



Retrofitting towards climate neutrality

D4.2 Second report: End System Requirements & KPI's

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EXECUTIVE SUMMARY

This document is deliverable “D4.2 – Second report: End System Requirements & KPI’s” of the European Union project “Retrofitting towards climate neutrality” (herein referred to as “**Green Marine**”), with **grant agreement No. 101096522**.

The current version of this report contains updates and additions on KPIs and End System Requirements on a per work package basis. Namely WP1 – WP5 activities:

- WP1 – Demonstrate retrofitting of existing fleets (led by UoS)
- WP2 – Land based testing and integration of solutions (led by CMMI)
- WP3 – Solutions development and scale-up (led by SINTEF)
- WP4 – KPIs, Integration, TEA, SEA, LCA, Risk, Safety (led by UPM)
- WP5 – Software tool catalogue for GHG-emission reduction solutions (led by PDM)

The deliverable mainly targets the technology providers of the consortium which will guide their designs and scale-up for effective land-based testing and eventual integration and retrofit in CalMac’s vessel Coruisk with IMO/LR No.: 9274836. The deliverable also targets the simulation/modelling side in order to guide the consortium for an effective software tool catalogue and estimation of LCAs on a per technology basis.

Compared to the first version, deliverable D4.1 “First report: End System Requirements & KPI’s” submitted on M1 contains an updated and/or extended list of KPIs and End System Requirements as developed during current project activities and discussions. Therefore, information contained in the current version of the deliverable includes (a) feedback from all Green Marine partners, and (b) information obtained during WP1 – WP5 discussions.

This deliverable is understood to be a “living” document and it is scheduled to be updated on M18, M36 (interim reports) and M48 (final report).

1. INTRODUCTION

The main objective of **Green Marine** is to significantly accelerate climate neutrality of waterborne 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 for HVAC systems through air-reuse; carbon and water as a side product 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 allowing air-reuse saving energy for HVAC systems and operated as pre-treatment enhancing a membrane carbon capture process. The Ca/Mg – alkali solvent capture process is capable of removing 75% of the CO₂ from flue gases. All solutions will be theoretically evaluated before demonstration 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 be representative for the operation of a majority of vessel engines in use currently. 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, 1 shipping company, which will host a demo as end user and 5 SMEs.

The objectives of WP4 – KPIs, Integration, TEA, SEA, LCA, Risk, Safety, & Legal Evaluations are to evaluate the Demos, aid in cross-cutting activities and prepare for software tool integration of data:

- Provide a set of requirements for CCUS and relevant KPIs in terms of materials, end user design and quality monitoring, regulatory compliance, in order to help guide the Green Marine project and conduct evaluations.
- Quality, Safety, Environmental & Health (QSEH) control: ensure project goals in terms of QSEH can be achieved; making use of quality document & standards (align with Project Handbook).
- Risk (and Safety): conduct a Safety assessment for all demonstration activities.
- Perform evaluations on: Techno-economic evaluations (TEA) of at least 2 solutions based on preliminary land-based results and at least 2 assessments for vessels. Conduct Life Cycle Assessment (LCA), social economic assessment (SEA) for the technical solutions.
- Benchmark against alternative CO₂ capture technologies and investigate compatibility of 3rd party data to our platform.
- Internal exploitation: to determine the business case for end-users.

1.1 PURPOSE OF THE DOCUMENT

Task 4.1 is about the definition of End System Requirements & KPIs. In particular, Task 4.1 entails:

- Identification of technology requirements for the proposed retrofitting solutions.
- Definition of KPIs for the demonstrations. Towards the demonstrations and commercial application, the documented requirements will be updated regularly based on progressive insight throughout project execution.
- Definition of requirements and KPIs for the software tool, which will include for e.g., GUI, API interface. These KPIs will be used as evaluation method for future use, validation and application.

This report is an update of deliverable D4.1 “First report: End System Requirements and KPI’s” submitted on M1. Following updates of this deliverable will be submitted on M18, M36 (interim reports) and M48 (final report). Therefore, this is a “live” document which will be monitored and updated as needed throughout project activities. Note, the first version of this report included feedback and preliminary requirements of the technologies to be tested. These have been obtained from partners at the Green Marine Kick-Off Meeting (15th-16th February 2023, Larnaca, Cyprus; physical and online participation) and subsequent meetings. Note that information contained in the current version of the report includes (a) feedback from all Green Marine partners, and (b) information obtained during WP1 – WP5 discussions, which involves all corresponding Work Package and Task Leaders. Also note that feedback from this report and its upcoming revisions will be fed into the aforementioned work packages, namely:

- WP1 – Demonstrate retrofitting of existing fleets (led by UoS)
- WP2 – Land based testing and integration of solutions (led by CMMI)
- WP3 – Solutions development and scale-up (led by SINTEF)
- WP4 – KPIs, Integration, TEA, SEA, LCA, Risk, Safety (led by UPM)
- WP5 – Software tool catalogue for GHG-emission reduction solutions (led by PDM)

Also note that at this early stage of the report, some KPIs and End System Requirements are preliminary and thus qualitative and quantitative KPIs are described.

1.2 DOCUMENT STRUCTURE

§2 describes the KPIs and End System Requirements related to WP3 - Solutions development and scale-up.

§3 describes the KPIs and End System Requirements related to WP2 - Land based testing and integration of solutions

§4 describes the KPIs and End System Requirements related to WP4 - KPIs, Integration, TEA, SEA, LCA, Risk, Safety, in particular to the LCA analyses.

§5 describes the KPIs and End System Requirements related to WP5 - Software tool catalogue for GHG-emission reduction solutions.

§6 describes the KPIs and End System Requirements related to WP1 - Demonstrate retrofitting of existing fleets.

§7 presents the conclusions of this report.

Appendix A contains additional information of the SepaRaptor technology and Appendix B contains Safety protocols expected from CalMac's contractors – Managing contractors process as similarly reported in D4.1. Appendix C includes CalMac's internal procedures for Vessel Operations Manual; Vessel Inspection, Maintenance & Overhaul – Control of Contractors.

2. KPIs AND SYSTEM REQUIREMENTS ON A PER GREEN MARINE TECHNOLOGICAL SOLUTION LINKED TO WP3

2.1. CARBON CAPTURE MACHINE (CCM)

CCM's core land-based carbon capture and utilisation (CCU) technology is presently at TRL 5 with several ongoing industrial applications underway to achieve TRL 8-9. However, the focus of Green Marine requires adaptation of this core technology for marine applications which bring specific challenges, regulations, and performance characteristics. In this case, it is essential to verify the broader design specifications prior to implementation of system construction and testing.



Figure 1. The standard CCM process and design will be customized for maritime applications.

CCM has already begun testing of individual components and subsystems to confirm feasibility and performance to TRL 5, but the complete definition of KPIs and end system requirements will mature in later versions of the report. The preliminary KPIs and End System Requirements of Carbon Capture Machine include the following:

- Size: Estimated to fit in the volume of a typical 20ft container; but to be designed in a modular framework to use available space at land-based testing and vessel-based demonstrations/integration.
- The CCM 'Green Marine' modules will include:
 - Emission diversion, cooling, treatment
 - CO₂ Capture
 - CO₂ Conversion
 - Carbonate Utilization and Dissemination
- Storage requirements of chemicals
 - The system will require on-board storage of Sodium Hydroxide (NaOH), and this feedstock will be stored either as a pure solid or as a 47% aqueous dilution to optimize storage space. The size of the storage area and/or tank will be sized in relation to the anticipated test duration (e.g., 250 hours)

- The emissions of both the land-based marine genset and the CalMac vessel-based auxiliary engines have a relatively high output temperature, so the CCM system requires a heat exchanger to cool the emission to approximately 25°C.
 - CCM will optionally explore whether the cooling provided by the Thermoelectric element (TEE) can provide a sufficient level of cooling, or whether the TEE solution can be further cooled via a supplemental heat exchanger.
 - CCM will also explore whether the system can reclaim waste heat if not in competition with the TEE.
- Demonstrate GHG emission reduction >35%:
 - Target CO₂ capture efficiency >50%
 - Target CO₂ conversion efficiency >85%
- The CCM solution will optimize energy consumption to ensure demonstrable CO₂ removal (CDR) as verified by Life Cycle Assessment (LCA). Energy efficiency will be a determining factor whether to utilize Reverse Osmosis (RO) or water evaporation technology to produce the necessary concentration of brine.
- Preliminary specification for carbon capture is 60-120 kg CO₂/hr (1 ktCO₂/yr).
- Low CAPEX and OPEX with significant cost advantage versus direct competition due to the production of valuable carbonate end-products.
- Minimum electricity consumption.
- CCM will work closely with Scottish Association for Marine Science (SAMS) or other research institutes to optimise carbonate production to the specific morphological characteristics required for effective ocean alkalinity enhancement.

How does it work?

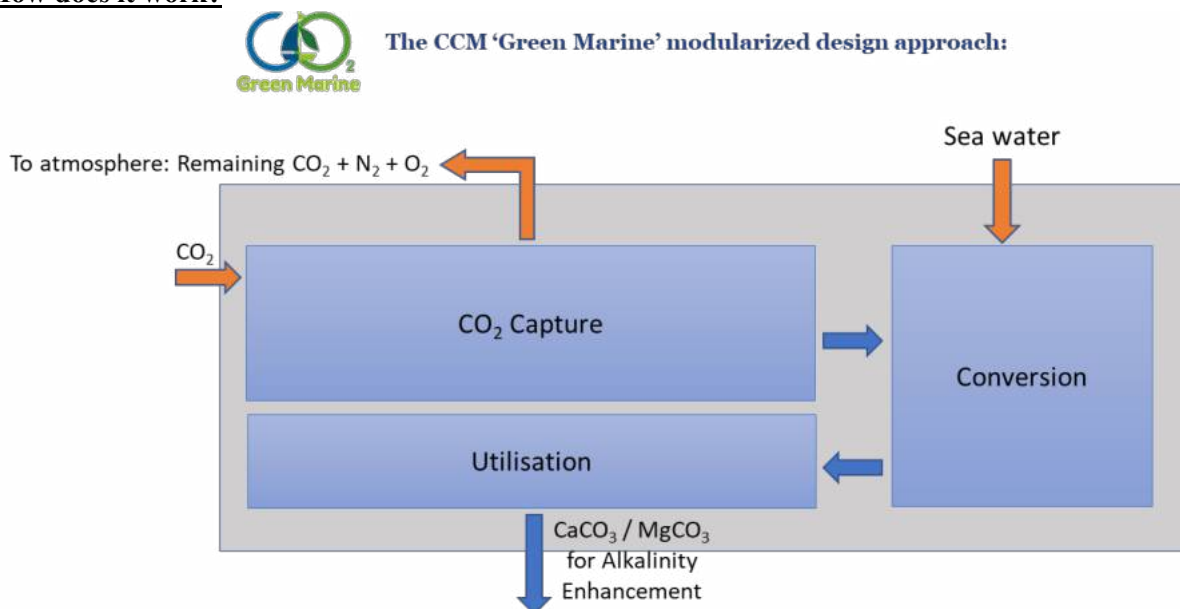


Figure 2. Carbon Capture Machine principle of operation.

2.2. SEPARAPTOR (SPM/WPS)

The main benefit of the SepaRaptor is the agglomeration of nano-particles (5-300 nm) to micro-particles (2-6 µm) which will enable their eventual removal from the air and flue gas. Appendix A: SepaRaptor Technology provides additional explanations on how the SepaRaptor technology works. HEPA, high efficiency performance filters, have a filter gap for air filtration at nano-size range. As per Appendix A, the following KPIs regarding SepaRaptor:

- Typical HVAC filters have an MPPS around 200–300 nm, whereas the MPPS of high efficiency (HEPA and ULPA) filters is smaller, according to ISO 29463 mostly in the range from 120 nm to 250 nm. This is exactly the size of the SARS CoV-2 where the HEPA and ULPA filter exhibit the lowest filter efficiency.
- Efficiency removal: nanoparticles >90% and >95% aerosols, viruses.
- Use low cost and durable equipment, electric consumption piezos: it is estimated a 20 – 40% OPEX improvement on membranes operation for CO₂ capture from flue gas when separator is used as a pretreatment to remove particulate matter in front of membrane separation.
- 50% HVAC energy savings (air reuse increase).
- 99.9% removal of viruses for air ventilation systems.
- The maximum efficiency found in this study was approximately 35% for F7 HEPA Filter systems.

In terms of measurements, a SMPS (scanning mobility particle sizing) device is needed to measure the size of the particles before and after the SepaRaptor for effective monitoring.

Properties that affect toxicity: To be quantified at later versions/updates of this report

- Size is a key factor in determining the potential toxicity of a particle,
- Chemical composition,
- Shape,
- Surface structure,
- Surface charge,
- Aggregation and solubility, and
- Presence or absence of functional groups of other chemicals.

The large number of variables influencing toxicity means that it is difficult to generalize about health risks associated with exposure to nanomaterials – **each new nanomaterial must be assessed individually, and all material properties must be taken into account.**

How does it work?

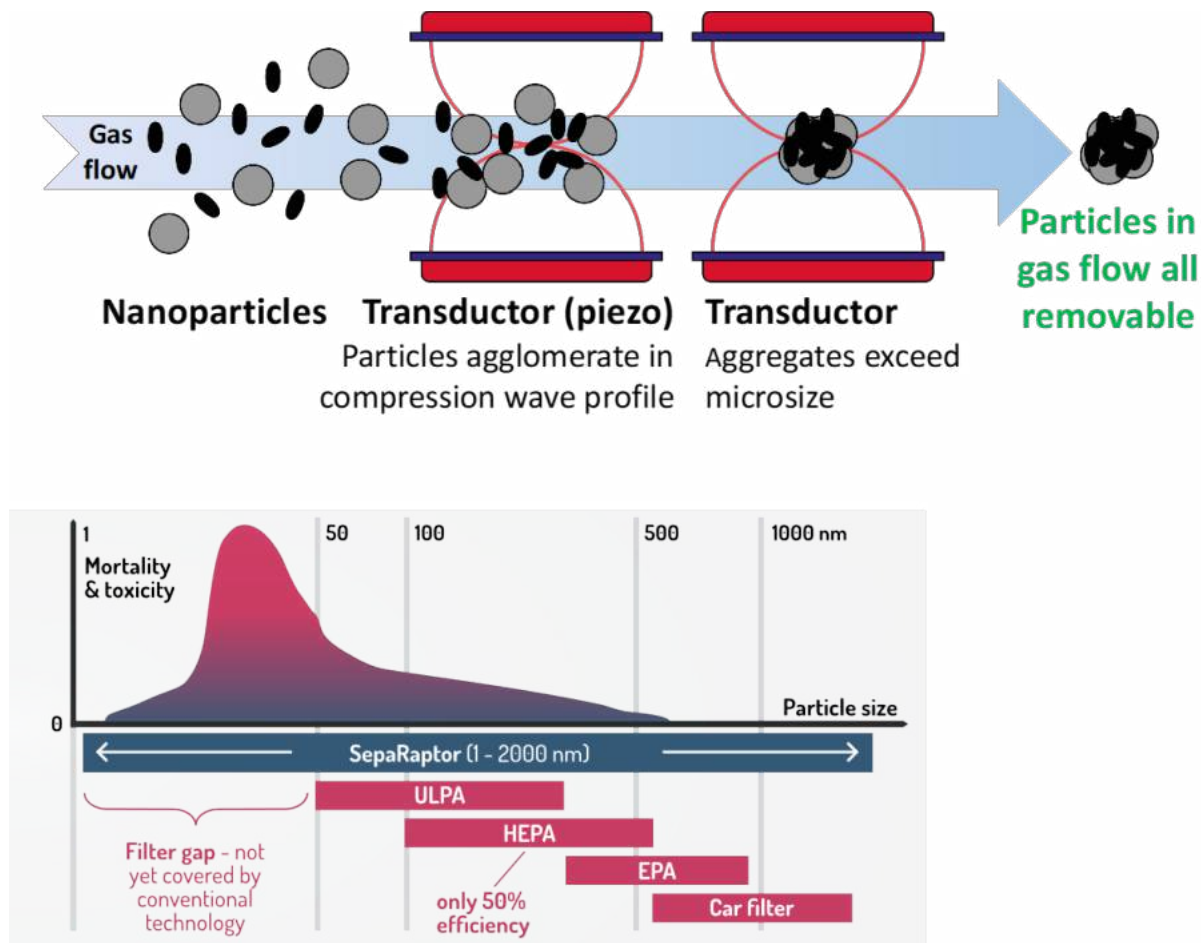


Figure 3. SepaRaptor principle of operation (top) and filter gap with standard filters (bottom).

The principle of operation of the SepaRaptor unit is detailed in Appendix A. However, in short, the SepaRaptor agglomerates small particles into larger particles (agglomeration of nanoparticles (5-300nm) to microparticles (2-6 μ m)). In the case of use with the exhaust gases, the SepaRaptor will agglomerate and ultra-fines (less than 2.5PMs) the HVAC system, as will be explained in §3.2.4, the SepaRaptor will be used to agglomerate viruses and/or bacteria. Together with the use of UV light, the air will be able to be resued.

2.3. THERMOELECTRIC ELEMENT - TEE (SPM/WPS)

The genset could be water-cooled or air-cooled, preferably water-cooled system to avoid a different setup from the demonstrations of WP1. In the event of an air-cooled engine, the TEE heat exchanger will be modified accordingly by designing, building, and testing new system.

The additional benefit of water-cooled TEE for marine engines is that we close the coolant loop and thus, there is no potential pollution of the environment by chemicals like oils.

The KPI of the electricity energy gain to be determined in following reports after the complete definition of the overall system requirements.

In addition, as per the Grant Agreement, the following KPIs and end system requirements for the Thermocouple-System are expected (or defined if not yet known):

- High efficiency.
- Minimum amount of space required; measured in space required over nominal electric power produced (m^3/kW_e) and weight over nominal electric power produced (tons/kW_e).
- Operational temperature range.
- Electricity produced per thermal Watt heat; measured in electric power overheat recovered ($\text{kW}_e/\text{kW}_{th}$) or electric energy over recovered energy ($\text{kW}_{eh}/\text{kW}_{th}$).
- Working fluid selection, depending on temperature range (as per Subtask 3.3.2):
 - Water: 170 – 600°C; water was selected because the coolant temperature will stay within its range. NOTE: for such large temperature range, especially temperatures lower than the water dew point, the water phase change and pressure impact must be taken into consideration so as to predict the working fluid's behaviour and eventual system performance.
- Protection of piping from thermal, mechanical and chemical effects with coating.
- Electrolyser selection (as per Subtask 3.3.2): a Polymer Electrolyte Membrane (PEM) to be selected. Note since TEE output is always the same (DC current) and cannot be optimised.

How does it work?

Thermoelectric elements (TEEs) are based on the Peltier principle where transform the thermal energy, i.e., use waste heat from an engine and transform it into electricity.

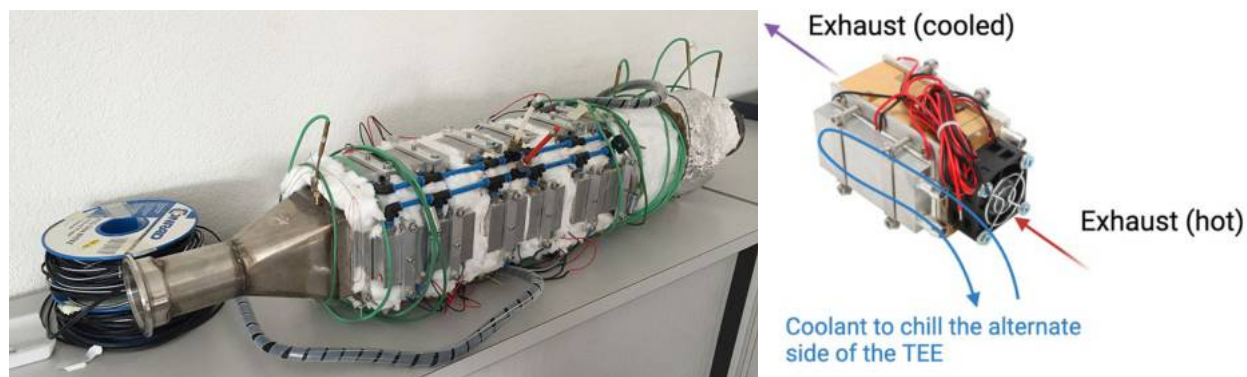


Figure 4. TEE principle of operation

In **Green Marine** two options will be considered as per the following Figure 5. The figures also contained expected operating temperatures which serve as KPIs.

As per the Green Marine WP2 and WP3 discussions, preliminary two options have been discussed. Namely these are:

TEE option 1 – combined loop of fluegas and engine coolant. The solder used in TEEs can soften or melt at flue gas temperatures. To overcome this problem a gas-liquid heat exchanger with

minimal impact on exhaust flow will be introduced. We can simply cool the coolant of the flue gas loop with the engine coolant loop.

TEE option 2 – based on the layout of the engine and temperatures, we can opt to create two separate TEE loops. For this, the engine coolant and flue gas loops will have separate TEEs.

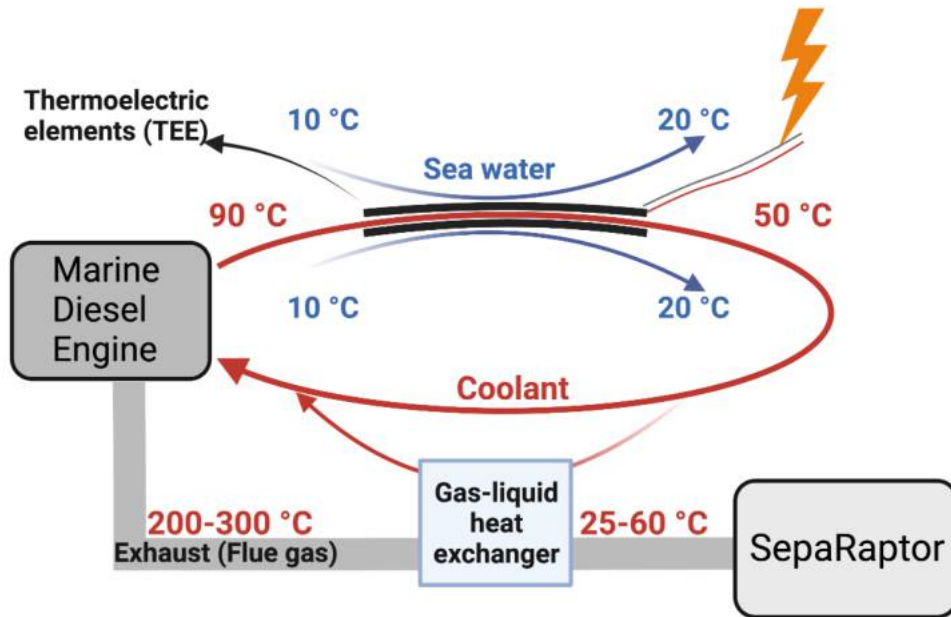


Figure 5. TEE option 1 – heat obtained from engine flue gases and engine coolant as one closed system.

TEE option 2 – flue gas section will be uncoupled from the coolant loop to have two separate loops.

2.4. PEM MEMBRANES - (SMP/WPS)

The objective of the PEM membranes is the production of H_2 by water electrolysis as depicted in Figure 6. The TEE will provide DC power as detailed in §2.3.

These hydrogen cell membranes can be recycled (ThorSpin) to recoup some of the precious metals as described in §2.5.

The following preliminary KPIs and end system requirements are expected (or defined if not yet known). These depend on WP3 activities:

- Recycle material of membrane (time to be determined in future versions of this report)
- Membranes to be purchased off the shelf (cost to be determined in future versions of this report)
- Quantity of water needed (depends on TEE electricity produced; to be determined in future versions of this report)
- Quantity of H_2 to be produced (depends on TEE electricity produced; to be determined in future versions of this report)

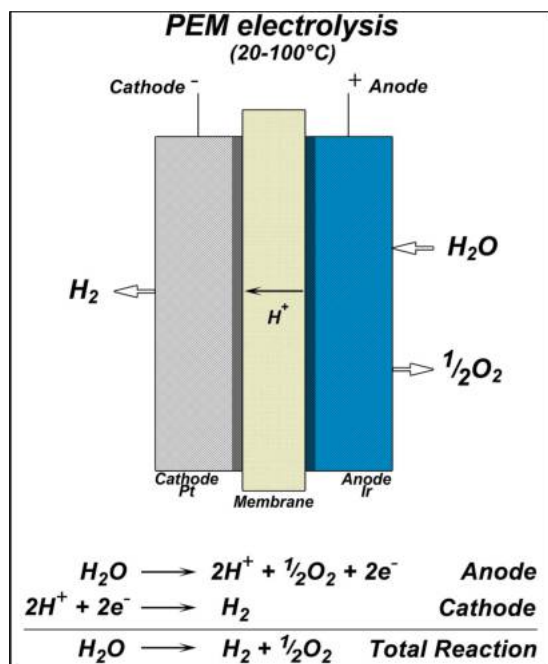


Figure 6. PEM water electrolysis to enable the production of Hydrogen

2.5. THORSPIN UNIT - (SMP/WPS/BX)

The following KPIs and end system requirements are expected (or defined if not yet known):

- Definition and selection of suitable catalysts non-precious metals: as per Subtask 3.3.1, such as Ni, Cu, Ir and Pt - based materials (as indicated in Figure 6)
 - Exposure of catalyst materials to flue gas environments and heat to determine the efficiency ratios; aim is 50 or 80% from original value
 - 10-20 grams are foreseen for each catalyst type
- Catalyst regeneration – MechanoChemistry (from ThorSpin unit): maintain purity of catalyst
- Removal of contaminants of catalyst
- Processing time
- CAPEX and OPEX of ThorSpin unit
- Electricity consumption to be quantified in kWh/kg

NOTE: This component will be developed in WP3, but not be used in WP2 and WP1 activities.

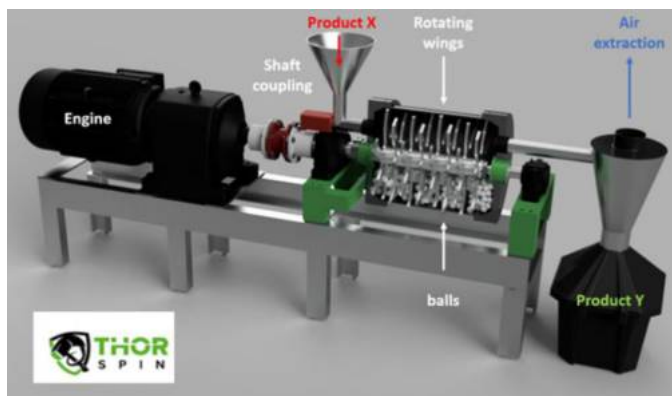


Figure 7. Depiction of the ThorSpin unit

How does it work?

Use mechanochemistry principle. Catalyst regeneration to recover precious materials via collision forces (mechanical energy with localized temperatures reaching 1,000 – 10,000 °C). ThorSpin unit uses high speeds and torsional forces that destruct materials to elementary atoms. In Green Marine this will allow to recover precious metals (Ir and Pt).

2.6. CO₂ MEMBRANES - (SINTEF)

The following KPIs and end system requirements are expected (or defined if not yet known):

- Base case for the current capture technology assessment is capture from a flue gas for a ship engine running at 66% load producing 50-150 Nm³/h flue gas with a CO₂ content of up to ~5.0 vol% (wet) with Diesel as fuel.
- Aim is a CO₂ recovery of >35%
- Membrane KPIs: CO₂/N₂ selectivity 50-100, CO₂ permeability up to 1000 Barrer. Maintain or increase permeability & selectivity ≥100
- Membrane area: >1.0 and up to 10 m² per module for land-based testing, up to 2x 10 m² semi-commercial module size on ship testing
 - Membrane area installed per module will depend on commercial membrane manufacturer specifications and availability. Several smaller modules can be combined to achieve required membrane area.
 - Two membrane geometries are developed in parallel and tested in the SINTEF laboratory at laboratory scale (20- 500 cm² area) using synthetic exhaust gas 5% CO₂ in N₂, fully humidified at temperatures between 25 and 55 °C and at atmospheric pressure:
 - flat sheet membrane: facile fabrication in the laboratory but more challenging to upscale the module area. Membranes will be packed in frame by frame or spiral wound type of membrane modules
 - hollow fibre modules: more challenging membrane fabrication but more facile upscaling the module membrane area
 - Performance of both options to be determined and then decide the optimum membrane geometry and area to be used in WP2.

- Process simulation for CO₂ capture using membranes is ongoing using CoCo simulator based on flat sheet membrane lab-based results. Several process configurations with one or multiple membrane separation stages are investigated in terms of energy consumption, membrane area needed, and CO₂ capture rate and purity.
- Water recovery as by-product: possibility to recover water vapour to be determined to avoid membrane flooding. Drainage may be needed to remove the condensed water vapour and recover the high-water purity water for other use on ship.

The effect of pretreatment of diesel exhaust for particulate removal by SepaRaptor in front of membrane separation will be possible to investigate only on WP2 land-based testing using real diesel exhaust gas. Test with and without flue gas pretreatments should be performed to assess the effect of pretreatment on membrane performances and life time: KPIs strongly depend on genset final specifications and engine size (amount of CO₂ in flue gases).

How does it work?

Membranes are defined by Mulder, pg 7 [1] as a permselective barrier or interface between two phases. A simple representation of a membrane is shown Figure 8. The driving force for transport of a species is the potential difference across the membrane and may be in the form of a pressure (or more correctly, fugacity) difference, concentration difference, temperature difference or an electrical field [2].

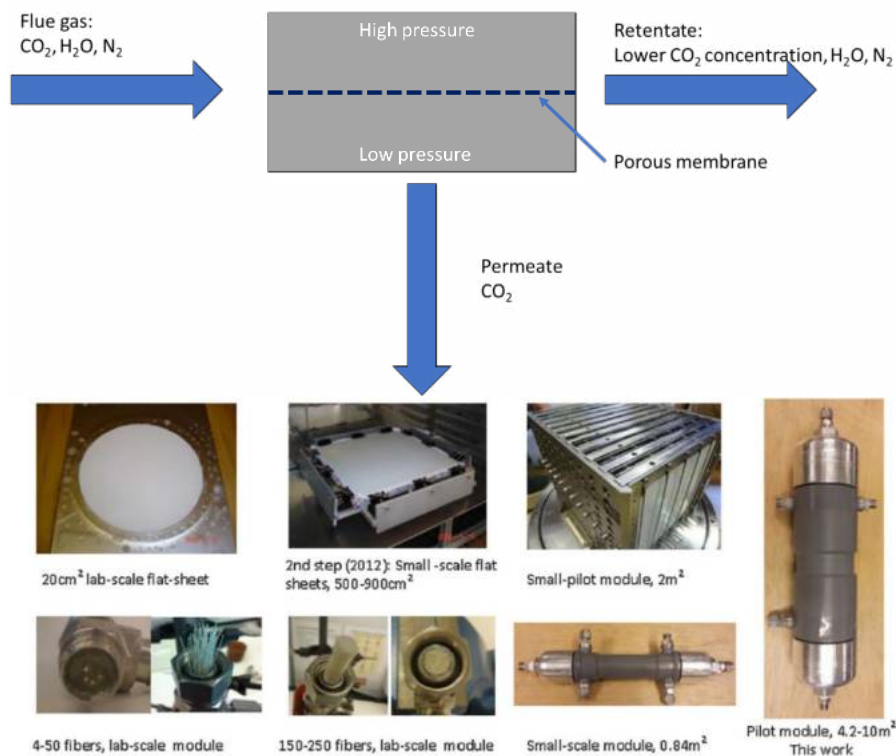


Figure 8. Membrane principle of operation (top). Illustration of different paths for membrane area upscaling and two membrane geometries (flat sheet upper and hollow fiber bottom of image) (TRL > 5-6) (bottom; reproduced from Ref [3]).

The KPIs and end system requirements are derived from SINTEF research activities related to CO₂ capture [4, 5, 6, 7].

Regarding the CO₂ capture membranes, it is proposed to have either one-stage or two-stage process. Depending on number of stages CO₂ content can reach up to 80% (see Figure 9) or over 95 %, as required for transport and storage in CCUS.

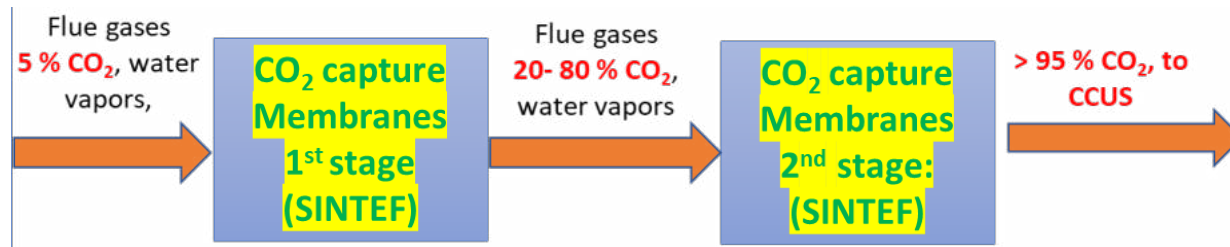


Figure 9. Conceptual use of two-stage CO₂ capture membranes. Number of stages to be determined in later versions of this report and WP3 activities. Expected CO₂ capture efficiencies are shown (expected KPIs).

Note that the number of stages will be determined in future versions of this report and WP3 activities.

2.7. SYNGAS AS A DUAL FUEL

2.7.1. Syngas on-board production (SMP/WPS)

Paykani et. al. [8] list the possible composition of syngas and a range of LHV values gathered from the open literature. The exact composition depends on the production method and feedstock used.

Table 1. Range of possible syngas composition on a volume percent basis. Reproduced from [8], data obtained from [9, 10]. *Note that in the open literature, studies include even higher H₂: CO ratios.

Species	Min	Max
H ₂ (%v/v)	8.6	61.9
CO (%v/v)	22.3	55.4
CH ₄ (%v/v)	0.0	8.2
CO ₂ (%v/v)	1.6	30.0
N ₂ +Ar (%v/v)	0.2	49.3
H ₂ O (%v/v)	-	39.8
H ₂ :CO ratio (-)	0.33	2.36*
LHV (MJ/m ³)	5.02	12.57

Preliminarily, **Green Marine** will use Catalytic CO₂ hydrogenation reaction. The production of syngas on-board can be achieved through the catalytic reverse water gas-shift (RWGS) reaction and methanation.

The water-gas shift (WGS) and reverse water-gas shift (RWGS):



[1]

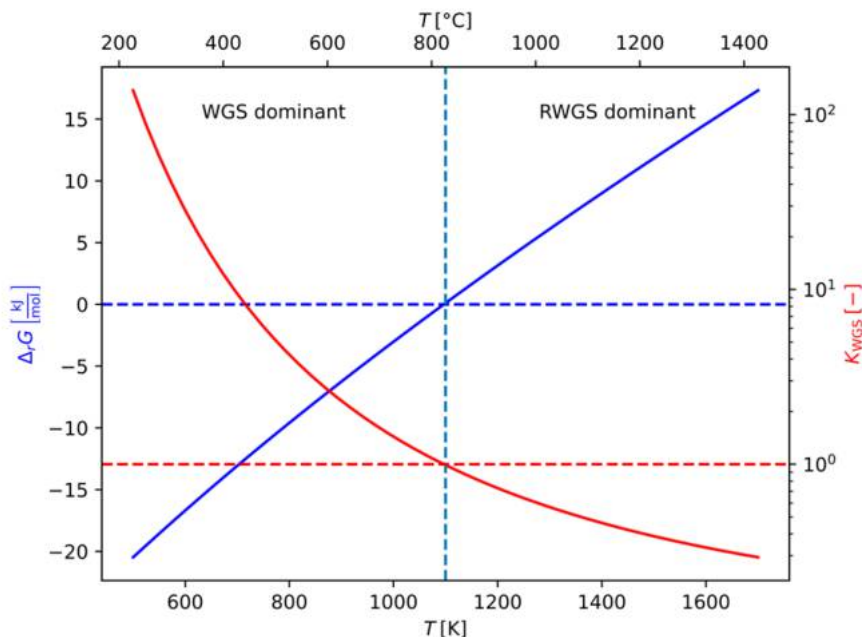


Figure 10. Change in Gibb's Free energy and reaction rates as a function of temperature.

Figure 10 shows that shift the reaction to RWGS, i.e. production of CO, a temperature $>600^{\circ}\text{C}$ is needed. There is also the possibility to produce methane via the methanation process:



[2]



[3]

Expected KPIs and end system requirements for CO production are:

- Precious (Pt and Ru) metals and non-precious metals can be considered
- Temperature to produce CO ($>600^{\circ}\text{C}$ if RWGS pathway is chosen); reheat of exhaust gases
- Quantity and type of feedstock needed (to be determined in future versions of this report)
Quantity of CO to be produced (to be determined in future versions of this report)

Hydrogen production will be occur via electrolysis of water as described in §2.3 and §2.4.

However, mixing of CO and H_2 will need the following KPIs and end-system requirements:

- Expected pressures & temperature (to be defined in future versions/updates of this report). Depends on injection strategy to be discussed in §2.7.2
- Expected mass flow rates (to be defined in future versions/updates of this report)
- Expected H_2 :CO ratio (Table 1 and literature review performed under Subtask 3.3.3 (internal **Green Marine** report) indicates a ratio of 3:1 for optimal engine performance). However, the ratio depends on the expected volumes to be produced. Note that it is not anticipated CH_4 to be produced due to the expected low volumes

- Energy density depends on $H_2:CO$ ratio but indicatively LHV of various syngas compositions is provided in Table 1.

2.7.2. Syngas re-injection (CMMI/SMP)

Mapping of the engine and relevant ship compartments, to consider the different operational modes which will enable the optimal spec design of the solution. The KPIs are:

- Weight (to be defined in future versions/updates of this report)
- Safety – safe re-injection in engine without syngas slipping with consideration of relevant IMO regulations – in terms of CO , H_2 , CH_4 slipping; preliminary:
 - Sensors to monitor CO , H_2 , CH_4 (see gas analyzers to be used in land based experiments §3.2.2.1)
- Injection strategy (to be defined in future versions/updates of this report)
- Combustion control (to be defined in future versions/updates of this report)

In dual fuel engines, the gaseous fuel can be either injected via in the intake manifold via Fumigation or Port Fuel Injection (PFI) or directly injected in the cylinder via Directly Injection (DI), while liquid fuel can be directly injected into the combustion cylinder [11]. Note that multiple injections with gaseous dual fuels can produce a homogenous mixed lean fuel-air mixture [12, 13, 14] whereby the reactivity and thus combustion duration is controlled by the injection rate of the added gaseous fuels [15, 16].

3. LAND BASED ENGINE TESTS LINKED TO WP2

WP2 activities entail the retrofitting of a land-based engine with the carbon and capture technologies (that includes SINTEF's membranes, CCM's technology and the SepaRaptor and Thermoelectric Element; TEE by SMP). The genset will be first identified, retrofitted and tested with emissions measuring equipment provided by CMMI and the electric energy gain by the TEE. The genset and testing site will be obtained via subcontracting as per the GA provisions. Land based testing activities require the operation, retrofitting and testing of a marine genset. The subcontracting activities require the following:

- Provision of a genset (including O&M services) to accommodate emissions and other measurements by CMMI
- Engine to be tested for approximately for up to 250 hrs (exact duration to be determined in following reports)
- Support the installation of the carbon capture machine by CCM, CO₂ capture membranes by SINTEF and SepaRaptor by SMP/WPS
- Verification and compatibility of genset with technology providers (CCM, SINTEF, WPS & SMP)
- Appointment of a health and safety manager

3.1 DUTIES OF ENVIRONMENT, HEALTH & SAFETY OFFICER FOR LAND BASED TESTING

The duties and responsibilities of the Environment, Health & Safety (EHS) officer for land-based testing (WP2) has been defined in the Project Management Handbook (D7.2). The allocated EHS manager for WP2 activities is Mr Angelos Ktoris (CMMI).

For completeness the duties are reiterated in this report:

WP2 Land based site inspections

The EHS WP2 officer will and in accordance with the appointed subcontractor's internal EHS procedures (this list will be revised upon appointment of the subcontractor):

1. check the allocated subcontractors site health, safety and any other relevant policies and procedures and if needed align them with **Green Marine** land-based testing activities;
2. update the land-based site inspection procedures to be verified once subcontractor is appointed and to be included in "D2.1 - Preliminary report on results of land-based testing" due on M17;
3. collect feedback from all technology providers to produce health & safety guidance and guidelines for appropriate use based on operational requirements during testing and validations;
4. consolidate the **Green Marine** technologies with the subcontractors guidelines and procedures (points 2 and 3) in the form of a check list for an on-site enforcement;
5. create a policy on Protective Personal Equipment (PPE), such as use as of protective helmets, overalls, goggles, gloves, masks, eye protection, etc.;

6. ensure during site inspections that the proposed experimental methodology is adhered and if needed adjustments to be carried out on-site with the collaboration of WP2 leader, technology providers and the allocated subcontractor;
7. offer training on health and safety and disseminate health and safety brochures at first site visit before commencement of testing activities (induction course).

3.2 LAND BASED TESTING OF DEVELOPED SOLUTIONS

3.2.1. Genset engine specifications & operation

Preliminary the genset specifications, and as discussed at the Kick-Off Meeting, are provided in the Table 2 below. Note that the final genset will be determined in following reports, after the appointment of the relevant subcontractor.

Table 2. Preliminary genset engine specs (as described and presented in the Grant Agreement) at the Port of Limassol.

Engine Model	Deutz A12L 714—Diesel Engine
Model year	1966
Displacement (cm ³)	19,000
Compression Ratio	19.2
Bore X Stroke (mm)	120 × 140
Configuration	Naturally aspirated, air-cooled, 12-cylinder, No EGR available
Rating power (kW/rev. min ⁻¹)	112/1800
Injection timing	24° BTDC
Injection nozzle	Opens at 126.66 bar
Approximate flue gas flow rate	50-150 Nm ³ /hr (to be verified). Flue gas flow rate (Nm ³ /h) to be determined when genset selection is finalised
Nominal fuel consumption @80% power	To be determined from engine owner/manufacture
Power	146kW

As per Mallouppas et. al. [17] the genset has the following performance at diesel only conditions (see Table 3).

Table 3. Genset performance at diesel only conditions

Parameter	Diesel only operation
Exhaust gas temperature (°C)	237
O ₂ (%)	14.8
CO ₂ (%)	3.3
UHC (ppm)	54.7
NO (ppm)	271

Parameter	Diesel only operation
Smoke (opacity)	4.5
Knock phenomena	No

Note the genset will need to be able to combust dual gaseous fuels (necessary retrofits are needed), in particular syngas with $H_2:CO$ composition 3:1 on a vol/vol basis.

3.2.2. Specifications of measuring equipment

3.2.2.1. Gas analyzers

The flue gas analyzer is Lancom 4 from Land Ametek. Lancom 4 is a portable analyzer designed to measure flue gas emissions [18]. Up to nine flue gases, flue gas temperature and pressure can be measured.

- Temperature units: °C, K
- Gas concentration units: mg/Nm^3 , ppm
- Pressure units: in H_2O , hPa
- Hydrocarbon concentration units: %, ppm

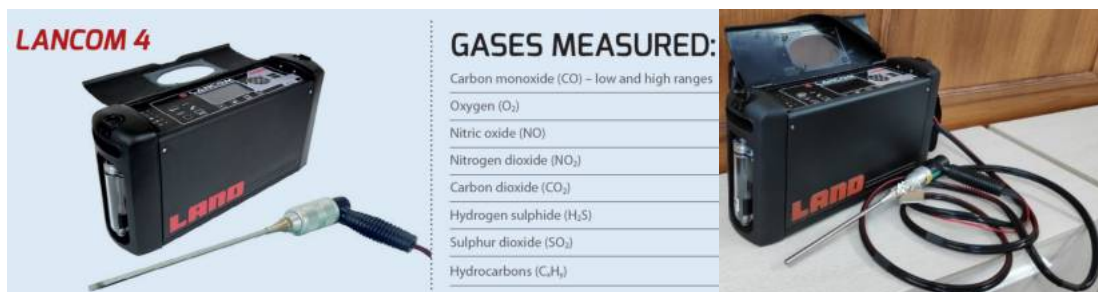


Figure 11. Lancom 4 Gas analyzer [18]

In addition, VARIOluxx [19], which is a portable syngas analyser for long-term measurements of special gases (see Figure 12), will be used to measure the syngas composition at the exhaust outlet. The analyzer extracts partial volume of the flue gas from the combustion channel and analyses it for its components by means of sensors. The analyser can measure O_2 , CO, CO_2 , CH_4 , H_2 and H_2S gases. The syngas analyser will enable measurements for syngas reinjection as a dual-fuel.



Figure 12. Syngas emission analyzer [19].

3.2.2.2. *Smoke detector*

Smoke detector connected to Lancom 4 Gas Analyzer to measure smoke emissions for exhaust gas analysis.



Figure 13. Smoke detector connected to Lancom 4 Gas Analyzer

3.2.2.3. *Thermocouples*

The Type T45 thermocouples of Sika are DNV approved for marine use (see Figure 14). The temperature sensor is a robust sensor designed to measure exhaust gas temperatures for large diesel engines (include marine engines). The following specifications are listed below:

- Thermocouple class 1
- Interchangeable measuring insert
- 4.5mm diameter
- IP54 degree of protection
- 800°C maximum measuring exhaust temperature
- Fitting SW5, 3-4mm stainless steel 1.4571 process connection



Figure 14. DNV approved

3.2.2.4. Fuel/oil flow meter

Contoile fuel oil meters for measurement of fuel and oil flow rates (4-200 litres/hr); see Figure 15. Areas of application:

- to measure heating fuel consumption by oil burners (for example, in heating boilers, industrial furnaces, tar processing plants)
- consumption monitoring and optimisation



Figure 15. Fuel/oil flow meter

3.2.2.5. Air (thermal mass) flow meter



Figure 16. Air (thermal mass) flow meter

The S401 is a flow sensor which is designed to measure the consumption of compressed air and gases within the permissible operating parameters (see Figure 16). The S401 can measure the following values:

- Volumetric flow of the compressed air or gas.
- Total consumption of the compressed air or gas

3.2.2.6. In cylinder pressure sensor analyser

PREMET® diesel indicators compatible with low-, medium- and high-speed engines (see Figure 17). This device provides the opportunity to fine tune an engine to a higher efficiency resulting in lower costs.



Figure 17. In-cylinder pressure sensor analyser.

3.2.2.7. Vibration monitoring and analysis equipment

VA5 Pro A4404 – SAB Virtual Unit is a portable vibration analyzer which is based on unique Digital Signal Processing (DSP) board developed by Adash [20]; see Figure 18. Adash's A4500-VA5 Pro is a vibration analysis instrument, amongst many others in the market, including several additional features for machine diagnosis, such as thermal imaging, ultrasound detection and provides direct measurement processing. In addition, DDS software, the company's appurtenant software, allows for a more detailed analysis via built-in packages to facilitate the measurements. The methodology of VA5 incorporates monitoring phenomena related to degeneration or tracking the



Figure 18. VA5 Pro A4404 vibration analyzer

- CCM: 25 – 30°C
- Typical exhaust temp. 400°C – 500°C, thus the exhaust gases will need to be cooled down to required operating temperatures of membranes, SepaRaptor and CCM.
- 35% GHG reduction as per WP1

3.2.4. Process Flow Diagram for HVAC retrofits

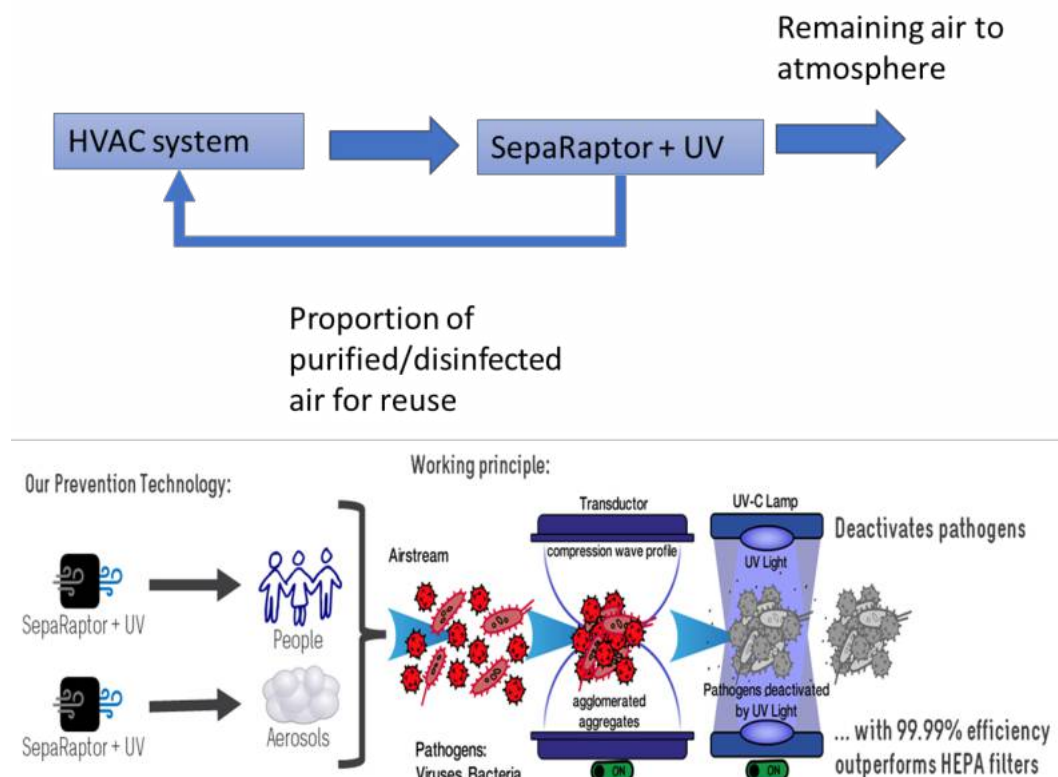


Figure 20. Process Flow Diagram for HVAC retrofits utilizing the SepaRaptor + UV light.

Preliminary KPIs (to be reassessed in future versions of this report):

- Depending on WP3 activities: decide on Standalone unit vs dedicated to be centrally installed HVAC system
- Power requirements of standalone unit (to be determined)
- Throughput flow rate (to be determined)
- Expected Pressure drop: <1%
- Expected exposure time for UV to be effective (to be determined)
- Estimated length of ductwork for UV light to be effective (to be determined)
- Expected mass (or flow) rate needed to remove 99.99% efficiency that will outperform the HEPA filters
- See §5.4.2. for expected KPIs of HVAC system

4. GREEN MARINE LIFE CYCLE ASSESSMENTS (LCA) LINKED TO WP4

4.1. LIFE CYCLE ASSESSMENTS (LCA)

As per Task 4.3, LCA will be carried out according to ISO 14040. which include the following phases (see Figure 21):

1. Goal and scope definition for the system to be assessed.
2. Inventory analysis, requiring the compilation of data on all the inputs and outputs of the system that occur within the system boundary.
3. Impact assessment, in which the output of the inventory is manipulated to extract data on the magnitude and significance of the potential environmental impacts.
4. Interpretation, involving the evaluation of the findings from either the inventory stage or impact assessment stage (or both) based on methodology defined in the scope to reach a set of conclusions.

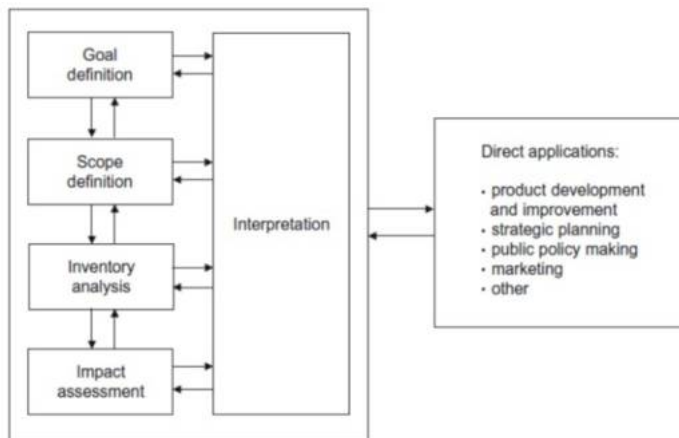


Figure 21. LCA in accordance with ISO 14040

The LCA will be performed on a per technology basis, and these require information about:

1. Boundary conditions
2. Control volume
3. Mass and energy balances
4. Inventory creation:
 - a. **input** of resources, materials, semi-products and products;
 - b. **emissions**;
 - c. **output** of waste and valuable products for the product system, according to the definition of goal and scope.

Note that the inventory analysis considers all the processes belonging to the product system, and the flows are scaled according to the reference flow of product that is determined from the functional unit.

Preliminary KPIs of LCA analyses are:

- Global Warming (kg CO₂ eq)
- Stratospheric Ozone Depletion (kg CFC11 eq)
- Terrestrial Acidification (Kg SO₂ eq)
- Marine Eutrophication (kg N eq)
- Terrestrial Ecotoxicity (kg 1,4-DCB)
- Freshwater Ecotoxicity (kg 1,4-DCB)
- Marine Ecotoxicity (kg 1,4-DCB)
- Human Carcinogenic Toxicity (kg 1,4-DCB)
- Mineral Resource Scarcity (kg Cu eq)
- Fossil Resources Scarcity (kg oil eq)

Specific LCA use cases will be determined in future versions of this report after finalization of WP3 activities.

5. SOFTWARE TOOL CATALOGUE LINKED TO WP5

As per the Grant Agreement, general KPIs regarding the software tool are:

- Number of software tool users = 100
- User engagement survey feedback = satisfactory engagement of 500 users

Ability to integrate a new module within a timeframe to be defined in later versions of the report. Figure 22 illustrates the Green Marine software catalogue tool with different “software modules” or “Service Provider Layers”. Figure 22 provides the high-level visual understanding of data flow to be used within the Green Marine software platform.

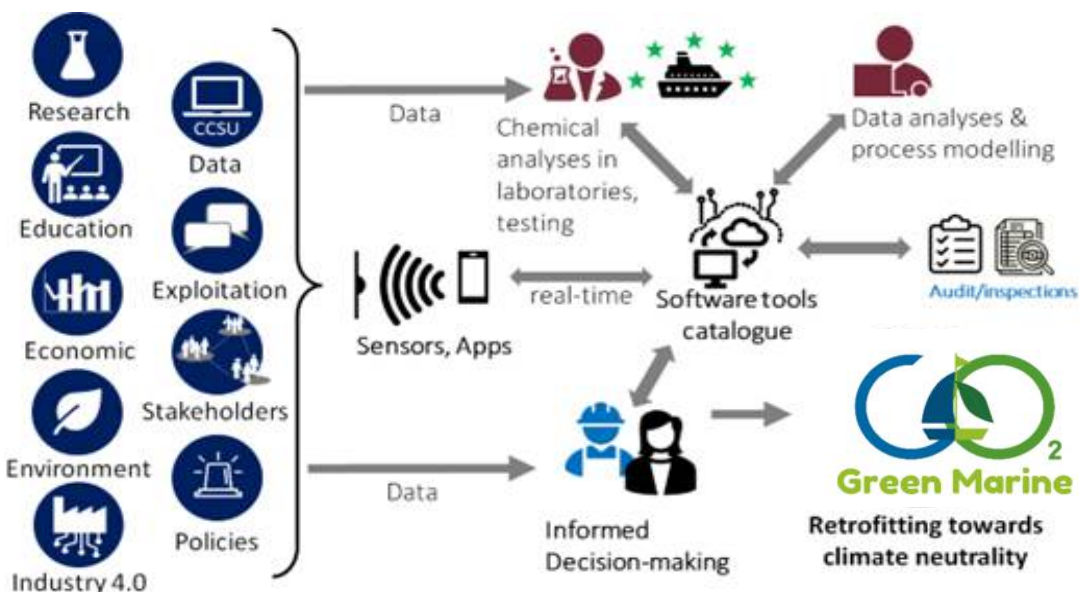


Figure 22. As per the Grant Agreement; the envisioned Green Marine software decision tool catalogue

5.1 APIs AND INDIVIDUAL SOFTWARE MODULES

The following KPIs and end system requirements for Task 5.1 are expected (or defined if not yet known). As per the Grant Agreement these are:

- Exact definition of API interfaces to allow 3rd parties to connect to the platform with their tools or software apps
- GUI definition (see §4.2.2)
- Data security
- User engagement (see §4)
- Quality and validation of data for benchmarking/model development
- Stakeholder acceptance and engagement

5.2 SOFTWARE PLATFORM

The software platform will integrate independent physical models of the different technological solutions and addresses the lack of integrated environment for complex distributed simulations and lack of data validation (see §4.2.1) that are needed to feed the models to be developed. Thus, the requirement of the software platform is to provide a fully integrated CCUS platform by using the state-of-the-art tools.

5.2.1 Tailor existing AI technologies

AI technologies to facilitate predictive performance of the technologies and retrofits. The AI algorithms will “learn” from the land-based test data (WP2) and demonstration data (WP1). Thus, predictions and recommendations for GHG avoidance measures based on ship operations, engine type etc.

Thus, preliminary KPIs and end system requirements regarding the AI technologies are:

- Large data samples to train the deep neural networks (DNN)
 - This requires the duration of the tests to be long enough for a statistical acceptable sample
 - If this is not achievable, closure models will be needed
- Creation of repository data / models that can be used by researchers in a privacy-preserving way ensuring collaboration without sharing of proprietary data (using federated learning techniques by not sharing raw data)
- Reliable algorithms that do not lead to Floating Point Exceptions or any other issue; quality assurance to filter out bugs
- Optimised algorithms in terms of performance depending on techniques for digital mimic (up to x10 speed-up of current GPU architectures with usual federated learning techniques of the current state of the art)
- Accurate algorithms; up to 10% variation with land-based and demonstration data

5.2.2 Software framework

As per the Grant Agreement, for easy processing of all results can be visually presented, including different circularity scenario options – computers do not make decisions on a set of parameters, people do so, based on their understanding. Therefore, also “gamification” of the tool is envisaged, where the user interacts with the platform to try a circular scenario.

Thus, preliminary KPIs and end system requirements regarding the software framework are:

- Opensource user friendly GUI with multiple visual interfaces (for example Graphana). KPI: Approval rate from end user feedback > 80%
- Development of a high-quality technical documentation that is openly available. KPI: Technical Operational & user-Manual available by M43 (D5.5). Approval rate from end user feedback > 80%. Instructions Handbook available by M43 (D5.6). Approval rate from end user feedback > 80%. Measurement of users ability to perform tasks after reading the documentation > 70%

- Advanced navigation and visualisation interface to simplify information access and usage (effective information management) KPI: Time spent on site by end users before finishing a task and Number of clicks by end users before finishing a task. See following table:

Table 4. Time spent on site and Number of clicks by end users per visit

Visit	Average Time	Average clicks
3	<10m	<30
5	< 5m	<20
10	< 2m	<15

- Organisation management configuration & administration features. KPI: Approval rate from Organisation Administrators configuration and features from user feedback > 80% KPI: Usage of functionalities regarding Organisation management configuration & administration by Organisation Administrators >70%. Platform downtime after entering production as per following table:

Table 5. Targeted uptime per month

Month	Target Uptime
37-39	90%
40-48	95%

- APIs for data visualization
- Independent reference modules for calculation decisions
- Facilitate gamification user experience
- Facilitate logistics process
- Seamless interaction and coordination of modules
- Number of simulations executed as per following table:

Table 6. Simulations per month during project implementation

Month	Simulations per month
37-39	60
40-42	120
43-48	200

5.2.3 Use case definition

Preliminary KPIs for use case definition are:

- Minimum 50 user stories
- Minimum 100 technical requirements

5.3 COMPUTATIONAL FLUID DYNAMICS (CFD) SIMULATIONS

CFD simulations will provide physical models which will iterate to be part of the software framework. However, CFD activities are planned in WP3, WP4 and WP5.

5.3.1 Activities related to Task 3.1 “Tailor (Develop) aerosol control solutions”

CFD simulations will optimise the flow streams passing through the membranes of the SepaRaptor and UV system. The following requirements are needed for successful CFD simulations:

- Selection of a CFD software package & estimation of computational power and estimated CPU time
- Definition of boundary and initial conditions (definition of inlet velocities, temperatures, species composition, pressure etc)
- Definition of physical models, such as membrane porosity and appropriate numerical schemes to be used
- Provision of CAD model (SepaRaptor + UV system)
- Generation of a suitable mesh

KPIs of CFD simulations for Task 3.1 “Tailor (Develop) aerosol control solutions” are:

- Verification/validation with available experimental data as generated by WP2 activities and open access literature, and any deviation of results to be within 10% of experimental data.
- Optimisation of system, once verified, through various simulations to mitigate back-pressures and improve overall efficiencies of the system.
- Scale up of overall system via optimised flow streams.

5.3.2 Activities related to Subtask 4.4.1 “Process modelling”

As needed in Subtask 4.4.1 “Process modelling”, to determine the back-pressures of the overall system (genset + CCM + membranes as set by the WP2 setup), the following requirements are needed for successful CFD simulations:

- Selection of a CFD software package & estimation of computational power and estimated CPU time
- Definition of boundary and initial conditions (definition of inlet velocities, temperatures, species composition, pressure etc)
- Definition of physical models and appropriate numerical schemes to be used
- Provision of CAD model of genset + CCM + membranes
- Generation of a suitable mesh

KPIs of CFD simulations for Subtask 4.4.1 “Process modelling” are:

- Verification/validation with available experimental data as generated by WP2 activities, and any deviation of results to be within 10% of experimental data.
- Optimisation of system, once verified, through various simulations to mitigate back-pressures and improve overall efficiencies of the system (eg reduction of fuel consumption).

5.3.3 Activities related to Task 5.2 “Air circulation”

As needed in Task 5.2 “Air circulation”, the HVAC system will be modelled via CFD calculations to determine with the air circulation using the SepaRaptor with UV technologies. The following requirements are needed for successful CFD simulations:

- Selection of a CFD software package & estimation of computational power and estimated CPU time
- Definition of boundary and initial conditions (definition of inlet velocities, temperatures, species composition, pressure, passive scalar etc)
- Definition of physical models and appropriate numerical schemes to be used
- Provision of CAD model of a cabin
- Generation of a suitable mesh

KPIs of CFD simulations for Task 5.2 “Air circulation” are:

- Verification/validation with available experimental data and any deviation of results to be within 10% of experimental data.
- Optimisation of system, once verified, through various simulations to mitigate back-pressures and improve overall efficiencies of the system.

5.4 DIGITAL MIMIC OF CRITICAL PARTS/TECHNOLOGIES OF VESSEL

Under Task 5.3, the KPIs and end system requirements will be defined in future versions/updates of this report.

- Three validated retrofitting approaches
- Create models (digital mimicking of models) of the three technologies to be retrofitted
- Technology providers will need to develop/provide the model
- Option 1: Will need the physical model in order to create its digital mimic
- Option 2: Use neural networks to re-create the model from a large pool of inputs/outputs

5.5 RETROFIT DESIGN CATALOGUE TOOLS

Under Task 5.5, the KPIs and end system requirements will be defined in future versions/updates of this report.

6. DEMONSTRATIONS LINKED TO WP1

6.1 DUTIES OF HEALTH AND SAFETY ADVISOR DURING DEMONSTRATIONS

Procedures will be documented, especially in regard to risk & eventual approval (under Lloyds Register) by the Health & Safety Advisor. The specific role to be allocated to CalMac to deliver obligations, through CalMac's internal "HSQE department". The department has the relevant competencies and skills to ensure Health and Safety during the WP1 demonstrations.

Briefly these roles and scope of work in relation to **Green Marine**:

- Head of Safety and Security; responsible for providing professional support to vessel and shore-based operations for all relevant safety and security matters.
- Environmental Manager; responsible for providing professional support to vessel and shore-based operations for all relevant environmental matters.
- Health and Safety Manager; responsible for providing professional support to shore-based operations for all relevant safety and security matters.
- Marine Safety Advisors; responsible for providing professional support to vessel operations for all relevant safety and security matters.

In Appendix B: Safety protocols expected from CalMac's contractors – Managing contractors process, the safety protocols expected from CalMac's contractors, also known as Managing Contractors Process, is presented. This document will form the basis of the safety protocols in the WP1 demonstrations.

As per the D7.2 "Project Management Handbook and draft Data Management Plan", the vessel demonstrations site inspections check list is defined.

WP1 Vessel demonstrations site inspections

The EHS WP1 officer will follow CalMac's procedures as described in the internal document "*Vessel Operations Manual; Vessel Inspection, Maintenance & Overhaul – Control of Contractors (Procedure VOM 06.03)*". The document is included in Appendix C - CalMac's procedures as described in internal document "Vessel Operations Manual; Vessel Inspection, Maintenance & Overhaul – Control of Contractors" (Procedure VOM 06.03). The procedure includes quality records on (1) Contractor Risk Assessments, (2) Contractor Method Statements, (3) Purchase Orders, (4) Job Instruction Sheets, (5) Planned Maintenance Records, (6) Contractor Insurance Certificates, (7) Permits to Work, (8) Safety Induction Records, (9) Near Miss Reports, (10) Accident Reports, and (11) Hours of Work Records, which are all relevant to **Green Marine** WP1 demonstrations. Note that for **Green Marine** WP1 demonstrations the term "*Contractors*" refers to **Green Marine** researchers/scientists needed to install the various technologies on-board CalMac vessels.

6.2 PERMITS AND ACTION PLANS FOR ALL DEMOS

For the effective vessel demonstrations, the relevant sites and permits will be required. Demonstrations will possibly occur where CalMac ferries operate, as shown in Figure 23. A demonstration route will be and defined at later versions of this report.

The necessary action plans as per the Grant Agreement are:

- GHG emission reduction goals;
- responsible contact person;
- quality reviewer;
- safety and environmental issues;
- test campaigns;
- planning;
- quality monitoring;
- Classification Society/regulatory authority compliance (under an appropriate classification society – the majority of CalMac ferries are registered with Lloyds Register);
- onboard technologies evaluation, certification procedures.

As per the Grant Agreement, the final action plan and test campaign will be authorised by the end users responsible site's Environmental, Health & Safety manager (as defined in §4.1).

As discussed at the Kick-Off meeting, during the General Assembly, all partners have agreed that the discharge of de-acidification minerals into the sea requires interaction from the start of the project with the relevant authorities (Subtask 4.4.3) will require compliance with MARPOL strict regulations (environmental rules). Hence, the proposition is to produce lab-scale testing with sea samples in a controlled environment to investigate the impact of de-acidification of minerals from CCM's products. Thus, this will be a simulation of the discharge of de-acidification minerals into the sea.

6.3 ENGINEERING AND PREPARATIONS FOR RETROFITTING

The mapping of new technology approval process from classification societies will be described as part of D1.1 “Report for engineering and preparations for retrofitting” deliverable due on M8. Description of risk approval process and approval in-principle, as such at the moment there are no specific KPIs and end system requirements. However, these. will be defined in detail in future versions/updates of this report.

Preliminary KPIs and end-system requirements are:

- as per technology the technology approval to be aligned with specs (energy efficiencies, mass flow rates, how devices operate);

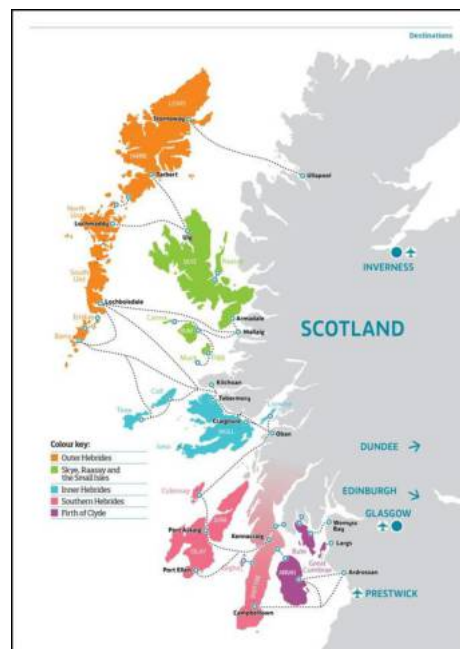


Figure 23. Region of operation of CalMac ferries, as discussed at the Green Marine Kick-Off Meeting

- approval to be performed in 6 months, depending on available information and overall progress of **Green Marine** – harmonisation of KPIs as per appointed classification society;
- 3 workshops of 10 Green Marine participants and 5-10 experts (class society, tech. providers) from industry providing high-level information and maritime background.

6.4 RETROFITTING SHIPS

Based on internal CalMac's Risk Assessment process with input from technology providers the selected vessel is Coruisk as shown in Figure 24. The Risk Assessment will be used by Lloyd's Register, the classification society of the Coruisk vessel. Therefore, the setup of the land based technologies should be similar to the retrofits on-board. The Coruisk vessel, with IMO/LR No.: 9274836, is a passenger/Ro-Ro Ship with carrying capacity of 40 cars, crew 7 and 250 passengers.



Figure 24. Coruisk vessel to be used for **Green Marine** demonstrations.

6.4.1. Engine specifications and available space of CalMac possible vessels

The auxiliary engine specifications of the Coruisk is detailed below. It should be mentioned that there will most probably be other pieces of machinery and equipment within the same space. Both auxiliary engines operate at fixed engine speed of 1500 rpm (i.e., at 50Hz) and use Marine Gas Oil (MGO) fuel.

Auxiliary engines on-board: Cummins, Engine Builder: Cummins 1 x 6BT5.9-D(M), 4 Stroke 6Cy. 102 x 120, Mcr: 91 kW (Emergency Generator) Design: Cummins, Engine Builder: Cummins 2 x 6CTA8.3-D(M), 4 Stroke 6Cy. 114 x 135, Mcr: 150 kW. The engine is operated up to **80% load**.

The auxiliary engine to be utilized is the 6CTA8.3-D(M); Table 7 depicts the engine performance at various loads:

Table 7. Engine performance data as per the manufacturer [21]

Output Power		Fuel consumption	
%	kW _m	kg/kWh	Lt/hr
110% (overload)	181	0.216	45.8
Prime Power			

100%	164	0.214	41.3
75%	123	0.212	30.7
50%	82	0.216	20.8
25%	41	0.251	12.1
10%	16	0.300	5.8
Continuous Power			
80%	134	0.211	33.3

Note that the engine is turbocharged, which use the exhaust gas as a driving force to compress the incoming air, and aftercooled. Hence any system retrofitted must not affect back pressure which will therefore impact the turbocharger performance.

In addition, based on the General Arrangement drawings of the engine room (see Figure 25), several options are to be considered for the retrofits.

6.4.2. HVAC system of Coruisk

Any additions and/or modifications to the HVAC system will need to ensure the dimensioning of the system to external conditions. Any KPIs will need to follow the Coruisk HVAC manual [22]. Figure 26 illustrates preliminary option for the SepaRaptor + UV system indicating available space.

These KPIs are related to the SepaRaptor + UV technology is envisioned to be integrated in the HVAC system. KPIs of the SepaRaptor + UV technology are provided in §3.2.4. The specific KPIs of the SepaRaptor are provided in §2.2.

6.4.3 Sea water inlet of Coruisk

Approximate depth below water line: 2.6m~3.1m (depth below water line)

Please note that the following can impact depth of the seawater intake and therefore the salinity of the seawater taken on board. The vessels draft can change depending on how much cargo is loaded and how much fuel/ballast water is carried, there are slight changes in depth based on vessels speed (Squat effect) and salinity/density of the water.

6.4.4 Dry-docking scheduling

Alignment of **Green Marine** activities in terms of demonstration/installation/retrofitting activities planned for 2026 with dry-docking schedule is needed. Dry-docking is very strict to cover CalMac's vessels. Only one month extension is allowed, hence there is no flexibility.

Therefore, process and installation of technologies on-board the chosen vessel should be ready in Autumn (October-November) 2025. Alignment of classification societies (Lloyd's Register), who will a) supervise the dry-docking sequence, and b) the overseeing of the installation of proposed **Green Marine** technologies. Paperwork from appointed subcontractors will potentially be considered (such as WP2 land-based pre-approval process report).

Figure 25. Options for modifications/retrofits in engine room of Coruisk, indicating available space. More details to be discussed in deliverable D1.1 “Report for engineering and preparations for retrofitting”.

Figure 26. HVAC preliminary option for SepaRaptor+UV system on Coruisk, indicating available space. More details to be discussed in deliverable D1.1 “Report for engineering and preparations for retrofitting”.

6.4.5 Carbon Capture Machine (CCM) on-board Coruisk

CCM will observe the key considerations of the marine industry for the design of the vessel-based solution. Reference standards include:

- DNV RECOMMENDED PRACTICE DNV-RP-A203
Technology qualification
Edition September 2019, Amended September 2021
- DNV RECOMMENDED PRACTICE DNV-RP-J201
Qualification procedures for carbon dioxide capture technology
Edition September 2019, Amended September 2021
- Lloyd's Register – Shipboard Carbon Capture and Storage
RINA – Guide for Approval in Principle of Novel Technologies
Effective from 1 January 2014
- RINA – Guide for Technology Qualification Processes
Effective from 15 December 2016
- RINA – Rules for the certification of marine equipment in accordance with
European Directive 2014/90/EU
Effective from 1 July 2018
- RINA – Rules for Testing and Certification of Marine Materials and Equipment
Effective from 1 January 2023
- BUREAU VERITAS – RULES FOR THE CLASSIFICATION OF STEEL SHIPS –
NR467
January 2023 amendments

Other key considerations, reiterated from §2.1. as per CCM's technology:

- Size: Estimated to fit in the volume of a typical 20ft container; but to be designed in a modular framework to use available space at land-based testing and vessel-based demonstrations/integration.
- The CCM 'Green Marine' modules will include:
 - Emission diversion, cooling, treatment
 - CO₂ Capture
 - CO₂ Conversion
 - Carbonate Utilization and Dissemination
- Storage requirements of chemicals – The system will require on-board storage of Sodium Hydroxide (NaOH), and this feedstock will be stored either as a pure solid or as a 47% aqueous dilution to optimize storage space. The size of the storage area and/or tank will be sized in relation to the anticipated test duration.

CCM will work closely with Scottish Association for Marine Science (SAMS) or other research institutes to optimize carbonate production to the specific morphological characteristics required for effective ocean alkalinity enhancement.

These KPIs will be re-evaluated in future versions of this report.

6.4.6 Other Green Marine technologies on-board Coruisk

KPIs of other technologies are described in §2, but these will be re-evaluated in future versions of this report.

6.5 DEMONSTRATE GHG EMISSION REDUCTION BY >35%

KPIs and end system requirements will be defined in future versions/updates of this report.

6.6 COMMERCIALISATION APPLICATIONS

KPIs and end system requirements will be defined in future versions/updates of this report.

7. CONCLUSIONS

The second version of this report is to document the necessary End System Requirements and KPIs under deliverable D4.2 of WP4 due on M6. This deliverable is a follow up of the first version of D4.1 First report: End System Requirements & KPI's. This document has updated and/or incorporated the requirements needed for:

- WP1 – Demonstrate retrofitting of existing fleets (led by UoS)
- WP2 – Land based testing and integration of solutions (led by CMMI)
- WP3 – Solutions development and scale-up (led by SINTEF)
- WP4 – KPIs, Integration, TEA, SEA, LCA, Risk, Safety (led by UPM)
- WP5 – Software tool catalogue for GHG-emission reduction solutions (led by PDM)

Most importantly and as per §6, the Coruisk vessel (IMO/LR No.: 9274836) has been selected by CalMac as the vessel to demonstrate the various **Green Marine** technologies. More details will be discussed in deliverable D1.1 “Report for engineering and preparations for retrofitting” due on M8. The vessel is a passenger/Ro-Ro Ship with carrying capacity of 40 cars, crew 7 and 250 passengers.

This report is scheduled to be updated on M18, M36 (interim reports) and M48 (final report). Therefore, this is a “live” document which will be monitored and updated as needed throughout project activities. Note that at this early stage of the report, some KPIs and End System Requirements are qualitative and quantitative.

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As per Todea et. al.², the following extracted text applies for the SepaRaptor technology:

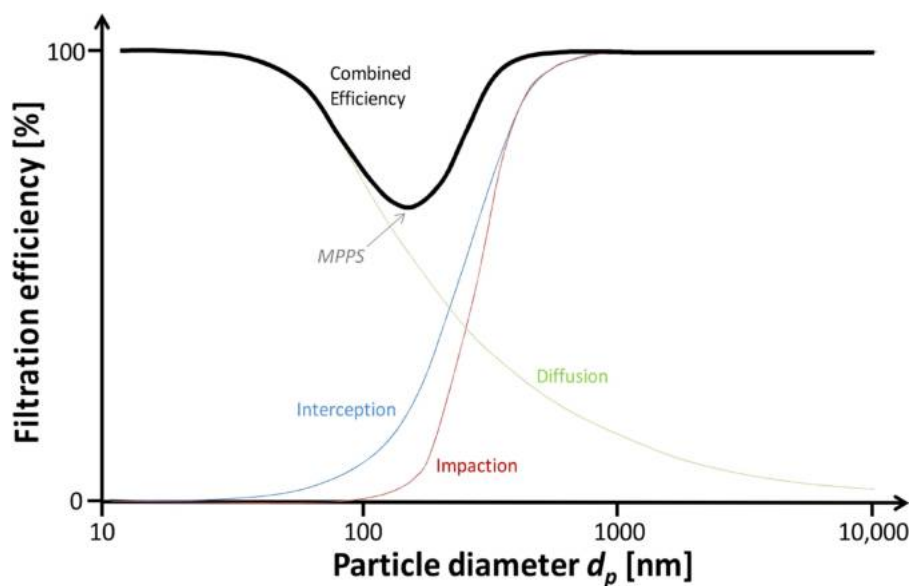


Figure 2A: Filter gap demonstrated as exemplary fractional filtration efficiency of filters. Adapted from Hinds, W. *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles*; Wiley: New York, NY, USA, 1999.

“As can be seen from Figure 2A, the filtration efficiency for small nanoparticles is very high, but decreases with increasing particle size until it reaches a minimum, before interception and impaction become dominant. Fractional filtration efficiency curves have been experimentally determined down to the nanometer size range for flat sheet media samples, wire screens, and respirators. Recently, a method has been developed to determine the fractional filtration efficiency of flat sheet media in a particle size range from 3 nm to 500 nm and successfully undergone an inter-laboratory validation. Experimental studies were also used to verify numerical data.

According to EN 779³, the classes of full-scale HVAC filter cassettes ($\leq F9$) are only rated based on the fractional filtration efficiency at a particle size of 0.4 μm . It is determined for a polydisperse DEHS test aerosol using an optical aerosol spectrometer. As of now, an established method to determine the fractional filtration efficiency of full-scale HVAC filters down to the nanometer size range is lacking. Published data on the filtration efficiency of HVAC filter cassettes for nanoparticles are therefore scarce. Hecker and Hofacre⁴ investigated for the US Environmental Protection Agency (EPA), how the filtration efficiency of HVAC filters with different MERV classes (according to ASHRAE 52.2) changes with filter aging for a wide particle size range from 30 nm to 10 μm . In their study they used a potassium chloride (KCl) aerosol, but do not specify how it

² Todea et. al. Development of a Method to Determine the Fractional Deposition Efficiency of Full-Scale HVAC and HEPA Filter Cassettes for Nanoparticles ≥ 3.5 nm. *Atmosphere* 2020, 11(11), 1191; <https://doi.org/10.3390/atmos11111191>

³ EN. DIN EN779:2012 Particulate Air Filters for General Ventilation—Determination of the Filtration Performance; Beuth Verlag: Berlin, Germany, 2012

⁴ Hecker, R.; Hofacre, K. Development of Performance Data for Common Building Air Cleaning Devices (Final Report No.: EPA/600/R-08/013); U.S. Environmental Protection Agency, Office of Research and Development/Homeland Security Research Center: Research Triangle Park, NC, USA, 2008

was generated. Their data were later used by Azimi et al.⁵ to estimate the filtration efficiency of HVAC filters for ambient fine and ultrafine particles. Stephens and Siegel⁶ determined the fractional filtration efficiency for particle sizes ranging from 7 nm to 100 nm in situ in HVAC systems with MERV4 to MERV16 filters, using ambient aerosol. According to EN 1822⁷ only the measurement of the deposition efficiency in MPPS, as well as a leak test, is carried out for full-scale filters.”

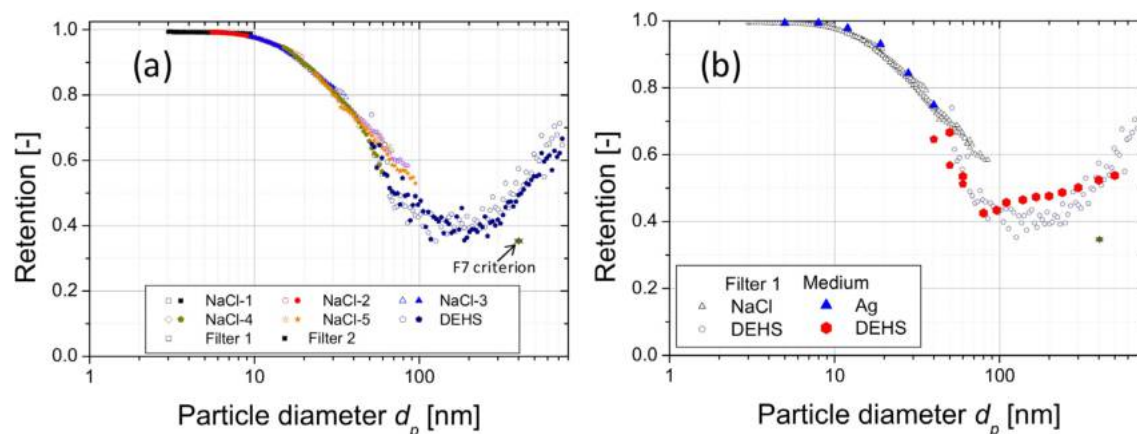


Figure 3A: Exemplary results for (a) two identical full-scale F7 filter cassettes, flow rate 4250 m³/h, tested with different NaCl and DEHS aerosols (see Table 3); open symbols: filter 1, closed symbols: filter 2; (b) comparison of results from filter cassette 1 with data obtained from media sample. Source: Atmosphere 2020, 11(11), 1191; <https://doi.org/10.3390/atmos11111191>.

The maximum efficiency found in this study was approximately 35% for F7 HEPA Filter systems.

Under normal working conditions there would be two PCBs with piezo's and UV light diodes across opposite other. A standing wave is formed between the piezos (distance 6-8 cm), shown in Figure 3A. This is an open structure allowing air to flow through without any restriction. Where the nodes meet, the pressure is ideally zero and agglomeration of nanoparticles occurs. However, there is always motion. They will bound to each other and to larger particles to form even more larger particles. This agglomeration occurs for nanoparticles sizes 1 to 5000 nm (or higher) for: particles, bacteria, metal salts, organics, acidic compounds, aerosols and *viruses*. The agglomeration of nanoparticles is well known. This has been identified by the US EPA in roadside measurements which classified four modes i.e., nucleation (average particle diameter: 6 nm), aitken (20 nm), accumulation (350 nm) and coarse mode (6,7 μ m). These agglomerated particles do not breakdown in smaller particles after assimilation. So once assimilated the size can be larger than 2 μ m.

⁵ Azimi, P.; Zhao, D.; Stephens, B. Estimates of HVAC filtration efficiency for fine and ultrafine particles of outdoor origin. Atmos. Environ. 2014, 98, 337–346

⁶ Stephens, B.; Siegel, J.A. Ultrafine particle removal by residential heating, ventilating, and air-conditioning filters. Indoor Air 2013, 23, 488–497.

⁷ <https://smartairfilters.com/en/blog/en1822-hepa-filter-standard/>

Deutscher Wetterdienst⁸ highlights the following regarding particle size distribution, which is applicable to the SepaRaptor technology:

“The particle number size-distribution (PSD) and even more distinct the surface- and the volume size-distribution of the particle size typically exhibit one or several modes which result from different source and sink mechanisms. These modes overlap in the size spectrum, because the particles sizes continuously change due to condensation, coagulation, fragmentation and evaporation. In Figure 4A schematic view of a multi-modal particle size distribution illustrates the different growth- and shrink processes: The smallest particles form by Gas-to-particle conversion (nucleation mode) and grow through condensation of gases and water vapour, initially relatively fast (Aitken mode) and from size of 50-100 nm diameter (accumulation mode) slower in size by coagulation and coalescence. Beyond particle sizes of several 100 nm the efficiency of thermodynamic (evaporation, sublimation) and mechanical sink mechanisms (e.g., sedimentation, deposition/impaction) strongly increases. Simultaneously, fragmentation/grinding- and evaporation processes act against a growth of particle sizes.

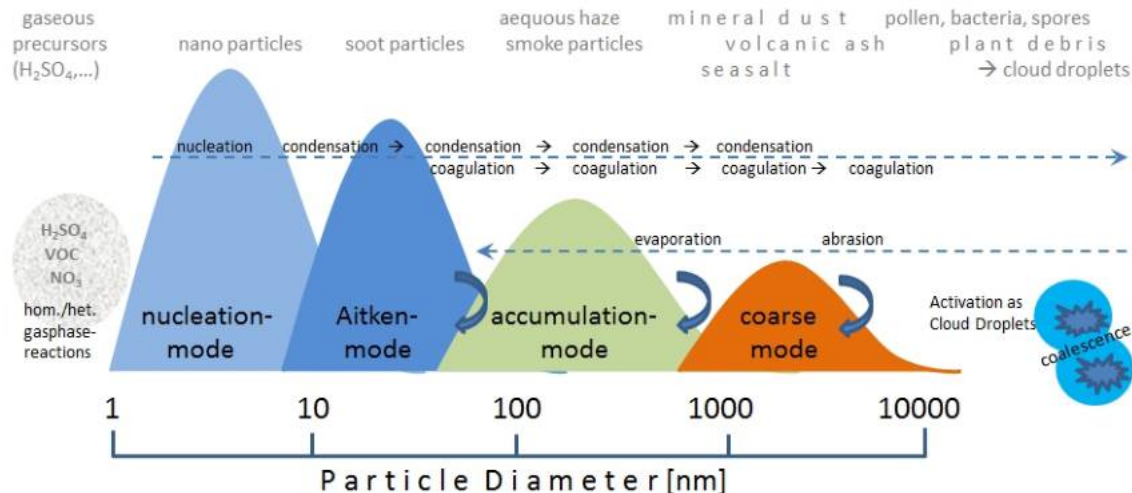


Figure 4A: Schematic multi-modal particle size distribution with typical transformations and example particle types within each mode. Source: Deutscher Wetterdienst⁸.

Directly emitted (primary) particles are distinguished from secondary particles which are formed by transformations. In the atmosphere each particle mode has its specific sources. Nucleation particles form by condensation of super-saturated gases, Aitken particles from the nucleation mode or incomplete combustion (e.g., soot), accumulation mode particles from Aitken particles or intensive mechanical processes and coarse particles from accumulation mode particles and moderate mechanical processes (e.g., abrasion of mineral dust, volcanic ash, sea spray). In most cases the modes are not monodisperse (of a single size) but polydisperse and the size distribution can be described mathematically in good approximation by one or more logarithmic normal

⁸ Deutscher Wetterdienst, Available online:

https://www.dwd.de/EN/research/observing_atmosphere/composition_atmosphere/aerosol/cont_nav/particle_size_distribution_node.html

distributions of the particle number concentration $dN/d\log r$ or $dN/D\ln r$ respective the particle surface- and volume-concentration:

$$\frac{dN}{d\ln r_p} = \frac{N_g}{\sqrt{2\pi} \ln \sigma_g} \exp \left[-\frac{(\ln r_p - \ln r_g)^2}{2(\ln \sigma_g)^2} \right]$$

with the geometric mode radius r_g and the mode width σ_g ($\sigma_g \approx 1.2 - 2$). In the troposphere the envelope of the modal PSD often can be approximated by a power law number size-distribution $N(r) \sim r^{-2 \dots -4}$ (Junge-distribution), but near sources and sinks it will in general be quite different. Often, volume- or mass size-distributions are used to highlight specific details of the size spectrum ($dV/d\log r = dN/d\log r * 4\pi r^3/3$ or $dM/d\log r = dN/d\log r * 4\pi r^3/3$, with density ρ)."

The nanoparticles aggregate due to dangling bonds. In chemistry, a dangling bond is an unsatisfied valence on an immobilized atom. An atom with a dangling bond is also referred to as an immobilized free radical or an immobilized radical, a reference to its structural and chemical similarity to a free radical. In order to gain enough electrons to fill their valence shells (see also octet rule), many atoms will form covalent bonds with other atoms. In the simplest case, that of a single bond, two atoms each contribute one unpaired electron, and the resulting pair of electrons is shared between them. Atoms which possess too few bonding partners to satisfy their valences, and which possess unpaired electrons are termed "free radicals"; so, often, are molecules containing such atoms. When a free radical exists in an immobilized environment (for example, a solid), it is referred to as an "immobilized free radical" or a "dangling bond".

Both free and immobilized radicals display very different chemical characteristics from atoms and molecules containing only complete bonds. Generally, they are extremely reactive. Immobilized free radicals, like their mobile counterparts, are highly unstable, but they gain some kinetic stability because of limited mobility and steric hindrance. While free radicals are usually short lived, immobilized free radicals often exhibit a longer lifetime because of this reduction in reactivity.

A1. TOXICITY OF NANOPARTICLES

As per Wikipedia regarding Nanotoxicology⁹, which is applicable to the SepaRaptor technology:

"Nanomaterials appear to have toxicity effects that are unusual and not seen with larger particles, and these smaller particles can pose more of a threat to the human body due to their ability to move with a much higher level of freedom while the body is designed to attack larger particles rather than those of the nanoscale¹⁰. For example, even inert elements like gold become highly active at nanometer dimensions. Nanotoxicological studies are intended to determine whether and

⁹ https://en.wikipedia.org/wiki/Nanotoxicology#cite_note-9

¹⁰ Sukhanova, Alyona; Bozrova, Svetlana; Sokolov, Pavel; Berestovoy, Mikhail; Karaulov, Alexander; Nabiev, Igor (2018-02-07). "Dependence of Nanoparticle Toxicity on Their Physical and Chemical Properties". *Nanoscale Research Letters*. 13 (1): 44

to what extent these properties may pose a threat to the environment and to human beings¹¹. Nanoparticles have much larger surface area to unit mass ratios which in some cases may lead to greater pro-inflammatory effects in, for example, lung tissue. In addition, some nanoparticles seem to be able to translocate from their site of deposition to distant sites such as the blood and the brain.

Nanoparticles can be inhaled, swallowed, absorbed through skin and deliberately or accidentally injected during medical procedures. They might be accidentally or inadvertently released from materials implanted into living tissue^{12,13,14}. One study considers release of airborne engineered nanoparticles at workplaces, and associated worker exposure from various production and handling activities, to be very probable¹⁵."

¹¹ Sukhanova, Alyona; Bozrova, Svetlana; Sokolov, Pavel; Berestovoy, Mikhail; Karaulov, Alexander; Nabiev, Igor (2018-02-07). "Dependence of Nanoparticle Toxicity on Their Physical and Chemical Properties". *Nanoscale Research Letters*. 13 (1): 44

¹² Oberdörster, Günter; Maynard, Andrew; Donaldson, Ken; Castranova, Vincent; Fitzpatrick, Julie; Ausman, Kevin; Carter, Janet; Karn, Barbara; Kreyling, Wolfgang (October 2005). "Principles for characterizing the potential human health effects from exposure to nanomaterials: elements of a screening strategy". *Particle and Fibre Toxicology*. 2: 8

¹³ Hoet, Peter HM; Bröske-Hohlfeld, Irene; Salata, Oleg V. (December 2004). "Nanoparticles - known and unknown health risks". *Journal of Nanobiotechnology*. 2 (1): 12

¹⁴ Oberdörster, Günter; Oberdörster, Eva; Oberdörster, Jan (July 2005). "Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles". *Environmental Health Perspectives*. 113 (7): 823–39

¹⁵ Ding, Yaobo; Kuhlbusch, Thomas A.J.; Tongeren, Martie Van; Jiménez, Araceli Sánchez; Tuinman, Ilse; Chen, Rui; Alvarez, Iñigo Larraza; Mikolajczyk, Urszula; Nickel, Carmen (January 2017). "Airborne engineered nanomaterials in the workplace-a review of release and worker exposure during nanomaterial production and handling processes". *Journal of Hazardous Materials*. 322 (Pt A): 17–28.

APPENDIX B: SAFETY PROTOCOLS EXPECTED FROM CALMAC'S CONTRACTORS – MANAGING CONTRACTORS PROCESS

CalMac safety protocol internal document follows overleaf.

Management of Contractors on CFL Operated Shore Locations

Process

Rev No. and Date	Description of Revision	Approved by	Authorised by
Rev 0 28/10/20	Final draft – for release	HSQE Manager	HSQE Director
Rev 1 November 2021	Review and amend for inclusion in HSE Manual	HSQE Manager	HSQE Director

1. Introduction

CalMac Ferries Ltd. (the Company) recognises its moral responsibility and legal duty under the Health and Safety at Work Act 1974 to ensure the health, safety and welfare of all employees and any other person involved in and affected by its shore operations. This includes contractors and sub-contractors ("Contractors").

As part of this general commitment and specifically in relation to Contractors, in compliance with The Management of Health and Safety at Work Regulations 1999 (the Management Regulations) the company will ensure consideration is given to Contractors when undertaking:

- Risk assessments;
- Setting up emergency procedures;
- Co-operating with others, including other employers, on health and safety matters;
- Providing health and safety information.

To ensure compliance with the relevant legal and contractual obligations the Company will:

- Ensure a structured approach to health, safety and welfare for duties and activities which are undertaken by Contractors at CFL operated ports, including any other shoreside locations at which CFL retain responsibility for certain or specific operations.
- Ensure that adequate information is provided to all Contractors.
- Ensure that all hazards that could affect Contractor's personnel are clearly defined and controlled.
- Ensure that the interests of company operations, staff, customers, site users, visitors and the environment are protected before and during any work carried out by Contractors.

This process sets out the arrangements in place for the safe management of Contractor activity and provides guidance on the preparation for site visits and undertaking Contractor Induction.

To ensure that all work undertaken by outside contractors is carried out safely, with the minimum interference to the company's operations, having regard to relevant statutory requirements and company standards, and with the minimum impact on the environment.

This process defines Responsible Managers as any person with managerial or supervisory responsibility for a department, location, site, activity or number of colleagues.

For work on shore the term Responsible Manager includes but is not exclusive to Line Manager, Harbour Manager, Port Manager, Harbour Supervisor and Port Supervisor as appropriate.

Guidance in support of this process are available from the HSE Manual on the Company Management System.

2. Scope

This process applies to all contractors engaged by any party to carry out work at all CFL operated ports, including any other shoreside locations at which CFL retain responsibility for certain or specific operations.

This process is also applicable for any planned work being undertaken by any 3rd Party when the work being undertaken may have an impact upon CFL operations.

This process is applicable from the planning stage through to completion of all work.

2.1 Exceptions

This process is applicable for Contractors working on vessels – but only specifically to any direct interaction with shoreside and/or harbour operations. Work onboard vessels that has no direct impact on or places any risk upon the shoreside and/or harbour operations is not in scope. See further detail in section 3.1.2.

Specific arrangements for the management of commercial diving contractors can be found within the Diving section of the HSE Manual. Detailed within are all relevant information, guidance and necessary forms.

3. Responsibility

3.1 All persons responsible for engaging contractors (the Client)

Must ensure that the designated contractor is competent to carry out the required works safely and in compliance with relevant statutory requirements and company standards.

The person engaging the contractor (the Client) must liaise with and involve the Responsible Manager in the planning of any contractor works or activities that may directly affect the operation of the port, shore or harbour areas and shall provide the Responsible Manager with copies of the Contractor RAMS a minimum of **four** days in advance of the proposed work.

The Responsible Manager will require additional advance notice for significant works and works with the potential to seriously disrupt operations.

In certain cases, primarily with critical or emergency works it may not be possible to produce RAMS within the required time period. In this case prior agreement must be reached with the Responsible Manager and RAMS must be provided regardless, prior to any works commencing on site, with the Responsible Manager afforded necessary time to review and comment as applicable.

Where the Client is CMAL, RAMS shall be submitted by CMAL and the Port Diary updated by CMAL (noting the date and timescale of works and the relevant RAMS reference) using the CMAL IT reporting system (SharePoint).

Where the Client is CFL, support and guidance in relation to the appointment of contractors may be sought from the CFL Procurement Dept.

3.1.1 Contractor RAMS

In this context, 'Contractor RAMS' shall include appropriate Risk Assessment & Method Statements but may also include other appropriate documentation such as: Contractors programme, scope of works, insurances, drawings, contact details, Construction Phase Health & Safety Plan and so on.

3.1.2 Work onboard Vessels

The process as defined in *Section 1 – Vessel Safe Working Practices* of the HSE Manual, in the CMS, will apply for the management of contractors onboard CFL Ferries.

However, in all circumstances the Port Manager must be provided with sufficient details in order to evaluate the interaction with shoreside and/or harbour operations and ensure necessary controls are implemented. In this case the Port Manager will undertake the relevant responsibilities as defined for The Responsible Manager in Section 3.2.

Contractors intending to work on board a vessel at berth in a CFL Operated Harbour, must report to the Responsible Manager at the Port in the first instance.

The Responsible Manager at the Port will:

- Contact the vessel to confirm that they are expecting the contractor;
- Finalise and confirm the proposed work;
- Confirm all shore side safety, environmental, security and operational factors are suitably managed, where appropriate;
- Issue the contractor identification badge, where appropriate;
- Confirm site opening times and availability of parking and storage;
- Collect identity badges at the end of each working day, as appropriate.

The vessel Master/Skipper is responsible for managing all contractors aboard the vessel and will delegate a responsible person to manage the contractor, whilst onboard, as appropriate.

3.1.3 Work being undertaken at locations not directly within CFL responsibility but where CFL may be impacted in some way

The Port Manager must be made aware of the planned works and provided with sufficient details in order to evaluate the interaction with shoreside operations and ensure necessary controls are implemented. In this case the Port Manager will undertake the responsibilities as detailed in step 3.2.

3.2 The Responsible Manager

Has overall responsibility for the management of Contractor operations to ensure the work is carried out safely, with the minimum interference to the company's operations, having regard to relevant statutory requirements and company standards, and with the minimum impact on the environment.

The Responsible Manager will review the provided information, and shall provide the following response to the Client and/or Contractor (dependant on the specific circumstances):

1. Advise where the planned works will or may affect ferry, port or harbour operations and raise any issues and concerns.
2. Provide information on known operational hazards and risks with the potential to affect the contractor works.

The Responsible Manager shall provide such review/comments to the contractor direct or via the Client, as appropriate.

The Responsible Manager shall NOT comment on the methods of work proposed by the Contractor, unless they have specific concerns that the proposed method of work is clearly unsafe and/or will have direct impact on the shore, port or harbour operations.

Specifically, for work at harbours or within operated facilities which are operated by CFL on behalf of CMAL the [HOM – Contractor RAMS Process](#) should be referenced by the Responsible Manager for detailed instruction relating to:

1. Review of RAMS provided by CMAL;
2. Review and Upload of RAMS provided by any other Client than CMAL;
3. The update of the CMAL SharePoint Port Diary by the Responsible Manager.

4. Process

4.1 The process starts with a decision to carry out work which is defined in Scope above.

- 4.2 Initial discussion must be undertaken between the person engaging the contractor (the Client) and the Responsible Manager to ensure clarity and understanding of on-site requirements. In relation to Vessel work this will also include the Port Manager.
- 4.3 Contractor RAMS will be provided for review, with all relevant feedback given by the Responsible Manager (as per the requirements detailed in Section 3 Responsibilities).
- 4.4 Start date and time for commencement of work must be agreed in advance.
- 4.5 All contractors arriving at site must report to the Responsible Manager prior to the commencement of any works and **every day** thereafter, or at an agreed interval. Agreed interval to be documented within the formal **Contractor Site Induction**.
- 4.6 Using the Contractor Port Induction Form 2.348 the responsible manager will conduct a Site Induction with the contractor to;
- a) Finalise and confirm the proposed work;
 - b) Confirm all safety, environmental, security and operational factors are suitably managed;
 - c) Issue the contractor identification badge;
 - d) Issue the **Rules and Conditions for Contractors on Site**;
 - e) Confirm any additional site information on operational hazards and risks with the potential to affect the contractor works;
 - f) Provide details of emergency contact and arrangements; including local first aid provision;
 - g) Provide details of available site services and welfare facilities;
 - h) Confirm site opening times and availability of parking and storage;
 - i) Complete the relevant **Permits to Work**;
 - j) Provide details on collection of identity badges at the end of each working day.
- 4.7 Where face to face site meetings are not possible owing to logistics, operational constraints and/or any restrictions in force the Client, Contractor and Responsible Manager shall agree methods for ensuring that necessary Site Inductions and Permits to Work (as described in 4.6 above) are still completed in line with contingencies in place. The contractors work shall not proceed until the necessary elements are undertaken with completed records in place.
- 4.8 The Responsible Managers will only allow contractor employees on site on the successful completion of all aspects of the Site Induction.
- 4.9 The Responsible Manager will monitor the contractor at regular intervals, as deemed appropriate by the manager, to ensure the contractor follows the agreed working methods.
- 4.10 The Responsible Manager retains the right to stop work and/or remove contractors from site, where in their opinion, an act or omission by the contractor has the potential to cause injury, damage to property, environmental impact or unplanned disruption to operations.
- 4.11 In the event of unacceptable performance or behaviour, the contractor or individual employees may be removed from site.
- 4.12 Such events of stopping work or removal of a contractor from site must be reported by the Responsible Manager to the Client, in addition to any such incident or near miss PURE reporting.
- 4.13 The Responsible Manager has access to support, guidance and information on all aspects of managing contractors at ports or within shore facilities from;

- CMS HSE Manual;
- HSQE;
- Harbour Operations Department.

APPENDIX C - CALMAC'S PROCEDURES AS DESCRIBED IN INTERNAL DOCUMENT "VESSEL OPERATIONS MANUAL; VESSEL INSPECTION, MAINTENANCE & OVERHAUL – CONTROL OF CONTRACTORS" (PROCEDURE VOM 06.03)

CalMac vessel inspection, maintenance & overhaul internal document follows overleaf.

VESSEL OPERATIONS MANUAL**VESSEL INSPECTION, MAINTENANCE & OVERHAUL - CONTROL OF CONTRACTORS**

Issued by: Head of Technical Operations

Procedure: VOM 06.03

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SCOPE

This Procedure describes the requirements for the control of contractors on-board managed vessels.

RESPONSIBILITIES

1. Responsibility for review of this procedure rests with the Head of Technical Operations, Head of Engineering Performance & Policy and Head of Marine. in consultation with Marine Managers, Technical Managers and Superintendents. The responsibilities of shipboard personnel are itemised where appropriate throughout the text.
2. Notwithstanding paragraph 1 above, all personnel have a responsibility to use this procedure critically and to forward any suggestions for its improvement to the Company through the Master.
3. This procedure affects the following personnel. Their responsibilities and authority are defined within the text.

Master
Skipper
Engineer Officers
Deck Officers
Technical Operations – Technical Managers or Superintendents
Marine Managers

QUALITY RECORDS

1. Contractor Risk Assessments
2. Contractor Method Statements
3. Purchase Orders
4. Job Instruction Sheets
5. Planned Maintenance Records
6. Contractor Insurance Certificates
7. Permits to Work
8. Safety Induction records
9. Near Miss Reports
10. Accident Reports
11. Hours of Work Records



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1.00 CONTROL OF CONTRACTORS WORKING ONBOARD

- 1.01 This procedure details the Company requirements for any and all contractors undertaking work on board Company vessels, where their work activities could potentially cause harm to themselves, others, property, or the environment. If Shore Support engineers require to work onboard vessels, then this activity is controlled by Procedure VOM 06.07.
- 1.02 This procedure places a requirement on contractors to provide risk assessments and method statements for the work they are to perform. Contractors need to be made aware of these requirements to give them sufficient time to provide the necessary documentation before work starts.
- 1.03 The requirement for risk assessments and method statements shall be included in purchase orders placed on contractors and also progressively populated on the job instruction sheet in the planned maintenance system where there is a requirement for contractor assistance to carry out the works.
- 1.04 Contractors should only be arranged to attend vessels when there is a company representative in attendance.
- 1.05 These procedures apply to non-crew personnel carrying out:
- Investigatory work;
 - Installation;
 - Testing;
 - Commissioning;
 - Repair; and
 - Maintenance activities.
- 1.06 This procedure applies when non-crew personnel are working:
- On board Company operated vessels, in service, alongside, slipped or in dry dock;
 - On behalf of owners.
- 1.07 It does not apply to:
- Diving operations - which are covered by separate instructions in the Company Management System;
 - To shipyard workers working on board vessels when slipped, or in dry dock.
- 1.08 Shore Support engineers are expected to carry out their work in accordance with the relevant Company Management System instructions as applicable to the vessel they are visiting.
- 1.09 If in doubt as to applicability, please contact the vessels Technical Manager or Superintendent for advice.



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2.00 COMPANY REPRESENTATIVE

2.01 Whenever non-crew personnel are working on board a Company vessel there shall be a Company Representative present to co-ordinate the work, and to ensure that non-crew personnel are given an appropriate safety brief.

2.02 Company Representatives can be:

- Vessel Masters, Skippers, Chief Engineers, Heads of Departments or SF Motorman;
- Technical or Marine Managers;
- Technical Superintendents;



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3.00 RISK ASSESSMENTS AND METHOD STATEMENTS

- 3.01 A safe system of work shall be adopted before each work activity commences; the following action shall be taken:
- Risk Assessments shall be carried out to identify hazards, assess risk, and introduce any necessary control measures by the contractor Company Representative;
 - A Method Statement shall be compiled by the contractor detailing any control measures will be implemented, and how the work activity will be accomplished.
- 3.02 Contractor Risk Assessments, Method Statements and Insurance Certificates shall be submitted prior to work commencing to the relevant vessel Master / Skipper, or Company Representative, for his/her formal approval. These documents should normally be submitted at least 48 hours prior to commencement of work but in any case, shall be submitted in sufficient time for formal approval to be given. No work shall take place until such formal approval has been given. The relevant Marine Manager, Technical Manager or Superintendent, Project Manager and HSQE Department shall be copied in on the documentation and the approval email.
- 3.03 Any concerns highlighted with contractors' risk assessments and method statements should first be discussed with the Technical Manager or Superintendent or Marine Manager. The HSQE Department remain available for advice should the vessel be concerned with any matters regarding safety and safe system of work.



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4.00 PERMIT TO WORK (PTW)

- 4.01 The Master/Skipper and/or Company Representative, is responsible for ensuring that risk assessments are carried out, and that any PTW Permits to Work are processed correctly.
- 4.02 Contractors may have their own PTW system. This does not remove the requirement for issuing a Company PTW. Both permits can refer to and inform the other, with the Company PTW taking precedence.
- 4.03 Further guidance of the company PTW requirements may be found in Procedure VOM 02.03.



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5.00 SUPERVISION OF CONTRACTORS

- 5.01 The activities of all contractors shall be closely monitored by the Master/Skipper and/or the Company Representative.
- 5.02 For the avoidance of doubt, the Master/Skipper is legally responsible for the safety of all on board.
- 5.03 The contractors should be given single nominated contact on board, normally the Master/Skipper / senior officer through which all requests for assistance should be communicated. In the absence of the Master/Skipper/senior officer, this should be the Company Representative.



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6.00 SAFETY INDUCTION

- 6.01 All contractors shall report to the Master/Skipper and/or the Company Representative, on arrival. All contractors are to attend a vessel safety brief/induction prior to commencing work. The safety induction shall be recorded on Form 2.125.
- 6.02 The safety induction should highlight the hazards that the contractor might be exposed to, whilst on board, and informed as to what control measures are to be implemented.



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7.00 PERSONAL PROTECTIVE EQUIPMENT (PPE)

- 7.01 When a requirement to use PPE has been identified, the PPE shall be provided, and shall be worn without exception. Contractors are expected to provide their own PPE.



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8.00 ACCIDENT AND NEAR MISS REPORTING

- 8.01 Accidents and near misses involving contractors working on board Company vessels shall be reported in the same way as incidents involving the vessel's crew, and using the same Company forms. Crew Accident forms shall be clearly annotated that the accident occurred to a contractor.



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9.00 MEETINGS

9.01 A start-up meeting shall be held before work commences on the vessel. A Plan of the Day meeting shall be held daily to discuss progress. These meetings shall be attended by the vessel Master/Skipper and/or the Company Representative and the contractor's site supervisor. Standing agenda items shall include the following:

- Permits to Work
- Other work activities occurring that may affect the contractor's work
- Potential for disruption of services and/or operations
- Newly identified hazards, and mitigation

9.02 The above list is not exhaustive



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10.00 WORKING OUT OF HOURS

- 10.01 When it is necessary for non-crew personnel to work out of normal working hours, their work activities should be monitored by the Master/Skipper and/or the Company Representative. Where the monitoring of the work activities would lead to potential breaches of the Hours of Rest regulations, then the Marine Manager shall be informed at the earliest opportunity in order that additional manning can be arranged.



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11.0 SECURITY

- 11.1 Contractors shall carry passes and photo ID with them when visiting Company sites and attending vessels.

