



Comparison of Methanol Electric Hybrid methods for replacing conventional drivelines

Master's thesis in MSc. Mobility Engineering (Marine)

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MASTER'S THESIS IN MSC. MOBILITY ENGINEERING

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Division of Marine Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2026

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Abstract

The effects of emissions from energy consumption across various activities in the world continues to be major global concern. From a marine perspective, it is marked by numerous initiatives being tested and implemented to push towards zero emissions. This study was carried out to identify the possibilities of implementing hybrid methanol electric design options to replace the existing conventional drivelines for two different vessels; a pilot boat and a service vessel with diverse functionalities. Three different design options were considered for both the vessels. Different design options of machineries using methanol and electricity as energy carriers were analysed and compared to estimate the consumptions involved in each case and also the emission of CO₂. The effective added weight was calculated for the pilot boat and the hydrostatic analysis of the Baltica was carried out for the different design options considered. The same were also analysed in the perspective of operational expenditures involved and the results showed comparable expenses. Although the electric options show significant advantages from the emission perspectives, implementing them is a lot tougher as there has to be high initial investments for covering the cost of batteries from a vessel's perspective. Also, there has to be also availability of power and charging stations for supporting the electric propulsion systems. So apart from the operational expenditure and quantities of consumption, a wide range of regulatory and regional factors are also to be weighed while a decision for selection is taken.

Key words: emissions, methanol, hybrid propulsion, electric propulsion.

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Preface

In this study, a comparison of various hybrid driveline options using methanol and electricity as energy carriers are carried out. The study involved the following softwares : Autodesk AutoCAD LT 2027, Maxsurf Stability 2025, Caeses 5.3.8. The project is carried out in ScandiNAOS, Gothenburg.

I would like to express my deepest gratitude to my supervisors Mr. Patrik Molander and Mr. Yu Sheng Lee, naval architects from ScandiNAOS group. Their ongoing support, guidance, and assistance over the duration of the thesis has been vital to shape the results of the study. I'm very grateful Mr. Bengt Ramne of ScandiNAOS group who has been very enthusiastic on the matter and a great support for me during and before the thesis. I'm also very grateful to the ScandiNAOS group and Sjöfartsverket for providing the necessary real world data, for the purpose of this study.

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List of acronyms

AIS	Automatic Identification System
CII	Carbon Intensity Indicator (CII)
D-F	Dual Fuel
DP	Dynamic Positioning
DWT	Dead Weight Tonnage
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
EU ETS	European Union Emission Trading System
GA	General Arrangement
HFO	Heavy Fuel Oil
IMO	International Maritime Organisation
ISO	International Organization for Standardization
ITTC	International Towing Tank Conference
LFO	Light Fuel Oil
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
MEPC	Marine Environment Protection Committee
MV	Motor Vessel
OCIMF	Oil Companies International Marine Forum
PD ratio	Pitch-to-Diameter ratio
SFC	Specific Fuel Consumption
SFOC	Specific Fuel Oil Consumption
SMA	Swedish Maritime Administration
SMHI	Swedish Meteorological and Hydrological Institute

1 Introduction

Marine transport still acts as the arteries and veins of the world, providing logistical assistance to the great majority of the world's trade. It shows no signs of cutting down its contribution towards the world's economy and always adapts to the ever changing global scenarios. However the International Maritime Organization's push towards net zero emission target for year 2050 [1] has put additional pressure on the various forces in the marine sector to decarbonize while still maintaining the collective status as the backbone of world economy.

The United Nations Conference on Trade and Development (UNCTAD) [2] states that goods and services of maritime origin generated about 2.5 trillion USD in 2018, which amounted to approximately 2.5% of the global GDP. However, in 2030, it is projected to rise to more than 3% of the global GDP crossing 3 trillion USD in monetary value.

The global climate change has become a great concern in the recent years and the contribution of each industry is being scrutinized in this regard. Continued growth of the maritime transportation has also increased its contribution to emissions. The emissions typically include carbon dioxide (CO₂), oxides of sulphur, oxides of nitrogen, particulate matter etc. [3] states that the emissions from the whole of marine sector amounts to around 3.43% to 4.97% of the total CO₂ emissions globally. The biggest share in this is from maritime transportation and the followed by offshore crude oil extraction industry. The statistics also show that global maritime transportation is emitting 831 Mt to 1,135 Mt of CO₂ per year at present, accounting to approximately 2.5% to 3.0% of global CO₂ emissions.

In 2018, IMO announced their initial plans to reduce the green house gases emission from international shipping, which was more like a declaration of intent. In 2023 during MEPC 80, the IMO published more defined strategies and goals towards this target. The recent proposals are envisaging to reduce CO₂ emissions across international shipping, by at least 40% by 2030, when compared to 2008 [3].

Certain indicative checkpoints set out with regards to green house gases prior to achieving the net zero emissions near the year 2050 are:

- Reduce the total annual GHG emissions from international shipping by at least 20%, striving for 30%, by 2030, compared to 2008.
- Reduce the total annual GHG emissions from international shipping by at least 70%, striving for 80%, by 2040, compared to 2008.

There are several studies that map out six possible methods through which the possible CO₂ emission reductions can be achieved in ships [4]. They are to do with aspects such as switching to alternative energy solutions, alternative fuels, vessel speed, economy of scale, propulsion and power, integration of energy saving devices. As per their findings, a combination of all these six are to be executed to enter into the conversation of net-zero CO₂ emissions.

The Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII), are also part of significant steps taken by IMO towards the same goal. Apart from this there are also many other initiatives taken by European Union in particular and also nations such as Norway who strives for zero-emissions in the Norwegian fjords. European Union Emissions Trading System (EU ETS) is one such initiative in which

there are set capping limits to the amount of green house gases (GHGs) that is be permitted to be produced. This is not a static cap; it gets cut down each year. This capping system works with purchase and trade of emission allowances by the companies that come under its scope. The money raised from the selling and trade of allowances is then invested back to funding projects and initiatives to develop new innovations for emission reductions by the member states or countries.

This thesis aims to investigate the possible advantages that hybrid methanol and electric propulsion solutions can provide when replacing conventional drivelines, while moving towards the zero net emissions goal.

AIS (Automatic Identification System) data is a transmission of a package of data aimed at informing the other vessels in the vicinity with certain parameters of the vessel at all times. This include data such as vessel name, position, course, destination, speed, cargo details etc over radio signal frequencies. The AIS data is helpful for many players in the marine industry apart from just the vessels at sea in the vicinity of a particular vessel. It is extensively used to extract data so as to track vessels in a fleet, avoid collisions, plan logistics, improve navigational safety, plan port operations and other associated supplies to a vessel, as well as analyse global maritime traffic and activities. In present times, AIS data is also used for data analytics and environmental monitoring.

Methanol as an alternative marine fuel has the potential to be a solution as shipping industry works to reduce greenhouse gas emissions and meet stricter environmental regulations as mentioned above. However this shift has not gained enough momentum in the recent years possibly due to the lack of availability of the fuel as well as the shipowners not seeing enough incentives to change to renewable fuels. Methanol is a liquid fuel that can be produced from natural gas, biomass, or renewable sources such as green hydrogen and captured carbon dioxide. The low toxicity, the properties normal atmospheric conditions, and ease of handling are attractive for methanol as a marine fuel. However a lower calorific value in comparison with fossil fuels and production cost of methanol from renewable sources are challenging factors for methanol to replace the conventional fuels in use.

It also emits lower emissions of sulfur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter. Given all these, methanol is slowly becoming an important option for the shift to a cleaner and more sustainable maritime transportation.

The following is an extract from IMO circular MEPC (308) 73^[15] indicating the properties of energy carriers used in Energy Efficiency Design Index (EEDI) calculations of new vessels.

Type of fuel	Reference	Calorific value (kJ/kg)	t-CO ₂ / kJ	Carbon Content (%of mass)	C _f (t-CO ₂ / t-fuel
Diesel / gas oil	ISO 8217 Grades DMX through DMB	42700	7.51×10^{-8}	0.8744	3.206
Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	41200	7.65×10^{-8}	0.8594	3.151
Liquefied Petroleum Gas (LPG)	Propane	46300	6.48×10^{-8}	0.8182	3.000
	Butane	45700	6.63×10^{-8}	0.8264	3.030
Liquefied Natural Gas (LNG)		48000	5.73×10^{-8}	0.7500	2.750
Methanol		19900	6.91×10^{-8}	0.3750	1.375
Ethanol		26800	7.14×10^{-8}	0.5217	1.913

Table1.1 : Properties of common marine fuels adopted from IMO MEPC circ.308(73) [\[15\]](#)

The figures from table 1.1 above are the emission factors for various marine fuels which are used to quantify CO₂ emissions released from combustion onboard as vessel. It is referred to as tank to wake or pipe end emissions. These values do not account for the emissions associated in activities such as fuel extraction, refining, transportation, storage etc. which come prior to the actual combustion of the fuel. The Energy Efficiency Design Index (EEDI) calculations introduced by the IMO does not consider factors such as cofferdams, cryogenic or pressurised storage requirements associated with some of these fuels. So these values are not representation of a full life cycle emission of the fuels.

Apart from the usage of fuels, there is also a market shift towards electrification of marine transport as well. The usage of electricity for marine propulsion techniques offer many attractive advantages such as low emission, reduced noise and vibrations, high efficiencies of electric machines, faster response etc. These make electric propulsion a popular choice for supply vessels, ferries etc. Although battery technology has made great advancements in recent past, it still has not managed to meet with the longer range requirements of international cargo movement. But they are an attractive option in hybrid solutions.

1.1 Purpose

The purpose of the thesis is to identify possible hybrid driveline techniques to replace conventional ones using combinations of methanol and electricity as energy carriers. This study also aims at estimating the operational costs involved in these techniques and the emission characteristics of the same.

1.2 Outline of the thesis

To achieve the objective of the thesis, different design options of drivelines are introduced and analysed for operational cost and CO₂ emission implications. The design basis adopted for the study is discussed in section 2. The section 3 describes the various design options considered and the calculation and distribution of power in various scenarios. The comparison between the design options are presented in Section 4 and finally concluded in Section 5.

2 Design Basis And Energy Estimation

In order to obtain a tangible result from this study it was decided to perform the study for existing vessels that has a conventional driveline onboard. In order to achieve this, two existing vessels of different operational profiles operated by the Swedish Maritime Administration (Sjöfartsverket) were selected and through ScandiNAOS AB, they provided us with the essential data to determine the operational profiles of the vessels for the study. The two vessels that were brought under the study were, Pilot 755 and MV Baltica.

Pilot 755 is pilot boat used for transportation of the pilots to incoming vessels that have requested for pilotage service and to get the pilot back for departing vessels after the pilot assisted passage is completed. The Swedish Maritime Administration has provided the Automatic Identification System (AIS) data transmitted from this vessel over a period of 13 months. This data was decoded and used to determine an operational profile for the vessel

The Baltica is a buoy maintenance vessel which is Ice classed ICE IA, with dynamic positioning capabilities as well. The vessel is generally operated for picking up buoys out of the water and carrying out the maintenance of the same as well as perform functions of a service vessel such as surveying the coast and providing ice breaking assistance in winters. The operational profile for this vessel was adopted from Marine Design project done by the MSc. Mobility engineering (marine) students of Chalmers in 2024 for a similar vessel Scandica operated by the Swedish Maritime Administration (Sjöfartsverket).

2.1 Analysis of the operational profile for Pilot 755

2.1.1 AIS Data analysis

The Automatic Identification System (AIS) data transmitted by the pilot boat between the 1st of January 2025 and the 17th February 2026 was decoded and plotted, in order to determine the distances covered in voyages, the speeds attained by the boat, the turnaround time of the boat between voyages etc.

The figures and table shown below are the data extracted from the AIS data of Pilot 755 over the course of the above mentioned period.

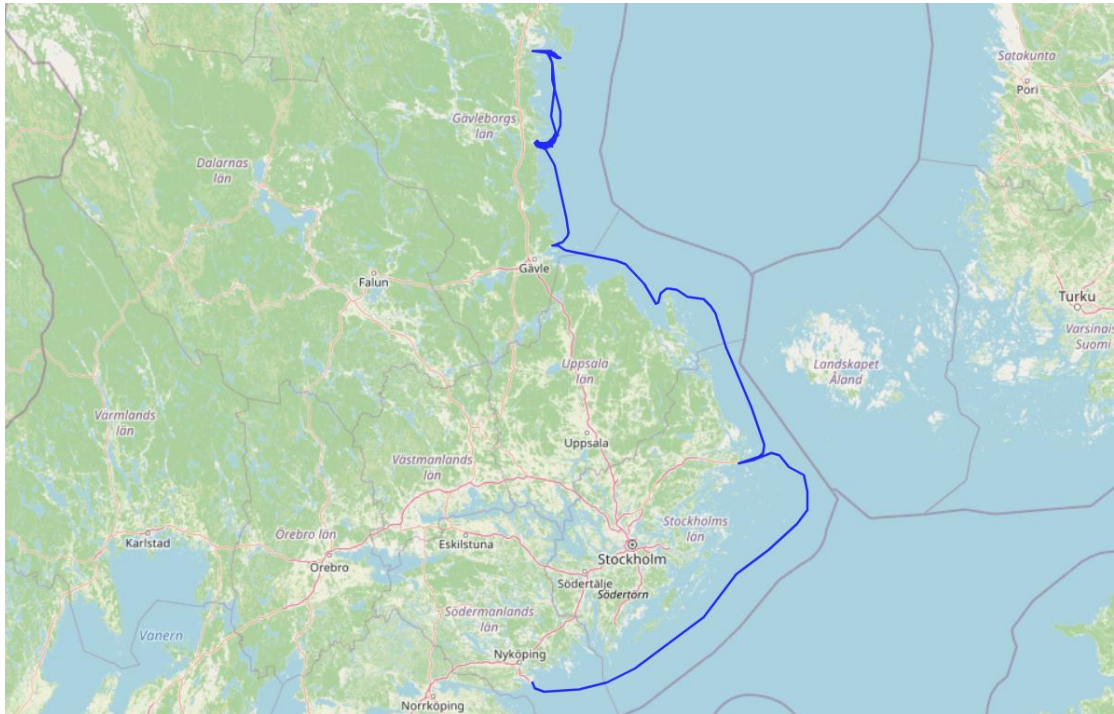


Fig2.1: Plot showing the route travelled by Pilot boat 755 , extracted from AIS data.

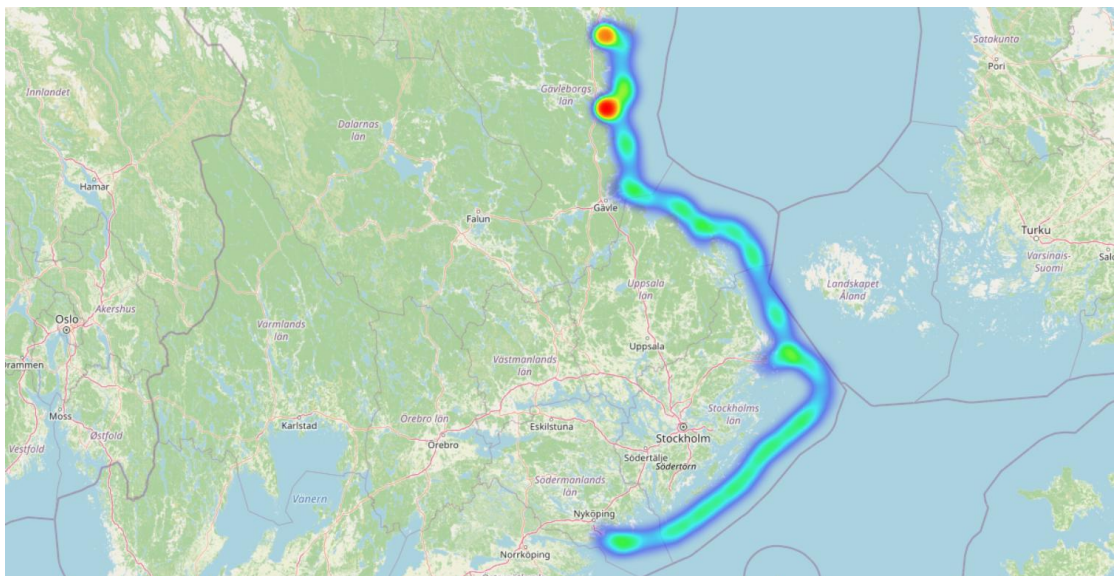


Fig 2.2: Plot showing the heat map of Pilot 755 showing the most frequented locations.

All individual voyages were separated out of the decoded Automatic Identification System (AIS) data and the voyages from winter season and non-winter seasons were analysed separately. It can be seen that the distances are generally lesser than 18NM, but there are a few with longer distances as well.

The top 7 non winter season voyages in terms of distance covered were found as below in table 2.1:

Date of voyage	Duration (hrs.)	Distance covered (NM)	Average speed (knots)	Maximum speed attained (knots)
27 May 2025	4.1	34.6	8.8	15.3
4 Nov. 2025	3.6	34.1	9.6	20.1
12 July 2025	3.1	17.7	6.3	14.6
27 July 2025	2.0	15.7	7.9	15.1
9 Aug. 2025	2.0	15.6	7.9	14.7
24 July 2025	2.1	15.3	7.5	14.8
23 Aug. 2025	1.6	14.4	8.9	15.2

Table 2.1: Non winter season voyages ranked based on the distance covered in a voyage

The top 7 winter season voyages in terms of distance covered were found as below in table 2.2:

Date of voyage	Duration (hrs.)	Distance covered (nm)	Average speed (knots)	Maximum speed attained (knots)
26 Feb. 2025	3.0	22.0	7.4	14.8
3 Jan. 2025	1.8	15.7	8.2	11.1
9 Feb. 2026	1.9	15.1	7.2	18.8
22 Jan. 2025	1.8	14.5	7.7	9.9
15 Jan. 2026	1.9	14.5	7.4	18.8
27 Jan. 2025	1.6	13.5	8.3	10.3
23 Jan. 2025	1.6	12.4	7.3	10.7

Table 2.2: Winter season voyages ranked based on the distance covered in a voyage

The top seven shortest turn around time between voyages identified were as shown below in table 2.3:

Date of voyage	Duration of turn around(min.)	Duration of turn around time (hrs.)
12 Feb. 2025	31.2	0.5
22 Jan. 2025	86.6	1.4
12 Jan. 2025	96.1	1.6
22 Jan. 2025	98.1	1.6
13 Jan. 2026	168.4	2.8
22 Jan 2025	191.6	3.1
4 Sep. 2025	250.7	4.1
11Feb 2025	348.3	5.8
15 Jan. 2026	418.6	6.9

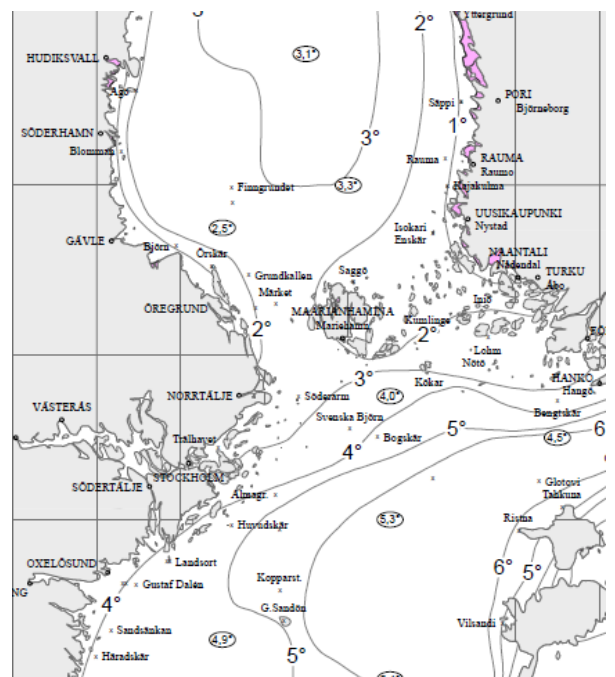
Table 2.3: Voyage turn around times ranked from the least.

2.1.2 Historical Ice data analysis

The historical Ice data was referred to, on those days that were listed in table 2.2. The ice data recorded were as below:

Ice type Istyp Jäätyyppi	Concentration Koncentration Peittävyys	Symbols Symboler Merkinnät
Ice free Isfritt Jäätön	-	▼ Brash ice barrier Stampsivall Sohjovyö
New ice (< 5 cm) Nyis (< 5 cm) Uusi jää (< 5 cm)	7 - 10/10	⋈ Rafted ice Hopskjuten is Päällekkäin ajautunut jää
Thin level ice (5-15 cm) Tunn jämn is (5-15 cm) Ohut tasainen jää (5-15 cm)	9 - 10/10	▲▲ Ridged or hummocked ice Vallar eller upptomad is Ahtautunut tai röykkiöitynyt jää
Fast ice Fastis Kiintojää	10/10	∞ Strips and patches Strängar av drivis Ajojäänauhoja
Rotten fast ice Rutten fastis Hauras kiintojää	-	⚠ Floe-bit, floeberg Isbumling Ahtojää- tai röykkiöläutta
Open water Öppet vatten Avovesi	< 1/10	⊥ Fracture Spricka Repeämä
Very open ice Mycket spridd drivis Hyvin harva ajojää	1 - 3/10	⚡ Fracture zone Område med sprickor Repeämävyöhyke
Open ice Spridd drivis Harva ajojää	4 - 6/10	⋯ Estimated ice edge Uppskattad iskant Arvioitu jään reuna
Close ice Tät drivis Tiheä ajojää	7 - 8/10	ATLE* Icebreaker (* koordinating) Isbrytare (* koordinerande) Jäänmurtaja (* koordinaattori)
Very close or compact ice Mycket tät / kompakt drivis Hyvin tiheä ajojää	9 - 9+/10	2° Water temperature isotherm (°C) Vattentemperaturisoterm (°C) Veden lämpötilan tasa-arvokäyrä (°C)
Consolidated ice Sammanfrusen drivis Yhteenjäätynyt ajojää	10/10	2.1° Mean water temperature Ytvattnets medeltemperatur Meriveden pintalämpötilan keskiarvo (2008 - 2022)
Ice thickness (cm) Istjocklek (cm) Jään paksuus (cm)		ICE = ice covered täckt av is jään peitossa

Fig 2.3: Ice chart legend from SMHI historical ice data



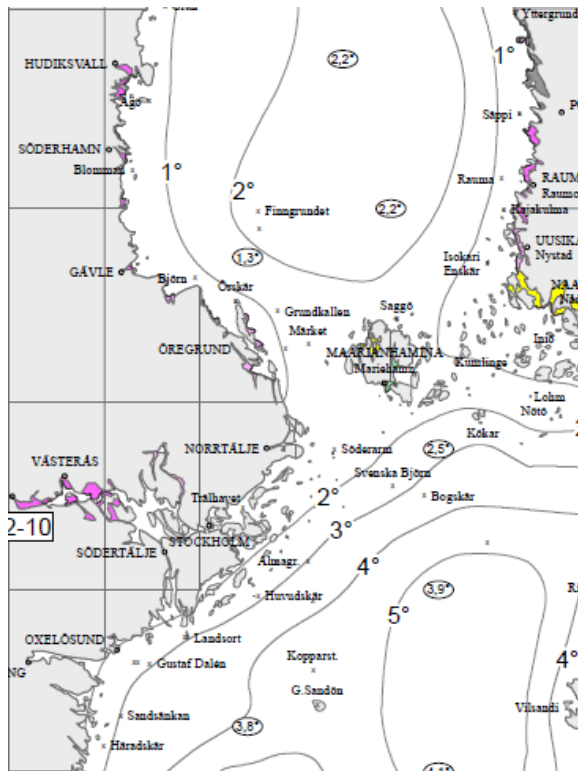


Fig 2.8: Ice chart from 27 Jan. 2025

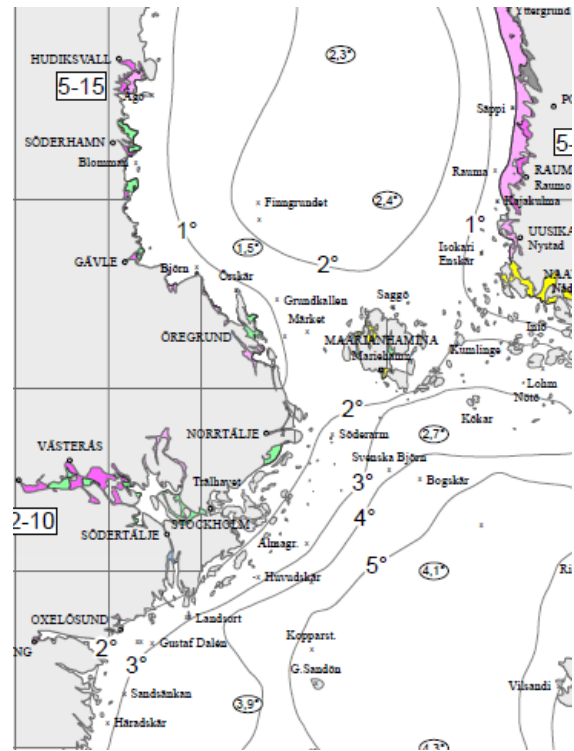


Fig 2.9: Ice chart from 23 Jan. 2025

The above figures 2.3 through 2.9 show the historical ice data from the operational region of the Baltica in the year 2025. From the above ice chart data, it was seen that

the ice is not very thick in the region of operation for the pilot boat and was upto 5cm or lesser. So an additional of 10% power requirement is considered for winter operations of the vessel.

The total operating hours of the vessel was also identified over one year (2025) was also extracted from the AIS data and listed in table 2.4 below:

Total operational hours in year 2025	108.4
Total operational hours in non winter season	70.03
Total operational hours in winter season	38.43

Table 2.4: total operating hours of the boat over an year

2.1.3 Hull resistance estimation

In order to estimate the energy and power requirements of the vessel the approximate resistance acting on the vessel's hull was calculated. The Holtrop-Mennen method widely used for ship resistance calculations couldn't be employed for the Pilot 755 due to factors like higher dead rise angle, low block coefficient etc. The resistance of the hull was then calculated by Savitsky method [5] which is used for smaller vessels.

Parameter	Symbol	Value	Unit
Length Overall	LOA	16.21	m
Length Between Perp.	LPP	14.77	m
Beam	B	5.26	m
Draft	T	2.6	m
Depth	D	3.6	m
Displacement	Δ	57.93	MT
Block Coefficient	C_b	0.285	—
Longitudinal Center of Gravity (from transom)	LCG	6.6	m
Design speed	v	22	kt
Deadrise Angle	β	18	deg

Table 2.5: Principal dimensions of the pilot boat used for resistance calculation

The Savitsky method [6] determines the resistance by considering the lift generated by planing hull and the boat's weight; determining an equilibrium between them at a planing speed. The key parameters considered in this calculation are:

The beam of the vessel, the dead rise angle which is a significant measure to determine the lift and drag of the vessel, the length of the vessel, the displacement of the vessel and the longitudinal center of gravity, and the design speed of the vessel.

These parameters are then used to compute following :

Froude number

$$Fn = V / \sqrt{(g \times LOA)}$$

The displacement

$$\nabla = \Delta / (\rho \times g)$$

Lift coefficient

$$CL = \Delta / (0.5 \times \rho \times V^2 \times B^2)$$

Drag coefficient

$$CD = (0.3 + 0.1 \times \cos 2\tau) \times \tan \tau + 0.005$$

Wetted length

$$Lw = LOA \times (0.6 + 0.2 \times \cos \tau)$$

Wetted area

$$A_w = B \times Lw \times (0.7 + 0.3 \times \cos \tau)$$

Reynold's number

$$Rn = (V \times Lw) / \nu$$

where $\nu = 1.188 \times 10^{-6} \text{ m}^2/\text{s}$ (seawater at 15°C)

ITTC 1957 Friction Coefficient

$$CF = 0.075 / (\log_{10} Rn - 2)^2$$

Total Fiction coefficient with roughness

$$CF_{total} = CF + \Delta CF$$

where $\Delta CF = 0.0004$ (roughness allowance)

Friction resistance

$$R_F = CF_{total} \times (0.5 \times \rho \times V^2) \times A_w$$

Wave resistance

$$R_{wave} = C_w \times (0.5 \times \rho \times V^2) \times B \times LOA$$

where $C_w = 0.012 \times e^{-6} \times Fn$ (for Displacement Mode ($Fn < 0.5$))

$C_w = 0.0025 \times e^{-1.5} \times (Fn^{-0.7}) + 0.0005$ (for planing Mode ($Fn > 0.7$))

$C_w = (1 - \lambda) \times Cw_{disp} + \lambda \times Cw_{plane}$ (Transition Mode ($0.5 \leq Fn \leq 0.7$))

where $\lambda = (Fn - 0.5) / 0.2$

Spray resistance

$$R_{spray} = k_{spray} \times (0.5 \times \rho \times V^2) \times B^2$$

for $Fn < 0.55$: $k_{spray} = 0$

for $0.55 \leq Fn < 0.7$: $k_{spray} = 0.012 \times (Fn - 0.55) / 0.15$

for $Fn \geq 0.7$: $k_{spray} = 0.012 + 0.008 \times (1 - e^{-2\tau})$

Total resistance

$$R_{total} = R_F + R_{wave} + R_{spray}$$



Fig 2.10: Resistance curve for the pilot boat hull by Savitsky method

From the Savitsky method for calculation the resistance on planning hulls, the resistance acting on the pilot boat is estimated as 48.5kN at 22kt speed.

The Effective power required is therefore calculated as:

$$P_{eff} = R_{total} v$$

Where v is the speed in m/s

Therefore

$$P_{eff} = 548.4kW$$

2.1.4 Propeller curve and Power prediction

The propeller curve is generated to identify the efficiency at which the resistance is overcome and the design speed and it helps to understand the power required to propel the vessel. It also helps to understand how effectively the driveline power can be converted into useful propulsive power for the vessel.

The Wageningen B-screw series [7] was used to determine the base propeller characteristics. It is a widely used systematic propeller series, which gives a good estimation of the propeller characteristics for a hull. It was done using a computational tool openly available in Matlab (MatWorks, 2024).

The parameters used to generate the propeller curve for the pilot boat were:

Parameter	Value	Unit
Propeller diameter	1.4	m
Number of blades	4	

Blade area ratio	0.5	
Propeller type	FPP	
Operational speed	22	kn
Propeller input thrust	48.5	kN
Wake fraction	0.12	
Water density	1024	kg/m ³
PD ratio	0.8	

Table 2.6: Input parameters for propeller calculation for pilot boat

The generated propeller curve using the Wageningen B series is shown in Fig 2.11:

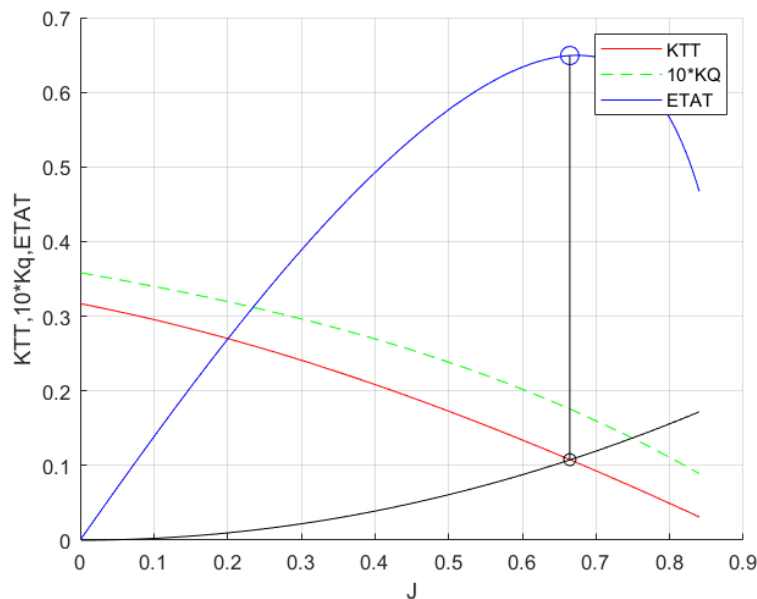


Fig 2.11: Open water diagram for optimal propeller generated by Wageningen B series with the data mentioned in table 2.6

The efficiency of the propeller was estimated to be 66% .
So the shaft power required to be generated is calculated as :

Shaft power

$$P_{shaft} = \frac{P_{eff}}{\eta_{prop}}$$

$$P_{shaft} = 830.9 \text{ kW}$$

Assuming 3% loss of power in gear box and another 3% loss of power in transmissional losses [8], the brake power necessary from the propulsion power source is calculated as:

Brake Power

$$P_{brake} = 883.9 \text{ kW}$$

2.1.5 Operational profile definition for the study

Since the maximum speed the vessel runs at, mostly fall close to 15 knots, and the voyages with durations more than 3 hours are very limited in number, those two are considered as two limiting parameters for the study.

From Fig 2.10, at 15knots we see that the hull resistance is 15kN.

Converting this to power in a similar manner as above in section , we find the brake power necessary is for the vessel is about $P_{brake} = 190\text{kW}$.

Adding an additional power requirement of 10% as mentioned in section 2.1.2, for the losses due to the added resistance for operation in ice region, the brake power required is 211kW.

2.2 Analysis of operational profile for the Baltica

The operational profile of the Baltica was also analysed in a similar manner considering the winter and non winter season operations separately. This is even more significant for this vessel as it is Ice 1A class vessel used for ice breaking assistance also. The table 2.7 below shows the principal dimensions of MV Baltica.

Parameter	Symbol	Value	Unit
Length Overall	LOA	57	m
Length Between Perp.	LPP	50	m
Beam	B	12	m
Draft	T	3.45	m
Depth	D	6.1	m
Displacement	Δ	1170.4	MT
Block Coefficient	C_b	0.55	–
Longitudinal Center of Gravity (from transom)	LCG	25.74	m
Design speed	v	14	kt

Table 2.7: Pricipal dimensions of M/V Baltica

2.2.1 Hull resistance estimation

The Holtrop-Mennen (1982) [9] method is commonly used empirical method for resistance estimation of vessels. This method was employed for the resistance calculation of the vessel M/V Baltica.

According to the Holtrop- Mennen method, the resistance is calculated as the following:

$$R_{total} = R_F(1 + k_1) + R_{APP} + R_W + R_B + R_{TR} + R_A + R_{AA}$$

where:

R_F is the frictional resistance according to the ITTC friction formula 1978

$(1 + k_1)$ is form factor

R_{APP} is the resistance of appendages
 R_W is the wave making and wave breaking resistance
 R_B is the bulbous bow resistance near the wetted surface area
 R_{TR} is the pressure resistance of the immersed transom stern
 R_A is the model- ship correlation resistance (roughness)
 R_{AA} is the air resistance

Using this method, the resistance curve for Baltica was generated as shown in Fig 2.12.



Fig 2.12: Resistance curve for M V Baltica

From the Holtrop Mennen method for calculation the resistance on hulls, the resistance acting on the Baltica's hull is estimated as 87kN at 14kt speed.

The Effective power required is therefore calculated as:

$$P_{eff} = R_{total} v$$

Where v is the speed in m/s

Therefore

$$P_{eff} = 626.052 \text{ kW}$$

2.2.2 Propeller curve and Power prediction

As discussed before, the propeller curve is generated to identify the efficiency at which the resistance is overcome and the design speed and it helps to understand the power required to propel the vessel. It also helps to understand how effectively the driveline power can be converted into useful propulsive power for the vessel.

The Wageningen B-screw series [7] was used to determine the base propeller characteristics for this vessel as well. It is a widely used systematic propeller series, which gives a good estimation of the propeller characteristics for a hull. It was done using a computational tool openly available in Matlab (MatWorks, 2024).

The parameters used to generate the propeller curve for the Baltica are listed in table 2.8.

Parameter	Value	Unit
Propeller diameter	2.64	m
Number of blades	4	
Blade area ratio	0.37	
Propeller type	FPP	
Operational speed	14	kn
Propeller input thrust	87	kN
Wake fraction	0.12	
Water density	1024	Kg/m ³
PD ratio	0.8	

Table 2.8: Input parameters for propeller calculation for pilot boat

The generated propeller curve using the Wageningen B series is shown in fig 2.13.

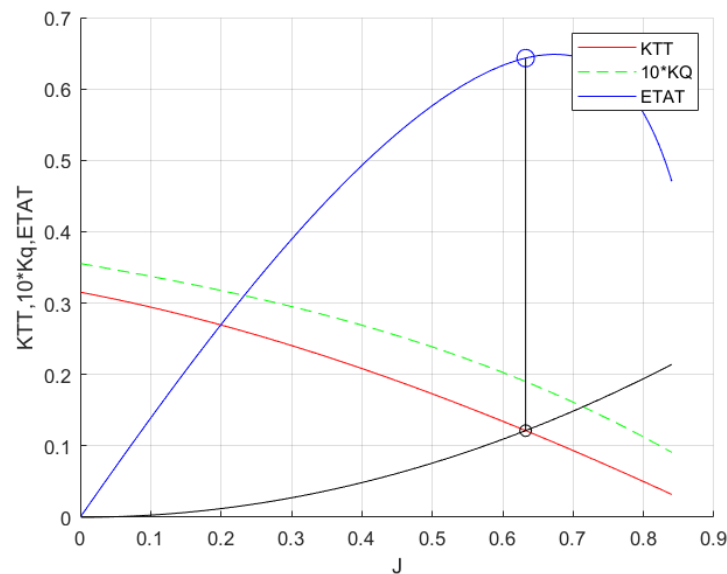


Fig 2.13: Open water diagram for optimal propeller generated by Wageningen B series.

The efficiency of the propeller was estimated to be 64% .

So the shaft power required to be generated is calculated as :

Shaft power

$$P_{shaft} = \frac{P_{eff}}{\eta_{prop}}$$

$$P_{shaft} = 978.2 \text{ kW}$$

Assuming 3% loss of power in gear box and another 3% loss of power in transmissional losses [8], the brake power necessary from the propulsion power source is calculated as:

Brake Power

$$P_{brake} = 1039.64 \text{ kW}$$

The above break power is the power necessary for hull of the given characteristics in table 2.7 to be propelled.

However since the Vessel Baltica Ice class 1A certified the vessel has to comply with the Finnish- Swedish Ice class rules [10]. It has listed out specific requirements for vessels constructed after 1st September 2003, including the propulsive power requirement.

According to this, the resistance is calculated as

$$R_{CH} = C_1 + C_2 + C_3(H_F + H_M)^2(B + 0.658H_F) + C^4 L_{par} H_F^2 + C^5 \left(\frac{LT}{B^2}\right)^3 \frac{B A_{wf}}{4 L}$$

And the power is calculated as:

$$P = K_e \frac{(R_{CH}/1000)^{\frac{3}{2}}}{D_p} \text{ kW}$$

where:

- K_e Propulsion machinery coefficient
- L Length of the ship between the aft and fore perpendicular
- L_{par} length of parallel midbody of the ship
- B maximum breadth of the ship
- T Maximum actual ice class draughts of the ship
- A_{wf} Area of the waterline of the bow
- D_p Diameter of the propeller
- c resistance coefficients
- H_M thickness of brash ice in mid channel
- H_F Thickness of brash ice layer displaced in the bow

From the above equation the power required for the vessel for Ice 1A class is calculated as

$$P_{brake} = 2828.6 \text{ kW}$$

2.2.3 Operational profile definition for the study

For the purpose of this study and approximated operational profile of the vessel is generated from available data. It has been separately identified as non winter season and winter season operations as listed in table 2.9 and table 2.10.

2.2.3.1 Non winter season operation

The operations assumed for Baltica during a typical non winter day are listed in table 2.9.

Duration	Description	Average Power consumption (auxiliary) kW	Power kW	Average Power consumption (propulsion) kW	Power kW
3 hours	Transit	120		1682	
1.5 hours	Surveying (DP operation)	160		80	
4 hour	Transit	120		1604	
2 hours	Buoy maintenance (DP operation)	160		500	
2.5hours	Rough weather Transit	160		1992	
1 hour	Transit	120		1552	
10 hours	Drifting / Anchorage	100		0	

Table 2.9: Typical non winter day operational profile for the Baltica

Graphical representation of the power consumption for the Baltica as listed in table 2.9 shown in fig.2.14

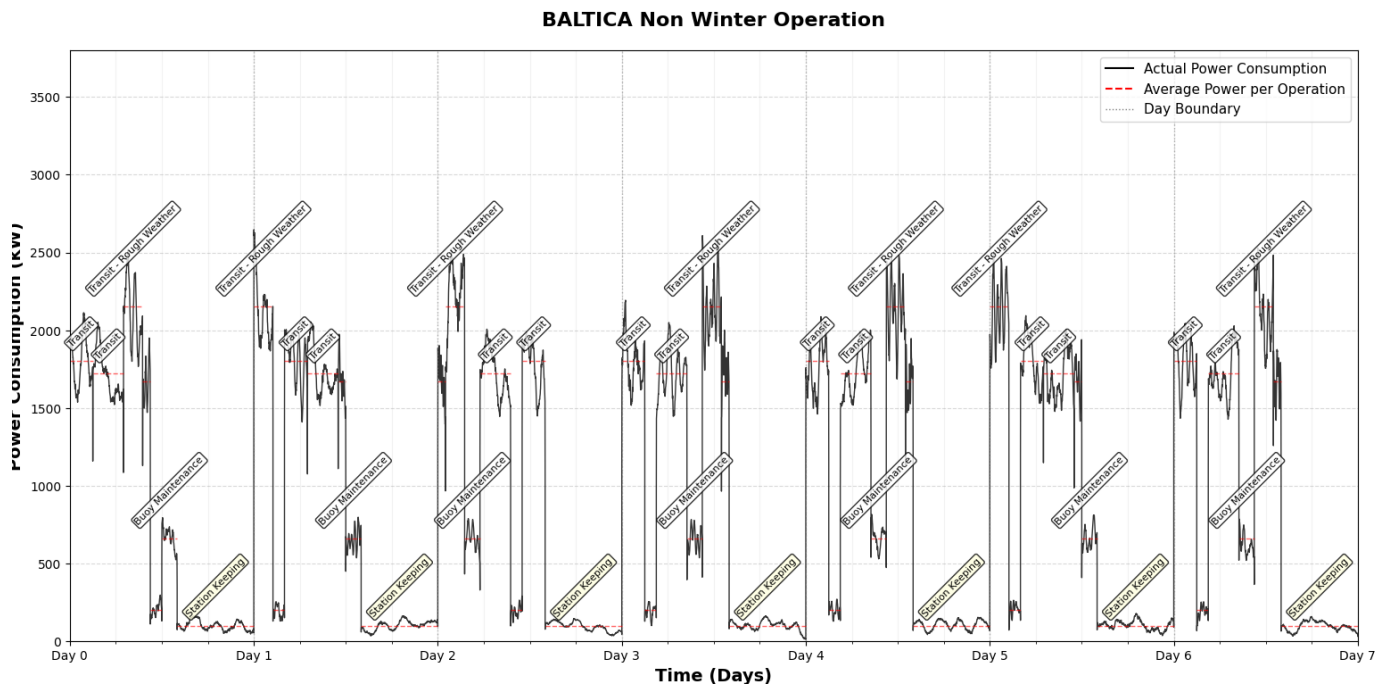


Fig 2.14: Non winter operational profile of the Baltica

2.2.3.2 Winter season operation

Now in a similar fashion the winter day operation of the Baltica is defined as shown in table 2.10. During the winter among the 7 days in the week, 2 days are assumed to be designated to ice breaking operations with no surveying and buoy maintenance operation.

Duration	Description	Average Power consumption kW (auxiliary)	Average Power consumption kW (auxiliary)
3 hours	Transit	120	1682
1.5 hours	Ice breaking	100	2420
4 hour	Transit	120	1604
2 hours	Ice breaking	100	2420
2.5hours	Rough weather Transit	160	1992
1 hour	Transit	120	1552
10 hours	Drifting / Anchorage	100	0

Table 2.10: Typical winter day operational profile for the Baltica

Graphical representation of the power consumption for the Baltica is shown in fig.2.15

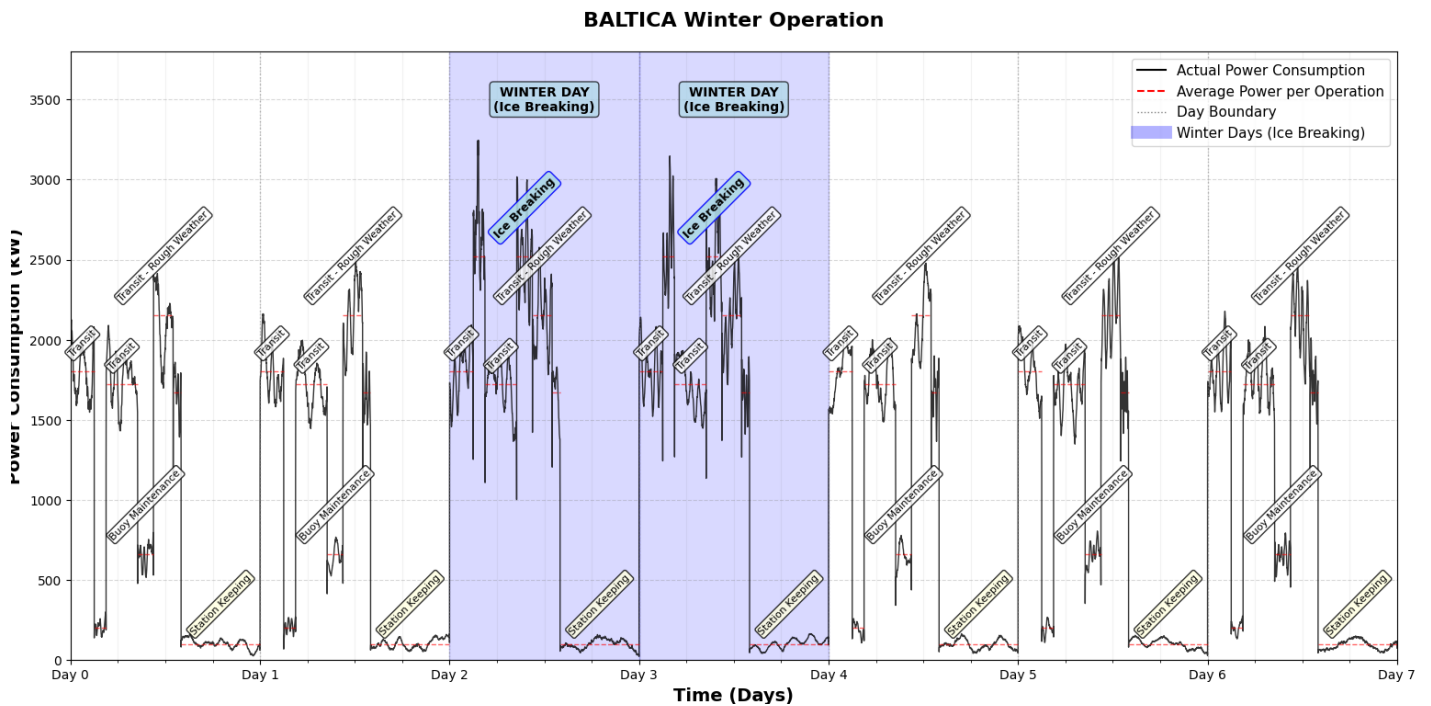


Fig 2.15: Non winter perational profile of the Baltica

3 Selection and comparison of different design options and selection of machinery

The existing vessels, both the Baltica and the pilot boat are currently run on conventional diesel propulsion drivelines. In this thesis, the study is focussed on the possibility of replacing the same with more environment friendly propulsion solutions that produce lesser carbon foot print. It aims at estimating how much carbon dioxide production can be prevented and the monetary implications of the same.

Among the available renewable fuels available today, methanol has emerged as a viable option due to the ease of handling in ambient conditions, non toxicity, its ability to be made available in renewable methods, its potential for a favorable emission reduction etc. The electric modes of propulsion is also maturing quite well as it offers almost zero emission operation at the point of use. However it has still a drawback of lower energy density, which in turn affects the range. Keeping this in mind, hybrid design options are also brought under this study, to learn how they could be advantageous.

Three alternative design options are considered in case of both the vessels and they are focussed upon in the coming sections.

3.1 Baltica Design option 1

This design option consists of two identical dual fuel generator sets of same power rating and a third generator set of lower power rating which runs completely on methanol. These gensets produce the electric power necessary for the vessel's entire operation. The propulsion is achieved by two identical AC electric motors. The smaller capacity methanol generator would be able to supply the consumers in low load operations at better fuel efficiency and the larger gensets need to be run only at higher load demands. This can also be advantageous in reducing the maintenance intervals of the engines.

A diesel replacement of 70% for the dual fuel engine is assumed for the purpose of calculations in this study.

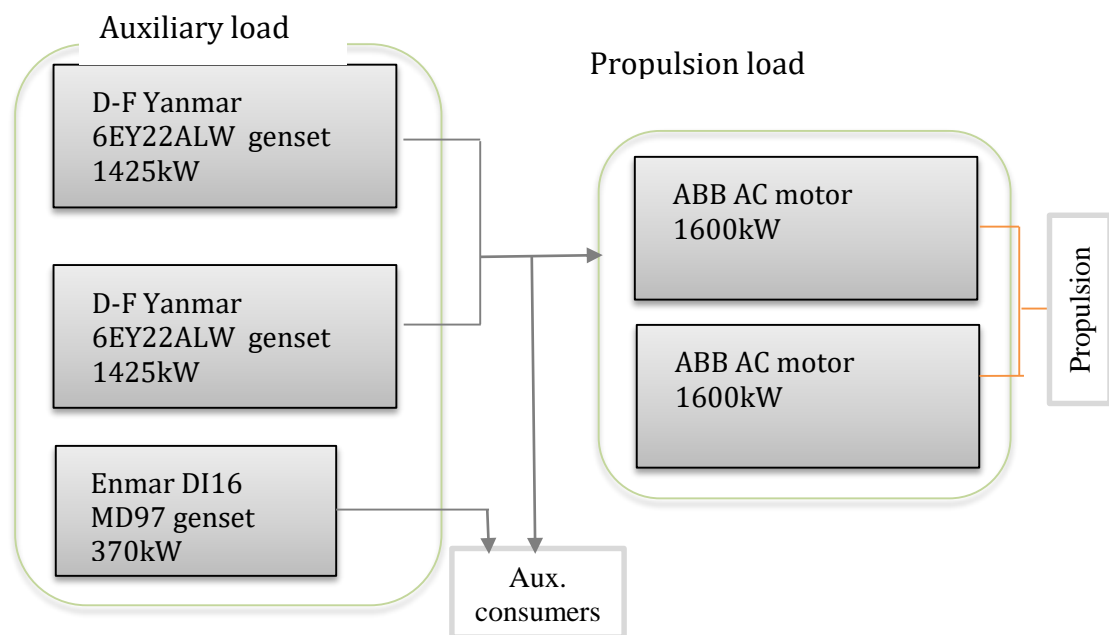


Fig 3.1: Block representation of the major machineries in the design option 1

The following are the machineries considered for this design option:

Yanmar 6EY 22ALW

Base engine manufacturer: Yanmar
 Power output: 1425kW
 Dimension: 5.647m x 1.782m x 2.907m
 Weight 18.5T
 Assumed diesel replacement: 70%



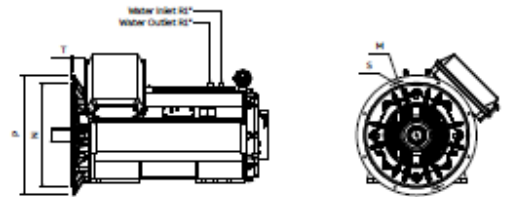
Enmar Engines DI 16 MD97 methanol genset

Base engine manufacturer: Scania
 Power output: 370kW
 Weight 1.7T
 Dimension: 5.647m x 1.782m x 2.907m



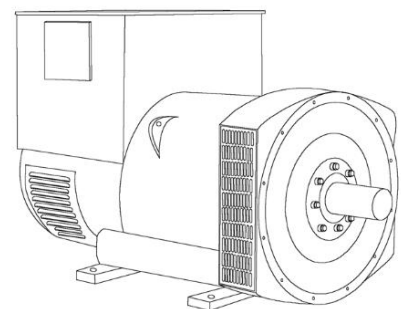
ABB AC motor

Water cooled
 Power rating 1600kW,
 Efficiency 97.5%
 Weight 5.35T
 Dimension: 2.241m x 1.120m x 1.120m



Stamford HCI 434F/ 444F alternator

Weight 1T
 Dimension 1.2m x 0.6m x 0.8m



The table 3.1 and table 3.2 lists the specific fuel consumption for diesel engines and the methanol generator considered for the study.

Engine load	SFOC (g/kWh)
25%	221
50%	198
75%	192
85%	191
100%	191

Table 3.1: SFOC values for diesel base engine

Engine load	SFOC (g/kWh)
10%	733
25%	530
50%	485
75%	457
85%	449.8
100%	439

Table 3.2: SFC values for methanol genset

3.1.1 Non – winter operation

The following table 3.3 shows the non- winter day operation of the design option to comply with the power demand of the Baltica with respect to the non – winter day operations discussed in the section 2.2.3.1. The table lists which engine need to be run in different event listed in table 2.9. The fuel consumption is calculated based on the specific consumption values listed in table 3.1 and table 3.2.

Event	Engines in operation	Total power output req. from gensets (kW)	Diesel consumption (kg)	Methanol consumption (kg)
3 hour transit	2 DF generator	1909	333	1669
1.5hour surveying (D.P operation)	1 methanol generator	245	0	245
4 hour transit	2 DF generator	1826	427	2139
2 hour buoy maintenance	1 DF generator	692	82	411
2.5 hour rough weather transit	2 DF generator	2279	326	1634
1 hour transit	2 DF generator	1771	103	519
10hour drifting\ anchor	1 methanol generator	100	0	560
Total daily fuel consumption			1273	7177

Table 3.3: Power and fuel data for non- winter day operation of the design option

The total consumption from the non winter day and correspondingly for 39 non winter weeks can therefore be calculated as the following table 3.4:

Fuel consumption per week (tons)	9	50
Fuel consumption in 39 week (tons)	348	1959

Table 3.4: Fuel consumption for non- winter weeks operation of the design option

3.1.2 Winter operation

The following table shows the Winter day operation of the design option to comply with the power demand of the Baltica with respect to the winter day operations discussed in the section 2.2.3.2

In winter operation, 2 days of the 7 days in a week are considered to be scheduled for ice breaking operation with the winter day events listed in the table 2.10. The same is listed in table 3.5 below from the perspective of the design option 1.

Event	Engines in operation	Total power output req. from gensets per hour (kW)	Diesel consumption (kg)	Methanol consumption (kg)
3 hour transit	2 DF engines generator	1909	333	1668
1.5hour Ice breakiing	2 DF engines generator	2674	230	164
4 hour transit	2 DF engines generator	1826	427	2139
2 hour Ice breakiing	2 DF engines generator	2674	306	1534
2.5 hour rough weather transit	2 DF engines generator	2279	326	1634
1 hour transit	2 DF engines generator	1771	104	519
10hour drifting\ anchor	1 methanol generator	100	0.0	560

Table 3.5: Power and fuel data for winter day operation of the design option 1

This design option would require methanol tanks with capacity of 66m³ of more to power a week's operation without intermediate bunkering operations.

Combining the operations in the winter and non winter seasons, the total annual consumption and carbon emission are obtained as shown in table 3.6

	diesel	methanol
Annual consumption of fuel (in tons)	475.2	2639.4
Carbon factor for diesel	3.206	
Carbon factor for methanol		1.375
	diesel	methanol
Annual CO2 emissions (tons)	1523.5	3629.2
Total CO2 emission (tons)	5152.6	

Table 3.6: Annual fuel consumption and carbon emissions in the design option1

**ANNUAL FUEL CONSUMPTION DISTRIBUTION
(Diesel vs Methanol)**

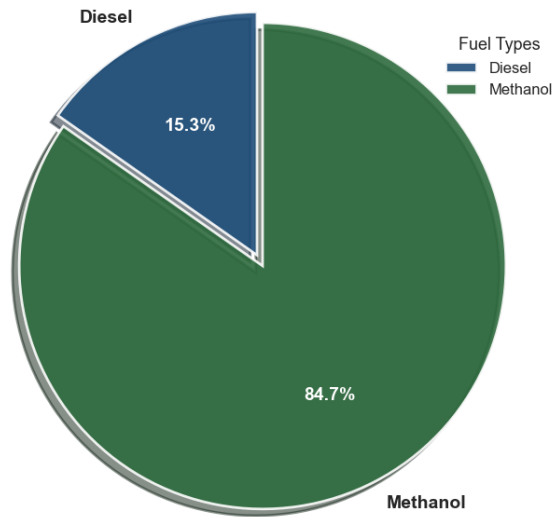


Fig 3.2: Representation of fuel consumption share for the Baltica design option 1

The general arrangement of the vessel as per the design option 1 is shown in the following fig. 3.3. As can be seen in the GA the original tanks 19.BR.OilTank and 21.BR.OilTank [Appendix 3] are replaced with methanol tanks with a cofferdam of 0.5m to the adjacent tanks. There are also two additional methanol tanks arranged with a cofferdam with the heating tanks on either sides of the vessel.

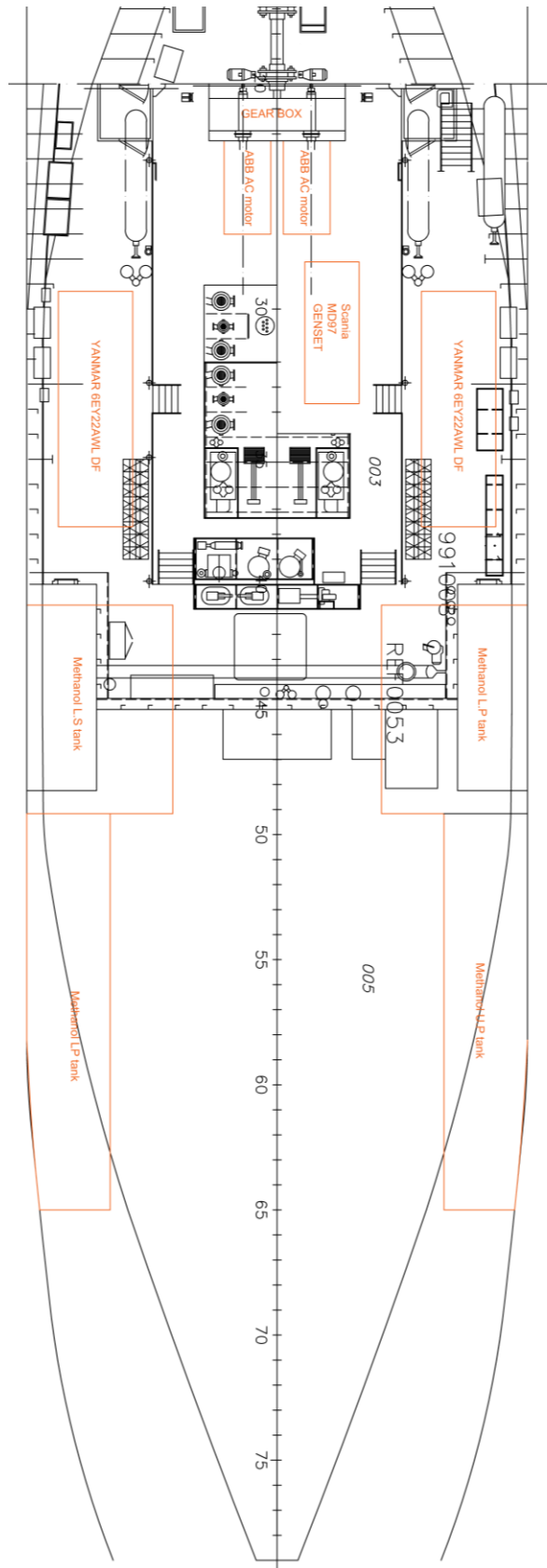


Fig 3.3: Allocation of space for machineries in the proposed design option 1

3.2 Baltica Design option 2

This design option consists of two methanol generator sets of same power rating and two battery compartments supplying 5051kWh . The dual fuel main engine can be run at steady load and the best SFOC ranges (80% load) to reduce fuel consumption while the battery can supply for the remaining loads. The dual fuel engine is aimed to run at 80 % and any additional load demand or fluctuations can be supplied by the batteries. At very low load operations such as drifting or surveying the batteries can meet the power demand of the vessel.

The battery packs are arranged in two battery compartments as the maximum battery capacity in one single compartment cannot exceed 5MW (DNV 2024). The methanol gensets can be run to charge the battery compartments. It is also possible to run the one methanol genset for double the time and avoid the installation of the other genset in order to charge the batteries. But to have redundancy, it would be better suited to have two gensets as the vessel would need battery power without fail in ice breaking operations. If a situation arises when one genset is out of service, the other can still be able to provide charge to the batteries with sensible operation of the main engine and still be able to complete the ice breaking operations without fail.

A diesel replacement of 70% for the dual fuel engine is assumed for the purpose of calculations in this study.

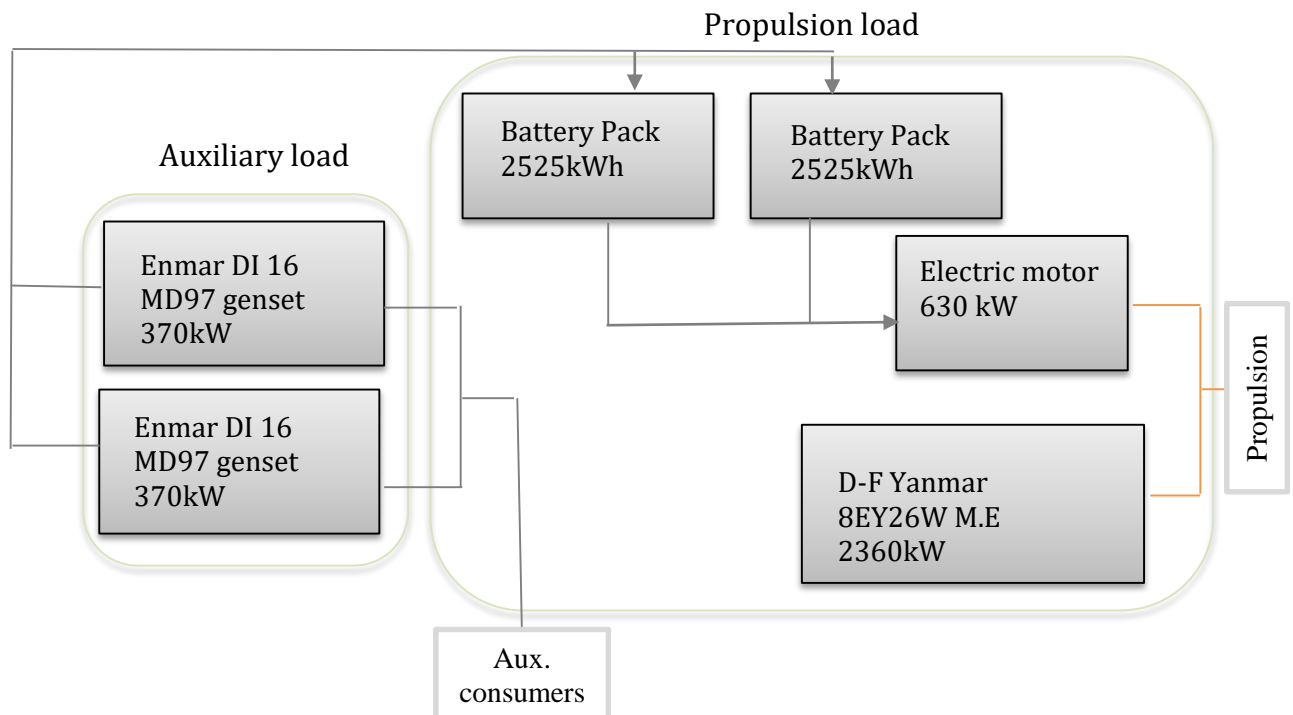


Fig 3.4: Block representation of the major machineries in the design option 2

The following are the machinery considered for this design option are the following:

D.F Yanmar 8EY26W

Base engine manufacturer: Yanmar
Power output: 2360kW
Dimension: 5.090m x 2.085m x 3.257m
Weight 24.5T
Assumed diesel replacement: 70%



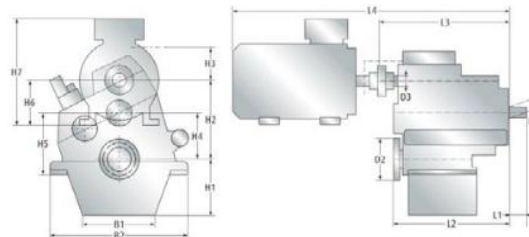
Enmar Engines DI 16 MD97 methanol genset

Base engine manufacturer: Scania
Power output: 370kW
Weight 1.7T
Dimension: 5.647m x 1.782m x 2.907m



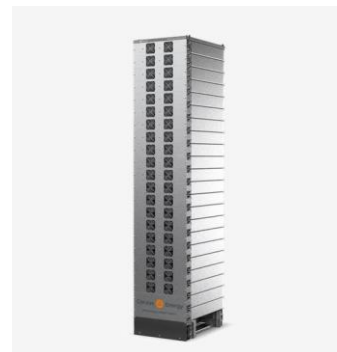
Reintjes Hybrid gear box HS 63

weight 5110kg
630kW electric motor.
Dimension 3.115m x 1.3m x 8.367m

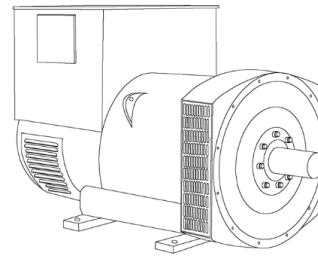


Corvus Dolphin NxtGen ESS Energy Chemistry Lithium ion NCA

Energy: 8.2 kWh
Weight: 45.5kg
Cooling: Forced air
Dimension: 666 x 500 x 100 mm
A total of 616 modules should be installed to provide 5051kWh of stored energy (net wt. 28.02T)



Stamford HCI 434F/ 444F alternator
 Weight 1T
 Dimension 1.2m x 0.6m x 0.8m



The table 3.7 and table 3.8 lists the specific fuel consumption for diesel engines and the methanol generator considered for the study.

Engine load	SFOC (g/kWh)
25%	221
50%	198
75%	192
85%	191
100%	191

Table 3.7: SFOC values for diesel base engine

Engine load	SFOC (g/kWh)
10%	733
25%	530
50%	485
75%	457
85%	449.8
100%	439

Table 3.8: SFC values for methanol genset

3.2.1 Non – winter operation

The following table 3.9 shows the non- winter day operation of the design option to comply with the power demand of the Baltica with respect to the non – winter day operations discussed in the section 2.2.3.1.

	Engines in operation	Total power output req. from M.E per hour (kW)	Total power consumption from battery (kW)	Diesel consumption (kg)	Methanol consumption (kg)
3 hour transit	1 DF M.E	1888	64	325	1629
1.5hour surveying (D.P operation)	—	—	368	0	0
4 hour transit	1 DF M.E	1826	0	420	2104
2 hour buoy maintenance	—	—	1320	0	0
2.5 hour rough weather transit	1 DF M.E	1888	978	271	1357
1 hour transit	1 DF M.E	1771	0	102	511
10hour drifting\ anchor	—	—	1000	0	0
Daily fuel consumption (kgs.)				1119	7464

Table 3.9: Power and fuel data for non- winter day operation of the Baltica design option 2

The total battery output drawn is 3729.6kWh, which is 73.8% of the battery capacity. It is . The methanol gensets if run at 85% load of 629kW, it could charge the batteries in 6.5 hours.

The total consumption from the non winter day and correspondingly for 39 non winter weeks can therefore be calculated as the following in table 3.10:

Fuel consumption per week (tons)	8	52
Fuel consumption in 39 week (tons)	305	2038

Table 3.10: Fuel consumption for non- winter weeks operation of the design option

The following table shows the Winter day operation of the design option to comply with the power demand of the Baltica with respect to the non – winter day operations discussed in the section 2.2.3.2

3.2.2 Winter operation

In winter operation, 2 days of the 7 days in a week are considered to be scheduled for ice breaking operation as indicated in the table 2.10. The same is allocated in table 3.11 below with respect to the design option 2.

Event	Engines in operation	Total power output req. from M.E per hour (kW)	Total power output req. from Genset per hour (kW)	Total power consumption from battery (kW)	Diesel consumption (kg)	Methanol consumption (kg)
3 hour transit	1 DF M.E	1888	–	64	325	1629
1.5hour Ice breaking	1 DF M.E	2044	–	945	176	164
4 hour transit	1 DF M.E	1826	–	0.0	420	2104
2 hour Ice breaking	1 DF M.E	2044	–	1260	234	1172
2.5 hour rough weather transit	1 DF M.E	1888	–	978	271	1357
1 hour transit	1 DF M.E	1771	–	0	102	511
10hour drifting\ anchor	1 methanol generator	–	100	–	0	560
Daily fuel consumption (kgs.)					1529	9131

Table 3.11: Power and fuel data for winter day operation of the design option 2

In the winter operational days, the due to the additional additional power drawn from the batteries for ice breaking operation, the anchorage / drifting operation is proposed to be powered by running a methanol genset.

The total battery output drawn is 3247kWh, which is 64.3% of the battery capacity. It is . The methanol gensets if run at 85% load of 629kW, it could charge the batteries in 5.7 hours.

The total consumption from the winter day and correspondingly for 13 winter weeks can therefore be calculated as found in table 3.12.

Total fuel consumption	diesel	methanol
Fuel consumption per week (tons)	9	56
Fuel consumption in 13 week (tons)	112	723

Table 3.12: Fuel consumption for winter weeks operation of the design option 2

Combining the operations in the winter and non winter seasons, the total annual consumptions and carbon emission are obtained as shown in table 3.13 below.

	diesel	methanol
Annual consumption of fuel (in tons)	417.9	2760.3
Carbon factor for diesel	3.206	
Carbon factor for methanol		1.375
	diesel	methanol
Annual CO2 emissions (tons)	1339.8	3795.4
Total CO2 emission (tons)	5135.3	

Table 3.13: Annual fuel consumption and carbon emissions in the design option 2

ANNUAL FUEL CONSUMPTION DISTRIBUTION
(Diesel vs Methanol)

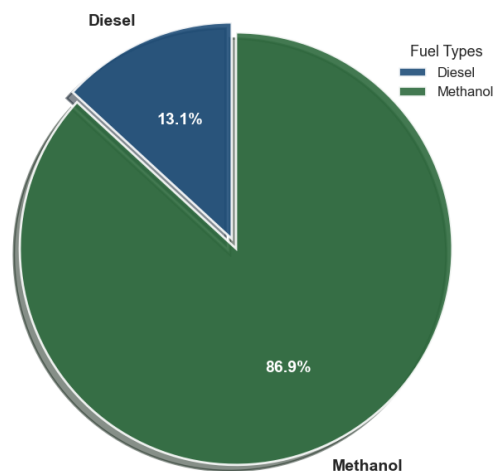


Fig 3.5: Representation of fuel consumption share

The general arrangement of the vessel as per the design option 1 is shown in the following fig. 3.3. As can be seen in the GA the original tanks 19.BR.OilTank and 21.BR.OilTank [Appendix 3] are replaced with methanol tanks with a cofferdam of 0.5m to the adjacent tanks. There are also two additional methanol tanks arranged with a cofferdam with the heating tanks on either sides of the vessel. The battery compartments are also arranged in front of the engine room split longitudinally to house 2525kWh of charge each.

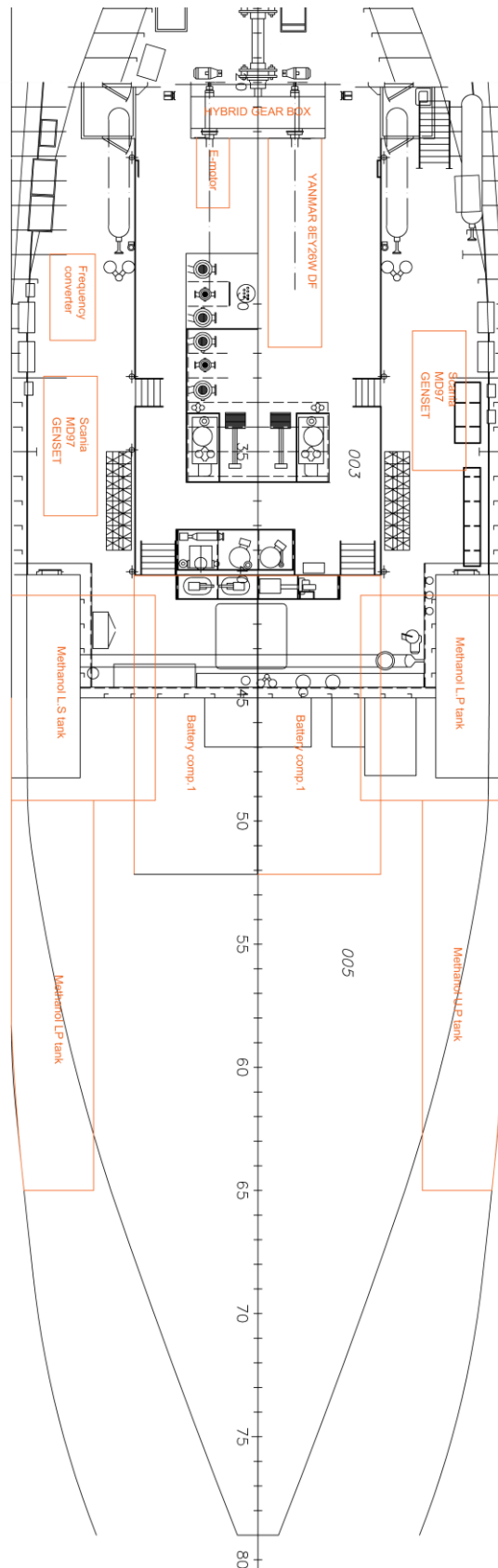


Fig 3.6: Allocation of space for machineries in the new design option 2

3.3 Baltica Design option 3

This architecture consists of two dual fuel genset of 200 kW to supply the auxiliary loads at all times and a dual fuel main engine to power the propulsive power requirements. This design option is very similar to the existing conventional driveline but replaced with renewable fuel partially.

A diesel replacement of 70% for the dual fuel engine is assumed for the purpose of calculations in this study.

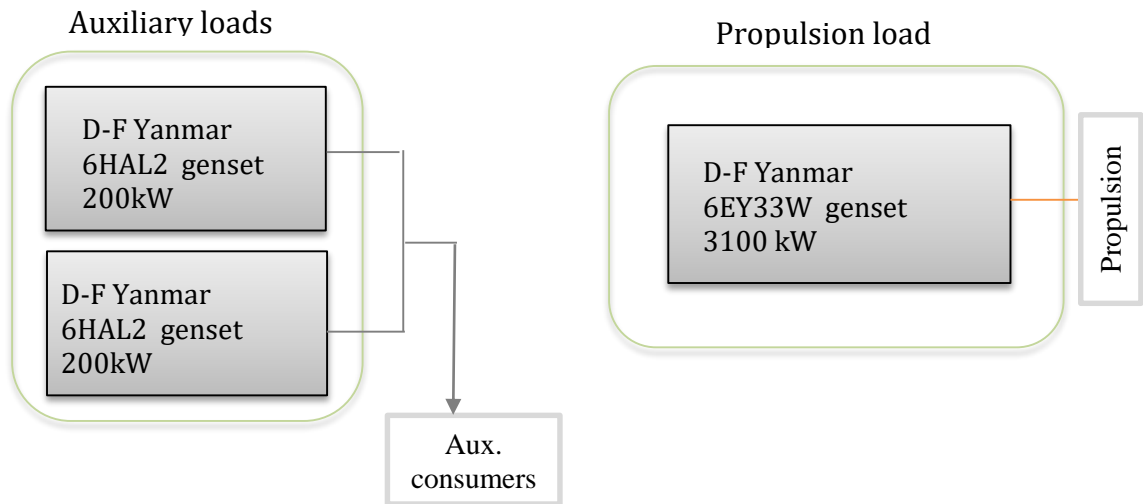
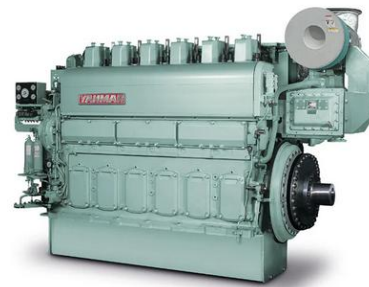


Fig 3.7: Block representation of the major machineries in the design option.

The following are the machineries considered for this design option:

D-F Yanmar 8EY33W

Base engine manufacturer: Yanmar
 Power output: 3100kW
 Dimension: 5.7m x 2.335m x 3.695m
 Weight: 38.8T
 Assumed diesel replacement: 70%



D-F Yanmar 6HAL2

Base engine manufacturer: Yanmar
 Power output: 200kW
 Weight: 1.43T
 Dimension: 1.654m x 1.164m x 1.804m



Engine load	SFOC (g/kWh)
25%	221
50%	198
75%	192
85%	191
100%	191

Table 3.9: SFOC values for diesel base engine

3.3.1 Non – winter operation

The following table 3.14 shows the non- winter day operation of the design option to comply with the power demand of the Baltica with respect to the non – winter day operations discussed in the section 2.2.3.1

Event	Engines in operation	Aux.Power consumption (kW)	Total power output req. from M.E per hour (kW)	Diesel consumption for the event (kg)	Methanol consumption for the event(kg)
3 hour transit	1 DF generator & 1 DF M.E	120	1789	338	1690
1.5hour surveying (D.P operation)	2 DF generator	160	_	14	71
4 hour transit	1 DF generator & 1 DF M.E	120	1706	432	2160
2 hour buoy maintenance	1 DF generator & 1 DF M.E	160	532	255	92
2.5 hour rough weather transit	1 DF generator & 1 DF M.E	160	2119	333	1666
1 hour transit	1 DF generator & 1 DF M.E	120	1651	105	524
10hour drifting\ anchor	1 DF generator	100	_	59	297
Daily fuel consumption (kgs.)				153	6499

Table 3.14: Power and fuel data for non- winter day operation of the design option 3

In this design option while operating the main engine in the buoy maintenance operation the load is only 17% of the rated. So the engine on is considered to be run on diesel with no replacement with methanol.

The total consumption from the non winter day and correspondingly for 39 non winter weeks can therefore be calculated as in the following table 3.15.

Total fuel consumption	diesel	methanol
Fuel consumption per week (tons)	11	45
Fuel consumption in 39 week (tons)	419	1774

Table 3.15: Fuel consumption for non- winter weeks operation of the design option 3

The following table shows the Winter day operation of the design option to comply with the power demand of the Baltica with respect to the non – winter day operations discussed in the section

3.3.2 Winter operation

In winter operation, 2 days of the 7 days in a week are considered to be scheduled for ice breaking operation as indicated in the table 3.16 below . The same is discussed in the section 2.2.3.2

Event	Engines in operation	Aux.Power consumption (kW)	Total power output req. from M.E per hour (kW)	Diesel consumption (kg)	Methanol consumption (kg)
3 hour transit	1 DF generator & 1 DF M.E	120	1789	338	1690
1.5hour Ice breakiing	1 DF generator & 1 DF M.E	100	2575	230	1152
4 hour transit	1 DF generator & 1 DF M.E	120	1706	432	2160
2 hour Ice breakiing	1 DF generator & 1 DF M.E	100	2575	307	1536
2.5 hour rough weather transit	1 DF generator & 1 DF M.E	160	2119	333	1666
1 hour transit	1 DF generator & 1 DF M.E	120	1651	105	524
10hour drifting\ anchor	1 DF generator	100	0	59	297
Daily fuel consumption (kgs.)				1803	9025

Table 3.16: Power and fuel data for winter day operation of the design option

The total consumption from the winter day and correspondingly for 13 winter weeks can therefore be calculated as seen in the table 3.17.

Total fuel consumption	diesel	methanol
Fuel consumption per week (tons)	11	51
Fuel consumption in 13 week (tons)	147	658

Table 3.17: Fuel consumption for winter weeks operation of the design option

Combining the operations in the winter and non winter seasons, the total annual consumption and carbon emission are obtained as :

	diesel	methanol
Annual consumption of fuel (in tons)	566	2431
Carbon factor for diesel	3.206	
Carbon factor for methanol		1.375
	diesel	methanol
Annual CO2 emissions (tons)	1813	3343
Total CO2 emission (tons)	5156	

Table 3.18: Annual fuel consumption and carbon emissions in the design option

**ANNUAL FUEL CONSUMPTION DISTRIBUTION
(Diesel vs Methanol)**

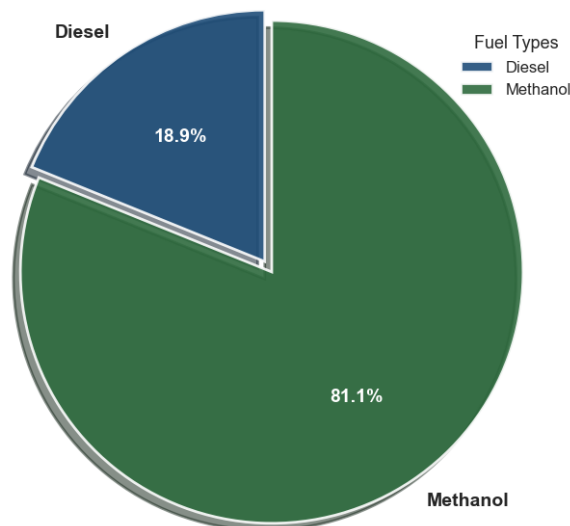


Fig 3.8: Representation of fuel consumption share in design option 3

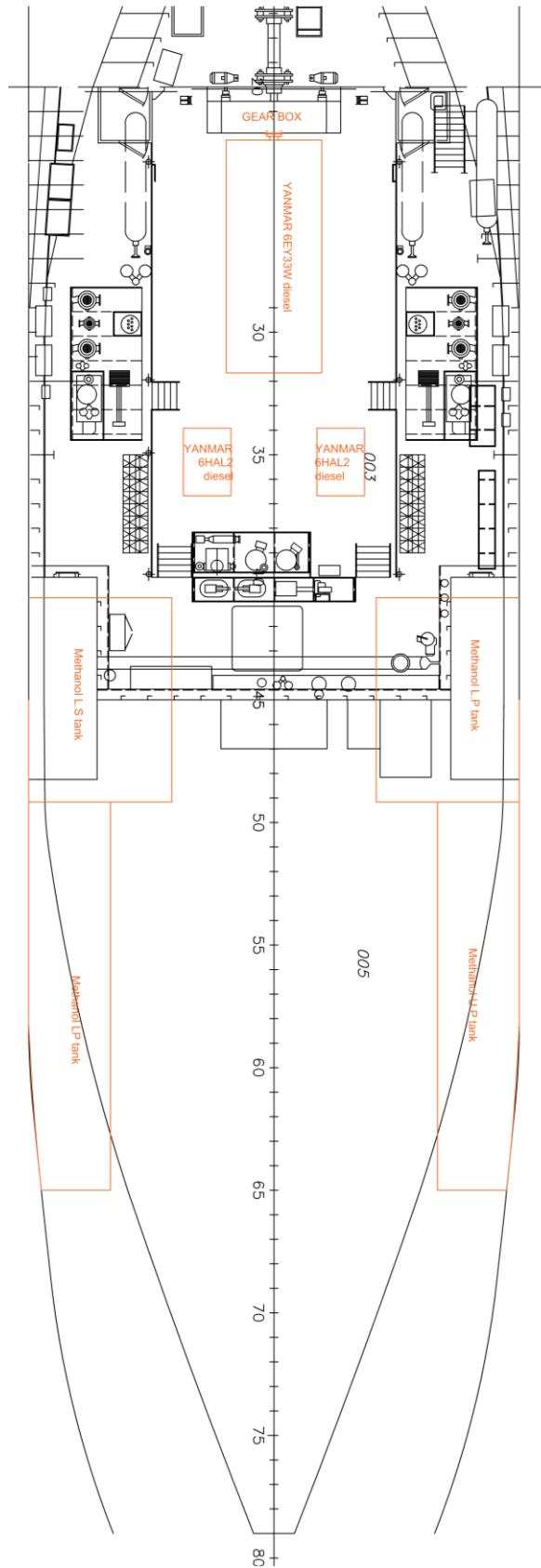


Fig 3.9: Allocation of space for machineries in the design option 3

3.4 Pilot 755 Design option 1

The pilot boat design option 1 is a hybrid design that incorporates an IC engine and as well as electric propulsion. The E machines can be connected to the same shaft from the IC engine and it can be disconnected from operation internally without physically removing them. It has a PTI/PTO option as well. The E- machines are powered by electric power stored in the battery compartment with 90 battery module holding 590.4kWh of charge capacity. The DC power stored in the batteries have to be converted to AC before supplying it to the E machines. This function is done by the frequency converters.

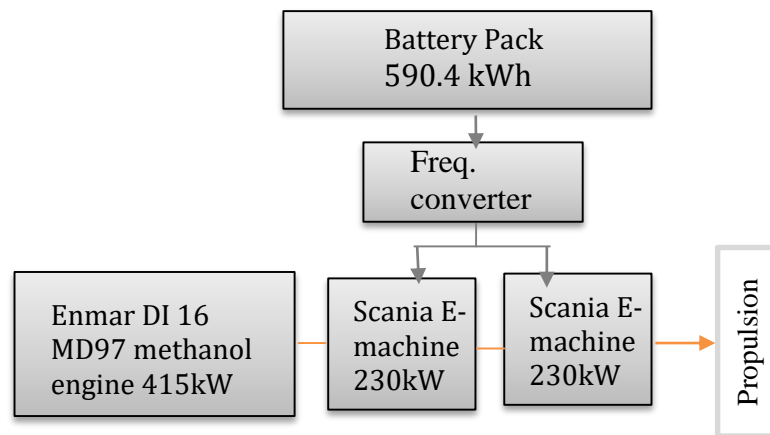


Fig 3.10: Block representation of the major machineries in the design option 1

The following are the machineries considered for this design option:

Enmar Engines DI 16 MD97 propulsion engine

Base engine manufacturer: Scania
Power output: 415W
Dimension: 1.9m x 1.3m x 1.6m
Weight : 1700kg



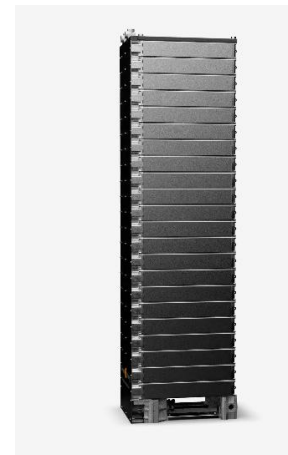
Scania E machine

Manufacturer: Scania
Power output: 230kW
Dimension: 0.49m x 0.61m x 0.59m
Weight: 250kg



Corvus Dolphin NxtGen ESS Power

Chemistry: Li-ion NCA
Energy : 6.56 kWh
C-rate: 1.5
Weight : 46.5kg
Dimension: 0.66m x 0.5m x 0.1m



90 modules would hold a charge capacity of 590.4kWh
(Net weight 4.18T)

Engine load	SFOC (g/kWh)
25%	456
50%	457
75%	461
100%	470

Table 3.19: SFC values for methanol propulsion engine

3.4.1 Non – winter operation

Non Winter day operation	Engines in operation	Total power output req. from engine per hour (kW)	Methanol consumption (kg)
1 hour transit at 15knt	1 methanol engine	202	92

Table 3.20: Methanol consumption for non winter day operation

As discussed in section 2.1.5, the operational profile defined for the pilot boat is said to have an operational duration of 3 hours. In this design option to gain the advantages of the hybrid installation the the methanol engines is proposed to be used in operation for the first 30 minutes while leaving the port and the final 30 minutes while returning to

port at the end of operation. This would split the operation of the engine to one third of the whole running and the battery would take up the two-third of the operation. The consumptions from the engine is listed in table 3.20.

And if the remaining two hours are powered by the batteries, the batteries would be supplying a total of 404.2kWh in 2 hours, is 68.46 % of the installed battery capacity. The battery can be charge back to full capacity in just over an hour with installed charging power of 440kW. But if the charging station is of 1MW rating, then the charging time can be reduced to just over 30 minutes which can accomodate the worst turn around situation obesevered from AIS data listed in table 2.3. Although 1MW charging station is bit tough to have, there are higher powered charging stations today as listed in Appendix B

3.4.2 Winter operation

Winter day operation	Engines in operation	Total power output req. from engine (kW)	Methanol consumption (kg)
1 hour transit at 15knt	1 methanol engine	225	103

Table 3.21: Methanol consumption for winter day operation

Splitting the operational profile mentioned in section 2.15, as explained above the consumptions from the engine in winter operation is listed in table 3.21.

And in this case too, if the remaining two hours are powered by the batteries, the batteries would be supplying a total of 449kWh in 2 hours, is 76 % of the installed battery capacity.

The battery can be charge back to full capacity in just over 70 minutes with installed charging power of 440kW. But if the charging station is of 1MW rating, then again the charging time can be reduced to just over 30 minutes which can accomodate the worst turn around situation obesevered from AIS data listed in table 2.3

So in total, based on the operational hours listed in table 2.4 from 2025 AIS data the following consumption and emission over a span on one year is calculated.

Projected fuel consumption annually (kg)	Kg	3470
Electricity consumed Annually (kWh)	kWh	15172
Carbon factor for methanol		1.375
Total CO2 emission (tons)	tons	4.8

Table 3.22: Total fuel consumption dnd electricity consumption in the design option

ANNUAL ENERGY/FUEL CONSUMPTION DISTRIBUTION

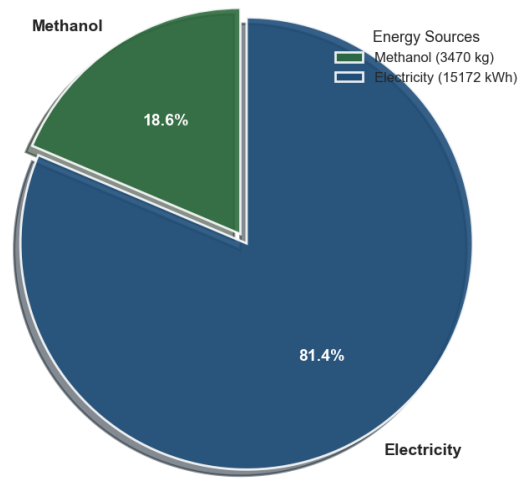


Fig 3.11: Representation of fuel consumption share

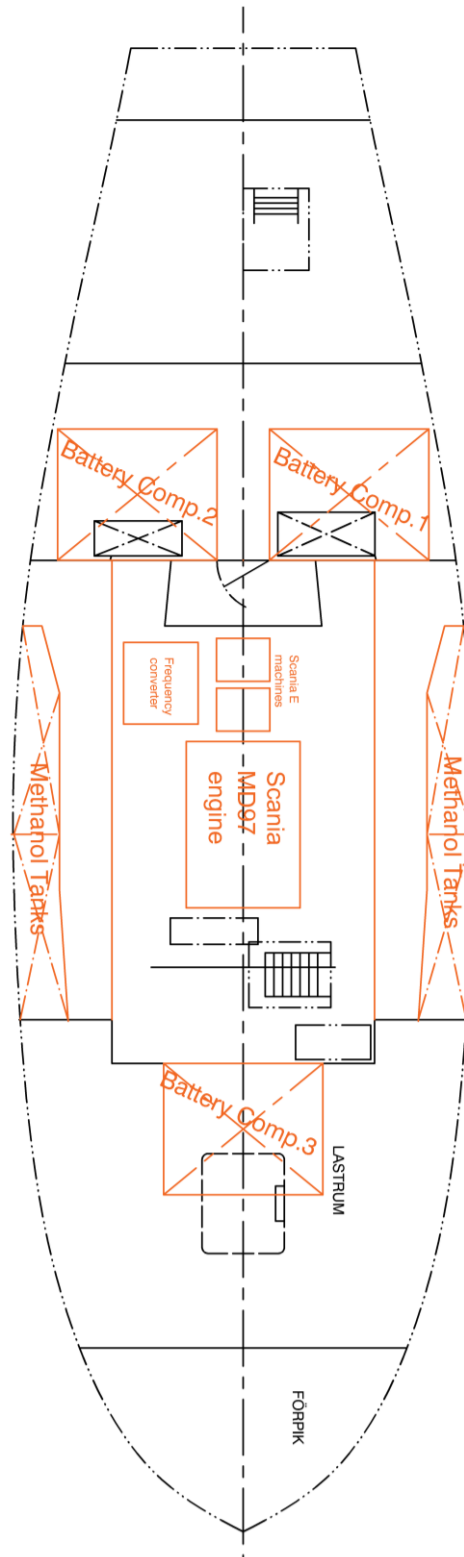


Fig 3.12: Allocation of space for machineries in the new design option 1

In this hybrid design option, the ballast water tank onboard is converted into battery compartments 1 and 2. Both these battery compartments are of dimension 1.5m x 1.82m x 0.9m. that would house 36 modules of batteries each. The battery compartment 3 is

designed with dimensions 1.5m x 1.82m x 0.5m which would house 18 battery modules. The methanol tanks are arranged on either side of the engine room below the water level with a cofferdam of 0.5m between the tank and the engine room at the closest point. The engine room consists of two Scania E machines and a fully methanol powered propulsion engine.

3.5 Pilot 755 Design option 2

This design option consists of two fully methanol powered MD97 propulsion engines to propel the boat. The auxiliary loads in the boat can be covered by the alternators built into the engines. Since they are completely powered by methanol, the emissions are significantly lower than the conventional diesel drivelines. The methanol powered engines would require additional equipments such as leakage sensors, additional filters etc.

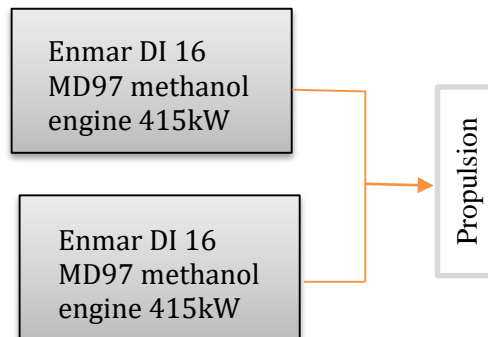


Fig : Block representation of the major machineries in the design option.

The following is the machine considered for this design option:

Enmar Engines MD97 propulsion engine

Base engine manufacturer: Scania
 Power output: 415W
 Dimension: 1.9m x 1.3m x 1.6m
 Weight : 1700kg



Engine load	SFOC (g/kWh)
25%	456
50%	457
75%	461

100%	470
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Table 3.23: SFC values for methanol propulsion engine

3.5.1 Non – winter operation

Non Winter day operation	Engines in operation	Total power output req. from engine per hour (kW)	Total Methanol consumption (kg)
3 hour transit at 15knots	1 methanol engine	202	277

Table 3.24: Methanol consumption for non winter day operation

In this design option the methanol engine is responsible for the propulsion of the engine at all times. However, only one engine is needed to be operated for normal operation defined in section 2.1.5.

3.5.2 Winter operation

Winter day operation	Engines in operation	Total power output req. from gensets (kW)	Methanol consumption (kg)
3 hour transit at 15knt	1 methanol engine	225	308

Table 3.25: Methanol consumption for winter day operation

Once again , the methanol engine provides the necessary power for the winter operation as well.

So in total, based on the operational hours listed in table 2.4 from 2025 AIS data:

Projected fuel consumption annually (kg)	10411
Carbon factor for methanol	1.375
Total CO2 emission (tons)	145

Table 3.26: Total fuel consumption and electricity consumption in the design option

ANNUAL FUEL CONSUMPTION DISTRIBUTION
(100% Methanol)

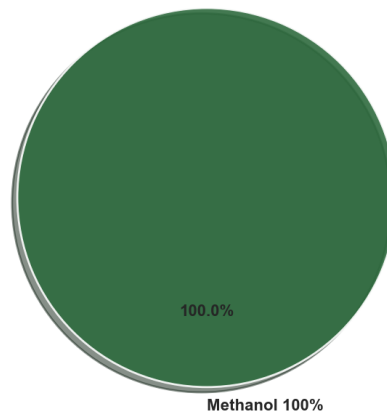


Fig 3.13: Representation of fuel consumption share

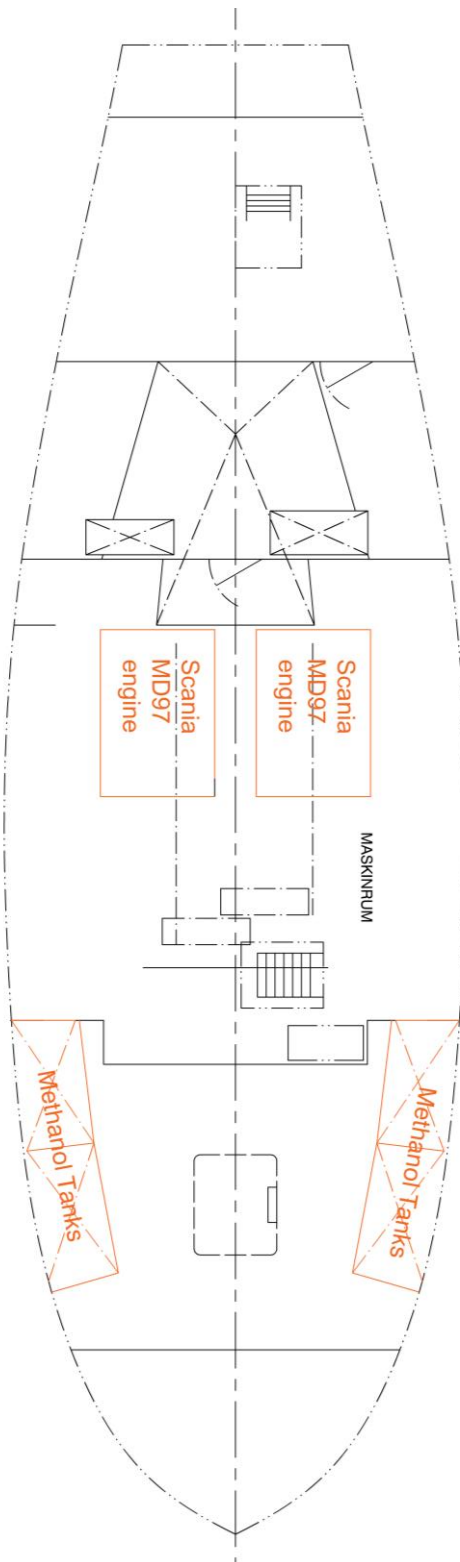


Fig 3.14: Allocation of space for machineries in the new design option 2

In this design option, the methanol tanks are arranged outside the machinery space and below the water line. The engine room has two fully methanol powered engines.

3.6 Pilot 755 Design option 3

This design option consists of two AC electric motors powered from the stored electric power from batteries. It is a fully electric option for the boat. The battery packs are divided into three compartments as can be seen in fig. 3.16. The battery power stored in DC is converted to AC through the frequency converters before it is fed to the electric motors for propulsion

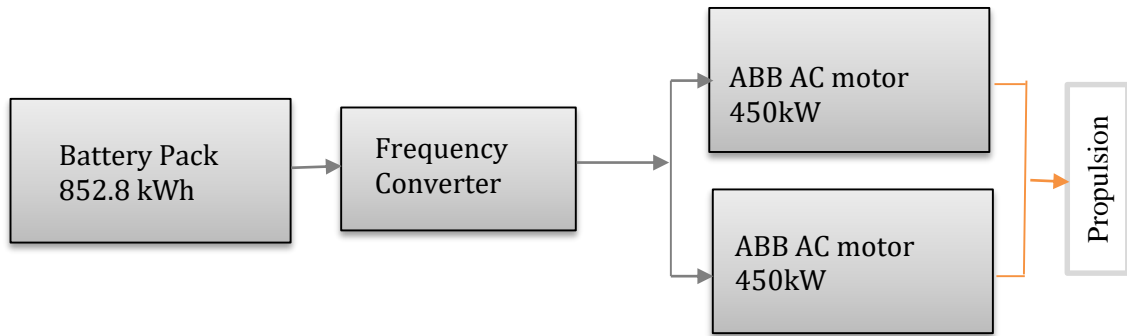


Fig 3.15: Block representation of the major machineries in the design option.

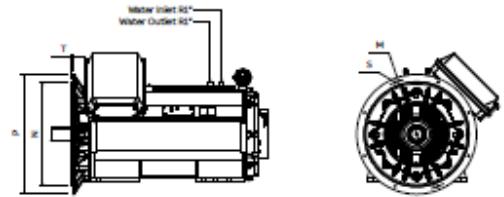
The following are the machineries considered for this design option:

ABB AC motor

Water cooled

Power rating 450kW,
efficiency 97.5%, 2180kg

Dimension: 2.241m x 1.120m x 1.120m



Corvus Dolphin NxtGen ESS Power

Chemistry: Li-ion NCA

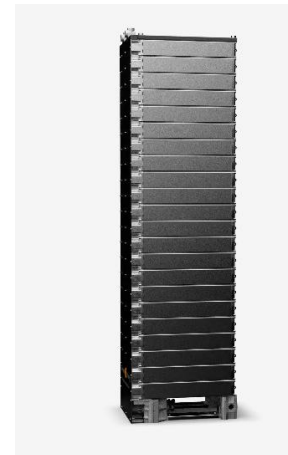
Energy : 6.56 kWh

C-rate: 1.5

Weight : 46.5kg

Dimension: 0.66m x 0.5m x 0.1m

130 modules would hold a charge capacity of 852.8 kWh
(Net weight 6.04T)



3.6.1 Non – winter operation

In non- winter conditions as discussed in section 2.1.5, the vessel has a power demand of 195kWh which adds upto 585 kWh that in turn is 68.5% of the installed battery capacity. The charging time for this would be slightly less than 1.5 hours with a charging station capacity of 440kW. However it will reduce to around 40 mins if the charging station is 1MW rated.

3.6.2 Winter operation

In winter conditions, the vessel has a power demand of 216kWh which adds upto 649 kWh that in turn is 76.1% of the installed battery capacity. The charging time for this would be little over 1.5 hours with a charging station capacity of 440kW. However it will reduce to around 45 mins if the charging station is 1MW rated.

So, the total electric power consumed through the battery, annually = 21964 kW.

In this fully electric design option, the ballast water tank onboard is converted into battery compartments 1 and 2. Both these battery compartments are of dimension 1.5m x 1.82m x 1.1m. that would house 44 modules of batteries each. The battery compartment 3 is designed with dimensions 1.5m x 1.82m x 1.1m which would house 42 battery modules. The engine room will house the electric motors and the frequency converter.

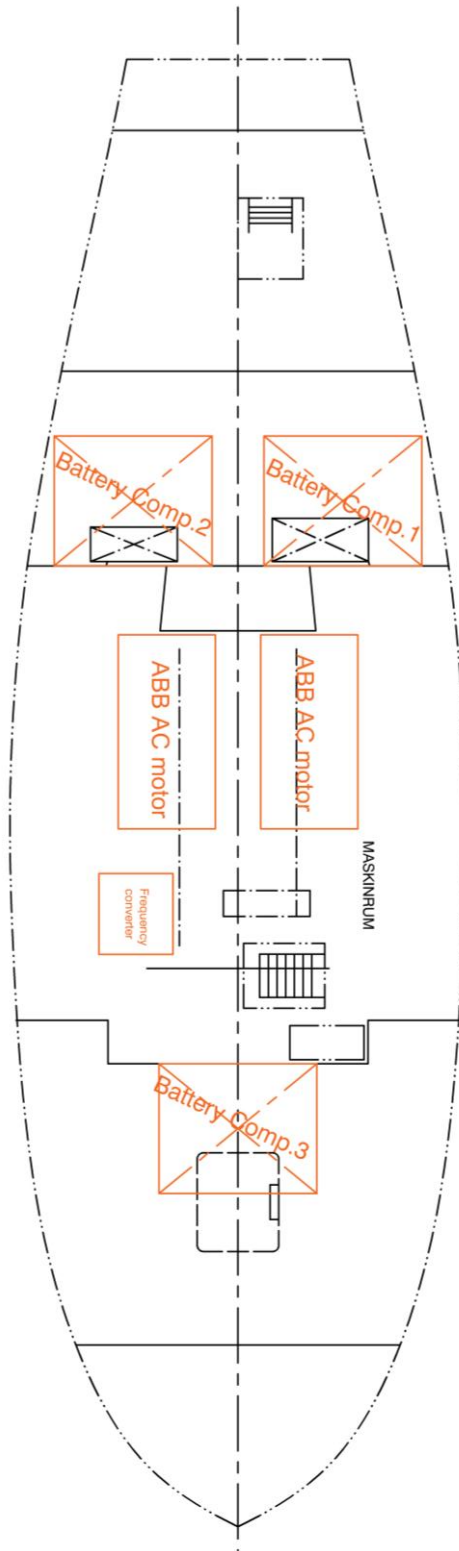


Fig 3.16: Allocation of space for machineries in the new design option 3

4 Results and Discussion

4.1 Hydrostatic analysis of the Baltica initially

Now, for the design option 3 of the Baltica, the intact hydrostatic analysis was carried out. For this purpose a similar hull was modelled with main dimensions, displacement and approximate hull shape matching the existing vessel.

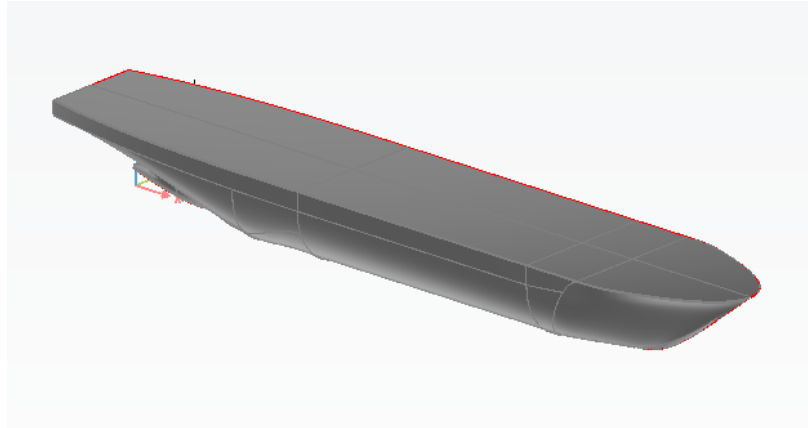


Fig 4.1: Model hull generated for hydrostatic analysis

The hull model as seen in fig. 4.1 was generated using Caeses software and the same was used for stability analysis in the Maxsurf Stability software. The upright hydrostatics, large angle stability and equilibrium analysis were carried out for the initial vessel modelled with the existing general arrangement of the vessel [Appendix C] as well as the three design options considered. For the analysis weights were assumed for each component in the engine room and the tanks were modelled same as it is arranged in the GA drawing. The engine room was divided into various sections to apply the weight acting different parts. All tanks were assumed to be filled by 50% for the loadcase.

The weight of the existing two main engines assumed: 32 tons combined.

The weight of the existing four genset assumed: 14 tons combined.

The arrangement of tanks and loads for the design option 1 is listed in table 4.1 below.

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m ³	Total Volume m ³	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m
Lightship	1	1170,000	1170,000			24,226	0,000	1,943	0,000
1CooingWaterTank	50%	102,460	51,230	99,961	49,980	3,374	0,000	3,088	256,250
5TorrTankP	50%	13,610	6,805	15,644	7,822	19,841	1,832	0,352	16,704
6TorrTankP	50%	13,610	6,805	15,644	7,822	19,841	-1,832	0,352	16,704
7SludgeTank	50%	9,819	4,909	11,286	5,643	22,202	-2,312	0,587	12,816
13BlackWaterTank	50%	11,286	5,643	11,286	5,643	22,202	2,312	0,587	14,731
8BilgeWaterTank	50%	11,383	5,691	11,383	5,691	23,401	-2,336	0,578	14,731
12GreyWaterTank	50%	11,383	5,691	11,383	5,691	23,401	2,336	0,578	14,731
22HealingTank(P)	50%	25,503	12,752	24,881	12,441	26,400	-4,391	2,750	2,317
23HealingTank(S)	50%	25,503	12,752	24,881	12,441	26,400	4,391	2,750	2,317
19BR.OilTank	50%	28,852	14,426	33,944	16,972	26,990	-3,395	0,623	15,015
20BR.OilTank	50%	39,538	19,769	46,515	23,258	27,000	0,000	0,501	27,200
21BR.OilTank	50%	28,852	14,426	33,944	16,972	26,990	3,395	0,623	15,015
24BWT	50%	33,854	16,927	33,028	16,514	32,982	-3,236	0,771	20,663
25BWT	50%	56,176	28,088	54,806	27,403	33,526	0,000	0,527	39,360
26BWT	50%	33,854	16,927	33,028	16,514	32,982	3,236	0,771	20,663

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m ³	Total Volume m ³	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m
27FreshWaterTank	50%	15,230	7,615	15,230	7,615	38,507	-1,280	0,800	20,118
28FreshWaterTank	50%	15,230	7,615	15,230	7,615	38,507	1,280	0,800	20,118
31BWT	50%	29,288	14,644	28,574	14,287	45,604	-0,994	2,288	25,374
32BWT	50%	29,288	14,644	28,574	14,287	45,604	0,994	2,288	25,374
ERsec1	1	1,000	1,000			21,000	4,400	3,000	0,000
ERsec2	1	1,000	1,000			21,000	-4,400	3,000	0,000
ERsec3	1	1,000	1,000			16,200	0,000	1,000	0,000
ERsec4	1	4,000	4,000			11,500	0,000	1,000	0,000
ERsec5	1	1,000	1,000			7,300	-5,000	1,000	0,000
ERsec6	1	1,000	1,000			11,500	-5,000	1,000	0,000
ERsec7	1	1,000	1,000			7,300	5,000	1,000	0,000
ERsec8	1	1,000	1,000			11,500	5,000	1,000	0,000
ERsec9	1	3,000	3,000			7,300	4,200	1,000	0,000
ERsec10	1	3,000	3,000			7,300	-4,200	1,000	0,000
ERsec11	1	40,000	40,000			8,000	0,000	1,800	0,000
ERsec12	1	7,000	7,000			11,500	4,400	1,500	0,000
ERsec13	1	7,000	7,000			11,500	-4,400	1,500	0,000
Total Loadcase			1508,360	549,222	274,611	23,814	0,001	1,844	580,203
FS correction								0,385	
VCG fluid								2,229	

Table 4.1: arrangement of tanks and loads for the Baltica initially

The results from the analysis carried out for the initial vessel are shown below

Draft Amidships m	3,888
Displacement t	1508
Heel deg	0,0
Draft at FP m	3,592
Draft at AP m	4,185
Draft at LCF m	3,911
Trim (+ve by stern) m	0,593
WL Length m	54,772
KB m	2,269
KG fluid m	2,229
BMt m	2,990
BML m	68,289
GMt corrected m	3,030
KMt m	5,258
KML m	70,553
Immersion (TPc) tonne/cm	5,194
MTc tonne.m	20,613
RM at 1deg = GMt.Disp.sin(1) tonne.m	79,760
Max deck inclination deg	0,6799
Trim angle (+ve by stern) deg	0,6799

Table 4.2: Equilibrium characteristics of the Baltica initially

4.2 Comparison of the design options considered for the Baltica

This chapter focuses on the comparison of operational costs involved in terms of fuel consumption, fuel costs and the EU ETS taxation for CO₂ emissions [11].

For the purpose of this study, [11] the emission taxation for CO₂ is valued at 85 EUR per tonnes. The estimated costs of methanol and diesel are considered to be 850EUR

and 750EUR respectively for the study. However, over the years, it can be seen that this cost keeps climbing over time and is expected to maintain the same trend.

4.2.1 Baltica Design option 1

Operational Cost analysis

Annual expense for diesel	332 637	EUR
Annual expense for methanol	2 243 484	EUR
Annual expense for CO2	437 975	EUR

Table 4.3: Operational costs involved for fuel and emission in design option 1

The total expenses in the operational expenditure adds upto €3014096 upon summing the the above listed expenses.

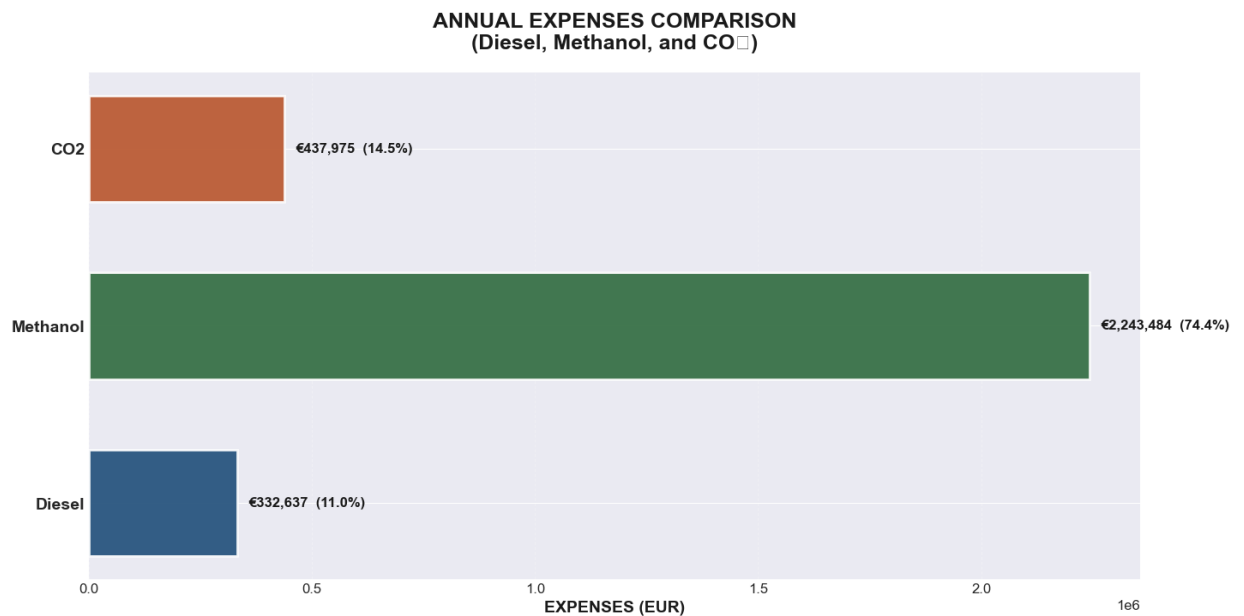


Fig 4.2: Representation of operational costs involved for fuel and emission in design option 1

Weight analysis

The weight of the machinery were changed from the initially assumed values with the new machinery weights as mentined in section 3.1. This design option requires approximately 53 tons of methanol and 9tons of diesel for a week’s uninterrupted operation. The tanks 19.BR.OilTank and 21.BR.OilTank from the initial GA were replaced with Methanol LP tank and Methanol LS with a cofferdam space of 0.5m from the adjacent tanks. Additionally two methanol tanks Methanol UP tank and Methanol US tank were introduced. An added steel weight of 8 tonnes was considered for the two new tanks.

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m ³	Total Volume m ³	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m
Lightship	1	1179,000	1179,000			24,226	0,000	1,943	0,000

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m ³	Total Volume m ³	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m
1CooingWaterTank	50%	102,460	51,230	99,961	49,980	3,374	0,000	3,088	256,250
5TorrTankP	50%	13,610	6,805	15,644	7,822	19,841	1,832	0,352	16,704
6TorrTankP	50%	13,610	6,805	15,644	7,822	19,841	-1,832	0,352	16,704
7SludgeTank	50%	9,819	4,909	11,286	5,643	22,202	-2,312	0,587	12,816
13BlackWaterTank	50%	11,286	5,643	11,286	5,643	22,202	2,312	0,587	14,731
8BilgeWaterTank	50%	11,383	5,691	11,383	5,691	23,401	-2,336	0,578	14,731
12GreyWaterTank	50%	11,383	5,691	11,383	5,691	23,401	2,336	0,578	14,731
22HealingTank(P)	50%	21,253	10,626	20,734	10,367	26,400	-4,391	3,125	2,317
23HealingTank(S)	50%	21,253	10,626	20,734	10,367	26,400	4,391	3,125	2,317
Methanol LP tank	50%	18,573	9,287	23,511	11,755	26,993	-3,665	0,645	7,082
20BR.OilTank	50%	39,538	19,769	46,515	23,258	27,000	0,000	0,501	27,200
Methanol LS tank	50%	18,573	9,287	23,511	11,755	26,993	3,665	0,645	7,082
24BWT	50%	33,854	16,927	33,028	16,514	32,982	-3,236	0,771	20,663
25BWT	50%	56,176	28,088	54,806	27,403	33,526	0,000	0,527	39,360
26BWT	50%	33,854	16,927	33,028	16,514	32,982	3,236	0,771	20,663
27FreshWaterTank	50%	15,230	7,615	15,230	7,615	38,507	-1,280	0,800	20,118
28FreshWaterTank	50%	15,230	7,615	15,230	7,615	38,507	1,280	0,800	20,118
31BWT	50%	29,288	14,644	28,574	14,287	45,604	-0,994	2,288	25,374
32BWT	50%	29,288	14,644	28,574	14,287	45,604	0,994	2,288	25,374
ERsec1	1	1,000	1,000			21,000	4,400	3,000	0,000
ERsec2	1	1,000	1,000			21,000	-4,400	3,000	0,000
ERsec3	1	1,000	1,000			16,200	0,000	1,000	0,000
ERsec4	1	6,500	6,500			11,500	0,000	1,000	0,000
ERsec5	1	1,000	1,000			7,300	-5,000	1,000	0,000
ERsec6	1	1,000	1,000			11,500	-5,000	1,000	0,000
ERsec7	1	1,000	1,000			7,300	5,000	1,000	0,000
ERsec8	1	1,000	1,000			11,500	5,000	1,000	0,000
ERsec9	1	3,000	3,000			7,300	4,200	1,000	0,000
ERsec10	1	3,000	3,000			7,300	-4,200	1,000	0,000
ERsec11	1	15,000	15,000			8,000	0,000	1,800	0,000
ERsec12	1	18,500	18,500			11,500	4,400	1,500	0,000
ERsec13	1	18,500	18,500			11,500	-4,400	1,500	0,000
Methanol UP tank	70%	19,335	13,535	24,475	17,133	34,215	-4,384	3,029	3,535
Methanol US tank	70%	19,335	13,535	24,475	17,133	34,215	4,384	3,029	3,535
Total Loadcase			1529,401	569,013	294,296	24,024	0,001	1,870	571,407
FS correction								0,376	
VCG fluid								2,246	

Table 4.4: arrangement of tanks and loads for the Baltica design option 1

In this case it can be seen that the displacement has increased to 1529T compared to the 1508T in the initial case with 50% loading.

Draft Amidships m	3,919
Displacement t	1521
Heel deg	0,0
Draft at FP m	3,701
Draft at AP m	4,137
Draft at LCF m	3,935
Trim (+ve by stern) m	0,436
WL Length m	54,848
KB m	2,281
KG fluid m	2,246
BMt m	2,979
BML m	68,673
GMt corrected m	3,013
GML m	68,708
KMt m	5,259

KML m	70,951
Immersion (TPc) tonne/cm	5,219
MTc tonne.m	20,906
RM at 1deg = GMt.Disp.sin(1) tonne.m	80,007
Max deck inclination deg	0,4994
Trim angle (+ve by stern) deg	0,4994

Table 4.5: Equilibrium characteristics of the Baltica design option 1

4.2.2 Baltica Design option 2

Operational Cost analysis

Annual expense for diesel	292 543	EUR
Annual expense for methanol	2 346 262	EUR
Annual expense for CO2	436 498	EUR

Table 4.6: Operational costs involved for fuel and emission in design option 2

The total expenses in the operational expenditure from consumptions and emissions adds upto €3075304 upon summing the the above listed expenses, and turns out to be the highest among the three.

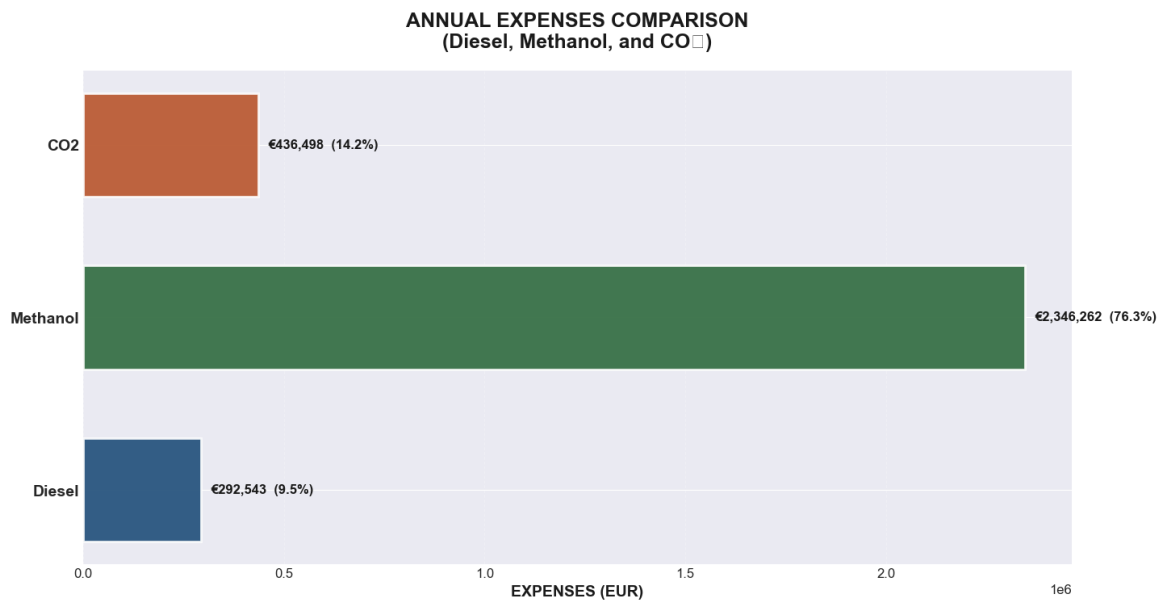


Fig 4.3: Representaion of operational costs involved for fuel and emission in design option 2

Weight analysis

The weight of the machinery were changed from the initially assumed values with the new machinery weights as mentined in section 3.2. This design option requires approximately 56 tons of methanol and 9tons of diesel for a week's uninterrupted operation. The tanks 19.BR.OilTank and 21.BR.OilTank from the initial GA were replaced with Methanol LP tank and Methanol LS with a cofferdam space of 0.5m from the adjacent tanks. Additionally two methanol tanks Methanol UP tank and Methanol US tank were introduced and considered to be filled by 70%. An added steel weight of 8 tonnes was considered for the two new tanks.

A battery weight of 28.02T was also considered, which was arranged into 5 rows. Each row is designed to have 12 modules arranged transversally and 10 modules stacked vertically. A longitudinal distance of 1m is left between these rows for inspection and maintenance.

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m ³	Total Volume m ³	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m
Lightship	1	1178,000	1178,000			24,226	0,000	1,943	0,000
1CooingWaterTank	50%	102,460	51,230	99,961	49,980	3,374	0,000	3,088	256,250
5TorrTankP	50%	13,610	6,805	15,644	7,822	19,841	1,832	0,352	16,704
6TorrTankP	50%	13,610	6,805	15,644	7,822	19,841	-1,832	0,352	16,704
7SludgeTank	50%	9,819	4,909	11,286	5,643	22,202	-2,312	0,587	12,816
13BlackWaterTank	50%	11,286	5,643	11,286	5,643	22,202	2,312	0,587	14,731
8BilgeWaterTank	50%	11,383	5,691	11,383	5,691	23,401	-2,336	0,578	14,731
12GreyWaterTank	50%	11,383	5,691	11,383	5,691	23,401	2,336	0,578	14,731
22HealingTank(P)	50%	21,253	10,626	20,734	10,367	26,400	-4,391	3,125	2,317
23HealingTank(S)	50%	21,253	10,626	20,734	10,367	26,400	4,391	3,125	2,317
Methanol LP tank	50%	18,573	9,287	23,511	11,755	26,993	-3,665	0,645	7,082
20BR.OilTank	50%	39,538	19,769	46,515	23,258	27,000	0,000	0,501	27,200
Methanol LS tank	50%	18,573	9,287	23,511	11,755	26,993	3,665	0,645	7,082
24BWT	50%	33,854	16,927	33,028	16,514	32,982	-3,236	0,771	20,663
25BWT	50%	56,176	28,088	54,806	27,403	33,526	0,000	0,527	39,360
26BWT	50%	33,854	16,927	33,028	16,514	32,982	3,236	0,771	20,663
27FreshWaterTank	50%	15,230	7,615	15,230	7,615	38,507	-1,280	0,800	20,118
28FreshWaterTank	50%	15,230	7,615	15,230	7,615	38,507	1,280	0,800	20,118
31BWT	50%	29,288	14,644	28,574	14,287	45,604	-0,994	2,288	25,374
32BWT	50%	29,288	14,644	28,574	14,287	45,604	0,994	2,288	25,374
ERsec1	1	1,000	1,000			21,000	4,400	3,000	0,000
ERsec2	1	1,000	1,000			21,000	-4,400	3,000	0,000
ERsec3	1	1,000	1,000			16,200	0,000	1,000	0,000
ERsec4	1	4,000	4,000			11,500	0,000	1,000	0,000
ERsec5	1	1,000	1,000			7,300	-5,000	1,000	0,000
ERsec6	1	1,000	1,000			11,500	-5,000	1,000	0,000
ERsec7	1	1,000	1,000			7,300	5,000	1,000	0,000
ERsec8	1	1,000	1,000			11,500	5,000	1,000	0,000
ERsec9	1	3,000	3,000			7,300	4,200	1,000	0,000
ERsec10	1	3,000	3,000			7,300	-4,200	1,000	0,000
ERsec11	1	29,600	29,600			8,000	0,000	1,800	0,000
ERsec12	1	2,700	2,700			11,500	4,400	1,500	0,000
ERsec13	1	3,500	3,500			11,500	-4,400	1,500	0,000
Batterycompartment	1	28,020	28,020			27,000	0,000	3,000	0,000
Methanol UP tank	70%	19,335	13,535	24,475	17,133	34,215	-4,384	3,029	3,535
Methanol US tank	70%	19,335	13,535	24,475	17,133	34,215	4,384	3,029	3,535
Total Loadcase			1538,721	569,013	294,296	24,198	-0,001	1,899	571,407
FS correction								0,373	
VCG fluid								2,272	

Table 4.7: arrangement of tanks and loads for the Baltica design option 2

In this case it can be seen that the displacement has increased to 1539T compared to the 1508T in the initial case.

Draft Amidships m	3,942
Displacement t	1531
Heel deg	0,0
Draft at FP m	3,788
Draft at AP m	4,095
Draft at LCF m	3,952
Trim (+ve by stern) m	0,306
WL Length m	54,911
KB m	2,289
KG fluid m	2,272

BMt m	2,972
BML m	69,048
GMt corrected m	2,989
GML m	69,064
KMt m	5,261
KML m	71,336
Immersion (TPc) tonne/cm	5,240
MTc tonne.m	21,144
RM at 1deg = GMt.Disp.sin(1) tonne.m	79,843
Max deck inclination deg	0,3507
Trim angle (+ve by stern) deg	0,3507

Table 4.8: Equilibrium characteristics of the Baltica design option 2

4.2.3 Baltica Design option 3

Operational Cost analysis

Annual expense for diesel	395 916	EUR
Annual expense for methanol	2 066 583	EUR
Annual expense for CO2	438 285	EUR

Table 4.9: Operational costs involved for fuel and emission in design option 3

In this design option the total expenses in the operational part adds upto €2900785 upon summing the the above listed expenses, which turns out to be the least among the three design options in consideration.

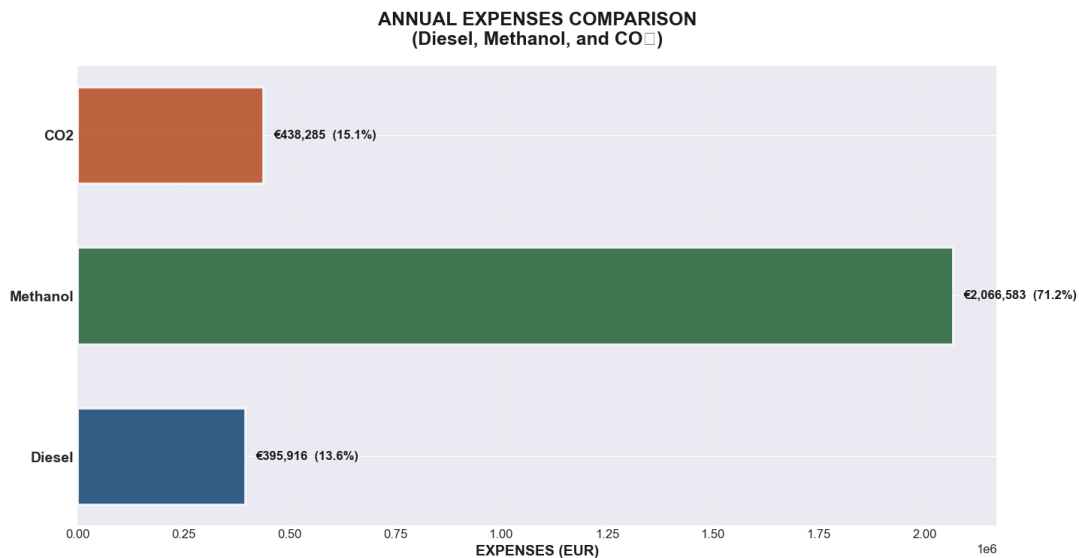


Fig 4.4: Representaion of operational costs involved for fuel and emission in design option 3

Weight analysis

The weight of the machinery were changed from the initially assumed values with the new machinery weights as mentined in section 3.3. This design option requires approximately 51 tons of methanol and 11 tons of diesel for a week’s uninterrupted operation. The tanks 19.BR.OilTank and 21.BR.OilTank from the initial GA were replaced with Methanol LP tank and Methanol LS with a cofferdam space of 0.5m from the adjacent tanks. Additionally two methanol tanks Methanol UP tank and Methanol

US tank were introduced and considered to be filled by 70%. An added steel weight of 8 tonnes was considered for the two new tanks.

Item Name	Quantity	Unit Mass tonne	Total Mass tonne	Unit Volume m ³	Total Volume m ³	Long. Arm m	Trans. Arm m	Vert. Arm m	Total FSM tonne.m
Lightship	1	1178,000	1178,000			24,226	0,000	1,943	0,000
1CooingWaterTank	50%	102,460	51,230	99,961	49,980	3,374	0,000	3,088	256,250
5TorrTankP	50%	13,610	6,805	15,644	7,822	19,841	1,832	0,352	16,704
6TorrTankP	50%	13,610	6,805	15,644	7,822	19,841	-1,832	0,352	16,704
7SludgeTank	50%	9,819	4,909	11,286	5,643	22,202	-2,312	0,587	12,816
13BlackWaterTank	50%	11,286	5,643	11,286	5,643	22,202	2,312	0,587	14,731
8BilgeWaterTank	50%	11,383	5,691	11,383	5,691	23,401	-2,336	0,578	14,731
12GreyWaterTank	50%	11,383	5,691	11,383	5,691	23,401	2,336	0,578	14,731
22HealingTank(P)	50%	21,253	10,626	20,734	10,367	26,400	-4,391	3,125	2,317
23HealingTank(S)	50%	21,253	10,626	20,734	10,367	26,400	4,391	3,125	2,317
Methanol LP tank	50%	18,573	9,287	23,511	11,755	26,993	-3,665	0,645	7,082
20BR.OilTank	50%	39,538	19,769	46,515	23,258	27,000	0,000	0,501	27,200
Methanol LS tank	50%	18,573	9,287	23,511	11,755	26,993	3,665	0,645	7,082
24BWT	50%	33,854	16,927	33,028	16,514	32,982	-3,236	0,771	20,663
25BWT	50%	56,176	28,088	54,806	27,403	33,526	0,000	0,527	39,360
26BWT	50%	33,854	16,927	33,028	16,514	32,982	3,236	0,771	20,663
27FreshWaterTank	50%	15,230	7,615	15,230	7,615	38,507	-1,280	0,800	20,118
28FreshWaterTank	50%	15,230	7,615	15,230	7,615	38,507	1,280	0,800	20,118
31BWT	50%	29,288	14,644	28,574	14,287	45,604	-0,994	2,288	25,374
32BWT	50%	29,288	14,644	28,574	14,287	45,604	0,994	2,288	25,374
ERsec1	1	1,000	1,000			21,000	4,400	3,000	0,000
ERsec2	1	1,000	1,000			21,000	-4,400	3,000	0,000
ERsec3	1	1,000	1,000			16,200	0,000	1,000	0,000
ERsec4	1	3,000	3,000			11,500	0,000	1,000	0,000
ERsec5	1	1,000	1,000			7,300	-5,000	1,000	0,000
ERsec6	1	1,000	1,000			11,500	-5,000	1,000	0,000
ERsec7	1	1,000	1,000			7,300	5,000	1,000	0,000
ERsec8	1	1,000	1,000			11,500	5,000	1,000	0,000
ERsec9	1	3,000	3,000			7,300	4,200	1,000	0,000
ERsec10	1	3,000	3,000			7,300	-4,200	1,000	0,000
ERsec11	1	38,800	38,800			8,000	0,000	1,800	0,000
ERsec12	1	1,000	1,000			11,500	4,400	1,500	0,000
ERsec13	1	1,000	1,000			11,500	-4,400	1,500	0,000
Methanol UP tank	70%	19,335	13,535	24,475	17,133	34,215	-4,384	3,029	3,535
Methanol US tank	70%	19,335	13,535	24,475	17,133	34,215	4,384	3,029	3,535
Total Loadcase			1514,701	569,013	294,296	24,091	0,001	1,880	571,407
FS correction								0,379	
VCG fluid								2,259	

Table 4.10: arrangement of tanks and loads for the Baltica design option 3

In this case it can be seen that the displacement has increased to 1514T compared to the 1508T in the initial case.

Draft Amidships m	3,893
Displacement t	1507
Heel deg	0,0
Draft at FP m	3,696
Draft at AP m	4,089
Draft at LCF m	3,907
Trim (+ve by stern) m	0,393
WL Length m	54,840
KB m	2,264
KG fluid m	2,259
BMt m	3,004
BML m	69,242
GMt corrected m	3,009
GML m	69,247
KMt m	5,268
KML m	71,504
Immersion (TPc) tonne/cm	5,216

MTC tonne.m	20,867
RM at 1deg = GMt.Disp.sin(1) tonne.m	79,132
Max deck inclination deg	0,4506
Trim angle (+ve by stern) deg	0,4506

Table 4.11: Equilibrium characteristics of the Baltica design option 3

4.2.4 In summary

Design	Displacement (T)	GM (m)	Operational cost (€)
Initial	1 508	3.030	
Design option 1	1 529	3.013	3 014 095
Design option 2	1 538	2.989	3 075 303
Design option 3	1 515	3.009	2 900 785

Table 4.12: Comparison between the three design options for Baltica

- The effect of added weights is not very significant for a vessel of this size and installed power. The differences in displacement and the metacentric heights for the hydrostatic analysis tells a similar story.
- From the comparison of the the operational costs involved in the these three design options, it can be observed that the third design option is the most cost efficient.
- The third achitecture is also the simplest when looking at a point of view of a shift from the conventional driveline.
- The third design option might also probably be the most coefficient in terms of initial investment as the number of new and additional equipments necessary are not many, when compared to a conventional driveline.
- This design option also cuts down on the CO₂ emissions significantly and the difference between the other two are not very wide either

4.3 Comparison of the design options considered for Pilot 755

The present engine onboard the pilot boat is 2 x Scania DSI 11 engines

The assumed weight of the current engine onboard the pilot boat 2 x 1.3ton

As a rule of thumb, the steel weight \approx tank volume \times steel factor, for smaller vessels, the steel factor is taken as 80kg/m³.

For the purpose of this study the price per unit kWh of electricity is assumed as € 0.18

4.3.1 Pilot 755 Design option 1

Operational Cost analysis

Annual expense for methanol	2 950	EUR
Annual expense for electricity	2 731	EUR
Annual expense for CO2	406	EUR

Table 4.13: Operational costs involved for fuel and emission in design option 1

The total annual operational expenditure adds upto €6086 upon summing the the above listed expenses for this design option

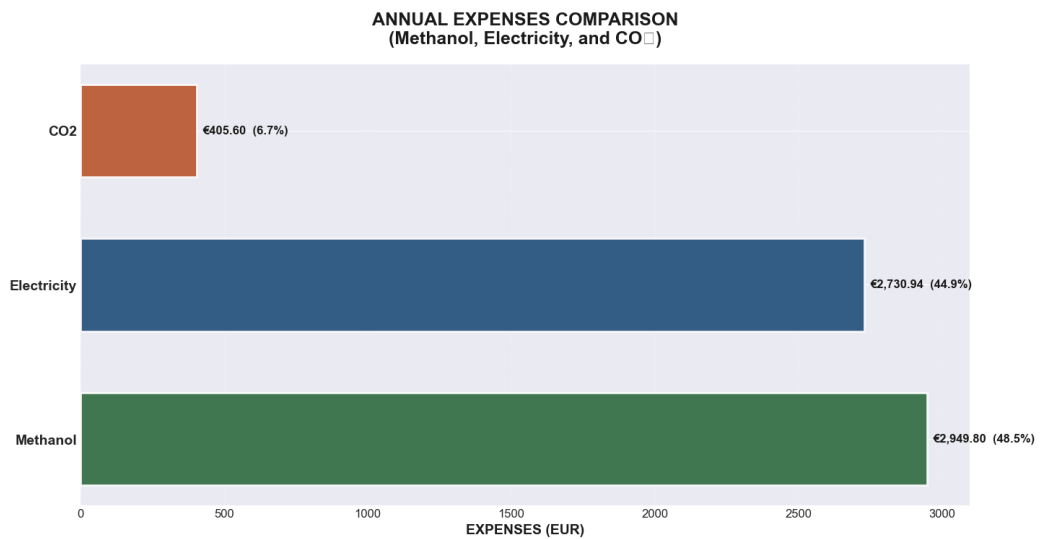


Fig 4.5: Representaion of operational costs involved for fuel, electricity and emission in design option 1

Weight analysis

<u>Item removed</u>	<u>Weight reduced</u>
2 x propulsion engine Scania DSI 11	2.6 tons
Ballast tank (4m ³) steel	0.32 tons
Diesel tanks (5.5m ³)	0.44tons
Diesel weight	4.21tons
<u>Item added</u>	<u>Weight increased</u>
1x propulsion engine Enmar engines MD97 methanol engine	1.7 tons
2 x Scania E machines	0.5 tons
Battery compartment 1 (2.4 m ³)	0.19 tons
Battery compartment 2 (2.4 m ³)	0.19 tons
Battery compartment 3 (1.3 m ³)	0.1 tons
Battery modules	4.1 tons
2 x Methanol tank steel (5.9 m ³)	0.9 tons
Methanol weight	4.21tons
Frequency converter	1.5 tons
Net weight added	5.82 tons

Table 4.14:Weight analysis for pilot boat design option 1

4.3.2 Pilot 755 Design option 2

Operational cost analysis

Annual expense for methanol	8849	EUR
Annual expense for CO2	1217	EUR

Table 4.15: Operational costs involved for fuel and emission in design option 2

The total annual operational expenditure adds upto €10066 upon summing the the above listed expenses for design option 2.

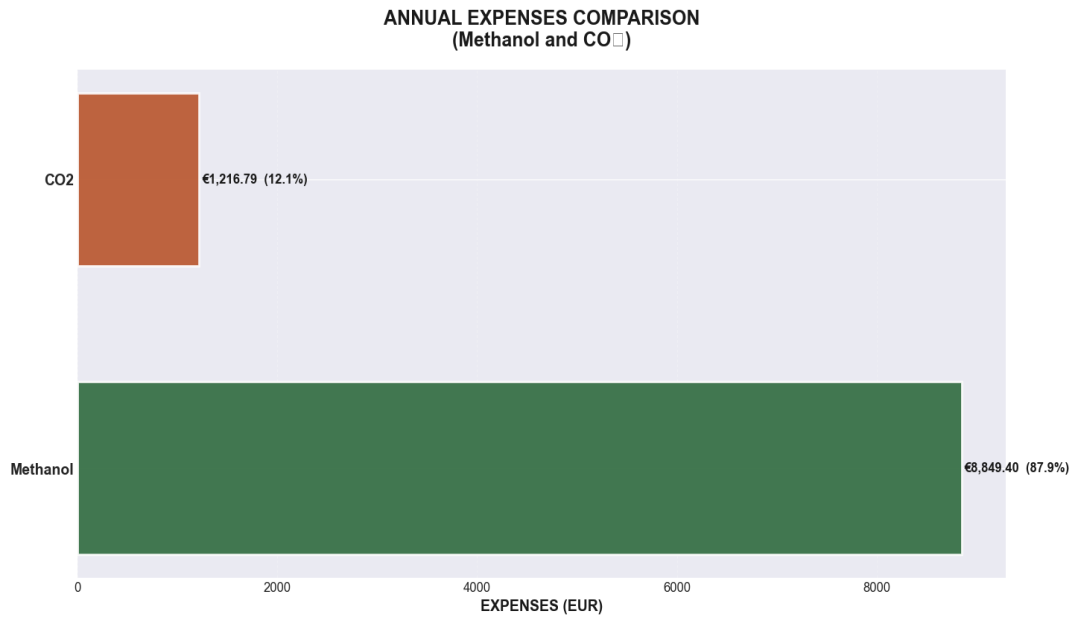


Fig 4.6: Representaion of operational costs involved for fuel and emission in design option 2

Weight analysis

<u>Item removed</u>	<u>Weight reduced</u>
2 x propulsion engine Scania DSI 11	2.6 tons
Diesel tanks (5.5m ³)	0.44tons
Diesel weight (4.95 m ³)	4.21 tons
<u>Item added</u>	<u>Weight increased</u>
2 x propulsion engine Scania MD97 methanol engine	3.4 tons
2 x Methanol tank steel (5.9 m ³)	0.96 tons
Methanol weight (5.31 m ³)	4.21 tons
Net weight added	1.32 tons

Table 4.16: Weight analysis for pilot boat design option 2

4.3.3 Pilot 755 Design option 3

Annual Electricity consumed	21 964	kWh
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Annual expense for electricity	3 953	EUR
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Table 4.17: Operational costs involved for electricity consumption in design option 3

The total annual operational expenditure adds upto €3953 upon summing the the above listed expenses for design option 3 and understandably it comes out to be the most cost efficient from an operational expenditure point of view. However, there are a few factors that need to align to power a fully electric propulsion outside the scope of the vessel alone such as the electric power handling infrastructure at the quay.

Weight analysis

<u>Item removed</u>	<u>Weight reduced</u>
2 x propulsion engine Scania DSI 11	2.6 tons
Ballast tank (4m ³) steel	0.32 tons
Diesel tanks (5.5m ³)	0.44tons
Diesel weight (4.95 m ³)	4.21 tons
<u>Item added</u>	<u>Weight increased</u>
2 x propulsion electric motor	4.4 tons
Battery compartment 1 (3 m ³)	0.24 tons
Battery compartment 2 (3 m ³)	0.24 tons
Battery compartment 3 (3 m ³)	0.24 tons
Battery modules	6.04 tons
Frequency converter	1.5 tons
Methanol weight (5.31 m ³)	4.21 tons
Net weight added	9.3 tons

Table 4.18:Weight analysis for pilot boat design option 3

4.3.4 In summary

Design	Added weight (tons)	Annual operational cost (€)
Design option 1	5.82	6 086
Design option 2	1.32	10 066
Design option 3	9.3	3 953

Table 4.19: Comparison between the three design options for the pilot boat

- In case of the pilot boat the fully electric option is feasible to have and it turns out to be the cost efficient option in terms of operational expenses.
- However, the initial investment in this design option could be the highest, with an arguably big investment required for covering the cost of batteries and to set

up the shore charging infrastructure. It can also be noticed that the added weight is also quite significant and more structural strengthening would be necessary.

- Once the whole system is in place, from that point, the fully electric option would turn out to be a very environment friendly solution.
- The design option 1 is a hybrid option and would provide much more flexibility for the operations as it is not solely reliant on electricity or methanol. As seen from the AIS data, the operation station of the pilot boat was shifted and a hybrid option can be attractive on a such situations.
- In the design option 3, the weight additons are significantly large that would increase the draught of the vessel too. This design would also then require major hull modifications to cope with the added weight

5 Conclusion

The operational profile of the two specific vessel under study were analysed with the available data. The AIS data gave clear picture of the operations of the vessel pilot 755 and it was used to extract various information such as distances, turn around time, duration and distances etc. The analysis was done separately for winter and non winter season anticipating the possible added loads involved in ice conditions. For the Baltica, a similar approach was carried out and an approximate operational profile of the vessel was generated for winter and non winter seasons separately. This was important as this vessel also assists with ice breaking operations during the winter season. This part of the study helped create the outlines within which the designs had to be selected and analysed. The design speeds, range, effects of environmental conditions etc were identified from this part of the study.

Energy calculations for the vessel was carried for both the vessels in order to identify the possible design options that could meet them and then framed three design options for both the vessels. After the different design option combining different energy carriers were formed, the necessary machineries that could be combined to build up the design options were identified along with the main technical data on them.

Further, the power distribution between various machineries involved were calculated and the consumption of the energy carriers involved were also estimated. The carbon dioxide footprint of the energy consumed annually was also estimated along with the cost of fuel and the emission taxation associated with it. Upon comparison of the operational expenditure of the design option, the cost efficient one was identified. The effect of added weights and the additional tanks was analysed for the Baltica and the net weight addition on the pilot boat was also analysed. Thus a comparative study of the hybrid methanol and electric driveline combinations was carried out, aimed at replacing existing conventional driveline.

For the design options considered for Baltica, the design option 3 was found to be the preferable option in terms of low operational costs, and better emission parameters. This design option could also be implemented without too much changes to the existing vessel and would definitely be the recommended option for a conversion project. However the other design options have their merits as well, as they are hybrid options combining the merits of electric power into the system. They would require more initial investments and the vessel operator's policies also would have a role to play, when it comes to the final selection.

For the pilot boat the design option 2 would be the most suited for a conversion project that would be quick and easy. The methanol powered internal combustion engines are quite simple in principle and is a more mature technology than batteries. But the option 1 could also be attractive as it would give more flexibility of operation and the range as it's a hybrid system. The design option 3 which is a fully battery powered arrangement that would be much cheaper once it's in place and very low on emissions. However the initial capital investment is also an important factor for possible adoption of this design option. Apart from these, many other factors such as availability of different fuel, infrastructure for handling electric power, regional preferences etc also carry high weightages when a final selection is carried out.

6 Future Works

- Detailed system drawings have to be made for each of the design options including all the detailed specifications, smaller components such as additional valves, sensors, pipe dimensions etc.
- The dependance of the added weights on the resistance need to be studied and the effect of the same on the power requirements should be incorporated into the energy calculations for all the design options considered.
- A comprehensive study on the intial costs of equipments and machinery need to be carried out to make a better judgement when it comes to the final selection of design,

7 References

References are given according to the schemes given below for some applications: papers, publications, books and handbooks/codes. (informations given within { } are optional.

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8 Appendices

Appendix A

Representation of terms for Power calculations in in Ice classed vessels [\[11\]](#)

The dimensions of the ship and some other parameters are defined below:

- L = length of the ship between the perpendiculars [m]
- L_{BOW} = length of the bow [m]
- L_{PAR} = length of the parallel midship body [m]
- B = maximum breadth of the ship [m]
- T = actual ice class draughts of the ship [m] according to 3.2.2
- A_{wf} = area of the waterline of the bow [m^2]
- α = the angle of the waterline at $B/4$ [degrees]
- φ_1 = the rake of the stem at the centreline [degrees]
- φ_2 = the rake of the bow at $B/4$ [degrees]
- D_P = diameter of the propeller [m]
- H_M = thickness of the brash ice in mid channel [m]
- H_F = thickness of the brash ice layer displaced by the bow [m]

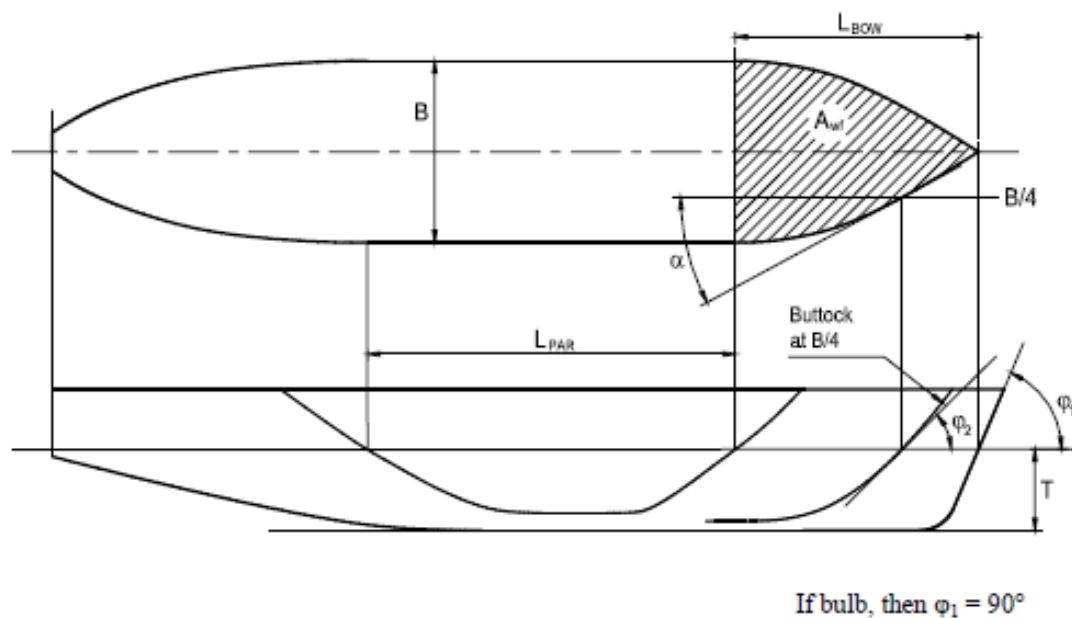


Figure 1

Appendix B

Electric Charging stations installed by Cavotech Group AB [14]

Country	Sites	Ferry operator	E-ferry name	Cavotec solutions	In operation
Sweden	Göteborg	Styrsöbolaget		7 Megawatt Charging System (MCS)	Since 2025
Netherlands	Various	Various Barges		20 Megawatt Charging System (MCS)	2024
Sweden	Port of Umeå	Wasa Line		2 PowerAdapt systems	Since 2023
Finland	Port of Vaasa	Wasa Line		2 PowerAdapt systems	Since 2023
Norway	Kvanne, Rykkjem, Halså, Kanestraum, Sandvika, Edøy	Fjord 1		6 PowerRamp systems	Since 2021
Norway	Kvanndal, Utne, Kinsarvik, Skånepik, Matre, Utåker, Sydnes, Utbjoa	Boreal		6 PowerAdapt systems and 8 MoorMaster® systems	Since 2020
Norway	Hatvik, Venjanaset, Leirvag, Slovag, Jektevik, Hodnanes, Langevag, Buavag, Saevroy, Fedje	Fjord 1	various	10 PowerAdapt systems	Since 2020
Norway	Port of Aker Brygge	Norled	various	1 PowerAdapt systems	Since 2020
USA	Niagara Falls	Maid of the Mist	various	1 PowerReach system with manual Plug-in	Since 2019
Taiwan	Kaohsiung	Kaohsiung Port		1 PowerRun system with manual plug-in	Since 2018
Finland	Parainen and Nauvo	Finferries	Elektra	2 MoorMaster® systems and 2 PowerDrop systems	Since 2017
Norway	Flåm and Gudvangen	Fjord Fartøy I DA	Vision of the Fjords	2 PowerReach systems with manual plug-in	Since 2016
Norway	5 ferry terminals	Norled	Ampere and others	4 MoorMaster® systems and 2 PowerDrop systems	Since 2015

Appendix C

MV Baltica original GA drawing and Engine room arrangement (copyright of Swedish Maritime administration)

Appendix D

Pilot 755 original GA drawing
(copyright of Swedish Maritime administration)

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