



Retrofitting towards climate neutrality

D2.2 First report: work procedure or best practice methods for retrofitting

Programme: HORIZON EUROPE

Grant agreement number: 101096522

Project acronym: Green Marine

Project title: Retrofitting towards climate neutrality

Prepared by: CMMI

Date: 30/01/2025

Report version: v2.0



Funding acknowledgement

Green Marine is funded by the European Union funding from the European Union's Horizon Europe research and innovation program under grant agreement No. 101096522. UK participants in Horizon Europe Project Green Marine are supported by UKRI grant numbers 10064539 (University of Strathclyde), 10068477 (CalMac Ltd) and 10064666 (CCM).

HISTORY OF CHANGES		
Version	Publication Date	Changes
1.0	27/08/2024	First draft
1.1	22/11/2024	Information collected and drafted
1.1	02/12/2024	Second draft
1.2	25/11/2024 – 20/12/2024	Review by Technology providers
1.3	20/12/2024	Information added related to IoT platform
1.3	18/01/2025	Review by reviewers on page 4 – first round
1.4	28/01/2025	Input specifications of bypass valves & CCM
1.4	28/01/2025	Review by reviewers on page 4 – second round
2.0	30/01/2025	Submission to portal

DETAILS	
Grant Agreement No.	101096522
Project acronym	Green Marine
Project full title	Retrofitting towards climate neutrality
Dissemination level	Public
Due date of deliverable	M24
Actual submission date	M24
Deliverable name	First report: work procedure or best practice methods for retrofitting
Type	Report
Status	Final version
WP contributing to the deliverable	WP2
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Other Contributor(s)	Technology providers: SINTEF, SMP/WPS, and CCM
Reviewer(s)	Iraklis Lazakis (UoS), Alex Cross (CalMac)
Keywords	Green Marine, Land Based Testing, Engine Performance, Turbocharged Marine Diesel Engine, Backpressure, Classification society, Flag state, Bypass system, Exhaust pipelines, Sensors and DAQs

Nomenclature

PPE	Personal Protecting Equipment
DAQ	Data Acquisition
FAT	Factory Acceptance Test
RAMS	Risk Assessment Method Statement
HVAC	Heating, Ventilation and Air Condition
SME	Small and Medium Enterprise
PAT	Portable Appliance Testing
LR	Llyods Register
MCA	Maritime and Coast Guard Agency. U.K
PML	Petronav Shipmanagement Limited
IoT	Internet of Things
HAZID	Hazard identification
HAZOP	Hazard operation
ECU	Engine Control Unit
UV	Ultraviolet

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EXECUTIVE SUMMARY

This document is deliverable “D2.2 – First report on work procedure or best practice methods for retrofitting” of the European Union project “Retrofitting towards climate neutrality” (herein referred to as “**Green Marine**”), with **Grant Agreement** No. 101096522.

Deliverable D2.2, part of WP2 – Land-Based Testing and Integration of Solutions, provides details on Tasks 2.1 outcomes. It discusses the best practices for retrofitting compression ignition engines to combust syngas (gaseous fuel) in dual fuel mode, engine back pressure and bypass system requirement, retrofitting protocols and safety regulations set by PML (allocated subcontractor for land-based tests). A detailed description of data acquisition system, monitoring sensors, in-house IoT platform are included in this document. Overall, this document can be used as a reference document to the Green Marine technology developers to achieve successful integration (necessary retrofits) of their technologies with the exhaust of the marine genset for land-based tests at the initial stages (to mimic the onboard scenarios at controlled conditions) and onboard the vessel at the final stages.

This report will be updated in Deliverable D2.3, "Second report: work procedure or best practice methods for retrofitting," in M36.

1. INTRODUCTION

The main objective of **Green Marine** is to significantly accelerate climate neutrality of water borne transport through retrofitting existing fleets with cost and emission control solutions. To support decision makers retrofitting protocols and a software tool catalogue that gathers knowledge will be developed and validated. We will demonstrate these tools, and the innovative solutions aimed at carbon capture mineralization, which also aids in deacidifying our seas; energy savings in vessel ventilation systems; carbon and water capture with membranes, and the use of excess engine heat to produce a syngas to save on fuel consumption. An ultra-sound technology will be tailored to suit vessels (such as cruise ships) allowing air-reuse saving energy for HVAC systems and operated as pre-treatment enhancing a membrane carbon capture process. For MV Coruisk, the SepaRaptor with UV technology will be tested in the ventilation system of the vessel. The Ca/Mg – alkali solvent capture process is capable of removing 75% of the CO₂ from flue gases.

All solutions will be demonstrated first on a land-based engine followed by the selection of the most suitable solution for a demonstration on a waterborne vessel. The (land-based) demonstrations will represent the operation of a majority of vessel engines. By developing retrofitting protocols, simulations of the solutions, data generated at the demonstrations a software catalogue tool will be developed. Through engagement activities this tool will gain more users and more knowledge, its value and effectiveness will increase for all users. The project aims to bring the different solutions to TRL 8. The demonstrations, the software tool catalogue, and the dissemination and exploitation activities ensure that project results will be replicated globally. The consortium consists of 10 partners from 7 countries with 4 research institutes and 1 ship company, which will host a demo as end user and 5 SMEs.

The objectives of the WP2 are categorised into three as listed below.

- Create support for solutions through land-based testing, considering regulations, classifications, engine manufacturers and shipowner needs.
- Performance testing of the retrofitting solutions
- CAPEX & OPEX estimations

1.1 PURPOSE OF THE DOCUMENT

This deliverable provides details regarding the first overview of the best practices and recommendations for retrofits on the land-based genset, which could eventually be adopted for on-board demonstrations. The land-based tests are intended to mimic the onboard scenarios and test various technologies under controlled conditions. These procedures must comply with PML's protocols wherever applicable.

1.2 DOCUMENT STRUCTURE

§2 concerns appropriate injector configurations for dual fuel Direct Injection in compression ignition engines.

§3 concerns the back pressure requirements and its importance of how the Green Marine technologies will impact the performance of the engine.

§4 details the sensors and DAQ systems (including the IoT platform developed at CMMI) to be used by the technology provides for land-based testing.

§5 presents the details about the bypass system and process of integration with exhaust system of the genset.

§6 details the safety procedures and risk register by PML (the allocated subcontractor for land-based testing).

§7 presents the indicative location where potentially the Green Marine technologies could be integrated on the exhaust system of the vessel, but always in consultation with Classification society and Flag state.

§8 summarises the report.

2. APPROPRIATE INJECTION STRATEGY AND RETROFITS OF SYNGAS

In Deliverable D2.1 “Preliminary report on results of land-based testing” submitted on M17, options regarding injecting gaseous fuels in compression ignition engines were presented. The advantages and disadvantages of fumigation, port fuel injection (indirect injection) and direct injection were highlighted. The main issue of fumigation and indirect injection is the high syngas slipping due to the nature of compression ignition engines.

In general, direction injection of gaseous fuels in dual-fuel mode in compression ignition engines is the preferred option as presented in Figure 1. To achieve direct injection, common-rail injectors (solenoid type for small engines such as the land-based auxiliary genset to be used for land-based tests) are needed. In addition, necessary modifications are needed in the engine’s ECU system for appropriate injection timing and valve opening. In addition, a high pressure pump is needed to inject the gaseous fuel at high pressure into the combustion chamber. More detailed information can be found under the following references [1, 2, 3, 4].

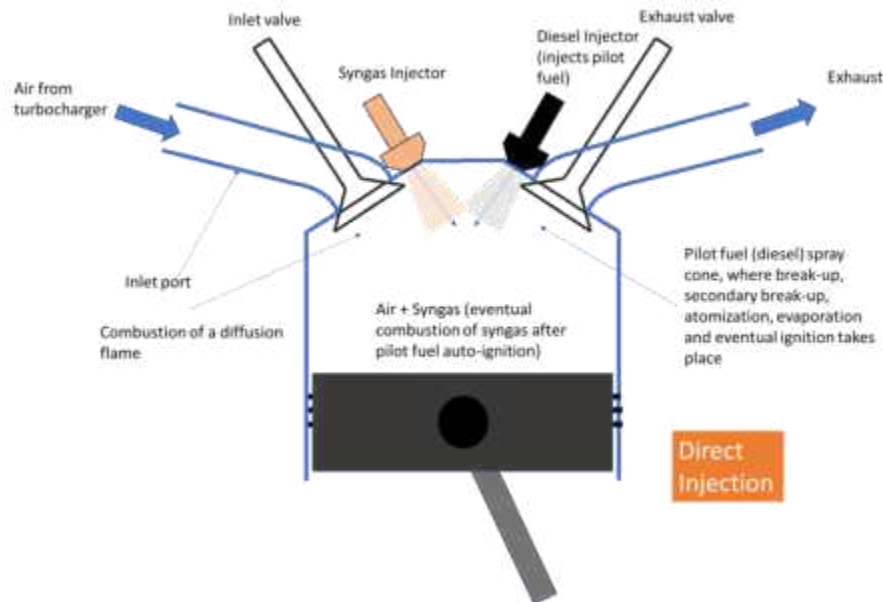


Figure 1. Diagram of a dual fuel CI engine, illustrating direct injection strategy in dual fuel mode (already discussed and presented in Deliverable D2.1 “Preliminary report on results of land-based testing” submitted on M17).

The configuration of diesel and gaseous fuel injectors is very important and thoroughly discussed by Yip et.al. [5]. Images have been reproduced from Trusca [6] to highlight the importance and numerous options available to ensure appropriate mixing and eventual combustion of the gaseous fuel from the pilot fuel (autoignition of diesel).

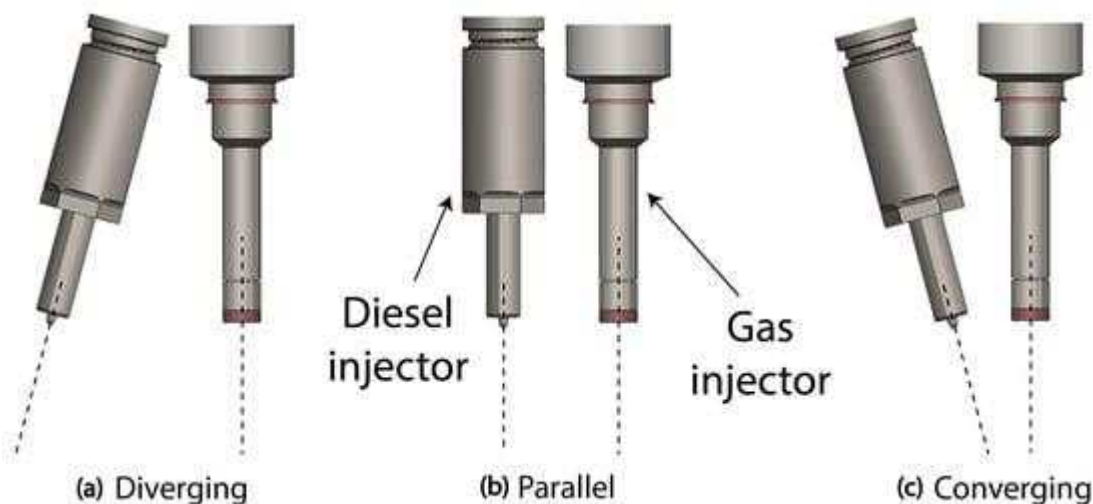


Figure 2. Potential injector configurations for dual-fuel DI: (a) diverging, (b) parallel and (c) converging nozzle orientation. Image reproduced from Yip et.al. [5].

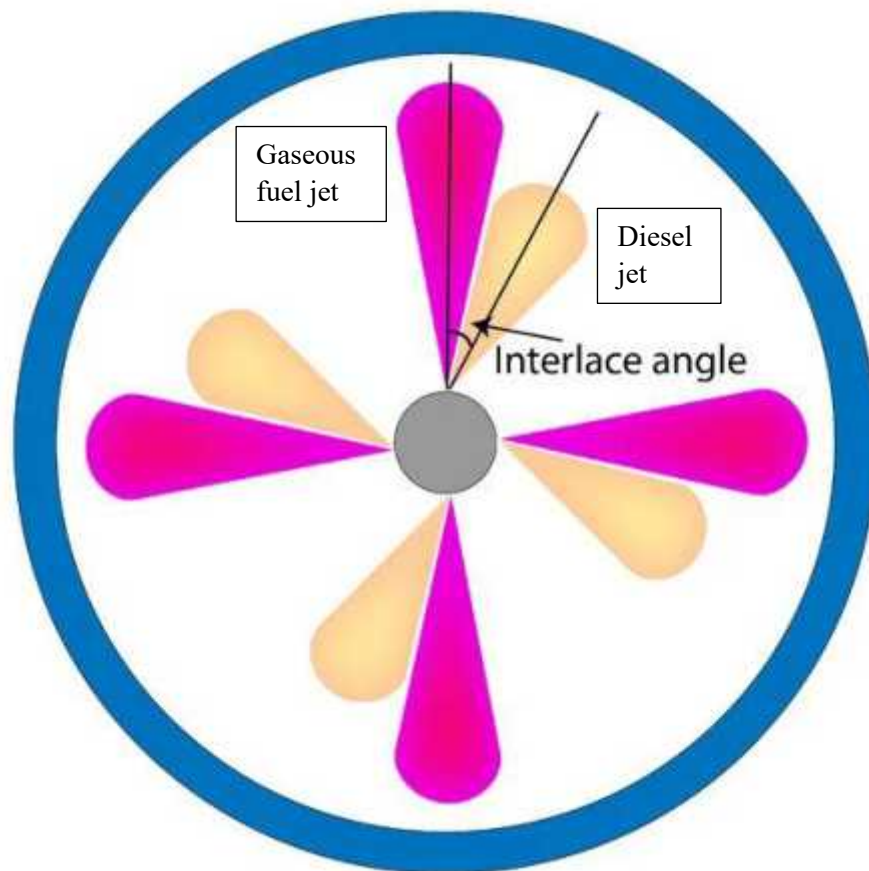


Figure 3. Schematic of the dual-fuel DI concentric injector jet configuration on the axial cross-sectional plane. The injection angle is defined as the angle between the jet axis and the horizontal axis in this plane. Reproduced from Trusca [6].

3. BACK PRESSURE REQUIREMENTS FOR A TURBOCHARGED MARINE ENGINE

As already mentioned in Deliverable D2.1 “Preliminary report on results of land-based testing” submitted on M17, the manufacturer of the land-based genset for WP2 land-based tests is recommending a **max backpressure of 10.1 kPa(g) and a minimum of 5.0 kPa(g) at rated conditions** [7, 8]. This is also a requirement by CalMac and Lloyd’s Register, where the selected vessel MV Coruisk is registered. The pressure at the exhaust will be monitored via a pressure sensor (pressure range up to 4 bar, suitable for a turbocharged engine; see future plans in section 3.1.1.7). Note that monitoring of the backpressure is needed to assess that the performance of the engine’s turbocharger, and hence the overall engine performance, is not affected.

4 DETAILS OF SENSORS AND DAQ SYSTEMS FOR THE LAND-BASED TESTING

4.1 CMMI

The list of sensors and DAQ systems along with the experimental setup were detailed in Deliverable D2.1 “Preliminary report on results of land-based testing” submitted on M17 for the land-based testing. During the current reporting period progress was made such as engine procurement and installation at the test site, procurement and installation of sensors such as fuel and air flow meter. Figure 4 illustrates the installation of Air flow meter on the modified intake air manifold (after the filter). Note, a small drill was made on the retrofitted elbow-pipe to accommodate the air flow meter to measure the air flow.

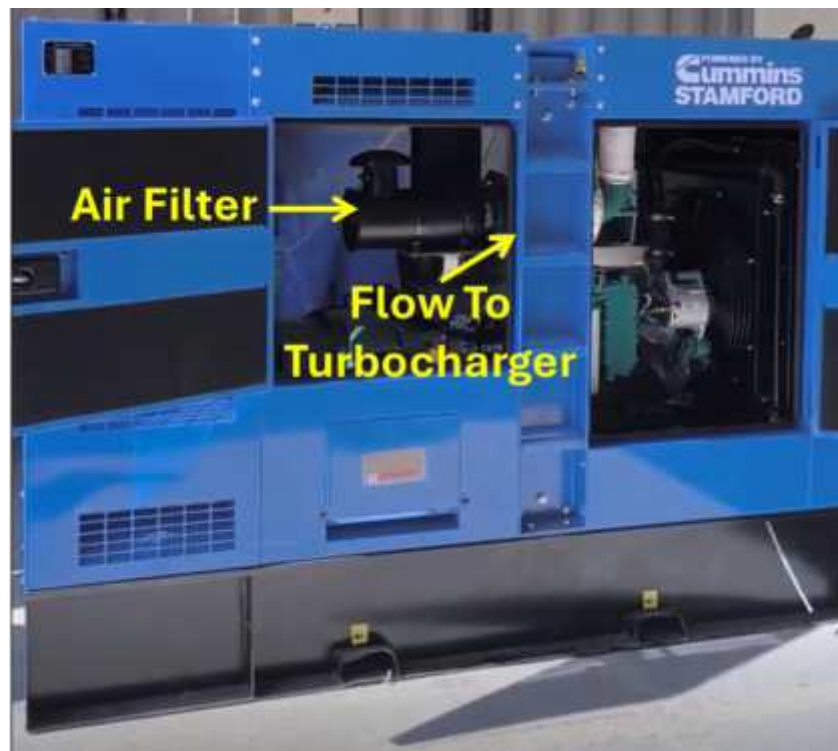


Figure 1: (a)

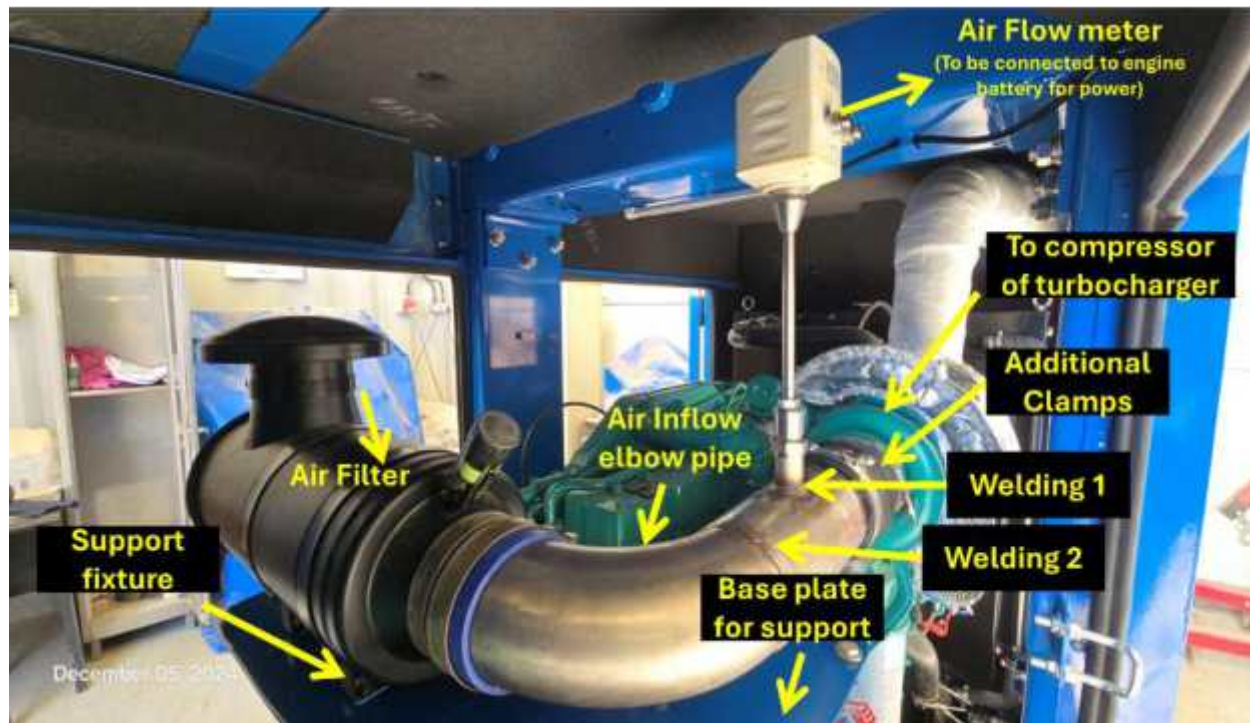


Figure 1: (b)

Figure 4: (a): Before retrofits to integrate the air flow meter. (b): Installation of air flow meter on the marine genset. The air filter was removed, a base plate (in blue) was added to support the elbow bent pipe (grey). On the elbow pipe the air flow meter was installed. The air flow meter is connected on the genset's battery for the sensor power requirements.

Similarly, the fuel flow meter was installed on the fuel pipeline (after the fuel filter) to estimate the fuel flow characteristics. The sensor was attached to the base plate for rigid support and connected to the existing ductwork. Both the above-mentioned sensors are IoT compatible which will be integrated to the inhouse platform being developed by CMMI. Figure 5 depicts the location and installation of fuel flow meter. In addition, a pressure sensor (maximum capacity of 4 bar) has been procured and will be installed to the bypass system.

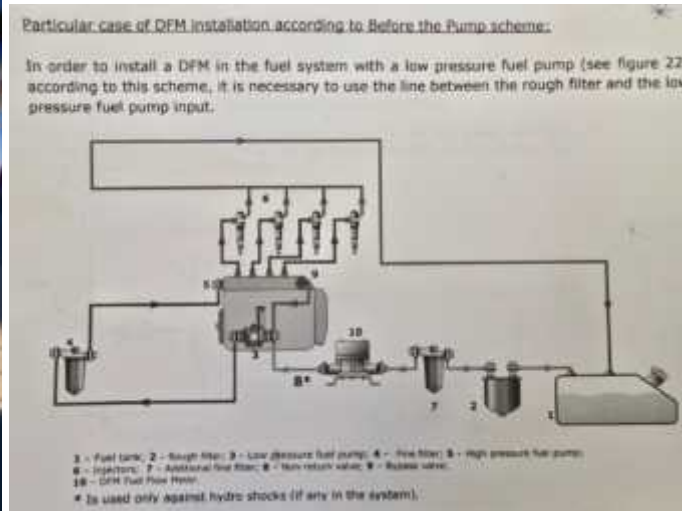


Figure 5: Left: Installation of fuel flow sensor on the marine genset. A plate was used to support the fuel flow meter. Right: The integration of the sensor was setup as per the fuel flow meter manufacturer's instructions.



Figure 6: Left: Installation of wires with clamps the load bank. Right: Installation of wires with clamps the genset side. Note: Additional clamps were used for smooth integration.

4.1.1 IoT platform to enable real time continuous monitoring

Continuous monitoring and automation for land-based marine engine tests using IoT platforms involves integrating IoT sensors with marine engines to monitor key parameters like temperature, pressure, vibration, fuel consumption, and emissions. The data set is sent to an in house built IoT platform where it's analyzed in real-time to quantify the engine performance, detect anomalies, and operation of bypass valve.

Key benefits for onboard applications include real-time monitoring, predictive maintenance, automation, remote access, improved safety, and data-driven insights for performance optimization. It helps in engine testing, condition monitoring, and green marine technology efficiency optimization.

Challenges include handling large data volumes, system complexity, skilled personals and initial setup costs. More detailed information on IoT platform is available in D2.1 Preliminary report on results of land-based testing” submitted on M17.

To optimize the operation of both the membrane and chemical absorption systems for exhaust gas capture, process controls and monitoring systems can be implemented that leverage real-time data from the engine's exhaust composition. By continuously analyzing parameters such as CO₂ levels, temperature, pressure, and flow rates, the system can dynamically adjust operational settings for both systems to enhance capture efficiency. The membrane system can be fine-tuned for optimal separation, while the chemical absorption system can adjust reagent flows and chemical reactions to ensure maximum absorption efficiency. This real-time optimization ensures that the systems operate at peak performance, reducing emissions while maintaining energy efficiency and minimizing operational costs.

The Green Marine project integrates various sensors and Engine Control Unit (ECU) system via an Internet of Things (IoT) device to enable real-time monitoring and visualization of sensor data. This report outlines the development and implementation of the IoT platform, focusing on data collection, processing, and user interaction through a web interface. Figure 7 presents the installation of the IoT Device (Raspberry Pi5), IoT Network device. Power from the genset's battery is used for integrated sensors (air flow meter, fuel flow meter, and pressure sensor). To protect the genset's battery from overload a fuse is also installed.

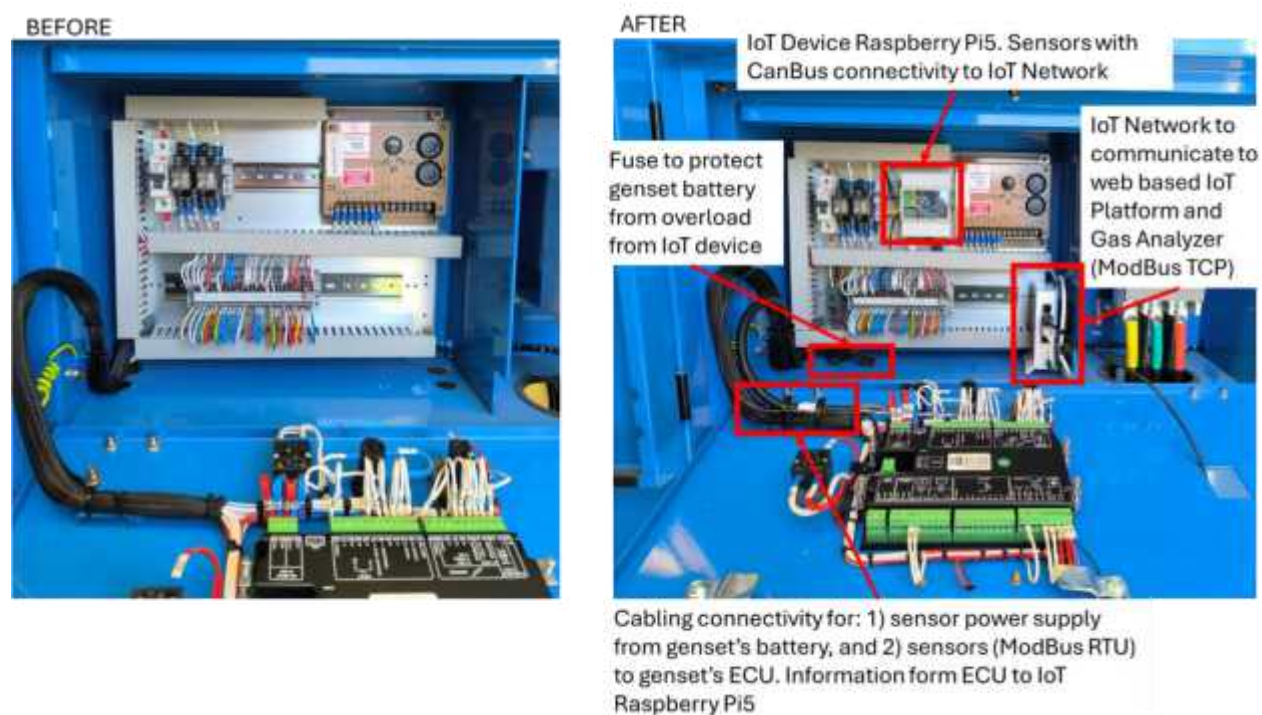


Figure 7. Integration of IoT Device and IoT Network, connectivity of built-in sensors from the genset's ECU and other installed systems onto the IoT Platform for real-time monitoring.



Figure 8. Fuel and air flow meter sensors connected to IoT Raspberry Pi5 (CanBus) and ECU (ModBus RTU) respectively. The flow meters have also been calibrated.

4.1.1.1 System Overview

The IoT platform connects to the ECU of a marine engine and other sensor systems to gather critical operational data. An illustration is shown in Figure 9. This includes:

- Modbus RTU: Communicates with the ECU to collect engine parameters.
- Modbus TCP: Collects data from the MRU sensors.
- CanBus: Gathers data from a diesel flow meter.

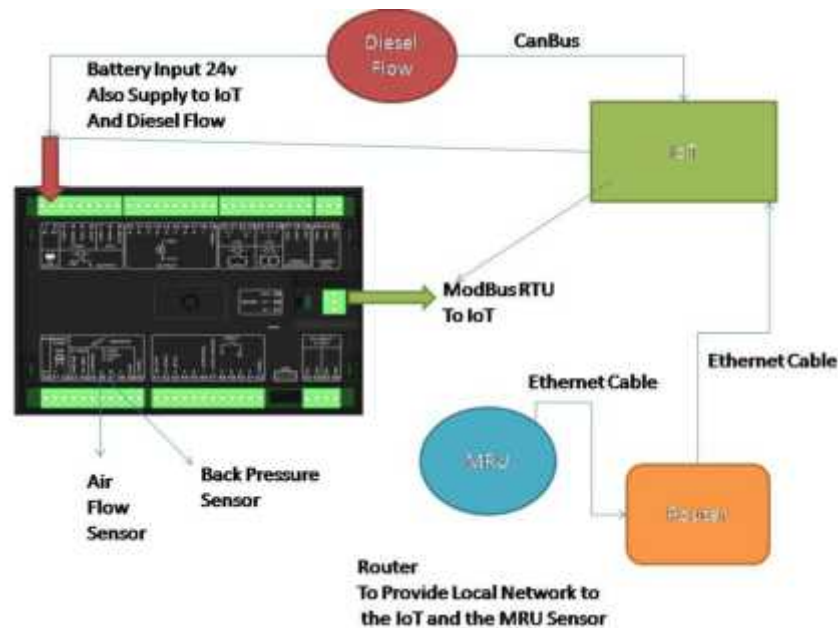


Figure 9: Wiring ECU and IoT.

Figure 9 illustrates the wiring and connectivity of the ECU, MRU, diesel flow meter, air flow sensor, and back pressure sensor. The system also includes a router for establishing a local network to communicate with the MRU sensor. This router provides local access to the IoT device via Ethernet and Wi-Fi for accessing the web interface. However, due to environmental constraints on ships, Wi-Fi may not be reliable. Thus, an Ethernet connection is recommended, running from the engine to the captain's area (up to 100 meters). In the captain's area, Wi-Fi can be added to avoid using Ethernet cables. For the land-based testing, Ethernet was adopted.

The engine has two batteries connected to the ECU. These batteries also power the IoT device and diesel flow meter. The ECU connects to the IoT device via Modbus RTU, and the air flow and back pressure sensors are connected to the ECU on pins 36 and 37 as 4-10mA inputs. The diesel flow meter is powered by the batteries and communicates with the IoT device through the CanBus network. The MRU requires 230V power but can operate on a battery for approximately one hour. It connects to the router via Ethernet, obtaining an IP address for communication with the IoT device through Modbus TCP.

The collected data includes:

- Engine parameters: RPM, water temperature, oil temperature, oil pressure, and battery voltage.
- Universal sensor inputs: Back pressure, flow meter readings.

A Python script serves as the core of the IoT device, processing data from Modbus RTU, Modbus TCP, and CanBus. This data is then made accessible via a web interface for real-time monitoring and historical analysis.

4.1.1.2 Web Server and Interface Development

The web server, built using Python's Flask framework, provides a user-friendly interface for accessing and visualizing sensor data. Key features include:

- Real-time Data Visualization: Displays live sensor data from the engine and connected devices.
- Graph-Based Data Representation: Allows users to view performance trends over time.
- Data Filtering: Users can select specific sensors and time durations for detailed analysis.
- CSV Export: Facilitates data download for offline analysis.

Data collected by the IoT device is stored in a local database, such as SQLite, to ensure fast and reliable access for both real-time and historical views.

4.1.1.3 Web Interface Design – Home page tab

The home page provides:

- Real-time Data: Displays live readings for each installed sensor in a clear and intuitive format.
- Sensor Information: Each sensor's data is labelled and updated in real time to reflect current conditions.

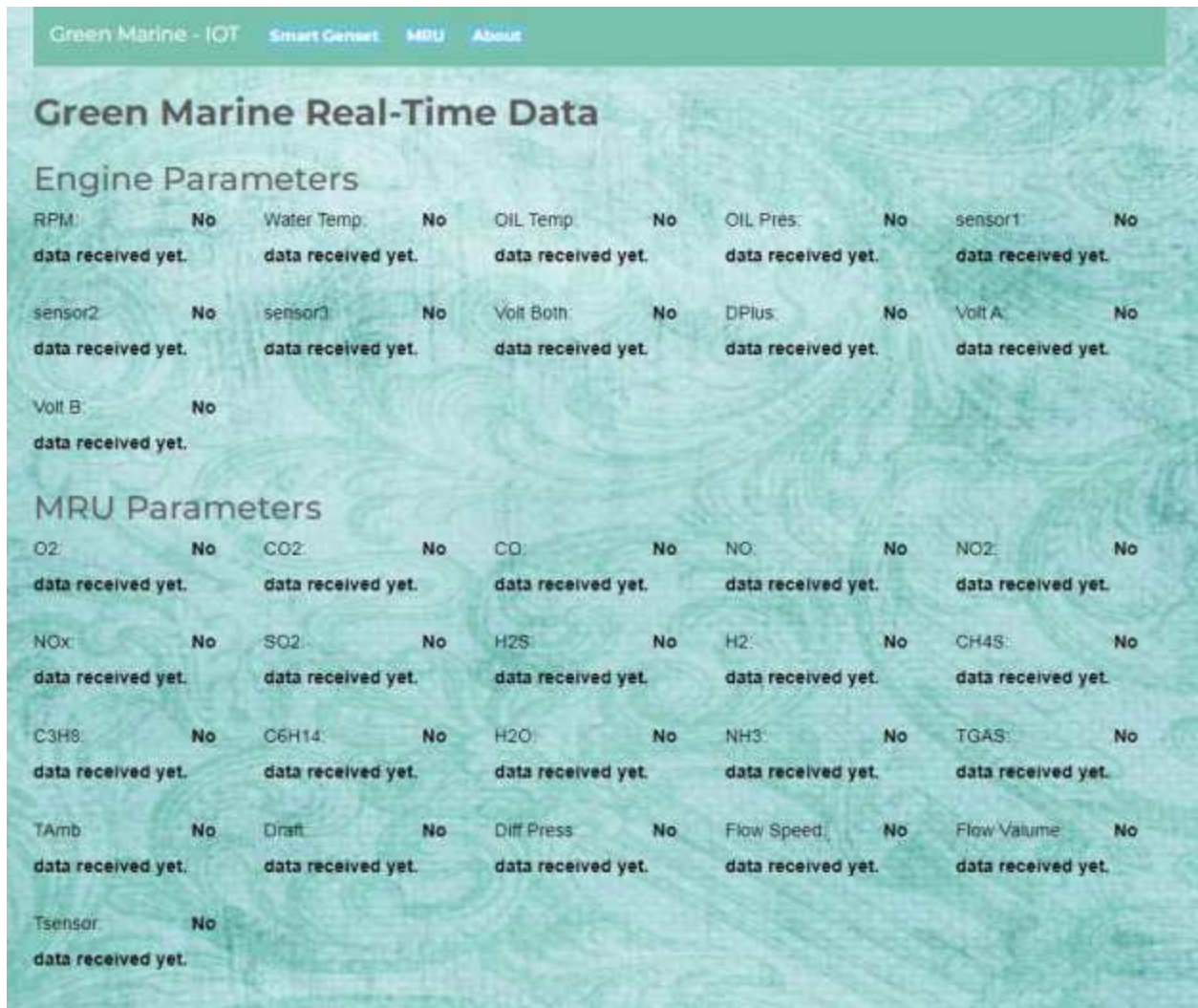


Figure 10: Home page or Landing page.

4.1.1.4 Smart Genset Tab

This section focuses on engine performance data:

- **Graph Visualization:** Displays performance metrics such as water temperature and oil pressure.
- **Custom Duration Selection:** Users can choose data ranges (e.g., last 2 hours).
- **CSV Export:** Data displayed in graphs can be downloaded in CSV format.

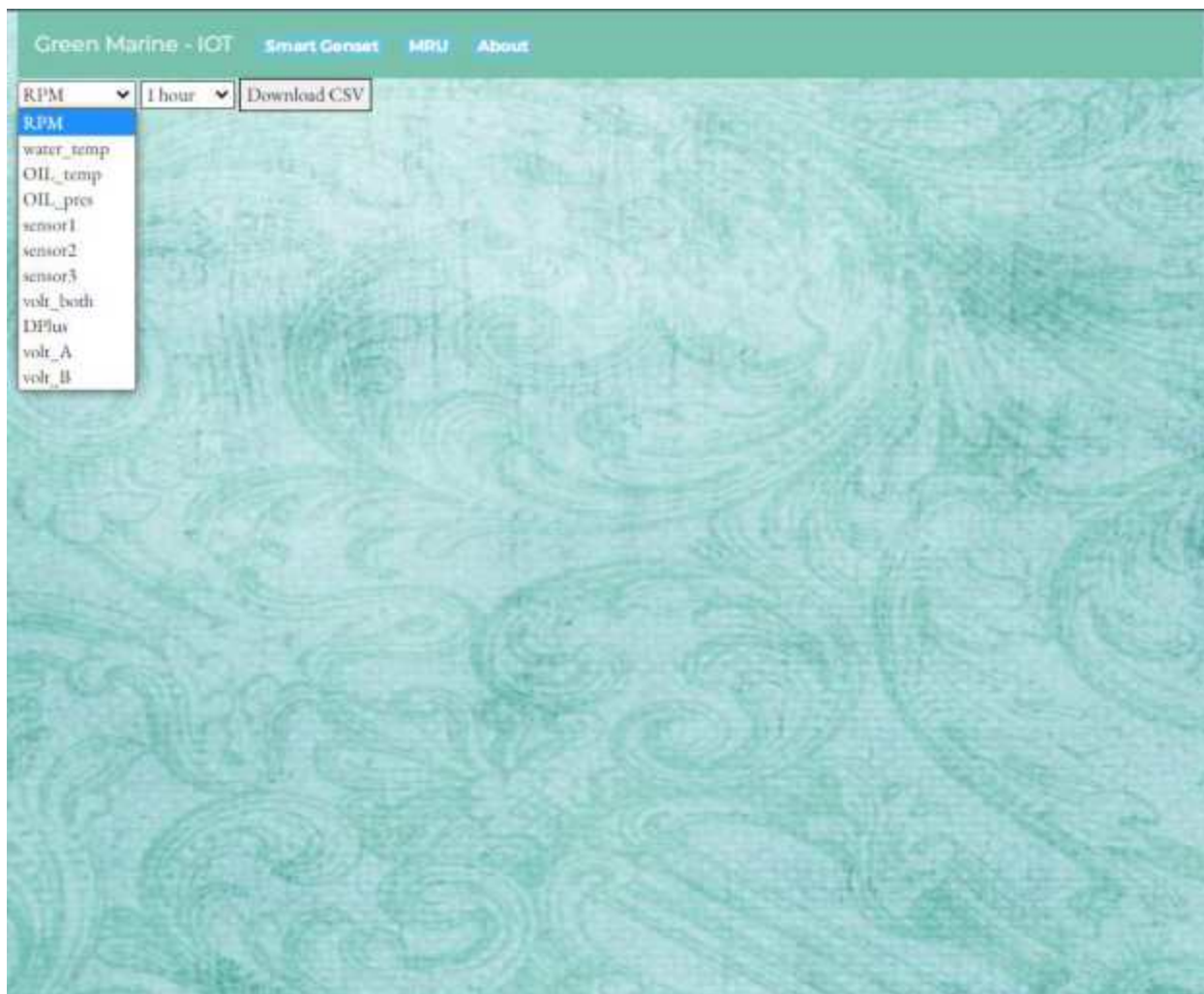


Figure 11: Smart Genset Tab.

4.1.1.5 MRU Tab (Gas analyzer tab)

The MRU tab provides insights into exhaust-related data:

- **Graph Visualization:** Visualizes data from MRU sensors, such as NO and CO₂ levels.
- **Sensor and Duration Selection:** Users can filter data by specific sensors and time periods.
- **CSV Export:** Supports offline analysis by allowing CSV downloads of MRU data.

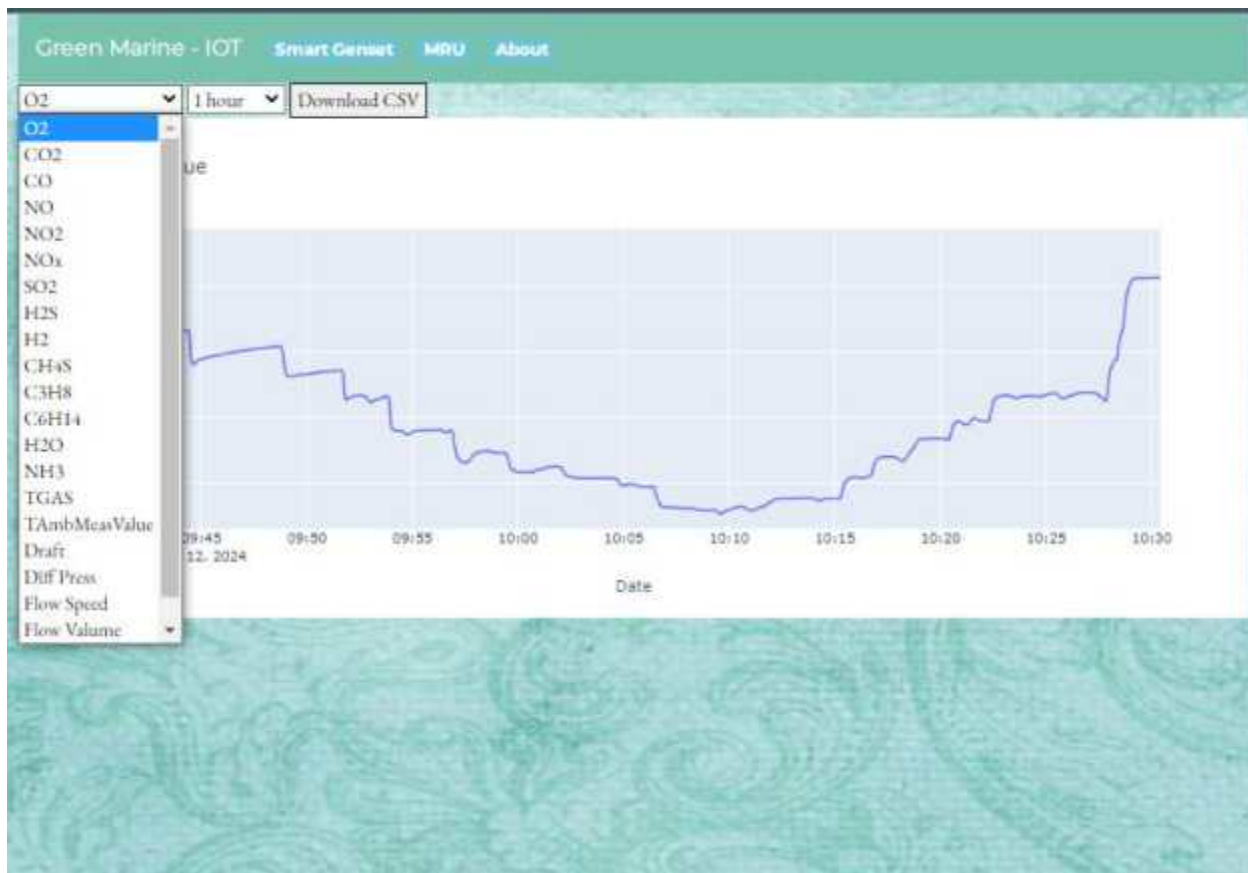


Figure 12: MRU Tab

4.1.1.6 About Tab

The About tab provides context related to the project:

- **Project Overview:** Explains the goals and technology to be developed for the Green Marine project.
- **Technical Background:** Describes the integration of sensors and the IoT platform.

4.1.1.7 Future Plans

To enhance the functionality and usability of the IoT platform, the following features are planned:

- **Sensor Configuration Page:** A new page will allow users to configure parameters for each sensor. Users will also be able to set or modify the IP address for Modbus communication.
- **Exhaust Bypass System Tab:** This tab will manage the bypass system for the exhaust. The bypass system will include an emergency button, located in the captain's area, which can bypass the green box via hard wiring instead of software. The distance between the captain's area and the green box will need to be measured to select the appropriate voltage for the emergency button. Currently, specific details about the type of control for the bypass valve and the power requirements for the green box are unavailable. The bypass system

needs to disconnect the green box power and reroute the exhaust output. Additional technical details will be integrated as they become available.

- **Integration of Additional Sensors and Actuators:** The system will be expandable to include more sensors or actuators using CanBus, Modbus, or API communication. For any new integrations, detailed specifications and communication protocols must be provided by the parent system. We will integrate a pressure sensor on the bypass system to monitor the backpressure on the marine genset.

4.2 SMP/WPS

Table 1: Sensors for the SepaRaptor for membrane life assistance.

Name of component	Power supply	Description
CS712 current sensor module ACS712ELCTR 5A	5 V, ≥ 20 mA, DC	5 Units of these will be in use for the Separaptor, controlling the input current and therefore verifying the function of the system. They can be connected by a wire with WAGO 221-2401 or 221-412 type connectors
TSL2561 Lux sensor	5 V, ≥ 20 mA, DC	2x Light sensors to control the UV lights being switched on during operation. They can be connected by a wire with WAGO 221-2401 or 221-412 type connectors

These sensors are IoT capable and are generally used in Arduinos, ESP 32 systems, etc. It is possible to equip the SepaRaptor with an ESP 32 device to enable IoT communication with the bigger system, without the need for running cables to the main board.

Table 2 will further describe the sensors used by the TEE unit. Values for power supply is mentioned, but in case the sensors run by the electricity generated by the TEE unit, no external power supply is needed.

Table 2 : Sensors for the TEE unit.

Name of component	Power supply	Description
CS712 current sensor module ACS712ELCTR 5A	5 V, ≥ 20 mA, DC	One unit will be in use for the TEE unit to verify amperage output of the system. They can be connected by a wire with WAGO 221-2401 or 221-412 type connectors.
Stemedu DC 0-25V	5 – 25 V, ≥ 20 mA, DC	One sensor to verify the voltage output of the TEE unit. They can be connected by a wire with WAGO 221-2401 or 221-412 type connectors.

Arceli water sensor	3 – 5 V, >= 20 mA, DC	4 x water sensors to control any leakage inside the housing of the TEE unit. They can be connected by a wire with WAGO 221-2401 or 221-412 type connectors.
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Preliminary, these are the sensors SMP/WPS intends to use for the TEE unit. Same as described for the SepaRaptor, it needs to be verified if a microcomputer needs to be implemented for sensor communication. Additionally, the TEE unit should be attached to the cooling system by a bypass and that leakage or out of parameter values for voltage or amperage appear, the device can be disconnected for maintenance. In the scope of the Subtask 2.1.1 Air-reuse, the following SepaRaptor unit was developed, as displayed in Figure 13. Herewith this system can in a modular way, be integrated in an existing HVAC system (for a vessel that has an HVAC system on-board such as cruise-ships).

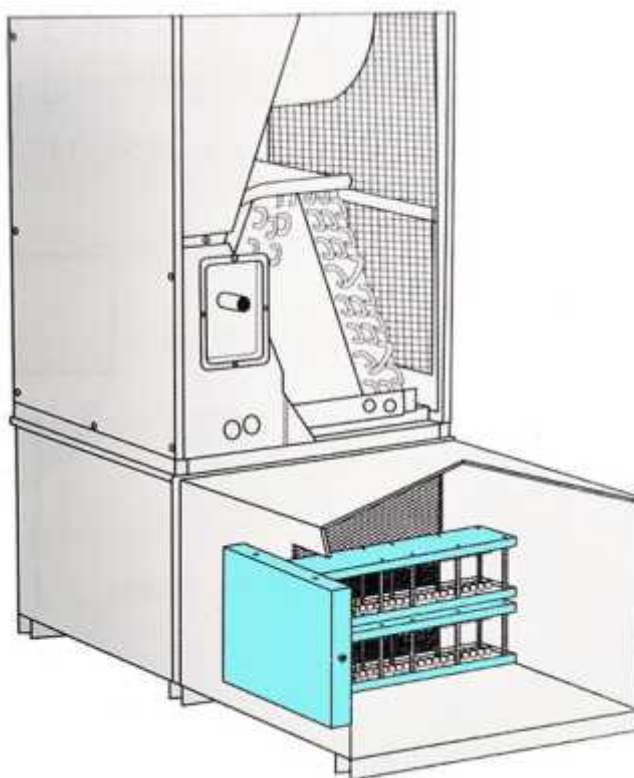


Figure 13: Illustration of HVAC system.

Additionally, we provide some additional information about this unit in Figure 14.



Figure 14 : Information about the SepaRaptor for HVAC systems.

Sensors included in this SepaRaptor for HVAC are two current sensors of Table 1.

4.3 SINTEF

The membrane based CO₂ capture unit illustrated in Figure 15 will be connected to CMMI's marine genset, during land-based testing in Cyprus.

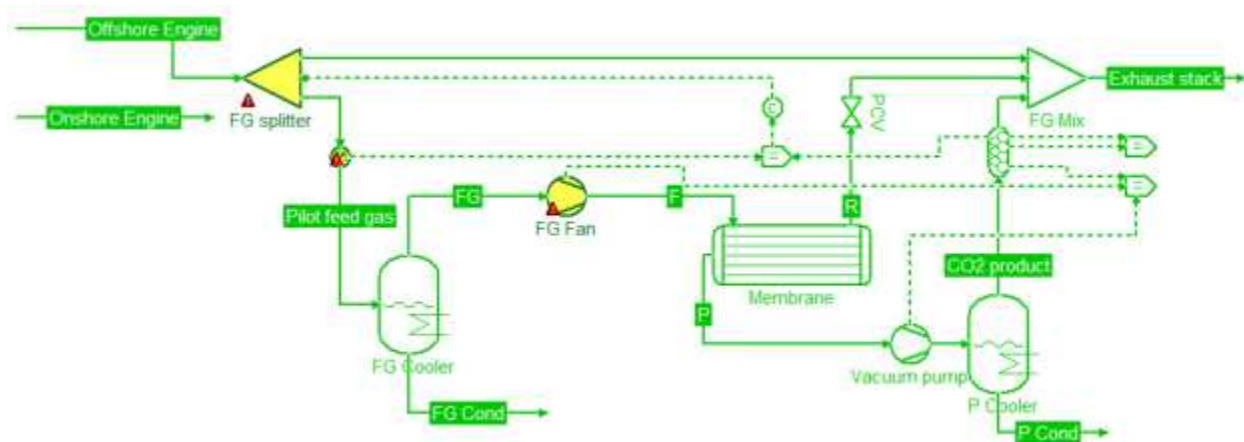


Figure 15. Simplified process diagram of the single stage membrane based CO₂ capture unit to be connected to an exhaust by-pass system during land-based testing in Cyprus.

The pilot is connected to the “On-shore / ship infrastructure” which provides access to exhaust from the ship engines, access to the exhaust stack for disposal of treated exhaust gas, access to sea water for cooling and finally storage of condensate water from the treated exhaust gas. In addition, sensor information is provided characterising the amount and quality of the available exhaust gas.

The pilot is designed to ensure no interference with the operation of the ship engine. It is a requirement that the CO₂ capture process will not create an increase back pressure in exhaust channel, and that the CO₂ capture unit can be shut down or malfunction without affecting the operation of the ship engine.

The pilot will be equipped with internal process sensors which are connected to a dedicated PLC (programmable logic computer) which will be part of the membrane pilot. The PLC will implement

the necessary process control logic, including a software-based emergency shutdown system. Storage and retrieval of process data will also be linked to the PLC. The ambition is to provide remote access to process data and potentially a link to a digital twin solution. The emergency shutdown system will also be connected to relevant instrumentation in connection to the exhaust bypass system which is part of the land-based test facilities at CMMI in Cyprus. Corresponding connections to relevant on-board instrumentation (and emergency shutdown functionality) on MV Coruisk will be established for the subsequent offshore testing of the technology.

Details on the PLC are as follows: A Wago PFC200 PLC will be equipped with I/O modules for analogue control and monitoring from the pilot sensors. The PFC200 has an onboard html5 webserver that can be setup with an HMI for the process. The PLC can be connected to internet for remote monitoring using a vpn-solution currently in development by SINTEF. OPC UA and modbus connectivity is available on the PLC, for potential connectivity against ship control system and digital twins. The PFC200 will save log data internally and via a gateway to a postgresql database in the SINTEF cloud, available for external sharing through an API (under development).

4.4 CCM

CCM will install, commission and test the carbon capture and conversion process to apply for approval in principle from the classification society as significant step towards the demonstration of the technology in operational environment (e.g. CalMac vessel and other vessels). The land-based testing will take place at the third-party Petronav Ship Management Ltd (for more details refer to Deliverable D2.1 “Preliminary report on results of land-based testing” submitted on M17).

The CCM pilot plant to be installed at Petronav Ship Management Ltd. in Cyprus requires specific electrical connections to ensure proper operation and compliance with local standards. For single-phase electricity, the system will utilize 230 V connections adhering to the British Type G socket and plug system, which features three rectangular pins arranged in a triangular configuration and operates at 230 V with a frequency of 50 Hz. Specifically, six Type G sockets are required, each equipped with a 16 A circuit breaker for powering auxiliary devices and standard operations.

For three-phase electricity, the system will require a 400 V, five-pin connection conforming to the IEC 60309 standard, which is widely used for industrial and high-power applications in Cyprus. This connection will include three phase pins (L1, L2, L3), one neutral pin (N), and one protective earth pin (PE) arranged in a circular pattern, with the connector color-coded red to indicate its 400 V rating. The connection must be rated for 32 A to accommodate high-load equipment, with appropriate circuit breakers installed. Both the single-phase and three-phase connections must be installed in compliance with Cyprus’s electrical standards and regulations, ensuring safe and reliable operation of the pilot plant. Proper grounding, surge protection, and consultation with a certified local electrician are essential for a compliant and robust setup.

CCM requires a supply of fresh or drinking water at a minimum flow rate of 30 liters per minute at room temperature (approximately 20°C). Additionally, a suitable drainage system is needed to ensure proper discharge of the used water. The water supply and discharge must be installed in compliance with local plumbing standards to ensure safe and reliable operation.

5. INTEGRATION OF ENGINE EXHAUST WITH GREEN MARINE TECHNOLOGIES

CalMac requires a bypass system to ensure safety (passengers, crew and equipment) and continuous operation of the vessel. The requirement is also needed for manual shut-off of power of Green Marine technologies as well as electronic shut-off by the captain at the bridge of the vessel. As mentioned in Deliverable D2.1 “Preliminary report on results of land-based testing” submitted on M17, the bypass valve will be controlled by an IoT platform which also integrates the continuous monitoring of the engine performance as well as the respective Green Marine technologies to be tested. This section presents how the auxiliary engine exhaust will be retrofitted to feed flue gases to the Green Marine technologies discussed in Section 4. To achieve connectivity and safety requirements as discussed in Deliverable 2.1 ‘1 Preliminary report on results of land-based testing’. To achieve this CMMI designed the bypass system illustrated in the following figures.

Figure 17 and Figure 18 present the updated final bypass system, compared to the preliminary design presented in Deliverable D2.1 “Preliminary report on results of land-based testing” submitted on M17. The changes incorporate feedback and comments from the consortium and the industry. The design changes aimed to optimize the flow to the Green Marine technologies. Material specifications of the bypass system are:

- Flange specifications (DN 80) used in the bypass system are described in Figure 16.

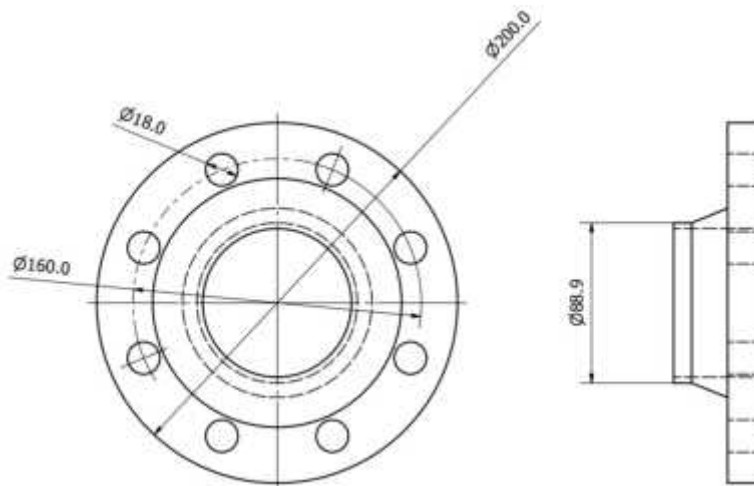


Figure 16: DN80 flanges used to connect the Green Marine technologies with the genset.

- Steel Grade: S235JRH
- Circular Hollow Sections – EN 10219-1:2006
- Mechanical properties:
 - o Minimum yield strength: 235MPa
 - o Tensile strength: 360-510 MPa
 - o Minimum elongation (%): 24*% *(T>3 mmL 24%, D/T<15:22%, T≤ 3mm: Min 17%)

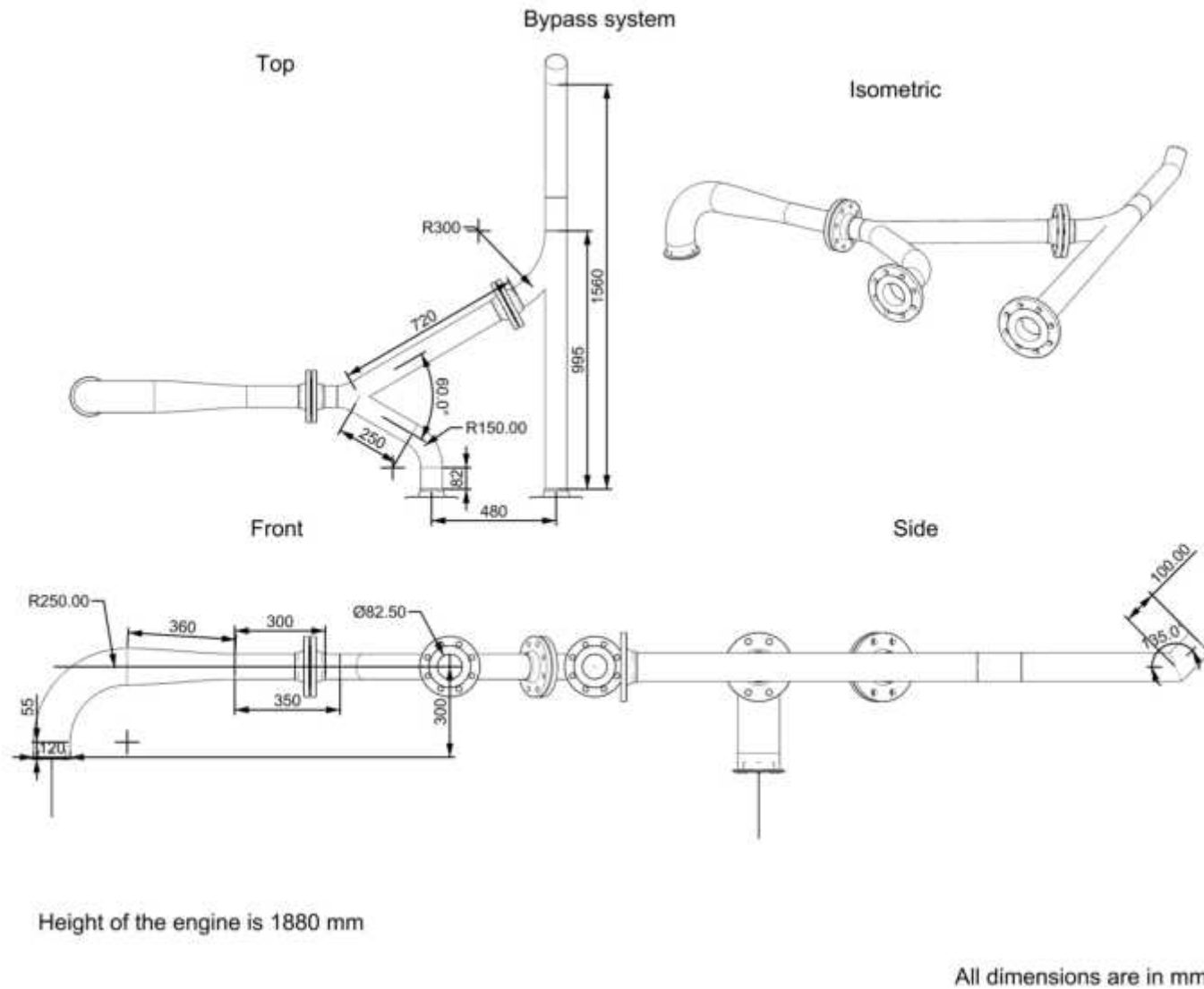


Figure 17. Updated bypass model after receiving feedback from industry. The model includes flanges for easy integration with the marine genset exhaust and respective Green Marine technologies. The pipe diameters are 82.5mm (inner).

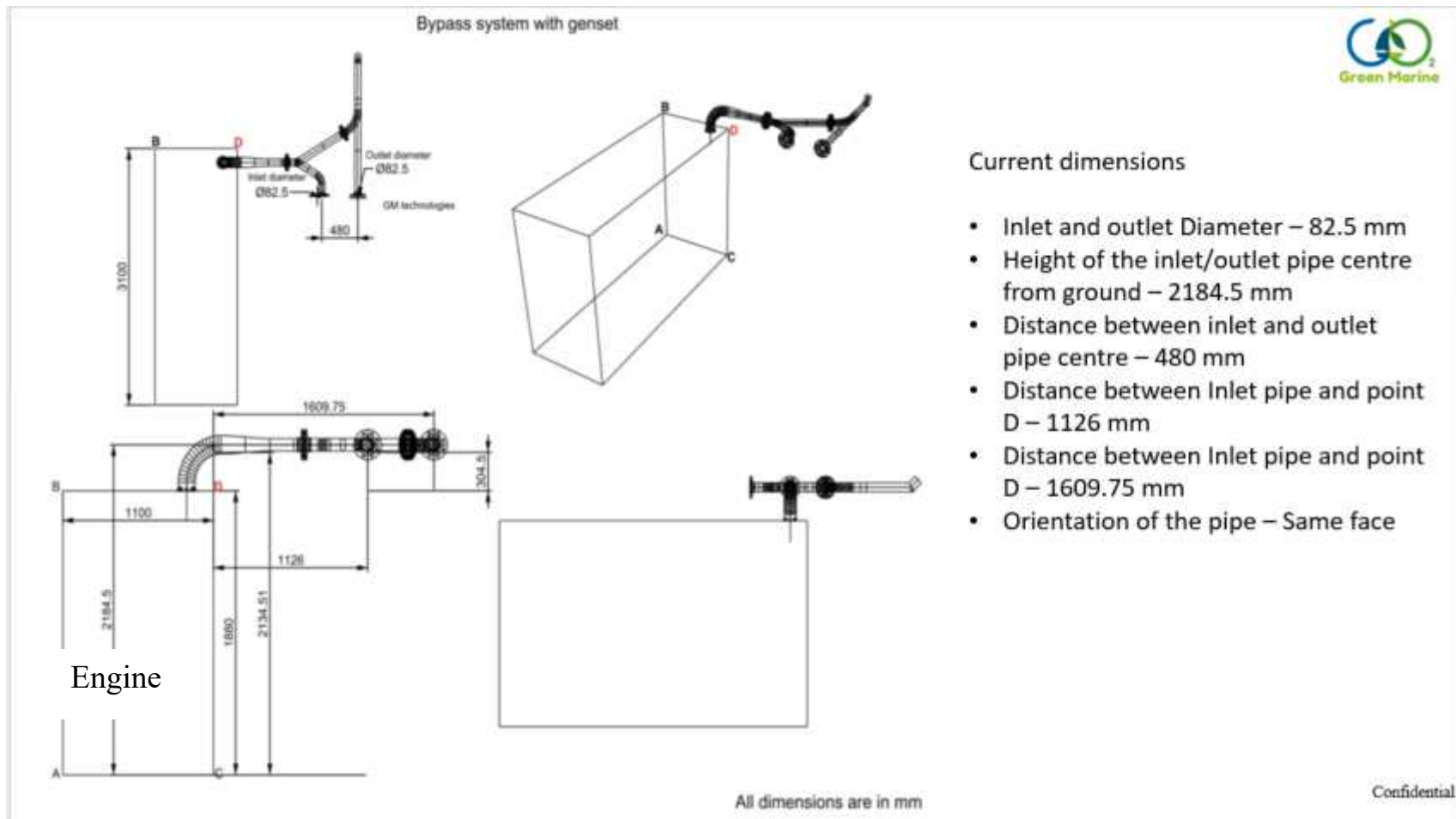


Figure 18. Updated bypass design integrated with engine. Note: The design is continuously evolving to optimize the orientation, space and material.

The potential butterfly valve to be (procurement on-going) integrated at the inlet side of the bypass exhaust system is shown in Figure 19.



Figure 19. Electrically actuated bypass valve (left) and specifications (right).

The non-return valve (check valve) to be integrated at the outlet side of the bypass exhaust system is shown in Figure 20.

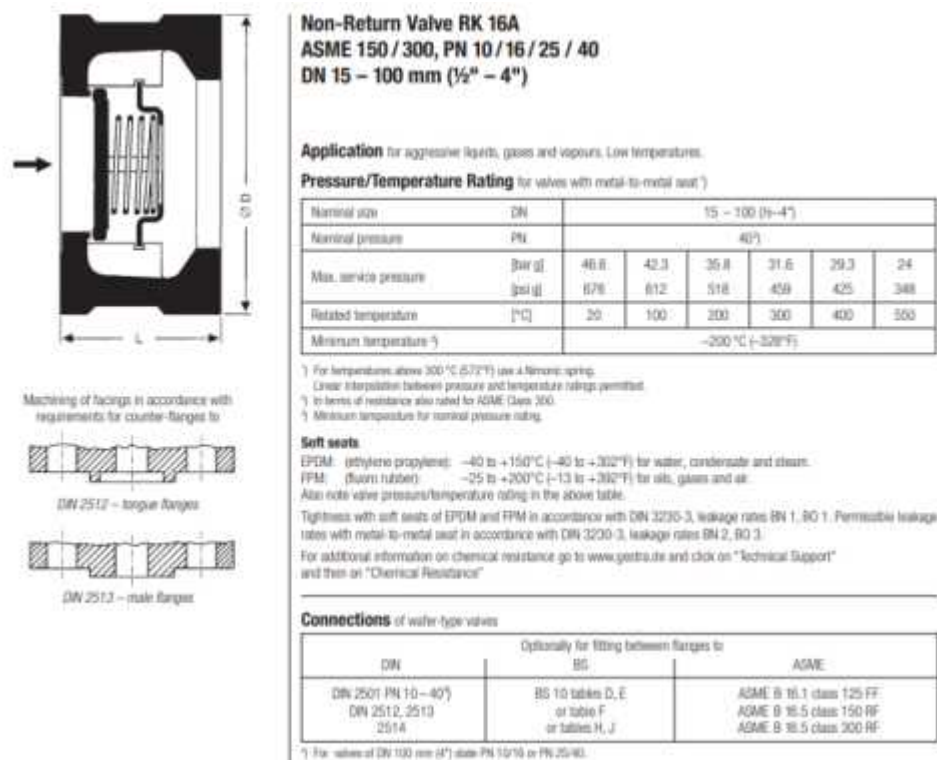


Figure 20. Non-return valve (left) and specifications (right).

Prior to the bypass valve a pressure sensor (see Figure 21) will be installed to monitor the pressure fluctuations and relative magnitude of the exhaust flue gases. The pressure sensor's max pressure values are up to 4 bar, suitable for a turbocharged compression ignition engine. The pressure sensor has RoHS Certificate of Compliance and a REACH certificate.



Figure 21. Left: RS PRO Pressure Sensor, 0 bar Min, 4 bar Max, Gauge Reading. Right: Electrical, Mechanical specifications and accuracy.

6. SAFETY PROCEDURES AND RISK REGISTER BY PML FOR LAND-BASED TESTS

The following is a brief summary by the risk requirements and mitigations regarding the use of the marine diesel generator in order to enable land-based tests at PML's premises.

1. Annual PAT
2. Information to be given to all operatives regarding the risks and associated control measures.
3. Maintenance should always be in accordance with the manufacturer's instructions and recommendations
4. All power voltage supplies should be turned off at the source while installing or servicing the generator
5. The area around the generator must be clean and free of clutter and any combustible material that can be hazardous.
6. The unit should not be opened or dismantled while it is functioning. Moving or hot parts should not be tampered with.
7. The frame of the generator and any external conducting parts should have proper rounding / earthing wiring. This should never be disconnected.
8. Inspection of generator prior to use. The equipment must be regularly inspected, and defective or damaged parts must be replaced in a timely manner.

9. Instruction manual/booklet - Installation, repair and maintenance should always be in accordance with the manufacturer's instructions and recommendations
10. The generator should be installed near the location of the transfer switch and the fuel supply, to reduce the required length of cabling and piping respectively
11. A fire extinguisher should be readily available. Use of extinguishers that operate on carbon tetrachloride is strictly prohibited since the fumes are toxic and can deteriorate the insulation on the wiring of generators. Do not extinguish it with water.
12. Use of PPEs and follow safe handling processes of chemicals (such as chemicals needed for carbon capture and storage) and batteries
13. Ensure exhaust systems are correctly installed and ventilate the engine room adequately
14. Monitor load limits ($\leq 95\%$ for parallel units). Use alarms to notify operators of overload conditions.
15. Regularly test control systems, including alarms and emergency stop functions.
16. Use corrosion-resistant materials. Conduct routine cleaning and inspections

Additional risk control measures:

1. Induction training prior to the commencement of works (action timeline: prior to the commencement of works)
2. Communication between all involved personnel (action timeline: continuous)
3. Supervision of works by a skilled and competent person (action timeline: continuous)
4. Use of PPE kits and equipment always inside the land-based test premises (action timeline: continuous)

Furthermore, the attendees at the land-based test site must adhere to PML's Health & Safety policy. It is mandatory for all attendees to have the necessary personal protective equipment (PPE) to gain entry to our premises. The required PPE includes:

- Helmet or Safety Cap
- Safety Shoes
- Safety Vests
- Safety Glasses
- Earmuffs
- Gloves

Note: It is the responsibility of each attendee to arrange their own PPE as PML/CMMI will not be provided at the test site (Port of Limassol). The detailed plan has been shared with the relevant project partners involved in the land-based measurement campaigns and incorporated in Deliverable D4.6 – "First report Quality, health, safety, regulatory and environment document, and standards" submitted in M24.

Furthermore, Deliverable 2.1 includes the WP2 land-based inspection procedures and requirements as set out by PML.

7. INDICATED LOCATION TO RETROFIT GREEN MARINE TECHNOLOGIES ON-BOARD MV CORUIK

The relevant retrofits and installation of equipment **must be done in accordance and in consultation with Classification society and Flag state**. The land bases setup will try to emulate the on-board installation.

As mentioned in Deliverable D2.1 “Preliminary report on results of land-based testing” submitted on M17, CMMI reproduced the exhaust pipeline system of the auxiliary engine on board MV Coruisk up to the engine room deck level to numerically establish the variation in the value due to the technology intervention and performances. General Arrangement drawings were provided by CalMac as shown in Figure 22 which indicate the body plan view of the MV Coruisk vessel in the forward engine room.

The updated CAD model of the bypass system is shown in Figure 17 and an illustration with engine is depicted in Figure 18. The bypass system has been designed in a modular way by including flanges for ease of integration. In addition, to facilitate the setup of the land-based measurements and to ensure safety of equipment and personnel, the system splits into two sections. One section directs the flue gases into the Green Marine technologies to be tested, whereas the other section directs the flue gases outside the warehouse to the atmosphere at PML’s premises. After the flue gases have been processed by the Green Marine technologies, they are redirected to the atmosphere via the existing main pipe. Appropriate thermal insulation will be sought to ensure safety and to be aligned with Class requirements.

A similar modular approach will be pursued for the on-board installation and integration to ensure proper maintenance and inspection of operations and equipment within the engine room. The integration will also take into account the location of the muffler and spark-arrestor on the existing exhaust system on-board the vessel. Appropriate thermal insulation will be sought to ensure safety and to be aligned with Class requirements.

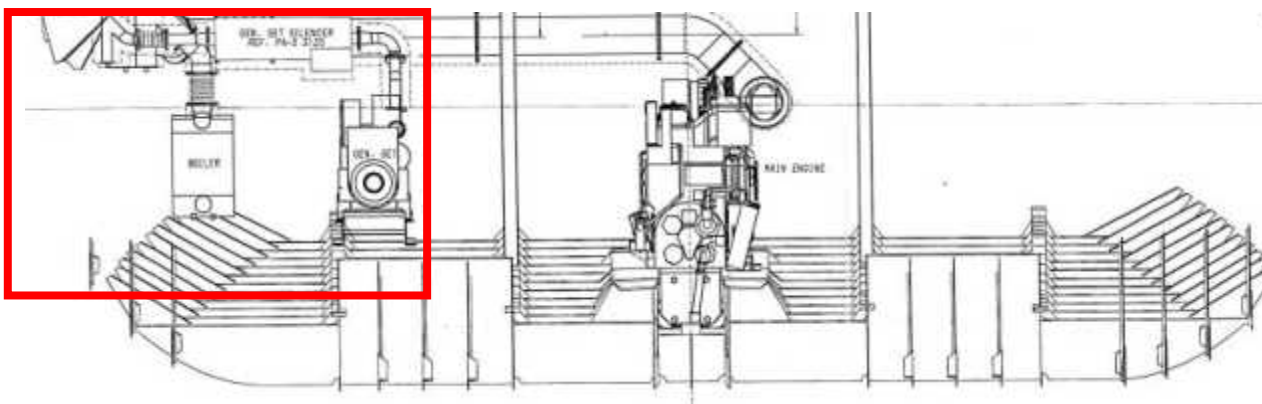


Figure 22. Body plan view with the exhaust system, auxiliary genset and main propulsion engine in the forward engine room from existing General Arrangement Drawings. In red, the exhaust system and auxiliary genset under investigation by Green Marine.

8. CONCLUSIONS

This deliverable purpose is to present the requirements to ensure safety and hence enable the assessment of technologies in the lab-based environment (WP2). The work procedures and practices to ensure safety and handling of equipment etc has been presented. The details about potential retrofits and injection strategy of syngas, back pressure, DAQ systems, and IoT platforms were discussed with references to planned future work.

The requirements by PML (the allocated subcontractor for land-based tests) were summarised in this document. Possible location of retrofitting activities was indicated along with the bypass system, which must be approved by Classification Society (Lloyd's Register, classification society where MV Coruisk is registered) and Flag state (MCA UK). Detailed documentation of requirements is available on the internal Green Marine SharePoint site, which is available to all project partners.

8.1. FUTURE WORK & NEXT STEPS

- Construct the bypass system and finalise IoT platform and real time monitoring including the actuation of the valve and remaining sensors (pressure sensor)
- Map the performance of the genset without the Green Marine technologies
- Assess the Green Marine technologies in the land-based setup

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