D3.13 Evaluation report viadonau push boat

Synergetics | Synergies for Green Transformation of Inland and Coastal Shipping

GRANT AGREEMENT NO.	101096809
DURATION OF THE PROJECT	42 months
DELIVERABLE NUMBER	D3.13
DELIVERABLE LEADER	MARIN
STATUS	FINAL
SUBMISSION DATE	29-06-2025
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Release Approval

Table 1: Release Approval

NAME	ROLE	REMARKS
G. Giurco	WP-Leader	28-06-2025
M. Quispel	Reviewer 1	25-06-2025
C. Chirita	Reviewer 2	23-06-2025
B. Friedhoff	Project Coordinator	29-06-2025

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Abbreviations

AC	Alternating Current
BDA	Bad Deutsch-Altenburg
BIO	Bunker Independent Operation
CI	Compressed Ignited
CO2eq	Carbon Dioxide equivalent emissions
CWL	Centre Waterline
DC	Direct Current
DF	Dual Fuel
GM	Metacentric height
GHG	Green House Gase
GZ	Righting lever
HAZID	Hazard Identification
HVO	Hydrotreated Vegetable Oil
ICE	Internal Combustion Engine
LCG	Longitudinal Centre of Gravity
Li-NMC	Lithium - Nickel Manganese Cobalt Oxides
LHV	Lower Heating Value
LNG	Liquid Natural Gas
LSW	Lightship Weight
MCR	Maximum Continuous Rating
NG	Natural Gas
PPE	Propulsion, Power & Energy
POME	Palm oil mill effluents
PS	Portside
PTS	Point Source
SB	Starboard
SCR	Selective Catalytic Reduction
SF	Single Fuel
SFC	Specific Fuel Consumption
SI	Spark Ignited
SPEC	Ship Power & Energy Concept tool
Ta	Trim aft
TCG	Transversal Centre of Gravity
Tf	Trim forward
TPTC	Task Power Time Charts
TTW	Tank to Wake
UCO	Used cooking oil
UPS	Uninterruptible Power Supply
VCG	Vertical Centre of Gravity
vZEL	virtual Zero Emission Lab
WTT	Well to Tank

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WTW	Well to Wake
ZEL	Zero Emission Lab
η_g	Genset efficiency

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Executive Summary

This report provides an overview of the selection and concept design of the propulsion, power and energy (PPE) systems of demonstrator 6, as well as a performance evaluation of the systems in MARIN's Zero Emission Lab (ZEL).

The Operational Analysis and Technology Selection conducted for subtask 3.1.1 and reported in deliverable D3.1, provided a high-level overview on the consequences on the design of the ship when using alternative energy carriers and power systems. Based on the results of the SPEC analysis, viadonau indicated methanol as the preferred option/solution for their new push boat. A second analysis was carried out to evaluate the performance of different methanol architectures, or topologies, at part load conditions, considering therefore the complete operational profile. The part-load assessment aimed to identify the best option between Single Fuel and Dual Fuel. For this reason, four methanol-electric architectures were compared, specifically: two Single Fuel (SF) methanol architectures and two Dual Fuel (DF) methanol architectures

Based on the insights from the part-load assessment, viadonau identified the Single Fuel (SF) methanol architecture, with a smaller and a bigger gensets, as the preferred solution. A diesel backup genset, initially intended to operate the ship in case of methanol unavailability or system failure, was subsequently replaced with a battery pack. This change reflects the stakeholders' intention to minimize the use of diesel as much as possible.

For the concept design, the Bad Deutsch Altenburg was used as reference ship. First, the power and energy components of this ship were removed (propulsion engines, diesel tanks, etc.), to make room for the new propulsion, power and energy systems. Next, following the design requirements, the rest of the design was developed.

The concept design was developed with an overall satisfactory result. It was concluded that a limited amount of additional superstructure volume is required. This means that the main dimensions of the vessel do not need to be changed if methanol is used as fuel. However, it was observed that the use of methanol introduces hazardous areas which extend throughout most of the length of the ship, making it not possible to arrange the ventilation and entrances to non-hazardous spaces. Furthermore, the additional weight of the methanol concept would increase the draught, which may require larger scantlings if the scantling draught is exceeded. The equilibrium trim, based on the loading conditions, is within a reasonable value. Regarding stability, initial intact stability (based on GM value) is sufficient, but intact stability at larger angles (criteria based on GZ curve) should be checked, as the reduced freeboard will reduce the down-flooding angle.

In addition to the general arrangement plan, a conceptual fuel system diagram, indicating the main components of the fuel system, was elaborated.

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1. | Introduction

As part of Innovation Action SYNERGETICS, Demonstrator 6 aims to investigate which retrofit/new build solution will be optimal for a 500 kW push boat. For this purpose, the push boat Bad Deusch Altenburg is used as reference ship.

In addition to the operational analysis and technology selection conducted as part of Subtask 3.1.1, it is important to give a more detailed overview of the impact on the design and the performance of the vessel when alternative energy carriers are used instead of fossil diesel or the renewable low carbon drop-in fuel solutions such as HVO (Hydrotreated Vegetable Oil). The work conducted for this deliverable aims to serve as an example for future retrofits of inland vessels.

This report is divided into two main parts. The first part deals with the concept design and focuses on the impact of the new PPE concept on the ship's design. The second part presents the measurements from the model-scale version of the PPE system and focuses on its performance.

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2. | Description of the vessel

The Bad Deutsch-Altenburg is a push boat dedicated to the maintenance of the Danube River, owned by the Austrian waterway operator viadonau. The main particulars of the vessel are presented in Table 2-1. The boat is dedicated to waterway marking and maintenance of buoys and other aids to navigation to ensure the safe passage of vessel traffic through the Danube.

Despite being a low-emission vessel fitted with main engines compliant with EU Stage V NRE-v-6 emission regulations that can run on HVO100, viadonau is interested in exploring new concepts to reach lower emission levels for its future push boats.

The new push boat should carry out the same tasks as the Bad Deutsch-Altenburg. The new pusher would be similar to the Bad Deutsch-Altenburg, and viadonau aims for a solution as close as possible to zero emission.

Table 2-1: Main particulars of the Bad Deutsch Altenburg.

Ship type:	Push boat	
Propulsion type	Diesel direct	
Length over all	22.15	m
Length between perpendiculars	20.54	m
Beam, moulded	5.40	m
Beam, maximum	5.60	m
Depth, to main deck	2.25	m
Draught, design	1.10	m
Draught, maximum	1.20	m
Draught, ballast (Tf/Ta)[1]	1.116 /1.125	m
Deadweight, at maximum draught	11.00	t
Displacement, at design draught	73.40	t
Displacement, at maximum draught	82.98	t
Air draught above CWL	5.85	m
Speed (at 7 m draught and 90 % MCR)	19.9	km/h

[1] 10 % provisions and fuel, 80 % waste water, 3 crew members

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3. | Concept design

The conceptual design started with an initial selection of the Propulsion Power and Energy (PPE) concept. Then, different system architectures of the selected PPE concept were compared in terms of efficiency and fuel consumption, from which one architecture was selected. Afterwards, the main PPE components of the selected architecture were sized. Last, the general arrangement and the fuel system diagram of the new design was made, following the design requirements stablished for this project.

In the following sections the work mentioned above is described in more detail.

3.1 Design requirements

When designing, requirements define what needs to be achieved by the design not only in terms of performance (e.g. endurance, capabilities of the design, emissions, etc.), but also in terms of safety and regulatory compliance. Design requirements may be defined by stakeholders and users, or by regulatory bodies such as classification societies, flag states, port authorities, etc. Requirements therefore have consequences on many aspects of the design and, for this reason, they play a key role in all of the steps in the design process. Requirements are not static, but evolve throughout the design process and design iterations: they can be enriched or refined once the goal and the scope of a high-level requirement is clearer or better understood, adjusted in response to new insights from design decisions, or used to derive new requirements. Keeping track of requirements and design decisions linked to them is fundamental to achieve consistency and traceability throughout the design.

Depending on the topic addressed by the requirements, the following requirement types, or categories, were defined:

- Performance;
- Safety;
- Security;
- Environment;
- Cost;
- Human Machine Interface (HMI);
- Operational Profile;
- Reliability;
- Generic;
- Maintenance;
- Legislation.

The list of requirements presented in Annex 1 provides an overview of all the requirements considered in the design of the push boat. The 'Remark' column indicates whether each requirement is fully or partially fulfilled by the design, or if it should be addressed in a later design phase.

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3.2 Selection of PPE concept

From the operational and SPEC[2] analyses conducted in Deliverable D3.1[3], the following concepts were ranked as possible solutions for Demo 6 (see also Table 3-1):

- **Diesel direct with bio-diesel (concept #4):** Propulsion and energy concept of current vessel.
- **Methanol-electric with dual fuel gensets (concept #9)**: eMethanol generated using renewable energy (mix of electricity produced from solar and wind energy);
- **LNG-electric with dual fuel gensets (concept #19)**: eLNG generated using renewable energy (mix of electricity produced from solar and wind energy);
- **Battery electric (concepts #21 and #26):** Concept 21 electricity is generated via renewable energy (mix of electricity produced from solar and wind energy), whereas for concept 26 is generated using fossil fuels.

In Table 3-1 a more detailed description of these concepts is given. From the concepts above, battery-electric was discarded first as it requires an amount of volume and weight not feasible for this small vessel. Since the concept of using bio-diesel as fuel has already been implemented on the Bad Deutsch Altenburg, this solution was not considered, as the intention is to explore other technologies and test an alternative fuel on the push boat to further reduce emission levels.

After the first design iteration, viadonau indicated methanol as the preferred option.

Table 3-1: Description of possible propulsion and energy concepts for Demo 6 resulting from the SPEC analysis.

Concept	Description
#4 = Diesel (POME, UCO) CI ICE	Diesel (HVO from UCO, POME) ICE CI 4-stroke high speed (diesel)
#9 = e-CH3OH (CO2 PTS)/Dsl 95/5%vol CI ICE	e-CH3OH 95%vol + Diesel 5%vol ICE CH3OH 4-stroke high speed
#19 = e-LNG (CO2 PTS) SI ICE	e-LNG (renewables + flue gas CO2) ICE NG SI 4-stroke high speed
#21 = Battery-electric (renewable)	Electricity (renewable) stored in Li-NMC battery
#26 = Battery-electric (fossil)	Electricity (fossil) stored in Li-NMC battery

[2] SPEC (Ship Power and Energy Concepts) analysis is a technology selection analysis which evaluates what solutions are feasible for a vessel based on a set of operational and design requirements.

[3] D3.1 - SPEC analyses of full scale and model scale demonstrators. See for the report:

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3.3 Selection of methanol technology and power system architecture

While SPEC gives a quick, high level assessment of different solutions, a second analysis was carried out to evaluate the performance of different methanol architectures, or topologies, at part load conditions, considering therefore the complete operational profile as defined in Deliverable D3.1. The part-load assessment aimed to identify the best option between Single Fuel and Dual Fuel.

Another goal of this second analysis was to evaluate different combinations of power sources to optimally cope with the power variation and distribution during the operational profile. For the same reasons as above (see Section 3.1), the operational profile from BIO II was used in the analysis.

Before developing and evaluating any methanol architecture, a preliminary qualitative assessment was carried out to consider the type of propulsion configuration. The reference vessel is powered by two diesel engines directly coupled on the propulsion shafts (two shafts, one engine per shaft), on the other hand the application of methanol made electric propulsion attractive. Finally, the following considerations in favour of the electric propulsion were made:

- A generic market trend is to go towards electrification;
- Although initially more expensive, electrification allows for future power generation changes without having to change the propulsion system (f.e. implementing battery systems, fuel cells, etc.). Regarding this topic, it was decided to keep the current AC electrical distribution system to keep the complexity and cost of the retrofit low, however for future new builds a DC system may be more suitable and shall be considered;
- Despite having a longer propulsion power efficiency chain, it has a better performance compared to direct propulsion when it comes to slow speed operations or station keeping operation. Both are quite typical operations for the push boat.

Despite ES-TRIN contains regulations for the usage of methanol on board, combustion engines for inland waterway vessels require an approval within the scope of Regulation (EU) 2016/1628 (NRMM Stage V). This regulation does not list methanol as a reference fuel. Recently, it was announced by DG GROW that hydrogen will be included. For methanol the situation remains unclear due to formaldehyde forming and corresponding unregulated and secondary pollutant emissions. As a consequence of this legal barrier, manufacturers of engines with a power range matching inland waterway vessels have reduced or even stopped their activities to solve technical issues and produce engines for this niche market. For this reason, pollutants were left out of the analysis.

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3.3.1 Calculation of genset efficiency and fuel consumption at part load

First, using the gravimetric and volumetric energy densities of the fuel[4] in combination with the engine nominal efficiency, the specific fuel consumption, genset efficiency and CO2 emissions per energy unit were calculated for each methanol-electric concept. The results are presented in Table 3-2 and Table 3-3.

Table 3-2: Part load assessment, input overview

Methanol SF ICE concept		
Engine		
ICE CH_3OH 4-stroke high speed		
Gravimetric Power Density	4	kg/kW
Volumetric Power Density	5.8	l/kW
Nominal efficiency	0.42	
Alternator efficiency	0.95	
Genset nominal efficiency	**0.40**	
Specific Fuel Consumption	**458**	g/kWh
Fuel		
e-CH_3OH (renewable electricity + flue gas CO_2)		
Contained Gravimetric Energy Density	14	MJ/kg
Uncontained Gravimetric Energy Density	19.7	MJ/kg
Contained Volumetric Energy Density	14.08	MJ/l
Uncontained Volumetric Energy Density	15.6	MJ/l
CO2 emission TTW (Tank To Wake)	69.66	kg/GJ
CO2 emission WTT (Well To Tank)	-64.3	kg/GJ

The efficiency and specific fuel consumption values from Table 3-2 and Table 3-3 correspond to the engine nominal power. However, to compare different architectures, part-load conditions need to be assessed as well. This was done by using the engine efficiency curve.

Due to the limited number of reference methanol engines of small size, the efficiency curve of engines with comparable injection and combustion characteristics were scaled to match the nominal efficiency of the smaller gensets. An example of this calculation is shown in Table 3-4, where the scaled efficiency values at different engine loads are presented. A cubic polynomial was then fitted through the scaled efficiency points, which is further used to build the engine efficiency curve.

[4] Based on MARIN's sustainable power database: https://sustainablepower.application.marin.nl/

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Table 3-3: Overview of the genset gravimetric and volumetric energy densities, genset efficiency and specific fuel consumption considered for the dual fuel methanol solution.

Methanol DF ICE solution		
Engine		
ICE CI DF 4-stroke medium speed		
Gravimetric Power Density	9.3	kg/kW
Volumetric Power Density	18.4	l/kW
Efficiency	0.42	
Alternator Efficiency	0.95	
Genset Efficiency	**0.399**	
Specific Fuel Consumption	**322**	g/kWh
Fuel		
e-CH_3OH 65%vol + Diesel 35%vol		
Contained Gravimetric Energy Density	20.0	MJ/kg
Uncontained Gravimetric Energy Density	28.1	MJ/kg
Contained Volumetric Energy Density	20.5	MJ/l
Uncontained Volumetric Energy Density	22.7	MJ/l
CO2 emission TTW (Tank To Wake)	71.7	kg/GJ
CO2 emission WTT (Well To Tank)	20.5	kg/GJ

Table 3-4: Example of scaling of the efficiency curve of a DF methanol engine.

Engine load [%MCR]	Efficiency Reference Engine	% difference (w.r.t. nominal efficiency)	Scaled efficiency of DF methanol genset
100%	40.4%	0%	39.9%
75%	38.7%	-4%	38.2%
50%	36.4%	-10%	35.9%
25%	28.6%	-29%	28.2%

Using the genset efficiency and the gravimetric energy density[5] of the dual fuel blend, the specific fuel consumption was calculated as follows:

$$SFC = \frac{1}{\frac{\eta_g \cdot LHV}{3.6}} \cdot 1000 \qquad (3\text{-}1)$$

where:

- SFC is the specific fuel consumption in g/kWh;

[5] Which is equivalent to the low heating value (LHV)

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- η_g is the genset efficiency;
- LHV is the low heating value of the fuel blend in MJ/kg

Figure 3-1 shows an example on how the efficiency and specific fuel consumption curves were obtained for the dual-fuel methanol gensets.

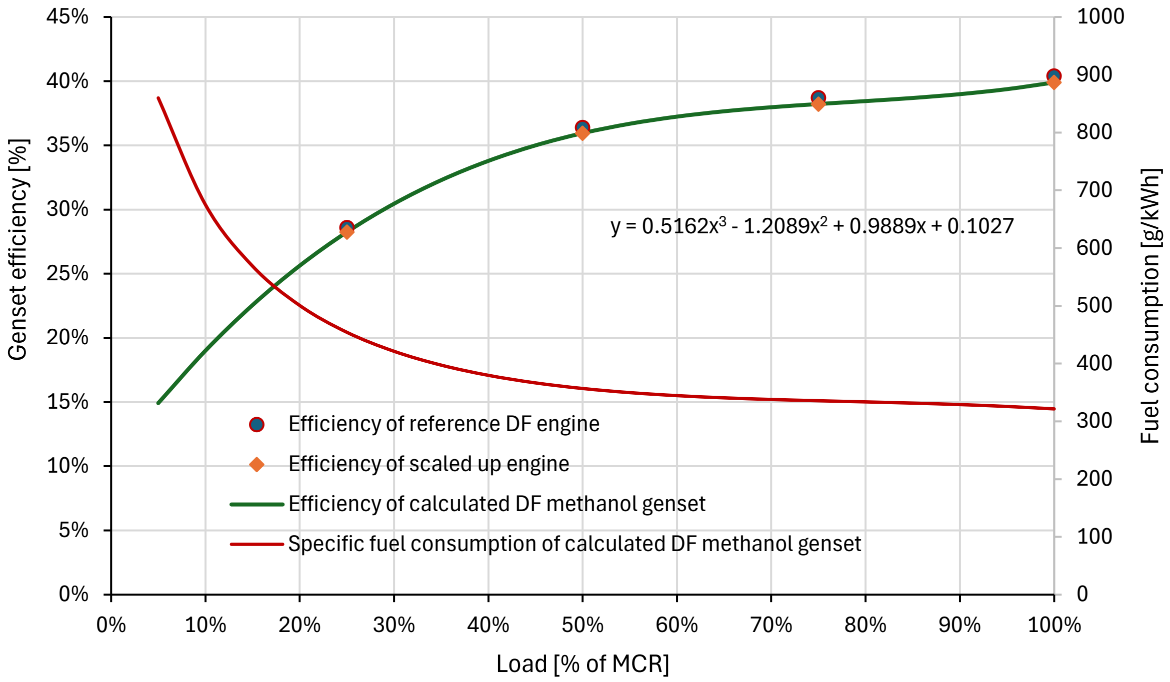

Figure 3-1: Example of the calculated efficiency and fuel consumption for the dual-fuel methanol genset.

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3.3.2 Architectures Comparison

Together with viadonau, it was decided to keep the same installed power of 500 kW as in the reference vessel. The nominal power of the gensets was selected based on the total power demand during the operation derived from the operational analysis conducted in deliverable D3.1. Configurations with one and two gensets were studied, for different nominal engine powers. As viadonau requested to include a back-up with diesel, a diesel genset was added for the single fuel methanol architectures. For the dual fuel solutions this was not necessary, as the engines could run on diesel as well. The following architectures were selected as candidates:

Dual Fuel 1

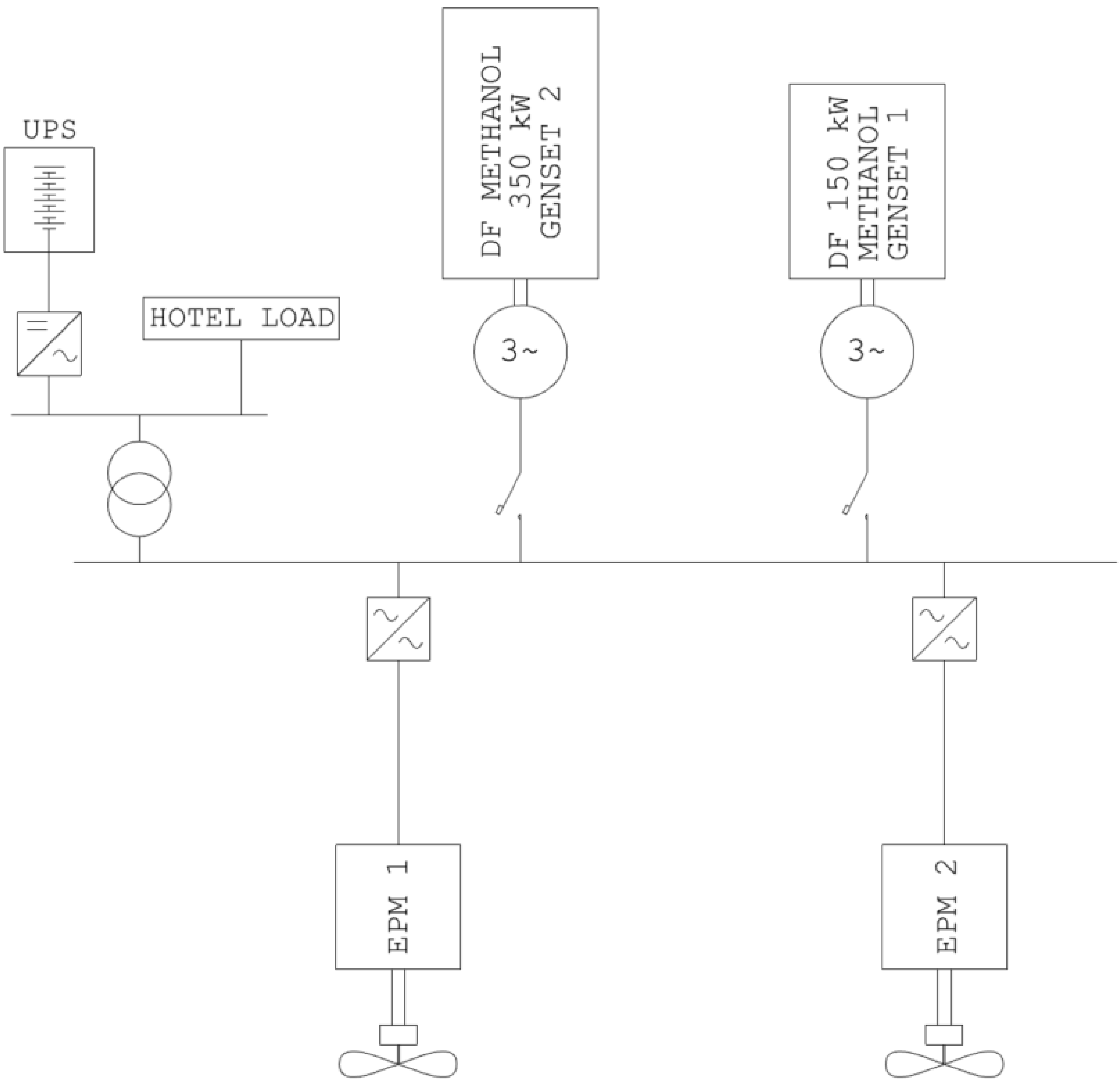

Figure 3-2: Dual Fuel Architecture 1

In this architecture, the total installed power is distributed among two gensets of different nominal power, the first one of 150 kW, the second one of 350 kW. The battery system consists in the 24V Uninterruptible Power System as present in the reference vessel.

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Dual fuel 2

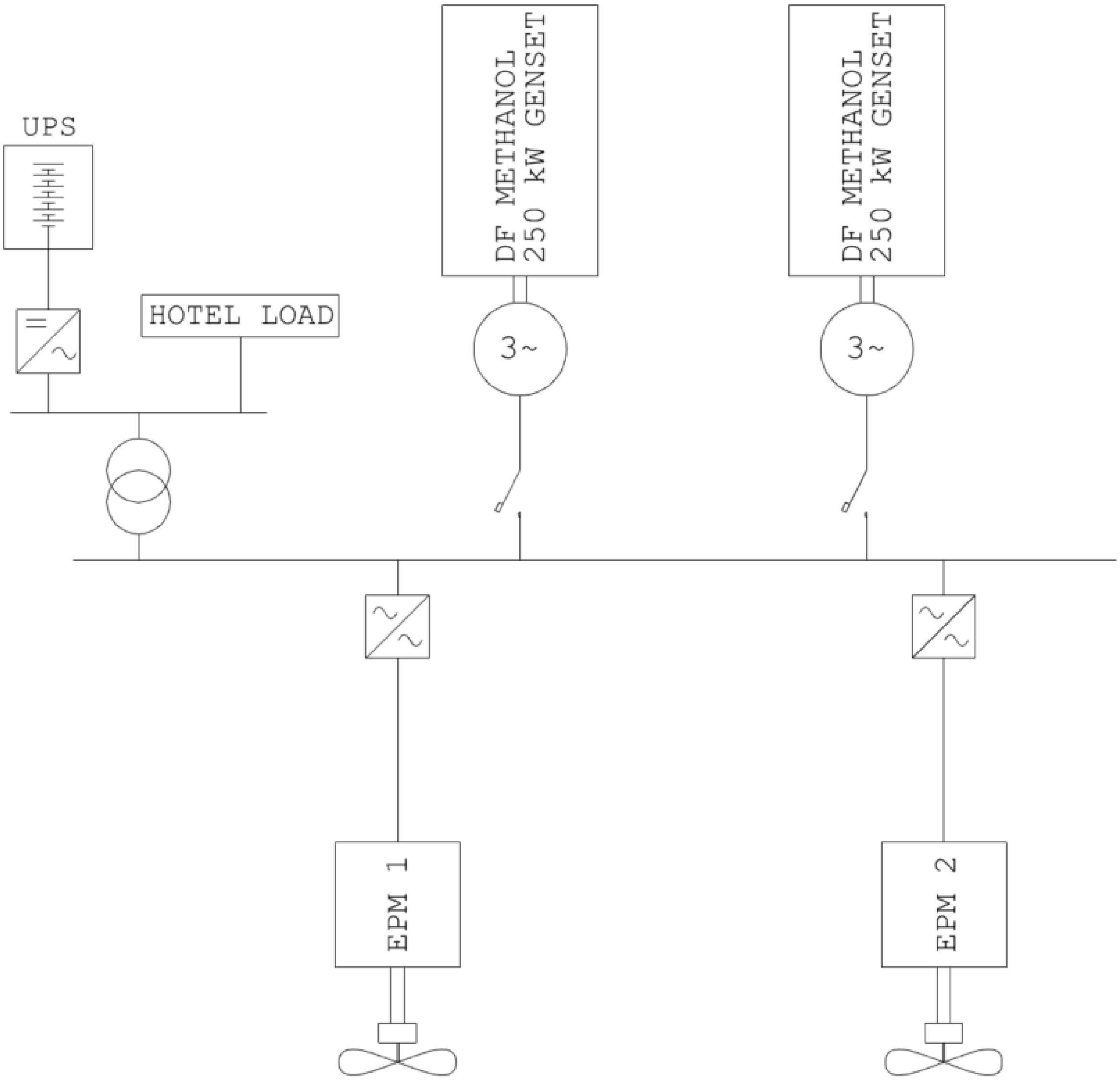

Figure 3-3: Dual Fuel Architecture 2

In this architecture, the total installed power is distributed among two gensets of equal nominal power, of 250 kW. The battery system consists in the 24V Uninterruptible Power System as present in the reference vessel.

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Single fuel 1

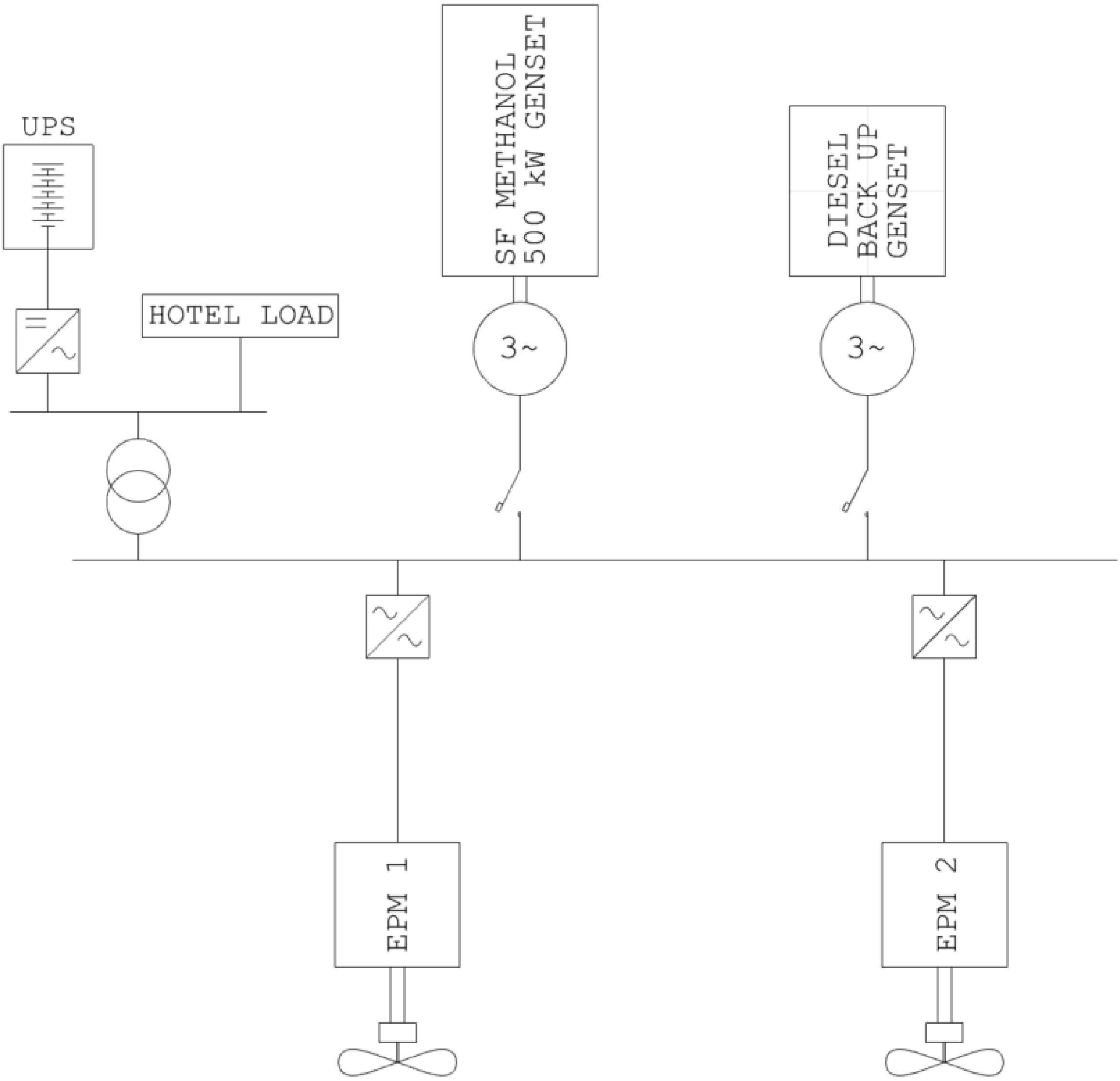

Figure 3-4: Single Fuel Architecture 1

In this architecture, the total installed power is distributed in one "big" genset only. A diesel genset of 150 kW is allocated for back up only in case of emergency. The battery system consists in the 24V Uninterruptible Power System as present in the reference vessel.

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Single fuel 2

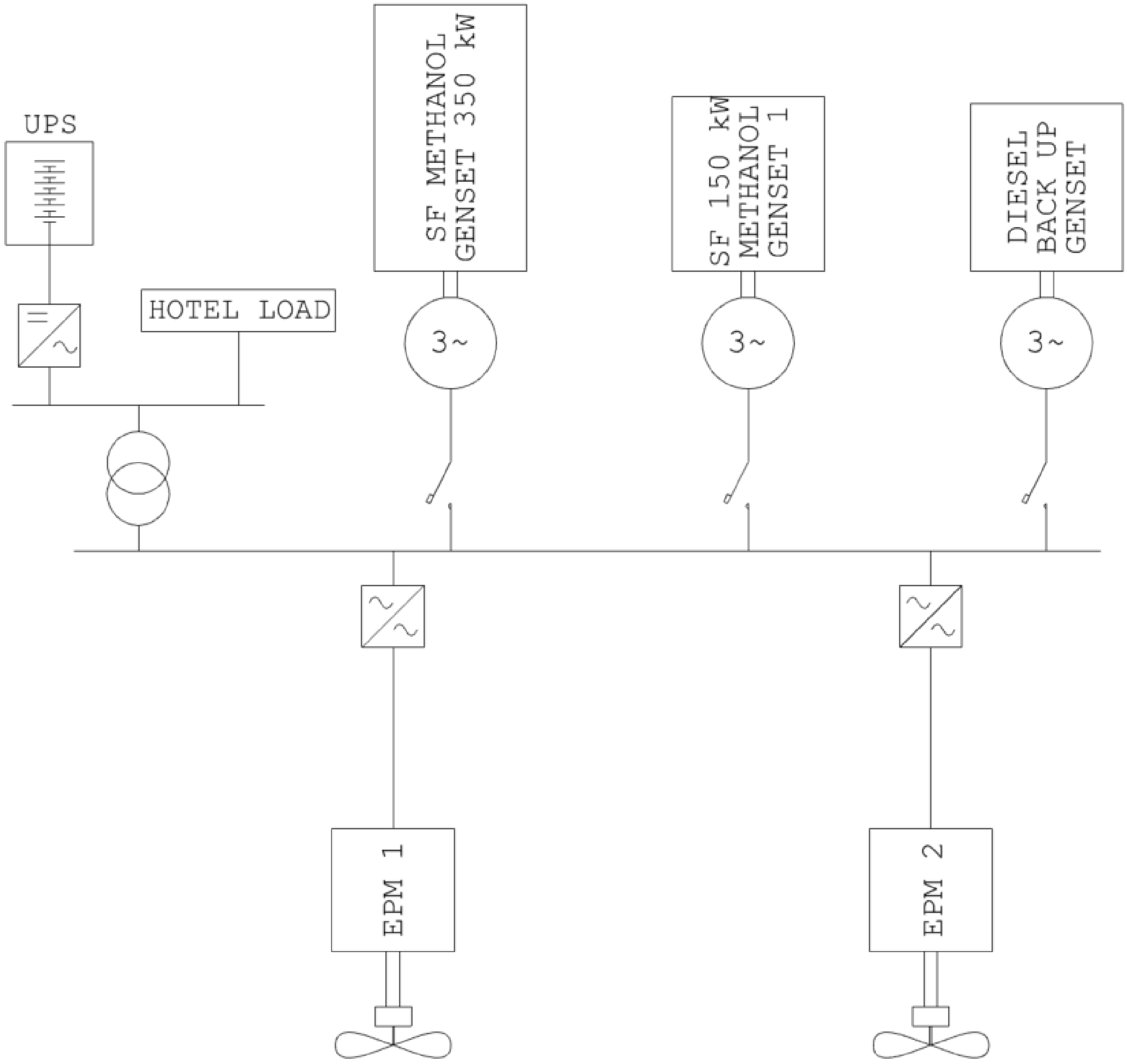

Figure 3-5 Single Fuel Architecture 2

In this architecture, the total installed power is distributed among two gensets of different nominal power, the first one of 150 kW, the second one of 350 kW. A diesel genset of 150 kW is allocated for back up only in case of emergency. The battery system consists in the 24 V Uninterruptible Power System as present in the reference vessel.

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3.3.3 Comparison of system architectures

The analysis was carried out for all four Bunkering Independent Operation (BIOs):

- BIO I (round trip Krems-Bad Deutsch Altenburg at high speed)
- BIO II (waterway maintenance)
- BIO III (Bathymetric survey)
- BIO IV (waterway maintenance after high water event)

BIO I, II and III, which define the typical operation of the vessel, were used to evaluate the performance in terms of efficiency. BIO IV, which is the most energy demanding, was used to calculate the amount of maximum fuel required.

To evaluate the average efficiency of each methanol solution, the Task Power Time Charts (TPTC) developed in deliverable D3.1 for Demo 6 were used. These charts represent the power demand as function of time, as shown in Figure 3-6. The TPTC are divided into N equally-spaced time intervals, in where the required shaft and auxiliary power are defined. To arrive at the power demand at the switch-board, a chain efficiency of 0.92 is applied on the shaft power to account for the power losses in the electric system. For the auxiliary power, no chain efficiency was applied because this was already calculated as the power demand at the switchboard. By adding up the required power for propulsion and auxiliary consumers, the total power demand at each time interval is obtained.

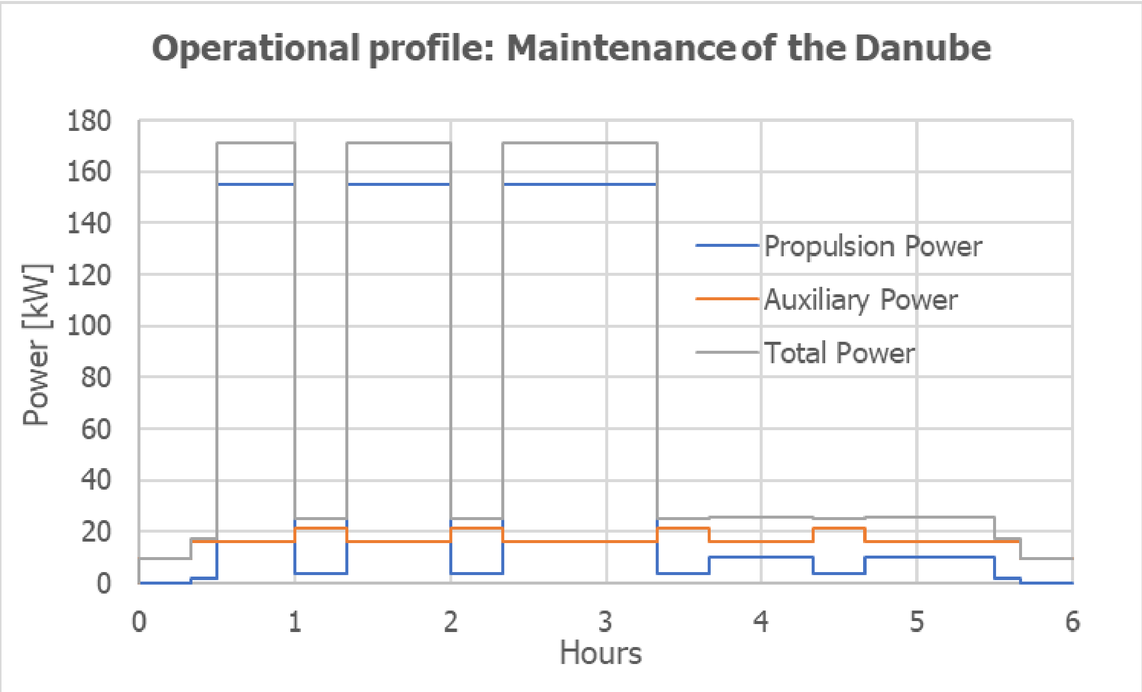

Figure 3-6: Example of a Task Power Time Chart (TPTC) of Demo 6.

For the architectures defined in previous section, the propulsion modes presented in Table 3-5 were defined. At each time interval within the TPTC, the optimum propulsion mode was selected based on the highest engine efficiency.

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Table 3-5: Propulsion modes defined for the candidate system architectures.

Propulsion modes	Architectures			
	Dual Fuel		Single Fuel	
	DF.1	DF.2	SF.1	SF.2
Mode 1: genset 1 only	150	250	500	150
Mode 2: genset 2 only	350	250	-	350
Mode 3: both genset on	500	500	500	500

At a i-th time interval of the TPTC, the load R_i at which the genset(s) are working is calculated as follows:

$$R_i = \frac{P_{tot,i}}{P_{Nom}} \tag{3-2}$$

where:

- R_i is the load at which the genset(s) are operating, defined as % of the nominal power;
- $P_{tot,i}$ is the total electric power demanded at the i-th time interval, in kW; and
- P_{Nom} is the nominal power of the genset(s), in kW.

Based on the engine load, the corresponding genset efficiency and specific fuel consumption are obtained using the efficiency and SFC curves described in section 3.3.1.

At each i-th time interval, the energy consumed is calculated as:

$$E_i = P_{tot,i} \cdot \Delta t \tag{3-3}$$

where:

- E_i is the energy consumed at the time interval, in kWh;
- Δt is the duration of the time interval, in hours; and
- $P_{tot,i}$ is the total electric power demanded at the i-th time interval, in kW.

In addition, the fuel consumed at a i-th time interval can be calculated using the following expression:

$$FC_i = E_i \cdot SFC_i \cdot 1000 \tag{3-4}$$

where:

- FC_i is the fuel consumption at the i-th time interval in kg;
- E_i is the energy consumed at the i-th time interval; and
- SFC_i is the specific fuel consumption of the genset(s) at the i-th time interval, in g/kWh.

Thus, the total fuel consumption can be calculated by summing the fuel consumption for each time interval, as expressed in equation below:

$$FC = \sum_{i=1}^{N} FC_i = 1000 \sum_{i=1}^{N} E_i \cdot SFC_i \tag{3-5}$$

The average efficiency of the genset(s) for a BIO was calculated as the average efficiency of all the intervals.

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The total weight and volume of the gensets for each architecture was calculated based on the gravimetric and volumetric properties from Table 3-2 and Table 3-3. These particulars are only dependent on the size of the gensets, they have the same values for all the BIOs. Ultimately, the well to wake (WTW) GHG emissions were calculated by adding the tank to wake (TTW) and well to tank (WTT) GHG emissions, which were calculated based on the total energy consumed within a BIO and the CO2 emissions per unit energy from Table 3-2 and Table 3-3.

The results of the analysis are presented in Table 3-6, Table 3-7 and Table 3-8. From the results the following observations can be made:

- The fuel weight and volume of the dual fuel architectures is significantly lower than for the single fuel ones. This is because for the dual fuel solutions, part of the energy is provided by diesel, which has a much higher volumetric and gravimetric energy density than methanol.
- The power systems in the single fuel architectures require less weight and volume, due to the simpler injection and limited after treatment systems.
- Architectures DF.1, DF.2 and SF.2, which have two gensets, display a higher efficiency than architecture SF.1 which consists of only one large engine. Despite the maximum power demand is 500 kW, the power demand is significantly lower for most of the operation, causing the single engine to run at low load and therefore low efficiency.
- Single fuel methanol solutions display a much larger reduction in CO2 emissions than the dual-fuel ones, due to the lower carbon content of biomethanol or emethanol compared to diesel.
- Architectures DF.1 and SF.2, consisting of 2 gensets of different size, display a better efficiency than architecture DF.2 consisting of 2 gensets of same size. This is because in DF.1 and SF.2 the smaller engine operates at a higher efficiency point when the total power demand is low, and the larger engine operates at a more efficient load when the total power demand is higher.

Table 3-6: Results overview for BIO I (round trip Krems-Bad Deutsch Altenburg at high speed) different systems architecture.

		BIO I			
		DF.1	DF.2	SF.1	SF.2
Power system weight	kg	4650	4650	2619.5	2619.5
Power system volume	m3	9.2	9.2	4.1	4.1
Uncontained Methanol weight	kg	1239.1	1312.5	2070.3	1755.5
Uncontained Diesel weight	kg	450.4	477.1	147.7	147.7
Uncontained fuel volume	m3	1.5	1.6	2.6	2.4
System efficiency	[-]	39.0%	36.8%	35.8%	39.2%
WTW emission	kgCO2eq	1791.2	1897.2	203.0	185.4

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Table 3-7: Results overview for BIO II (waterway maintenance) for different systems architecture.

		BIO II			
		DF.1	DF.2	SF.1	SF.2
Power system weight	kg	4650	4650	2619.5	2619.5
Power system volume	m3	9.2	9.2	4.1	4.1
Uncontained Methanol weight	kg	189.1	193.7	442.8	407.3
Uncontained Diesel weight	kg	68.7	70.4	147.7	147.7
Uncontained fuel volume	m3	0.23	0.24	0.55	0.50
System efficiency	[-]	33.0%	32.2%	30.1%	34.2%
WTW emission	kgCO2eq	273.3	279.9	31.2	27.4

Table 3-8: Results overview for BIO III (bathymetric survey) for different systems architecture.

		BIO III			
		DF.1	DF.2	SF.1	SF.2
Power system weight	kg	4650	4650	2619.5	2619.5
Power system volume	m3	9.2	9.2	4.1	4.1
Uncontained Methanol weight	kg	82.4	96.6	298.5	259.7
Uncontained Diesel weight	kg	29.9	35.1	147.7	147.7
Uncontained fuel volume	m3	0.10	0.12	0.37	0.32
System efficiency	[-]	32%	28%	25%	34%
WTW emission	kgCO2eq	119.1	139.6	15.9	11.8

3.3.4 Selected architecture

The results from the comparison of architectures presented in previous section were shared with viadonau. After an internal evaluation, viadonau decided to continue with architecture SF.2, due to the higher efficiency, the significant reduction in emissions, and their wish to not use fossil energy carriers in the future. In addition, to avoid the use of diesel in their future push boat, viadonau opted for a 100 kWh battery system instead than the back-up diesel genset.

The architecture showed in Figure 3-7 is a refinement of the architecture already presented in Figure 3-5. The power is generated by two single fuel methanol engines of 350 kW and 150 kW each, connected to the main switchboard at 400 V and 50 Hz, as in the reference vessel. The larger consumers are directly connected to the main switchboard, including the propulsion motors. The secondary switchboard, working at 230 V and 50 Hz, is connected to the main switchboard, and it supplies energy to consumers that require a lower power demand. The 100 kWh back up battery pack is also connected to the secondary switchboard. Ultimately, a 24 V DC board is kept as in the reference design for the electronic components and emergency lighting.

With this architecture, the battery pack could also be used for peak shaving. Based on the TPTC from the operational analysis, no significant power peaks are expected during the operation, so the necessity of using batteries for peak-shaving may be limited. However, the power demand described by the TPTC has a low resolution, therefore short isolated power peaks cannot be captured. It is expected these power peaks, if any, to be captured during the vZEL simulations with dynamic models, where different test cases will be simulated. However, as the main functionality of the battery is emergency back up power, its use during normal operations shall be further assessed.

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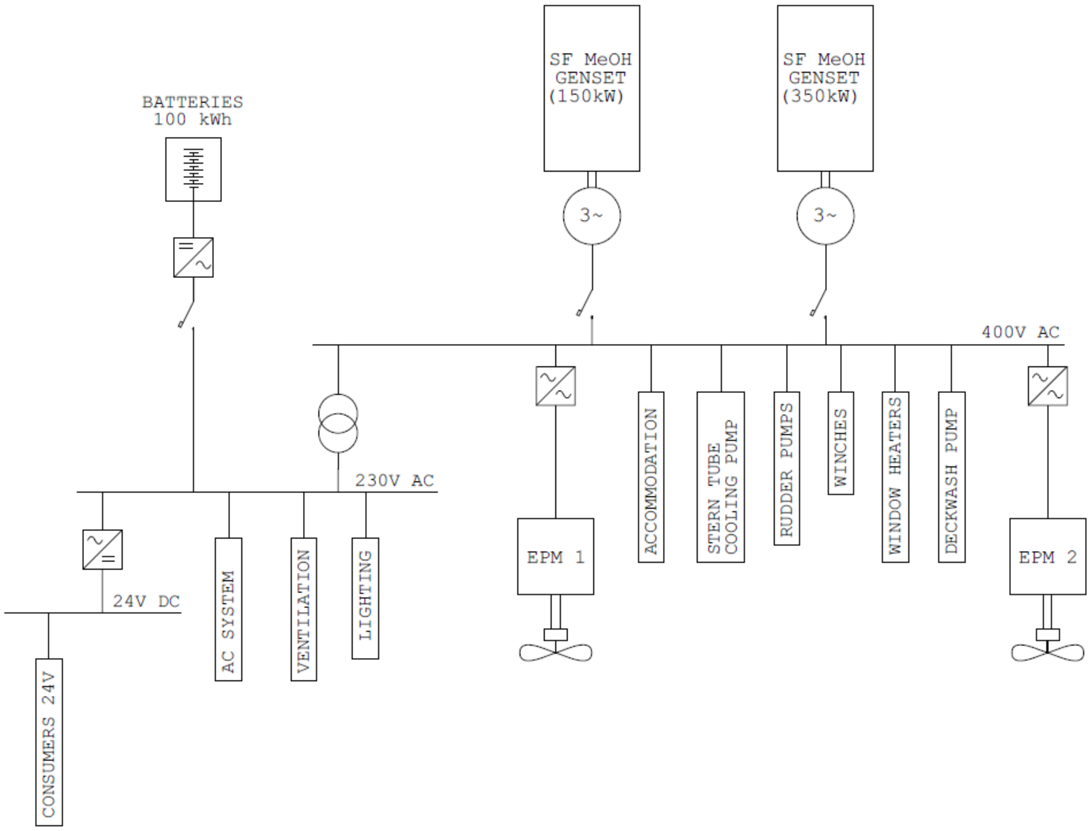

Figure 3-7: Single line diagram of power system architecture SF.2, selected for Demo 6.

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3.4 General arrangement

3.4.1 Description of the general arrangement

Generally speaking, the design philosophy has been to keep the modifications of the reference vessel to a minimum. This was intended to save cost, retrofit time and complexity. For this reason the reference vessel was used as a starting point to the design.

The structure of the vessel has been kept as close as possible to that of the reference ship. Similar to the Bad Deutsch Altenburg, the vessel has a transverse frame system with a frame spacing of 500 mm from the aft end up to frame 29. From frame 29 onwards, the spacing is reduced to 400 mm. The ship has a single bottom throughout its entire length, and is divided longitudinally by five watertight transverse bulkheads which extend from the bottom shell plating up to the main deck. The new design has then one more transversal bulkhead compared to the reference design, this was necessary to arrange the fuel tanks on board of the vessel.

Below main deck, the main compartments or group of compartments are as follows: forepeak, tank spaces, engine room, fuel preparation room, propulsion room, and aft peak. On main deck, the aft part of the superstructure between frame 5 and 14 was raised up to wheelhouse deck to create more space.

The general arrangement plan is presented in Annex 1 and in points below the main compartments of the ship are described in more detail:

- **Propulsion room:** The engine room of the previous ship was converted into a propulsion room, where the propulsion motors and their corresponding power converters are located. As this compartment requires less space, and to allow more room for the engine room, the bulkhead on frame 15 was moved to frame 13. This room is accessed using stairs with direct access from main deck.

- **Engine room:** The engine room was moved towards the midship, between frames 13 and 25, at a similar location as the tank compartment (Tankraum/Storeraum) in the Bad Deutsch Altenburg. At the sides of the aft end of the engine room are located the box coolers, which are used for the cooling system of the gensets. In addition, the aft end of the engine room is connected to the funnel casing, where the equipment related to the exhaust gas system is placed. The casing is also used as out duct for the ventilation of the engine room.

  In the middle/aft part of this compartment, the methanol gensets are located inside a casing which serves as secondary barrier for methanol. Also, at the mid-forward part of the engine room, an urea tank is placed for the SCR system.

  Air is supplied to the engine room via two ducts located between frames 18a and 18c, which have direct access to the outside at the wheelhouse deck. Inside these ducts, the ventilation fans are located. At the forward end of the engine room, on starboard side, the main switchboard and other main electrical equipment is placed.

  In addition to the equipment mentioned above, the engine room is used to allocate other equipment, such as the water boiler, heaters, general service, fi-fi and sanitary pumps, etc.

  The Engine room is accessed through via stairs connected to the accommodation space above, similar to the reference ship. Since the total floor area is less than 35 m^2, no secondary exit is required.

- **Fuel preparation room.** This compartment is located between frames 20 and 25 on the port side. Here, the equipment necessary to transfer and prepare the methanol is placed. The room is accessed via a ladder with direct access to the main deck.

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- **Methanol tanks.** The fuel bunker tanks are located between frames 26 and 29. These tanks are provided with a cofferdam that acts as secondary barrier at the forward, aft and top. As the tank are inerted, no secondary barrier is required with the shell plating. A minimum of 500 mm has been left for the cofferdam in case the space must be inspected. Due to the limited space of the cofferdam, attention should be paid when constructing the tank (direction of stiffeners) to allow for inspection of the cofferdam.

  At the aft side of the fuel tanks are located the overflow and bilge tanks. The overflow is located at the top to facilitate the connection when overflowing; the bilge tank is located at the lowest point to facilitate collection of methanol spillage.

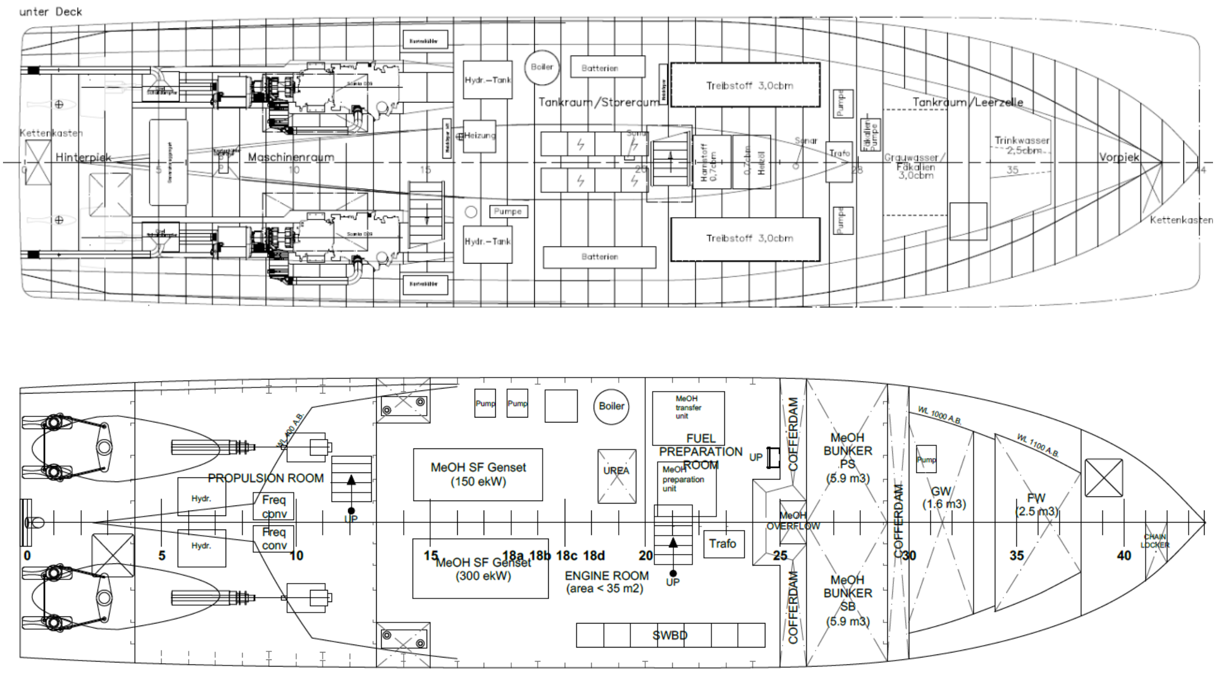

Figure 3-8: Comparison of the spaces below main deck for the Bad Deutsch Altenburg (top) and the new design (bottom).

- **Fresh water tank:** Located between frames 34 and 38 with a capacity similar to the fresh water tank of the reference vessel.

- **Grey water tank:** Located between frames 30 and 34 with a capacity similar to the grey water tank of the reference vessel.

- **Steering gear room:** Located between the aft end up to frame 4, similar to the reference vessel.

- **Accommodation spaces:** Accommodation spaces are located on the main deck, similar to the Bad Deutsch Altenburg. As the entrance to the fuel preparation room interferes with the accommodation spaces, these have been rearranged slightly.

- **Battery room:** Located in the superstructure between frame 5 and 11. Here, the batteries used for the 24V consumers and the 100 kWh back-up battery pack are placed.

- **Inert gas room:** Space where the inert gas generator and other main components of this system are placed. The nitrogen generator was preferred to the vessels ("bottles") option due

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to its higher autonomy. This was considered quite important as nitrogen gas is required at all time during methanol operations.

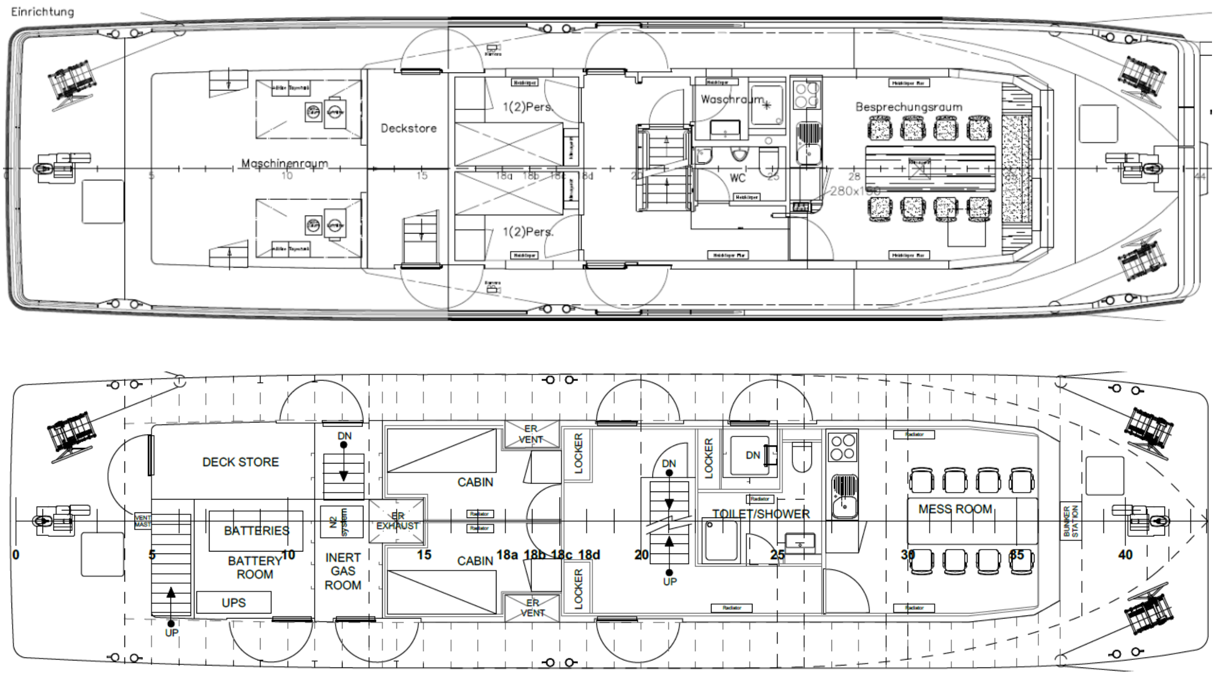

Figure 3-9: Comparison of the spaces on main deck for the Bad Deutsch Altenburg (top) and the new design (bottom).

3.4.2 Use of methanol, main influence on the design

The use of methanol influenced significantly the design of the vessel. In following subsections the main aspects of the design influenced by the use of methanol are described.

3.4.2.1 Methanol tanks

ES-TRIN allows two types of methanol tanks: inerted and non-inerted tanks. The major difference between the two is that for the non-inerted tanks the risk of explosive atmospheres is mitigated by increasing the number of air changes per hour in the surrounding spaces, whereas for inerted tanks this is achieved by introducing inert gas in the tank.

ES-TRIN regulations impose that methanol tanks located below deck shall be surrounded by a secondary barrier for leakage containment. As depicted in Figure 3-10, the extension and arrangement of the secondary barrier depend on the tank location, surrounding spaces, and tank type.

For non-inerted tanks, the tank must be surrounded by a secondary barrier with a distance of at least 0.6 m from the shell plating. The secondary barrier can be omitted when the tank is bounded to the shell plating and while it remains below the lowest possible waterline. For the inerted tanks, the secondary barrier can be omitted when the tank is bounded to the shell plating, but the tank can extend above the lowest possible waterline.

Due to the small size and reduced draught of this vessel, not much space is available to place the methanol tanks, unless the inerted tank option is selected. Therefore it was decided to continue with this option.

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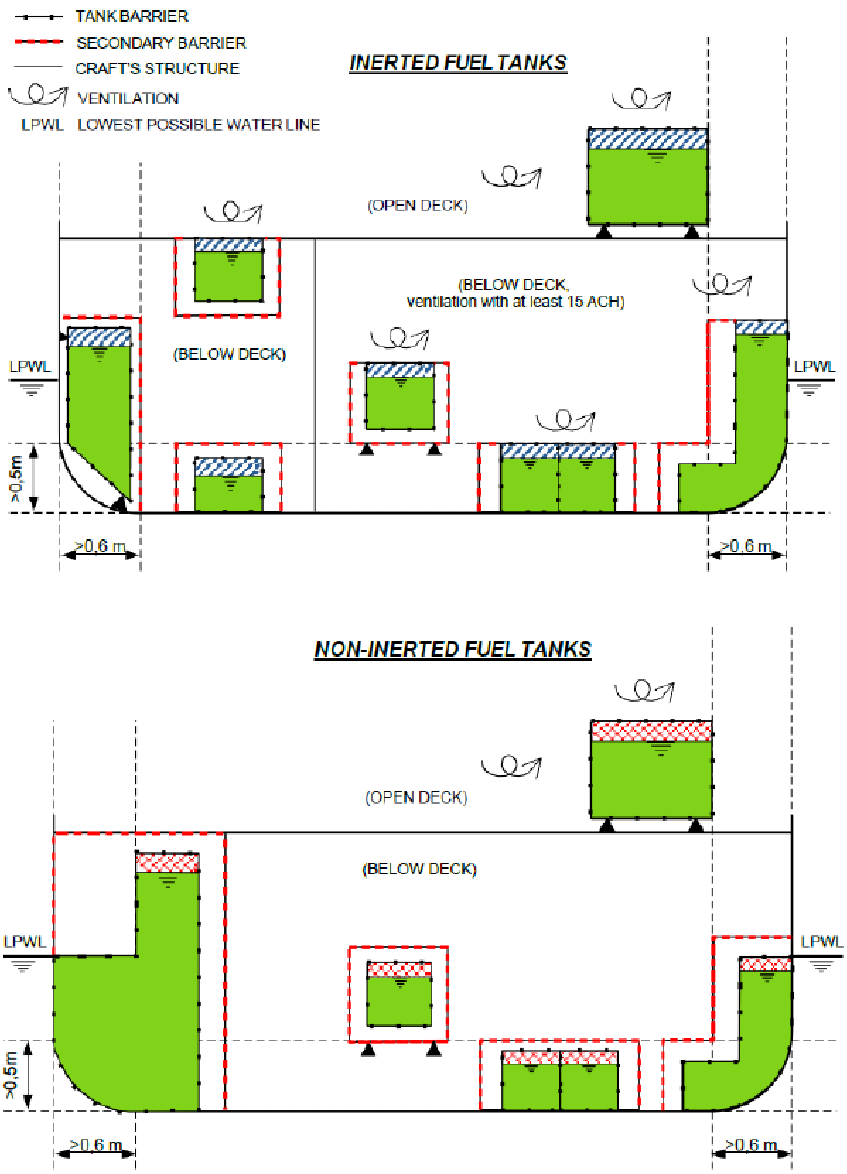

Figure 3-10: Illustration of typical tank arrangements in accordance with ES-TRIN, Annex 8, (2.2.3) and (2.2.4); other configurations are possible

3.4.2.2 Engine room

ES-TRIN regulations allow two options for the engine room: ventilated or gas-safe engine room. Similar to the tank case, for the ventilated engine rooms the risk of explosive atmospheres is mitigated by increasing the number of air changes per hour, whereas for gas-safe engine rooms this is achieved by implementing a design that ensures no methanol leakage in the engine room when a single failure in the methanol system occurs.

Gas safe engine rooms are considered non-hazardous areas, in contrast to ventilated engine rooms. If the engine room is of ventilated type, it will be considered a hazardous area. This means that in the engine room only electric equipment suitable for that hazardous area is permitted. In addition, the location of the main switchboard might compromise the use of this compartment.

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As the entrance to the engine room is via a staircase through the accommodation spaces on main deck, an airlock shall be fitted to avoid extending the hazardous area into the accommodation spaces. This would complicate the design and would reduce the available space in the engine room. Based on these considerations, a gas safe engine room concept was selected. This concept requires that methanol piping and equipment should be installed within ventilated ducts or enclosures with mechanical ventilation for extraction.

3.4.2.3 Hazardous areas

The use of methanol introduces hazardous areas on the ship, which are areas where explosive atmospheres may occur. To avoid explosive atmospheres from extending into other less hazardous or non-hazardous areas, the ventilation inlets/outlets of these spaces should be located from a certain distance of spaces onboard. ES-TRIN regulations state the following:

- *Air for ventilation of non-hazardous spaces shall be taken from non-hazardous areas which are located at least 1,50 m from the boundaries of any hazardous area.*
- *Air outlets from hazardous spaces shall be located in an open area which has the same or less hazard than the ventilated space*
- *Air outlets from non-hazardous spaces shall be located outside any hazardous area*

However, ES-TRIN regulations do not specify the extension of the hazardous zones. In this regard, in the case of methanol ES-TRIN refers to the standard EN 60079-10-2:2015, concerning explosive gas atmospheres. Standard EN 60079-10-2:2015 is meant mainly for industrial chemical plants, where the definition of hazardous areas is rather complex. First, the sources of release are identified, and then depending on the grade of release in combination with the effectiveness of ventilation (dilution effectiveness), the type and extension of the hazardous area is defined.

As such detailed study of the hazardous areas is out of the scope of this project, a simpler approach was followed. For such, it was checked how regulations for seagoing vessels sailing on methanol would affect the design. The choice for using regulations for seagoing vessels is because they are simpler to apply. For seagoing ships, the definition and extension of hazardous zones is based on the type of compartment and/or opening, and the distance to these spaces or openings. For the definition of hazardous zones, the regulations defined in MSC.1/Circ.1621[6], were used.

Following the regulations for methanol fuelled sea-going ships, the hazardous areas shown in Figure 3-11 will be present on the vessel. It can be seen that the majority of the ship would be influenced by the hazardous areas, making the design impractical. The item that limits the design the most is the methanol ventilation mast, which introduces a sphere and cylinder of hazardous zone 1 with 6 m radius, with 4 m additional radius for zone 2. The ventilation inlet/outlet of the engine room and other spaces are within these hazardous areas, in contradiction with what ES-TRIN and MSC.1/Circ.1621 require.

An option could be to move the ventilation mast to the foreship, but this would interfere with the operation of the vessel, would add a blind zone for wheelhouse, and the entrance to the wheelhouse would be located inside the hazardous area. If the hazardous area introduced by the ventilation mast were not present, it could be possible to fulfil the regulations for the minimum distance between ventilation openings and hazardous areas. However, the design would become more complex as the entrance

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[6] This MSC Circular introduces amendments to SOLAS chapters II-1, II-2, and the IGF Code, to include the use of methanol as low flash point.

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and ventilation of the spaces located at the foreship, and the deaeration of fresh water and grey water tanks, should be rerouted to avoid being located inside the hazardous area at the bow.

It seems that regulations concerning hazardous areas for methanol fuelled sea going ships are too conservative for smaller ships, as they are independent of the ship size. For instance, for a 200 m LNG tanker the hazardous areas of the ventilation mast have little influence on the design, whereas for a 20 m push boat it makes its design impractical.

Maybe the application of the EN 60079-10-2:2015 results in hazardous areas of less extension, but its complexity makes it hard to check at initial design stage. An option could be to perform an early HAZID study as stated in Article 30.04 of ES-TRIN, with the goal to identify and evaluate the risks associated with the use of methanol, instead of limiting the design based on too conservative rules that may not be suitable for the limited amount of methanol present on the vessel.

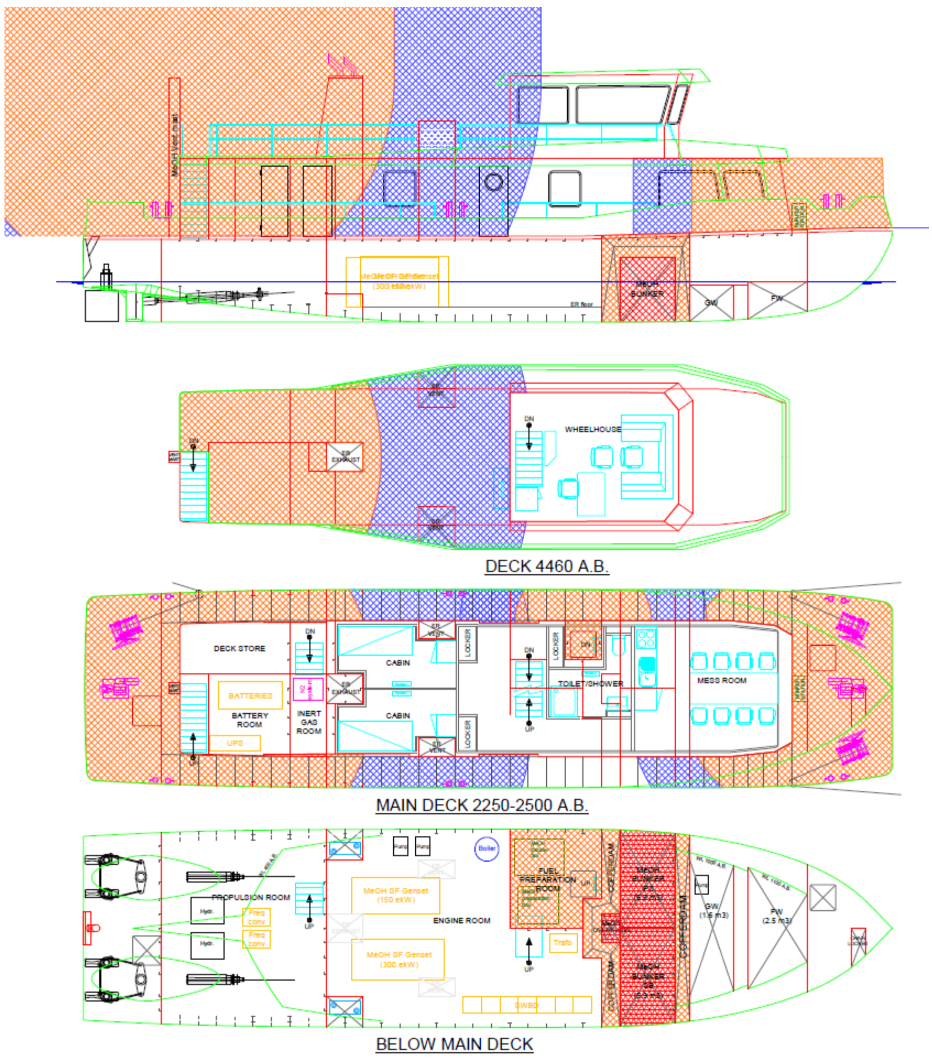

Figure 3-11: Hazardous areas on the methanol-fuelled push boat according to IMO MSC.1/Circ.1621.

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3.5 Lightship weight calculation

The lightship weight of the Bad Deutsch Altenburg and its centre of gravity were used as starting point for the calculation. Then, the components of the diesel system were removed, and other components necessary for the use of methanol were added. In addition, the increase in weight due to the structural changes was also estimated based on the additional volume and a steel weight coefficient. As a summary, the following items were removed, added or moved:

- **Removed items:**
  - Propulsion engines
  - Gearboxes
  - Auxiliary genset

- **Added items:**
  - Propulsion motors and other main electrical components
  - Additional steel weight of superstructure
  - Additional steel weight of cofferdams around methanol tanks
  - Steel weight of funnel
  - Inert gas system
  - Back-up battery pack
- **Moved Items:**
  - Main switchboard
  - SCR components
  - 24V batteries

The change of location of smaller items such as pumps, boilers, box coolers, etc. was not considered as the influence of their location on the calculation of the centre of gravity is limited. In Table 3-9 an overview of the lightship calculation is presented.

From the lightship calculation presented in Table 3-9, it is expected that the lightship increases 14 % with respect to the reference ship.

Regarding the longitudinal position of the centre of gravity of the lightship weight, it would move 1 % to the aft, which is not considered an extreme change. In addition, as the bunker tanks are located at the bow, they will (partly) compensate the additional trim to the aft, at least at the loading conditions with 100 % and 50 % consumables.

Concerning the vertical position of the lightship weight, it is expected to remain practically at the same location, which is positive in terms of stability. However, as the tank arrangement has changed with respect to the Bad Deutsch Altenburg, the hydrostatic equilibrium and the initial stability of the new design must be evaluated considering the influence of the consumables on the stability for all loading conditions.

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Table 3-9: Lightship weight calculation for the new methanol-powered push boat.

Item	Weight [t]	LCG [m]	TCG [m]	VCG [m]	L. Mom [t*m]	T. Mom [t*m]	V. Mom [t*m]
LSW BDA	71.980	10.082	0.000	2.196	725.70	0.00	158.07
Removed items							
Propulsion engine SB	-0.998	6.390	-1.400	1.200	-6.37	1.40	-1.20
Propulsion engine PS	-0.998	6.390	1.400	1.200	-6.37	-1.40	-1.20
Gearbox SB	-0.400	5.400	-1.400	0.910	-2.16	0.56	-0.36
Gearbox PS	-0.400	5.400	1.400	0.910	-2.16	-0.56	-0.36
Auxiliary Genset	-0.730	2.680	0.000	2.300	-1.96	0.00	-1.68
Added items							
MeOH SF genset 150 ekW	2.185	8.900	0.900	1.100	19.45	1.97	2.40
MeOH SF genset 350 ekW	2.783	8.950	-0.880	1.100	24.91	-2.45	3.06
MeOH preparation box	0.300	12.300	0.620	0.750	3.69	0.19	0.23
MeOH transfer box	0.300	12.300	1.930	0.750	3.69	0.58	0.23
N2 generator	0.330	6.900	1.290	3.450	2.28	0.43	1.14
Batteries	0.910	5.800	-0.220	3.400	5.28	-0.20	3.09
Propulsion motor SB	1.250	5.200	-1.400	0.800	6.50	-1.75	1.00
Propulsion motor PS	1.250	5.200	1.400	0.800	6.50	1.75	1.00
Frequency converters	0.720	4.600	0.000	1.500	3.31	0.00	1.08
Additional superstructure volume (aft)	1.402	4.500	0.000	3.900	6.31	0.00	5.47
Funnel	0.432	7.000	0.000	5.600	3.02	0.00	2.42
Extra steel volume cofferdams	1.130	15.250	0.000	1.250	17.23	0.00	1.41
Stores in new deck store	0.500	4.400	1.000	3.200	2.20	0.50	1.60
Moved items							
Batteries PS old location	-0.800	10.700	1.780	1.200	-8.56	-1.42	-0.96
Batteries SB old location	-1.000	10.88	-1.780	1.200	-10.88	1.78	-1.20
Batteries (UPS) new location	1.800	4.000	-1.500	3.200	7.20	-2.70	5.76
Main SWBD old location	-2.000	10.620	0.000	1.050	-21.24	0.00	-2.10
Main SWBD new location	2.500	12.000	-2.100	1.050	30.00	-5.25	2.63
Particulate filter unit SB old loc.	-0.027	4.400	-1.300	2.000	-0.12	0.04	-0.05
Particulate filter unit PS old loc.	-0.027	4.400	1.300	2.000	-0.12	-0.04	-0.05
SCR unit SB old loc.	-0.065	4.400	-1.300	2.000	-0.29	0.08	-0.13
SCR unit PS old loc.	-0.065	4.400	1.300	2.000	-0.29	-0.08	-0.13
Reductant tank SB old loc.	-0.053	4.400	-1.300	2.000	-0.23	0.07	-0.11
Reductant tank PS old loc.	-0.053	4.400	1.300	2.000	-0.23	-0.07	-0.11
Particulate filter unit SB new loc.	0.027	6.800	-1.300	2.000	0.18	-0.04	0.05
Particulate filter unit PS new loc.	0.027	6.800	1.300	2.000	0.18	0.04	0.05
SCR unit SB new loc.	0.065	6.800	-1.300	2.000	0.44	-0.08	0.13
SCR unit PS new loc.	0.065	6.800	1.300	2.000	0.44	0.08	0.13
Reductant tank SB new loc.	0.053	6.800	-1.300	2.000	0.36	-0.07	0.11
Reductant tank PS new loc.	0.053	6.800	1.300	2.000	0.36	0.07	0.11
New LSW	**82.447**	**9.803**	**-0.080**	**2.202**	808.26	-6.59	181.52

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3.6 Equilibrium condition and stability check

In order to evaluate the stability of the new design, the equilibrium condition was calculated and a first check on the initial intact stability was carried out.

The initial stability check was performed at the same loading conditions as for the Bad Deutsch Altenburg, namely:

- LC1 - 10% consumables, 100% grey water
- LC2 - 50% consumables, 50% grey water
- LC3 - 100% consumables, 0% grey water

Where the consumables consist of the fuel, fresh water and urea tanks. The part of the deadweight concerning crew and stores remained unchanged.

For the stability calculation, the weight and centre of gravity of the ship was calculated using the new lightship weight and the deadweight with the new tank arrangement. In addition, a free surface correction was applied for the vertical position of the centre of gravity.

Regarding the stability criterion to fulfil, for this type and size of vessel ES-TRIN[7] does not specify a minimum value of the metacentric height GM. In order to stablish a criterion for the minimum GM, a minimum value of 15 cm was selected based on the Intact Stability Code (IS 2008), for sea-going ships.

From the draught and trim values in Table 3-10, it can be seen that the trim of the new design will be slightly more pronounced to the stern for condition 1, and to the bow for conditions 2 and 3, but within an acceptable range, close to the reference vessel.

The draught will increase about 10 to 15 cm, due to the additional weight of the methanol-electric concept. As a result, the following points should be further assessed in the design:

1. Compliance with the minimum freeboard required by ES-TRIN, as the deeper draught will reduce the freeboard of the vessel.
2. Area under the GZ curve, as the downflooding points will be reached at a lower heeling angle,
3. Structural scantlings, as the deeper draught may exceed the scantling draught of the reference vessel, which will require a new scantling calculation based on a deeper scantling draught.

Table 3-10, it can be seen that for loading condition 1 and 2 the GM is reduced about 30 cm with respect to the reference vessel. For loading condition 3, corresponding to 100% provision, the reduction in GM is less due to the positive effect of the filled fuel tanks, which lower the KG. However, despite this reduction in GM, the minimum GM value is about 78 cm, which is a high value and well above the 15 cm criterion.

It should be noted that in this preliminary concept design, only a check on the intact stability at small heeling angles was conducted. To determine the intact stability of the vessel as a whole, a check of the area under the GZ curve, considering the downflooding angle, must be conducted at a later stage.

From the draught and trim values from Table 3-10, it can be seen that the trim of the new design will be slightly more pronounced to the stern for condition 1, and to the bow for conditions 2 and 3, but within an acceptable range, close to the reference vessel.

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[7] ES-TRIN Article 3.02 Rg. 3: *"The stability of vessels shall correspond to their intended use."*

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The draught will increase about 10 to 15 cm, due to the additional weight of the methanol-electric concept. As a result, the following points should be further assessed in the design:

1. Compliance with the minimum freeboard required by ES-TRIN, as the deeper draught will reduce the freeboard of the vessel.
2. Area under the GZ curve, as the downflooding points will be reached at a lower heeling angle,
3. Structural scantlings, as the deeper draught may exceed the scantling draught of the reference vessel, which will require a new scantling calculation based on a deeper scantling draught.

Table 3-10: Results of the equilibrium and initial intact stability check of the reference ship Bad Deutsch Altenburg (BDA) and the new design. Negative trim values are for trim to the stern.

Loading condition	Ship	Mean draught [m]	Trim [m]	KMt [m]	KG [m]	GMt [m]	GMt_0 Compliance
LC 1 - 10% provisions	BDA	1.10	-0.05	3.257	2.140	1.117	**OK**
	New design	1.20	-0.20	3.055	2.230	0.825	**OK**
LC 2 - 50% provisions	BDA	1.15	0.05	3.168	2.088	1.080	**OK**
	New design	1.30	0.10	2.934	2.152	0.782	**OK**
LC 3 - 100% provisions	BDA	1.20	0.17	3.089	2.069	1.020	**OK**
	New design	1.35	0.30	2.898	2.100	0.798	**OK**

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3.7 Fuel system diagram

In addition of the general arrangement plan, a conceptual P&I diagram was developed to support the concept design of the power and energy system of the methanol-electric push boat. The diagram is presented in Figure 3-12, and in more detail in Annex 2. The main components of the system are described in points below:

- **Bunker station.** The bunker station is located on open deck to provide sufficient natural ventilation. The station is provided with one connection for the liquid methanol and another one for the vapour line, which returns the displaced vapour from the fuel tanks when bunkering. To monitor the pressure and flow of the fuel while bunkering, the bunker station is provided with flow and pressure transmitters. In addition, a drip tray is located under the station to collect any fuel spillage.

- **Bunker tanks.** Bunker tanks are filled directly from the bunker station. They are provided with a secondary barrier when necessary, as described in section 3.4.2.1. The tanks are provided with level alarms as well as pressure and level transmitters. Also, the tank is provided with a pressure relief valve and a quick release valve for emergency shut-down and to avoid overpressure in the tank.

- **Overflow tank.** The overflow tank collects the excess of methanol when the bunker tanks are overfilled by accident. This tank is surrounded by a secondary barrier when necessary, as described in section 3.4.2.1. The tank is provided with a pressure relief valve to avoid overpressure in the tank.

- **Bilge tank.** The bilge tank collects any spillage that may occur in the interbarrier space of tanks, in the drip trays of equipment of the methanol fuel system, and in the bilge wells of compartments containing any equipment that belongs to the methanol fuel system. The spillage is transferred via the methanol drainage/bilge system, which is independent of the regular bilge system of the vessel. If a methanol spillage can not be discharged by gravity to the methanol bilge tank, an auxiliary bilge pump of another arrangement should be provided in the system for this purpose. Also, this tank is surrounded by a secondary barrier when necessary, as described in section 3.4.2.1. The tank is provided with a pressure relief valve to avoid overpressure in the tank.

- **Fuel transfer unit.** Located in the fuel preparation room, this unit is used to transfer the fuel between the bunker tanks and the preparation unit, and to transfer fuel between bunker tanks. The unit consists mainly of transfer pumps and valves.

- **Fuel preparation unit**. Located in the fuel preparation room, this unit is used to prepare the fuel for the consumers. It consists of filters and heat exchangers to heat the methanol running through the supply line and to cool the methanol from the return line.

- **Methanol gensets.** The gensets are located in the engine room inside a casing that acts as secondary barrier. Each genset is provided with a supply and return methanol line coming from the fuel preparation unit.

- **Methanol piping**. All piping containing liquid or vapour methanol is to be of double wall type as it is located below deck. The piping shall be grounded to the ship structure to dissipate static electricity. Even though not included in the diagram, all sections of the fuel system should be arranged so that the system can be drained and purged of fuel. In addition, the piping system should be arranged so that any leakage of methanol fuel into the interbarrier spaces can be drained or purged.

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- **Deaeration/venting piping.** Each methanol tank is provided with a deaeration pipe which leads overboard any vapour release in case the set point of the pressure release valves of the tanks is reached. Deaeration lines are also used as overflow lines, and are free of shut-off valves. To avoid the transmission of flames between tanks in the event of fire, a flame arrester is fitted between the single lines and the main venting line. Venting lines are not provided with a secondary barrier as it is assumed they will be located at least 0.6 m from the ship's side. If this is not possible, a secondary barrier must be provided following ES-TRIN regulations.

- **Inert gas piping**. To avoid the creation of a explosive atmospheres, all methanol tanks are provided with a connection from the inert gas system.

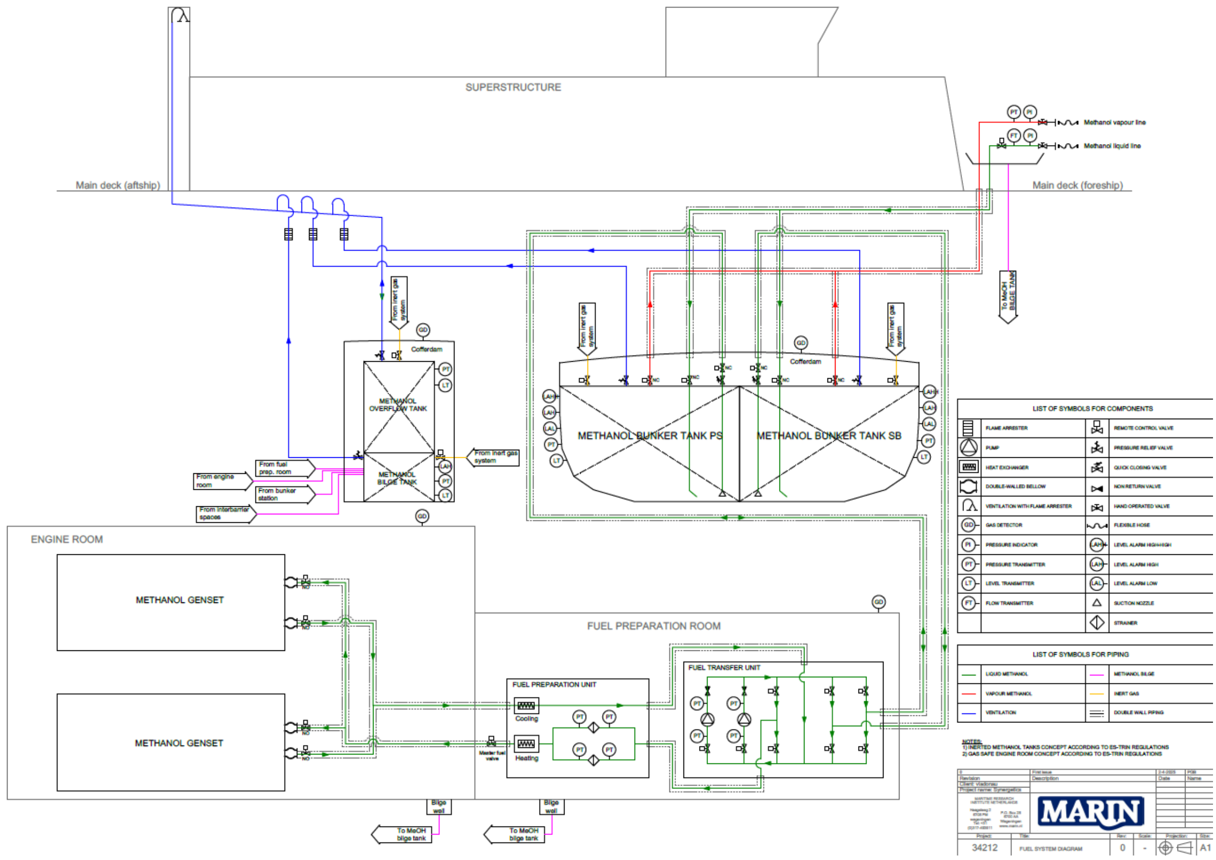

Figure 3-12: Fuel system diagram of the methanol-electric push boat indicating the methanol liquid line (green), methanol vapour line (red), venting/deaeration line (blue) and inert gas line (magenta).

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4. | Performance assessment in Zero Emission Lab

This section will be updated after the assessment of the performance is carried out in MARIN's Zero emission lab, scheduled by the end of 2025.

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5. | Conclusions and recommendations

This section will be updated after the assessment of the performance is carried out in MARIN's Zero Emission Lab (ZEL), scheduled by the end of 2025.

From the concept design carried out for this Demonstrator, the following conclusions found:

- From the methanol-electric architectures that have been compared, the single fuel architecture with two gensets of different size displays the highest efficiency and lowest fuel consumption based on the Bunker Independent Operations defined during the operational analysis.
- Based on the lightship calculation, the lightship weight of the new methanol-electric concept will be approximately 14 % higher than that of the reference vessel Bad Deutsch Altenburg (diesel direct concept).
- Based on the intact stability calculation for small heeling angles, the new design will have a high metacentric height but lower than the reference vessel Bad Deutsch Altenburg.
- The use of methanol introduces hazardous zones on the vessel that may make the design unfeasible, the design shall be subjected to a Risk Assessment. The definition and extension of the hazardous zones must be addressed at an early design stage. Close cooperation with Class during the design phase can be beneficial to assess these kind of safety aspects.
- Despite ES-TRIN contains regulations for the usage of methanol on board, combustion engines for inland waterway vessels require an approval within the scope of Regulation (EU) 2016/1628 (NRMM Stage V). This regulation does not list methanol as a reference fuel. Recently, it was announced by DG GROW that hydrogen will be included. For methanol the situation remains unclear due to formaldehyde forming and corresponding unregulated and secondary pollutant emissions. As a consequence of this legal barrier, manufacturers of engines with a power range matching inland waterway vessels have reduced or even stopped their activities to solve technical issues and produce engines for this niche market. As a result, no suitable engines will be available within the near future which will hinder the further development of the design of this ship.

The following recommendations are given for this Demonstrator based on the work carried out during the concept design:

- Due to the lack of methanol engines of low power range available on the market, the results of the conceptual design are based diesel gensets of comparable size and injection system as the methanol ones. At a later design stage, it is recommended to use engine data from manufacturers to check that the foreseen arrangement is still valid.
- The deeper draught of the new design may exceed the scantling draught of the current vessel. It should be checked if the scantlings of the reference vessel are still sufficient or if they need to be increased.
- Intact stability check of the new design has been carried for small angles only. It is recommended to carry out intact stability calculations for larger heeling angles (criteria based on GZ curve) to demonstrate the stability of the vessel is sufficient.
- An early HAZID study is recommended to identify and evaluate the risks associated with the use of methanol instead of limiting the design based on too conservative rules that may not be suitable for the limited amount of methanol present on the vessel.

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Annex 1 | List of design requirements

Design requirements considered in the concept design.

Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
Ship owner	Rules and Regulations	The design should be compliant with ES-TRIN rules	Legislation	
Ship owner	Reference vessel	The reference vessel is the vessel called Bad Deutsch-Altenburg Austrian waterway operator viadonau.	Generic	
Ship owner	Reference vessel	The dimensions of the refererence vessel can be varied in consultation with viadonau to explore the feasibility of alternative energy carriers	Generic	
Ship owner	Design Life	The design life of the vessel shall be 30 years	Generic	
Ship owner	Operational days per year	The vessel shall have 55 operational days per year (an average of 1 days per week + 5 days special mission)	Performance	
Ship owner	Operational Environment	The vessel operates along the Danube River and its operations range for 701 km	Performance	
Ship owner	Operational Environment	The new design shall be able to operate for about 100 hours (or little less) in consultation with viadonau.	Performance	
Ship owner	Emissions	The new design should be as close to zero emissions as possible. The reference design is made by a "traditional" diesel direct system running on HVO100 (Stage V engines)	Environment	
Ship owner	Bunker Independant Operation I	The new design shall be able to perform the Bunker Independent Operation I (BIO I), sailing from Bad Deutsch - Altenburg to Krems an der Donau and back	Operational Profile	

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
Ship owner	Bunker Independant Operation II	The new design shall be able to perform the Bunker Independent Operation II (BIO II), concerning maintenance tasks of the Danube River (waterway marking and maintenace)	Operational Profile	
Ship owner	Bunker Independant Operation III	The new design shall be able to perform the Bunker Independent Operation III (BIO III), bathymetric Survey operations	Operational Profile	
Ship owner	Bunker Independant Operation IV	The new design shall be able to perform the Bunker Independent Operation IV (BIO IV), Maintenance of the Danube River after extreme event (with barge).	Operational Profile	
Ship owner	Fuel Types	The new design shall run using methanol as main energy carrier	Performance	
Ship owner	Fuel Types	The vessel should be able to sail on Diesel when Methanol is not available and complete its route without stops to its next port of call.	Reliability	
Ship owner	Bunker margin	The bunker margin shall be 20% above the estimated required effective energy of the most criticial BIO	Performance	
ES-TRIN Article 5.07.1	Stopping capacity	Vessels and convoys shall be able to stop facing downstream in good time while remaining adequately manoeuvrable.	Safety	

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN Article 5.07.2	Stopping capacity	Where vessels and convoys with a length L of not more than 86 m and with a breadth B of not more than 22,90 m the stopping capacity mentioned above may be replaced by turning capacity.	Safety	
ES-TRIN Article 5.08.1	Capacity for going astern	Where the stopping manoeuvre required by Article 5.07 is carried out in standing water it shall be followed by a navigation test while going astern.	Safety	
ES-TRIN Article 5.09.1	Capacity for taking evasive action	Vessels and convoys shall be able to take evasive action in good time. That capacity shall be proven by means of evasive manoeuvres carried out within a test area as referred to in Article 5.03.	Safety	
ES-TRIN Article 5.10.1	Turning capacity	Vessels and convoys with a length L of not more than 86 m or with a breadth B of not more than 22,90 m shall be able to turn in good time. That turning capacity may be replaced by the stopping capacity referred to in Article 5.07. The turning capacity shall be proven by means of turning manoeuvres against the current.	Safety	
Outcome of the operational analysis	BIO I - Effective Energy	The required energy to perform BIO I is 3485.8 kWh, without considering any bunker margin	Performance	
Outcome of the operational analysis	BIO I - Average power	The required average power during BIO I is 201.1 kW	Performance	

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
Outcome of the operational analysis	BIO I - Maximum power	The max power required during BIO I is 316.2 kW	Performance	
Outcome of the operational analysis	BIO I - Autonomous range	The autonomous range for BIO I is 227 km	Performance	
Outcome of the operational analysis	BIO I - Endurance	The required endurance for BIO I is 17.3 hours	Performance	
Outcome of the operational analysis	BIO II - Effective Energy	The required energy to perform BIO I is 455 kWh, without considering any bunker margin	Performance	
Outcome of the operational analysis	BIO II - Average power	The required average power during BIO I is 75.8 kW	Performance	
Outcome of the operational analysis	BIO II - Maximum power	The max power required during BIO I is 171.1 kW	Performance	
Outcome of the operational analysis	BIO II - Autonomous range	The autonomous range for BIO I is 36.7 km	Performance	
Outcome of the operational analysis	BIO II - Endurance	The required endurance for BIO I is 6 hours	Performance	
Outcome of the operational analysis	BIO III - Effective Energy	The required energy to perform BIO I is 195.9 kWh, without considering any bunker margin	Performance	
Outcome of the operational analysis	BIO III - Average power	The required average power during BIO I is 49 kW	Performance	
Outcome of the operational analysis	BIO III - Maximum power	The max power required during BIO I is 91.3 kW	Performance	
Outcome of the operational analysis	BIO III - Autonomous range	The autonomous range for BIO I is 26.2 km	Performance	
Outcome of the operational analysis	BIO III - Endurance	The required endurance for BIO I is 4 hours	Performance	

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN Article 8.05.1	Fuel tanks, pipes and accessories	See ES-TRIN regulations	Safety	Comply
ES-TRIN Article 8.05.3	Fuel tanks, pipes and accessories	See ES-TRIN regulations	Safety	Comply
ES-TRIN Article 8.05.4	Fuel tanks, pipes and accessories	See ES-TRIN regulations	Safety	Comply
ES-TRIN Article 8.06.1	Storage of lubricating oil, pipes and accessories	See ES-TRIN regulations	Safety	Comply
ES-TRIN Article 8.06.3	Storage of lubricating oil, pipes and accessories	See ES-TRIN regulations	Safety	Comply
ES-TRIN Article 8.06.4	Storage of lubricating oil, pipes and accessories	See ES-TRIN regulations	Safety	Comply
ES-TRIN Article 10.10.2	Generators, engines and transformers	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 10.11.2	Batteries, Accumulators and their charging devices	See ES-TRIN regulations	Safety	Comply
ES-TRIN Article 10.11.3	Batteries, Accumulators and their charging devices	See ES-TRIN regulations	Safety	Comply
ES-TRIN Article 10.11.6	Batteries, Accumulators and their charging devices	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 10.11.7	Batteries, Accumulators and their charging devices	See ES-TRIN regulations	Safety	Later design phase

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN Article 10.11.12	Batteries, Accumulators and their charging devices	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 10.11.15	Batteries, Accumulators and their charging devices	See ES-TRIN regulations	Legislation	Later design phase, strictly connected with the choice of the battery system
ES-TRIN Article 10.11.16	Batteries, Accumulators and their charging devices	See ES-TRIN regulations	Safety	Later design phase, strictly connected with the choice of the battery system
ES-TRIN Article 10.11.17	Batteries, Accumulators and their charging devices	See ES-TRIN regulations	Safety	Later design phase, further investigate the fire protection system
ES-TRIN Article 10.12.4	Switchgear and controlgear	See ES-TRIN regulations	Safety	Partly comply, details about piping and insulation to be checked at later stage
ES-TRIN Article 11.01.2	General provisions for electric propulsion systems	See ES-TRIN regulations	Safety	Partly comply, the control, monitoring and alarm systems to be further verified
ES-TRIN Article 11.01.3	General provisions for electric propulsion systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 11.01.4	General provisions for electric propulsion systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 11.01.5	General provisions for electric propulsion systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 11.01.6	General provisions for electric propulsion systems	See ES-TRIN regulations	Safety	Later design phase

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN Article 11.02.2	Generators, transformers and switchgear for electric vessel propulsion	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 11.02.3	Generators, transformers and switchgear for electric vessel propulsion	See ES-TRIN regulations	Safety	Later, to be integrated in the control system
ES-TRIN Article 11.03.4	Electric propulsion motors for electric vessel propulsion	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 11.06.3	Control, regulation and automatic power limitation	See ES-TRIN regulations	Safety	Later, to be integrated in the control system
ES-TRIN Article 11.07.2	Protection of the electric propulsion systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 30.04.1	Risk Assessment	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 30.04.6 a)	Risk Assessment	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 30.04.6 d)	Risk Assessment	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 30.07.1	Independent propulsion	See ES-TRIN regulations	Reliability	Later design phase
ES-TRIN Article 30.08.1	Fire Safety	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 30.08.2	Fire Safety	See ES-TRIN regulations	Safety	Later design phase

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN Article 30.08.3	Fire Safety	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 30.09.2	Electrical installations	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 30.10.1	Control, monitoring and safety systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN Article 30.10.2	Control, monitoring and safety systems	See ES-TRIN regulations	Safety	Comply, included in the P&ID
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.1.1	General	See ES-TRIN regulations	Safety	Comply, included in the P&ID
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.2.1	Methanol fuel tanks	See ES-TRIN regulations	Safety	Comply
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.2.3	Methanol fuel tanks	See ES-TRIN regulations	Safety	Later, piping layout to be later arranged
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.2.4	Methanol fuel tanks	See ES-TRIN regulations	Safety	Comply
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.2.5	Methanol fuel tanks	See ES-TRIN regulations	Safety	Comply
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.2.6	Methanol fuel tanks	See ES-TRIN regulations	Safety	Comply, included in the P&ID
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.2.8	Methanol fuel tanks	See ES-TRIN regulations	Safety	Comply, included in the P&ID
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.3.1	Inerted methanol fuel tanks	See ES-TRIN regulations	Safety	Comply, included in the P&ID
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.3.2	Inerted methanol fuel tanks	See ES-TRIN regulations	Safety	Later design phase

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.3.3	Inerted methanol fuel tanks	See ES-TRIN regulations	Safety	Comply
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.3.4	Inerted methanol fuel tanks	See ES-TRIN regulations	Safety	Comply
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.5.1	Tank venting system	See ES-TRIN regulations	Safety	Partly Comply, vent mast to be further assessed
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.5.2	Tank venting system	See ES-TRIN regulations	Safety	Comply, included in the P&ID
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.5.3	Tank venting system	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.5.7	Tank venting system	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.6.2	Methanol fuel piping systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.6.3	Methanol fuel piping systems	See ES-TRIN regulations	Safety	Comply, included in the P&ID
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.6.4	Methanol fuel piping systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.6.5	Methanol fuel piping systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.6.6	Methanol fuel piping systems	See ES-TRIN regulations	Safety	To be checked after piping layout
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.6.7	Methanol fuel piping systems	See ES-TRIN regulations	Safety	Later design phase

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.7.1	Drainage systems and drip trays	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.7.2	Drainage systems and drip trays	See ES-TRIN regulations	Safety	Comply, included in the P&ID
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.7.3	Drainage systems and drip trays	See ES-TRIN regulations	Safety	To be checked after piping layout
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.7.4	Drainage systems and drip trays	See ES-TRIN regulations	Safety	Comply - Applicable only for the bunker station
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.8.4	Arrangement of entrances and other openings	See ES-TRIN regulations	Safety	No airlocks foreseen with current arrangement, risk assessment ot further check this
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.9.1	Ventilation systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.9.2	Ventilation systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.9.3	Ventilation systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.9.5	Ventilation systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.9.6	Ventilation systems	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.9.7	Ventilation systems	See ES-TRIN regulations	Safety	Later design phase

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.9.8	Ventilation systems	See ES-TRIN regulations	Safety	Comply
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.9.11	Ventilation systems	See ES-TRIN regulations	Safety	To be further verified
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.9.12	Ventilation systems	See ES-TRIN regulations	Safety	To be further verified
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.10.1	Methanol bunkering system	See ES-TRIN regulations	Safety	Comply
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.11.1	Methanol fuel supply system	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.11.3	Methanol fuel supply system	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.12.2	Fire safety	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.12.3	Fire safety	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.13.1.2	Control, Monitoring and Safety Systems - General	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.13.1.3	Control, Monitoring and Safety Systems - General	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.13.2.1	Control, Monitoring and Safety Systems - Methanol fuel tank and bunkering system	See ES-TRIN regulations	Safety	Comply, included in the P&ID

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.13.2.6	Control, Monitoring and Safety Systems - Methanol fuel tank and bunkering system	See ES-TRIN regulations	Safety	Comply, included in the P&ID
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.13.3.1	Control, Monitoring and Safety Systems - Gas and leakage warning equipment	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. II Ch. 2 2.2.13.3.2	Control, Monitoring and Safety Systems - Gas and leakage warning equipment	See ES-TRIN regulations	Safety	Partly comply, final arrangement to be further assessed
ES-TRIN, ANNEX 8, Sec. III Ch. 3 3.3.1.1	Propulsion and auxiliary systems with internal combustion engines using methanol as fuel - General	See ES-TRIN regulations	Safety	Comply
ES-TRIN, ANNEX 8, Sec. III Ch. 3 3.3.1.2	Propulsion and auxiliary systems with internal combustion engines using methanol as fuel - General	See ES-TRIN regulations	Legislation	Later design phase
ES-TRIN, ANNEX 8, Sec. III Ch. 3 3.3.1.3	Propulsion and auxiliary systems with internal combustion engines using methanol as fuel - General	See ES-TRIN regulations	Safety	Comply, option a)

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN, ANNEX 8, Sec. III Ch. 3 3.3.2.1	Propulsion and auxiliary systems with internal combustion engines using methanol as fuel - Requirements for gas safe engine rooms	See ES-TRIN regulations	Safety	Comply
ES-TRIN, ANNEX 8, Sec. III Ch. 3 3.3.2.2 a)	Propulsion and auxiliary systems with internal combustion engines using methanol as fuel - Requirements for gas safe engine rooms	See ES-TRIN regulations	Safety	Comply
ES-TRIN, ANNEX 8, Sec. III Ch. 3 3.3.2.2	Propulsion and auxiliary systems with internal combustion engines using methanol as fuel - Requirements for gas safe engine rooms	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. III Ch. 3 3.3.2.3	Propulsion and auxiliary systems with internal combustion engines using methanol as fuel - Requirements for gas safe engine rooms	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. III Ch. 3 3.3.4.4	Propulsion and auxiliary systems with internal combustion engines using methanol as fuel - Engines	See ES-TRIN regulations	Safety	Later design phase

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Complete Article reference	Article header	Clause from regulation	Requirement type	Remark
ES-TRIN, ANNEX 8, Sec. III Ch. 3 3.3.4.5	Propulsion and auxiliary systems with internal combustion engines using methanol as fuel - Engines	See ES-TRIN regulations	Safety	Later design phase
ES-TRIN, ANNEX 8, Sec. III Ch. 3 3.3.5.2	Propulsion and auxiliary systems with internal combustion engines using methanol as fuel - Exhaust system	See ES-TRIN regulations	Safety	Later, to be checked after the piping layout

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Annex 2 | Drawings

General arrangement plan

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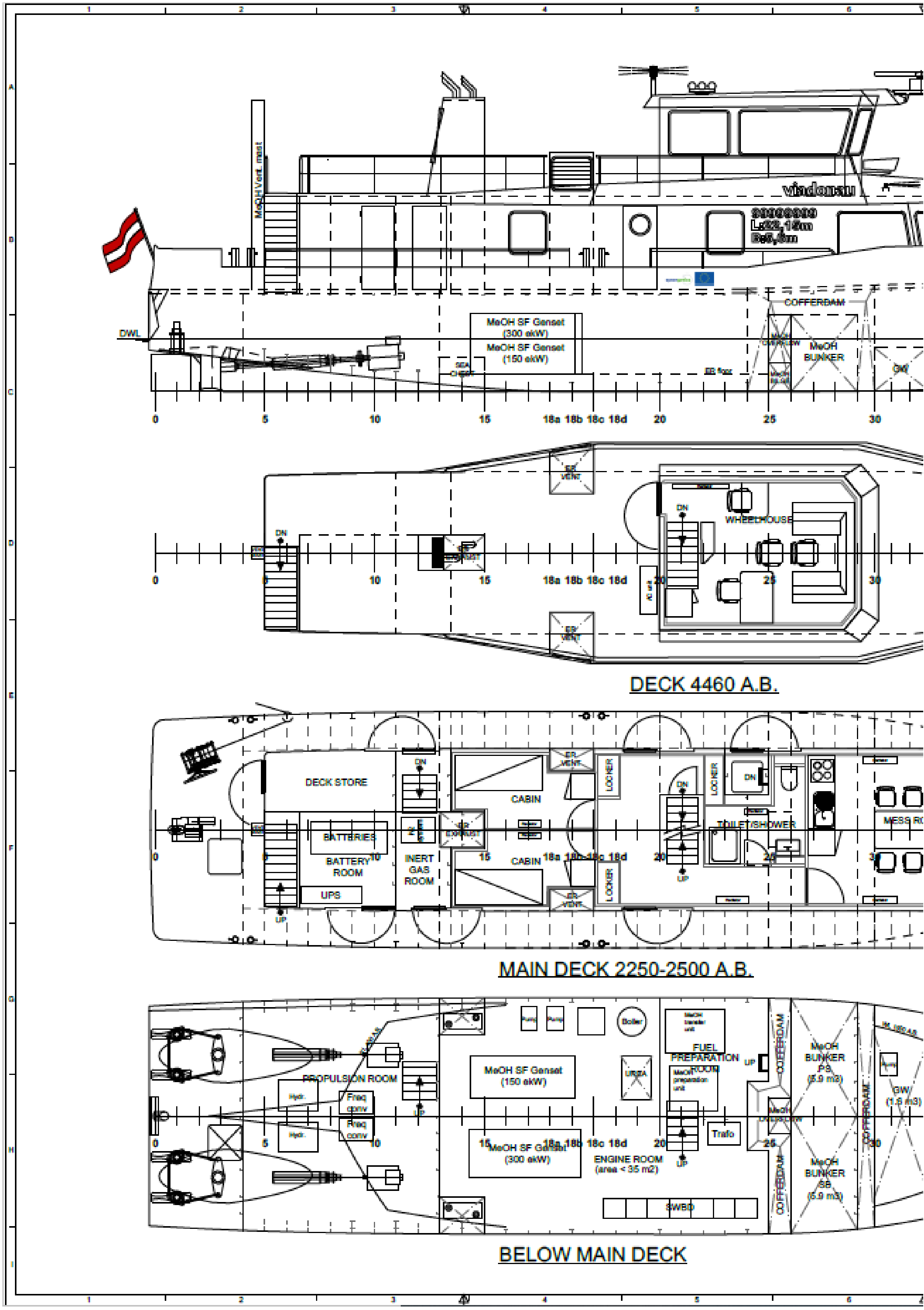

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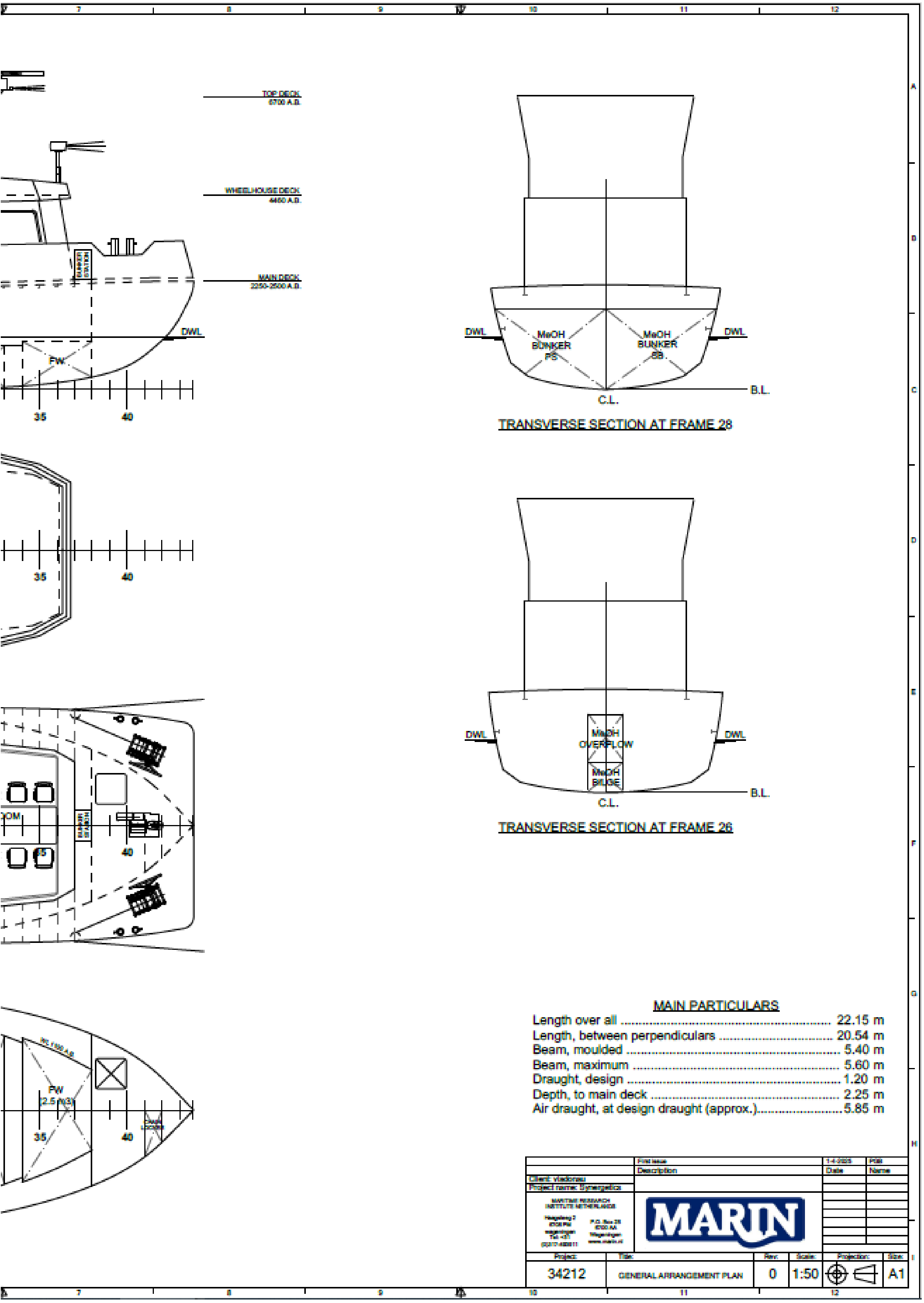

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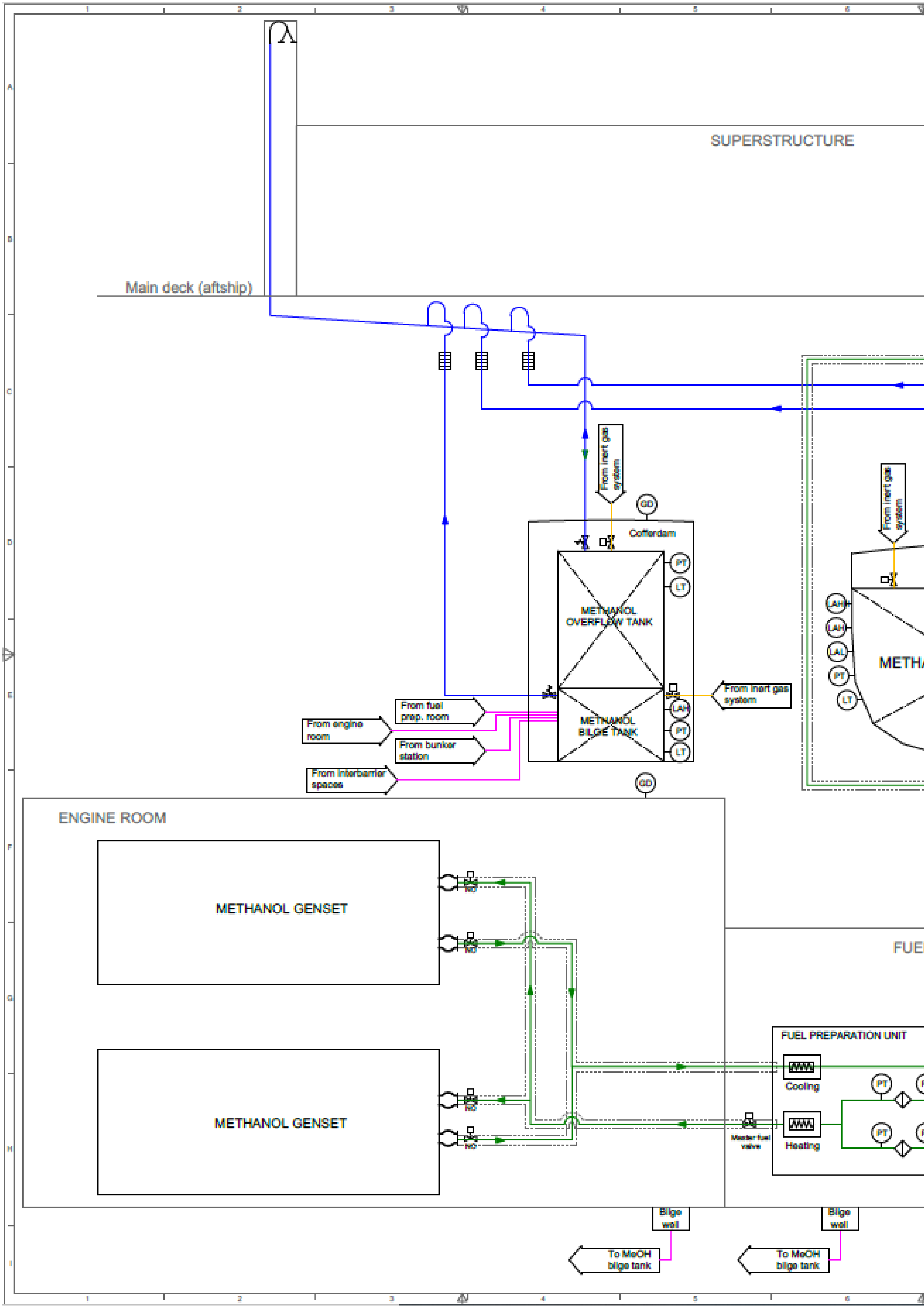
Fuel system diagram



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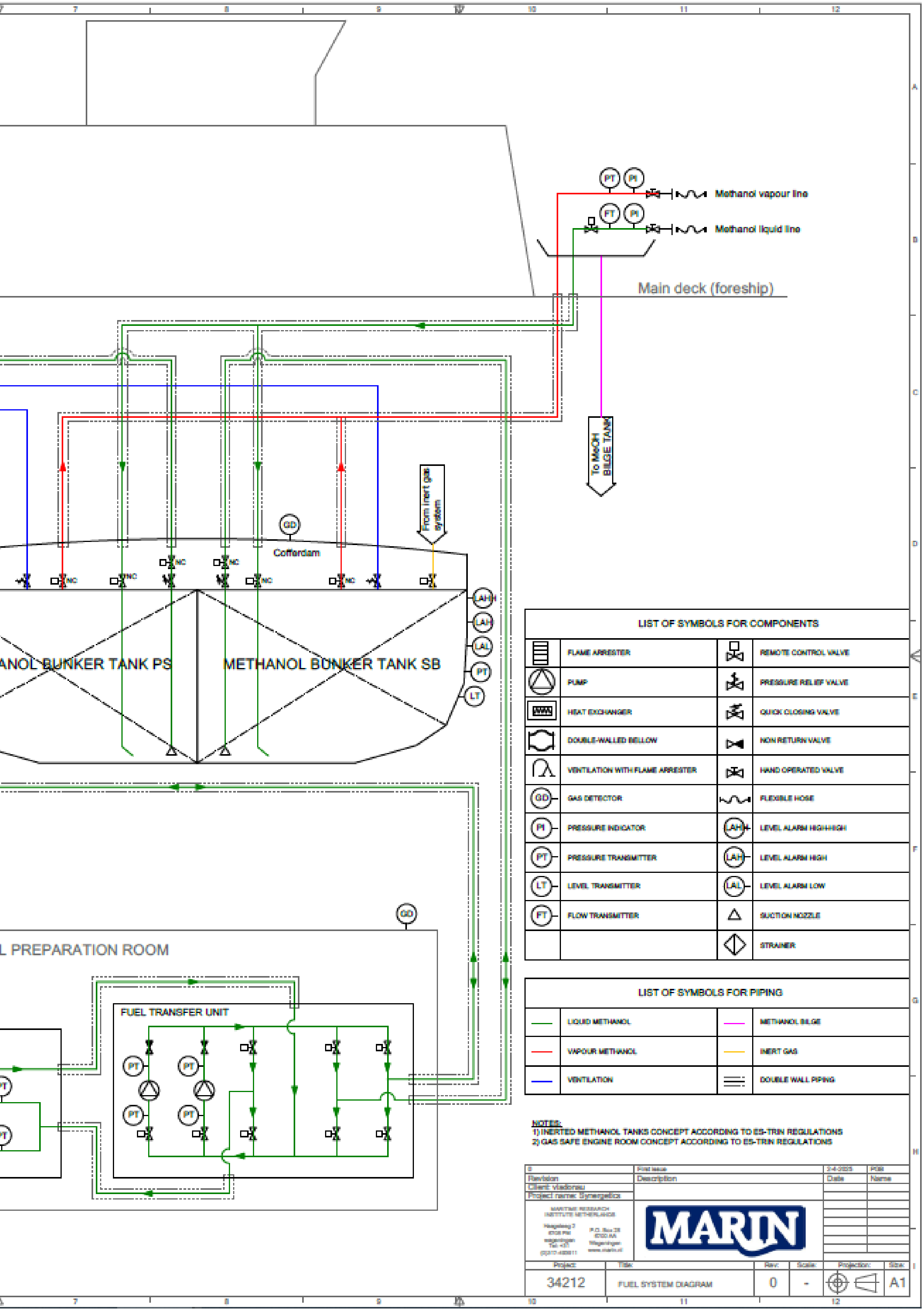

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