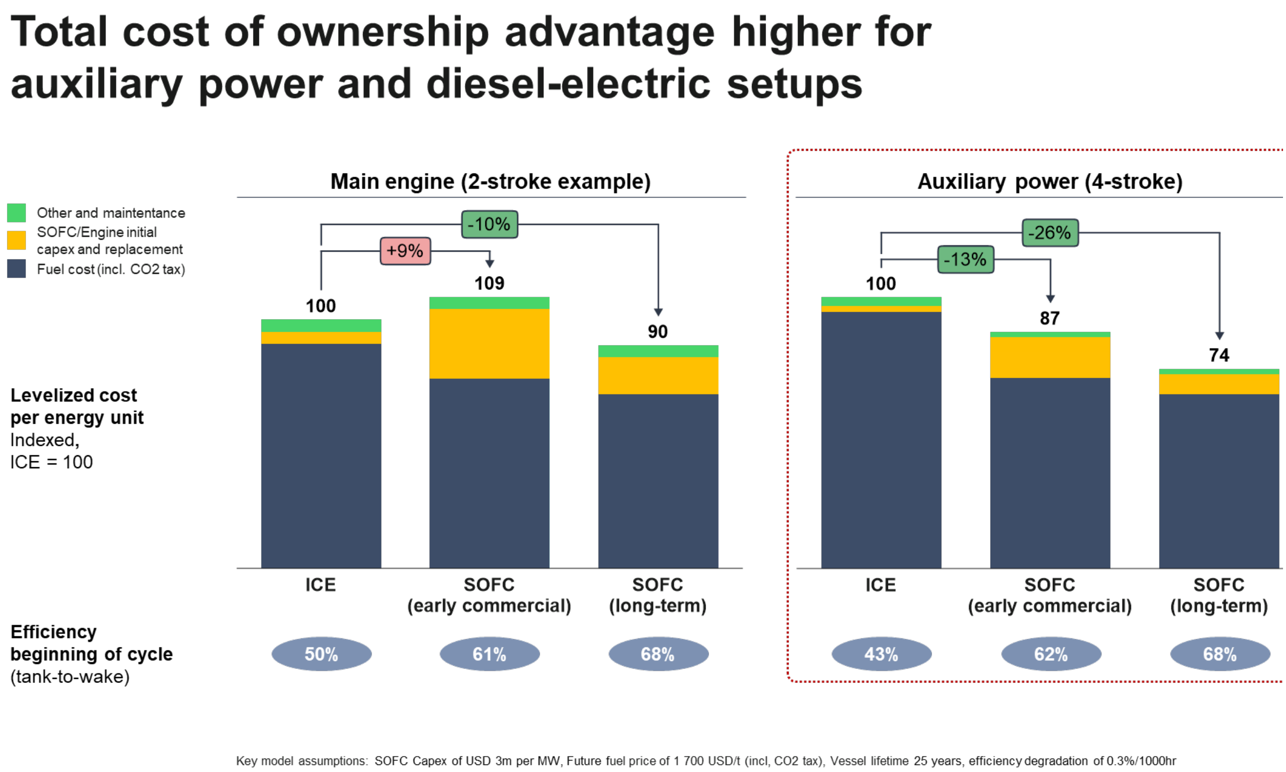


Fig 13.
Total Cost of Ownership (TCO) case shown as example

WP 1.5) TANK ARRANGEMENT FOR METHANOL LOW-FLASHPOINT LIQUID (LFL) FUEL CONTAINMENT

Low-flashpoint liquid (LFL) fuel containment

The containment of methanol fuel will not represent the same technical challenges as for LNG or other gases as fuel. The design of methanol fuel tanks with surrounding cofferdams is well known in the marine industry. Although the regulations do not impose restrictions on the use of independent or portable tanks, using integral tanks to store methanol remains the viable option in most cases. Due to methanol's low corrosivity, the class or statutory regulations do not specifically mention requirements for material selection. The most preferred options are stainless steel or coated carbon-manganese steels. It is necessary to achieve a clear segregation of the fuel tanks from the surrounding structure. Nevertheless, the regulations neither require cofferdams between fuel tanks nor shell plates below the waterline, other methanol fuel tanks and the fuel preparation room. A standard design for a containership could be an integral tank surrounded by cofferdams, except at boundaries to a fuel separation room if it is arranged adjacent to the tank. Access to the fuel tanks and cofferdams is regulated by the guideline MSC.1/Circ.1621 “Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel” (Annex 3) and by the DNV rules for classification DNVGL-RU-SHIP Pt.6 Ch.2 Sec.6 (Annex 4). In general, access is to be arranged from the open deck. However, it can often be challenging to achieve such an arrangement. An alternative solution could be to access from an enclosed space, provided that some conditions are fulfilled.

THE ENTRY SPACE SHALL BE EQUIPPED WITH:

- Independent mechanical ventilation providing six air changes per hour
- Gas detection
- Low oxygen alarm

THE SPACE SHALL NOT FALL UNDER ONE THE FOLLOWING CATEGORIES:

- Accommodation space
- Control station
- Machinery space of category A (“Structural fire protection and firefighting systems”)
- Service space

Service tanks arranged as independent gravity tanks are introduced by some propulsion system suppliers to achieve natural supply by gravity of fuel to the conditioning system. A second purpose is to provide the collection of returned fuel from consumers, thus acting as a filter for unburnt fuel circulating in the system. For these reasons, the service tanks are divided into two compartments: fuel and return chambers connected with each other by means of ventilation holes. While using a service tank is not a class requirement on dual-fuel installations, it remains a preferred solution for several design concepts. The venting of fuel tanks is achieved by using pressure vacuum (breathing) valves. The relief setting of the valves is to be 0.2 bar, due to the toxicity of methanol. LFL fuel tanks are usually cleaned with fresh water in an inerted atmosphere. Methanol is completely soluble in water. In general, the tank bottom and transfer lines need to be flushed. Cleaning techniques differ and can include fixed or portable tank cleaning machines. Residues can be removed by evaporation. The gas-freeing of LFL fuel tanks is another important operation that needs to be considered in the design phase. This can be carried out using the fuel supply line or portable fans fitted to a suitable branch on the tank’s top. There are basically two options that are accepted by the existing regulations: either through an opening located 3 metres (m) above deck or through an underwater discharge. The tanks shall be equipped with all instruments needed to monitor temperature, pressure, and the fluid level to ensure the safe containment of the fuel. Overfill protection is to be integrated into the Emergency Shutdown (ESD) system.

ELEMENTS OF THE SAFETY CONCEPT FOR METHANOL-FUELLED VESSEL

Safety arrangements play a crucial role in mitigating risks associated with the storage and supply of LFL fuel to consumers. The four elements of the safety concept are:

1. SEGREGATION - Protects fuel installation from external events.
2. LEAKAGE DETECTION - Gives warning and enable automatic safety actions.
3. DOUBLE BARRIERS - Protect ship against leakages.
4. AUTOMATIC ISOLATION OF LEAKAGE - Reduces consequences of a leakage.

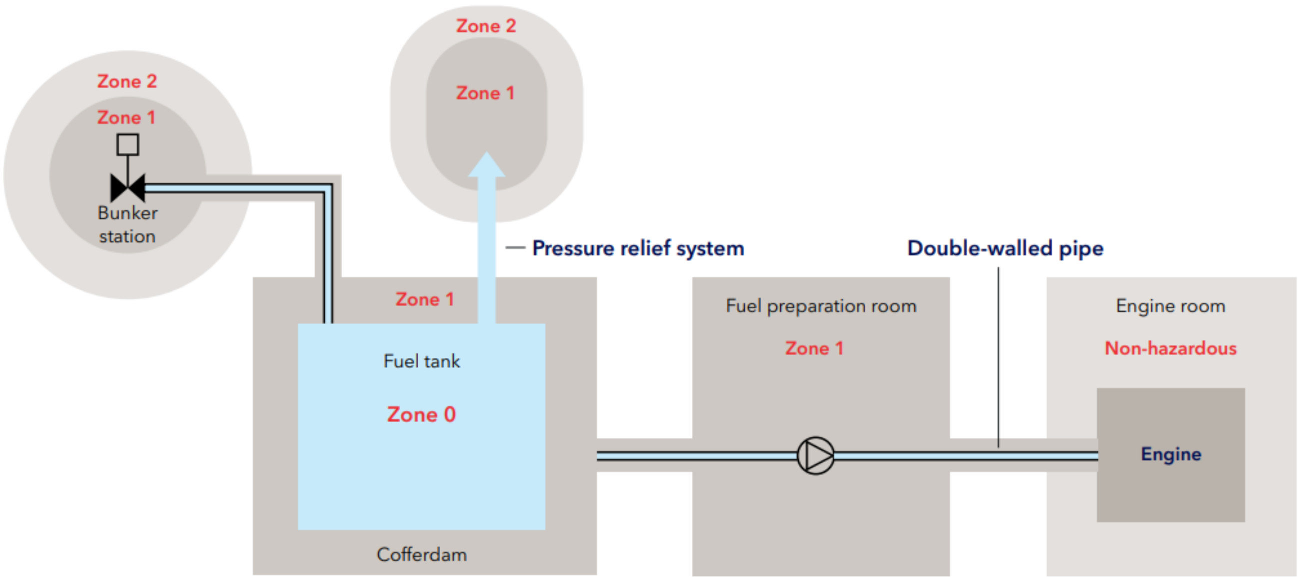


Fig 14.
Illustration of methanol handling on board a containership (Source: DNV)

CLASSIFICATION OF HAZARDOUS AREAS

The presence of methanol will introduce additional hazardous areas on board a typical containership. These areas limit cargo stowage and handling possibilities. Therefore, careful planning in the design stage is essential. Such hazardous areas will not only require certified explosion-proof (Ex) equipment. Due attention is needed with respect to the position of ventilation openings from storage rooms (LFL tanks, cofferdams, and supply systems), the fuel preparation room and annular spaces. The positions of ventilation inlets and outlets for non-hazardous areas require careful consideration, considering the hazardous zones. Moreover, due to methanol's toxic properties, a minimum distance of 15 m is regulated by class as being necessary between the fuel tanks' ventilation outlet and any openings to crew accommodation. The hazardous areas are defined as follows:

HAZARDOUS AREA ZONE 0

- The interiors of fuel tanks, pipes and equipment containing LFL.
- Any pipework for pressure relief or other venting systems for fuel tanks.

HAZARDOUS AREA ZONE 1

- Cofferdams and other protective spaces surrounding the LFL fuel tanks.
- Fuel preparation rooms.
- Open deck and semi-enclosed spaces on deck, within 3 m of any fuel tank outlet, gas or

vapour outlet, manifold valve, valve, pipe flange and the fuel preparation room's ventilation outlets.

- Fuel tank pressure/vacuum (P/V) vent outlets, within a vertical cylinder of unlimited height and 6 m radius cantered upon the centre of the outlet, and within a sphere of 6 m radius below the outlet.
- Open deck and semi-enclosed spaces on deck, within 1.5 m of fuel preparation room entrances, fuel preparation room ventilation inlets and other openings into Zone 1 spaces.
- Enclosed or semi-enclosed spaces in which pipes containing fuel are located, for example, ducts around fuel pipes, and semi-enclosed bunkering stations.

Hazardous area Zone 2

- Areas within 1.5 m surrounding open or semi-enclosed spaces of Zone 1.
- Spaces 4 m beyond the cylinder and 4 m beyond the sphere defined for vent mast outlets.
- Air locks.

VENTILATION

As in other alternative fuel systems, ventilation systems in LFL installations are considered essential safety barriers.

All LFL fuel tanks require air pipes, the cross-section of which shall be designed to accommodate 125% of the fuel supply rate to prevent overpressure. Controlled natural ventilation of LFL fuel tanks has to be redundant. As an alternative, it is possible to arrange only one air pipe and a pressure sensor with settings according to IACS SC 140 and within the design pressure of the fuel tank. The cofferdam surrounding the fuel tanks shall also be ventilated. To create another safety barrier, the cofferdam can either be inerted or filled with water. If the first option is chosen, the ventilation heads have to be closable. The protective effect of the mechanical ventilation is achieved through the use of fans certified as suitable for operation in hazardous areas with the capacity in air changes per hour defined for compartments with the LFL fuel components. The intention is that all hazardous compartments for fuel handling and annular space of fuel supply lines should be protected by mechanical ventilation. Ventilation is monitored to trigger shutdowns of the fuel supply in case ventilation in the protected spaces is lost.

GAS/FIRE DETECTION

A reliable gas/fire detection system is another important safety component of the LFL fuel system. In general, leaks of methanol are characterized by fast and complete vaporization. Methanol is also more flammable than other ship fuels and is known for its low detectability, as it burns with a nearly invisible flame. Therefore, a combination of different fire (heat, optic, and smoke) and gas

(IR principle) detectors shall be implemented in the dry compartments in which components of the LFL fuel system are installed. Such installations are required in engine and fuel preparation rooms. Bunker stations, unless arranged on open decks with ample ventilation, have to be equipped with gas detection, too. Gas detection shall be continuously carried out; therefore, the sampling principle is not applicable. Duplication of the detectors is necessary to activate the Emergency Shutdown (ESD) system.

EMERGENCY SHUTDOWN (ESD) SYSTEM

An essential element of the safety concept in the arrangement of alternative fuel systems is the separation of leakage sources identified by gas or liquid leakage detection. When leakage is detected, it needs to be isolated while the corresponding process is stopped. The ESD system is capable of fulfilling these tasks by operating key valves and pumps in the system. Triggering signals are primarily generated by leakage detection, the monitoring of ventilation, or manually. In addition, the bunker system needs to be designed to receive stop signals from the tank overfill protection. The ESD system is activated by signals from gas detection. It is worth noting that operational philosophy is based on the 'voting principle'. This term describes the arrangement in which fuel vapour sensed by just one detector only generates an alarm, while the corresponding part of the system is shut down only if two detectors discover a vapour level of at least 40% of the Lower Explosive Limit (LEL). The system may also be activated manually from strategic locations on board such as the bridge, control stations and the fuel preparation room, as well as positions inside engine rooms.

NITROGEN GENERATION/SUPPLY

Inert gas is widely used as a fire prevention measure to reduce the gaseous oxygen (O2) content in enclosures containing methanol. Nitrogen (N2) shall be permanently available on board. Capacity shall be sufficient to provide services for at least one trip at the maximum fuel consumption rate and to keep fuel tanks inerted for two weeks. It is advised to also consider other operations (e.g. gas-freeing, tank cleaning, purging) when calculating the required capacity. A production plant and/or adequate storage capacities might be considered to achieve the availability target. All connections shall be equipped with double block and bleed (DBB) assembly in the N2 line to prevent the backflow of hazardous gases into N2 system. The signal triggering the DBB shall be taken from the process, such as by measuring differential pressure or flows of N2. Non-permanent connections such as those for purging pipelines may be separated by two non-return (NR) valves fitted in series.

STRUCTURAL FIRE PROTECTION AND FIREFIGHTING SYSTEMS

The arrangement of fuel preparation rooms and bunkering stations has to be specially considered if they are made as enclosed or semi-enclosed compartments. Fuel preparation spaces are categorized as machinery spaces of category A. This necessitates Class A-60 fire divisions towards all surrounding compartments, including the machinery space of category A itself. Exemptions may be granted allowing A-0 divisions to other machinery or cargo spaces as regulated by SOLAS II-2/9. With respect to firefighting systems, LFL as fuel necessitates the use of alcohol-resistant foam. This system is required for bunker stations, fuel preparation rooms, tank top, and bilge wells in the engine room. However, a CO2 system may substitute the foam system in the engine room if approved by the flag state administration.

CONTROL STATIONS

Control and monitoring functions of the system are usually arranged in a centralized station, typically the engine control room (ECR) on a standard containership. Operator stations monitoring bunkering and fuel supply processes are integrated into ECR consoles. Emergency stops are arranged in strategic positions such as on the bridge and in the fire control station.

LFL FUEL CONDITIONING AND SUPPLY

The main components of the fuel supply system are typically located in a separate room often called the fuel preparation room – an independent space that, as minimum, shall not be located within a machinery space of category A. If it is not possible to arrange access from the open deck, an air lock must be arranged. For the air lock, independent ventilation shall be provided with eight air changes, increasing to up to 30 air changes in case of leakage detection. Typical fuel supply concepts consist of gravity supply of fuel from the service tank or storage tank to supply pumps or directly from submerged pumps in the tank. The fuel is then transferred and pressurized to the necessary pressure for delivery to consumers. The assembly of the pumps with ancillary components like heat exchangers and mixing tubes is often referred to as Liquid Fuel Supply System (LFSS) skid. The LFSS only supplies a maximum of 16 bar; typical operating pressure is 8-10 bar. The fuel is boosted right before injection through the fuel booster injection valves as required. For safety reasons, the LFL fuel supply line shall be equipped with a number of valves. An automatically controlled master valve shall be arranged in the main supply line to the consumers. The supply lines to each consumer shall be equipped with a manual valve and extra automatically controlled valves as required by the "Interim Guidelines for Safety of Ships Using Methyl/Ethyl Alcohol as Fuel" (MSC.1/Circ.1621). The classification rules require double block and bleed (DBB) assembly, which includes the individual automatically controlled valve. The assembly of the valves with associated instrumentation is often called Fuel Valves Train (FVT) skid. Primarily for the purpose of purging, both skids have an N2 system connected. Injection of water into the supply line has, for its technological simplicity, become a typical solution for methanol driven installations to achieve Tier III compliance of combustion engines. The skids need to be equipped with trays to collect all possible leakages, which in turn need to be drained into a suitable collecting tank. The inerted holding tank shall be equipped with level indication and alarms. Manual emptying is considered acceptable if drip trays are less than 10 litres in volume The bilge system in the fuel preparation room shall ensure collection and detection of possible leakages and ensure transfer to a suitable containment system. The system needs to be operable from outside the fuel preparation room to prevent exposure of the crew to toxic fumes released in the case of leakage, including the control of connected pumps and valves if located inside the compartment.

BUNKERING

Methanol is one of the top five chemical commodities shipped around the world each year. It is readily available through existing global terminal infrastructure (ref. to 4.3 Infrastructure) and well positioned to reliably supply the global marine industry. However, dedicated bunkering infrastructure for ships is currently limited. Distribution to ships can be accomplished either by truck or by bunker vessel. The maritime industry has extensive experience of handling low-flashpoint cargo, including methanol. This experience has been gained from transporting the product on board tankers between ports and to offshore units on board offshore supply ships. Therefore, different loading/unloading operations are well known, which could provide useful information for designers and shipowners. The location of bunker stations must be carefully considered with several factors in mind to ensure safe and efficient transfer of fuel from the bunker source. The optimal location would in some cases be areas on open decks, which might be conveniently designed on feeders and small-sized container carriers or other designs where hazardous zones and cargo operations make it feasible. The design must consider the location of openings into living quarters, service spaces, and control stations. Distance limitations of 15m set out in classification rules must be adhered to. The high freeboard of large containerships means it is not always possible to locate bunker manifolds in open air to achieve a well-ventilated environment during bunkering operations. Therefore, specially dedicated compartments may have to be arranged. The enclosed or semi-enclosed bunker stations have to be segregated from adjacent spaces by means of gas-tight and liquid tight bulkheads. Ventilation becomes an important factor to avoid methanol vapours accumulating in bunkering compartments. Efficient mooring is necessary for the safety of bunkering operations. Due consideration must be given to the arrangement of the mooring equipment to ensure compatibility with bunkering ships. Mooring lines should pass through fairleads and secured bollards and beats with an adequate safe workload. This especially concerns ships with high freeboard, for which chafing of mooring lines at the chocks must be prevented by all means. Having the capability to safely disconnect the supply source and ensure tightness of the transfer system is a necessary prerequisite to carrying out bunkering operations in an adequate manner. Therefore, the combination of locally controlled and remotely operated shutdown valve or, alternatively, a remotely operated shutdown valve with means of manual closing, is required to be positioned as close to the presentation flanges as possible. In addition, dry-disconnect type bunkering connections shall be equipped with additional self-sealing quick release. There shall also be an emergency breakaway coupling in use during bunkering. This coupling can either be installed at the bunker station or on the loading hose. It is necessary to provide sufficient degree of flexibility to carry out bunkering operations, which often coincide with container or cargo handling. The "Interim Guidelines for Safety of Ships Using Methyl/Ethyl Alcohol as Fuel" (MSC.1/Circ.1621) requires means of segregation between port and starboard-side bunker crossover pipes to avoid inadvertent transfer of fuel from side to side. The other safety precautions aimed at minimizing spills during routine connecting/disconnecting or emergency release include trays of sufficient volume and means of drainage. Methanol should not be drained overboard and has to be transferred to a dedicated containment. The safety of the crew conducting bunkering operations is a paramount aspect, which shall be considered in the design stage. Therefore, emergency showers and eyewash devices need to be provided in the vicinity of bunker stations. There are usually two, though this is subject to the ship's beam/breadth; meaning that designs with just one can be accepted if there is easy access to it from both sides.

FURTHER INFORMATION

For further information of the subject, please refer to the attached report from DNV on "Alternative fuels on containerships" (Annex 5).

TANK ARRANGEMENT SEALAND PHILADELPHIA

Estimated required tank volume for the Sealand Philadelphia operation is 1950 m3. The material in use would be zinc silicate coated carbon-manganese steel tanks surrounded by a water filled cofferdam.

Two different locations of the tanks have been considered:

1. Aft installation of a prefabricated zinc silicate coated tank with cofferdams, or
2. Installation of a prefabricated mid- ship section containing a tank of similar configuration.

For alternative one, the installation would decrease the cargo capacity by 62 TEUs. The day tank and fuel supply system would in this case be installed on main deck close to the storage tank. Installation work would be carried out during a main Dry Docking (DD), which normally last around 8 days. The steel weight of this in-hold installation is 265 tons. The cost for conversion is in the range of 0.9 MUSD.

For alternative two, the length of the vessel would increase by 4.74 meters and the additional weight is 460 tons. This solution would increase the cargo capacity by 70 TEUs. The day tank and fuel supply system would in this case be installed in the prefabricated mid-ship section. Again, the installation would be carried out during the main DD and would last for additional 2 weeks. Consideration to potential port limitations due to increased LOA is not considered in this report. The cost for conversion is in the range of 1.8 MUSD.

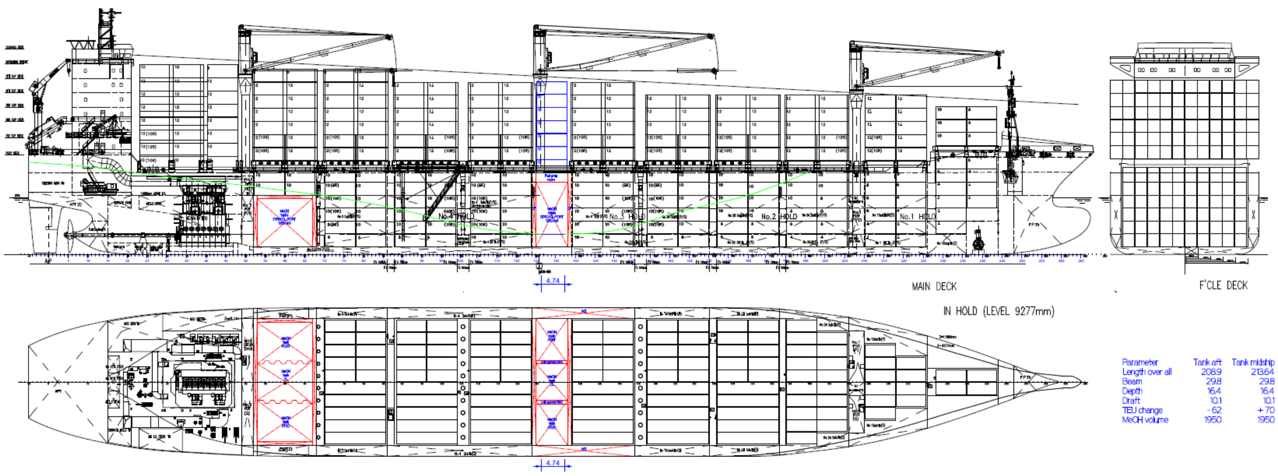


Fig 15.

Sketch of alternative locations of methanol bunker tanks (Source: Breeze Ship design)

WP 1.6) METHANOL FUEL SUPPLY SYSTEM

Main engine Fuel Supply System (FSS)

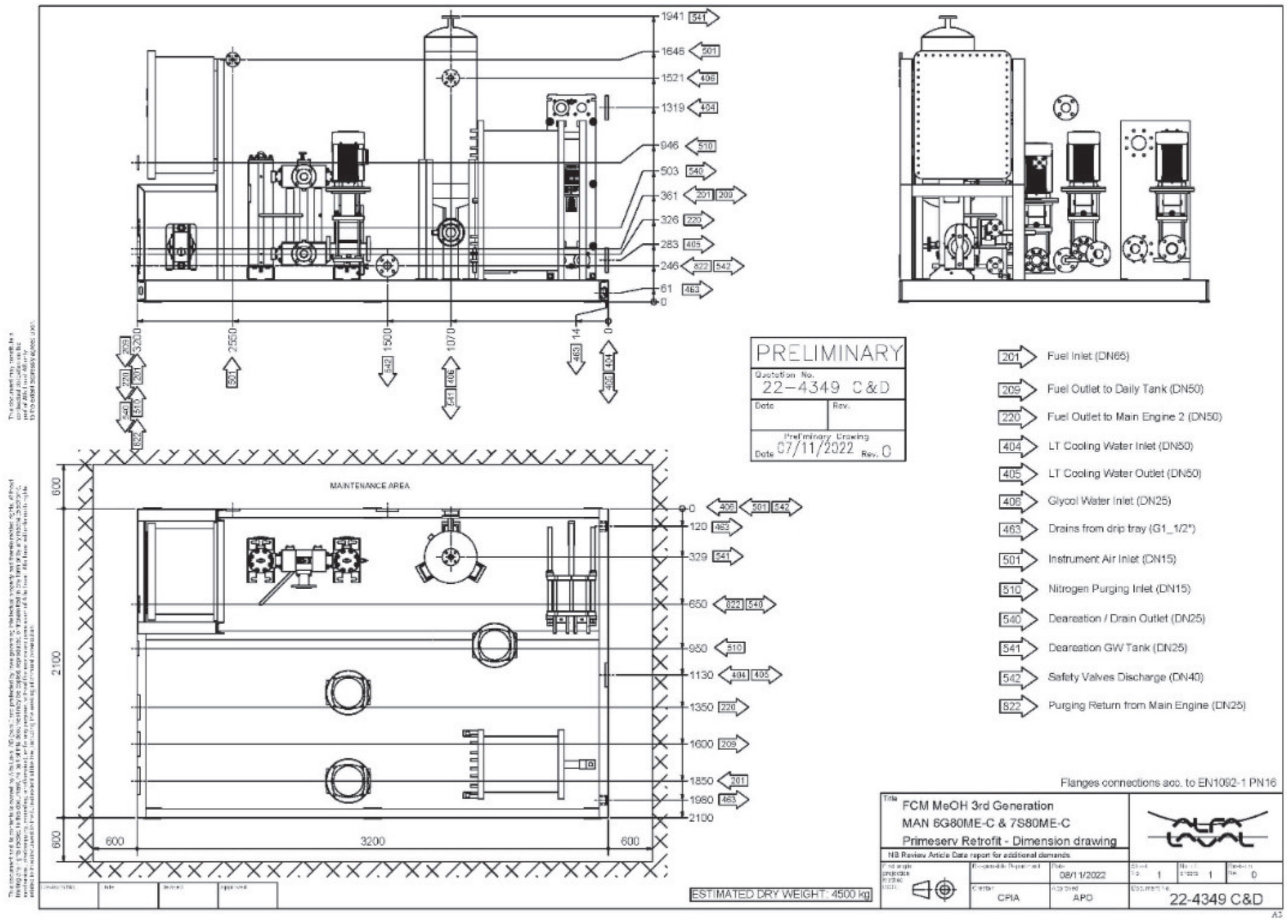


Fig 16.
Sketch of typical arrangement and components for main engine fuel supply system

Estimated budget price for the 24 MW 2-stroke main engine fuel supply system is 400 kEUR, plus cost for supervision, commissioning, and attendance at sea/gas trials at 50 kEUR.

Auxiliary engines Fuel Supply System (FSS)

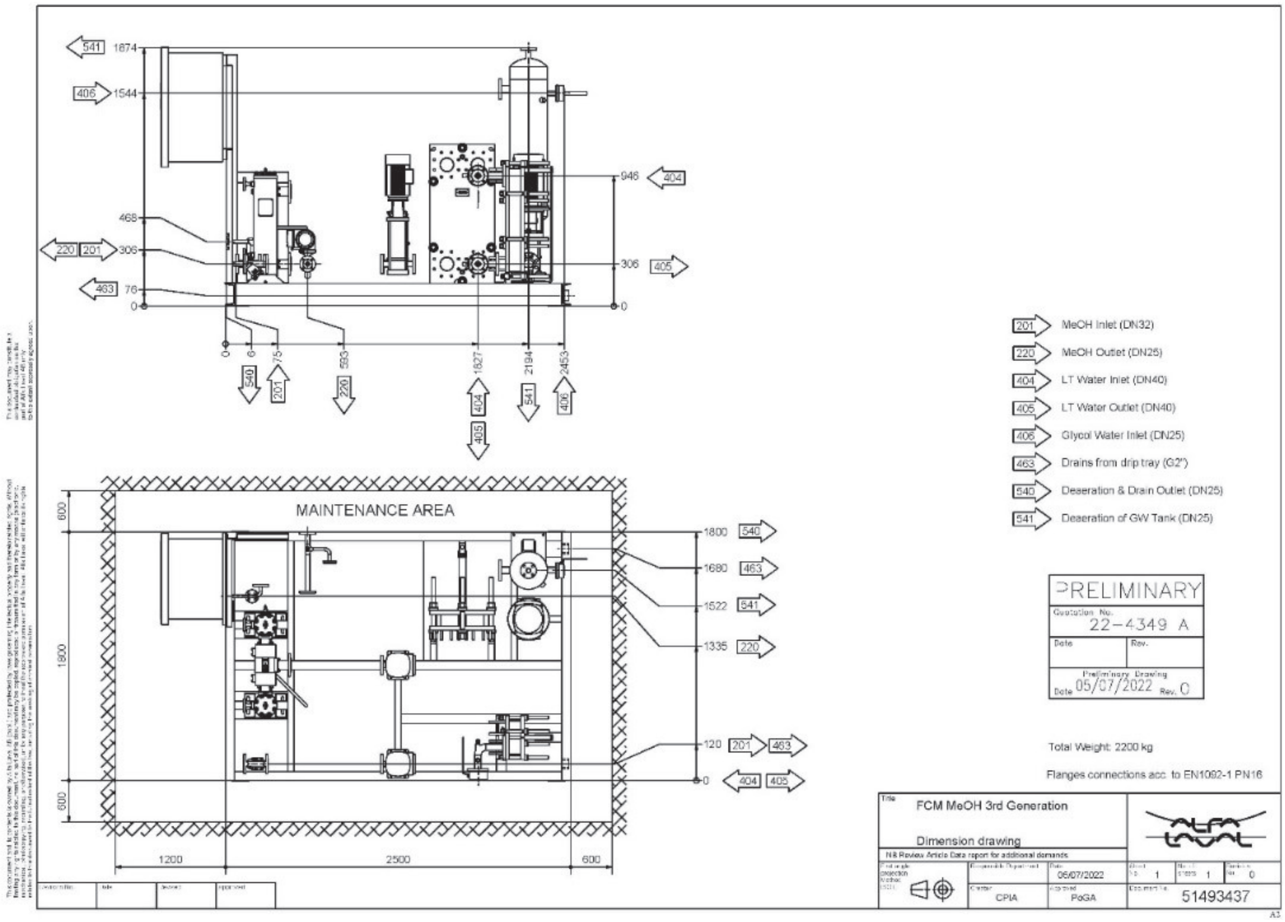


Fig 17.
Sketch of typical arrangement and components for auxiliary engines fuel supply system

Estimated budget price for the 2 x 1.600 kW and 2 x 1.800 kW 4-stroke auxiliary engines fuel supply system is 380 kEUR, plus cost for supervision, commissioning, and attendance at sea/gas trials at 50 kEUR.

Work Process 2, Safety/regulation - methanol conversion

WP 2.1) PORT RESTRICTIONS OPERATING ON METHANOL?

Today, methanol is available in more than 90 ports and is proven to be a viable fuel. Most methanol fuelled vessels in operation are chemical tankers, and therefore have a different bunkering arrangement than other methanol fuelled vessels, as the methanol is loaded through the cargo manifold. Also, the shore side facilities are arranged for bunkering of a chemical tanker, which is a well proven loading procedure. There is therefore a need for scaling and further develop the bunkering infrastructure for methanol fuel on a global basis, and also for the specific ports intended for this vessel.

The first ship-to-ship methanol bunkering took place in The Port of Rotterdam in 2021, fueling Waterfront Shipping's methanol dual-fueled vessel. The last five years, their methanol dual-fueled chemical tankers have been bunkering methanol via cargo shore pipelines near a production facility, while in 2023 January, another ship-to-ship bunkering operation was completed in the port of Gothenburg, with methanol supplier Methanex supplying Stena Germanica, and imposed restrictions for bunkering methanol has not been found.

WP 2.2) FLAG STATE

There are well established class rules for methanol fuelled and/or low flashpoint fuelled vessels. Owners are unable to plan newbuilds for an alternative fuel until IMO and other regulatory bodies have defined applicable rules and requirements (alternative design process as per IGF 2.3 is applicable in cases where there are no defined rules and requirements). The new IMO interim guidelines for ships using methyl or ethyl alcohol as fuel, MSC.1/Circ.1621, along with the IMO IGF Code for ships using low-flashpoint fuels and DNV's mandatory class rules for methanol-powered ships, now open the doors for investing in methanol-fuelled ships. The guidelines for methanol as fuel, MSC.1/Circ.1621, are foreseen to become mandatory in 2025 with entry into force in 2028. In addition to its class rules, DNV publishes regular updates to its document "Alternative

Fuels for Containerships", which aims to provide neutral, fact-based, scientifically sound decision support for newbuilding projects. The document's introductory sections explain the greenhouse gas (GHG) challenge, the IMO regulatory activities and the current market situation, followed by a comprehensive chapter about LNG as a ship fuel and its technical implications. The latest chapter examines the potential of methanol as a future alternative fuel for ships.

The new chapter of the DNV Alternative Fuels document provides comprehensive guidance on ship design arrangements, containment concepts, certification and training, essential steps before signing a contract, and cost considerations in the context of carbon trading. A list of relevant DNV and IMO rules and guidance documents including brief descriptions completes the discussion of methanol as a ship fuel.

As of flag states, NMA refers to the statutory rules, and don't have any stricter limitations and requirements to installations for methanol fuel. This is also the case for other flag states, and in this case no limitations have been identified for the flag this vessel is sailing under. Although, it should be confirmed in a potential next phase of this pilot with the current flag, and also confirmed with possible ports for methanol bunkering in case there are any local regulations.
The design of the vessel has not been evaluated by class or flag in detail, but from the presented drawings and information in WP 1.5 and WP.1.6, no showstoppers were identified. Although, detailed drawings and design must be provided in a potential next phase to further investigate the design in accordance with relevant rules. For design considerations, there would be recommendations to have the tank location closer to ER for less pipe work and no need to compensate for global movements of the ship. In addition, the location of fuel preparation room should also be indicated in a potential next phase. The closer this is located to the tank the better – the layout "next to each other" is commonly seen as a practical solution, though it is not exclusive.

WP 2.3) TANK DESIGN REQUIREMENT

Please refer to WP 1.5 and 1.6 regarding proposed solutions for methanol tank and FGSS. Further information can be found in the DNV Rules - Pt.6 Ch.2 Sec.6 - Propulsion, power generation and auxiliary systems (Annex 4). The scope for the additional class notation LFL fuelled includes requirements from the vessel's LFL fuel bunkering connection up to and including the consumers. The rules in this section have requirements for arrangement and location of fuel tanks and all spaces with fuel piping and installations, including requirements for entrances to such spaces. Hazardous areas and spaces due to the fuel installations are defined. Requirements for control, monitoring and safety systems for the fuel installations are included, also additional monitoring requirements for engines and pumps.

Work Process 3, Availability and cost of bio and e-methanol

WP 3.1) METHANOL BUNKER PROVIDERS

The Methanol Institute (MI) is tracking more than 80 renewable methanol projects around the globe that are projected to produce more than eight million metric tons (2.7 billion gallons or 10 billion litres) per year of e-methanol and bio-methanol by 2027. Curated by the MI team based on publicly announced projects, the database provides a novel look at the anticipated growth of renewable methanol production.

Methanol is an essential chemical building block and emerging energy resource. Methanol is synthesized using a mixture of hydrogen, carbon dioxide, and carbon monoxide. These elements can be derived from a variety of feedstocks and processes, with conventional methanol produced from natural gas or coal. Renewable methanol is a low carbon and net carbon neutral liquid chemical and fuel produced from sustainable biomass, often called bio-methanol, or from captured carbon dioxide and hydrogen produced from renewable electricity, referred to as e-methanol.

In addition to the growing number of renewable methanol projects, there is clear evidence that the sale of production for bio-methanol and e-methanol facilities is ramping up. With ongoing advancements in technology and increased government support, the capacity of individual renewable plants is expected to rise from 5.000 – 10.000 metric tons of methanol per year to 50.000 – 250.000 metric tons per year or more over the next five years.

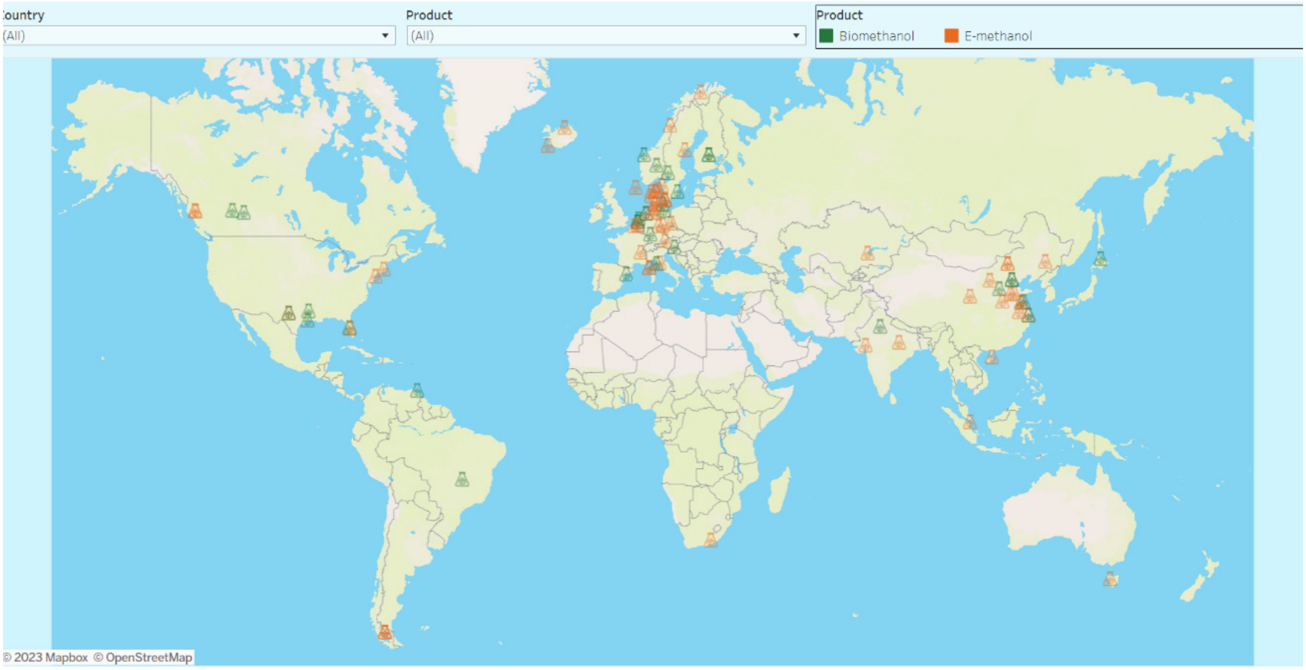


Fig 18.

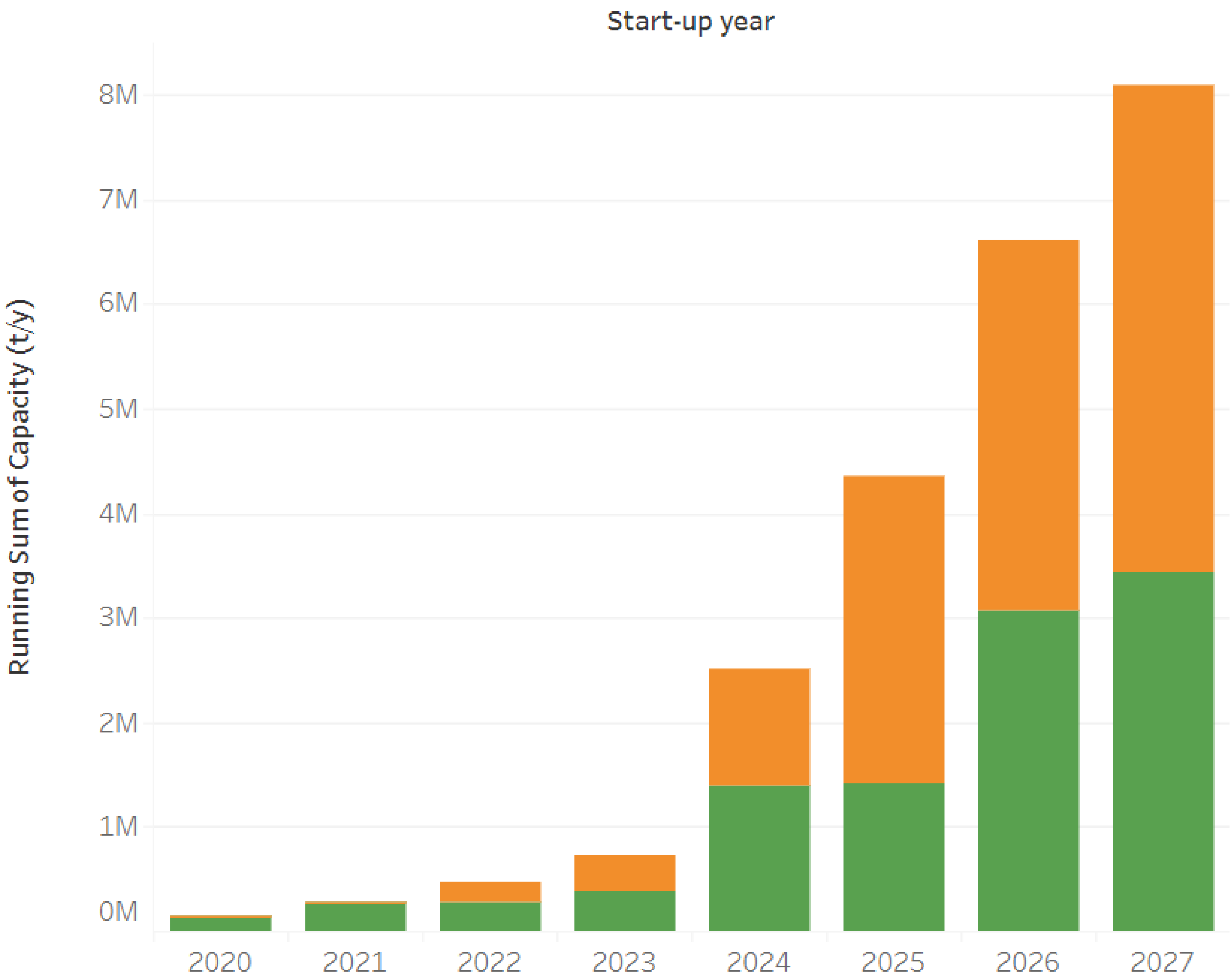
Current and upcoming renewable methanol projects across countries (source Methanol Institute)

As can be seen from the map in Fig. 18 there are no production or supply of renewable methanol on the route that Sealand Philadelphia (USWC, Central America or NWC South America) is currently trading. That said, there are methanol storage facilities in the area (Fig. 19), so future supply could potentially be possible.

LOCATION	STORAGE CAPACITY	SUPPLIER/OWNER
Long Beach, US	44,440 MT	VOPAK
Los Angeles, US	330,565 MT	VOPAK
Callao, Peru	30,000 MT	Proman
Barranquilla, Columbia	20,000 MT	Helm Proman
Cartagena, Columbia	50,000 MT	Helm Proman
Coatzacoalco, Mexico	20,000 MT	Helm Proman
Pajaritos, Mexico	30,000 MT	Helm Proman
Quintero, Chile	?	Methanex
Punta Arenas, Chile	?	Methanex

Fig 19.

Table over storage capacity (source Methanol Institute)



Source : Methanol Institute Renewable Methanol Database

Fig 20.
Projected renewable methanol production capacity (source Methanol Institute)

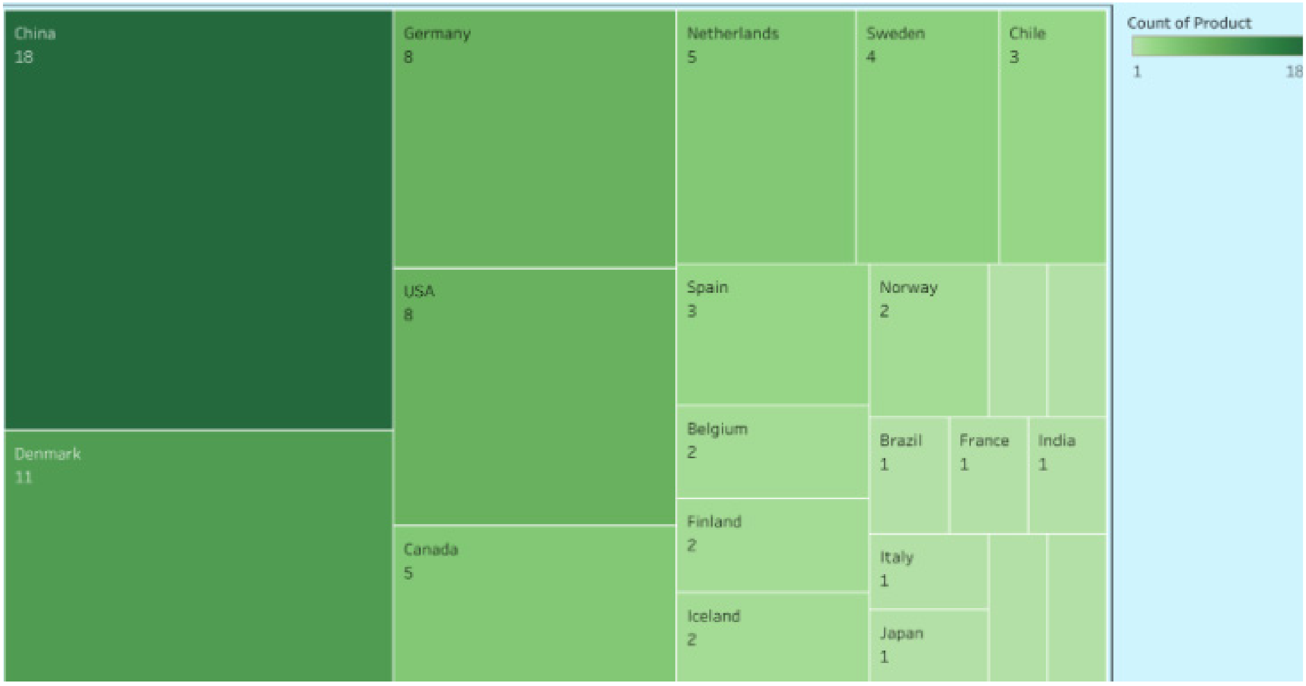


Fig 21.
Countries by count of renewable methanol projects (source Methanol Institute)

WP 3.2) FEEDSTOCKS/PRODUCTION

Based on input from the Methanol Institute there are several pathways to renewable methanol.

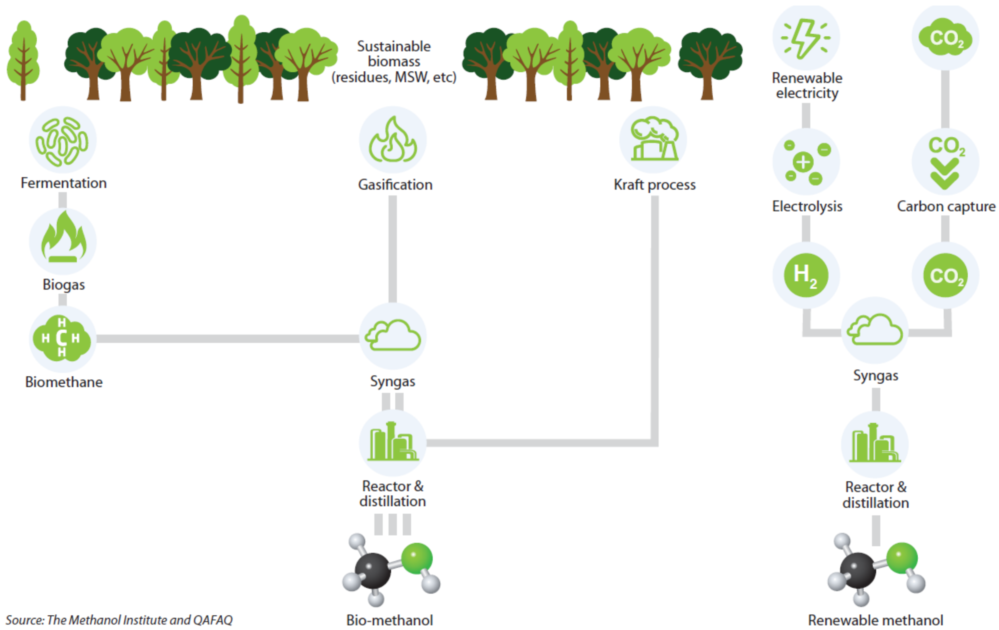


Fig 22.
Renewable methanol production processes from different feedstocks

THERE ARE SEVERAL PATHWAYS TO RENEWABLE METHANOL

In the electro-fuel pathway, renewable electricity is used to extract hydrogen from water by electrolysis. Hydrogen is then reacted with carbon dioxide captured from point sources (e.g. industrial exhaust streams) or from the atmosphere.

In the biomass pathway, organic matter undergoes fermentation or gasification (subjecting the biomass to high temperature in the absence of air) to produce synthesis gas (syngas) that is processed in a reactor and formed into bio-methanol.

Hybrid bio-methanol uses a combination of the two methods, combining biogenic syngas with hydrogen from electrolysis.

FEEDSTOCKS

Renewable methanol can be produced from a wide range of renewable feedstocks available worldwide. This section considers the availability of five main sources of feedstocks: municipal solid waste (MSW), agricultural waste, forestry residues, carbon dioxide (CO2) and renewable hydrogen. These are some of the largest sources but not the only ones.

AGRICULTURAL WASTE

Agricultural activity yields a great deal of biomass that can be converted into bio-methanol without interfering with food prices or availability or encroaching on agricultural land.

It has been estimated that around 998 million metric tons of agricultural waste is produced every year. In Europe, estimates say that up to 132.4 million metric tons of dry agricultural residues could be collected from the EU-27 states, with the potential to generate 639 TWh of energy. The DOE Billion Ton Report (2016) estimates that there will be 94.1 dry tons of forest biomass available by 2020 in the USA, assuming a cost of USD 60 per dry ton to roadside.

FORESTRY RESIDUES

A large amount of residual biomass, such as leaves, branches, needles, and woodchip, is produced in the process of harvesting trees. These by-products can be used as a feedstock for producing biochemicals such as renewable methanol.

Forestry biomass resources have been estimated at around 140 million metric tons in the USA7.

In the European Union, it has been estimated that total forest biomass amounts to 716 million m3 annually.

Swedish company Södra is building a plant that will produce bio-methanol from the raw methanol resulting from their pulp mill manufacturing. The company claims this is part of a sustainable circular process that uses all parts of forest raw materials to the best possible effect. Once completed, the plant will produce 5,000 metric tons of bio-methanol every year. According to Södra, their bio-methanol reduces CO2 emissions by 99% compared to fossil fuels.

MUNICIPAL SOLID WASTE (MSW)

Using Municipal Solid Waste (MSW) to produce renewable methanol creates value from unrecyclable garbage and relieves pressure on landfill sites. Every year, 1.3 billion metric tons of MSW are produced globally and this is expected to increase to 2.2 billion metric tons by 2025. Managing such volumes of waste poses great challenges for municipalities and governments.

Two thirds of MSW are either dumped in landfills or incinerated. A significant portion of this waste could be diverted towards producing sustainable chemicals, including renewable methanol.

Biochemical company Enerkem estimates that up to 420 million metric tons of unrecyclable waste could be turned into biochemicals, using their technology. Enerkem is building a plant in Rotterdam which will turn 350.000 metric tons of waste, including plastic matter, into 270 million litres of bio methanol every year.

CARBON DIOXIDE (CO_2)

Around 32.5 billion metric tons of CO_2 were released into the atmosphere in 2017 alone, rising 1.4% from 2016. This rise is the equivalent of having 170 million new cars on the roads.

With the current technology, it is possible to capture CO_2 from the atmosphere and from industrial exhaust streams. Power plants, steel and cement factories, and distilleries, among others, produce carbon dioxide that could be used as a source to produce methanol.

Carbon Recycling International takes 5.600 metric tons of carbon dioxide every year which is reacted with renewable hydrogen to synthesize 4.000 metric tons of renewable methanol (see CRI case study).

RENEWABLE HYDROGEN: HARNESSING RENEWABLE ENERGY FOR ELECTROLYSIS

As shown in Figure 22, renewable electricity is used to obtain hydrogen from water by electrolysis.

In recent years, solar PV, hydro, and wind have grown to account for a significant part of the energy mix in many parts of the world. These resources provide clean and affordable electricity, but maximum electric yield might not match peak demand. A wind power plant might peak at 3 am, when the wind blows strongly but there is little need for electricity. In this case, supply could outstrip demand and threaten to overload the electric grid.

When this happens, the Transmission System Operator (TSO) tends to disconnect the renewable resource to safeguard the integrity of the grid. As a result, renewable energy is wasted. In the energy industry, this is known as curtailment.

Curtailment costs can escalate. TenneT, a TSO, paid close to 1 billion euros in 2017 to wind energy operators as compensation for curtailment in the area it serves in Germany. In California, the grid operator states that, although only about 1% of solar energy is curtailed in the state, "during certain times of the year, it's not unusual to curtail 20 to 30% of solar capacity".

Instead of being wastefully curtailed, this electricity could be harnessed to generate renewable methanol, which could in turn be used to generate clean power or as a renewable fuel for cars and ships.

The price of electricity is one of the main cost drivers of renewable methanol, and excess renewable energy tends to command low prices because it is dispatched when demand is at its lowest.

A number of companies are exploring the idea of harnessing excess renewable energy to obtain clean hydrogen from electrolysis. One of them is Thyssenkrupp, which is also sourcing excess CO_2 from industrial sources to create renewable methanol.

WP 3.3) AVAILABILITY, LOCALLY AND GLOBALLY

As can be seen from Figure 19 below for Americas, and the global supply as per Figure 20 provided by Methanol Institute, there is a global supply of 8M tonnes bio-methanol and e-methanol expected in 2027 by the existing and planned facilities for production. For reference, please find the Methanol Availability Study from the Methanol Institute in Annex 6.

If also considering the infrastructure in port as per Fig. 23 below (AFI) there are existing terminals in ports along the Sealand Philadelphia trading pattern, so there is potential for methanol bunkering supply in some of the ports along the sailing route. However, the distribution network from existing fuel production facilities must be established, the cost for transporting and building relevant infrastructure should be considered, and the best options for how to bunker the vessel with methanol should be further evaluated in detail in a potential next phase, in addition to how such investments could be funded. It should also be evaluated how many vessels that would expected to bunker methanol along the sailing route for speeding up necessary bunkering investment.

Fig 23.
Existing/planned production of e-(blue) and bio (green) methanol

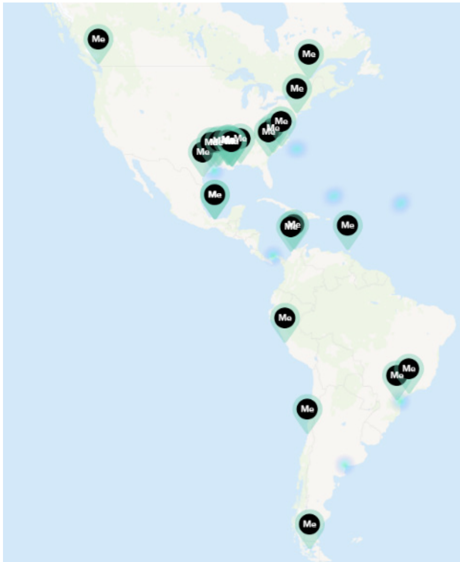


Fig 24.
Ports with methanol storage capacity

WP 3.4) GREEN CORRIDORS VS. SEALAND PHILADELPHIA TRADING PATTERN

There is no availability of renewable methanol on USWC today. One would think that if the methanol demand from, let's say for example, 20 – 30 vessels existed; this should likely increase the interest from suppliers to consider supply facilities. The number of vessels trading along the USWC from Panama to California is huge (see Fig. 25). Many of these are container vessels in different sizes. It would take a common effort by shipping companies, charterers and the methanol producing industry to get this going.

Ideal location of supply points would be the west entry of the Panama Canal and one major container port, or bunkering hub, in California.

Maersk is working with several suppliers of renewable methanol to cover the future need for their fleet. Some of these are located in US and will be able to produce ~650 kMt per year from 2025 to 2026. This could be a breaking point also for other suppliers to act.

This would be a topic to look into in a potential 2nd phase of this project.

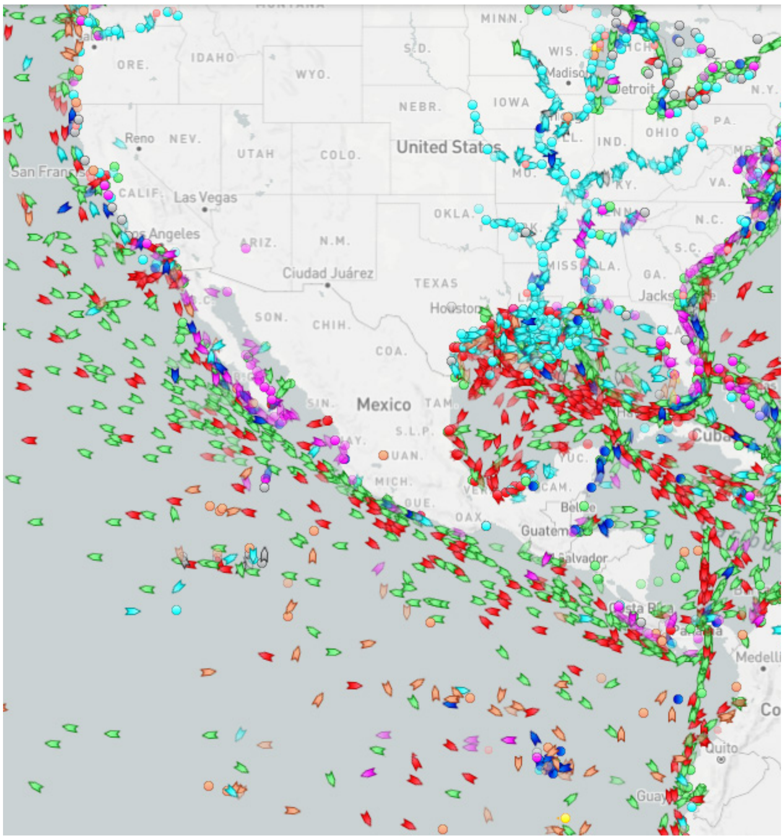


Fig 25.
Extract from AIS of traffic along USWC (green "dots" indicate container vessels)

WP 3.5) COST SCENARIOS AND PROJECTIONS

Renewable methanol is seen as a viable fuel option in accelerating the decarbonization of maritime industries. According to the Methanol Institute and the report it produced with the International Renewable Energy Agency (IRENA), bio-methanol will cost USD 700 to USD 900 per mt, while e-methanol cost looks to be USD 1,200 to USD 1,600 per mt. By 2050, methanol production can reach 500 million mt per year, out of which almost 400 million mt will be bio-methanol or e-methanol.

Bio-methanol is considered methanol that comes from waste streams, while e-methanol comes from green hydrogen and captured CO2. Both classify as renewable or green methanol. With carbon intensity accounting being the ultimate goal of the green methanol users, the carbon intensity of the fuel, in comparison to the fossil equivalent, will be one of the key drivers in determining the price and level of demand. Depending on the feedstock and production process, methanol's carbon footprint can be reduced by 65%-90%.

BIO-METHANOL

Since production of bio-methanol currently is low, limited data are available on actual costs, meaning that potential costs need to be estimated. The production cost will depend on the bio-feedstock cost, investment cost and the efficiency of the conversion processes. Biomass and MSW feedstock costs vary between USD 0 and USD 17 per gigajoule (GJ).

With a lower feedstock cost range of up to USD 6 per GJ, the cost of bio-methanol is estimated to be in the range USD 320 per mt and USD 770 per mt, with the range influenced by differences in the specific projects – including differences in CAPEX, OPEX and conversion efficiency.

With process improvements, the cost range could be reduced to between USD 220 per mt and USD 560 per mt for the lower feedstock price range up to 6 USD per GJ, with a correspondingly higher range for the higher feedstock price range.

Production of bio-methanol from the waste streams of other industrial processes (e.g. black liquor from paper mills and MSW) in particular offer opportunities to simplify the feedstock logistics and improve overall plant economics. Co-production of heat, electricity or other chemicals could also potentially improve the economics of bio-methanol production.

In the short-term biomass could be co-fed into a coal-based gasifier, or biogas fed into a natural gas-based methanol plant, so allowing for the gradual introduction of biomass as a feedstock and making methanol production more sustainable at a potentially lower cost.

E-METHANOL

The cost of e-methanol depends to a large extent on the cost of hydrogen and CO2. The cost of CO2 depends on the source from which it is captured – example: from biomass, industrial processes, or DAC.

The current production cost of e-methanol is estimated to be in the range USD 800 - 1 600 per mt assuming CO2 is sourced from BECCS at a cost of USD 10-50 per mt. If CO2 is obtained by DAC, where costs are currently USD 300 to USD 600 per Mt, then e-methanol production costs would be in the range of USD 1,200 to USD 2,400 per mt.

The future cost of green hydrogen production mainly depends on the combination of further reductions in the cost of renewable power generation and electrolysers, and gains in efficiency and durability. With anticipated decreases in renewable power prices, the cost of e-methanol is expected to decrease to levels between USD 250 and USD 630 per mt by 2050.

As in the case of bio-methanol, co-production of brown/grey (fossil) and green e-methanol could allow the gradual introduction of green e-methanol at a reasonable cost.

Based on forecasted methanol prices in the IRENA Innovation Renewable Methanol report (Annex 7), following assumptions has been made to see the effect of what impact different CO2 tax levels could play versuss future methanol prices. Assumed CO2 tax development in column 3 and cost of methanol in column 5 (table below).

Year	Cost of VLSFO USD/mt	CO_2 tax USD mt/CO_2	VLSFO + CO_2 USD/mt	Cost of MeOH USD/mt
2025	800	500	1300	1800
2030	800	600	1400	1500
2035	800	700	1500	1250
2040	800	800	1600	1000
2045	800	900	1700	750
2050	800	1000	1800	500

This could lead to a scenario as in Fig. 26. For Sealand Philadelphia, this would mean that if converted at next DD in 2027, the vessel would be CO2 free and the return of investments would kick-in when she is 25 years old. If the lifetime of the vessel could be extended to, let's say for example: 30 years; the investment would be recovered.

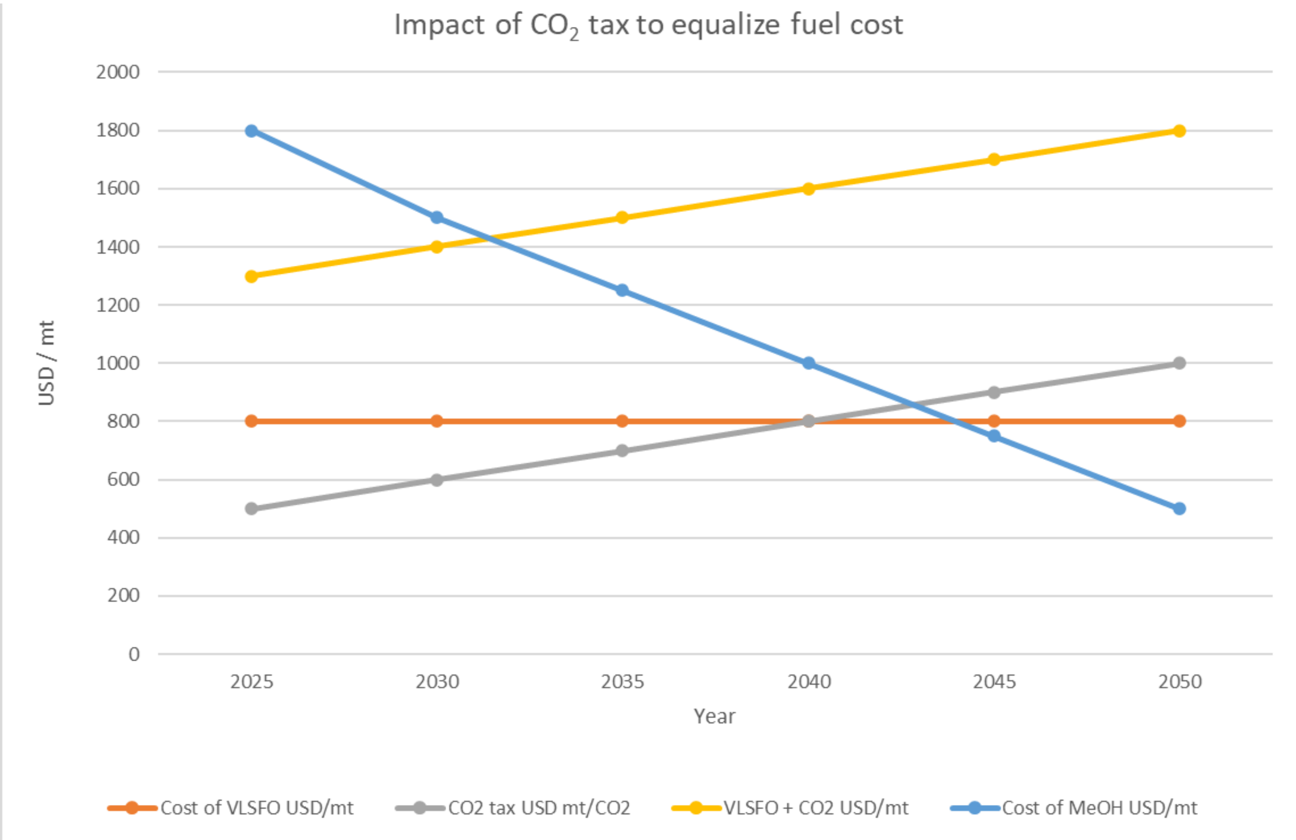


Fig 26.
Assumed impact of CO2 tax and methanol pricing

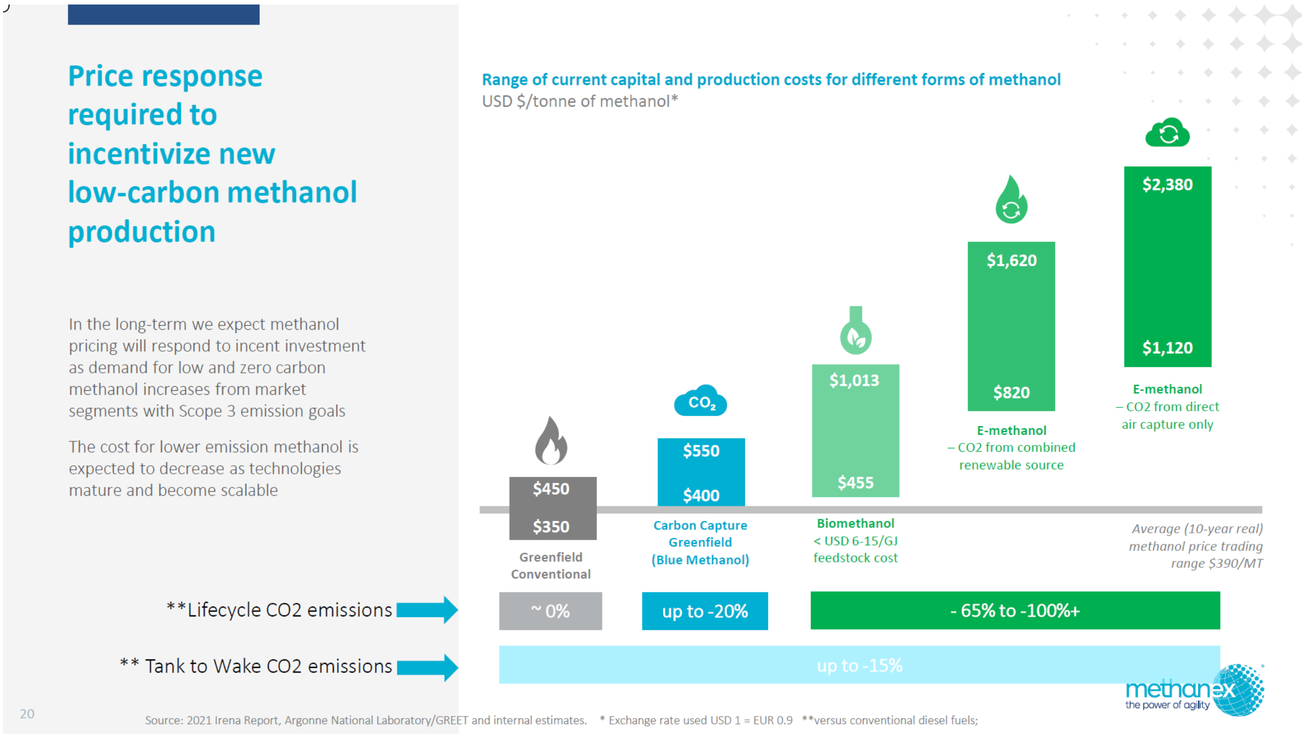


Fig 27.

Price forecast prepared by Methanex based on the 2021 IRENA report

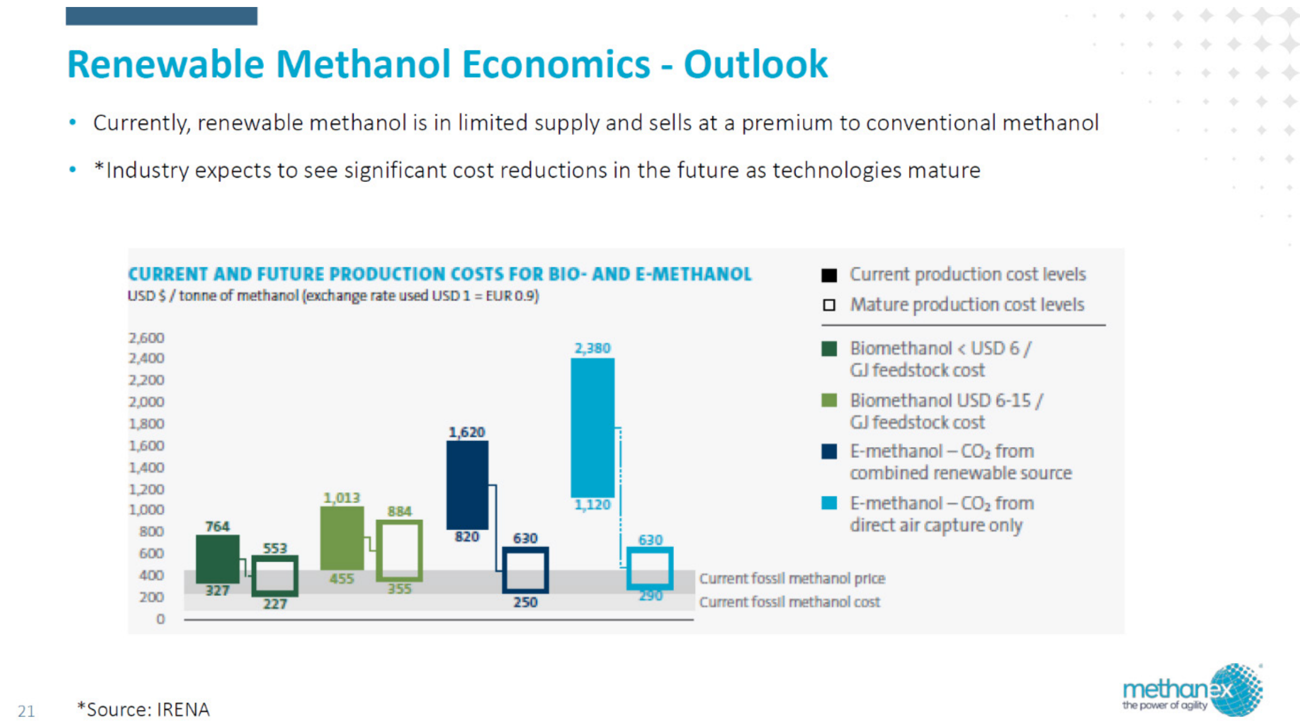


Fig 28.

Renewable Methanol pricing for 2050, prepared by Methanex based on the 2021 IRENA report

WP 3.6) VESSEL INFORMATION SUPPORT

All technical and operational inputs to this project are given by SinOceanic Shipping and the Technology Group in Thome Group. The gathered data is based on makers specifications and drawings, as well as monitored and recorded data from "Sealand Philadelphia" in operation.

Work Process 4, technical solutions, energy efficiency

In 2023, we will see the implementation of further regulatory measures to address the decarbonization of shipping. The IMO GHG Strategy will be revised, strengthening the GHG emissions-reduction ambitions for international shipping. Standards for calculating and verifying lifecycle emissions of marine fuels are maturing. Expectations from cargo owners and financial institutions continue to be strong drivers for ship decarbonization with increased requirements on transparency and reporting of emissions throughout the supply chain.

During 2021, we had significant developments on the regulatory arena with the IMO's adoption of carbon intensity requirements through CII, EEXI, and SEEMP. EU announced its Fit for 55 package including several proposals impacting ships directly. 2022 was a working year in the IMO and EU with multiple regulatory processes developing frameworks and standards that will shape shipping in the next decades.

Expectations on Environmental, Social and Corporate Governance (ESG) reporting and disclosure of emissions in practice means that shipping companies will need to provide more detailed reporting on emissions and ensure that future decarbonization requirements are met.

There are proposals presented on what type of regulations should be implemented to ensure that shipping achieves the strategy ambitions. One set of proposals consists of market-based measures (MBMs), which aim to set a price on CO_2 or GHG emissions, either well-to-wake or tank-to-wake; creating a financial incentive driving uptake of GHG emission reduction measures indirectly rather than through a technical requirement.

In addition to the MBMs, the IMO has also received a proposal for a technical requirement, the GHG Fuel Standard, which will set a requirement on the well-to wake GHG emission per unit of energy provided to the ship, either as a fuel or as electricity.

Besides new fuels, decarbonization requires greater onboard energy flexibility and efficiency. The internal combustion engine (ICE) will likely remain the dominant energy converter in the fleet, but future integration of marine fuel cells in power systems might have the potential to provide greater efficiency and thereby reduce fuel consumption. Nevertheless, we must focus on the existing fleet and what measures can be taken to improve the situation today. By converting existing fleet with available technology, operational efficiency measures can significantly reduce GHG emissions. In this report, we have looked into several technologies that can have severe impact on reduction of fuel consumption.

WP 4.1) HYBRID SYSTEM INTEGRATION

Electrification and hybrid power technologies offer exceptional optimization potential for today's vessels, helping to improve fuel efficiency and reduce emissions while improving reliability and load response across the integrated power system. Hybrid technologies that can help improve efficiency and reduce reliance on fossil fuels include shaft generators, batteries, solar/wind power generation, power converters, and when required, shore power interfaces.

As an example of a hybrid arrangement, a shaft generator driven by the two-stroke main engine can deliver electrical power that can be used for either propulsion or auxiliary demand, reducing fuel consumption and emissions. At the same time, such installations will improve EEXI and CII performance. The solution also reduce maintenance spend on auxiliary engines onboard due to lower running hours during the voyage.

By introducing a CPP propulsion and manoeuvring system including a battery hybrid solution, it would give great flexibility and the ability to operate the main engine as power generator also during manoeuvring. It is of course important to optimise and integrate the prime mover and electric power sources. This includes selecting appropriate technologies and crucially, the sizing of all system components. It is equally important to have a system integrator with capabilities to ensure that the chosen solutions – including main engine and electric power sources – are part of an optimised, fit-for-purpose, holistic energy system.

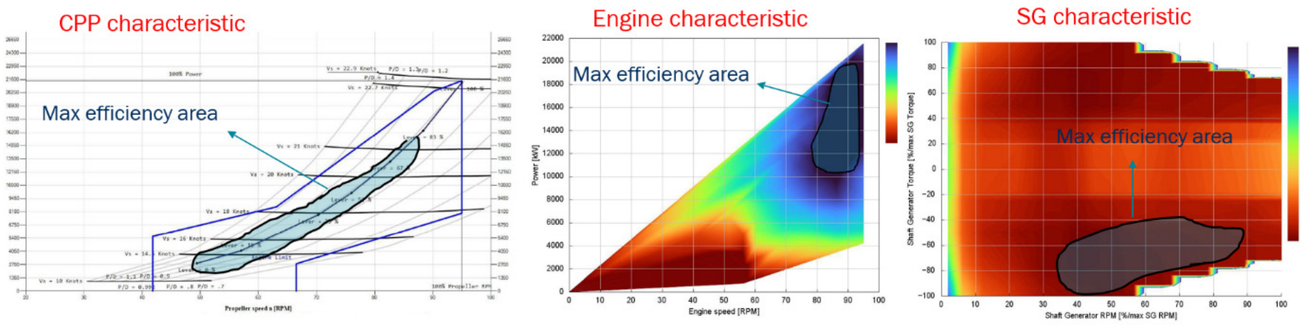


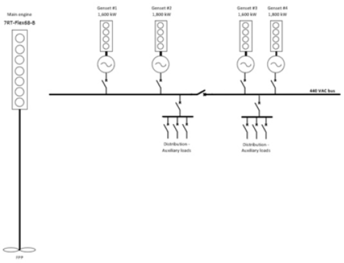
Fig 29.

Hybrid system simulations carried out for Sealand Philadelphia unveil great efficiency opportunities.

In this project, we have had four different vendors proposing their solutions, coming up with significant potential for reducing energy demand, and consequently fuel consumptions and CO_2 emissions. Four different solutions have been considered, whereof one the existing installation for benchmarking purposes.

1. The first alternative is based on the vessel as-is, with the traditional installation of a 2-stroke ME with Fixed Pitch Propeller (FPP), standard rudder, and 4 Auxiliary Engines (AE).
2. Alternative two is based on a FPP propulsion system. In addition, the vessel is considered equipped with an optimized rudder bulb which gives additional positive effects. The bulb optimises the hydrodynamic properties by reducing the creation of vortices, hub drag and improves the flow that allow for a more efficient propeller design. This is making the system more efficient in propulsion thrust and consumes lesser energy. In addition, a Shaft Generator (SG) is included. Estimated cost for such conversion is 2.6 MEUR and the estimated savings in the range of 9-11%. Estimated savings including a battery hybrid 11%.
3. Alternative tree is based on a Controlled Pitch Propeller (CPP) propulsion and manoeuvring system. Also, this system is equipped with an optimised rudder bulb with similar positive effects. This solution includes a 2.4 MW SG. Estimated installation cost for such system is 4.1 MEUR, including bulb rudder, CPP, shafting, hydraulics, and controls. Estimated savings for such system is in the range of 11-13%
4. Alternative four consists of system as mentioned in alternative three, but here an additional battery installation of 1.5 MW is considered. In such hybrid system, the saving would be 14.6% and combined with a CPP installation it would make the operation more or less “genset free”. Total cost is about 5.2 MEUR.

Configuration	Current configuration (baseline)
Engine Type	7RT-Flex68-B
Generating Sets	2x 1'800 kWm + 2x 1'600 kWm Diesel
Battery Capacity	-
Shaft Generator	-
Propeller type	FPP



Configuration	Shaft Generator solution w/ FPP
Engine Type	7RT-Flex68-B
Generating Sets	2x 1'800 kWm + 2x 1'600 kWm Diesel
Battery Capacity	-
Shaft Generator	SG 2'400 kWe (@45 - 84 RPM)
Propeller type	FPP

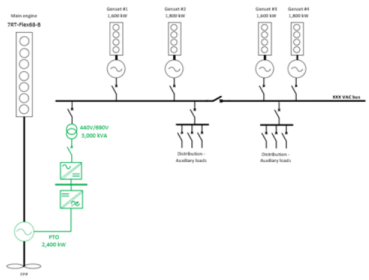
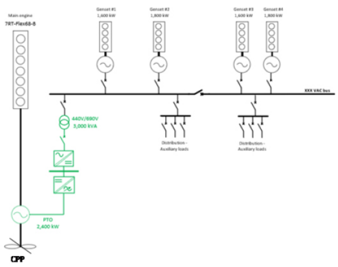


Fig 30.
Alternatives 1 and 2 (base case installation, and FPP including shaft generator)

Configuration	Shaft Generator solution w/ CPP
Engine Type	7RT-Flex68-B
Generating Sets	2x 1'800 kWm + 2x 1'600 kWm Diesel
Battery Capacity	-
Shaft Generator	SG 2'400 kWe (@45 - 84 RPM)
Propeller type	CPP



Configuration	Hybrid solution w/ CPP
Engine Type	7RT-Flex68-B
Generating Sets	2x 1'800 kWm + 2x 1'600 kWm Diesel
Battery Capacity	1'000 kWh
Shaft Generator	SG 2'400 kWe (@45 - 84 RPM)
Propeller type	CPP

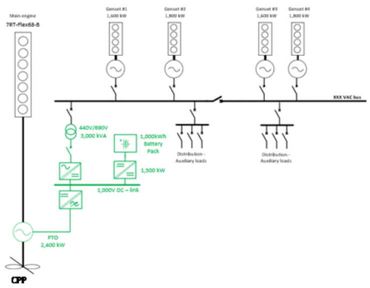


Fig 31.
Alternatives 3 and 4 (CPP with shaft generator installation, and CPP with hybrid shaft generator including

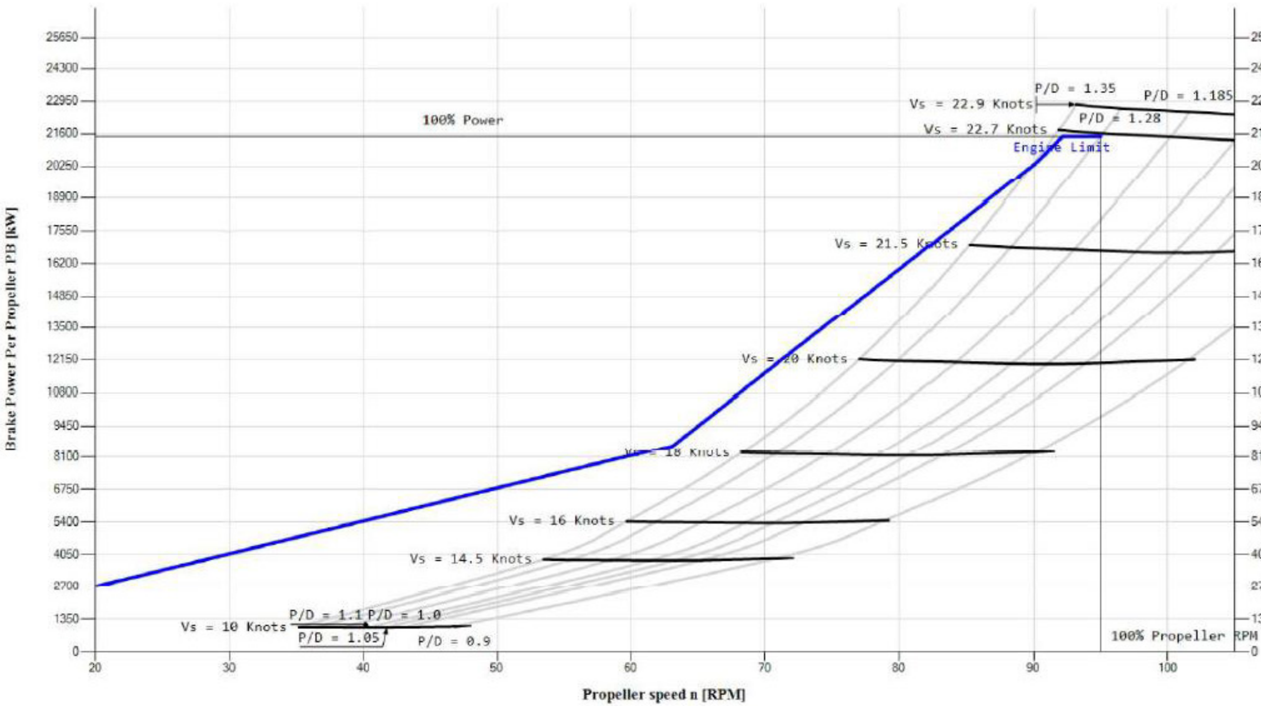


Fig 32.
Baseline, Fixed Pitch Propeller (FPP)

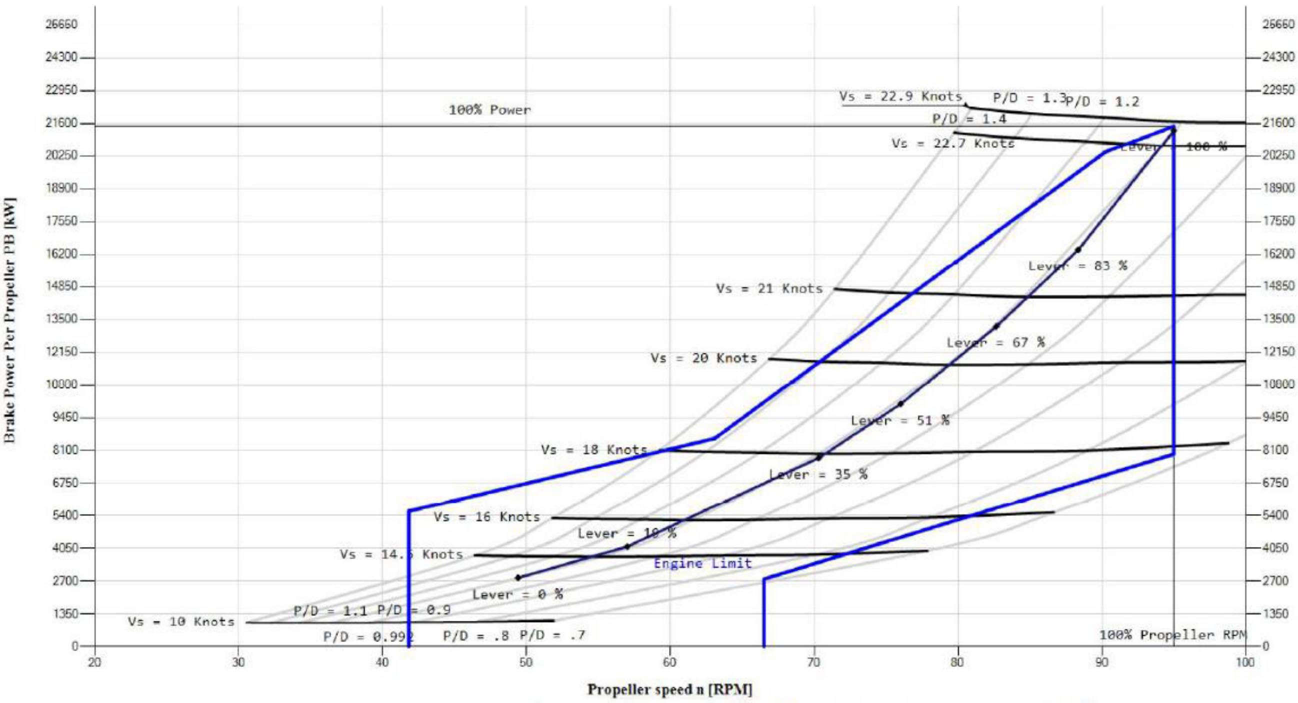


Fig 33.
Proposed, Controlled Pitch Propeller (CPP)

E-METHANOL

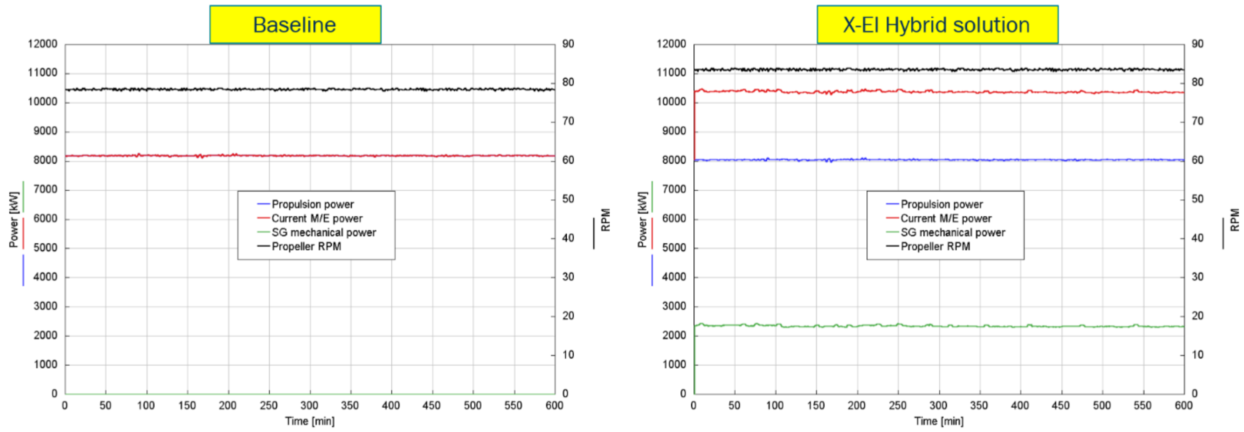


Fig 34.

Seagoing mode at 18 knots. Main engine, shaft generator and propulsion power.

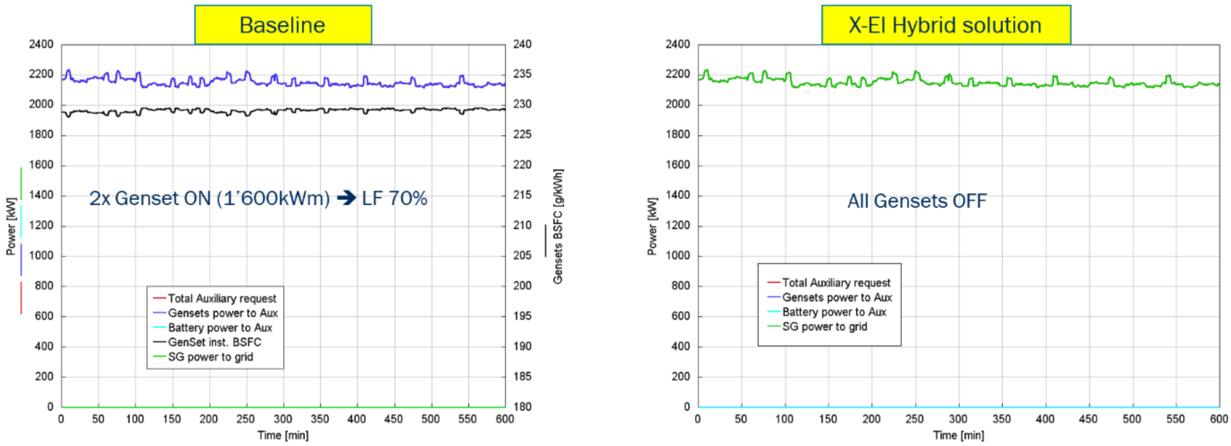


Fig 35.

Seagoing mode at 18 knots. Auxiliary loads management.

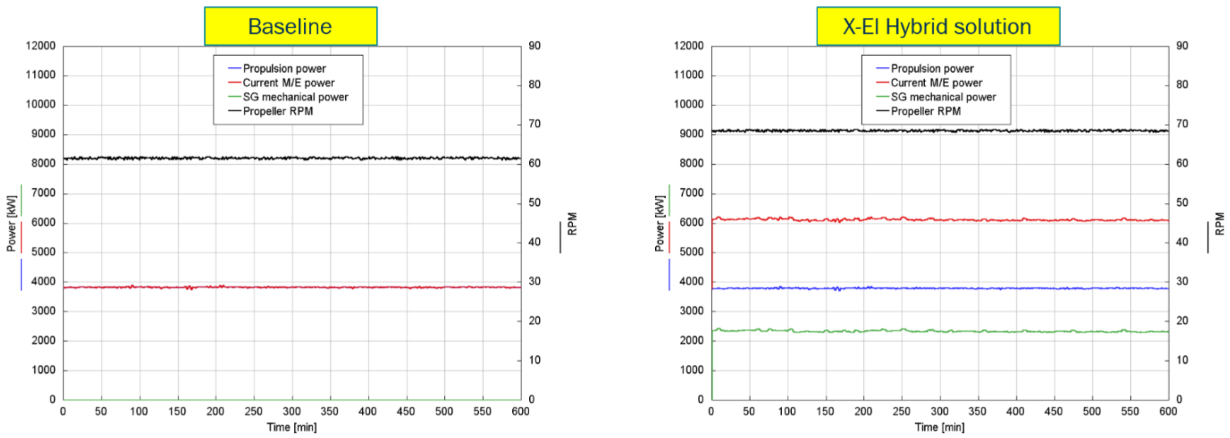


Fig 36.

Seagoing mode at 14.5 knots. Main engine, shaft generator and propulsion power.

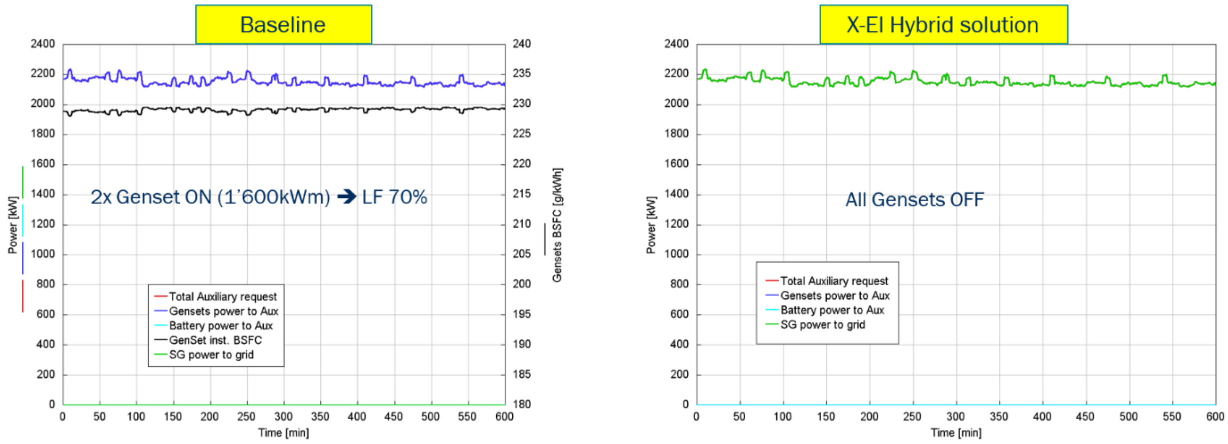


Fig 37.

Seagoing mode at 14.5 knots. Auxiliary loads management.

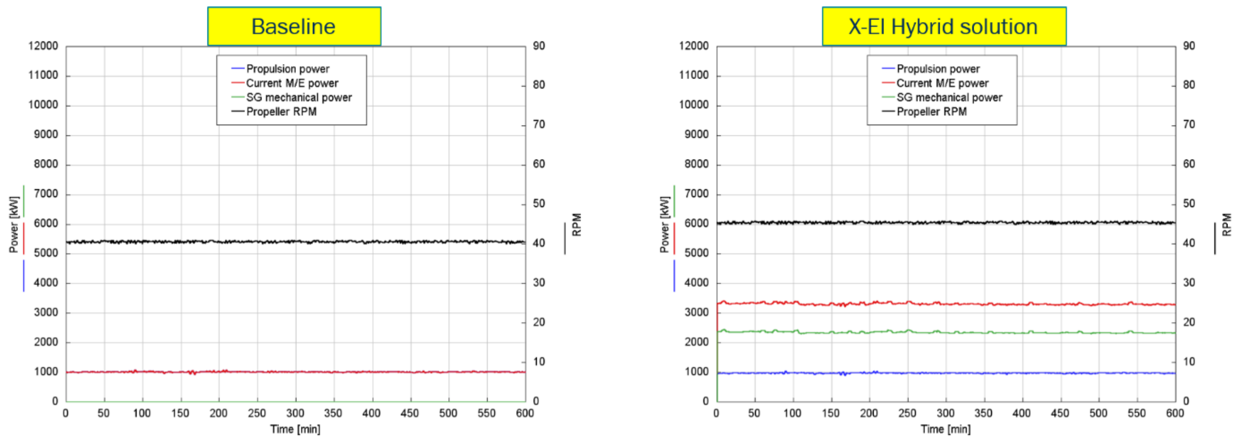


Fig 38.

Seagoing mode at 10 knots. Main engine, shaft generator and propulsion power.

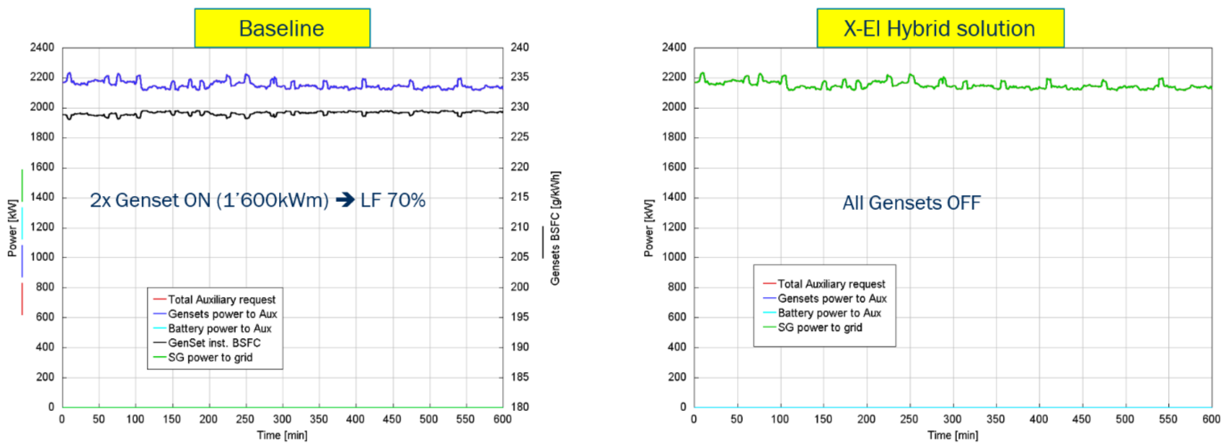


Fig 39.

Seagoing mode at 10 knots. Auxiliary loads management.

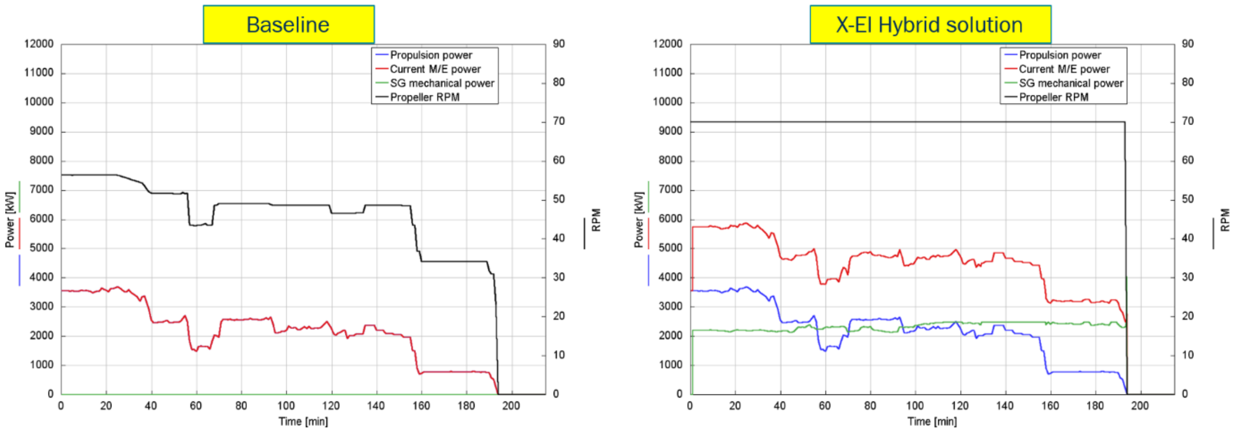


Fig 40.

Manoeuvring mode. Main engine, shaft generator and propulsion power.

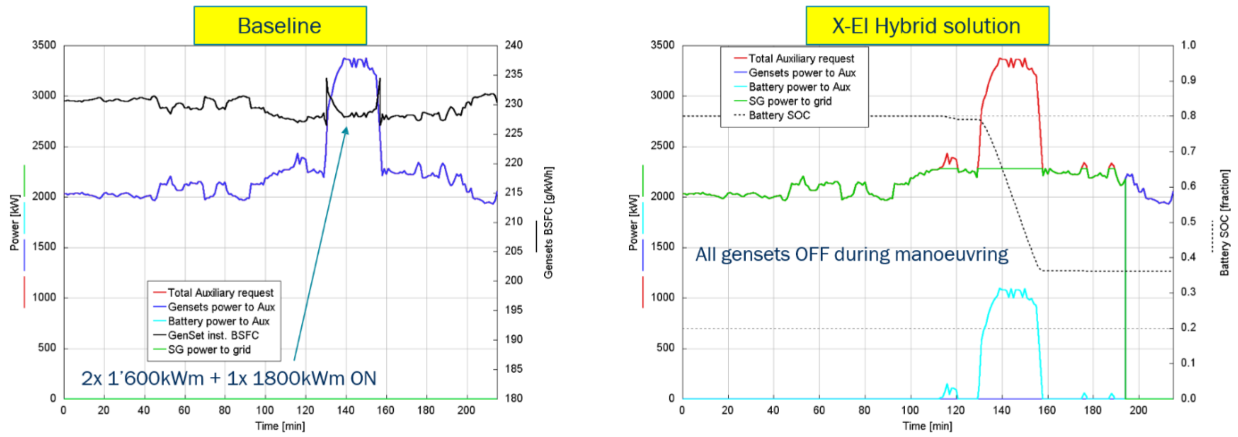


Fig 41.

Manoeuvring mode. Auxiliary loads management.

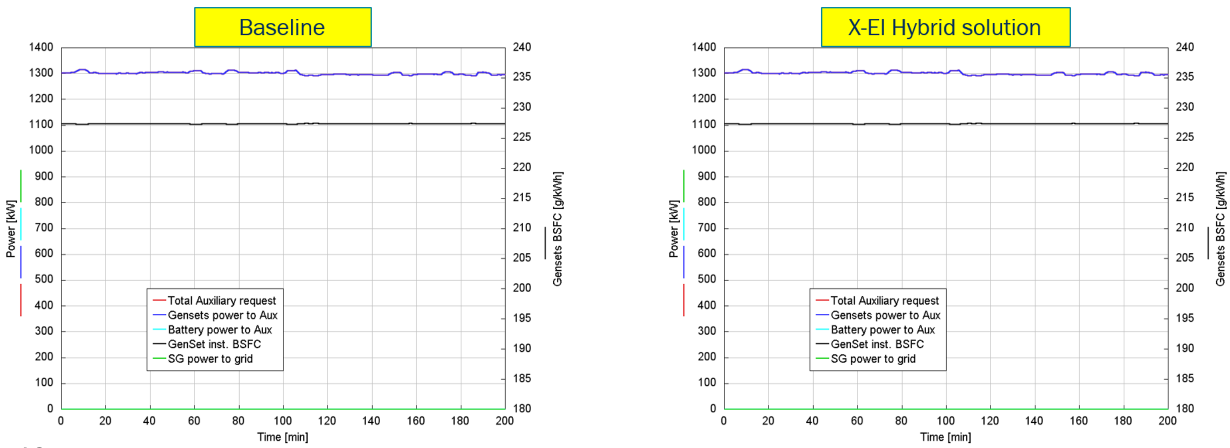
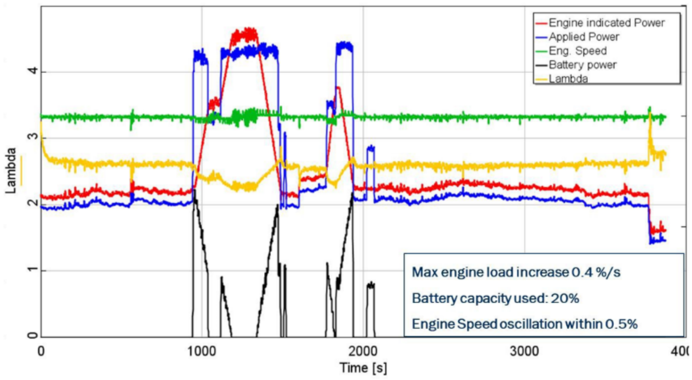


Fig 42.

Port staying mode, where possible shore power (batteries for peak shaving) is utilised instead of auxiliaries.



HCS communication with ECS ensure the SG request to the engine is compliant with the engine load acceptance limits. If SOC is available, The battery provides steep auxiliary load increase / drop when needed.

Feed forward control functionality is also integrated to reduce RPM noises during load up/down

Increased operation stability and safety with reduced GHG emissions.

Fig 43.
Test case: Dynamic operation with PTO + battery

CONCLUSIONS AND RECOMMENDATIONS

- The optimal size is of the shaft generator is 2.400 kWe. Larger sizes give no further benefits, while smaller sizes are notably suboptimal.

- Minimum recommended battery size is 1.000 kWe to maintain genset free operation during manoeuvring.

- Propeller efficiency of CPP is averagely four percent higher than baseline FPP. With larger RPMs and suboptimal P/D values, the efficiency tends towards the FPP solution.

- The proposed battery hybrid solution allows for up to 19% GHG emissions reduction during sea going compared to the current system.

- GHG emission reduction during manoeuvring is approximately 29% compared to the current system.

- The proposed battery hybrid solution allows for over 1.3 mUSD in Operational Expenditure (OPEX) reduction yearly compared to the current system.

- Gensets maintenance savings with proposed battery hybrid solution are in the range of 160 kUSD per year.

WP 4.2) UNDERWATER SOLUTIONS, ANTIFOULING

SeaQuantum Skate is an integral part of Jotun Hull Skating Solutions (HSS). Built on the concept of proactive cleaning, HSS delivers an always-clean hull, even for the most challenging operations. SeaQuantum Skate was developed specifically to optimise performance in combination with Jotun HullSkater. The coating endures repeated mechanical contact with the proactive cleaning brush without erosion of the coating. The hull is kept fouling free, contributing to a reduction in fuel consumption and carbon emissions by up to 16.2%*, ultra-low frictional resistance and effective biofouling control of the underwater hull.

Reactive hull cleaning; the cleaning operation undertaken by divers and/or underwater drones to remove macro-algae and macro-fouling from a ship's hull.

Proactive hull cleaning; proactive cleaning or grooming of a ship's hull, removing individual bacteria and biofilm at a very early stage before fouling is allowed to firmly settle.

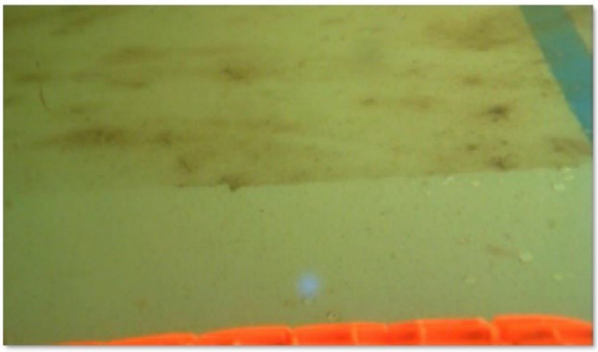


Fig 44.
Picture of reactive versus proactive hull cleaning.

In the case of “Sealand Philadelphia” the savings is estimated to approximately 5.3% and come with a total cost of 0.8 MUSD.

SeaQuantum Skate is the only coating tailored for hull skating and is one of the key components of Jotun HSS, combining SeaQuantum Skate with Jotun HullSkater, proactive condition monitoring, high-end technical service, and a clean hull guarantee. SeaQuantum Skate complies with the IMO Antifouling System Convention (AFS/CONF/26) and does not contain tributyltin (TBT) or cybutryne. SeaQuantum is a global leader in silyl-based anti-fouling coatings and is the market leader in verifiable speed-loss performance. The SeaQuantum brand has been the choice for over 16,000 vessel applications over the last two decades.

HullSkater can inspect a 10,000m2 hull in approximately two hours. As a permanent member of crew, it is always on station, ready to clean all known fouling from the hull, which if left to accumulate causes increased drag leading to extra fuel consumption and emissions to air (GHG and CO_2).

***Average in-service speed deviation over 60 months docking interval based on ISO 19030 measurement methods. Fuel saving estimates are compared with market average speed loss of 5.9% and a 1:3 power to speed ratio.**

WP 4.3) UNDERWATER SOLUTIONS, AIR LUBRICATION

Air lubrication systems changes the interaction between water and a vessel. It shears air from air release units in the hull to create a uniform carpet of microbubbles that coats the full flat bottom of a vessel. As a result, frictional resistance is decreased, and on certain vessel types quite dramatically reducing fuel consumption and associated emissions.

Some hull forms and main dimensions give additional benefit – the wider the vessel, the higher impact air lubrication has. A wider vessel also means more shallow draft.

On the other hand, on vessels with higher speed, there will be less impact of air lubrication. The following calculation has been done for "Sealand Philadelphia". As one can see from the table, the saving potential is only 0.2% and as such nothing to pursue for this project. The reason for this is the small flat bottom part of the vessel combined with a relatively high speed.

	CURRENT	With HSG + ALS
Propeller Power [kW]	9150	8464
ALS Reduction [kW]		**686**
Engine Power [kW]	9289	10593
Engine SFOC [g/kW]	172.9	171.8
Hotel Load [kW]	450	450
Reefer Load [kW]	1700	1700
Air Compressor Load [kW]	**0**	**1000**
Total El. Load [kW]	2150	3150
Total DG/PTO Power [kW]	2263	3316
Total PTO Power [kW]	0	2105
DGs Running [kW]	2	1
DGs Power [kW]	1132	1211
DG SFOC [g/kW]	229.1	228.0
Annual ME FOC [mT]	7739	8941
Annual DF FOC [mT]	2498	1440
Annual FOC [mT]	10234	10210
FOC Savings [mT]	**24mT / 0.2%**	

WP 4.4) UNDERWATER SOLUTIONS, BULB DESIGN

To determine the savings potential by changing the bulbous bow, Computational Fluid Dynamics (CFD) simulations was carried out.

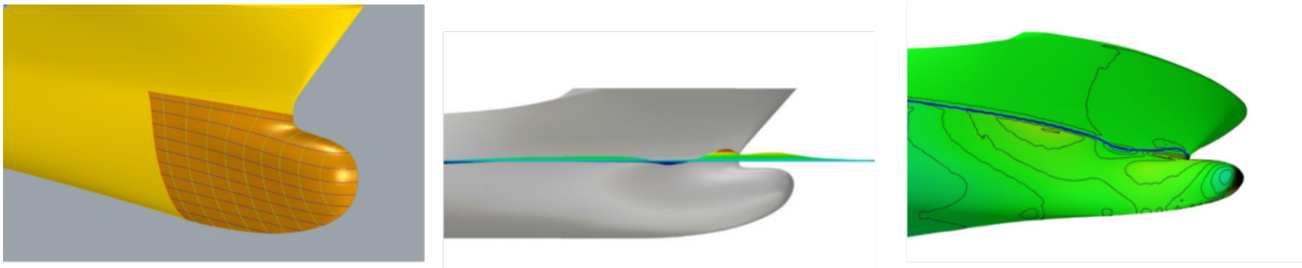


Fig 45.
Hull form 0 (existing hull shape) base case.

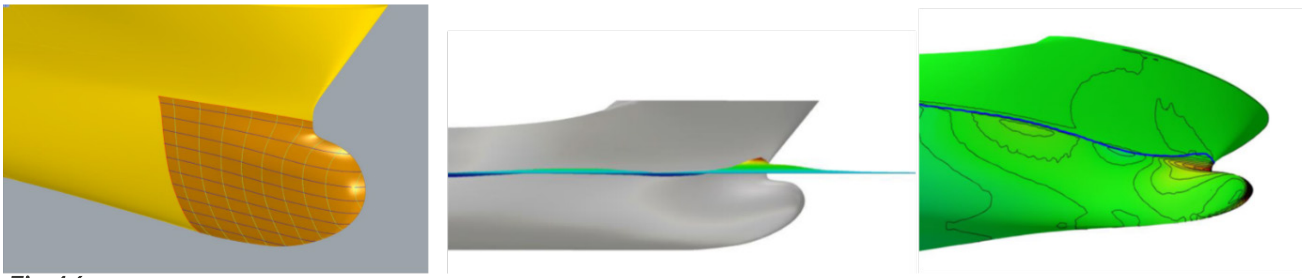


Fig 46.
Hull form 1 – hull resistance lowered by 0.30%

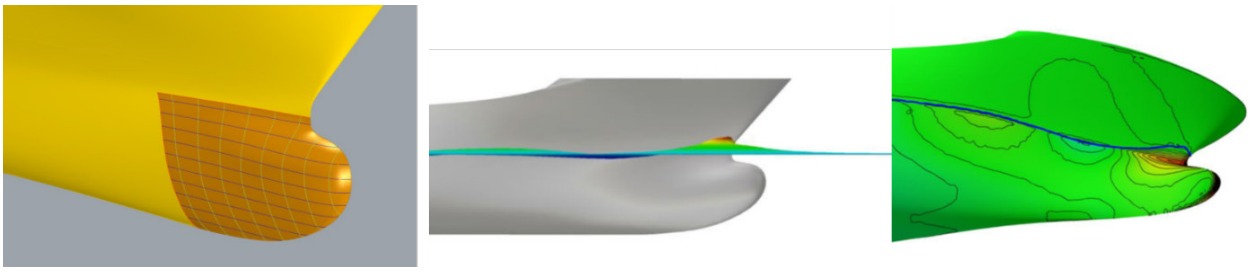


Fig 47.
Hull form 2 – hull resistance increased by 2.70%

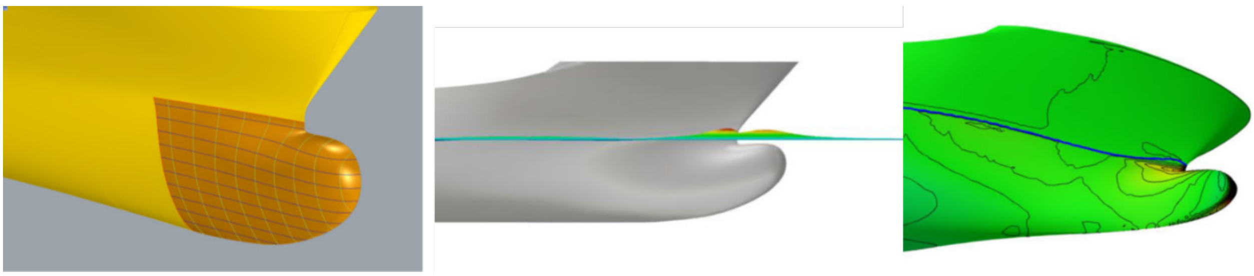


Fig 48.
Hull form 3 – hull resistance lowered by 2.50%

After the first run of CFD, it shows that converting the bulbous bow to hull form 3 the hull resistance will be lowered with 2.50%. It is likely that this can be fine-tuned and improved slightly, assumed closer to 3.00%. This in combination with improved propeller design – it should be a good opportunity for savings in fuel consumption here. The estimated cost for bulb conversion is 750 kUSD and could with prefabrication be carried out during main DD.

WP 4.5) WIND ASSIST

The mechanical means of converting the kinetic energy of the wind into thrust for a ship is the subject of much recent studies. As early ships were designed primarily for sailing, the design focus was around the sails that propelled them. Commercial ships are now designed largely around the cargo that they carry, requiring a large clear deck and minimal overhead rigging in order to facilitate cargo handling. Another consideration in designing a sail propulsion system for a commercial ship is that in order for it to be economically advantageous it cannot require a significantly larger crew to operate, and it cannot compromise the stability of the ship. Taking these design criteria into account, three main concepts have emerged as the leading designs for wind-assisted propulsion: "Wing Sail Concept", "Kite Sails", and the "Flettner Rotor."

In this study we have focused on the "Flettner Rotor" solution. This is a large cylinder mounted upright on a ship's deck and mechanically spun. The effect of this spinning area in contact with the wind flowing around it creates a thrust effect that is used to propel the ship. Flettner Rotors were invented in the 1920s and have seen limited use since then. In 2010 a 10,000-dwt cargo ship was equipped with four Flettner Rotors to evaluate their role in increasing fuel efficiency. Since then, several cargo ships and a passenger ferry have been equipped with rotors.

The only parameter of the Flettner Rotor requiring control is the rotational speed of the rotor, meaning this method of wind propulsion requires very little operator input. In comparison to kite sails, Flettner Rotors often offer considerable efficiency gains when compared to the size of a sail or kite, versus the size of the rotor and prevailing wind conditions.

Norsepower Rotor Sails are modernized versions of Flettner Rotors. The rotor sail technology is based on the Magnus effect (Fig. 49). When wind meets the spinning Rotor Sail, the air flow accelerates on one side of the Rotor Sail and decelerates on the opposite side of the Rotor Sail. The change in the speed of air flow results in a pressure difference, which creates a lift force that is perpendicular to the wind flow direction. The same principle applies to all rotating spheres and cylinders. This can also be observed, for example in golf, tennis, or football, where spinning balls curve in flight.

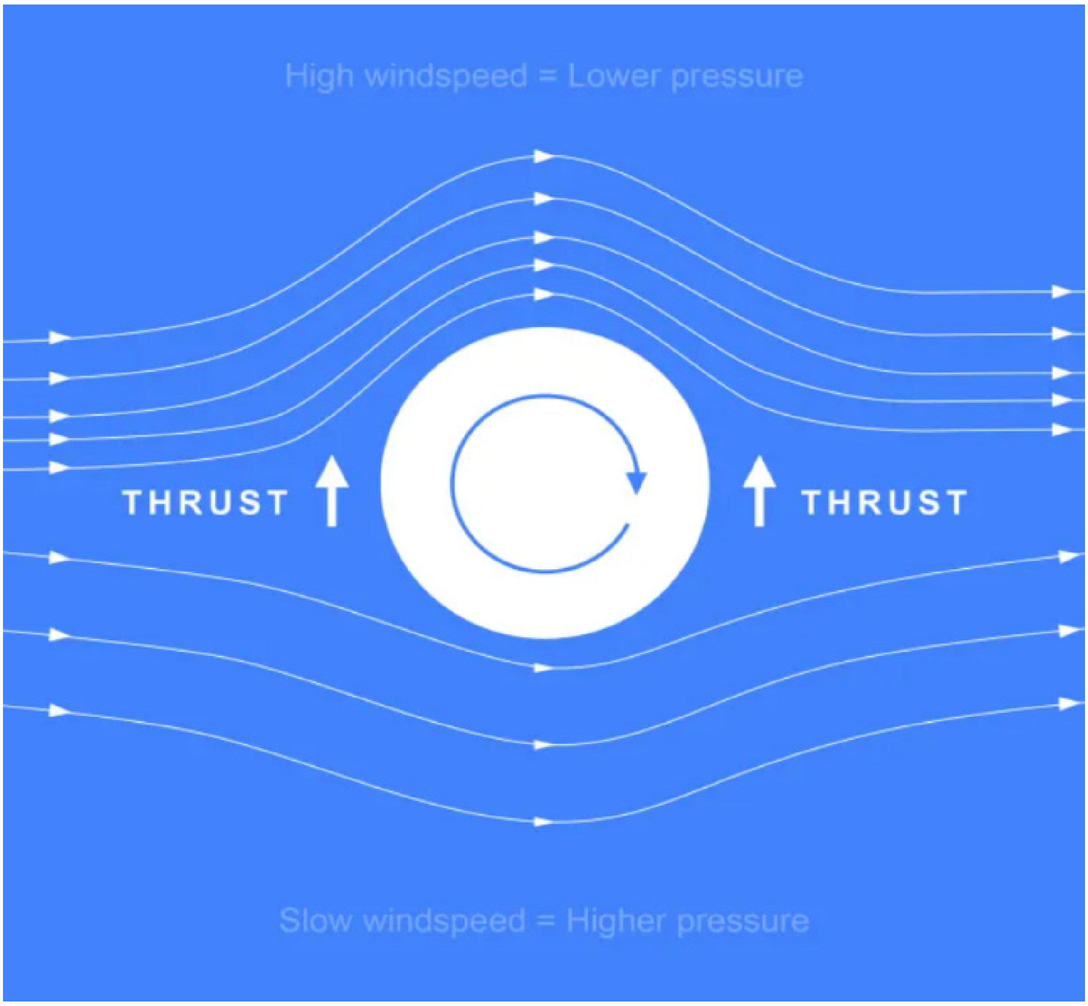


Fig 49.
Schematic description of the Magnus effect.

WIND PROPERTIES

The optimal wind direction for a Flettner Rotor installation is crosswind. By analysing the wind properties over the last 20 years on the route of Sealand Philadelphia (Fig.50), it appears that it is mainly head or downwind, with generally low wind speed in this geographical location. In other words, the operational profile is not optimal for converting the kinetic energy of the wind into thrust.

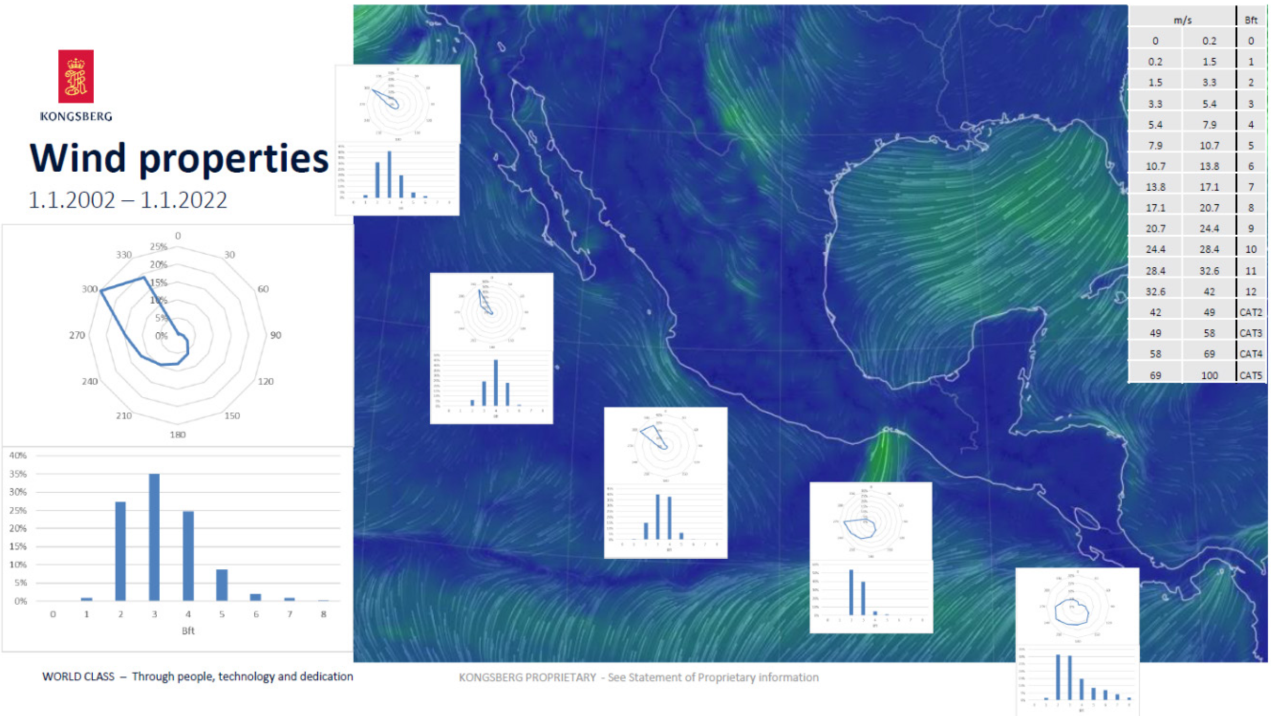


Fig 50.
Schematic description of wind measurements US West Coast and Latin America

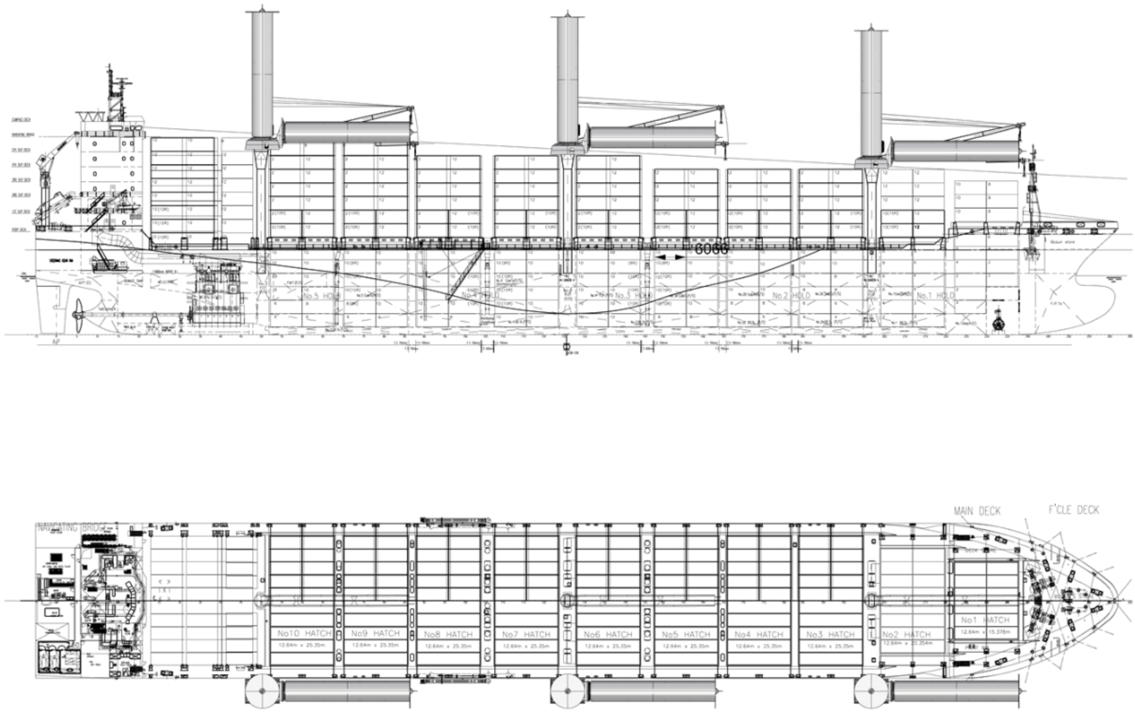
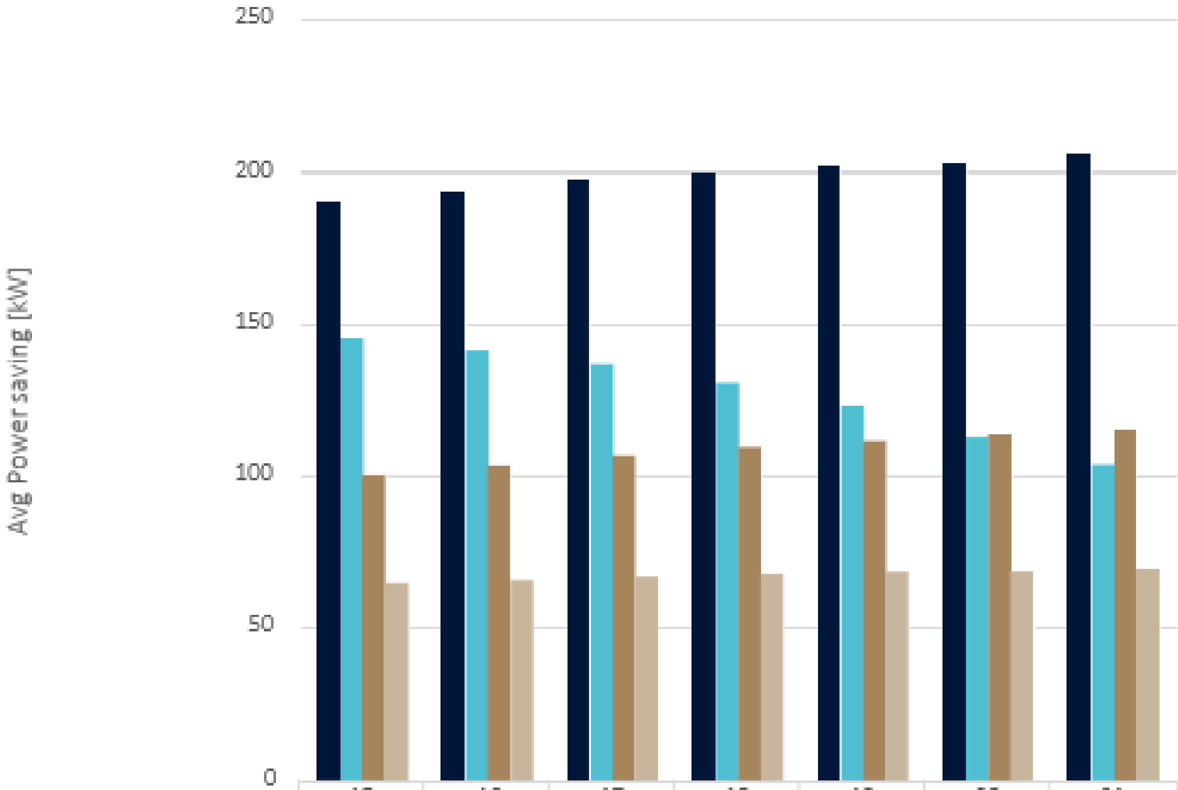


Fig 51.
Example of tilting rotors

CONCLUSIONS

- Increase of speed lower the percentual savings (speed sensitivity).
- For the route, it is crucial to have foldable/tilting rotor sails/wings.
- Generally, the wind speed is low on the route.
- Wind direction should ideally be from the side. The route has mainly headwind or downwind.



Operating speed [kn]	15	16	17	18	19	20	21
3 x Flettner, 24m	190,3	193,4	197	199,9	202,2	202,8	205,7
3 x Flettner, fixed, 24m	144,9	140,9	136,5	130,4	122,9	112,6	103,5
4 x Ventifoil, 20m	100,5	103,7	106,9	109,6	111,8	113,9	115,4
2 x Flettner, 18m	64,4	65,3	66,5	67,3	68	68,1	69

Fig 52.
Graphical presentation of power saving at different speeds

Even if fuel savings could be as much as 6.8%, the operational profile requires foldable or tilting rotors due to the air draft. The rotors would also add an extra constraint to cargo handling and would be exposed to damage. Therefore, rotors are not a good option for this vessel type and consequently not further considered in this project.

WP 4.6) HEAT RECOVERY SYSTEM

The Alfa Laval E-PowerPack (EPP) is a modular system for generating power from waste heat based on Organic Rankine Cycle (ORC) technology principle (Fig.53).

An ORC is a thermodynamic cycle in which an organic working fluid (instead of water in a normal Rankine Cycle) is used. The non-toxic and non-flammable working fluid completes a cycle and continuously converts waste heat into mechanical work. Waste heat is fed into the system at two different temperature levels. The high-temperature waste heat is extracted from its heat source (exhaust gas, thermal oil, or steam) via a heat exchanger and transferred to the EPP by means of an intermediate hot water loop. Jacket cooling water or high temperature water is fed – a fraction of the main flow – into the EPP directly, preheating water loop. The high temperature source enters the cycle via the evaporator. In the evaporator, the refrigerant is vaporized and routed to the expansion machine as superheated vapour. Here the highly pressurised refrigerant is expanded, thus releasing mechanical work, and driving the rotary screws in the expander. This rotational energy is in turn used to drive a generator (included in the module) that produces electricity. After the expansion machine the still gaseous refrigerant is liquefied again in the condenser and then re-pressurised by the feed pump. The refrigerant has now completed the cycle and again enters the preheater/evaporator to absorb waste heat.

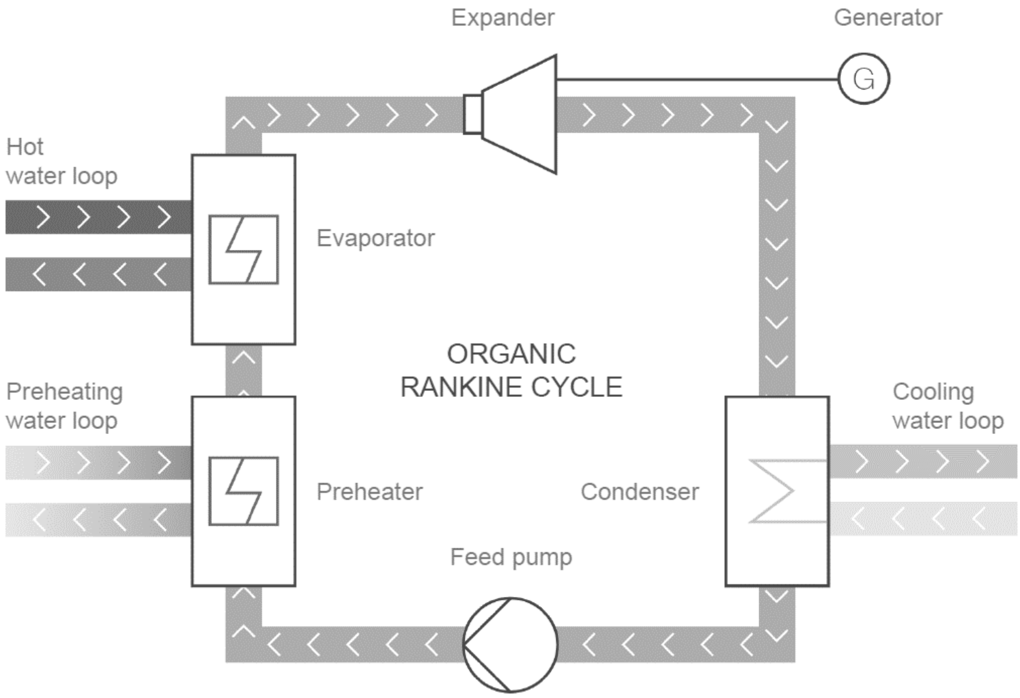


Fig 53. Description of the Organic Rankine Cycle

The energy output of the ORC system is converted into electricity to supply the on-board grid. Compared to many other sources of energy on ships the EPP generates power without additional CO_2 emissions.

The operation needs no human intervention except regular visual inspections and is mostly maintenance-free.

The CAPEX of this system varies according to the module's power rating and system design/scope of supplies. Assuming 2.3 t/h steam available for use of ORC, an EPP module can generate ~150-196 kW net power output depending on operating condition. With 270 days of sailing, the overall power generation becomes 1.2 GWh annually. Assuming 400 g/kWh SFOC, this is equivalent to 481 tons of methanol, which would have been consumed on auxiliary engines. CAPEX for this case will be around 320k EUR, net of installation costs.

In case of operation on VLSFO, it is assumed that the CAPEX and steam production would be similar, but the consumption of fuel will be less due to higher energy density. Assumed VLSFO consumption would be around 229 tons, based on 190 g/kWh SFOC.

WP 4.7) OPERATIONAL PROFILE INCL. LOAD BALANCE

Sealand Philadelphia is currently operating on the US West Coast, Central America, and Ecuador with around 110 port calls annually. This operation leads to many hours with manoeuvring and port stay, around 45% of the time is dedicated to such operation. In this scenario, a battery hybrid solution would prove to be useful to reduce fuel consumption and consequently emissions. The vessel is equipped with 536 reefer plugs whereof 346 on deck and 190 in hold. In the trade of Sealand Philadelphia it is a clear trend when it comes to cargo on the trading route. The South to North sailing includes a significant number of reefers compared to the opposite way (please see graph in Fig. 56).

OPERATIONAL PROFILE	Total time Port+Sea
Annual	100 %
Port + manoeuvring (<-- 6 knots)	45 %
At sea (6 knots -->)	55 %
At sea	55 %
Open sea - 10 knots	12 %
Open sea - 14,5 knots	15 %
Open sea - 18 knots	28 %
In port + manoeuvring	45 %
No of calls x 35 hrs/call per year	112
Manoeuvring with TT - 2hr/each call	3 %
Manoeuvring without TT - 8 hrs/each	10 %
Alongside - 25 hrs/each call	32 %

Fig 54.
Operational profile

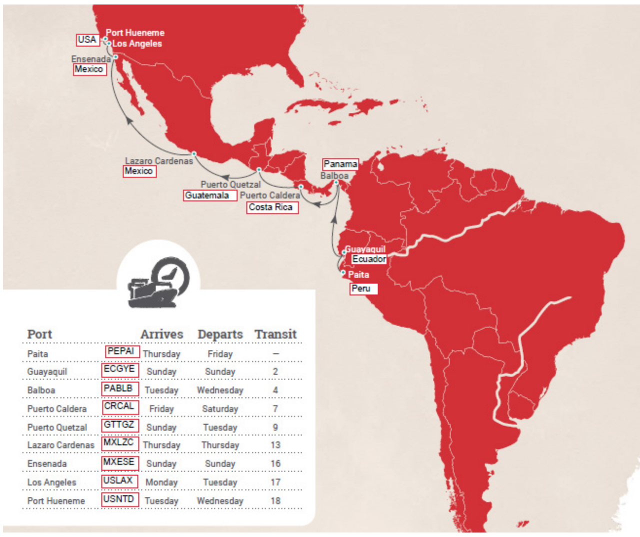


Fig 55.
Trading pattern

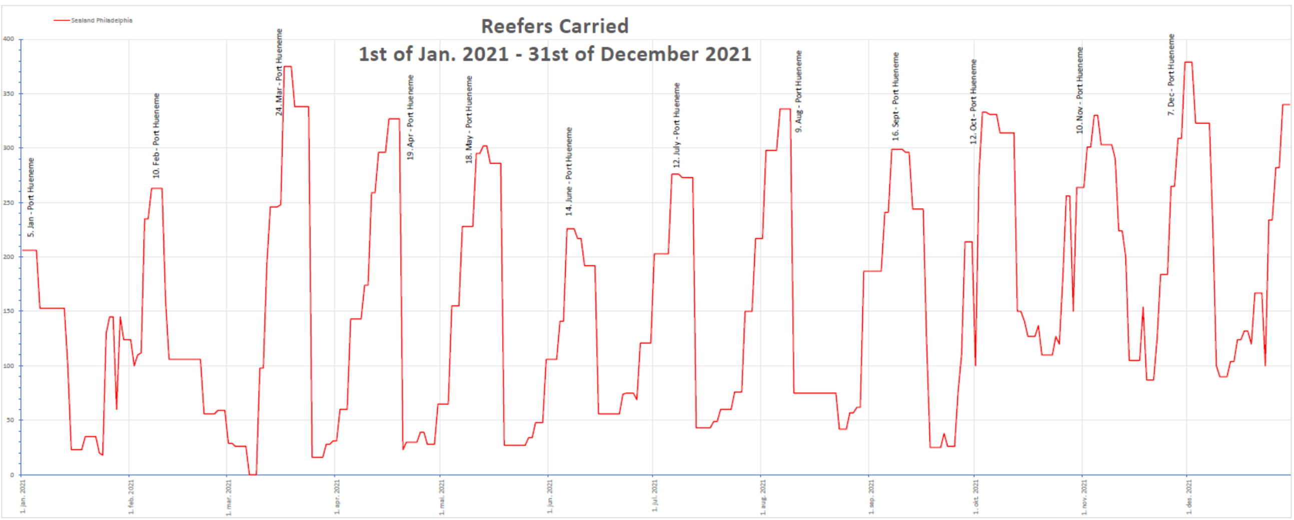


Fig 56.
Graph showing number of reefer containers carried per voyage in 2021.

WP 4.8) BENCHMARK 2008/2019 CONSUMPTION FIGURE

Historical development of FOC is shown in Fig. 57. The reason for the linear increase between 2008 and 2020 is that FOC only became mandatory from 2019, so exact data for this time period is missing. Therefore, we are looking at FOC monitoring from 2020. The increase is likely based on change of trade, port calls, hull fouling, etc. The FOC drop from 2022 to 2023 is due to DD and consequently new antifouling reducing friction.

Fig. 56 is predicting consumption alternatives based on alternative energy efficiency solutions as described in WP 4, above and below. In the graph, the time for conversion is considered to be done in 2024 (as an example). This will of course shift if the conversion is pushed to the next DD in 2027.

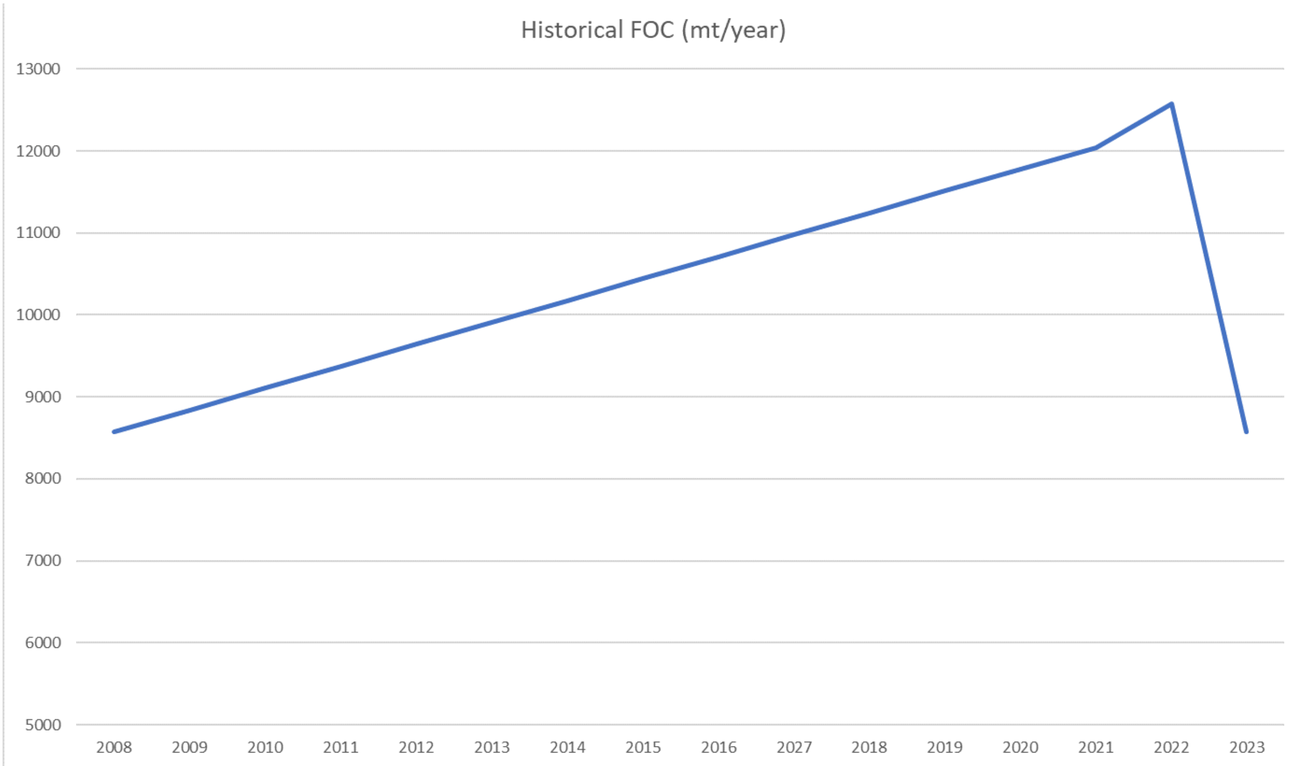


Fig 57.
Graph showing historical development of FOC

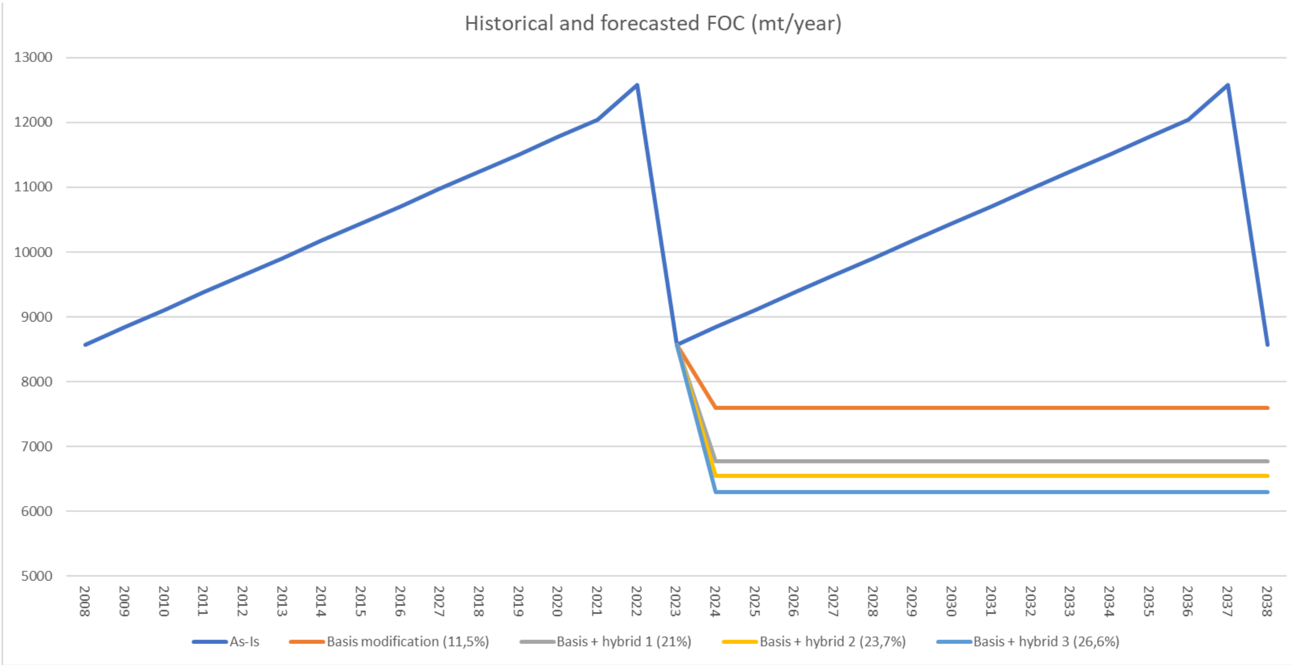


Fig 58.
Graph showing historical development and predicted FOC

WP 4.9) EEXI AND CII

Amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI entered into force on 1 November 2022. Developed under the framework of the Initial IMO Strategy on Reduction of GHG Emissions from Ships agreed in 2018, these technical and operational amendments require ships to improve their energy efficiency in the short term and thereby reduce their greenhouse gas emissions.

From 1 January 2023, it is mandatory for all ships to calculate their attained Energy Efficiency Existing Ship Index (EEXI) to measure their energy efficiency and to initiate the collection of data for the reporting of their annual operational carbon intensity indicator (CII) and CII rating.

EEXI

Fig 59.
The intention of Energy Existing Ships Index is to improve the technical performance of existing ships (Source IMO).

A ship's attained EEXI indicates its energy efficiency compared to a baseline. Ships attained EEXI will then be compared to a required Energy Efficiency Existing Ship Index based on an applicable reduction factor expressed as a percentage relative to the Energy Efficiency Design Index (EEDI) baseline. It must be calculated for ships of 400 gt and above, in accordance with the different values set for ship types and size categories. The calculated attained EEXI value for each individual ship must be below the required EEXI, to ensure the ship meets a minimum energy efficiency standard.

CII

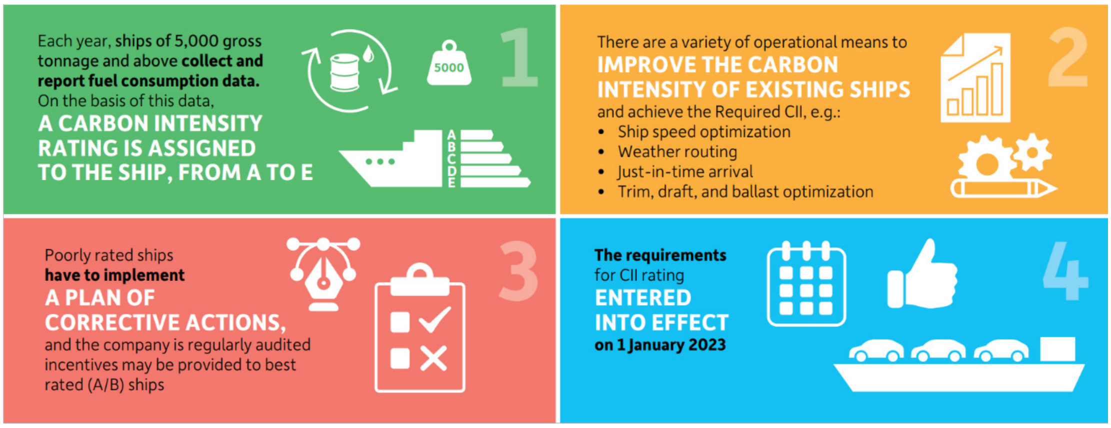


Fig 60.
The intention of the Carbon Intensity Indicator rating is to improve operational performance of existing ship

The CII determines the annual reduction factor needed to ensure continuous improvement of a ship's operational carbon intensity within a specific rating level. The actual annual operational CII achieved must be documented and verified against the required annual operational CII. This enables the operational carbon intensity rating to be determined.

HOW THE NEW RATINGS ARE INTENDED TO WORK

Based on a ship's CII, its carbon intensity will be rated A, B, C, D or E (where A is the best). The rating indicates a major superior, minor superior, moderate, minor inferior, or inferior performance level. The performance level will be recorded in a "Statement of Compliance" to be further elaborated in the ship's Ship Energy Efficiency Management Plan (SEEMP).

A ship rated D for three consecutive years or E for one year will have to submit a corrective action plan to show how the required index of C or above will be achieved. Administrations, port authorities and other stakeholders as appropriate, are encouraged to provide incentives to ships rated as A or B. A ship can run on a low-carbon fuel clearly to get a higher rating than one running on fossil fuel, but there are many things a ship can do to improve its rating. In this project we have looked into following:

- Conversion to methanol operation
- Methanol fuel cells
- Hybrid System Integration
- Underwater solutions:
    - Antifouling
    - Air lubrication
    - Bulb design
- Wind assist
- Waste heat recovery
- Increased scantling draft

Following CII results will be obtained through energy efficiency initiatives.

Task	Remarks	Overall CO2/ saving %	2022 (DD - May)	2023	2024	2025	2026	2027 (DD)	2028	2029	2030
Overridable EPL	**EPL % = 20.22 %**	NA	C	C	C	D	D	D	D	E	E
2-stroke methanol conversion	Grey methanol	3,60 %	B	C	C	C	D	C	D	D	E
	Green methanol	81,00 %	A	A	A	A	A	A	A	A	A
2-stroke main engine - derating	ME derating to EEXI output - 3,5% saving	3,20 %	B	C	C	C	D	C	D	D	E
A/E, methanol conversion	Grey methanol -5% C02 saving	0,50 %	C	C	C	D	D	D	D	E	E
	Green methanol - 100 % CO2 saving	10,00 %	B	B	B	C	C	C	C	D	D
Alma - high temp fuel cells	Replacing 2 A/E running of green methanol, 26% saving	2,60 %	B	C	C	C	D	C	D	D	E
Hybrid System Integration	Alt 1: Hybrid only	small	C	C	C	D	D	D	D	E	E
	Alt 2: Hybrid + existing FPP +ESS + ME derating + rudder bulb	10,80 %	B	B	B	C	C	C	C	D	D
	Alt 3: Hybrid + new FPP +ESS + ME derating + rudder bulb	15,30 %	A	B	B	B	C	B	C	C	D
	Alt 4: Hybrid + new CPP +ESS + ME derating + rudder bulb	17,10 %	A	A	B	B	C	B	C	C	D
Jotun Skater	Alt 1: Hull Skating Solutions versus SeaMate M/SeaQuantum Pro U	7,70 %	B	B	B	C	C	C	C	C	D
	Alt 2: Hull Skating Solutions versus SeaQuantum Pro U/SeaQuantum Classic III	4,80 %	B	B	C	C	C	C	C	D	D
Air lubrication	ALS reduction 686 kW. A/E driven compressor 1000 kW.	-2,50 %	C	C	C	D	D	D	D	E	E
New bulbous bulb	CFD of new bulbous bow including fuel saving and CAPEX.	2,70 %	B	C	C	C	D	C	D	D	E
Wind assist	Potentinal energy saving max 240 kw	2,00 %	B	C	C	C	D	C	D	E	E
Heat recovery system	Waste heat recovery from exhaust systems.	1,40 %	B	C	C	C	D	D	D	E	E

Fig 61.
CII projection for "Sealand Philadelphia" related to examined energy efficiency initiatives

By combining different initiatives, substantial savings can be obtained. In this project, 6 scenarios have been considered and following impact can be reached. The sixth scenario is conversion to green methanol and will give "A-score" throughout.

Task	Remarks	Overall CO2/ saving %	2022 (DD - May)	2023	2024	2025	2026	2027 (DD)	2028	2029	2030
Overridable EPL	**EPL % = 20.22 %**	NA	C	C	C	D	D	D	D	E	E
Basis Modification	ME Derating +Skater+Bulb+ WHRS	11,50 %	B	B	B	B	C	C	C	C	D
Basis + Hybrid I	ME Derating +Skater+Bulb+ WHRS+New FPP + SG	21,00 %	A	A	A	A	B	B	B	B	C
Basis + Hybrid II	ME Derating +Skater+Bulb+ WHRS+CPP+SG	23,70 %	A	A	A	A	A	A	B	B	B
Basis + Hybrid III	ME Derating +Skater+Bulb+ WHRS+CPP+SG+ESS	26,60 %	A	A	A	A	A	A	A	B	B

Fig 62.
CII projection for "Sealand Philadelphia" by combining different energy efficiency initiatives

SEEMP PART III

The SEEMP Part III is intended to help companies achieve the required CII (Carbon Intensity Indicator). Related to this annual rating, the SEEMP Part III is a mandatory, ship-specific document that lays out the plan to improve the CII, and therefore the vessel's operational energy efficiency, for the next three years.

The SEEMP Part III is a dynamic document subject to regular updates and revisions, reflecting changing performance and required measures. It must be verified and kept on board the respective vessel from January 1st 2023, together with the Confirmation of Compliance (CoC).

IMO'S DECARBONIZATION STRATEGY

The introduction of mandatory EEXI and CII comes under the framework of the Initial IMO Strategy for Reduction of GHG Emissions from Ships, adopted in 2018. The Initial Strategy sets out candidate's short, mid, and long-term measures.

The introduction of EEXI and CII measures falls under the Strategy's short-term measures which commit IMO to a target of reducing carbon intensity of international shipping by 40% by 2030, compared to 2008.

WP 4.10) BEYOND 2030

By implementing combined energy efficiency initiatives as shown in Fig. 60, significant saving will be obtained and keep the vessel CII compliant for many years. Of course, the installation will come at a significant cost and by prolonging the lifetime of the vessel would be important to consider. In the project, we have looked at the same initiatives as mentioned above and considered a lifetime of 30 years. The CII rating will then look as in Fig. 61. The calculations are based on MEPC 78 guidelines - 2020 (IMO DCS), 2021 (IMO DCS), and operational data from 2022 is used to obtain the respective CII ratings till 2038.

Essentially the vessel could sail until 2037 the "hybrid III" solution is chosen. Of course, extended vessel lifetime still will depend on acceptance from class, charterer, etc.

Task	Remarks	Overall CO2/ saving %	2022 (DD - May)	2023	2024	2025	2026	2027 (DD)	2028	2029	2030	2031	2032 (DD)	2033	2034	2035	2036	2037 (DD)	2038
Overridable EPL	**EPL % = 20.22 %**	NA	C	C	C	D	D	D	D	E	E	E	E	E	E	E	E	E	E
Basis Modification	ME Derating +Skater+Bulb+ WHRS	11,50 %	B	B	B	B	C	C	C	C	D	D	D	E	E	E	E	E	E
Basis + Hybrid I	ME Derating +Skater+Bulb+ WHRS+New FPP + SG	21,00 %	A	A	A	A	B	B	B	B	C	C	C	C	D	E	E	E	E
Basis + Hybrid II	ME Derating +Skater+Bulb+ WHRS+CPP+SG	23,70 %	A	A	A	A	A	A	B	B	B	C	C	C	D	D	E	E	E
Basis + Hybrid III	ME Derating +Skater+Bulb+ WHRS+CPP+SG+ESS	26,60 %	A	A	A	A	A	A	A	B	B	B	B	C	C	D	D	D	E

Fig 63.

CII projection for "Sealand Philadelphia" by combining different energy efficiency initiatives.

WP 4.11) BEYOND COMPLIANCE/JOINT BENEFITS

Sealand Philadelphia and her three sister vessels are all on Time Charter (TC) with Sealand Maersk. The findings from the studies and simulations carried out in this report will be presented to the management of Sealand Maersk for evaluation. A possible adjustment of the charter hire based on fuel saving, reduced emission to air and improved CII will be discussed and agreed prior to any investment made.

Work Process 5, Return of Investments, and Financing Opportunities

WP 5.1) COST BENEFIT ANALYSIS

A detailed cost benefit analysis has been carried out based on the various energy efficiency initiatives under WP 4. Further, proposals for combination of initiatives are considered.

ASSUMPTIONS

Basis for the calculation is assumed on sailing as per vessels operational profile:

- Annual fuel consumption of 9.221 mt VLSFO/MGO or 21.292 mt Methanol including MGO
- Cost of VLSFO 800 USD/mt
- Cost of green Methanol 2000 USD/mt
- CO_2 tax 200 USD/mt
- For NPV calculations, the USD interest rate of 8.4% is applied

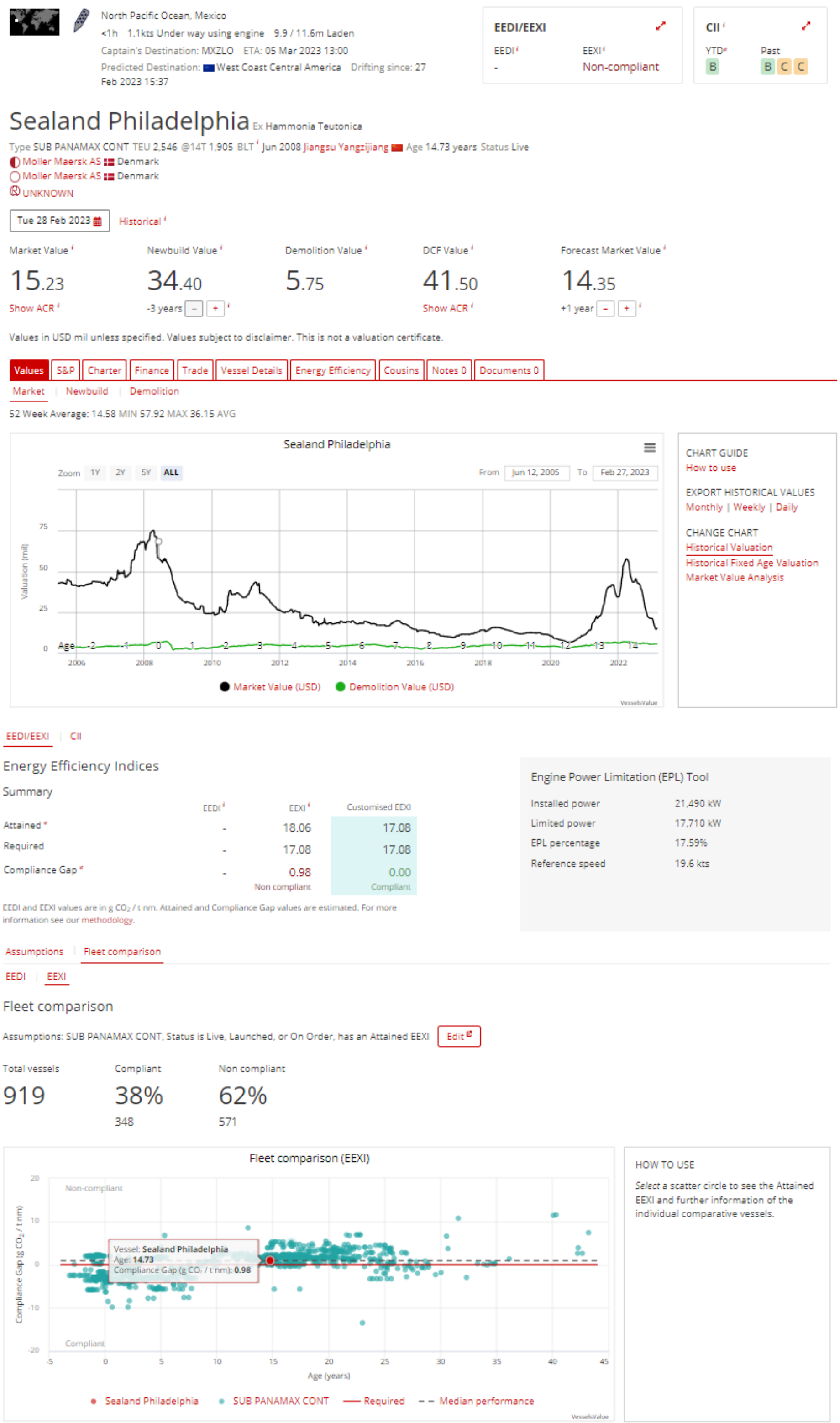
Rather than listing the saving potential of each and every optimisation initiative, it was decided to describe combined solutions with energy saving potential, estimated costs, and ROI period for operation on conventional fuel.

1. Doing nothing, only involve EPL (20.22%). This option is short sighted, and the vessel would not comply with regulations in 2027.
2. Basic modification involving ME derating, proactive hull cleaning, conversion of bulbous bow, and installing a waste heat recovery system. The reduced emission from such solution is estimated to be 11.5% at a cost of 1.9 MUSD and would keep the vessel compliant

until 2032. The payback period would be 1.4 years.

3. Basic modification involving ME derating, proactive hull cleaning, conversion of bulbous bow, and installing a waste heat recovery system. In addition, a change to an optimised fixed pitch propeller, and installation of a 2.4 MW shaft generator is required. The reduced emission from such solution is estimated to be 21% at a cost of 4.5 MUSD and would keep the vessel compliant until 2035. The payback period would be 1.8 years.
4. Basic modification involving ME derating, proactive hull cleaning, conversion of bulbous bow, and installing a waste heat recovery system. In addition, a change to an optimised controlled pitch propeller, and installation of a 2.4 MW shaft generator will enable the vessel to manoeuvre by changing pitch. The reduced emission from such solution is estimated to be 23.7% at a cost of 6.0 MUSD and would keep the vessel compliant until 2036. The payback period would be 2 years.
5. Basic modification involving ME derating, proactive hull cleaning, conversion of bulbous bow, and installing a waste heat recovery system. In addition, a change to an optimised controlled pitch propeller, and installation of a 2.4 MW shaft generator and a 1 MW battery will enable the vessel to manoeuvre by changing pitch, and no auxiliary engines will be required in this operation mode. The reduced emission from such solution is estimated to be 26.6% at a cost of 7.1 MUSD and would keep the vessel compliant until 2037. The payback period would be 2.1 years.

WP 5.2) RESIDUAL VALUE VS INVESTMENTS



WP 5.3) GREEN FINANCING

Public and private sources of funding are crucial for supporting an efficient green transition. Certain banks are very supportive for green, or sustainable financing. With that said, they also have an obligation to be commercially sensible and reasonable.

Most banks and financial institutions have set sustainability targets and allocated funds for sustainable finance. There are several alternative sustainable finance instruments on the market; green, sustainability linked or transition loans or bonds. Utilizing this opportunity can give better terms and/or increase the number of investors willing to participate in e.g., a bond offering. The key is to prove that the investment represents a substantial contribution to GHG reductions and go beyond business as usual (i.e., beyond short term compliance). The principles are governed by international frameworks for loans and bonds (LMA, ICMA). The Climate Bonds Initiative and the EU Taxonomy is often used as reference for what is considered green assets or projects.

The sustainable finance typically will require a sustainable finance framework with selected key KPIs (e.g., AER or EEOI) and annual verification of compliance with the KPIs.

By combining the measures outlined in WP 5.1 above and the ability to run the vessel fully or partly on methanol, the Sealand Philadeplhia could be eligible for Green financing if it meets the criteria outlined in the EU Taxonomy Technical Screening criteria 6.12; *Retrofitting of sea and coastal freight and passenger water transport "purchase, financing, chartering (with or without crew) and operation of vessels designed and equipped for transport of freight/passengers on sea or coastal waters" is considered environmentally sustainable if:*

The yearly average greenhouse gas intensity of the energy used on-board by a ship or a company's fleet during a reporting period does not exceed the limits set below:

- **76.4** gCO2e/MJ by 1 January **2025**
- **61.1** gCO2e/MJ by 1 January **2030**
- **45.8** gCO2e/MJ by 1 January **2035**

Due to the current trading pattern Sealand Philadelphia there are no known sources of green funding available today. However, this might change and therefore it is suggested that this will be a part of a potential phase 2 of this project.

WP 5.4) FUNDING/SUPPORT/SUBSIDIES, OPPORTUNITIES

CARBON OFFSETS AND INSETS

Cargo owners need to meet their climate targets. However, this is challenging when billions of tons of cargo are transported on assets (ships, trucks, and airplanes) mainly powered by fossil fuels. Offsetting and Insetting is used by transporters to compensate for emissions during transport. Offsets is a simple way to invest in projects that compensate for emissions. In 2018, more than 269 MUSD was spent in the voluntary Carbon Offset market. However, only 0,2% was spent on transport related projects. Cargo owners need opportunities to channel the offsetting funds into decarbonization projects within the transport industry and this is called Insetting.

Insetting opportunities include fleet renewals, engine, and retrofits, implementing low carbon solutions and scaling of sustainable fuels. An alternative fuel like methanol is a good insetting alternative, applying principles from Renewable Energy Certificates (REC). Availability of alternative fuels is limited though, and significant infrastructure investments are needed to be able to scale up. Insetting is a way to channel funds into this development. Another way is to apply a mass balance approach where fossil fuels and sustainable fuels are blended, but with separate bookkeeping for different fuel families. Verification of the bunkering, the use, and actual emission reduction is an essential part of the insetting process.

Insetting accounting methodology and reporting guidelines, quality criteria and boundaries for sustainable vessel fuel certificates needs to be developed. ISO is considering inclusion of biofuels in the 8217 Petroleum products — Fuels (class F) — Specifications of marine fuels update in 2024. The GHG Protocol is considering inclusion of market-based accounting mechanisms into the GHG framework.

WP 5.5) CO_2 TAX REGIME/TAXONOMY

As Sealand Philadelphia operate on the USWC to South America, there are currently no carbon tax regime in play. However, this might change in the future, and therefore it is suggested that this will be a part of a potential phase 2 of this project.

CLIMATE BONDS INITIATIVE (TAXONOMY)

The Climate Bonds Taxonomy is a guide to climate aligned assets and projects. It is a tool for issuers, investors, governments, and municipalities to help them understand what the key investments are that will deliver a low carbon economy.

The Taxonomy is grounded in the latest climate science and has been developed through an extensive multistakeholder approach, leveraging the work of our Technical and Industry Working Groups.

The Taxonomy aims to encourage and be an important resource for common green definitions across global markets, in a way that supports the growth of a cohesive thematic bond market that delivers a low carbon economy.

More information on the Climate Bonds Initiative can be found in Annex 8.

EU TAXONOMY

The EU taxonomy is a classification system, establishing a list of environmentally sustainable economic activities. It could play an important role in helping the EU scale up sustainable investment and implement the European green deal. The EU taxonomy would provide companies, investors, and policymakers with appropriate definitions for which economic activities can be considered environmentally sustainable. In this way, it should create security for investors, protect private investors from greenwashing, help companies to become more climate-friendly, mitigate market fragmentation and help shift investments where they are most needed.

More information on the EU taxonomy can be found in Annex 9.

EU ENVIRONMENTAL TRADING SCHEME (ETS)

The EU's legislative bodies have reached a preliminary agreement to implement the ETS for shipping from 2024, subject to final adoption expected in 2023.

This would entail a three-year phase-in period, increasing in scope from 40% of emissions in 2024 to 70% in 2025 and 100% in 2026. It would apply to cargo and passenger ships above 5,000 GT from 2024 and offshore ships above 5,000 GT from 2027. The EU ETS would initially cover CO2 emissions and be widened to include methane and nitrous oxide from 2026. Offshore ship and general cargo ships between 400 and 5,000 GT will also be required to report emissions and may be included in the EU ETS at a later stage.

On 14 July 2021, the European Commission adopted a series of legislative proposals setting out how it intends to achieve climate neutrality in the EU by 2050, including the intermediate target of an at least 55% net reduction in greenhouse gas emissions by 2030. The package proposes to revise several pieces of EU climate legislation, including the EU ETS, Effort Sharing Regulation, transport, and land use legislation, setting out in real terms the ways in which the Commission intends to reach EU climate targets under the European Green Deal.

To achieve the EU's overall greenhouse gas emissions reduction target for 2030, the sectors covered by the EU Emissions Trading System (EU ETS) must reduce their emissions by 43% compared to 2005 levels.

The revised EU ETS Directive, which will apply for the period 2021-2030, will enable this through a mix of interlinked measures.

STRENGTHENING THE EU ETS FOR THE NEXT DECADE

To increase the pace of emissions cuts, the overall number of emission allowances will decline at an annual rate of 2.2% from 2021 onwards, compared to 1.74% currently.

The Market Stability Reserve (MSR) is the mechanism established by the EU to reduce the surplus of emission allowances in the carbon market and to improve the EU ETS's resilience to future shocks – will be substantially reinforced.

Between 2019 and 2023, the number of allowances put in the reserve will double to 24% of the allowances in circulation. The regular feeding rate of 12% will be restored as of 2024.
As a long-term measure to improve the functioning of the EU ETS, and unless otherwise decided in the first review of the MSR in 2021, from 2023 onwards the number of allowances held in the reserve will be limited to the auction volume of the previous year. Holdings above that amount will lose their validity.

BETTER TARGETED CARBON LEAKAGE RULES

The revised EU ETS Directive provides predictable, robust, and fair rules to address the risk of carbon leakage.

The system of free allocation will be prolonged for another decade and has been revised to focus on sectors at the highest risk of relocating their production outside of the EU. These sectors will receive 100% of their allocation for free. For less exposed sectors, free allocation is foreseen to be phased out after 2026 from a maximum of 30% to 0 at the end of phase 4 (2030).

A considerable number of free allowances will be set aside for new and growing installations. This number consists of allowances that were not allocated from the total amount available for free allocation by the end of phase 3 (2020) and 200 million allowances from the MSR.

More flexible rules have been set to better align the level of free allocation with actual production levels:

- Allocations to individual installations may be adjusted annually to reflect relevant increases and decreases in production. The threshold for adjustments was set at 15% and will be assessed on the basis of a rolling average of two years. To prevent manipulation and abuse of the allocation adjustment system, the Commission may adopt implementing acts to define further arrangements for the adjustments.
- The list of installations covered by the Directive and eligible for free allocation will be updated every 5 years.
- The 54 benchmark values determining the level of free allocation to each installation will be updated twice in phase 4 to avoid windfall profits and reflect technological progress since 2008.

Overall, more than 6 billion allowances are expected to be allocated to industry for free over the period 2021-2030.

FUNDING LOW-CARBON INNOVATION AND ENERGY SECTOR MODERNISATION

Several low-carbon funding mechanisms will be set up to help energy-intensive industrial sectors and the power sector meet the innovation and investment challenges of the transition to a low-carbon economy.

These include two new funds:

- The Innovation Fund will support the demonstration of innovative technologies and breakthrough innovation in industry. It will extend existing support under the NER300 programme. The amount of funding available will correspond to the market value of at least 450 million emission allowances.
- The Modernisation Fund will support investments in modernising the power sector and wider energy systems, boosting energy efficiency, and facilitating a just transition in carbon-

dependent regions in 10 lower-income Member States.

In addition, the optional transitional free allocation under Article 10c of the EU ETS Directive will continue to be available to modernise the energy sector in lower-income Member States.

Summary

Conclusions from the study shows that, from a technical perspective, MV "Sealand Philadelphia" could be converted to a near carbon free operation. On the other hand, access to bio or e-methanol, combined with high cost, will be the main bottlenecks.

Six scenarios have been considered, to seek a realistic and feasible solution for keeping this mid-life vessel lady operational within regulation towards 2035. Following scenarios has been looked into:

1. As a bottom, we looked into how long it would be possible to operate MV "Sealand Philadelphia" "without doing anything", just implement an Engine Power Limitation (EPL) of 20.22%. CII wise she would be able to operate until 2025 before action must be taken as she will reach a "D" rating. She would then need to have a plan for upgrade in 2026 to get back to a better rating in 2027. The cost of this is low without significant payback time, but a "rolling improvement process" is needed to keep her compliant in 2030 (or beyond).
2. By doing a basic modification involving a full hull blasting during the next dry docking and using a hull skater, change of the bulbous bow, and install a Waste Heat Recovery System (WHRS), a fuel and emission reduction of 11.5% will be obtained. Looking at the CII compliance she would be able to sail until 2030 before reaching the mentioned "D" rating. In other words, a plan for improvement must be presented in SEEMP and implemented in 2031 to improve her rating before 2032. The cost such conversion is moderate and would have a payback time of 1.4 years.
3. Alternative 3 include the same elements as in alternative 2, but in addition installation of a shaft generator and upgrading the Fixed Pitch Propeller (FPP) is considered. In this scenario a fuel and emission reduction of 21% is achievable. Regarding CII compliance she can sail until 2034 before actions to improve the CII rating is necessary. The vessel age at this point is 26 years which normally is on the limit of the acceptable lifetime. The cost of such conversion is still relatively moderate, and the payback time will be 1.8 years.

4. In alternative 4, the same basic elements as in alternative 3 is included, but in addition an upgrading of the propulsion line to a Controlled Pith Propeller (CPP) system with a rudder bulb is necessary. In this scenario a fuel and emission reduction of 23.7% is achievable. Regarding CII compliance she can sail until 2034 before actions to improve the CII rating is necessary. A plan for improvement must be presented in SEEMP and implemented in 2035 to improve her rating before 2036. The cost of such conversion is increasing, the payback time is still reasonable and will be 2 years.
5. Alternative 5 involves the same elements as in alternative 4. In addition, a battery installation of 1 MW is considered, which will bring significant flexibility in operating such vessel, particularly in manoeuvring and port condition. In this scenario a fuel and emission reduction of 26.6% is achievable. Regarding CII compliance she can sail until 2035 before actions to improve the CII rating is necessary. A plan for improvement must be presented in SEEMP and implemented in 2035 to improve her rating before end of 2036. The cost of such conversion is higher, but the payback time is still reasonable and will be 2.1 years. In alternatives 1 – 5 all equipment is available in the market today.
6. The final alternative includes a methanol conversion of the Main Engine (ME) in combination with improvements as mentioned in alternative 5. The vessel will be CII compliant beyond 2038 and for as long as she would be allowed to sail. The fuel reduction would be 26.6% but the carbon emission would be reduced by 81%. Hence, this investment would highly depend on extended lifetime, pricing of renewable methanol, and carbon taxation levels. Most products for conversion to methanol will be available 2024-2025.

ANNEXES

1. Renewable Energy Directive II, Annex IX Part A
2. US Energy Policy Act 1992
3. Interim Guidelines for the safety of ships MSC.1 Circ. 1621
4. DNV – RU – SHIP Pt. 6 Ch. 2
5. DNV Alternative fuel for containerships
6. Methanol Availability Study – Methanol Institute
7. IRENA Innovation Renewable Methanol 2021
8. Climate Bonds Initiative (Taxonomy)
9. EU Taxonomy: Final report of the Technical Expert Group on Sustainable Finance
10. Energy Projections and opportunities Chile