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Danube Transnational Programme
GRENDEL

Green and efficient Danube fleet

"Towards modernisation & greening of Danube inland waterborne sector and strengthening its competitiveness"

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Work Package 4 Preparatory actions

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Table of contents

1 Table of figures

2 Table of tables

3 Abbreviations

Abbreviation	Explanation
B.L.	Baseline
CCNR	Central commission for navigation on the Rhine
CO	Carbon monoxide
CPP	Controllable pitch propeller
DPF	Diesel particulate filter
EATS	Exhaust after-treatment system
EC	European Commission
ESD	Emergency shut down (engine room)
FPP	Fixed pitch propeller
HC	Hydrocarbons
HP	Horse power
HPU	Hydraulic power unit
HVAC	Heating, ventilation and air conditioning
IMO	International maritime organization
kN	Kilo newton
kNm	Kilo newton meter
KW	Kilowatt
LNG	Liquefied natural gas
MCR	Maximum continuous rating
MWh	Megawatt hour
NOx	Nitrogen oxides
NRMM	Non-road mobile machinery
PM	Particulate matter
PTO	Power take-off
RPM	Revolutions per minute
SCR	Selective catalytic reduction
B.L.	Baseline
CCNR	Central commission for navigation on the Rhine
CO	Carbon monoxide

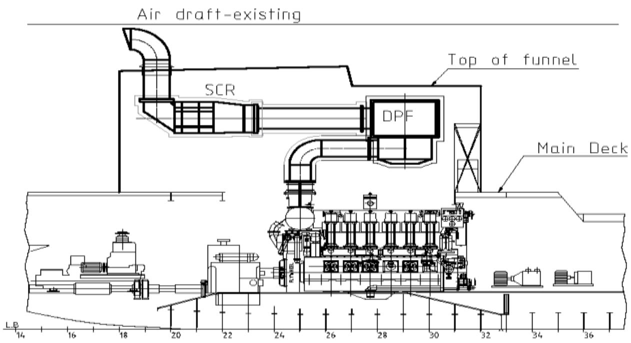
4 Executive Summary

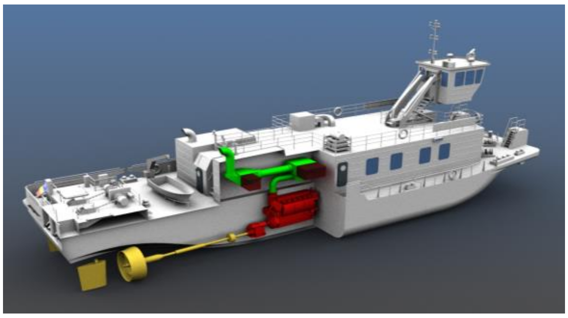
Stage V regulations put forth by the European Union will guide inland vessel operators through the transition stage towards zero-carbon transportation. Emission norms related to propulsion and auxiliary engines of inland vessels are included in these regulations. During the GRENDEL project, Ship Design Group and NAVROM worked together on two research pathways: retrofitting four inland pushers with Stage V compliant engines and after-treatment systems, as well as the development of an LNG powered inland pusher.

For the retrofit designs, NAVROM proposed four types of vessel, each with it's own particularities:

- Type 1 pusher – 2 x 1194 kW/1800 rpm – 2 vessels
- Type 2 pusher – 2 x 895 kW/1800 rpm – 4 vessels
- Type 3 pusher – 2 x 1185 kW/1000 rpm – 3 vessels
- Type 4 pusher – 2 x 925 kW/750 rpm – 2 vessels

After assessing the engines market, feasible arrangement proposals were made based on the layout of the engine room and equipment provided by the manufacturers. Once these were ready, the impact of the design was assessed and the modifications required were evaluated.





The modifications involved are as follows:

- Structural modifications
  - new main engine foundation
  - supports for the new exhaust treatment system
  - structural modifications of funnels
  - new urea tank
- Piping systems modifications
  - new exhaust after treatment system
  - modification of existing exhaust pipes for diesel generators
  - new cooling system
  - fuel oil system and lube oil – minor modifications regarding connections to new engine
  - engine room ventilation modifications
  - new urea system
  - new compressed air system for urea injection
- Electrical systems
  - main switch boards interventions related to new equipment
  - replacement of local and remote control and monitoring related to new engines
  - cables for new equipment
- Test and trials program

However, we consider that for vessels in operation retrofitting with an engine and after-treatment package is the most straightforward solution for Stage V compliance.

The pusher design tackles the LNG pathway towards decarbonization. Design restrictions were established by the two partners, the resulting vessel having the following characteristics:

Main dimensions		
Length overall	42.00	m
Breadth	13.5	m
Design draught	1.85	m
Air draft above B.L.	9.40	m
LNG (total/net)	220/190	m^3
Crew	8	
Equipment		
Propulsion engines	3x1460 kW @ 900 RPM	
Gearbox	1:2.548 gearbox ratio	
Shaft generator	100 ekW	
Gas generator	100 ekW	
Side thrusters	42”, 2x250 kW	
Propellers	2 x FPP, 1 x CPP, 1.8 m	
Hydraulic unit	600 kW	
LNG Pack	2 Bilobe tanks @ 110 m3	

Based on general inland vessel regulations as well as specific low-flashpoint fuels regulations, the basic concept, as well as the hull and piping technical designs were developed, since design decisions had to be taken considering their impact on the LNG and auxiliary systems. This resulted in a project that combines safety with energetic flexibility, high propulsion power and manoeuvrability.

The pusher design proposed is in line with current emission limits, LNG being considered a transition stage fuel and a viable alternative for the next 20 to 30 years. Other propulsion fuels and technologies are being considered, such as hydrogen, ammonia or bio/synthetic fuels. With protected accommodation, gas-safe engine room, protected fuel storage and safety mechanisms considered during the design stages, the pusher is a future-proof vessel, ready for alternative fuels implementations such as hydrogen.

5 Concept designs for NAVROM pushers retrofit

Retrofitting existing inland ships can be broken down into several points of action that need to be addressed. The most important one is reducing the environmental impact of existing inland waterborne transport. In this respect, a feasible solution is to act on the propulsion machinery by means of new technologies regarding fuel combustion and post processing.

A cheap and convenient way to reduce emissions is to use an after-treatment system for the propulsion engines. Current retrofit solutions are time-saving procedures when put into perspective with other alternatives.

The retrofit solution for an old ship is justifiable, especially taking into account the fact that manufacturers already have technically viable solutions and equipment is often relatively easy to replace.

Design-for-Retrofit needs to also lead to the establishing of principles that show potential benefits for future maintenance and ship repair scenarios. The obtained retrofit concept requires further definition and refinement work before being applied during a vessel's design process.

In order to meet Stage V emission norms, the exhaust gases produced in the engine have to undergo a cleaning process before being released into the environment. The system that cleans the exhaust gas is named Exhaust After-treatment System (EATS).

The most common types of after-treatment systems used in the inland shipping industry involve an SCR catalyst and particle filters. The SCR catalyst is installed to reduce the emission of NOx while the particle filters are used to reduce the emission of particulate matter (PM).

Selective Catalytic Reduction (SCR) technology is an advanced active emissions control technology system that injects a liquid reducing agent combined with a special catalyst into the exhaust gas of the diesel engine. The reducing agent is usually urea. The mixed compound undergoes a chemical reaction that converts nitrogen oxides (NOx) into non-toxic nitrogen (N_2), water (H_2O) and small amounts of carbon dioxide (CO_2). SCR technology has been proven to reduce NOx by up to 90 percent.

One common method for reducing particulate matter contents is using a DPF. The DPF is a device in which particles are collected and in some cases oxidised by using a burner. Advanced electronic control of the process is necessary to ensure effective PM removal for all engine cycles. To ensure proper function of the treatment system high quality fuel oil and lube oil need to be used.

The components of a typical exhaust after treatment system are: Diesel Particulate Filter (DPF), without afterburner, a mixing pipe, a Selective Catalytic Reduction unit (SCR) and a Control and Monitoring unit.

NAVROM's fleet includes 33 inland pushers, with a wide range of powers 2 x 280 HP, 2 x 370HP, 2 x 890 HP, 2 x 1200 HP, 2 x 1600 HP, and over 350 non-propelled units, consisting of different types of barges from 1000 t up to 3000 t deadweight.

The analysis made by the ship-owner showed that due to the total wear of the existing engines or maintenance problems for the old generation engines, the lack of replacement parts and the fact that existing engines have high emissions, in the near future the following types of ships are to be repowered with new engines:

- Type 1 pusher – 2 x 1194 kW/1800 rpm – 2 vessels
- Type 2 pusher – 2 x 895 kW/1800 rpm – 4 vessels
- Type 3 pusher – 2 x 1185 kW/1000 rpm – 3 vessels
- Type 4 pusher – 2 x 925 kW/750 rpm – 2 vessels

By retrofitting the existing pushers with new Stage V compliant engines the owner will increase the service life of the pushers by 10 years and reduce the level of emissions, improving the air quality for related inland navigation.

A 3D view of a typical NAROM pusher is presented in Fig. 5.1, with existing 2 x 1194 kW/ 1600 HP engines that was subject to retrofitting with new engines.

Figure 5.1: Typical NAVROM river pusher

After discussions with several engine manufacturers solutions for the pusher repowering were proposed. Depending on the speed and power of the available engines, the repowering can take place in the following ways:

- **Engine replacement only**

In order to replace the existing engine with a new one, without other modifications on the propulsion line, the new engine would have to meet two conditions:

- the power of the new engine should be similar to that of the current one; an interval from -2% to +10% difference from the initial power is acceptable
- the speed of the new engine should be similar to that of the existing engine; a margin of ±2% from the initial speed is acceptable

This solution is the most desirable for the owner as it involves the least modifications and investment.

- **Engine and gearbox replacement**

If the available engine has the requested power, within the margin mentioned above, but the rated speed is considerably different, the gearbox would need to be replaced as well. In order to keep the existing shaft line and propeller, the new gear box has to ensure the initial propeller RPM. It should be noted that in some situations it is possible that the new transmission ratio may not be among the standard values provided by the gearbox makers, so a custom ratio would be needed.

5.1 Operational profile of a Danube pusher

Since specific urea consumption depends on the kW output of the engine, dimensioning the urea tank required an operational profile of the pusher to be determined. Although scarce, data from Prominent's "WP1 – State of play" was used to approximate an operational profile for a typical Danube pusher. The means for determining the power distribution over time are described in document "List of operational profiles and fleet families V2", as well as details on the journeys considered and hydrographic data. Specific data for a Danube pusher was collected in the form of operational profiles for ten representative journeys. Even more, some data comes directly from NAVROM. Although cargo and voyage reporting on the Danube is not particularly developed, the data in Prominent's document seems to be the most consistent publicly available.

By applying the data, to a specific engine model, a fuel consumption can be obtained from the operational profiles.

The analysis of retrofitting solutions for NAVROM's different types of pushers is presented further ahead. The equipment solutions available on the market and existing layout on board were taken into account, and the aim was to minimize modifications. The present document summarizes an extended analysis on the feasibility of retrofitting inland vessels. It contains technical data obtained from engine manufacturers that were prepared with solutions for complying with Stage V emission limits. At least one proper solution for each analyzed vessel is presented in the document.

6 Concept design for type 1 retrofit - Project code ME809

6.1 General ship description

Type 1 ship is a river pusher for long voyages along the entire navigable sector of Danube, designed for pushing convoys made up of typical barges of 1000, 1500, 2000 or 3000 tons deadweight.

The standard convoy consists of 9 barges x 2000 t, with a total deadweight of 18000 tons and overall dimensions of 231 x 33 m.
In strong current, the convoy consists of 6 barges x 2000 t, with a total deadweight of 12000 tons and overall dimensions of 231 x 22 m.

Main particulars

Length over all	34.60 m
Length between perp.	33.00 m
Breadth moulded	11.00 m
Depth	2.80 m mid area
	3.30 m aft area
Max. draught	1.88 m
Air draft	8.80 m

Propulsion

Main engines: 2 x CUMMINS *KTA 50 M2*, 1194 kW / 1600 HP @ 1800 rpm, rating Continuous power
Gear box: approx. 5.75:1.
Propellers: two ducted propellers, fixed pitch, diameter: 1800 mm
Speed with typical convoy: 12-14 km/h

Tank capacities

Approximate capacities in cubic meters:

Ballast water	29
Fresh water	19
Fuel oil	97

Table 6.1.1: Type 1 tank capacities

Other small tanks are part of the steel structure (sewage, bilge, sludge, lube oil, dirty oil).
Crew: 8 people total.
Range

The store capacities ensure:

- 15 days of voyage with fresh water
- 230 hours continuous navigation, at 60% from MCR, without refuelling

Annual operating regime

The pusher has a typical operation regime of 5000 hours per year, with the engine operating at rated load and speed according to continuous / heavy duty rating.

6.2 Description of initial propulsion system and solutions proposed

Type 1 river pusher is equipped with two identical propulsion lines, each one consisting of: one fixed pitch ducted propeller, shaft line, reversing reduction gearbox and main engines with a classic exhaust system. The propulsion arrangement and the existing main engine exhaust system are presented in figure 6.2.1. According to data obtained from the engine makers, two solutions have been proposed: a) CATERPILLAR engine and EATS; b) Mitsubishi engine, new MASSON gearbox and an EATS.

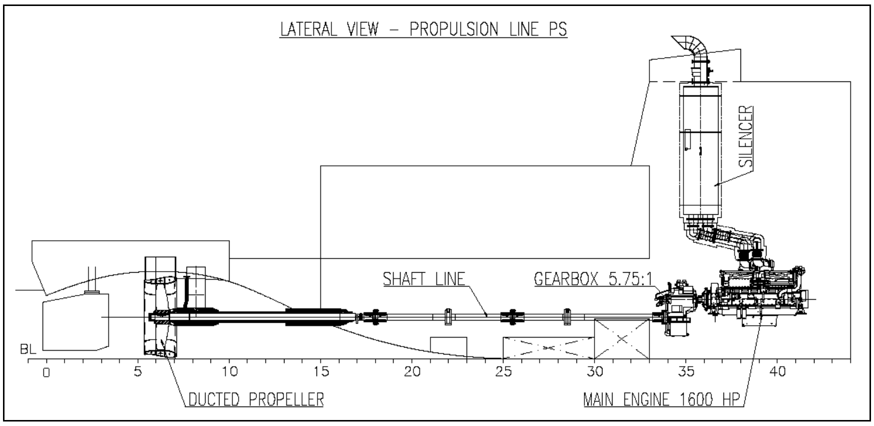


Figure 6.2.1: Type 1 pusher. Initial propulsion system

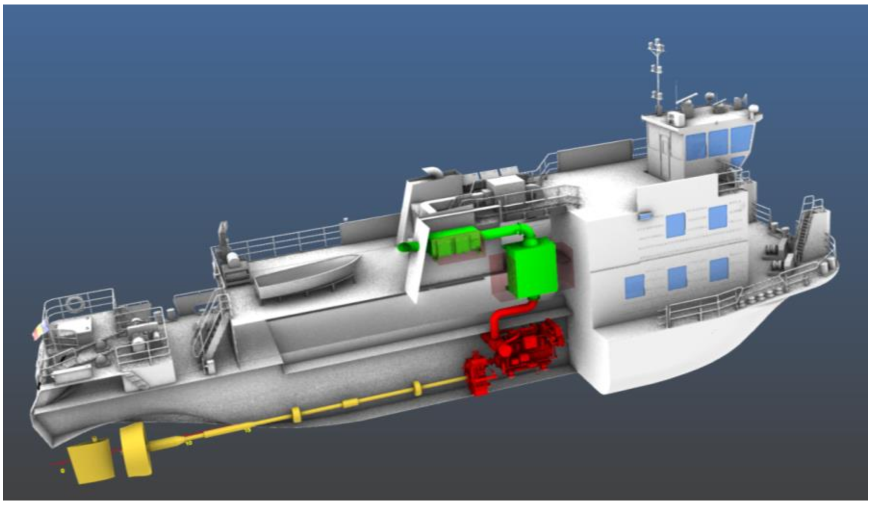


Figure 6.2.2: Type 1 pusher – 3D view, CATERPILAR engine and EATS

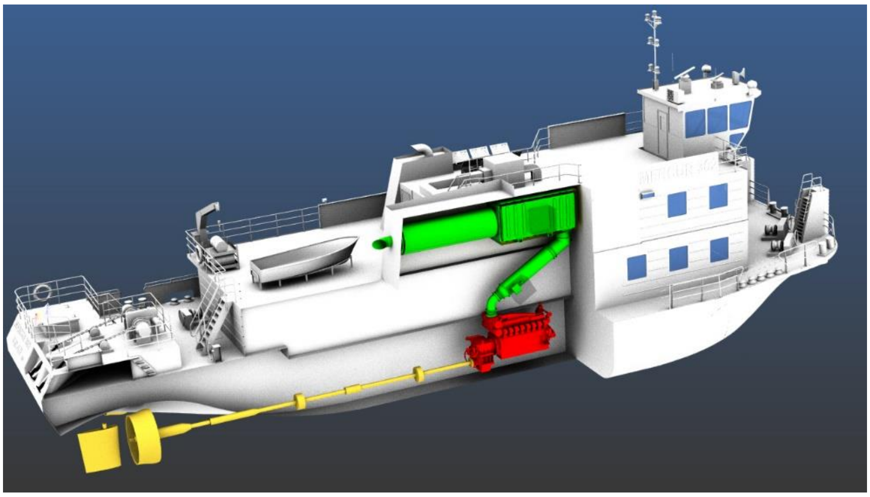


Figure 6.2.3: Type 1 pusher – 3D view, Mitsubishi engine, new gearbox and EATS

In figures 6.2.2 and 6.2.3, 3D views of the proposed solutions are presented. These help in better understanding table 6.2.1 below, which presents the modifications involved, with a short description of each activity.

Work	Description for CATERPILLAR solution	Description for MITSUBISHI and MASSON solution
SHIPYARD		
Engine	CATERPILLAR 3512C 1174 kW at 1800 rpm, rating A (unrestricted continuous)	MITSUBISHI S16R (Z3)MPTAW 1250 kW at 1600 rpm, rating A (unrestricted continuous)
EATS	(EATS included in engine package)	(EATS included in engine package)
Gearbox	No	MASSON MM W7400 Gearbox 5.032:1
HULL Structural modification		
Main engine foundation	4.5 tons steel	5 tons steel
EATS supports	0.8 tons steel	1.2 tons steel
Funnel modifications	3.0 tons steel	3.5 tons steel
Urea tank	0.6 tons painted steel/stainless steel	0.6 tons painted steel/stainless steel
New supporting structure		0.2 tons steel
PIPING		
Exhaust gas system ME	New system	New system
Exhaust gas system DG	Modifications in funnel	Modifications in funnel
Cooling system	New box coolers, modifications of pipes	New box coolers, modifications of pipes
Fuel oil system	Modifications for connection	Modifications for connection
Lube oil system	Modifications for connection	Modifications for connection
ER ventilation	Modifications of air ducts	Modifications of air ducts
Urea system	New system	New system
Compressed air system	New system	New system
ELECTRICAL		
Electrical system	New panels, cable modifications	New panels, cable modifications
TEST AND TRIALS	All systems that have undergone alterations will be tested	All systems that have undergone alterations will be tested
DESIGN		
Basic and detailed design		
Plan approval		
Yard survey		

Table 6.2.1: Type 1 list of modifications, for both solutions

7 Concept design for type 2 retrofit - Project code MD1266

7.1 General ship description

Type 2 ship is a river pusher for long voyages along the entire navigable sector of the Danube river, designed for pushing convoys made up of typical barges of 1000, 1500, 2000 or 3000tons deadweight.

The standard convoy consists of 9 barges x 1500 t, with a total deadweight of 13500 tons and overall dimensions of 210 x 33 m.
In conditions of strong current, the convoy consists in 6 barges x 1500 t, with total deadweight of 9000 tons and overall dimensions of 210 x 22 m.

Main particulars

Length over all	34.60 m
Length between perp.	33.00 m
Breadth moulded	10.10 m
Depth	2.65 m mid area
	3.30 m aft area
Max. draught	1.68 m
Air draft	8.80 m

Propulsion

Main engines: 2 x CUMMINS *KTA 38 M2*, 895 kW / 1200 HP @ 1800 rpm, rating Continuous power
Gear box: approx. 5.421:1.
Propellers: two ducted propellers, fixed pitch, diameter: 1600 mm
Speed with typical convoy: 12-14 km/h

Tank capacities

Approximate capacities in cubic meters:

Ballast water	34
Fresh water	30
Fuel oil	68

Table 7.1.1: Type 2 tank capacities

Other small tanks are part of the steel structure (sewage, bilge, sludge, lube oil, dirty oil).

Crew: 8 people total.

Range

The store capacities ensure:
- 25 days of voyage with fresh water
- 200 hours continuous navigation, at 60% from MCR, without refuelling.

Annual operating regime

The pusher has a typical operation regime of 5000 hours per year, with the engine operating at rated load and speed according to continuous / heavy duty rating.

7.2 Description of initial propulsion system and solutions proposed

Type 2 river pusher is equipped with two identical propulsion lines, each one consisting of: one fixed pitch ducted propeller, shaft line, reversing reduction gearbox and main engines with classic exhaust system. The propulsion arrangement and the existing main engine exhaust system are presented in Figure 7.2.1. According to data obtained from the engine makers, two solutions have been proposed: a) CATERPILLAR engine and EATS (Figure 7.2.2); b) Mitsubishi engine, new MASSON gearbox and an EATS (Figure 7.2.3).

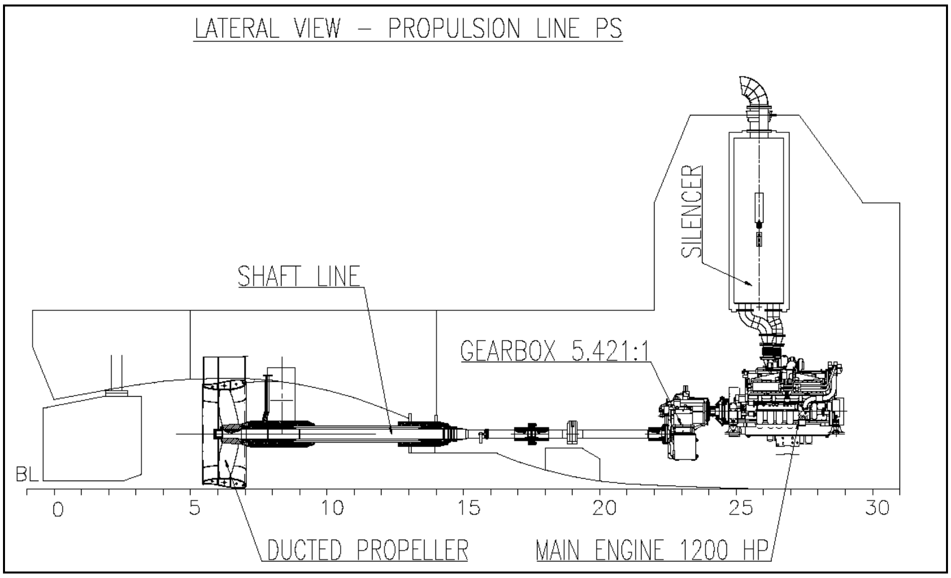


Figure 7.2.1: Type 2 pusher. Initial propulsion system

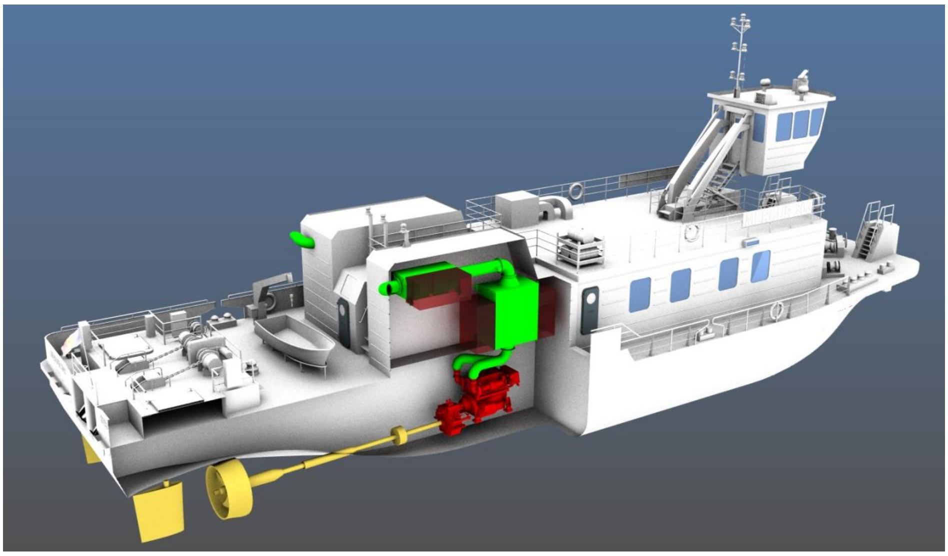


Figure 7.2.2: Type 2 pusher – 3D view, CATERPILLAR engine and EATS

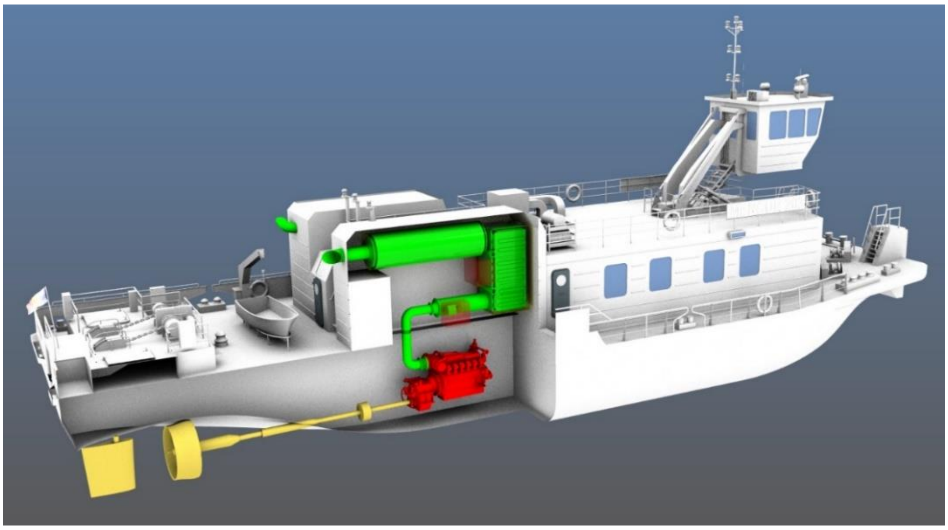


Figure 7.2.3: Type 2 pusher – 3D view, Mitsubishi engine, new gearbox and EATS

In figures 7.2.2 and 7.2.3, 3D views of the proposed solutions are presented. These help in better understanding table 7.2.1 below, which presents the modifications involved, with a short description of each activity.

Work	Description for CATERPILLAR solution	Description for MITSUBISHI and MASSON solution
SHIPYARD		
Engine	CATERPILLAR C32 SCAC 895 kW at 1800 rpm, rating B (heavy duty)	MITSUBISHI S12R (Z3)MPTAW 940 kW at 1600 rpm, rating A (unrestricted continuous)
EATS	(EATS included in engine package)	(EATS included in engine package)
Gearbox	No	MASSON MM W7200 Gearbox 4.925:1
HULL Structural modification		
Main engine foundation	4.1 tons steel	4.5 tons steel
EATS supports	0.8 tons steel	1.2 tons steel
Funnel modifications	4.0 tons steel	4.2 tons steel
Stair	0.3 tons steel	0.6 tons painted steel/stainless steel
Urea tank	0.6 tons painted steel/stainless steel	0.6 tons painted steel/stainless steel
PIPING		
Exhaust gas system ME	New system	New system
Exhaust gas system DG	Modifications in funnel	Modifications in funnel
Cooling system	New box coolers, modifications of pipes	New box coolers, modifications of pipes
Fuel oil system	Modifications for connection	Modifications and new pipelines
Lube oil system	Modifications for connection	Modifications for connection
ER ventilation	Modifications of air ducts	Modifications of air ducts
Urea system	New system	New system
Compressed air system	New system	New system
ELECTRICAL		
Electrical system	New panels, cable modifications	New panels, cable modifications
TEST AND TRIALS	All systems that have undergone alterations will be tested	All systems that have undergone alterations will be tested
DESIGN		
Basic and detailed design		
Plan approval		
Yard survey		

Table 7.2.1: Type 2 list of modifications, for both solutions

8 Concept design for type 3 retrofit - Project code M0292

8.1 General ship description

Type 3 ship is a river pusher for long voyages along the entire navigable sector of Danube, designed for pushing convoys made up of typical barges of 1000, 1500, 2000 or 3000tons deadweight.

The standard convoy consists of 9 barges x 2000 t, with a total deadweight of 18000 tons and overall dimensions of 231 x 33 m.
In strong current, the convoy consists of 6 barges x 2000 t, with a total deadweight of 12000 tons and overall dimensions of 231 x 22 m.

Main particulars

Length over all	32.00 m
Breadth moulded	11.40 m
Depth	3.00 m
Max. draught	1.80 m

Propulsion

Main engines: 2 x DETUZ SBV 6M 628, 1185 kW / 1600 HP @ 1000 rpm, rating Continuous power
Gear box: approx. 3.039:1.
Propellers: two ducted propellers, fixed pitch
Speed with typical convoy: 12-14 km/h

Tank capacities

Approximate capacities in cubic meters:

Ballast water	76
Fuel oil	90

Table 8.1.1: Type 3 tank capacities

Other small tanks are part of the steel structure (sewage, bilge, sludge, lube oil, dirty oil).

Crew: 8 people total.

Range

The store capacities ensure:

- 240 hours continuous navigation, at 60% from MCR, without refuelling

Annual operating regime

The pusher has a typical operation regime of 5000 hours per year, with the engine operating at rated load and speed according to continuous / heavy duty rating.

8.2 Description of initial propulsion system and solutions proposed

Type 3 river pusher is equipped with two identical propulsion lines, each one consisting of: one fixed pitch ducted propeller, shaft line, reversing reduction gearbox and main engines with a classic exhaust system. The propulsion arrangement and the existing main engine exhaust system are presented in Figure 8.2.1. According to data obtained from the engine makers, two solutions have been proposed: a) CATERPILLAR engine and EATS (Figure 8.2.2); b) Mitsubishi engine, new MASSON gearbox and an EATS (Figure 8.2.3).

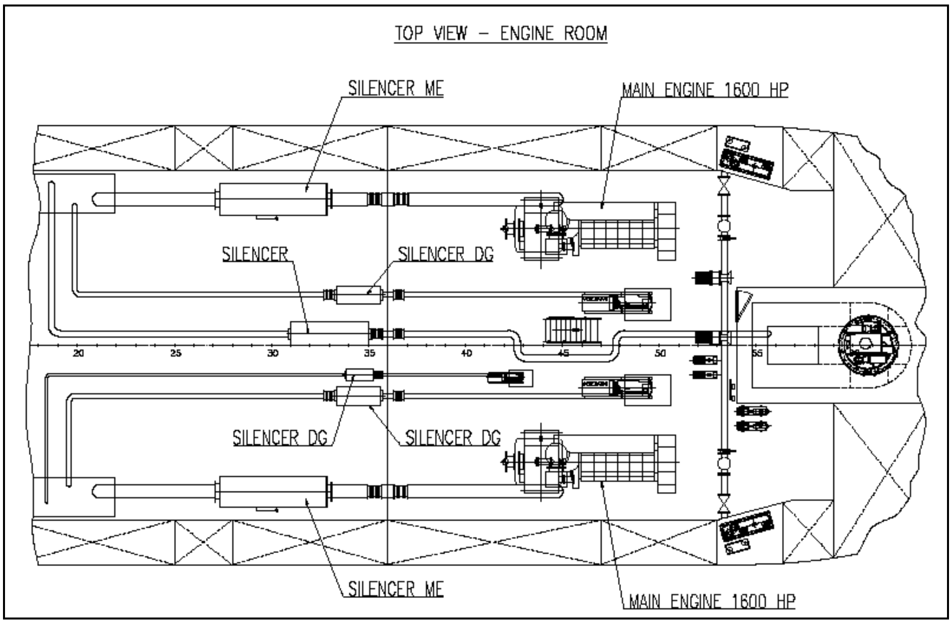


Figure 8.2.1: Type 3 pusher engine room. Initial propulsion system

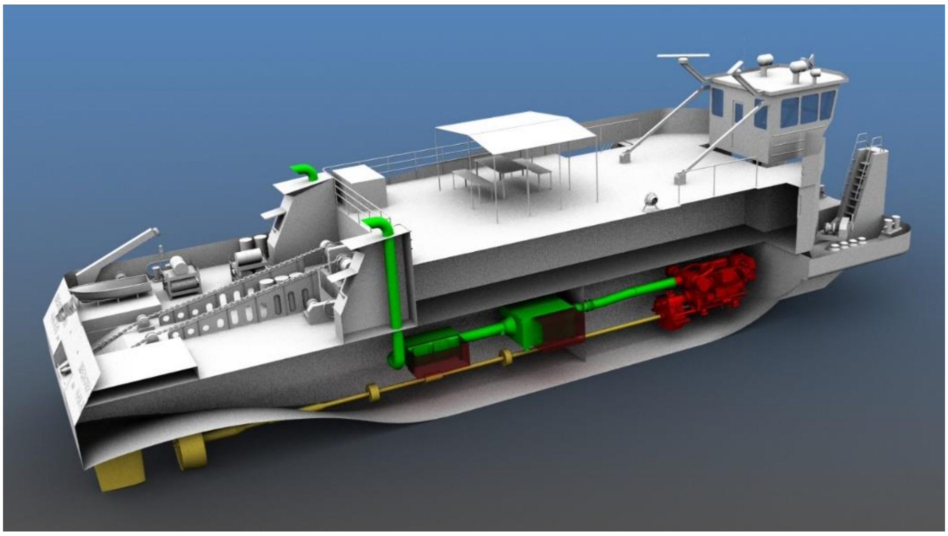


Figure 8.2.2: Type 3 pusher – 3D view, Caterpillar engine and EATS

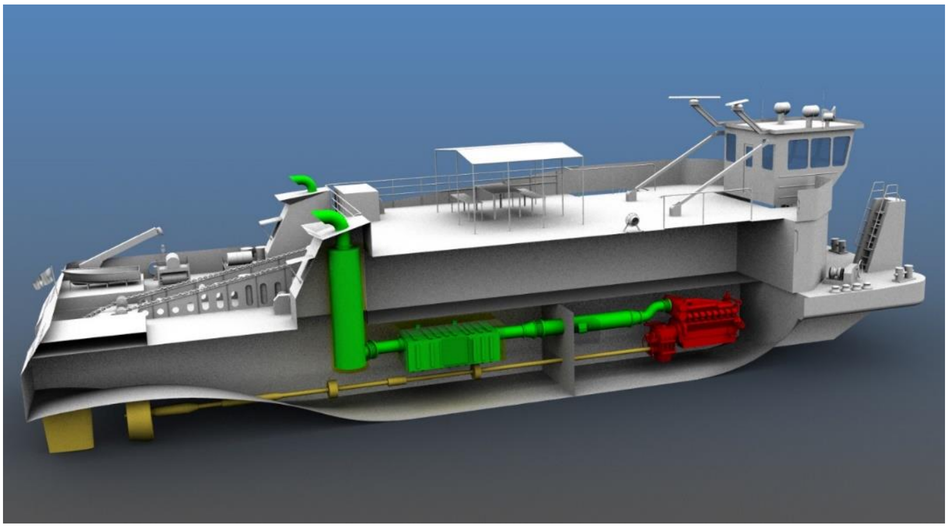


Figure 8.2.3: Type 3 pusher - 3D view, Mitsubishi engine, new gearbox and EATS

In figures 8.2.2 and 8.2.3, 3D views of the proposed solutions are presented. These help in better understanding table 8.2.1 below, which presents the modifications involved, with a short description of each activity.

Work	Description for CATERPILLAR solution	Description for MITSUBISHI and MASSON solution
SHIPYARD		
Engine	CATERPILLAR 3512C 1174 kW at 1800 rpm, rating A (unrestricted continuous)	MITSUBISHI S16R (Z3)MPTAW 1250 kW at 1600 rpm, rating A (unrestricted continuous)
EATS	(EATS included in engine package)	(EATS included in engine package)
Gearbox	No	MASSON MM W7400 Gearbox 4.816:1
HULL Structural modification		
Main engine foundation	2.2 tons steel	3 tons steel
EATS supports	0.6 tons steel	1.2 tons steel
Funnel modifications	-	1 tons steel
Stair	-	-
Urea tank	0.6 tons painted steel/stainless steel	0.6 tons painted steel/stainless steel
PIPING		
Exhaust gas system ME	New system	New system
Exhaust gas system DG	Modifications in funnel	Modifications in funnel
Cooling system	New box coolers, modifications of pipes	New box coolers, modifications of pipes
Fuel oil system	Modifications for connection	Modifications and new pipelines
Lube oil system	Modifications for connection	Modifications for connection
ER ventilation	Modifications of air ducts	Modifications of air ducts
Urea system	New system	New system
Compressed air system	New system	New system
ELECTRICAL		
Electrical system	New panels, cable modifications	New panels, cable modifications
TEST AND TRIALS	All systems that have undergone alterations will be tested	All systems that have undergone alterations will be tested
DESIGN		
Basic and detailed design		
Plan approval		
Yard survey		

Table 8.2.1: Type 3 list of modifications, for both solutions

9 Concept design for type 4 retrofit - Project code M2578

9.1 General ship description

Type 4 ship is a river pusher for long voyages along the entire navigable sector of the Danube, designed for pushing convoys made up of typical barges of 1000, 1500, 2000 or 3000tons deadweight.
The standard convoy consists of 9 barges x 1500t, with a total deadweight of 13500 tons and overall dimensions of 210 x 33 m.

In strong current, the convoy consists of 6 barges x 1500 t, with a total deadweight of 9000 tons and overall dimensions of 210 x 22 m.

Main particulars

Length over all	34.66 m
Length between perp.	33.00 m
Breadth moulded	10.10 m
Depth	2.65 m mid area
	3.30 m aft area
Max. draught	1.68 m
Air draft min	5.17 m

Propulsion

Main engines: 2 x DEUTZ SBV 6 M 628, 925 kW / 1260 HP @ 750 rpm, rating Continuous power
Gear box: approx. 2.239:1.
Propellers: two ducted propellers, fixed pitch, diameter: 1600 mm
Speed with typical convoy: 12-14 km/h

Tank capacities

Approximate capacities in cubic meters:

Ballast water	34
Fresh water	30
Fuel oil	68

Table 9.1.1: Type 4 tank capacities

Other small tanks are part of the steel structure (sewage, bilge, sludge, lube oil, dirty oil).

Crew: 12 people total.

Range

The store capacities ensure:
- 17 days of voyage with fresh water
- 230 hours continuous navigation, at 60% from MCR, without refuelling

Annual operating regime

The pusher has a typical operation regime of 5000 hours per year, with the engine operating at rated load and speed according to continuous / heavy duty rating.

9.2 Description of initial propulsion system and solutions proposed

Type 4 river pusher is equipped with two identical propulsion lines, each one consisting of: one fixed pitch ducted propeller, shaft line, reversing reduction gearbox and main engines with a classic exhaust system. The propulsion arrangement and the existing main engine exhaust system are presented in Figure 9.2.1. According to data obtained from the engine makers, two solutions have been proposed: a) CATERPILLAR engine and EATS (Figure 9.2.2); b) Mitsubishi engine, new MASSON gearbox and an EATS (Figure 9.2.3).

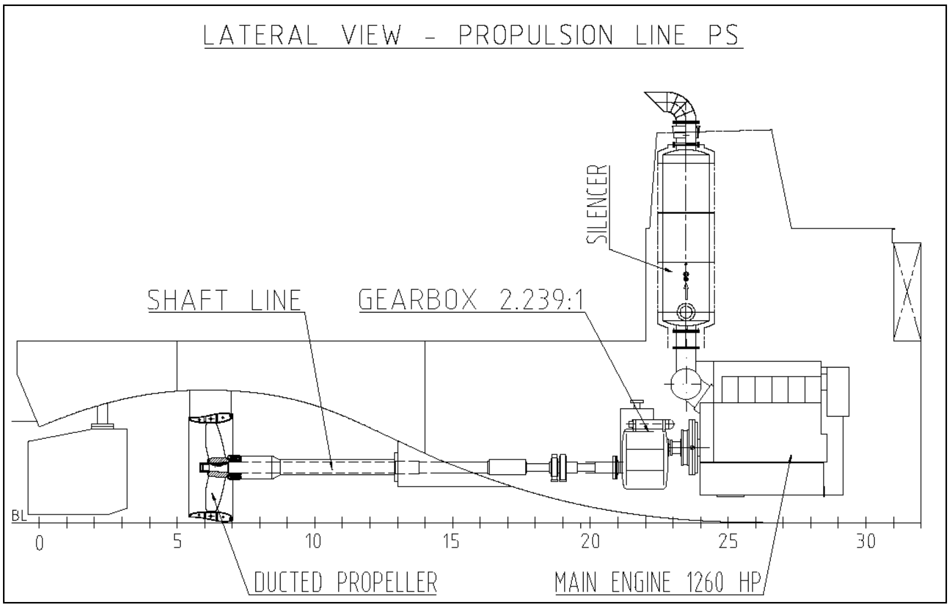


Figure 9.2.1: Type 4 pusher. Initial propulsion system

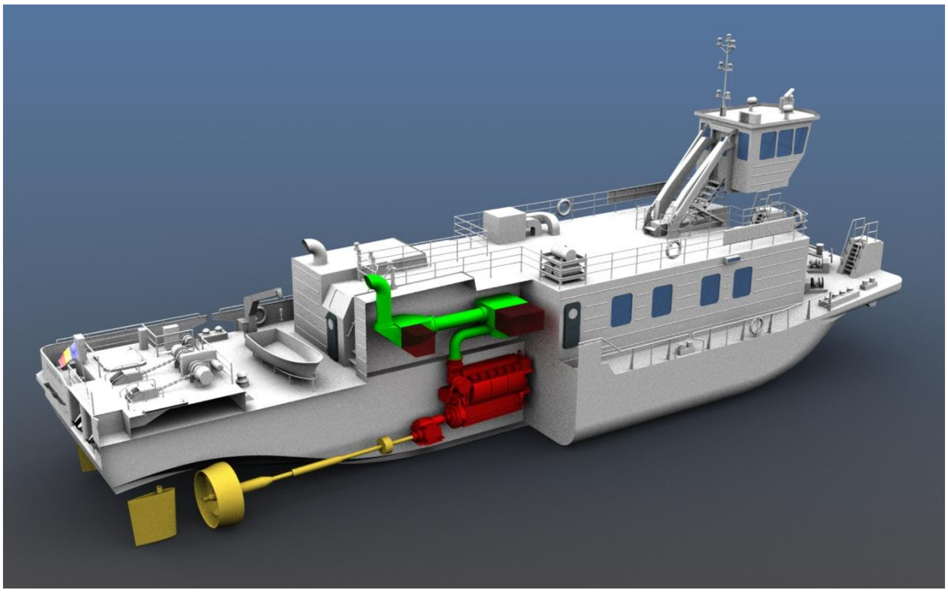


Figure 9.2.2: Type 4 pusher – 3D view, ABC engine and EATS

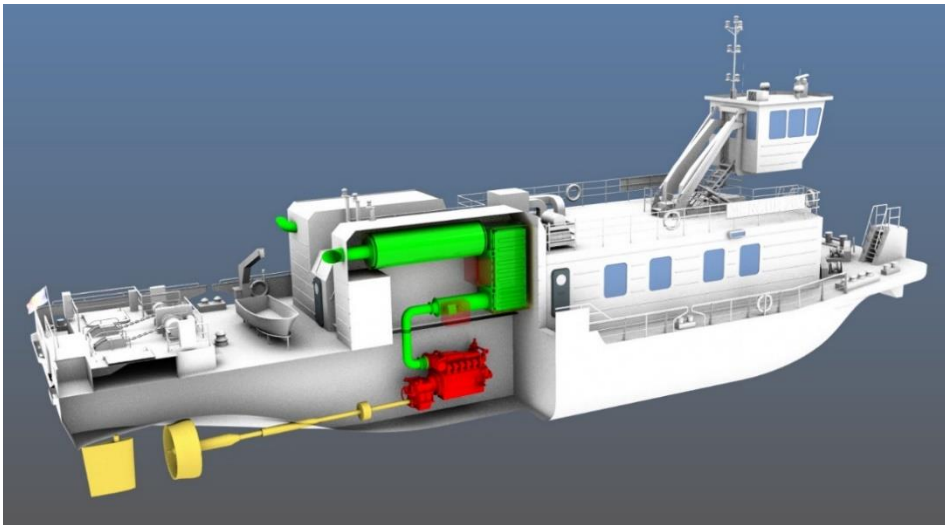


Figure 9.2.3: Type 4 pusher - 3D view, Mitsubishi engine, new gearbox and EATS

In figures 9.2.2 and 9.2.3, 3D views of the proposed solutions are presented. These help in better understanding table 9.2.1 below, which presents the modifications involved, with a short description of each activity.

Work	Description for ABC solution	Description for MITSUBISHI and MASSON solution
SHIPYARD		
Engine	ABC 6DZC-750-155 925 kW at 750 rpm, rating A (unrestricted continuous)	MITSUBISHI S12R (Z3)MPTAW 940 kW at 1600 rpm, rating A (unrestricted continuous)
EATS	(EATS included in engine package)	(EATS included in engine package)
Gearbox	No	MASSON MM W7400 Gearbox 4.925:1
HULL Structural modification		
Main engine foundation	2.2 tons steel	3 tons steel
EATS supports	0.6 tons steel	1.2 tons steel
Funnel modifications	-	1 tons steel
Stair	-	-
Urea tank	0.6 tons painted steel/stainless steel	0.6 tons painted steel/stainless steel
PIPING		
Exhaust gas system ME	New system	New system
Exhaust gas system DG	Modifications in funnel	Modifications in funnel
Cooling system	New box coolers, modifications of pipes	New box coolers, modifications of pipes
Fuel oil system	Modifications for connection	Modifications and new pipelines
Lube oil system	Modifications for connection	Modifications for connection
ER ventilation	Modifications of air ducts	Modifications of air ducts
Urea system	New system	New system
Compressed air system	New system	New system
ELECTRICAL		
Electrical system	New panels, cable modifications	New panels, cable modifications
TEST AND TRIALS	All systems that have undergone alterations will be tested	All systems that have undergone alterations will be tested
DESIGN		
Basic and detailed design		
Plan approval		
Yard survey		

Table 9.2.1: Type 4 list of modifications, for both solutions

10 Stage V retrofitting highlights

The modernization works necessary for installing the new engines and auxiliary systems on board of four existing pushers that were identified and presented in this report refer to:

- Structural modifications
    - new main engine foundation
    - supports for the new exhaust treatment system
    - new stair for access to top of superstructure
    - structural modifications of funnels
    - new urea tank
- Piping systems modifications
    - new exhaust after treatment system
    - modification of existing exhaust pipes for diesel generators
    - new box coolers
    - fuel oil system and lube oil – minor modifications regarding connections to new engine
    - engine room ventilation modifications
    - new urea system
    - new compressed air system for urea injection
- Electrical systems
    - main switch boards interventions related to new equipment
    - replacement of local and remote control and monitoring related to new engines
    - cables for new equipment
- Test and trials program

Some disadvantages of such a system are the increased maintenance costs as well as the reduced availability of replacement parts. For retrofitting of vessels with crowded engine room arrangements, merging an after-treatment solution might be impractical. NAVROM's economic impact will be influenced by the extra costs for replenishing urea, as well as possible lower maintenance costs for the new engine compared to existing old generation ones.

Repowering of the existing NAVROM inland pushers is a feasible solution for complying with the new emission norms imposed by CCNR Stage V.

10.1 Overall environmental impact

The minimum emission reduction of the vessels considered for retrofitting is:

Ship type	Emission reduction HC	Emission reduction NOx	Emission reduction PM	Number of ships	Total reduction HC	Total reduction NOx	Total reduction PM
	[tons]				[tons]		
Type 1	0.45	51.01	5.98	2	0.90	102.02	11.96
Type 2	0.05	36.03	4.49	4	0.20	144.12	17.96
Type 3	7.89	52.61	5.93	3	23.67	157.83	17.79
Type 4	6.16	41.07	4.64	2	12.32	82.14	9.28
				Total for all vessels	37.09	486.11	56.99

Table 10.1.1: Total emission reduction for the proposed vessels

Where data about the current engine emission output was unavailable, Stage I limits were used. In the same manner, where data about the new engine and after treatment system emission values was missing, Stage V limits were used. As such, the emission reduction is probably more significant than presented in Table 10.1.1.

11 Concept design of an LNG pusher, to be included in the NAVROM fleet

11.1 Introduction

Although international shipping and inland shipping are the most energy-efficient means of mass transportations, the global trend to decarbonize is also being followed by these industries as well. Along with other sectors, the marine industry is pursuing the limitation of greenhouse gas emissions and increase in energy efficiency.

Certainly, to achieve these emissions goals, both the industries and the governments need to play their part. Proper policies would have to keep in mind that the transition process depends on many factors.

One of the means for achieving these goals is the use of low or zero carbon fuels. The viability of these fuels needs to be assessed in terms of economic feasibility, technology readiness and community perspective. LNG technology has matured in the last couple of years, as well as seeing an improvement in community acceptance and perspective for the future. It has also overcome challenges that new fuels are facing, more specifically, bunkering and storage, although the supply chain still needs and will probably be improved. IMO's 2050 requirements and the European Union's NRRM Stage V regulations sent a clear message that the intent is to switch away from fossil fuels as soon as possible. This can also be seen as a trigger to ship designers, taking into account a possible switch to zero-carbon fuels during the lifetime of the vessel.

It is obvious that there is a strong link between the development of a fuel's price and the economic feasibility and general view on a new fuel. Other barriers in the way of modern fuels are regulation development, fuel bunkering solutions and standards, fuel quality assurance, improvement of the tech and auxiliary equipment and further research for optimization of the storage and burning processes. But what this leads to is an understanding of the fact that viable fuels will change in time, and there's no go-to solution that will satisfy the needs of the ship and all the other involved players, both now and in the several decades.

11.2 LNG technology for vessels

Conventional fuels are bound to remain the go-to choice for most vessels in the near future, however, LNG is coming along as a viable alternative with several advantages. One of the important aspects of LNG is that it will also comply with future regulations regarding the main types of emissions (CO_2, NO_x, PM, SO_x), making it a future proof technology for the time being. More specifically, NO_x emissions are reduced by more than 80%, SO_x emissions are eliminated since there is no Sulphur in LNG, particulate matter is close to zero and CO_2 emissions are reduced by approximately 20%.

But once the economic hurdles have been overcome, the issue of safety needs to be addressed. At first glance, the main issues that the designers, operators and crew of an LNG-powered vessel need to face are the explosion hazard due to leakages, the very low temperatures of the fuel in liquid state (-160 degrees), the importance of proper arrangement and layout of the vessel, distinction of spaces according to regulation in hazardous and non-hazardous, and to top it all up, the lack of experience of the crew in handling the new fuel.

For vessel applications, the main components of an LNG installation are the storage system, the processing and distribution system and the consumer, which is the engine.

The storage system has been developed over the last 50 years, with several storage solutions being available to designers. The trend is to increase the safety of the containment tanks and switch to modern materials such as lightweight composites. Several storage solutions are available for vessels, divided into Type A, B and C, with tank types A and B being non-pressurized. Membrane tank are also a solution, with a containment system attached to the hull.

The processing and distribution system needs to prepare the LNG by vaporizing, pressurizing and warming it, and then safely distribute it to the engine, through double walled or ducted piping.

Finally, the engines, which for this specific report are gas-only engines and are designed in such a matter that the engine room can be considered gas safe according to regulations.

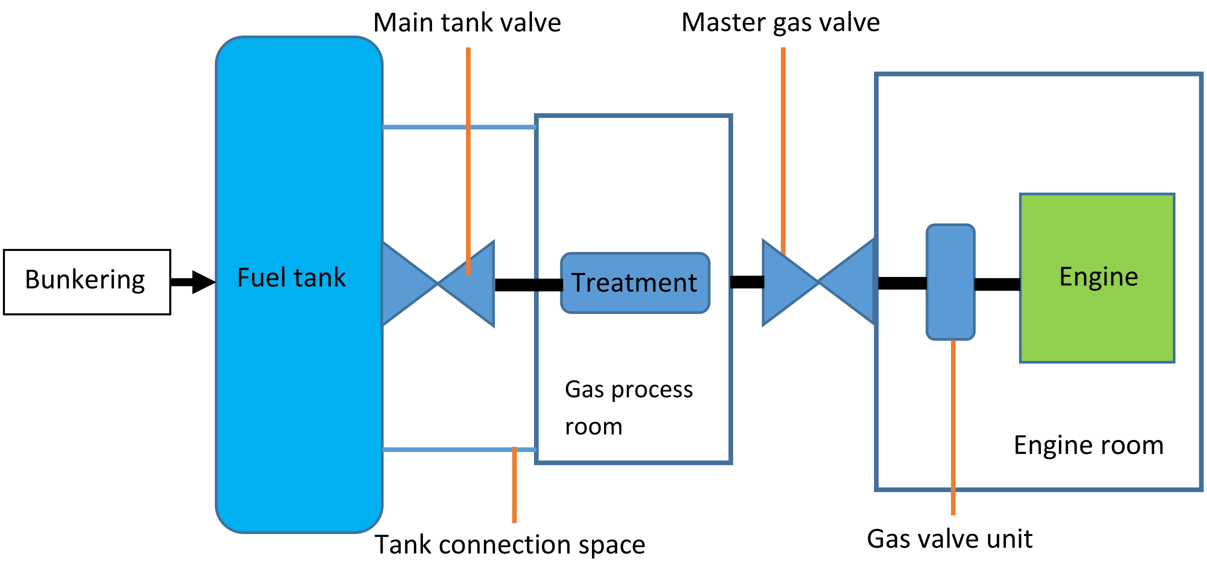


Figure 11.2.1: LNG system configuration of the pusher

11.3 Base of design and restrictions

11.3.1 Base of design

The initial design restrictions were set in place with the aid of NAVROM, and which will be referred as the Owner during the course of this document. The Owner's initial requirements are related to the dimensions of the vessel and the available power.

Ship type	Pusher	
Fuel	LNG only (no dual fuel)	
Power	> 4000 HP	
Range	> 1000 km upstream	
Navigation area	Danube and Danube-Black Sea Canal up to Passau	
Length	<42 m	limitation due to locks length
Breadth	< 23 m	limitation due to locks width
Draught	< 2 m - preferably 1.85 m	statistic depth of waterways
Air draft	< 7.70	bridge height at Passau

One particularly important request was that of the propulsion power. The Owner mentions that the additional power would allow them to increase the efficiency of their transports by being able to move larger convoys faster, as well as helping them with the bends and twists of the Danube.

In that regard, the convoy dimensions proposed are as follows:

- 9 Europa II b barges, in a 3x3x3 configuration, at approximately 16000 t cargo;
  Convoy dimensions are 230 m x 33 m x 2.7 m, without the pusher.
- 9 2000 t barges, in a 3x3x3 configuration, at approximately 16000 t cargo;
  Convoy dimensions are 230 m x 33 m x 3.0 m, without the pusher.
- 6 3000 t barges, in a 2x2x2 configuration, at approximately 18000 t cargo;
  Convoy dimensions are 267 m x 22 m x 3.8 m, without the pusher.

11.3.2 General Rules for inland vessels

Other design restrictions and solutions stem from the applicable rules specific for inland vessels. These include the following:

- European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN),
- Classification society rules, and for the current project the Bureau Veritas Rules NR217 – Rules for the classification of Inland Navigation Vessels were applied

11.3.3 Specific Rules for LNG-powered vessels

Additional requirements due to the nature of the fuel used can be found in the following:

- European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN) – Part II Additional requirements for specific equipment used on board – Annex 8 Supplementary provisions applicable to craft operating on fuels with a flashpoint equal to or lower that 55 °C.

- NR529 Gas Fuelled Ships – January 2017 which incorporates the text of the "International Code of Safety Using Gases or other Low-Flashpoint Fuels (IGF Code)".

11.3.4 Safety barriers

There are a number of safety barriers that need to kept in check when designing and operating an LNG powered vessel. The most important ones are:

1. Certified material for cryogenic temperatures

   LNG is liquefied by cooling it up to a temperature of approximately -160 degrees. It's also vaporized and prepared in order to be usable by the engine. As such, the piping and related material need to be able to withstand both extreme temperatures as well as rapid changes in temperature.

2. Pressure relief

   The gas in the storage tank vaporizes and the pressure inside needs to be released at times. Pressure relief and bleed valves are an integral part of an LNG system. These also add additional restrictions since the released gas needs to be controlled.

3. Placement of the LNG tank and processing units

   The LNG tank, the processing unit and additional parts of the system add restrictions by means of the hazardous areas plan, affecting the arrangement the vessel.

4. Arrangement of the ventilation system

   The ventilation system needs careful consideration, in order to prevent the accumulation of gas pockets, the absorption of LNG in spaces where it shouldn't be present and requires careful consideration of the openings placement.

5. Arrangement of the gas piping and tank storage, to be protected against damage

   The paramount principle is to try and separate the gas dangerous spaces from the gas safe spaces, and to position the tanks and piping so as to be protected from damage.

6. Arrangement of the ship systems and impact of LNG on the usual solutions

   Some conventional systems of the vessel are impacted by the addition of the LNG system, such as the bilge system or the drip-tray and drain system.

7. Possibility of leaks

Leaks are a significant risk during the operation of LNG-powered vessels. These need to be accounted for by all parties involved, such as the tank manufacturer, the distribution system provider, the ship designer and the vessel crew.

8. Access to hazardous areas and limitation of openings in hazardous areas

   A delicate matter in the design of such a vessel is evaluating and designing a general arrangement that leads to a proper degree of safety in terms of access points, accommodation layout and placement and general risk minimizing.

11.4 Vessel data

According to the safety barriers that need to kept in check when designing and operating an LNG powered vessel and the owner's requirements, the most important ship data are:

Main dimensions		
Length overall	42.00	m
Length hull	41.5	m
Breadth	13.5	m
Depth	3.0	m
Design draught	1.85	m
Scantling draught	2.0	m
Air draft above B.L.	9.40	m
Capacities		
Ballast	83	m^3
Fresh water	30	m^3
Sewage at 85% fill	26	m^3
Lubrication oil	8	m^3
LNG (total/net)	220/190	m^3
Crew	8	
Equipment		
Propulsion engines	3x1460 kW @ 900 RPM	
Gearbox	1:2.548 gearbox ratio	
Shaft generator	80 ekW	
Gas generator	80 ekW	
Side thrusters	42", 2x250 kW	
Propellers	2 x FPP, 1 x CPP, 1.8 m	
Hydraulic unit	600 kW	
LNG Pack	2 Bilobe tanks @ 110 m3	

Table 11.4.1: Vessel data

11.5 Hazardous areas

A hazardous areas plan is required during every stage of design, since it has such a great impact on the layout of the vessel. The goal is to keep the accommodation, the superstructure and the engine room safe and away from gas related equipment, as well as have an overview of all the openings, areas of interest and passage-ways.
First hazard area is **zone 0** presented in figure 11.5.1, in which an explosive atmosphere is continuously present.

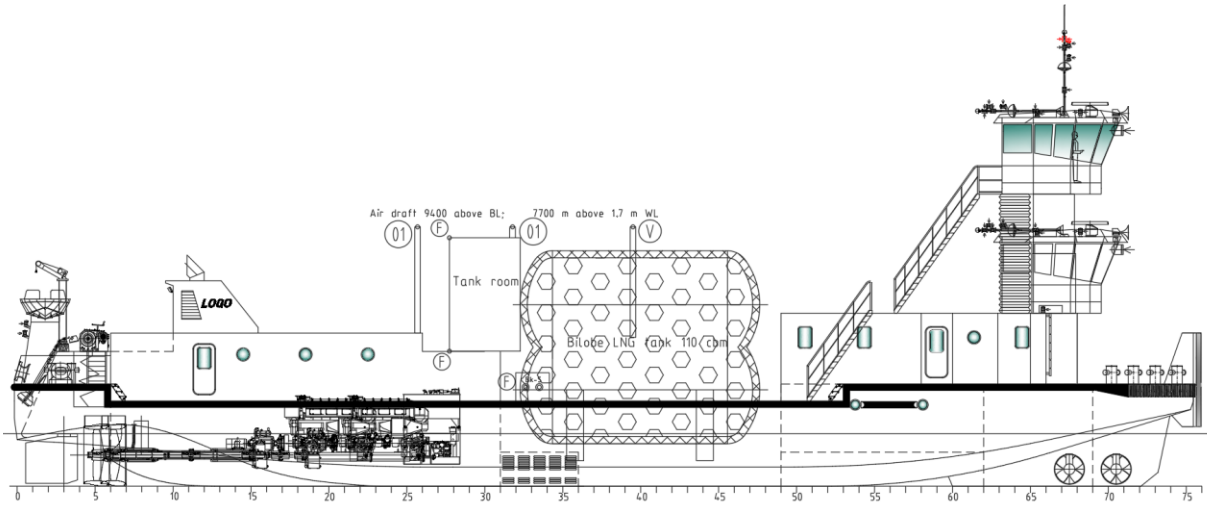


Figure 11.5.1: Hazardous areas plan – Zone 0

The second hazard area is **zone 1**, presented in figure 11.5.2, in which an explosive atmosphere is likely to occur occasionally, in normal operation.

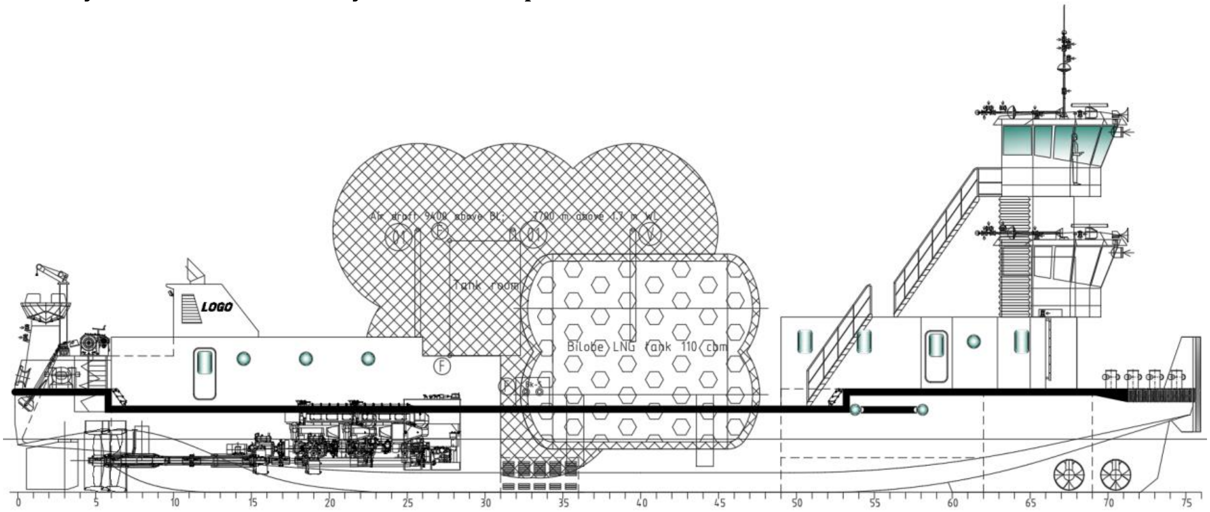


Figure 11.5.2: Hazardous areas plan – Zone 1

The last hazardous area is **zone 2**, presented in figure 11.5.3, where an explosive atmosphere might occur only accidentally, and will last for a short period of time.

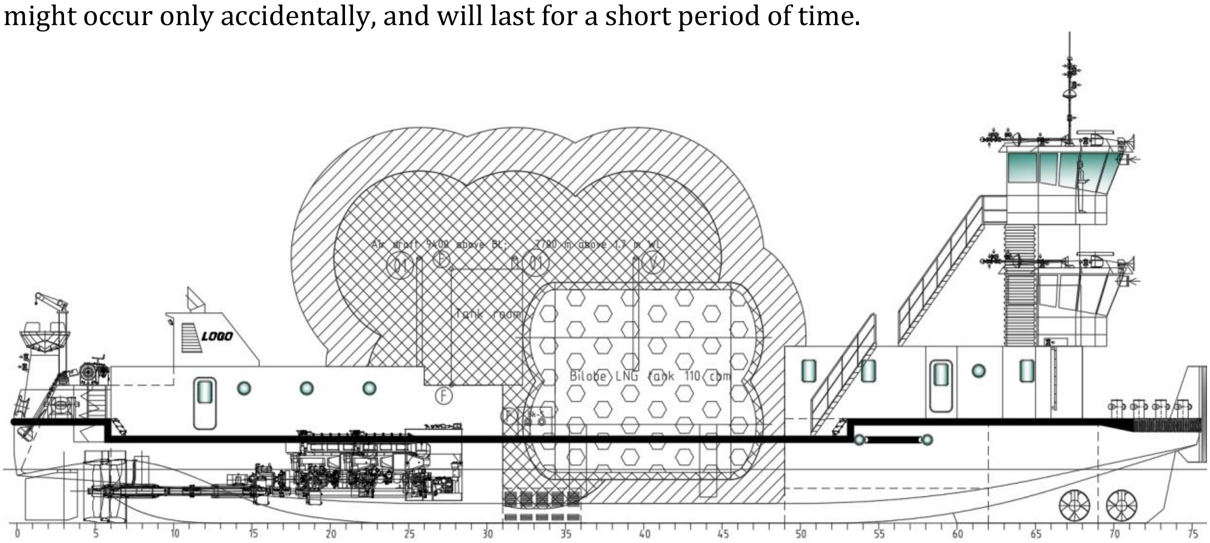


Figure 11.5.3: Hazardous areas plan – Zone 2

Arrangement of the vessel has to take into account all hazardous areas, meaning all the vent inlets and outlets need proper consideration.

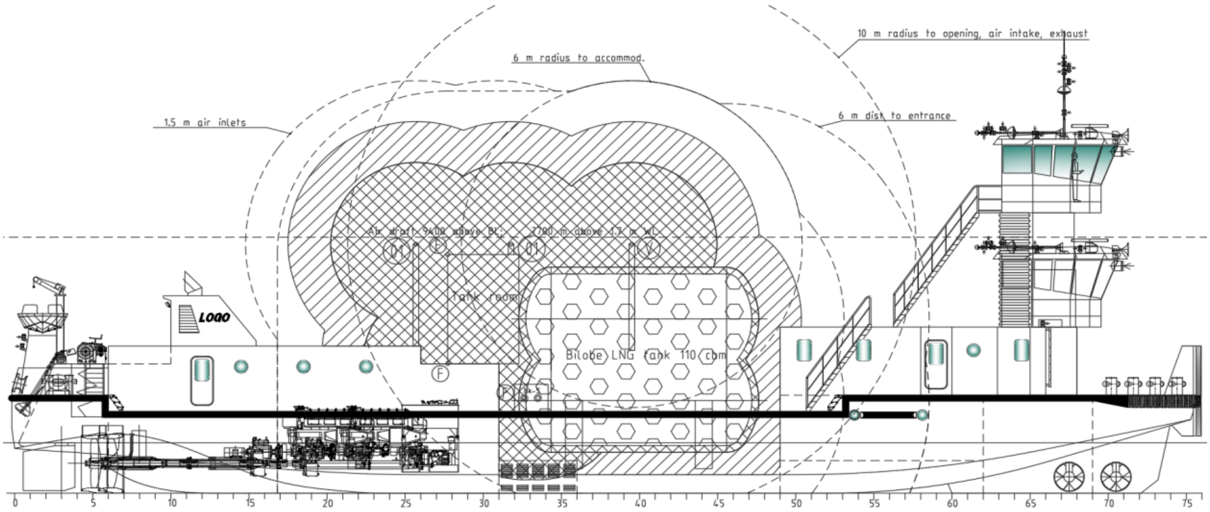


Figure 11.5.4: Hazardous areas plan – Ventilation outlets and inlets

Although still considering the specifics of it, the vessel incorporates a composite cover, with the purpose of protecting the gas related equipment (Fig. 11.5.5). It will also function as a platform for the solar panels and give to the vessel a modern and visually pleasant aesthetic. The cover will have a low weight, will be resistant to corrosion and will not require significant maintenance.

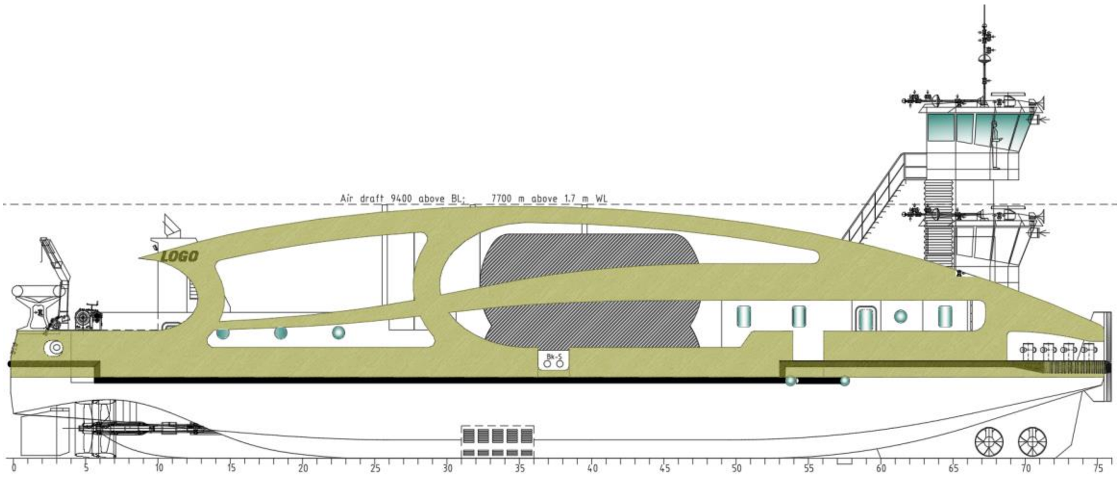


Figure 11.5.5: Protective composites cover

11.6 Ship propulsion system

11.6.1 Engine room definition

One main concern during the design of the vessel was the definition of the engine room. Two possibilities have been considered:

- ESD, Emergency Shut Down, in which the engine room is considered a hazardous area, and which demands special constructive measures difficult to implement into a small ship, and special equipment rated for such an environment
- Gas safe compartment, in which the engine room is not considered a hazardous area, and the equipment doesn't need to be of a special type. A compartment is considered gas safe if in the event of any single failure, LNG will not leak into the compartment. Gas piping needs to be double walled and gas related equipment, such as the engines, need to comply with certain requirements. The gas safe solution was selected for the pusher.

11.6.2 Power generation

Initial estimate of the maximum electrical power requirement of the vessel is at 80 ekW. In this respect, three sources of electrical power are considered:

- One gas-electric generator, LNG-fuelled, with a gas safe construction and 80 ekW output;
- One shaft generator, driven by the central main engine by a PTO on the gearbox, at 80 ekW output;
- 150 m^2 of solar panels, providing an output of 15 ekW;
- One battery group.

The electrical power sources will be used as follows:

- The shaft generator will be used in navigation when the central engine is running;
- The gas generator will be used when the vessel is stationary and the power requirement exceeds the capabilities of the solar panels;
- The solar panels will be used for charging the batteries in navigation and for the power requirements of the vessel when stationary.

The energetic configuration of the system is described in Fig. 11.6.2.1.

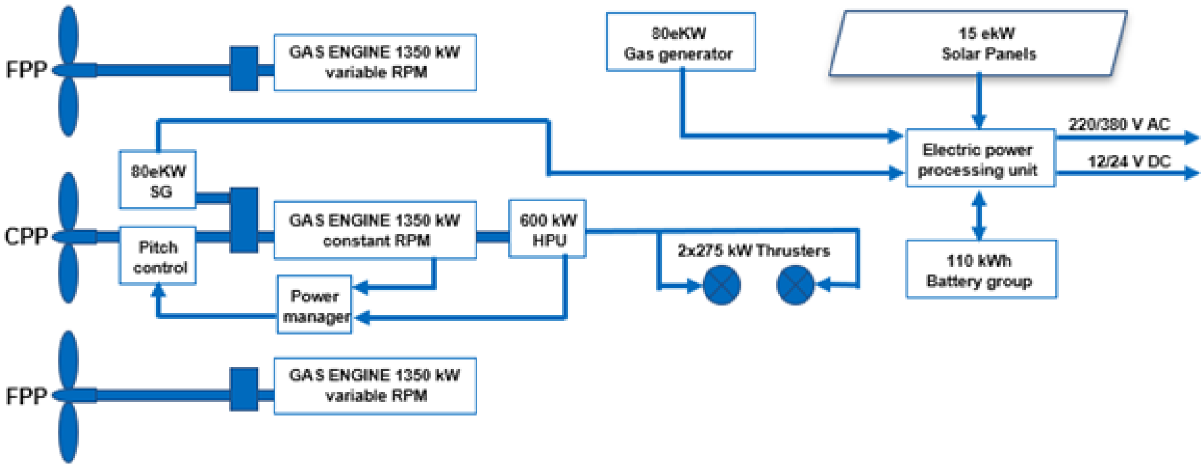


Figure 11.6.2.1: LNG pusher energetic configuration

The setup above allows for flexible operation:

- Three engines running depending on the load;
- Automatic power adjustment when side thrusters are used;
- Gas generator not needed when the central engine is running;
- Generators usually not required when the vessel is stationary due to the solar panels.

11.6.3 Propulsion

Going further, propulsion solutions had to be developed, with the pure gas engines considered. The selected propulsion engines compliant with the above criteria run at 1460 kW and 900 RPM. The engines selected are propulsion type, with variable RPM for the side engines and constant RPM for the central engine. They are double walled, to meet the gas-safe criteria. The central engine will have a 600 kW PTO attached to the shaft line.

With that, a series of design decisions were made:

- Three propellers, one of which is limited in power
- Nozzle propellers, for increased thrust at low speed
- Azimuth thrusters considered not to be viable due to the shallow waters
- Fixed pitch side propellers for reliability
- Controllable pitch central propeller for flexible operation
- Gearbox-Shaft line propulsion for increased efficiency

Due to the limitation of the propeller load factor, the design of the propeller should use only a fraction of the engine power, with an optimal design of the propeller for a power input of 1350 kW. The calm water resistance of a 3x3x3 convoy of 2000 t barges was considered when assessing the forward resistance and power requirements.

Propeller type	K-type (ducted)
Propeller diameter	1.80 m
Targeted speed	12 km/h
Propeller speed	353 rpm

Table 11.6.3.1: Propeller data

Consideration had to be given to the geometry of the hull in the aft area when establishing the propulsive elements. The propeller nozzle was integrated with the hull for added structural strength and to prevent it from going below the baseline. The rudder position at different turning angles was analysed to ensure that it doesn't interfere with the hull.

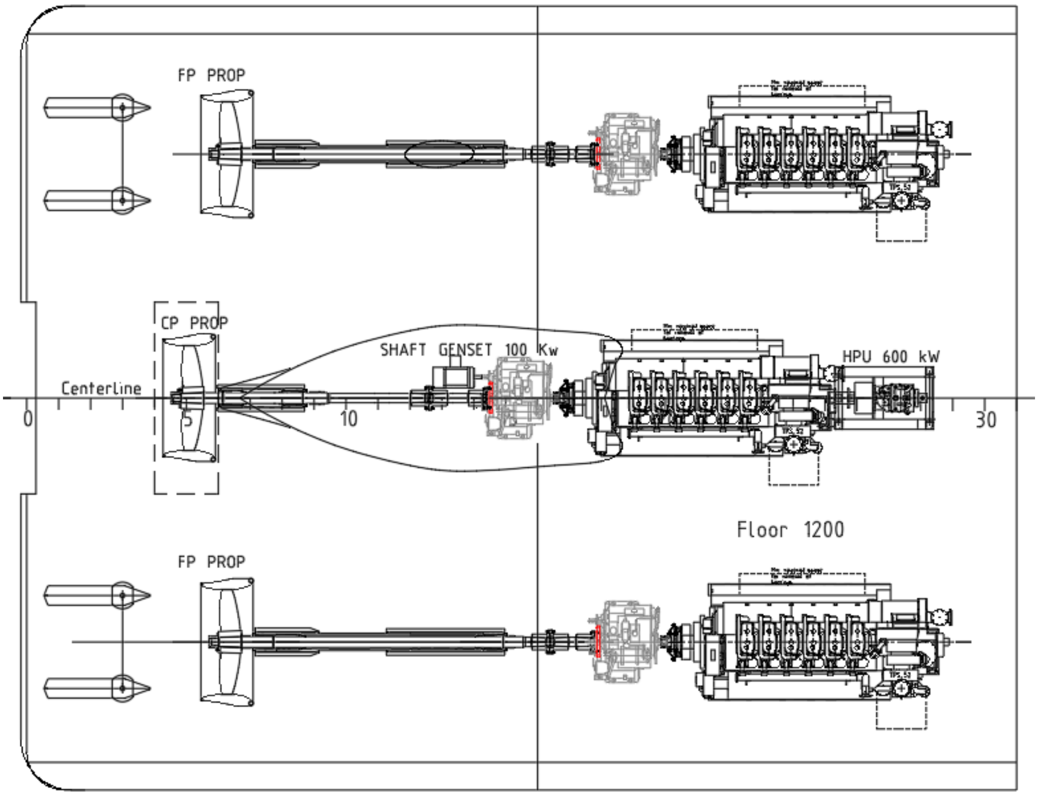


Figure 11.6.3.1: Propulsion arrangement, top overview

11.6.4 Manoeuvring

The manoeuvring capabilities of the vessel needed to be assessed for the typical convoys considered. In this respect, the following solutions were implemented:

- Two double rudders in the way of the side propellers, with a total maximum side force of around 310 kN;
- Two tunnel thrusters of 42" in diameter and 275 kW each, producing a total side force of about 90 kN;
- Hydraulic side thrusters, powered from a 600 kW HPU driven by the central engine and only used during power-heavy manoeuvring;
- No rudder in the way of the central propeller, since it wouldn't be as efficient, it would add drag and further complicate the construction.

Manoeuvring calculations were performed for a 2.84 m^2 rudder side area.

11.6.5 Operational profiles

Operational profiles were determined to assess an order of magnitude for LNG fuel consumption. The operational profiles considered during the design process are presented in Tables 11.6.6.1-11.6.6.3.

Condition	Propulsion [kW]	Thrusters [kW]	Generator [kW]	Total
Upstream	3450 (3 engines, 85% load)	30 (5% of the time)	50 (shaft generator)	3530
Downstream	2300 (2 engines, 85% load)	30 (5% of the time)	50 (gas generator)	2380
Maneuvering	800 (2 engines, 30% load)	150 (25% of the time)	50 (gas generator)	1000
Stationary	0	0	10 (gas generator*)	10

*25% of the time

Table 11.6.5.1: Estimated power requirements with respect to navigation conditions

One voyage operational profile

	Time	Power [kW]
Upstream	55%	3530
Downstream	40%	2380
Maneuvering	5%	1000
Mean power per voyage		2950

Table 11.6.5.2: One voyage power requirement

Year-round operational profile

	Time	Power [kW]
Voyage	70%	2950
Stationary	25%	10
Yard repair	5%	0
Mean power per year		2070

Table 11.6.5.3: Year-round power requirement

Based on the above, an energy consumption of around 18130 MWh was estimated for a year of operation, which results in approximately 3150 m^3 of LNG fuel.

11.6.6 Performance

Once the assumptions above were made, the performance of the pusher needed to be assessed. Particularly, the pushing capabilities are of utmost importance. Table 11.6.6.1 shows the presumed thrust of the vessel in three scenarios. The thrust is calculated at the convoy's service speed and the obtained speed is relative to the water.

Scenario	kW	HP	Thrust [kN]	Speed [km/h]
Maximum thrust	4050	5500	408	13
Using side thrusters and shaft generator	3400	4600	355	12
Side engines only	2700	3650	270	11

Table 11.6.6.1: Thrust performance in three different conditions

Considering the upstream and downstream operational profiles of the vessel, and an average flow speed of 4 km/h, the convoy speed relative to the land is at least:

- 8 km/h upstream
- 14 km/h downstream

A fuel consumption assessment was also performed for the vessel. Based on the calculations, the presumed range of the vessel is:

- Upstream: 1200 km
- Downstream: 3150 km

Certain solutions were implemented with the goal of achieving a flexible and efficient energy usage. Since the vessel will have at least two operational regimes, one upstream with a loaded convoy and one downstream with a loaded or light convoy, this lead to the necessity of flexibility in the power delivery design. In that respect, the central drive train consists of a constant RPM engine and a controllable pitch propeller. This allows for the engine to be turned off and the propeller to be feathered in light load, to minimize forward drag. The controllable pitch propeller also allows up to 50% of the central engine power to be distributed through a power take-off to consumers. The 600 kW HPU takes power from the central engine and eliminates the need for an additional generator, which would be a waste due to the thrusters only being used rarely and during heavy manoeuvring. In addition, the solar panels can provide 120 kWh/day. Coupled with a 111 kWh battery pack, the vessel should not need the electrical generator when operates in hotel regime.

One compromise that had to be made was that the propeller diameter was limited due to construction reasons, which in turn lead to a limitation of the installed power of the drive train. As such, the vessel is fitted with engines that have a higher power than the one that the propellers can efficiently use. More specifically, an engine output power of 1350 kW would be the maximum that the propellers can safely use, which is around 92.5% of the maximum available. However, this also leads to some benefits, such as slower wear of the engines, no overload during heavy manoeuvring and reserve power for other consumers.

Vessel-specific design decisions are also related to the shape of the hull, to ensure proper hydrodynamic efficiency in the aft area. Some of these are:

- A midship section with high bilge radius and slight V-shapes, to ensure proper flow towards the propeller, especially in shallow water conditions
- The propeller semi-tunnels limits were extended aft and side, to prevent air intake to the propeller; they are designed such that the side extension allows as much water as possible from the side of the ship to the propellers, while the aft extension is designed to reduce as much as possible the negative impact on the propeller thrust;
- The central shaft line is positioned inside a stern bulb, to minimize turbulence and direct the flow towards the central propeller;
- The fore shape allows a central skeg to be present, for mounting the side thrusters, and also limits the amount of green water on the deck when navigating without a convoy;
- The struts are oriented considering the flow streamlines to reduce turbulence in the propeller disk.
- The gas storage is placed close to the midship to minimize trim variations during navigation

11.7 Hull basic design

The hull girder strength criteria were determined, since these impact the scantlings of the structure significantly. For the concept pusher, these are presented in Table 11.7.1.

Design case	HOGGING (kNm)	SAGGING (kNm)
Design sea water bending moment in navigation	6511	-2524
Design vertical wave bending moment	6541	6541

Table 11.7.1: Hull girder strength criteria

The material chosen for the hull is standard marine Grade A steel, with a yield stress of 235 N/mm^2. A frame spacing of 550 mm was determined to be suitable. We notice that the hull design is quite advanced. The documents below contain construction plans, relevant decks, bulkheads and supporting structure, as well as additional information such as shell expansion, shell structure and relevant views. Vessel specific solutions include a strengthened fore structure for pushing the convoys and a change from a longitudinal stiffeners system to a transversal stiffener system for the engine room and aft structure. There are increased scantlings amidship to sustain the added weight of the LNG fuel, as well as pillars in the engine room to support the deck above the compartment. In figures 11.7.1-11.7.3 various views on ship structures are illustrated.

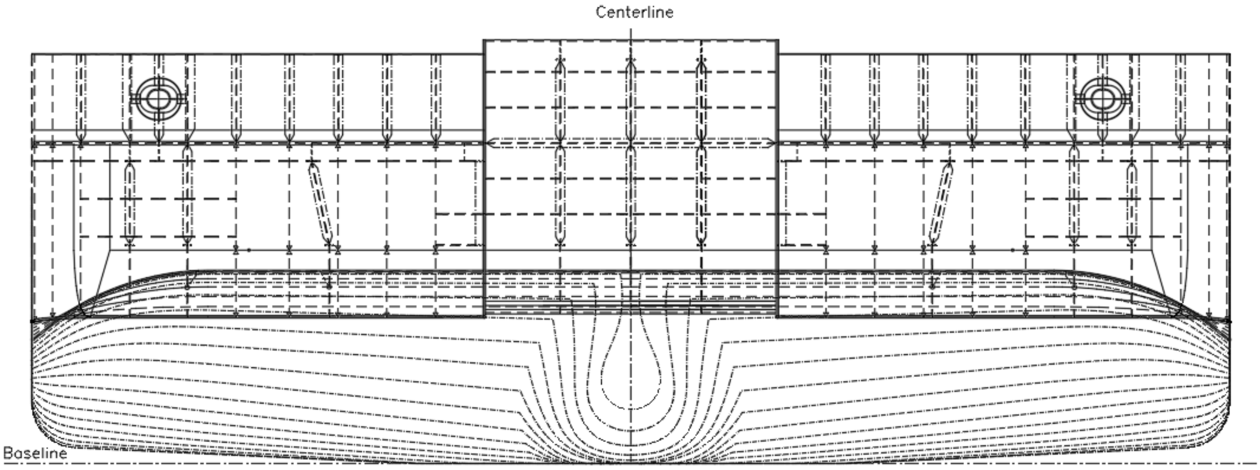


Figure 11.7.1: Aft structure

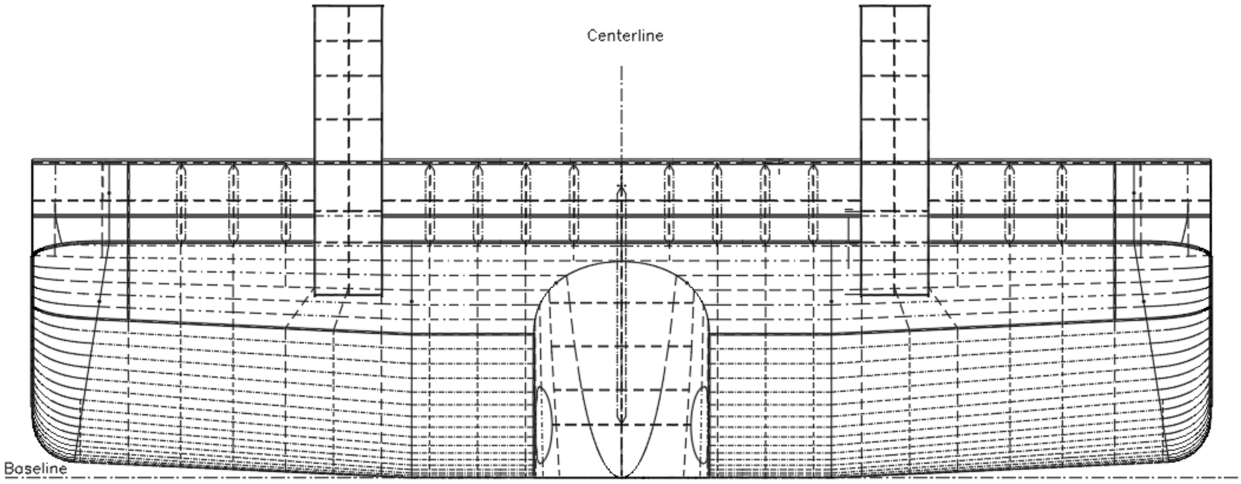


Figure 11.7.2: Fore structure

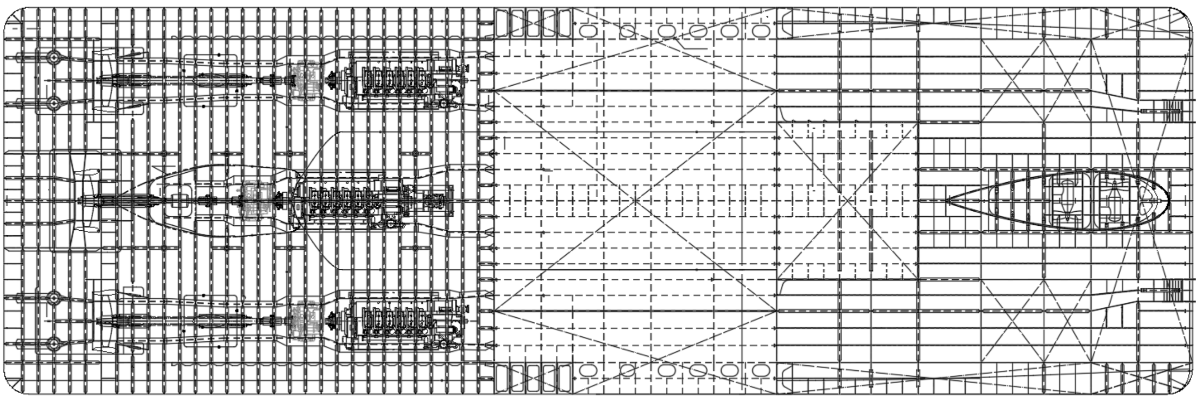


Figure 11.7.3: Bottom structure

11.8 Piping basic design

Special care was needed when designing systems that could interfere with the LNG system, or have an impact on the functionality of it, such as the ventilation system, the drain system or the exhaust system.
Vessel specific solutions are related, but not limited, to the following systems and layouts: Tank sounding system, Tank ventilation system, Bilge system, External drainage. HVAC system. Water fire extinguishing system. The other systems, specific for an LNG propelled ship, are described further.

11.8.1 Fuel gas system

One of the critical systems aboard the vessel, the fuel gas system was given special consideration when designing the functionality of the system. Some of the specifics of the system are that all connecting piping is double walled, and the gap between the two pipes is constantly ventilated, to prevent the accumulation of gas in case the inner pipe has a leakage. The gas valve unit needs to be outside of the engine room and ventilated as well. A three-way valve on the gas valve unit ensures that in case of emergency, the LNG supplied from the tanks can be discharged into the atmosphere, thus cutting the supply of gas to the engines.

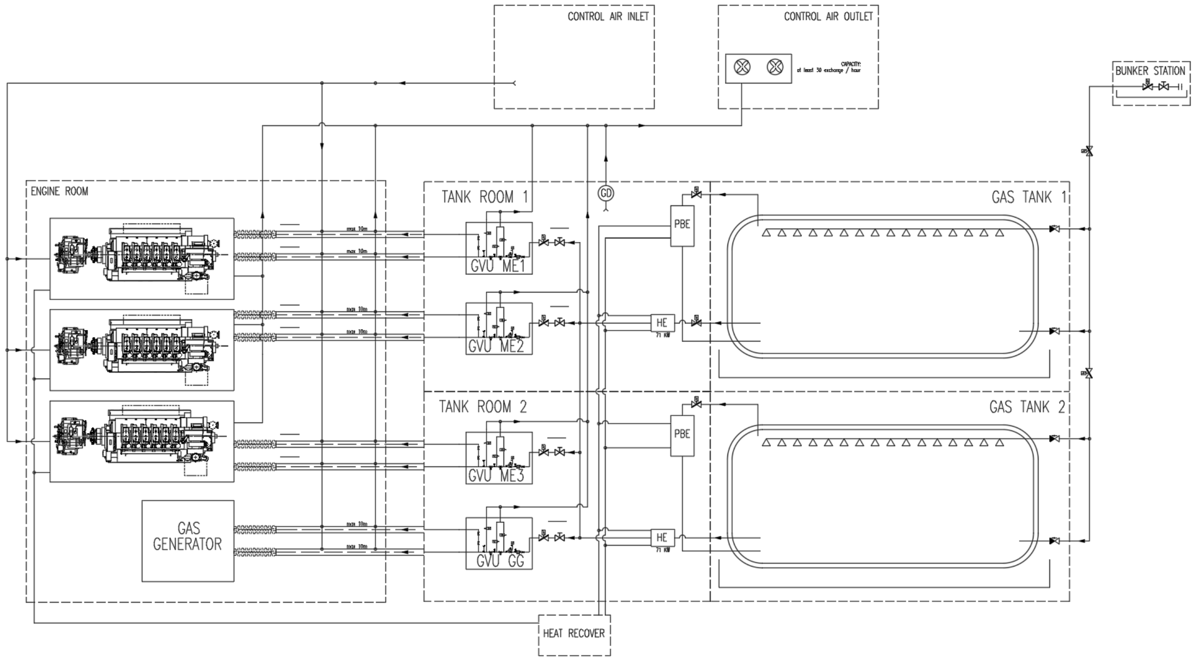


Figure 11.8.1.1: Fuel gas system configuration

11.8.2 Water cooling system

One particular aspect of the water cooling system is that the hot water required to vaporize the LNG gas inside the vaporizer is provided from the engine's cooling system. Other than that, the system employs a classical box-cooler system that is efficient for the shallow draught Danube navigation.

11.8.3 Exhaust gas system

The exhaust gas system has certain specifics related to the usage of LNG for propulsion. An additional function is needed which is not found on conventional vessels: there needs to be a way to ventilate the pipelines and components of the system when the engine is not running, to prevent the accumulation of gas. The system also needs to be sturdy enough and have safety valves that can withstand the over-pressure generated from explosions of gaseous LNG that has escaped from the engine. The exhaust pipelines also generate a hazardous area of type II around the funnels.

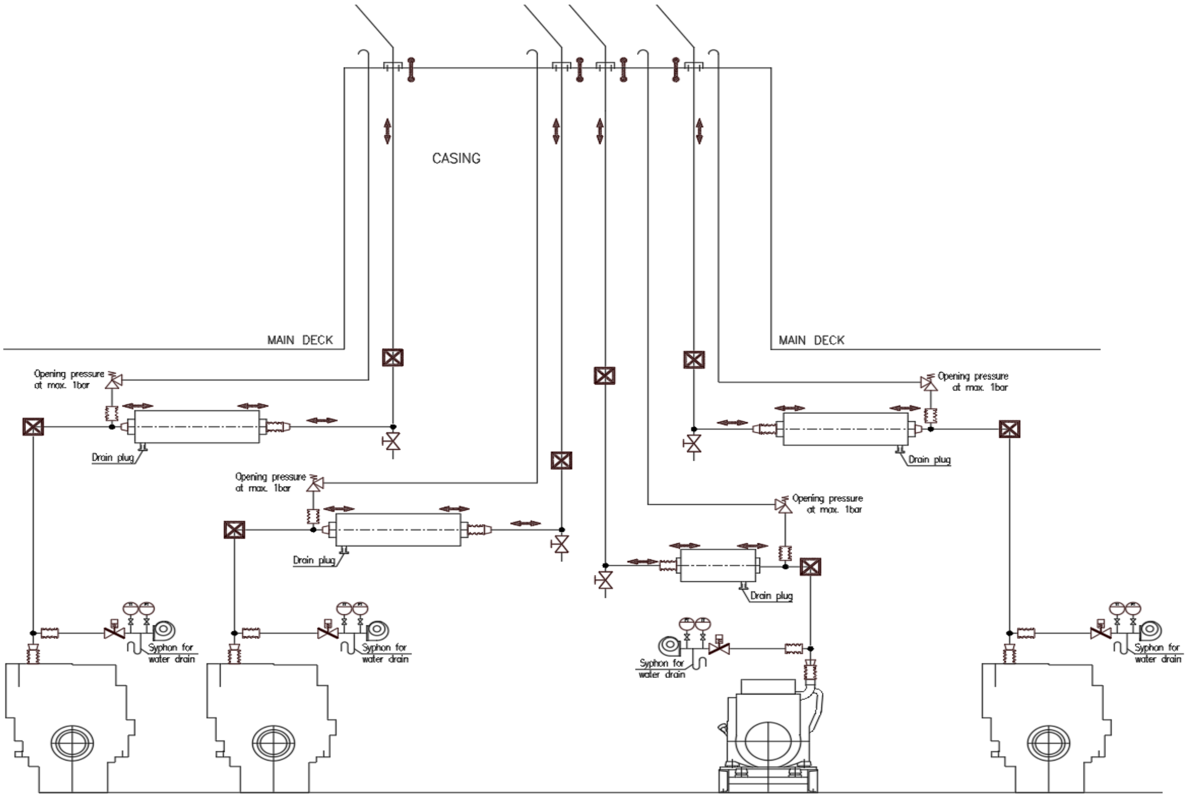


Figure 11.8.3.1: Fuel gas system configuration

11.9 Conclusions

The design process performed a concept for one of the most powerful pushers on the Danube. The concept is modern, with up-to-date technologies, and flexible both in operation and for design variations. The environmental footprint will be lower than that of a conventional vessel, and we expect the vessel to also be more cost-efficient than ones employing conventional fuel. It is also a step ahead of the STAGE V regulations, since it could transition between STAGE V and zero emissions, due to being hydrogen-ready.

The propulsion, manoeuvring and anchoring calculations have led to a robust and powerful vessel, well suited for navigating the Danube. The hazardous zones plan has been one of the go-to documents during the design process, since many of the vessels systems and layout decisions were based on the restrictions imposed by Regulations and showcased in the drawing. The hull and piping technical design stages have advanced and brought to limelight particularities specific to the usage of LNG as a propulsion fuel.

Figure 11.9.1: Concept design – Aft view

Figure 11.9.2: Concept design – Starboard view

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Interreg
EUROPEAN UNION
Danube Transnational Programme
GRENDEL

Annex 1.

Development of innovative and greening inland vessel concepts

Presentation held by Cristi Angheluță (SDG) at the GRENDEL Final Event (29 October 2020)

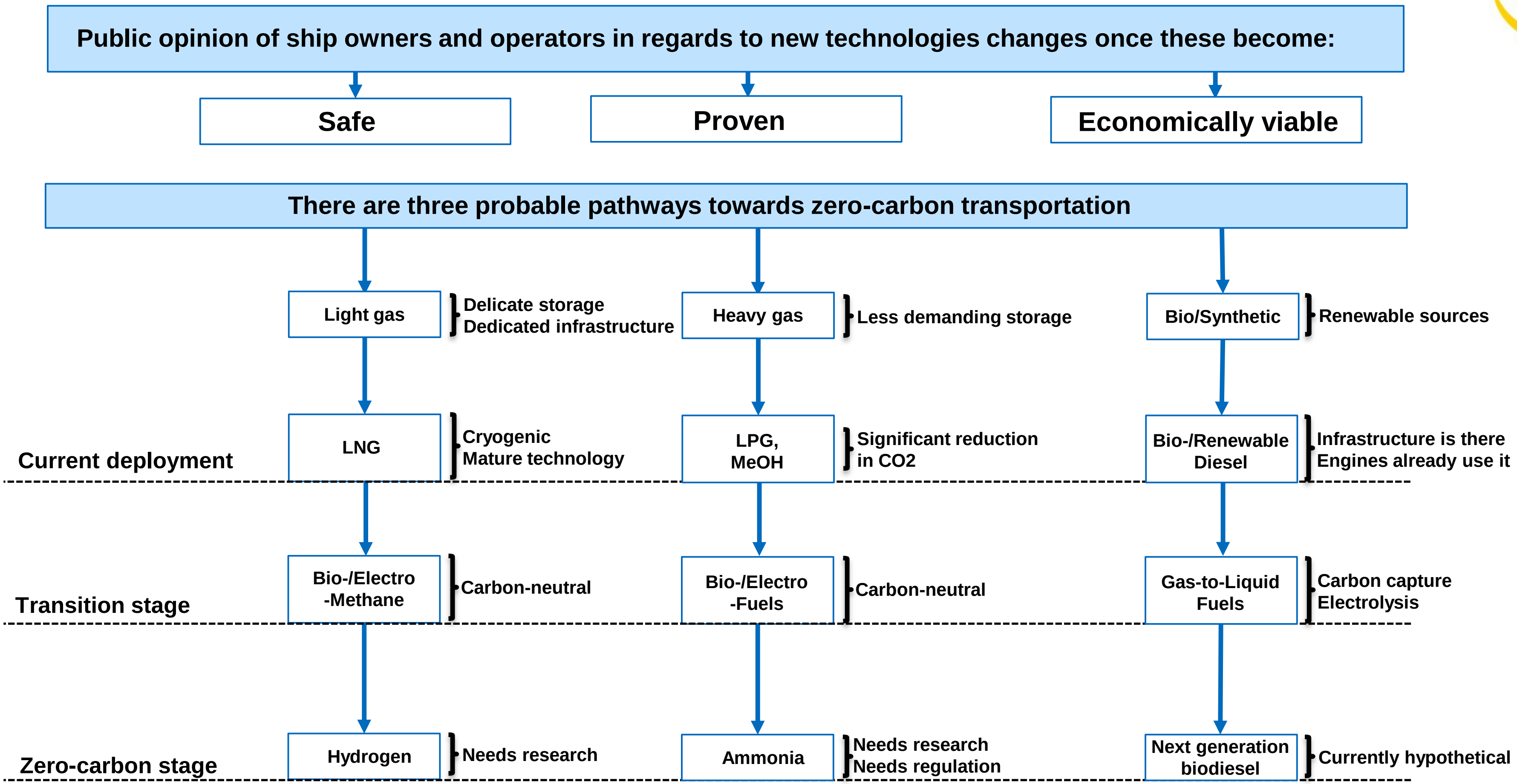
SHIP DESIGN GROUP (SDG) and NAVROM involvement

Cristi Angheluță, SHIP DESIGN GROUP Galati, Romania
Ionel Chirică, SHIP DESIGN GROUP Galati, Romania
Ionut Danaila, NAVROM Galati, Romania

Project co-funded by European Union Funds (ERDF, IPA)

29th of October 2020

Carbon neutral pathways and the transition



Project co-funded by European Union Funds (ERDF, IPA)

European regulation for the transition stage

Emission limits for non-road mobile machinery have been put forth to aid the process of transition. Inland waterway vessels have been included in the regulations.

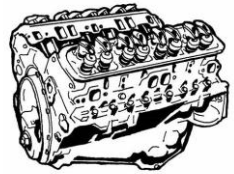
Engine Category	Power ranges (kW)	Sub-category (1)	Reference Power(2)	Placing of engines on the market	Emission durability period(3)	CO g/kWh	HC g/kWh (4)	NOx g/kWh (4)	PM mass g/kWh	PN #/kWh
IWP Inland waterway propulsion engines	19<P<75	IWP-1	Maximum/ Rated power	1st of January 2019	10000 hours	5.00	Total < 4.70		0.30	-
	75<P<130	IWP-2				5.00	Total < 5.40		0.14	-
	130<P<300	IWP-3				3.50	1.00	2.00	0.10	-
	P>300	IWP-4		1st of January 2020		3.50	0.19	1.80	0.015	1×10^{12}
IWA Inland waterway auxiliary engines	19<P<75	IWA-1		1st of January 2019		5.00	Total < 4.70		0.30	-
	75<P<130	IWA-2				5.00	Total < 5.40		0.14	-
	130<P<300	IWA-3				3.50	1.00	2.00	0.10	-
	P>300	IWA-4		1st of January 2020		3.50	0.19	1.80	0.015	1×10^{12}

Vessels already in operation

For existing vessels, one means of achieving emission reduction during the transition stage is by retrofitting with exhaust after-treatment systems or equivalent compliant systems.

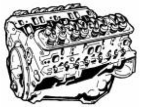
- **Replace the engine**
- **Replace the engine and the gearbox**
- **Replace the engine, gearbox and propeller**

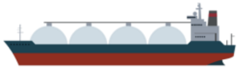
Add an after-treatment system → **Perform modifications to structure, piping, electrical systems and related trials**



The GRENDEL project is an attempt to modernize the inland Danube fleet and increase competitiveness of inland transportation. For GRENDEL, SHIP DESIGN GROUP and NAVROM have studied two propositions.

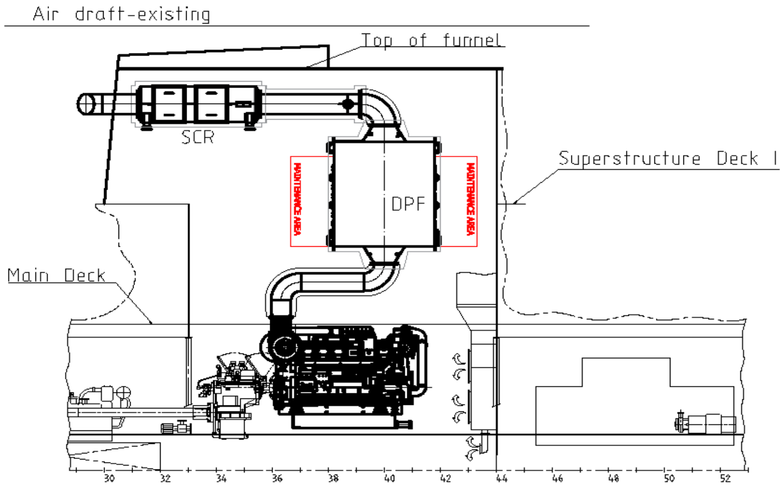
- **Retrofit technologies**
- **LNG for newbuilds**

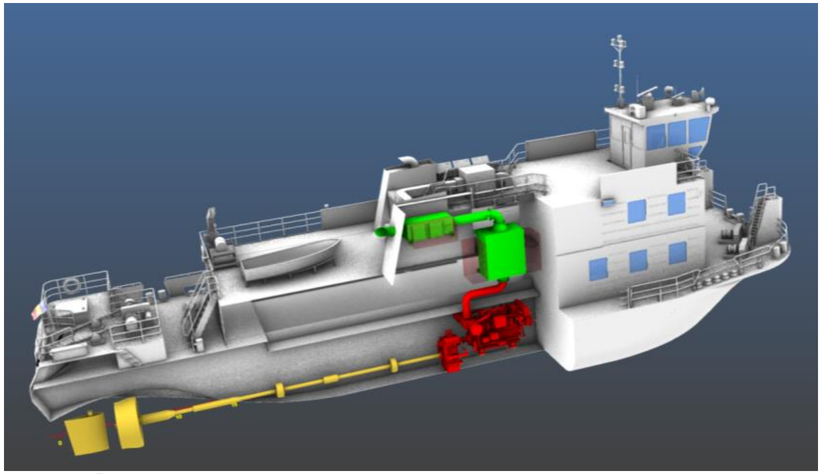




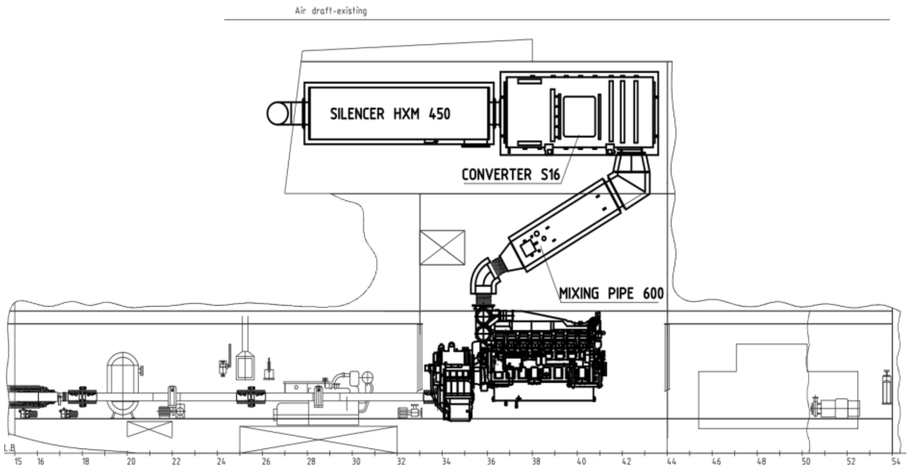
Retrofit solutions – Type 1 NAVROM pusher

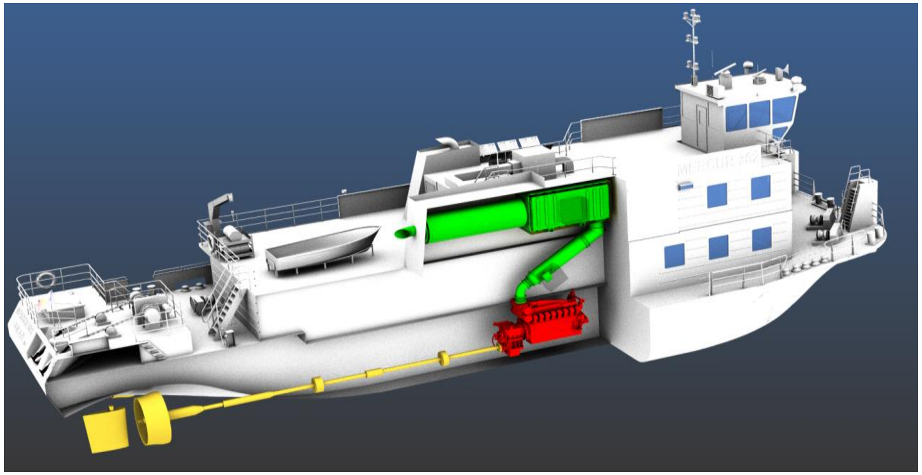
CATERPILLAR solution





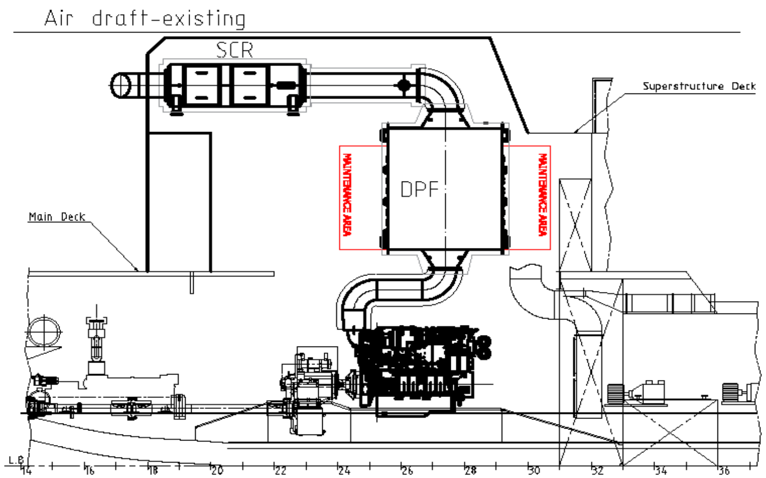
MITSUBISHI solution

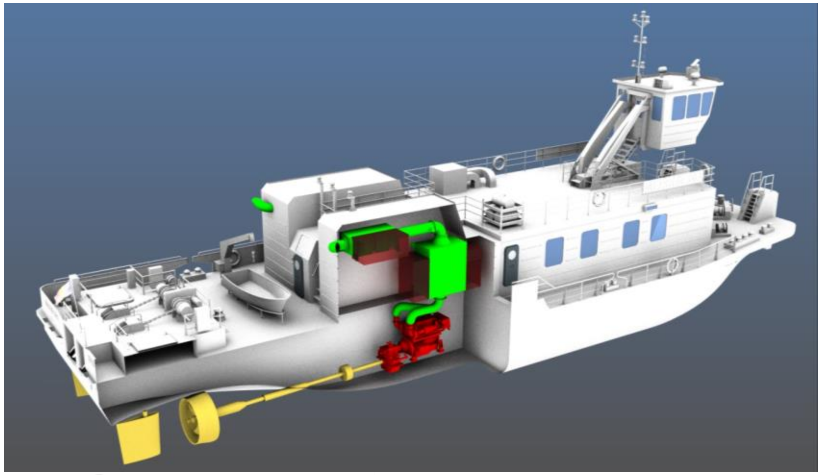




Retrofit solutions – Type 2 NAVROM pusher

CATERPILLAR solution





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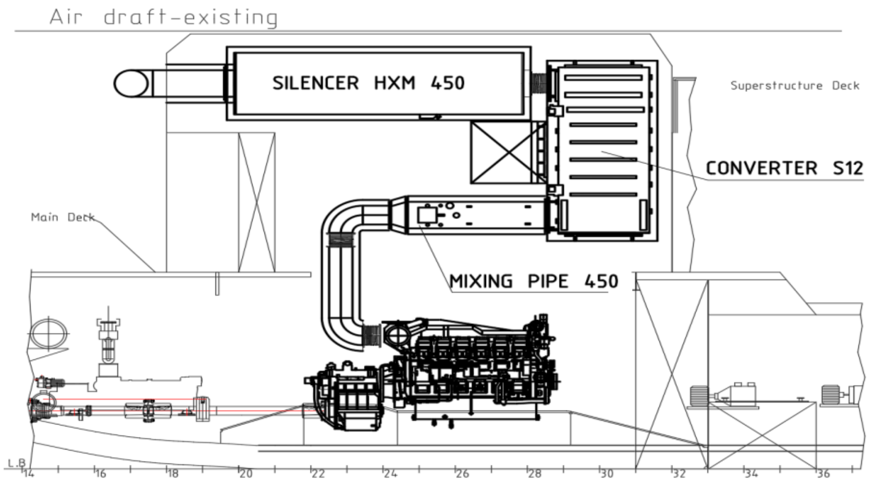
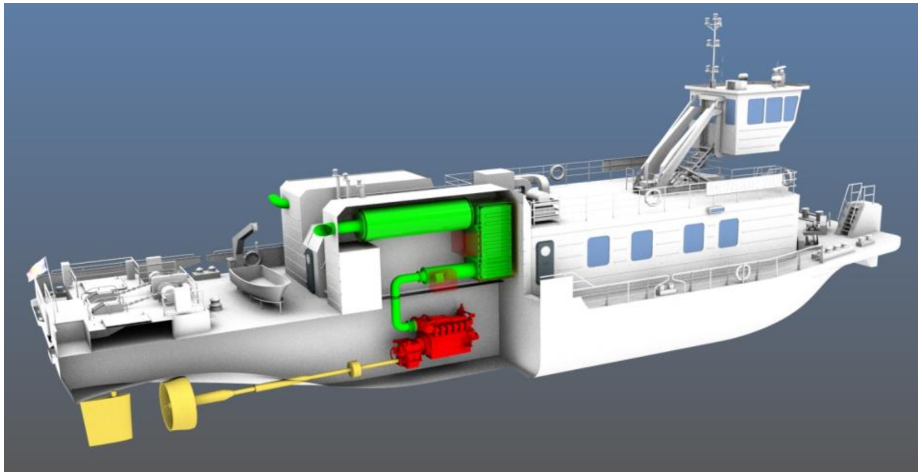
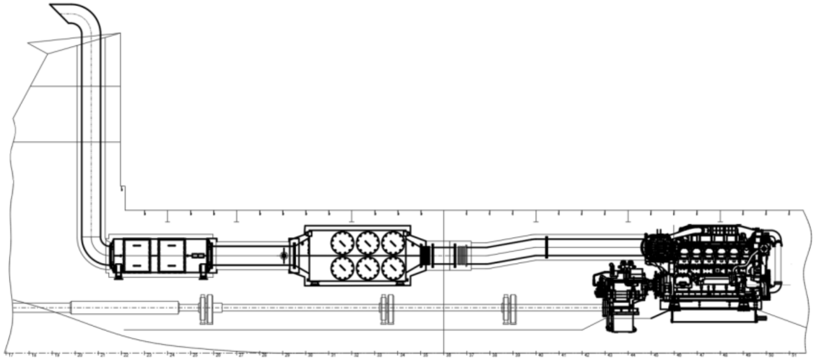


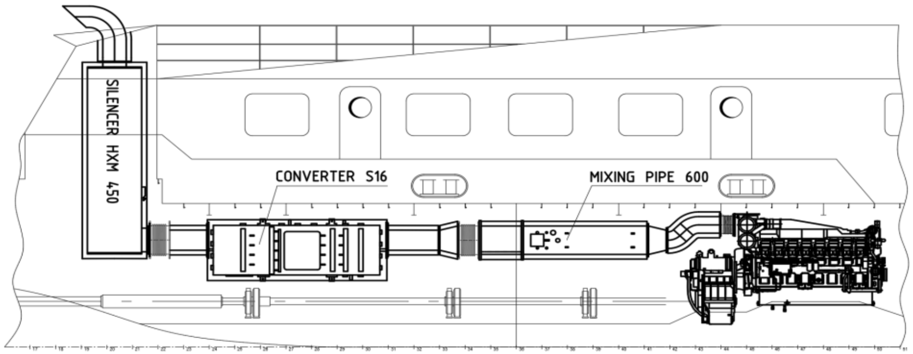


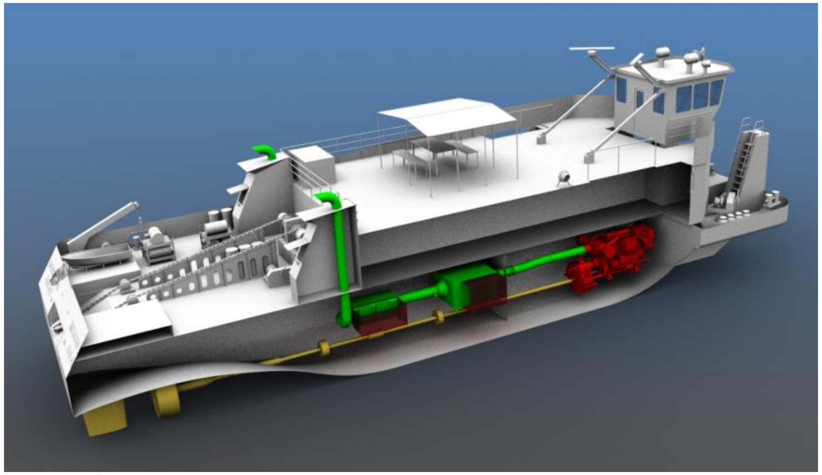
Retrofit solutions – Type 3 NAVROM pusher

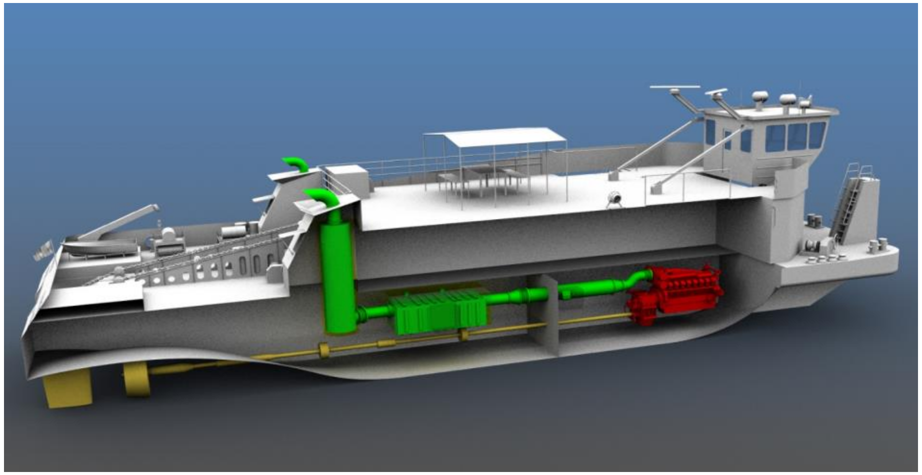
CATERPILLAR solution

MITSUBISHI solution



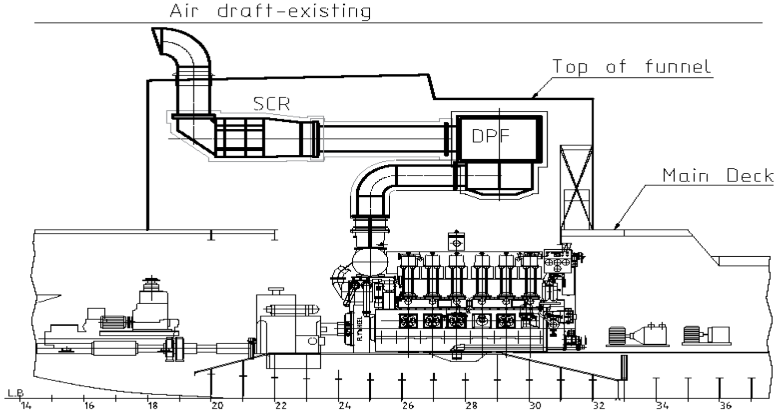


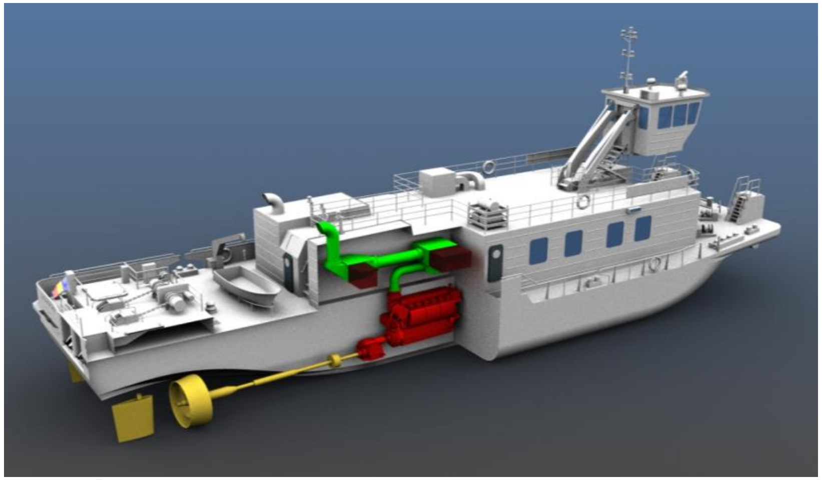




Retrofit solutions – Type 4 NAVROM pusher

ABC solution





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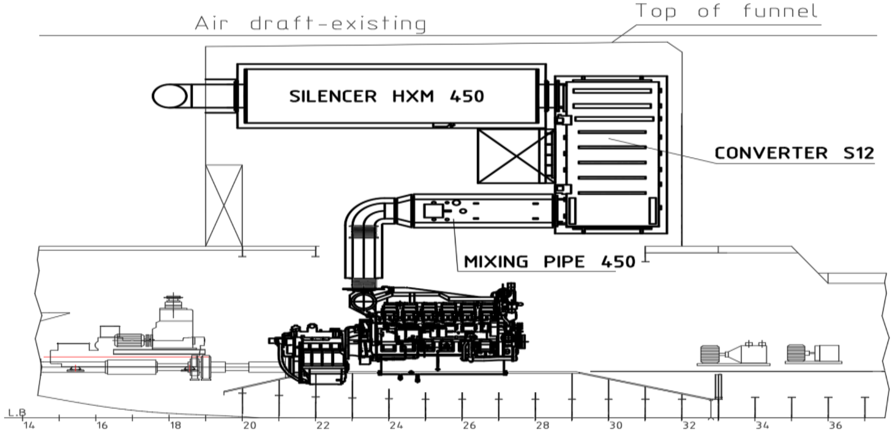
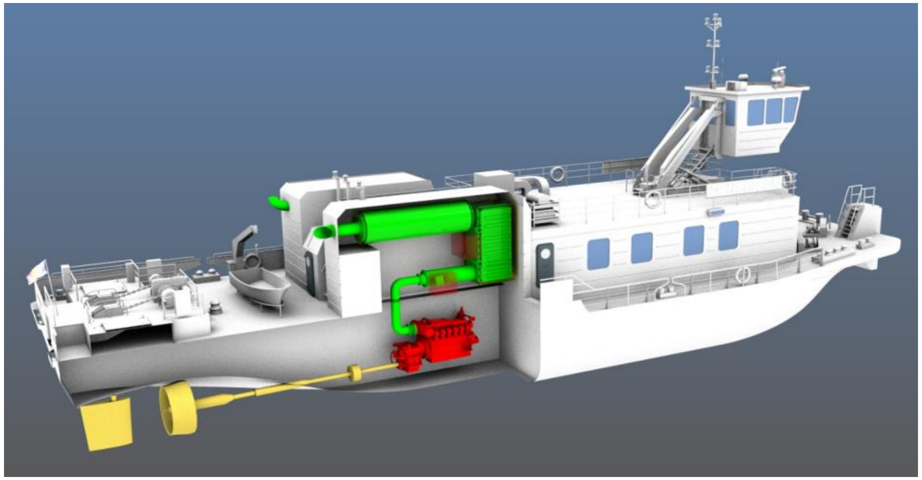




What have we learned, what can we achieve

Structural modifications

- New main engine foundation
- New supports for the EATS
- Funnel modifications
- New urea tank
- Miscellaneous structural modifications

Piping modifications

- New exhaust after-treatment system
- Modifications of engine-related piping
- New urea system
- New compressed air system
- Miscellaneous piping modifications

Electrical system modifications

- Main switchboard modifications
- Replacement of monitoring equipment
- Replacement of control equipment
- New cabling systems
- Miscellaneous electrical modifications

Results of modifications

Ship type	Number of ships	Total reduction HC	Total reduction NOx	Total reduction PM
Type 1	2	0.90	102.02	11.96
Type 2	4	0.20	144.12	17.96
Type 3	3	23.67	157.83	17.79
Type 4	2	12.32	82.14	9.28
	Total for all vessels (tons)	37.09	486.11	56.99

The LNG pusher – pathway towards zero-carbon

LNG technology

- **Economically feasible**

- **Community perspective improving**

- **Supply chains improving**

- **Technology is mature**

NAVROM requirements

Ship type	Pusher
Ship fuel	LNG
Power	> 4000 HP
Range	> 1000 km upstream
Navigation area	Danube river, up to Passau
Length	< 42 m, due to Danube locks
Breadth	< 23 m, due to Danube locks
Draught	< 2 m, due to Danube depth
Air draught	< 7.7 m, Passau bridge

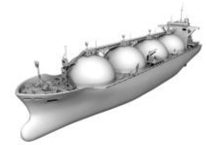
SDG input

The design process

The concept vessel

"One of the most powerful and modern pushers on the Danube River"

Why is LNG challenging



Engine manufacturers have been focusing on maritime applications

The materials used need to be certified for cryogenic temperatures

LNG related systems need to have carefully controlled pressure reliefs

The LNG tanks and the processing units need careful placement

The ventilation system is critical

The gas piping and tank storage need to be protected and separated from safe spaces

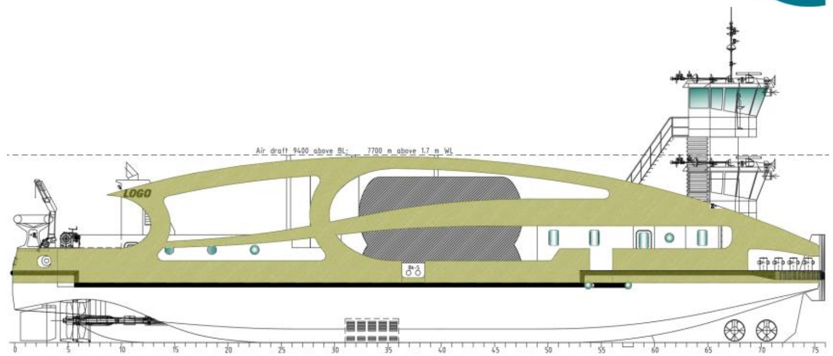
Conventional vessel systems are impacted by the LNG addition

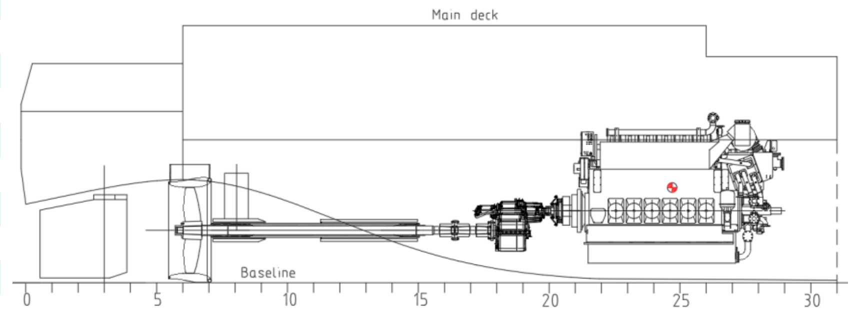
Leaks have to be controlled and accounted for during the design process

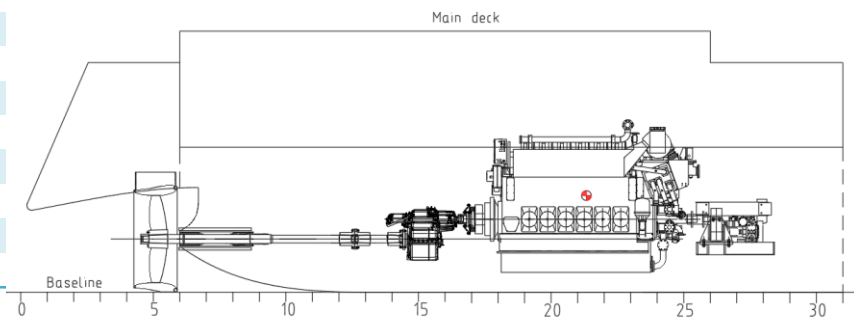
The general arrangement of the vessel is critical

Particular data

Main dimensions		
Length overall	42.00	m
Length hull	41.5	m
Breadth	13.5	m
Depth	3.0	m
Design draught	1.85	m
Scantling draught	2.0	m
Air draft above B.L.	9.40	m
Capacities		
Ballast	83	m^3
Fresh water	30	m^3
Sewage at 85% fill	26	m^3
Lubrication oil	8	m^3
LNG (total/net)	220/190	m^3
Crew	8	
Equipment		
Propulsion engines	3x1460 kW @ 900 RPM	
Gearbox	1:2.548 gearbox ratio	
Shaft generator	100 ekW	
Gas generator	100 ekW	
Side thrusters	42", 2x250 kW	
Propellers	2 x FPP, 1 x CPP, 1.8 m	
Hydraulic unit	600 kW	
LNG Pack	2 Bilobe tanks @ 110 m3	

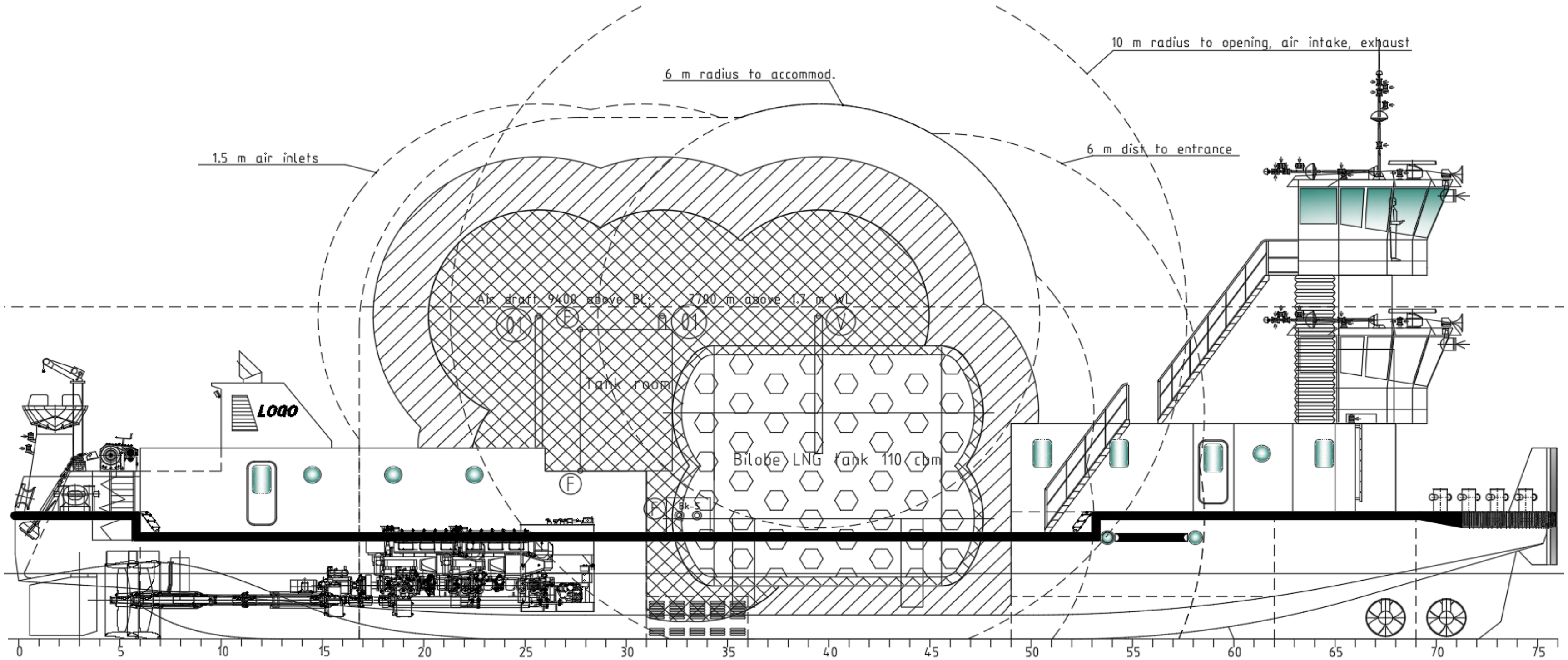




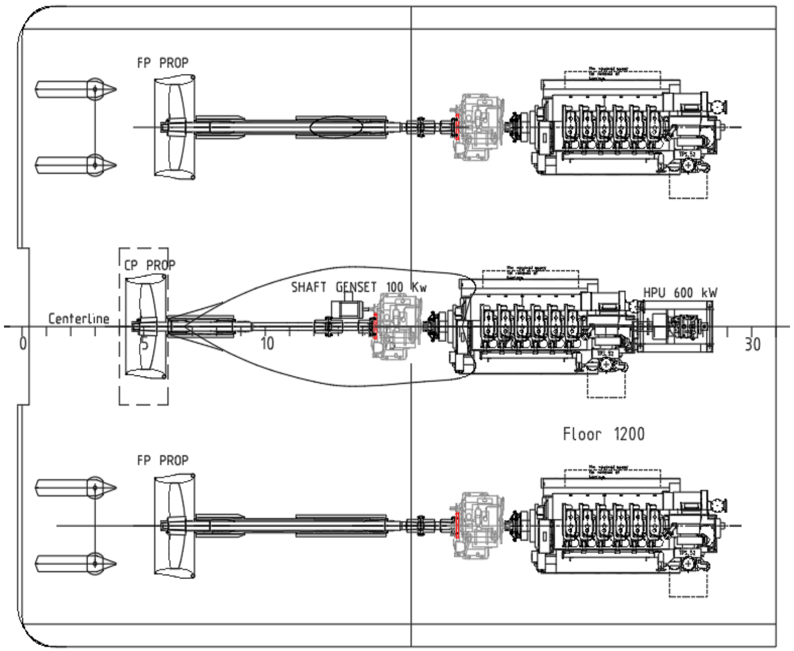


The hazardous areas plan

Critical for the design stage, the Hazardous Areas plan is done according to regulation and it dictates the layout of the vessel, the routing of piping systems and placement of equipment. The LNG concept has an engine compartment rated as ‘Gas safe’, due to employing double-walled piping and safety mechanisms.



Performances



With an average flow speed of 4 km/h, the convoy speed relative to the land is at least:

- **8 km/h upstream**
- **14 km/h downstream**

Presumed range of the vessel:

- **Upstream: 1200 km**
- **Downstream: 3150 km**

One year of operation results in approximately 3150 m^3 of LNG consumption.

Scenario	kW	HP	Thrust [kN]	Speed [km/h]
Maximum thrust	4050	5500	408	13
Using side thrusters and shaft generator	3400	4600	355	12
Side engines only	2700	3650	270	11

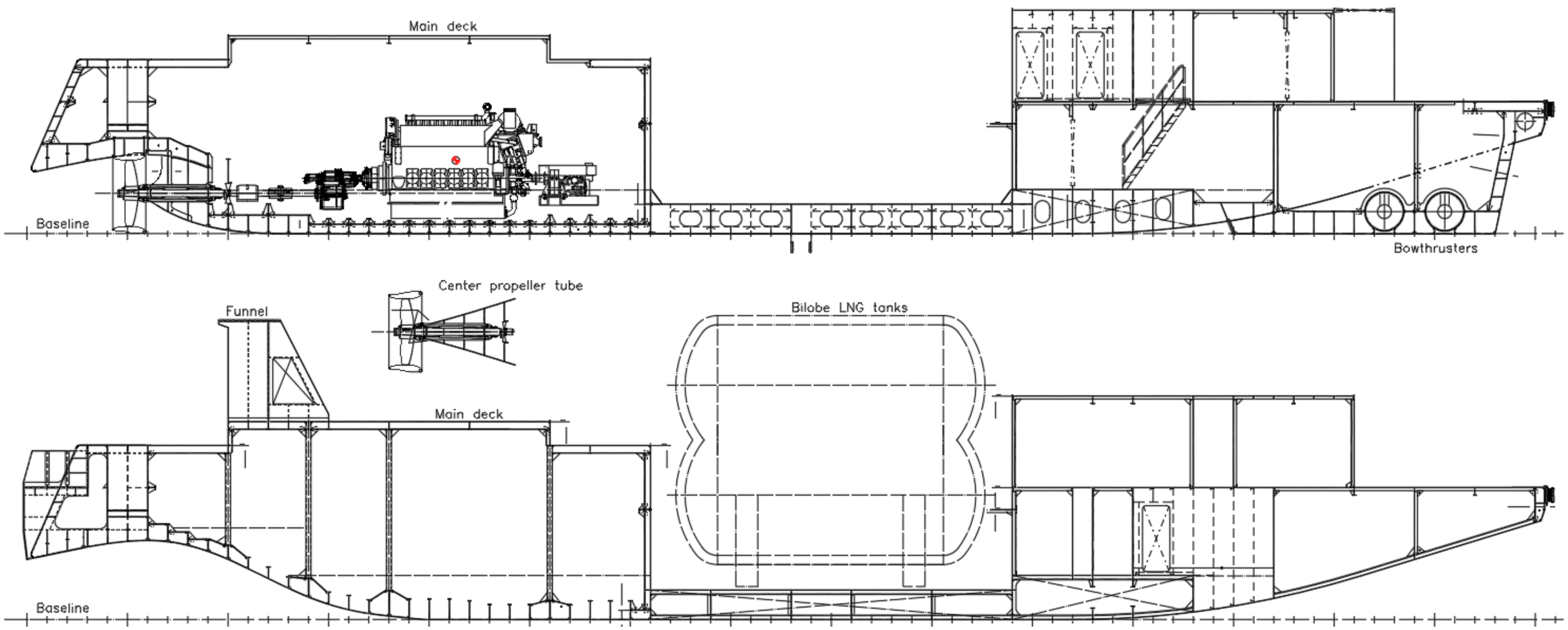
The hull basic design

The hull technical concept involves the assessment of relevant strength criteria and resulting structure scantlings.

Steel hull, grade A or equivalent

Vessel specific solutions

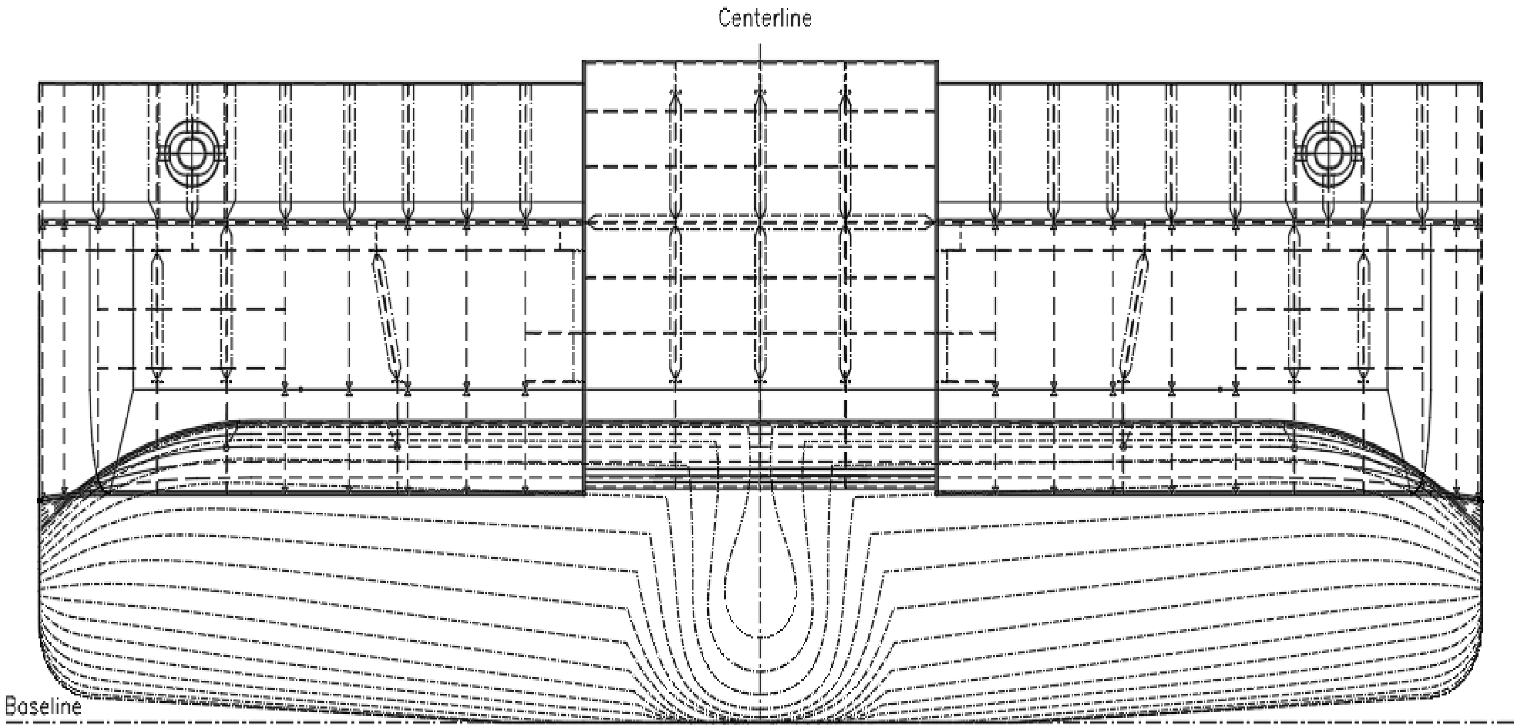
Designed for efficiency



The hull basic design

The hull technical concept involves the assessment of relevant strength criteria and resulting structure scantlings.

- **Steel hull, grade A or equivalent**
- **Vessel specific solutions**
- **Designed for efficiency**



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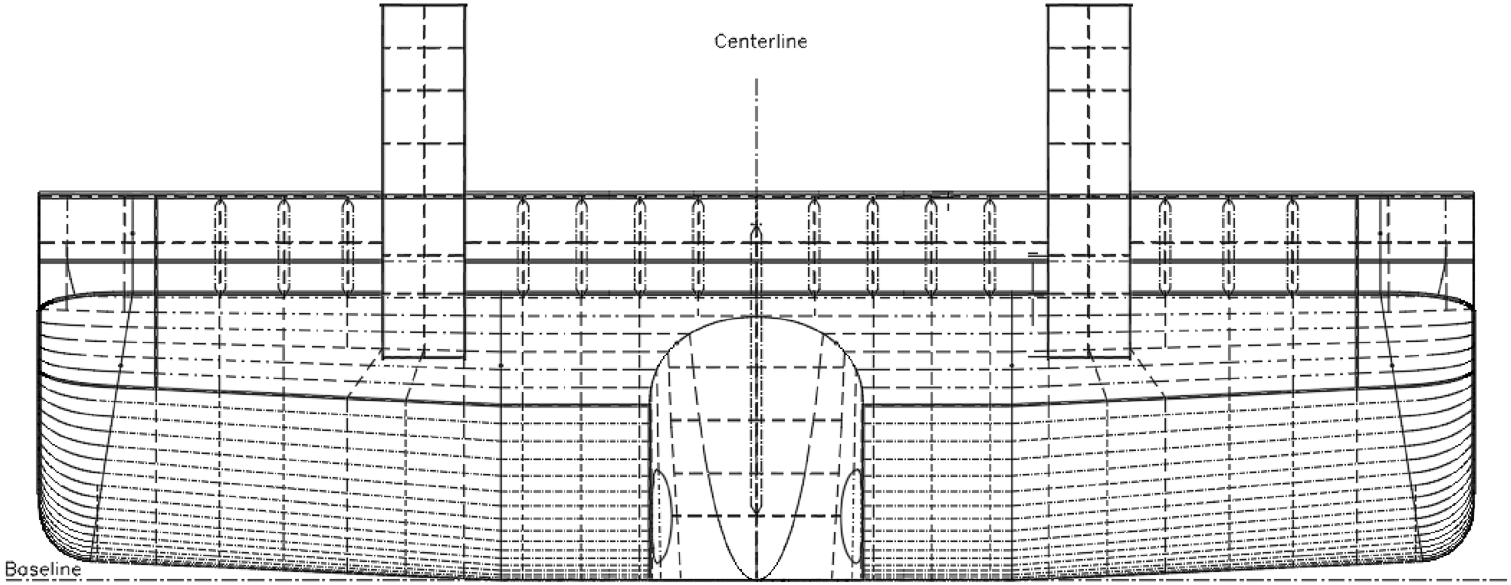

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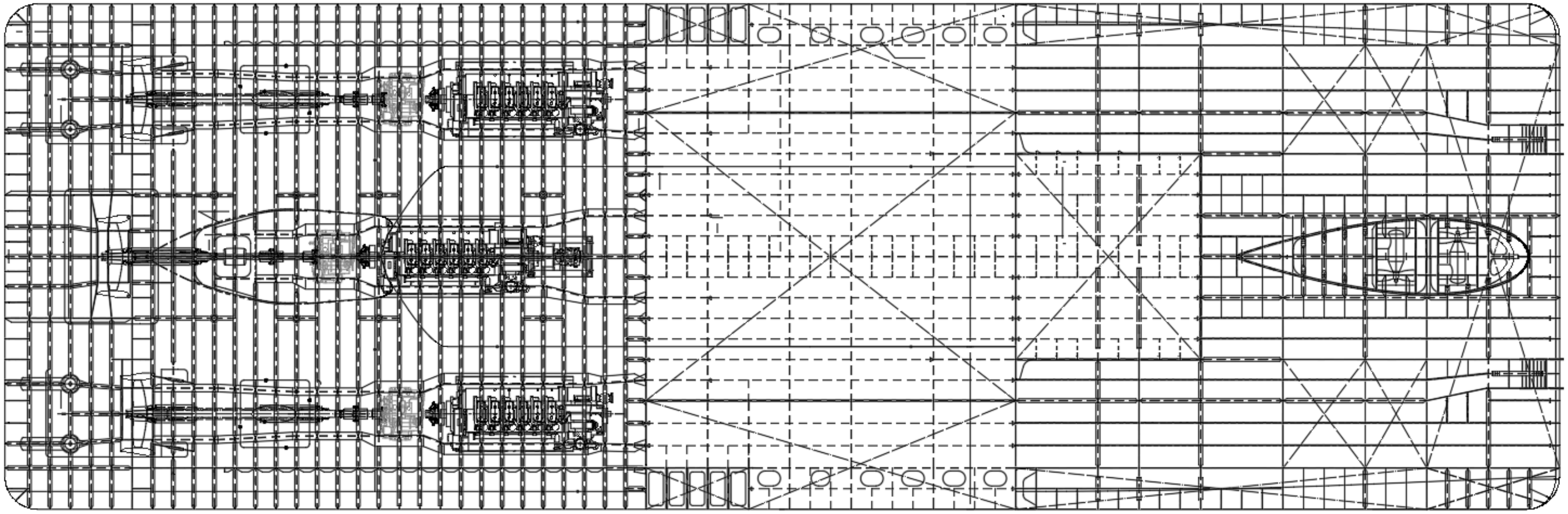

The hull basic design

The hull technical concept involves the assessment of relevant strength criteria and resulting structure scantlings.

- **Steel hull, grade A or equivalent**
- **Vessel specific solutions**
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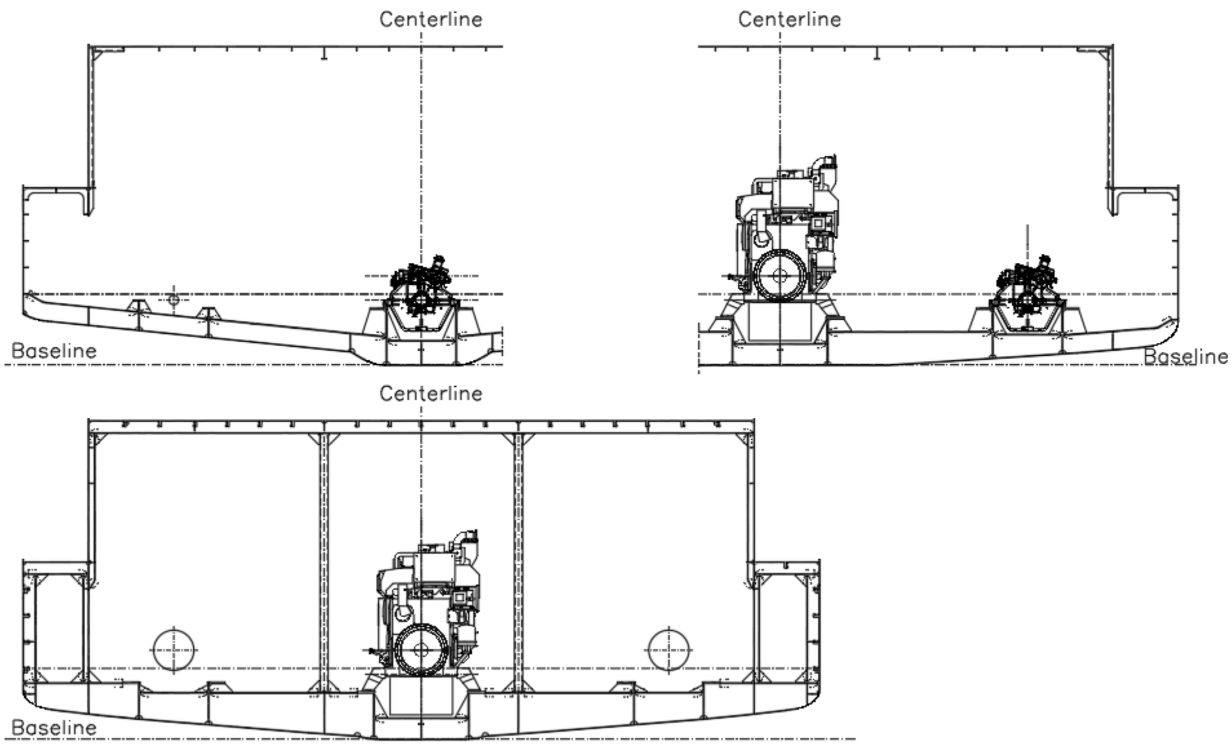


The piping basic design

Special care is needed when designing systems that can interfere with the LNG system or auxiliary ones.

The tank sounding system → **Sounding pipes connect spaces and need careful consideration**

The piping basic design

Special care is needed when designing systems that can interfere with the LNG system or auxiliary ones.

- **The tank sounding system**
- **The ventilation system** → **Can connect safe spaces with hazardous areas and the other way around.**

The piping basic design

Special care is needed when designing systems that can interfere with the LNG system or auxiliary ones.

- The tank sounding system
- The ventilation system
- The bilge system
  - Leakages underneath the LNG tanks need to be collected. The material used must be cryogenic. The piping used for LNG discharge must be separated from the rest of the system.

The piping basic design

Special care is needed when designing systems that can interfere with the LNG system or auxiliary ones.

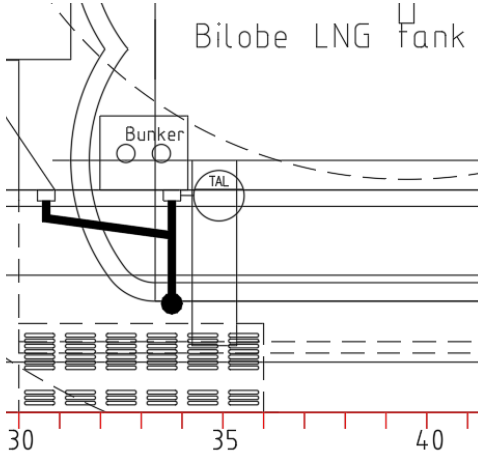
The tank sounding system

The ventilation system

The bilge system

The external drainage system

The bunker station drainage needs to lead overboard and beneath the waterline. Draining it on the hull plate exposes the steel to cryogenic temperatures.



The piping basic design

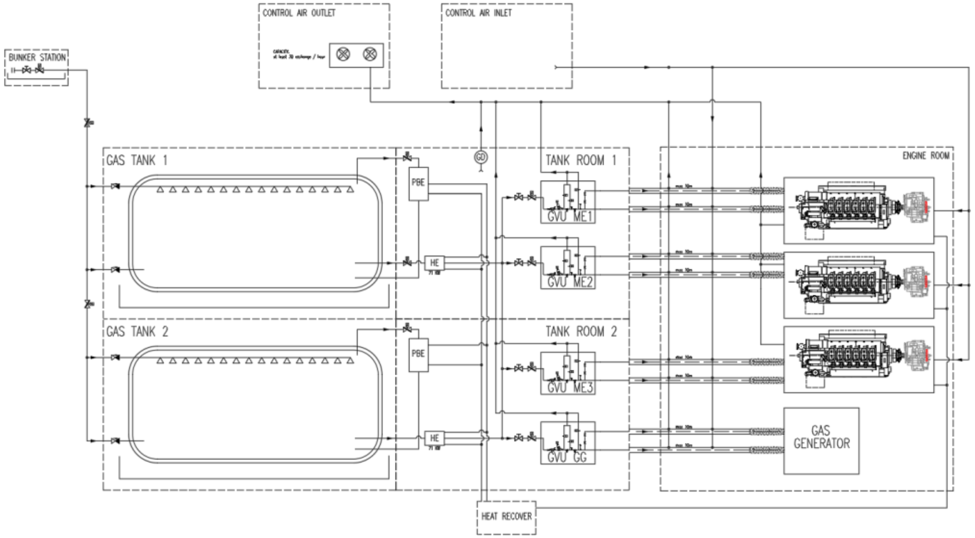
Special care is needed when designing systems that can interfere with the LNG system or auxiliary ones.

- **The tank sounding system**
- **The ventilation system**
- **The bilge system**
- **The external drainage system**
- **The water spray system** → **The system uses fresh water to cool the area around the LNG tanks in case of leakages, which prevents rapid evaporation of the gas.**

The piping basic design

Special care is needed when designing systems that can interfere with the LNG system or auxiliary ones.

- The tank sounding system
- The ventilation system
- The bilge system
- The external drainage system
- The water spray system
- The fuel gas system

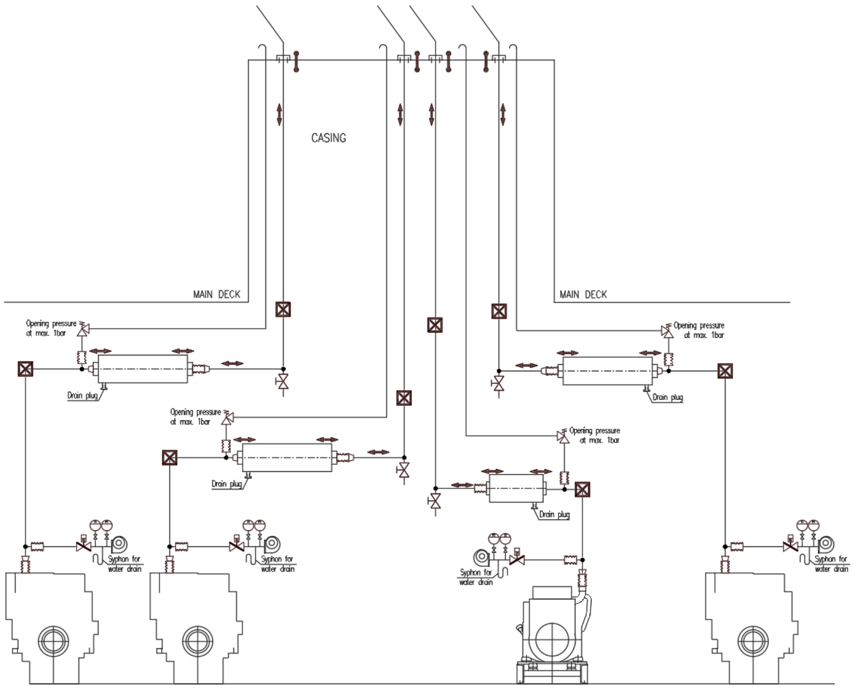


A critical system, piping is double walled, the gap between the pipes is constantly ventilated. A three way valve allows discharge to the atmosphere in case of emergency

The piping basic design

Special care is needed when designing systems that can interfere with the LNG system or auxiliary ones.

- The tank sounding system
- The ventilation system
- The bilge system
- The external drainage system
- The water spray system
- The fuel gas system
- The exhaust gas system

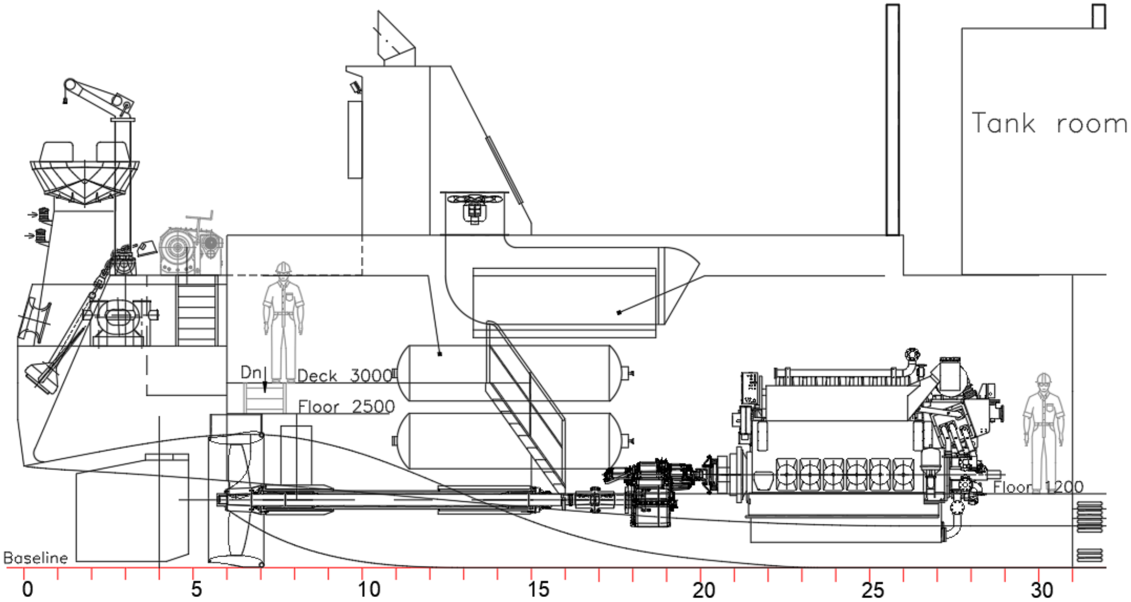


Pipes need to be ventilated to prevent accumulation of gas from methane slips. The system should be able to withstand over-pressure from LNG explosions. The pipelines create a hazardous area around the funnel.

The piping basic design

Special care is needed when designing systems that can interfere with the LNG system or auxiliary ones.

- The tank sounding system
- The ventilation system
- The bilge system
- The external drainage system
- The water spray system
- The fuel gas system
- The exhaust gas system
- The compressed air system



The air bottles of the starting system are large due to the nature of the fuel, the large capacity of the engine cylinders and the minimum startups required by Regulations.

Project co-funded by European Union Funds (ERDF, IPA)

Is Stage V achievable?

By retrofitting

Type 1 2 x 1600 HP	Yes	Caterpillar technology Mitsubishi technology
Type 2 2 x 1200 HP	Yes	Caterpillar technology Mitsubishi technology
Type 3 2 x 1600 HP	Yes	Caterpillar technology Mitsubishi technology
Type 4 2 x 1260 HP	Yes	ABC technology Mitsubishi technology

85% reduction of HC, 80% reduction of NOx, 98% reduction of PM, per ship

By new-builds

Yes

LNG technology
BIO/Synthetic LNG

25% reduction of CO2, 90% reduction of NOx, 100% reduction of PM

The LNG concept, towards zero-carbon

A modern concept, flexible both in operation and in design variations. A step ahead Stage V regulations and a future-proof vessel, ready to accommodate implementations of hydrogen as fuel. The design process was delicate, but has brought to limelight particularities of the technology. Once perspective of the inland shipping operators changes, the first-movers will be able to benefit from the insight provided by Ship Design Group and NAVROM via the GRENDEL project.