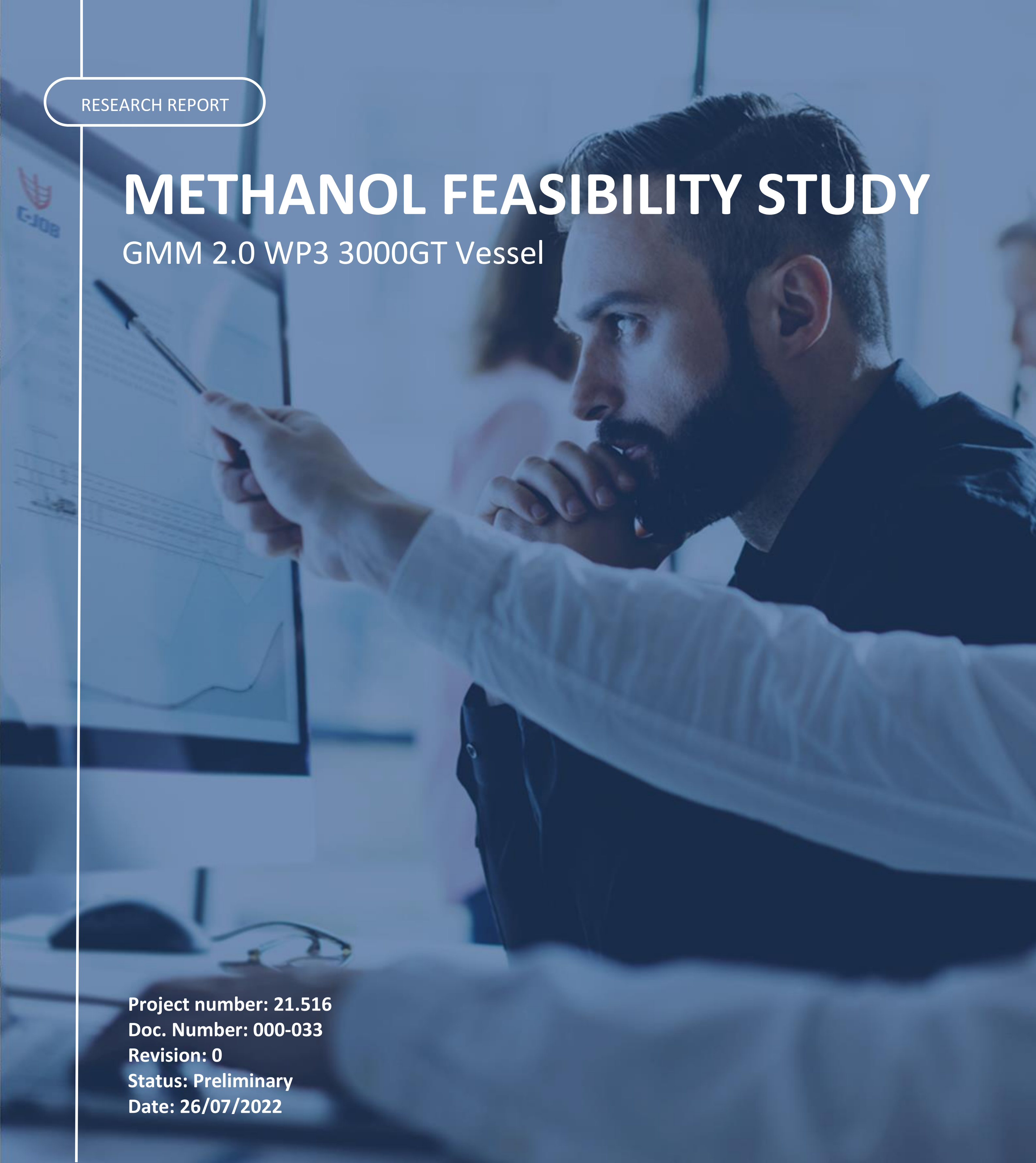
RESEARCH REPORT

METHANOL FEASIBILITY STUDY

GMM 2.0 WP3 3000GT Vessel



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DEDICATED NAVAL ARCHITECTS

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DEFINITIONS

BC	:	Black Carbon
Bmld	:	Breadth moulded
CH4	:	Methane
CO	:	Carbon monoxide
CO2	:	Carbon dioxide
Cuft	:	Cubic feet
D	:	Depth
DB	:	Double bottom
DF	:	Dual Fuel
DWT	:	Deadweight
ECA	:	Environmental Control Area
FW	:	Fresh water
GA	:	General Arrangement
GHG	:	Greenhouse Gasses
GT	:	Gross Tonnage
GWP	:	Global Warming Potential
HFO	:	Heavy fuel oil
ICE	:	Internal Combustion Engine
IMO	:	International Maritime Organization
LHV	:	Lower Heating Value
LO	:	Lubricating Oil
Loa	:	Length over all
Lpp	:	Length between perpendiculars
LSW	:	Light Ship Weight
MCR	:	Maximum Continues Rating
MeOH	:	Methanol
MGO	:	Marine Gas Oil
N2O	:	Nitrous oxide
NMVOC	:	Non-methane volatile organic compounds
NOx	:	Nitrogen oxides
PM, PM10, PM2.5	:	Particulate matter (<10 µm, <2.5 µm)
PS	:	Portside
SB	:	Starboard
SCR	:	Selective Catalytic Reduction
SFC	:	Specific Fuel Consumption
SOx	:	Sulphur oxides
ST	:	Side Tank
Tsummer	:	Design Summer Draught
TTP	:	Tank to Propeller
WB	:	Water Ballast
WTP	:	Well to Propeller
WTT	:	Well to Tank

1 INTRODUCTION

In the Green Maritime Methanol 2.0 consortium methanol as marine fuel is further investigated for various ship types and sizes including a 3000GT general cargo ship. Much is unknown about the technical and economic impact of using methanol on 3000GT vessel.

Therefore, the purpose of this document is to identify the consequences of methanol fuel for a 3000 GT vessel. A preliminary general arrangement of the methanol fueled ship will be delivered and compared to the conventional base case driven on HFO/MGO with focus on cargo volume and harmful emissions. At the end a conclusion will be provided with recommendations identifying topics for further research The project will run together with Arklow shipping, MARIN and Marine Service Noord.

2 CONVENTIONAL BASE CASE

2.1 Conventional Vessel

For this study a conventional design is used to define the base case. This base case will be used as reference in comparison to the methanol case. The conventional ship design is based on the Arklow V-line. It is important to note that all V line ships are under 3000 GT. Figure 2-1 portrays the general arrangement of the conventional vessel. Figure 2-2 portrays a perspective view on the 3D model of the vessel.

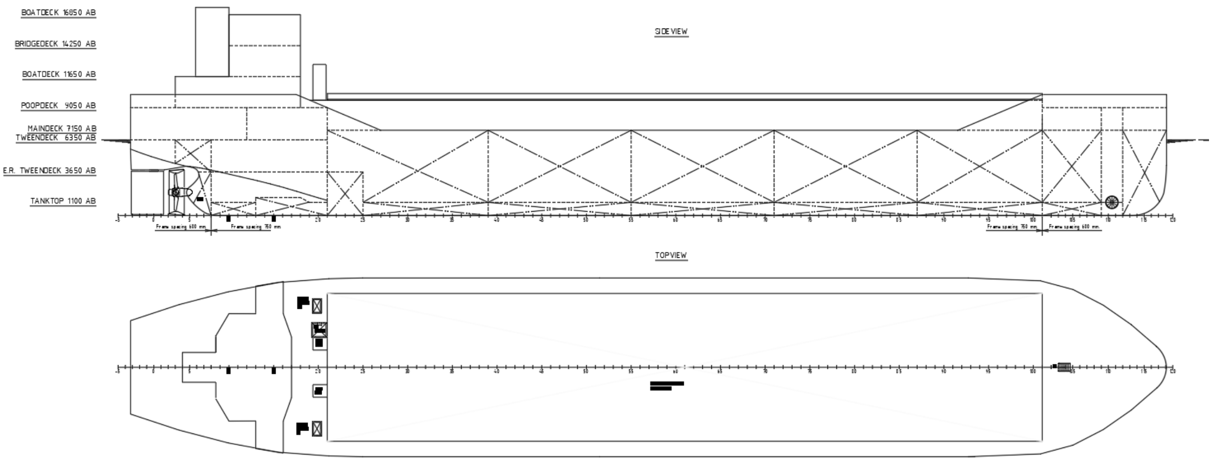

Figure 2-1 General arrangement of conventional vessel

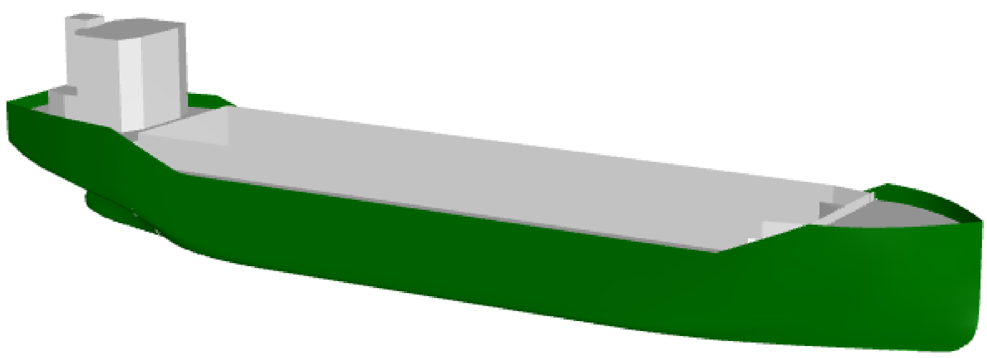

Figure 2-2 3D Perspective view of the vessel

2.2 General information

The main particulars of the conventional vessel are described in Table 2-1.

Main Particulars:	Unit:	
Loa	[m]	86.93
Lpp	[m]	84.98
Bmld	[m]	15.00
D	[m]	7.15
Tsummer	[m]	6.35

Table 2-1 Main particulars of the conventional vessel

The hold capacities of the conventional vessel are described in Table 2-2.

Hold capacities	Unit:	
Hold	[m3]	1
Grain & Bale	[m3]	6272
Grain & Bale	[cuft]	225,000
Hold dimensions	[m3]	60.00x 12.40x 8.644

Table 2-2 Hold capacities of the conventional vessel

The tank capacities of the conventional vessel are described in Table 2-3.

Tank Capacities:	Unit:	
HFO	[m3]	111.7
MGO	[m3]	99.4
WB	[m3]	2082.9
FW	[m3]	45.3

Table 2-3 Tank capacities of the conventional vessel

The tonnages of the conventional vessel are described in Table 2-4.

Tonnages:	Unit:	
GT:	[ton]	2943
NT:	[ton]	1730

Table 2-4 Tonnages of the conventional vessel

2.3 Operational Profile

The power output is based on the installation of the Arklow V-serie. The average operational power is based on 85% MCR. With this output the vessel sails a speed of 10.5 [kn]. See Table 2-5 for the power output of the conventional vessel.

	Installed	Operational
Power output [kW]:	1740	1479

Table 2-5 Power output of the conventional vessel

2.4 Conventional Power Generation

The Propulsion train contains a PTO for power generation (See Figure 2-3)

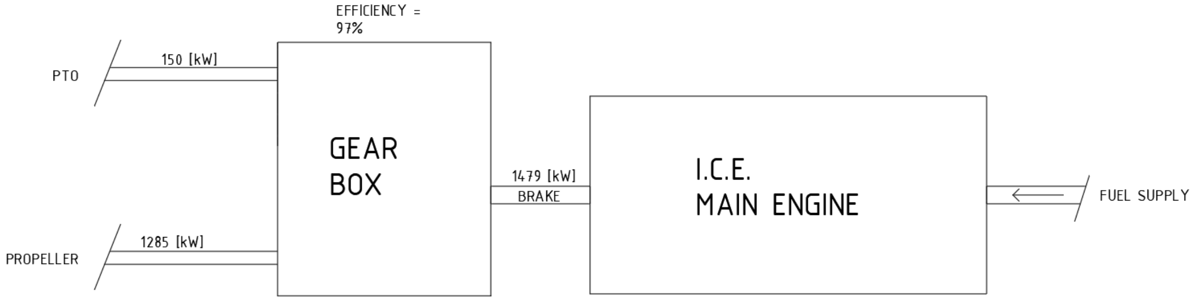

Figure 2-3 Overview propulsion train conventional vessel

In addition, the conventional vessel has 2x auxiliary generator sets containing 154 [kW] each. The total installed power is 308 [kW]. Furthermore, an emergency generator of 66 [kW] is also installed on board the vessel. However, both auxiliary and emergency generators are not included in this research.

2.5 System Efficiency

The system efficiency of the conventional vessel is provided in Table 2-6.The efficiencies are based on the average brake power output of 1479 [kW]. The SFC of MGO is given in the MAK 6 M 25 C specifications. The SFC of HFO is scaled to the LHV of the fuel.

FUEL:	SFC [g/kWh]	Efficiency*
HFO	202.8	44.4%
MGO	190.0	

Table 2-6 System efficiency conventional vessel

*Based on LHV 40.0 MJ/kg for HFO and 42.7 MJ/kg for MGO

2.6 Energy Storage

2.6.1 Capacities

Capacities of fuels are extracted from the 3D base case. These tanks are designed according to the given tank capacity plan. See Table 2-7.

Fuel	Unit	HFO	MGO	TOTAL
Gross volume	[m3]	94.3	76.7	171.0
Steel factor	[-]	0.98	0.98	-
Filling rate	[-]	0.98	0.98	-
Fuel capacity	[m3]	90.56	73.73	164.29
Density	[ton/m3]	0.98	0.86	-
Fuel capacity	[ton]	88.7	63.4	152.2

Table 2-7 Fuel capacities conventional vessel

2.6.2 Autonomy

Based on the operational profile combined with the system efficiency, the autonomy of the vessel is calculated as shown in Table 2-8

	Autonomy HFO [days]	Autonomy MGO [days]
Normal Operation	11.2	8.5

Table 2-8 Autonomy of conventional vessel

Based on the operational profile analysis done by MARIN it can be concluded that the longest measured trip is 2400 nm which is between 9 and 10 days. Comparing that to the available autonomy the vessel has more than sufficient capacity. If desired the operator can bunker less fuel for shorter trips to transport more cargo.

2.7 Cargo Volume & Deadweight

SeeTable 2-9 for values regarding the cargo capacity.

Hold:	Unit:	
Cargo	[m3]	6,272
Cargo	[cuft]	221,400

Table 2-9 Cargo capacity conventional vessel

The DWT components are based on the capacities determined in Table 2-7. The cargo DWT is calculated by subtracting the consumables from the total DWT. The DWT corresponds with the vessel ARKLOW VALIANT on a draft of 6.35 [m]. See for components of the DWT Table 2-10.

Deadweight:	Unit:	
Hold:	[ton]	-
Cargo	[ton]	4966.6
Consumables	[ton]	-
HFO	[ton]	88.7
MGO	[ton]	63.4
FW	[ton]	45.3
Other	[ton]	5.0
Total	[ton]	5169.0

Table 2-10 DWT components conventional vessel

The main hydrostatic data are obtained with the made 3D Model. The draft taken into account is the design draft of 6,35 [m]. See Table 2-11.

	Unit:	
Water displacement* (Based on 3D model)	[m3]	6563.7
Displacement	[ton]	6727.7
DWT	[ton]	5169.0
LSW	[ton]	1558.7

Table 2-11 Main hydrostatic data conventional vessel

*Volume of 3D model (carene) multiplied with a factor of 1.005 (for appendages and steel thickness)

2.8 Harmful Emissions

The GHG and air pollution emissions are portrayed in the following tables. The harmful emissions are calculated for the conventional vessel and the corresponding fuels. The Global Warming Potential (GWP) factors are based on [1].

2.8.1 HFO-mode

See Table 2-12 for the values of harmful emissions and the factors taken into account for the HFO-mode emissions.

		Emission types:	**Fuel based factors HFO [g/g-fuel] [2]**	**Emissions HFO [g/kWh]**	**Emissions CO2-eq [g/kWh]**
GHG	WTT**	CO_2-eq	0.577	117.0156	117.0
	TTP	CO_2	3.114	631.5192	631.5
		CH_4	0.00006	0.012	0.3
		N_2O	0.00017	0.034	9.1
		BC	0.00004	0.008112	7.3
	WTP	CO_2-eq	-		**765.3**
Air pollution		SOx	0.0508	10.3	
		NOx*	-	2.6	
		PM10	0.00755	1.5	
		PM2.5	0.00694	1.4	
		CO	0.00288	0.6	
		NMVOC	0.0032	0.6	

Table 2-12 Harmful emissions HFO-mode conventional vessel

*SCR is applied to reduce NOx emissions. Compliant with ECA and IMO Tier III regulations. [2]
** WTT HFO = 0.577 [g/g-fuel][3]

2.8.2 MGO-mode

See Table 2-13 for the values of harmful emissions and the factors taken into account for the MGO-mode emissions.

		Emission types:	Fuel based factors MGO [g/g-fuel] [2]	Emissions MGO [g/kWh]	Emissions CO2-eq [g/kWh]
GHG	WTT**:	CO2-eq	0.744	141.36	141.4
	TTP:	CO2	3.206	609.4	609.1
		CH4	0.00005	0.0095	0.3
		N2O	0.00018	0.0342	9.1
		BC	0.00004	0.0076	6.8
	WTP:	**CO2-eq**	-		**766.7**
Air pollution		SOx	0.00137	0.3	
		NOx*		2.6	
		PM10	0.00090	0.2	
		PM2.5	0.00083	0.2	
		CO	0.00259	0.5	
		NMVOC	0.0024	0.5	

Table 2-13 Harmful emissions MGO-mode conventional vessel

*SCR is applied to reduce NOx emissions. Compliant with ECA and IMO Tier III regulations. [2]
**WTT MGO= 0.744 [g/g-fuel][3]

3 METHANOL CASE

This chapter will discuss various methanol case options and select the most attractive one for comparison with the conventional base case. In this assessment only the main engine will be converted to a dual-fuel compression ignition internal combustion engine.

3.1 Power Generation

See Figure 3-1 for a schematic overview regarding the power generation for the vessel. The propulsion train contains a PTO for electric power generation.

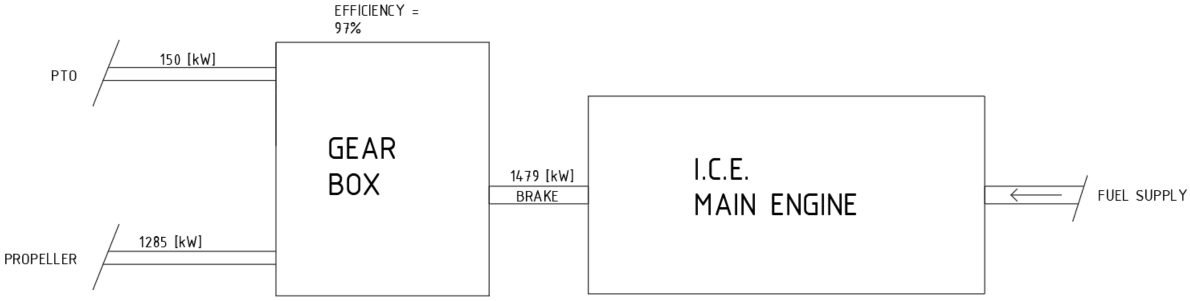

Figure 3-1 Overview propulsion train new design

As mentioned in the previous chapter, even though auxiliary and emergency generators are present on board, they are not considered in this research.

3.2 System Efficiency

The system efficiency during methanol mode is provided in Table 3-1. The system efficiency during MGO mode is provided in Table 3-2. The data is based on the average power usage of 1479 [kW]. The Brake power efficiency for both fuels is estimated to be the same. This efficiency is estimated and based of MGO usage mode due to non-existing info on methanol engines.

FUEL:	SFC (Mechanical output) [g/kWh]	Efficiency* [-]
Methanol (94%)	359.0	44.4%
MGO (6%)	22.7	

Table 3-1 system efficiency methanol-mode new design

*Based on LHV 19.9 MJ/kg for Methanol. and 42.7 MJ/kg for MGO

FUEL:	SFC [g/kWh]	Efficiency* [-]
MGO	190	44.4%

Table 3-2 System efficiency MGO-mode new design

*Based on LHV 42.7 MJ/kg for MGO

3.3 Energy Storage

3.3.1 Required storage

The capacities of the fuel tanks are based on the calculation of the required masses of Fuel. The netto volumes of the fuels are calculated. The gross volumes include a steel margin of 0.98 and a max filling margin of 98%. A 10% margin is also included.

The calculations regarding the capacities of methanol and MGO are based on the demanded ranges of 10 days on Methanol and 14 days on MGO. During Methanol operation, the vessel will operate on a mixture of Methanol and a pilot Fuel. The pilot Fuel is MGO in this case. During this operation the engine will run on 85% MCR where the combusted mass is divided in 94% methanol and 6%. The percentages derive from the 100% MCR operation where 95% MEOH is combusted against 5% MGO. The percentage of MGO rises when lowering the MCR because of the necessary constant pilot energy input. See Table 3-3 for the required fuel capacities.

Required fuel capacity	Unit:	Methanol	MGO
Range	[days]	10.0	14.0
Weight	[ton]	140.2	112.7
Volume (netto)	[m3]	177.4	131.1
Volume (gross)	[m3]	184.8	136.5

Table 3-3 Required fuel capacity new design

3.3.2 Concept storage 1

The first consideration of storing methanol will be in the aft of the hold. In Concept 1 an almost box shaped tank is provided. The tank will run between Frame 22 25. A cofferdam of 600 [mm] is provided between the 2 methanol tanks and other compartments/tanks. However, the tank is placed against the shell on the underside. This method is approved by Bureau Veritas. See Figure 3-2 for a 2D overview of the methanol storage and a 3D perspective view of the storage, looking at the front of the methanol tank.

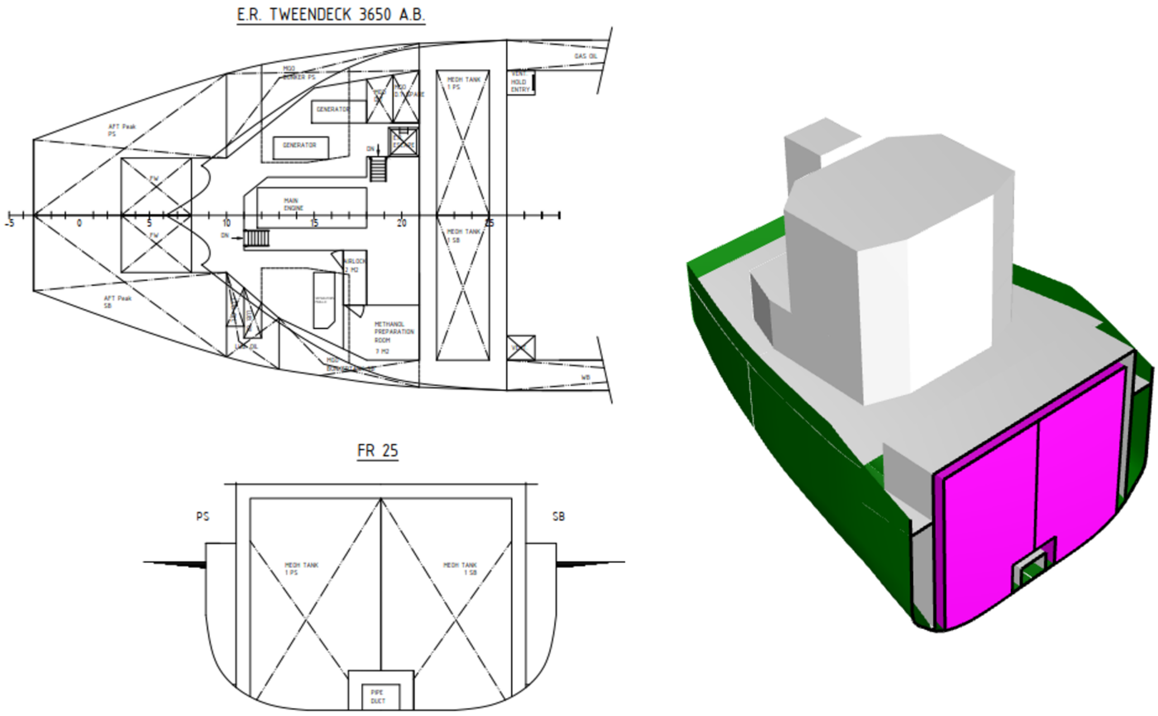

Figure 3-2 2D overview methanol storage of concept 1 (left), 3D perspective view of concept 1 (right)

Table 3-4 describes the fuel capacity of concept 1.

Fuel capacity	Unit:	Methanol	MGO	Total
Gross Volume	[m3]	210.0	139.8	349.8
Mass	[ton]	159.4	115.4	274.8

Table 3-4 Fuel capacity concept 1

Table 3-5 describes the autonomy resulted from the present fuel capacities of concept 1.

	Autonomy Methanol [days]	**Autonomy MGO [days]**
Normal Operation	11.3	14.2

Table 3-5 Autonomy belonging to storage concept 1

Table 3-6 describes the hold dimensions of concept 1.

Hold	**Unit:**	
Cargo	[m3]	5,871
Cargo	[cuft]	207,332

Table 3-6 Cargo capacity belonging to storage concept 1

Table 3-7 describes the DWT components of concept 1.

DWT	**Unit:**	**Total**
Hold		-
Cargo	[ton]	4843.9
Consumables		-
Methanol	[ton]	159.4
MGO	[ton]	115.4
FW	[ton]	45.3
Other	[ton]	5.0
Total	[ton]	5169.0

Table 3-7 DWT components belonging to storage concept 1

3.3.3 Concept storage 2

The second consideration of storing methanol will be aft of the hold. Concept 2 is similar to concept 1, only the tanks are wider. The tank will run between Frame 22-25. A cofferdam is provided between the tank and other compartments. However, the tank is placed against the shell on the underside. This is approved by Bureau Veritas. See Figure 3-3 for a 2D overview of the methanol storage and a 3D perspective view of the storage, looking at the front of the methanol tank.

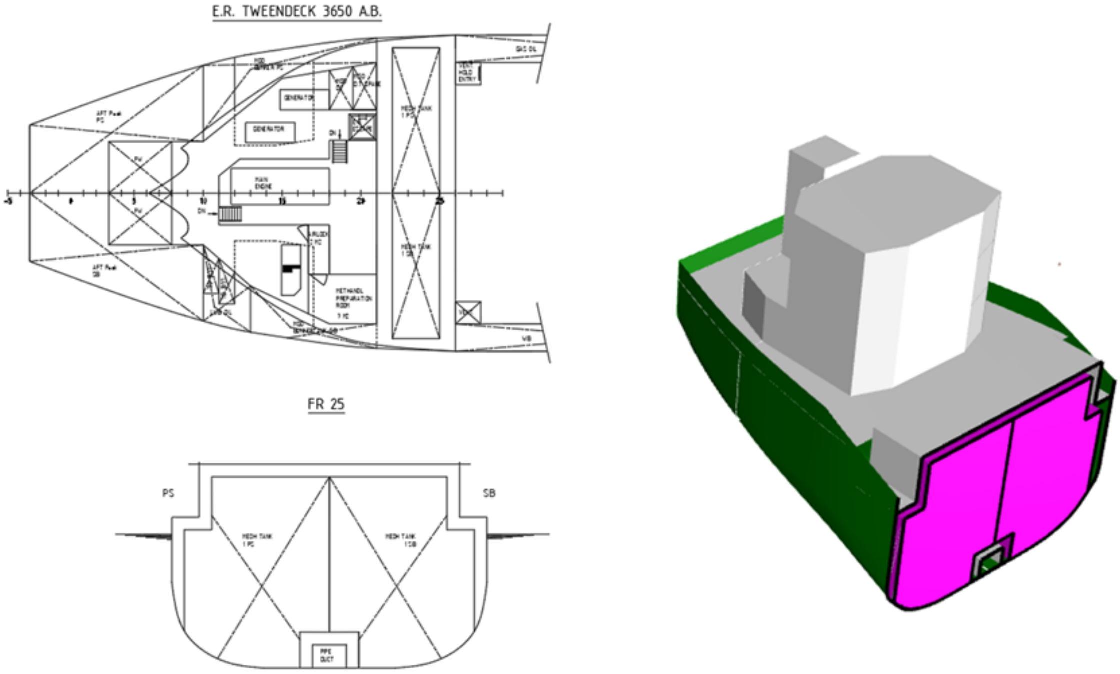

Figure 3-3 2D overview methanol storage of concept 2 (left), 3D perspective view of concept 2 (right)

Table 3-8 describes the fuel capacity of concept 2.

Fuel capacity	Unit	Methanol	MGO	Total
Gross Volume	[m3]	239.0	139.8	378.7
Mass	[ton]	181.3	115.4	296.7

Table 3-8 Fuel capacity of concept 2

Table 3-9 describes the autonomy resulted from the present fuel capacities of concept 2.

	Autonomy Methanol [days]	Autonomy MGO [days]
Normal Operation	12.9	14.0

Table 3-9 Autonomy belonging to concept storage 2

Table 3-10 describes the cargo capacity of concept 2.

Hold	Unit:	
Cargo	[m3]	5,871
Cargo	[cuft]	207,332

Table 3-10 Cargo capacity belonging to storage concept 2

Table 3-11 describes the DWT components of concept 2.

Deadweight	Unit:	Total
Hold		-
Cargo	[ton]	4822.0
Consumables		-
Methanol:	[ton]	181.3
MGO:	[ton]	115.4
FW:	[ton]	45.3
Other:	[ton]	5.0
Total:	[ton]	5169.0

Table 3-11 DWT components belonging to storage concept 2

3.3.4 Concept storage 3

The third consideration of storing methanol will be aft of the hold. Concept 3 is similar to the previous designs, a major change is the reduced length with 1 frame space. Furthermore, the tanks are maximised to the shell. The tank will run between Frame 22-24. A cofferdam is provided between the tank and other compartments. However, the tank is placed against the shell on the underside. This is approved by Bureau Veritas. See Figure 3-4 for a 2D overview of the methanol storage and a 3D perspective view of the storage, looking at the front of the methanol tank.

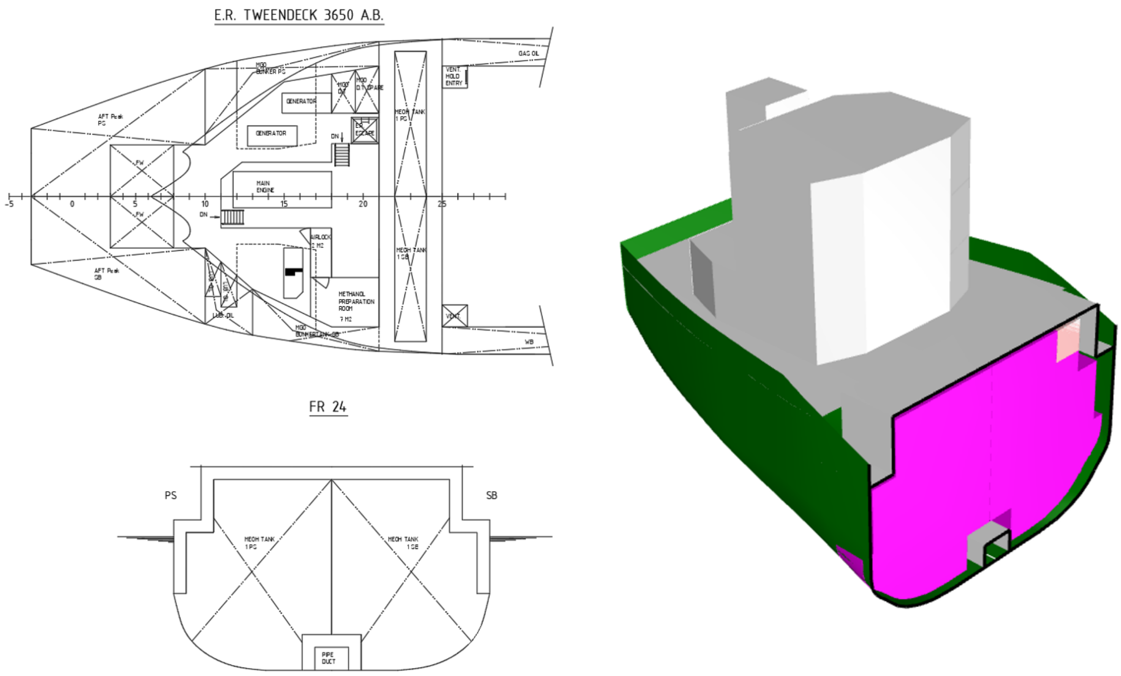

Figure 3-4 2D overview methanol storage of concept 3 (left), 3D perspective view of concept 3 (right)

Table 3-12 describes the fuel capacity of concept 3.

Fuel capacity	Unit:	Methanol	MGO	Total
Gross Volume	[m3]	158.5	139.8	298.3
Mass	[ton]	120.3	115.4	235.7

Table 3-12 Fuel capacities belonging to storage concept 3

Table 3-13.describes the autonomy resulted from the present fuel capacities of concept 3.

	Autonomy Methanol [days]	Autonomy MGO [days]
Normal Operation	8.5	14.5

Table 3-13 Autonomy belonging to storage concept 3

Table 3-14 describes the hold capacity of concept 3.

Hold	Unit:	
Cargo	[m3]	5,951
Cargo	[cuft]	210,157

Table 3-14 Hold capacity belonging to storage concept 3

Table 3-15.describes the DWT components of concept 3.

Deadweight	Unit	
Hold		-
Cargo	[ton]	4883.0
Consumables		-
Methanol:	[ton]	120.3
MGO:	[ton]	115.4
FW:	[ton]	45.3
Other:	[ton]	5.0
Total:	[ton]	5169.0

Table 3-15 DWT components belonging to storage concept 3

3.3.5 Concept storage 4

The fourth consideration of storing methanol will be in the Double bottom. In concept 4 the tanks will run between Frame 22-44. A cofferdam is provided between the tank and other compartments. However, the tank is placed against the shell on the underside. This is approved by Bureau Veritas. See Figure 3-5 for a 2D overview of the methanol storage and a 3D perspective view of the storage, looking at the front of the methanol tank.

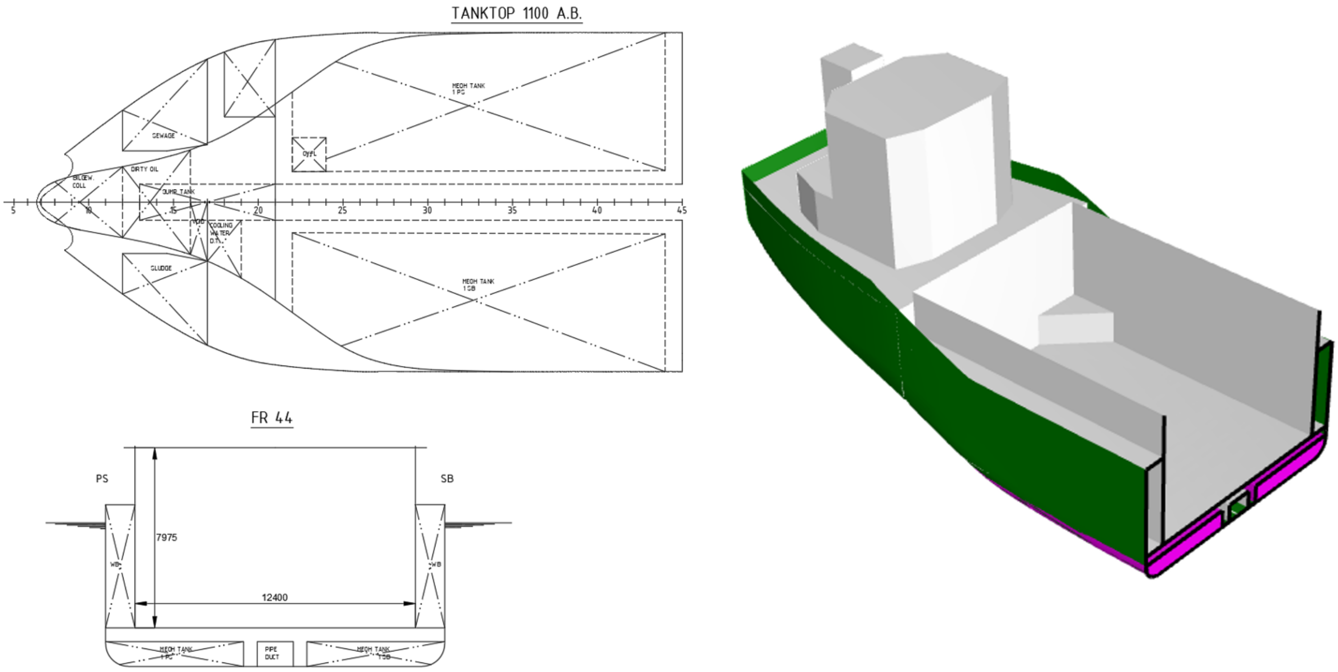

Figure 3-5 2D overview methanol storage of concept 4 (left), 3D perspective view of concept 4 (right)

Table 3-16 describes the fuel capacity of storage concept 4.

Fuel capacity	Unit:	Methanol	MGO	Total
Gross Volume	[m3]	188.4	139.6	328.0
Mass(netto)	[ton]	142.9	115.4	258.2

Table 3-16 Fuel capacity storage concept 4

Table 3-17.describes the autonomy resulted from the present fuel capacities of concept 4

	Autonomy Methanol [days]	Autonomy MGO [days]
Normal Operation	10.1	14.3

Table 3-17 Autonomy belonging to storage concept 4

Table 3-18 describes the cargo capacities of concept 4

Hold	Unit:	Volume
Cargo	[m3]	6,143
Cargo	[cuft]	216,938

Table 3-18 Cargo capacity belonging to storage concept 4

Table 3-19.describes the DWT components of concept 4.

Deadweight	Unit:	
Hold		-
Cargo	[ton]	4860.4
Consumables		-
Methanol:	[ton]	142.9
MGO:	[ton]	115.4
FW:	[ton]	45.3
Other:	[ton]	5.0
Total:	[ton]	5169.0

Table 3-19 DWT components of storage concept 4

3.3.6 Concept storage 5

The fifth and last consideration of storing methanol will be in the side tanks. In concept 5 the tanks will run between frame 22-28. A cofferdam is provided between the tank and other compartments. However, the tank is placed against the shell on the underside. This is approved by Bureau Veritas. See Figure 3-6 for a 2D overview of the methanol storage. See Figure 3-6 for a 3D perspective view of the storage, looking at the front of the methanol tank.

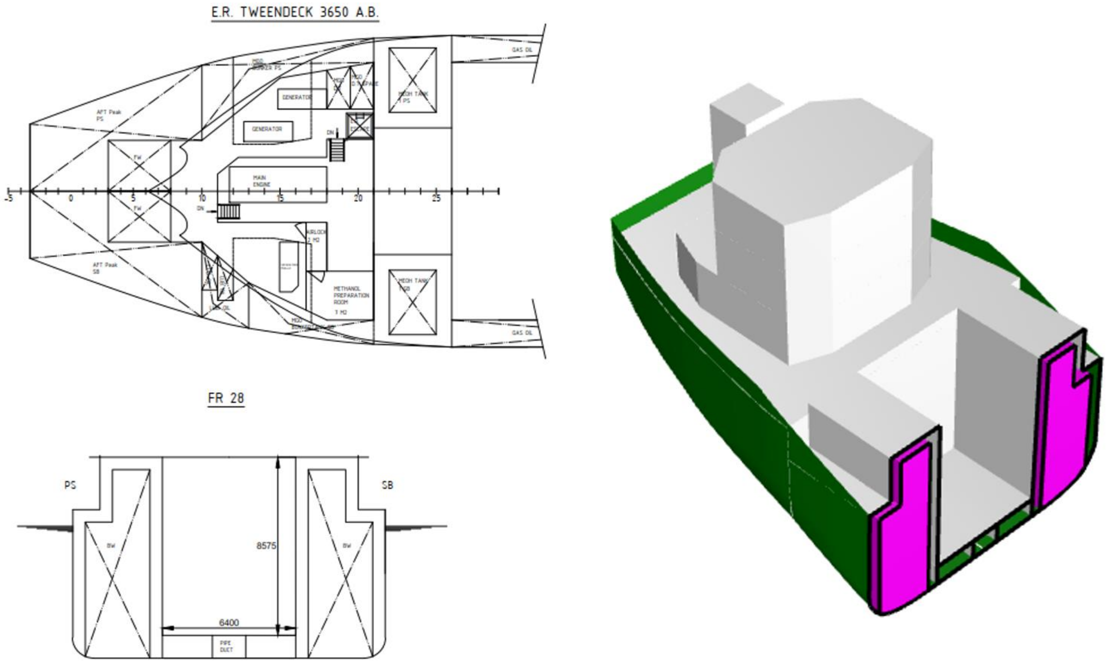

Figure 3-6 2D overview methanol storage of concept 5 (left), 3D perspective view of concept 5 (right)

Table 3-20 describes the fuel capacity of storage concept 5.

Fuel capacity	Unit	Methanol	MGO	Total
Gross Volume	[m3]	201.2	137.5	338.7
Mass	[ton]	152.7	113.6	266.2

Table 3-20 Fuel capacity of storage concept 5

Table 3-21 describes the autonomy resulted from the present fuel capacities of concept 5.

	Autonomy Methanol [days]	Autonomy MGO [days]
Normal Operation	10.8	14.0

Table 3-21 Autonomy belonging to storage concept 5

Table 3-22 describes the hold dimensions of concept 5.

Hold	Unit:	Volume
Cargo	[m3]	5,983
Cargo	[cuft]	211,288

Table 3-22 Cargo capacity belonging to storage concept 5

Table 3-23 describes the DWT components of concept 5.

Deadweight	Unit:	
Hold		-
Cargo	[ton]	4852.4
Consumables	[ton]	-
Methanol	[ton]	152.7
MGO	[ton]	113.6
FW	[ton]	45.3
Other	[ton]	5.0
Total	[ton]	5169.0

Table 3-23 DWT components of storage concept 5

3.3.7 Comparison different concepts

3.3.7.1 Assumptions

In this early stage of the project the LSW of the vessel is considered the same throughout all concepts. In reality there will be deviations with removal of old HFO equipment and addition of methanol tank structure and equipment. This will have to be investigated in a later design stage .

3.3.7.2 Required capacities & ranges new design

Required fuel capacity	MEOH	MGO	Range MEOH	Range MGO	Coverage MEOH Operation ALL*	Coverage MEOH Operation LOADED*
Unit:	[ton]	[ton]	[days]-[nm]	[days]-[nm]	[%]	[%]
100%	140.2	112.7	10.0 – 2520	14.0 – 3528	100%	100%
75%	105.2	84.5	7.5 – 1890	10.5 – 2646	96.4%	93.2%
50%	70.1	56.4	5.0 – 1260	7.0 – 1764	89.9%	81.8%

Table 3-24 Required capacities and ranges

*Based on distances [nm] of operations described in the 2 year leg list of the ARKLOW VENTURE delivered by Arklow shipping.

3.3.7.3 Capacities & hold volumes

Concept	MeOH		MGO		Cargo Volume	Cargo DWT**
Unit:	[ton]	[m3]*	[ton]	[m3]*	Hold [m3]*	Cargo [ton]
1	159.4	201.8	115.4	134.2	5871	4844
2	181.3	229.5	115.4	134.2	5871	4822
3	120.3	152.2	115.4	134.2	5951	4883
4	142.9	180.9	115.3	134.1	6143	4860
5	152.7	193.3	113.6	132.1	5983	4852

Table 3-25 Comparison of the five different storage concepts

*Netto volumes
**LSW, FW and stores are considered to be the same throughout all concepts.

3.3.7.4 Autonomy

Concept:	Range MEOH	Coverage required MEOH operation	Range MGO	Coverage required MGO operation
Unit:	[days]	[%]	[days]	[%]
1	11.3	113.0	14.2	101.4
2	12.9	129.0	14.0	100.0
3	8.5	85.0	14.5	103.6
4	10.1	101.0	14.3	102.1
5	10.8	108.0	14.0	100.0

Table 3-26 Comparison of the autonomies of the five different storage concepts

3.3.8 Selected concept

Concept 4 is the most attractive concept due to least cargo space loss compared to the conventional vessel. This has to do with the optimal usage of methanol tank surfaces allowed to touch the shell. Cargo space is an important value for 3000 GT coasters. Furthermore, the fuel capacity of concept 4 is the most similar to the required fuel capacity. It's not a really conventional design, the complexity of the tanks is not considered inside this report.

See Table 3-27 for a summary regarding the most important components of the selected storage design.

	Unit:	Methanol	MGO
Range	[days]	10.1	14.3
Coverage required operation	[%]	101	102
Weight	[ton]	142.9	112.6
Netto Volume storage	[m3]	180.9	139.8
Gross Volume storage	[m3]	188.4	134.3

Table 3-27 Summary selected storage design

See Table 3-18 for cargo volumes of concept 4. See Table 3-19 for the cargo deadweight of concept 4.

Figure 3-7 portrays a perspective view on the 3D model of the vessel. See Table 3-28 for the general information applying to the new design. Note that these particulars are the same as the conventional vessel.

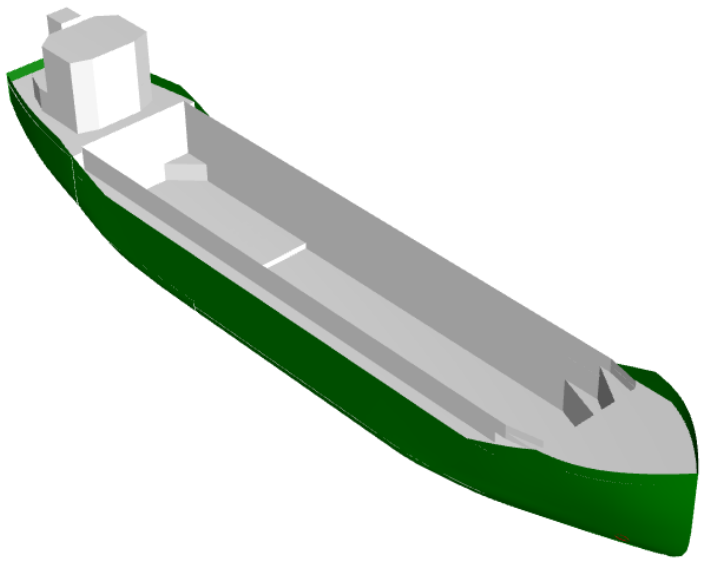

Figure 3-7 3D perspective view of the new design of the vessel

The main particulars of the new methanol design are described in Table 3-28.

Main Particulars	Unit:	
Loa	[m]	86.93
Lpp	[m]	84.98
Bmld	[m]	15.00
D	[m]	7.15
Tsummer	[m]	6.35

Table 3-28 Main particulars new methanol fuelled design

The hold capacities of the new design are described inTable 3-29.

Hold capacities	Unit:	
Hold	[m3]	1
Grain & Bale	[m3]	6143.5
Grain & Bale	[cuft]	216,956

Table 3-29 Hold capacities of the new design

The tonnages of the new design are described in Table 3-30.

Tonnages	Unit:		NOTES
GT:	[ton]	2943	Same as Conventional
NT:	[ton]	1694	Based on conclusion made in 3.5.8

Table 3-30 Tonnages of new design

3.3.8.1 Longitudinal trim check

To check the design on operational capability a longitudinal trim check has been done to ensure the design could fulfil demanded draughts. A 1.5 [m] draught fore is needed because of the bow thruster The longitudinal trim is checked and approved in DelftShip. For both the conventional as the new design 3 loadcases are created. These load cases are as follow: Loaded departure (100% consumables), Ballast departure (100% consumables) and ballast arrival. (10% consumables).

The LSW is constant throughout both designs. The LCG of the particular weight is kept the same and is based of the 0 trim condition of the conventional vessel. The results tell that the new design is still capable of maintaining the particular draughts without increasing the WB intake. The selected design even resulted in a more favourable outcome in ballast conditions. Appendix B describes an overview of the results from the Longitudinal trim check

3.4 Harmful Emissions

The GHG and air pollution emissions are portrayed in this chapter. The harmful emissions are calculated for the methanol case. The Global Warming Potential (GWP) factors are based on [1]

3.4.1 Methanol-mode

	Methanol	MGO
Fuel consumption [g/kWh]:	359.0	22.7
Energy contribution [%]:	90%	10%

		Emission types:	Fuel-based factors [g/g-fuel] [2]		Emissions [g/kWh]			Emissions CO2-eq [g/kWh]
		Emission types:	Methanol	MGO	Methanol	MGO	Total:	Total:
GHG	WTT**	CO2-eq	-0.975	0.744	-350.025	16.8888	-333.1362	-333.1
	TTP	CO2	1.375	3.206	493.625	72.7762	566.4012	566.4
		CH4		0.00005	0.0009	0.001	0.002035	0.1
		N2O		0.00018	0.00270	0.004	0.007	1.8
		BC	0	0.00004	0	0.000908	0.000908	0.8
	WTP	CO2-eq						235.9
Air pollution								
		SOx	0	0.00137	0	0.031099	0.0	
		NOx*		0.05671	2.34	0.26	2.6	
		PM10		0.00090	0	0.02043	0.0	
		PM2.5		0.00083	0	0.018841	0.0	
		CO		0.00259	0.0486	0.058793	0.1	
		NMVOC		0.0024	0	0.05448	0.1	

Table 3-31 GHG and air pollution emitted by new vessel during methanol-mode.

* SCR is applied to reduce NOx emissions. Compliant with ECA and IMO Tier III regulations.

**WTT

Methanol: Green electricity: [30g/kWh], assuming 50% solar [48g/kWh] and 50% wind [12 g/kWh] [4]
Methanol synthesis 2.411 [kWh/kWh] [Appendix A]
LHV: 19.9 [MJ/kg]
Carbon capturing: 1.375 [g CO2/g fuel]

MGO: WTT: 0.744 [g/g fuel] [3]

3.4.2 MGO mode

	MGO
Fuel consumption [g/kWh]:	190.0
Energy contribution [%]:	100.00%

		Emission types:	Fuel based factors MGO [g/g-fuel] [2]	Emissions MGO [g/kWh] [2]	Emissions CO2-eq [g/kWh]
GHG	WTT**	CO2-eq	0.744	141.36	141.4
	TTP	CO2	3.206	609.14	609.1
		CH4	0.00005	0.0095	0.3
		N2O	0.00018	0.0342	9.1
		BC	0.00004	0.0076	6.8
	WTP	**CO2-eq**	-		**766.7**
Air pollution		Sox	0.00137	0.3	
		Nox	2.6	2.6	
		PM10	0.00090	0.2	
		PM2.5	0.00083	0.2	
		CO	0.00259	0.5	
		NMVOC	0.0024	0.5	

Table 3-32 GHG and air pollution emitted by new vessel during MGO-mode

*SCR is applied to reduce Nox emissions. Compliant with ECA and IMO Tier III regulations.
**WTT
MGO: WTT: 0.744 [g/ g fuel] [3]

4 CASE COMPARISON

In this chapter the conventional vessel will be compared with the selected concept of the methanol case.

4.1 Energy Storage

Table 4-1 describes the fuel capacity comparison between the conventional design and the new methanol fuelled vessel.

Fuel type	Unit:	CONVENTIONAL DESIGN	NEW DESIGN
Methanol	[ton]	-	142.9
MGO	[ton]	63.4	112.6
HFO	[ton]	88.7	-

Table 4-1 Comparison fuel capacity

Table 4-2 describes the operational comparison between the conventional design and the new methanol fuelled vessel.

	Unit:	CONVENTIONAL DESIGN	NEW DESIGN
Autonomy Methanol*	[days]	-	10.1
Autonomy MGO	[days]	8.5	14.3
Autonomy HFO	[days]	11.2	-

Table 4-2 Comparison Autonomies

*MGO pilot-fuel included

4.2 Cargo Volume & Deadweight

Table 4-3 .describes the cargo capacity comparison between the conventional design and the new methanol fuelled vessel.

CARGO	Unit:	CONVENTIONAL DESIGN	NEW DESIGN
Cargo	[m3]	6,272	6,143
Cargo	[cuft]	221,400	216,956

Table 4-3 Cargo capacity comparison

Table 4-4 describes the DWT comparison between the conventional design and the new methanol fuelled vessel.

DWT	Unit:	CONVENTIONAL DESIGN	NEW DESIGN
Hold		-	-
CARGO	[ton]	4966.6	4863.2
Consumables		-	-
Methanol	[ton]	-	142.9
MGO	[ton]	63.4	112.6
HFO	[ton]	88.7	-
FW	[ton]	45.3	45.3
OTHER	[ton]	5.0	5.0
TOTAL	[ton]	5169.0	5169.0

Table 4-4 DWT components comparison

4.3 Harmful Emissions

4.3.1 Greenhouse gasses:

The calculation of the greenhouse gasses are described in [122.8] & [3.4]

	Emission types	CONVENTIONAL DESIGN Emissions CO2-eq [g/kWh]		NEW DESIGN Emissions CO2-eq [g/kWh]	
		HFO-mode	MGO-mode	Methanol-mode	MGO-mode
GHG	CO2-eq WTT	117.0	141.4	-333.1	141.4
	CO2	631.5	609.1	566.4	609.4
	CH4	0.3	0.3	0.1	0.3
	N2O	9.1	9.1	1.8	9.1
	BC	7.3	6.8	0.8	6.8
	CO2-eq WTP	**765.3**	**766.7**	**235.9**	**766.7**

Table 4-5 GHG comparison

To calculate the annual greenhouse gas emissions a 100% methanol-mode is assumed for the new design, for the conventional vessel a 50% HFO-mode and a 50% MGO-mode is assumed. Furthermore, a power output of 85% MCR is chosen for the loaded conditions, for ballast conditions a power output of 1250 [kW] is chosen. For the Conventional vessel the same ratios are assumed.

	Unit:	CONVENTIONAL DESIGN:	NEW DESIGN:
CO2-eq WTP	[ton]	2985.7	919.6

Table 4-6 Annual CO2-eq WTP comparison

4.3.2 Air pollution:

	Emission types	Conventional vessel air pollution emissions [g/kWh]		NEW DESIGN vessel air pollution emissions [g/kWh]	
		HFO-Mode	MGO-mode	Methanol-mode	MGO-mode
Air pollution	SOx	10.3	0.3	0.0	0.3
	NOx	2.6	2.6	2.6	2.6
	PM10	1.5	0.2	0.0	0.2
	PM2.5	1.4	0.2	0.0	0.2
	CO	0.6	0.5	0.1	0.5
	NMVOC	0.6	0.5	0.1	0.5

Table 4-7 Air pollution comparison

To calculate the absolute annual emissions a 100% methanol-mode is assumed for the new design, for the conventional vessel a 50% HFO-mode and a 50% MGO-mode is assumed,, furthermore a power output of 85% MCR is chosen for the loaded conditions, for ballast conditions a power output of 1250 [kW] is chosen. For the Conventional vessel the same engine outputs are assumed.

	Unit:	CONVENTIONAL DESIGN	NEW DESIGN
SOx	[ton]	20.6	0.1
NOx	[ton]	10.1	10.1
PM10	[ton]	3.3	0.1
PM2.5	[ton]	3.0	0.1
CO	[ton]	2.1	0.4
NMVOC	[ton]	2.2	0.2

Table 4-8 Annual air pollution comparison

4.4 Conclusion

4.4.1 Cargo capacities

Table 4-3. describes the comparison of the cargo capacities. See table Table 4-9 for an overview regarding the consequences of the hold capacity after methanol implementation compared to the conventional vessel.

	Unit:	
Lost cargo space	[m3]	129
	[cuft]	8,062
	[%]	3.6

Table 4-9 Cargo space consequences as a result of methanol implementation

Table 4-4 describes the comparison of the cargo DWT. See table Table 4-10 for an overview regarding the consequences of the cargo DWT after methanol implementation compared to the conventional vessel.

	Unit:	
Lost cargo DWT	[ton]	106.2
	[%]	2.1

Table 4-10 Cargo DWT consequences as a result of methanol implementation

4.4.2 Emissions

Table 4-5 describes the comparison of the harmful emissions. See Table 4-11. for an overview regarding the absolute and percentile annual reductions in CO2-eq emissions of the vessel after methanol implementation in comparison with the conventional vessel.

	Unit:	
Annual CO2-eq reduction	[ton]	1956.6
	[%]	68.0

Table 4-11 CO-eq reduction as a result of methanol implementation

See table Table 4-12 for an overview regarding the absolute and percentile annual reductions in Air pollution of the vessel after methanol implementation in comparison with the conventional vessel.

	Unit:	
Annual SOx reduction	[ton]	19.7
	[%]	99.4
Annual NOx reduction	[ton]	0
	[%]	0
Annual PM10 reduction	[ton]	3.1
	[%]	97.5
Annual PM2.5 reduction	[ton]	2.9
	[%]	97.5
Annual CO reduction	[ton]	1.6
	[%]	79.3
Annual NMVOC reduction	[ton]	1.9
	[%]	89.9

Table 4-12 Air pollution reduction as a result of methanol implementation

5 CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

In the Green Maritime Methanol 2.0 consortium methanol as marine fuel is further investigated for various ship types and sizes including a 3000GT general cargo ship. Much is unknown about the technical and economic impact of using methanol on 3000GT vessel.

Therefore, the purpose of this document is to identify the consequences of methanol fuel for a 3000 GT vessel. As a result the following conclusions can be made. Various options of methanol storage have been reviewed. Storing methanol in the double bottom seems the most promising in terms of cost effectiveness. The implementation of 10 days methanol autonomy (and 14 days MGO autonomy) resulted in a reduction of cargo volume from 6272 to 6143 m3 (129 m3, 2.1%) and a reduction of cargo DWT from 4967 to 4863 ton (104 ton, 2.1%). This is considered a minor loss while having a huge reduction in CO2-eq WTP from 2986 to 920 (2066 ton, 69.2%). Furthermore, the effects on trim seem limited and can be compensated with similar amounts of ballast water compared to the conventional ship.

5.2 Recommendations

With this research completed the following topics require further development. The selected option of methanol storage in the double bottom should be further detailed to obtain a more accurate LSW. This study did not look into the effects of LSW changes due removal of HFO equipment, adding of methanol equipment and additional steel for methanol tanks. Once a more accurate few on weight has been obtained the trim analysis should be redone to check the required amount of ballast water.

Additionally the current methanol tank arrangement can be further optimized. Besides that, also the required methanol autonomy can be reconsidered as only 5 days (50%) already offers 81.8% of the operability.

Furthermore, the methanol system in general requires further development including things like under water venting and hazardous zones.

6 REFERENCES

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APPENDIX A RENEWABLE SYNTHETIC FUEL PRODUCTION COST

	Methanol CH3OH
Energy [MJ]	1000
Energy density (LHV) [MJ/kg]	19.9
Mass [kg]	50.3
Carbon [kg-carbon] (*2)	18.8
CO2 [kg-CO2] (*3)	69.0
Air separation [MJ/kg-CO2]	6.6
Air separation [MJ]	455.5
Air separation [MJ/MJ]	0.45
Hydrogen [kg-hydrogen] (*4)	9.5
Water [kg-water] (*5)	84.8
Water cleaning [MJ/kg-water]	6.5E-3
Water cleaning [MJ]	0.6
Water cleaning [MJ/MJ]	5.5E-4
Hydrogen [kg-hydrogen] (*4)	9.5
Water splitting [MJ/kg-hydrogen]	180.7
Water splitting [MJ]	1714
Water splitting [MJ/MJ]	1.71
Synthesis [MJ/kg-fuel]	4.8 [5]
Synthesis [MJ]	241
Synthesis [MJ/MJ]	0.24
Total [MJ]	2411
Total [MJ/MJ]	2.41

Chemical data:

Type	Atom	g/mol	Mass % Hydrogen	Mass % Nitrogen	Mass % Carbon	Mass % Oxygen
Hydrogen	H	1.0079	100%			
Carbon	C	12.0107			100%	
Oxygen	O	15.9994				100%
Carbon dioxide	CO2	44.0095			27.29%	72.71%
Water	H2O	18.0153	11.19%			88.81%
Methanol	CH3OH	32.0419	12.58%		37.48%	49.93%
Hydrogen	H2	2.0159	100.00%			

<u>Hydrogen utilization factor:</u>

Methanol $CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$ 67%

(*1): Carbon mass calculated by multiplying total mass with carbon percentage given in chemical data table.

(*2): Carbon dioxide mass calculated by dividing carbon mass by carbon mass percentage given in chemical data table. (Oxygen demand covered with carbon dioxide supply as carbon demand is greater or equal to oxygen demand. Furthermore, carbon dioxide supply provides 2 oxygen atoms and 1 carbon atom. Thus, carbon is dominant)

(*3): Hydrogen mass calculated by multiplying total mass with hydrogen percentage, given in chemical data table, and dividing it by hydrogen utilization factor.

(*4): Water mass calculated by dividing hydrogen mass with hydrogen percentage given in chemical data table.

APPENDIX B LONGITUDINAL TRIM CHECK

WB intake is minimalised to fulfil a 3.5 [m] draught aft and a 1.5 [m] draught fore. This is for making sure the bow thruster and propeller are under water. WB Tanks are considered filled (98%) or not filled (0%). See table Table 6-1 for an overview regarding the weights of various Load cases. See table Table 6-2 for an overview regarding the LCG values of the components and totals.

CONVENTIONAL VESSEL:
LC 1 : LOADED DEPARTURE (100%)
LC 2 : BALLAST DEPARTURE (100%)
LC 3 : BALLAST ARRIVAL (10%)

METHANOL VESSEL:
LC 4 : LOADED DEPARTURE (100%)
LC 5 : BALLAST DEPARTURE (100%)
LC 6 : BALLAST ARRIVAL (10%)

	Unit:	LC 1	LC 2	LC 3	LC 4	LC 5	LC 6
HFO	[ton]	90.2	90.2	9.2	-	-	-
MGO	[ton]	64.6	64.6	6.6	114.5	114.5	11.7
MEOH	[ton]	-	-	-	142.5	142.5	14.5
FW	[ton]	46.0	46.0	4.7	46.0	46.0	4.7
WB	[ton]	0.0	806.7	949.6	0.0	644.0	933.9
LOAD	[ton]	4966.6	0.0	0.0	4860.43	0.0	0.0
TOTAL DWT	[ton]	5167.4	1007.5	970.1	5163.4	947.1	964.8
LSW	[ton]	1558.75	1558.75	1558.75	1558.75	1558.75	1558.75
T_{fore}	[m]	6.337	1.621	1.556	6.324	1.537	1.684
T_{aft}	[m]	6.337	3.667	3.659	6.344	3.636	3.528
TRIM	[m]	0.000	2.048	2.013	0.020	2.098	1.844

Table 6-1 Weights of various load cases

	Unit:	LC 1	LC 2	LC 3	LC 4	LC 5	LC 6
LCG Total	[m]	42.298	39.897	39.73	42.320	39.722	40.228
Fuel	[m]	15.586	15.586	16.428	19.218	19.218	20.03
FW	[m]	3.469	3.469	4.456	3.469	3.469	4.456
WB	[m]	-	40.972	35.106	-	48.825	36.532
	[m]						
LSW	[m]	42.890	42.890	42.890	42.890	42.890	42.890
Cargo	[m]	43.305	-	-	43.730	-	-

Table 6-2 LCG values of various load cases