



Retrofitting towards climate neutrality

D4.4 Fourth report: End System Requirements & KPI's

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1.1	[21/11/2025], [13-16/01/2026]	Inputs from partners
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DETAILS	
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1. INTRODUCTION

This document is deliverable “D4.4 – Fourth 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 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 (such as cruiseships) allowing air-reuse saving energy for HVAC systems and operated as pre-treatment enhancing a membrane carbon capture process. For MV Coruisk, the Separaptor with UV technology will be tested in the ventilation system of the vessel. The Ca/Mg – alkali solvent capture process is capable of removing 75% of the CO₂ from flue gases. All solutions will be 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.

1.2 DOCUMENT STRUCTURE

§2 describes the KPIs and End System Requirements related to:

- WP3 - Solutions development and scale-up;
- WP2 - Land based testing and integration of solutions;
- WP4 - KPIs, Integration, TEA, SEA, LCA, Risk, Safety, in particular to the LCA analyses;
- WP5 - Software tool catalogue for GHG-emission reduction solutions;
- WP1 - Demonstrate retrofitting of existing fleets.

§3 presents the conclusions of this report.

2. GREEN MARINE END SYSTEM REQUIREMENTS AND CURRENT KPIS

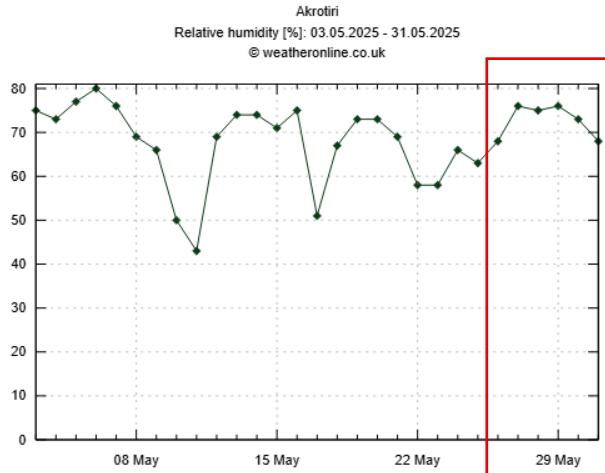
Note that UoS, UPM & CalMac confirmed no changes to the KPIS reported in D4.3.

CMMI has updated the land based WP2 KPIS based on the mapping of the engine done May - June 2025 (M28 – M29). The full spectrum of results of the mapping of the engine will be provided in D2.4 “Summary report of results of land-based testing” to be submitted on M42, along with the results and assessments of the abatement systems (carbon capture via chemical absorption, carbon capture via membrane separation and waste heat recovery using the TEE).

CCM, SINTEF, SMP/WPS, BX, and PDM have provided input, thus a summary of the main KPIS of the Green Marine project extracted from this report is shown below. In this report only the table of KPIS will be presented, for detailed information on technologies the reader is referred to D4.3 “Third report: End System Requirements & KPIS” submitted on M18.

2.1. FLUE GAS COMPOSITION – WP2 LAND BASED

<i>Entry</i>	<i>Demand / requirement</i>	<i>Unit</i>	<i>Average value</i>	<i>Minimum value</i>	<i>Maximum value</i>
1.1	<i>Land Based test site WP2 – KPIS based full mapping of the engine from 10 kW to 120 kW load without abatement system</i>				
1.1.1	Flue gas flow	kg/hr	1030.06	934.61	1147.50
1.1.2	Exhaust temperature	°C	286.3	169.71	391.79
1.1.3	CO ₂ concentration	% vol.	4.84%	3.02%	6.73%
1.1.4	Flue gas flow provided for testing to be provided after the bypass valve	Nm ³ /hr	869.42	794.98	953.89
1.1.5	Load bank – resistive	kW	Not applicable	10	120
1.1.6	CO ₂ capture rate goal* (To be determined in D2.4)	%	To be determined	35%	To be determined
1.1.7	Flue gas composition apart from CO ₂ measured prior to the entry of gases into the abatement system	% vol. ppm	CO: 138.29 ppm NO _x : 623.47 ppm O ₂ : 16 % vol. CxHy: 1241.61 ppm SO _x : n/a present only at low loads (up to 20 kW) N ₂ : 81.71% vol.	CO: 109.05 ppm NO _x : 168.14 ppm O ₂ : 16 % vol. CxHy: 237.69 ppm SO _x : 4.44 ppm N ₂ : 80.96% vol.	CO: 182.89 ppm NO _x : 1018.03 ppm O ₂ : 16 % vol. CxHy: 1516.22 ppm SO _x : 4.86 ppm N ₂ : 82.32% vol.

1.1.8	Water content in flue gas. Relative humidity on May – June 2025 in Limassol – red box indicates relative humidity during test runs.	 (Ref: https://www.weatheronline.co.uk/weather/maps/city)			
1.1.9	Engine Specs	155 kW engine, 8.3 lt displacement, 6 cylinder turbocharged and aftercooled.			
1.1.10	Engine backpressure range according to manufacturer	kPa	Not applicable	5.0	10.1

2.2. FLUE GAS COMPOSITION – WP1 ON-BOARD DEMONSTRATIONS

Entry	Demand / requirement	Unit	Average value	Minimum value	Maximum value
1.2	Onboard MV Coruisk – WP1 demonstrations				
1.2.1	Flue gas flow*	kg/hr	Not applicable	640	660
1.2.2	Exhaust temperature	°C	Depends on engine load	360	450
1.2.3	CO ₂ concentration	% vol.	Depends on engine load	7%	9%
1.2.4	Flue gas flow provided for testing	Nm ³ /hr	Not applicable	50	150
1.2.5	Engine load	% of rated engine power	To be determined during demonstrations	65%	80%
1.2.6	CO ₂ capture rate goal	%	To be determined	35%	To be determined
1.2.7	Impurities in flue gas	ppm	To be determined during demonstrations (depends on engine load)	To be determined during demonstrations (depends on engine load)	To be determined during demonstrations (depends on engine load)
1.2.8	Water content in flue gas	% vol.	To be determined during testing (depends on	3%	10%

			weather conditions)		
1.2.9	Engine specs	164 kW engine, 8.3 lt displacement, 6 cylinder turbocharged and aftercooled			
1.2.10	Maximum backpressure in the engine	kPa	Not applicable	0.0	10.1

* To be revised/confirmed in the final version of this report.

2.3. CARBON CAPTURE MACHINE

<i>Entry</i>	<i>Demand / requirement</i>	<i>Unit</i>	<i>Average value</i>	<i>Minimum value</i>	<i>Maximum value</i>
2.1	CCM – CO₂ capture				
2.1.1	CO ₂ removal from flue -gas	%	>50%**	>35%	
2.1.2	Operating range heat-exchanger: flue-gas engine to CCM unit	°C	25	25	180
2.1.3	CO ₂ conversion rate	%	>85%**		
2.1.4	Carbon capture rate	Kg/hour	1 kton/year	60	120
2.1.5	Power consumption	KWh/m. t. CO ₂	5	3	7
2.1.6	Flue gas flow	Nm ³ /hr		10	150
2.2	CCM – physical attributes				
2.2.1	Dimensions – capture unit	m		2x1 m	
2.2.2	Weight–capture unit	kg		540	
2.2.3	Operating temperature	°C		-10	65
2.2.4	Dimensions – Chemicals storage unit	cm		45x55 cm	
2.2.5	Weight – Chemicals storage unit	kg		14	
2.2.6	Dimensions – Product storage unit	cm		45x55 cm	
2.2.7	Weight – Product storage unit	kg	39	14	64

** target value

2.4. SEPARAPTOR

<i>Entry</i>	<i>Demand / requirement</i>	<i>Unit</i>	<i>Average value</i>	<i>Minimum value</i>	<i>Maximum value</i>
3.1	SepaRaptor with UV in ventilation system Coruisk				
3.1.1	Air filter used in Coruisk	Standard Euro 4 dust/dirt filter to prevent outdoor foreign contaminants			
3.1.2	Particle Efficiency removal SepaRaptor	%	Not applicable	>90% nanoparticles	>99.9% viruses >99.99%

				>95% aerosols, viruses	
3.1.3	HVAC energy savings (air reuse increase). Pressure drop in the HVAC system	%	50 <1%	The vessel has an open loop system. Ventilation system not HVAC. KPI's are not applicable	
3.1.4	Dimensions	mm	900 x 175 x 165		
3.1.5	Weight	kg	8.4		
3.1.6	Temperature	°C		5	65
3.1.7	Humidity range	%		5	99.9
3.1.8	Flow rate of ambient air	m³/h		1	> 1000
3.1.9	Exposure time for UV to be effective	s	TBD	TBD	TBD
3.1.10	Power supply / Input power	V, A		12 V and 12 A, 100 – 240 V, 50/60 Hz 1.4 A	
3.1.11	Power draw	W		15	
3.2	SepaRaptor – flue-gas CO ₂ capture				
3.2.1	Flow rate of flue gas	Nm³/hr		50	150
3.2.2	Particle Efficiency removal SepaRaptor	%	>80%		
3.2.3	Dimensions	mm	556 x 275 x 200		
3.2.4	Weight	kg	15.0		
3.2.5	Temperature	°C		5	65
3.2.6	Humidity range	%		5	99.9
3.2.7	Power supply / Input power	V, A		100 – 240 V, 50/60 Hz 1.4 A / 12 V; 2 A	
3.2.8	Power draw	W		15	

2.5. MEMBRANES

Entry	Demand / requirement	Unit	Average value	Minimum value	Maximum value
4.1	Membranes				
4.1.1	CO ₂ capture rate	%		>35%	>90% (in theory)
4.1.2	CO ₂ product purity	%		>40%	
4.1.3	CO ₂ concentration diesel exhaust	Vol%(dry)	5	3	8
4.1.4	Specific compressor duty	MJ/kg CO ₂		To be determined during WP2 tests	To be determined during WP2 tests
4.1.5	Specific membrane area	m ²	1	1	20
4.1.6	Membrane module dimensions (depends on final membrane area; see 4.1.5)	mm	Length 500 to 1000, diameter 100 to 200		
4.1.7	Weight of membrane module	kg	4 to 12		
4.1.8	Retentate pressure	kPa	130		

4.1.9	Permeate pressure	kPa	5 to 25		
4.1.10	Permeate flow rate	m³(STP)/hr	to be determined during land based testing		
4.1.11	Temperature of cooling water	°C	25-40		
4.1.12	Temperature vacuum pump exit	°C	< 100		
Parameters of flue gas conditioning skid					
4.1.13	Weight - Water cooler (empty/filled)	kg	(32/35)		
4.1.14	Dimensions – Water cooler	Mm	420 x 180 x 480		
4.1.15	Weight - Freshwater circulation pump	kg	to be determined		
4.1.16	Weight - FG cooler (empty/filled)	kg	(100/115) Cooling skid w/water glycol media		
4.1.17	Dimensions – FG cooler	mm	1800 x 800 x 1000		
Flue gas fan					
4.1.18	Weight	kg	53		
4.1.19	Dimensions	mm	528 x 656 x 420		
4.1.20	Operating temperature	°C	55		
4.1.21	Membrane-based CO ₂ capture unit				
4.1.22	Weight - Membrane module	kg	4-10		
4.1.23	Weight - Total unit	kg	250 (pilot skid w/flue gas connection)		
4.1.24	Weight – vacuum pump	kg	15		
4.1.25	Dimensions – vacuum pump	mm	198 x 328 x 243		
4.1.26	Temperature	°C		15	60
4.1.27	Humidity range	%		50	100%
4.1.28	Flow rate of flue gas	Nm³/h		5	150
4.1.29	Permeate flow (required to determine analytical equipment)	Liter/hour		1 % of feed	10% of feed
4.1.30	Power supply / Input power for industrial fan	V, A		3 phase, 400V 50 Hz max 1 A	
4.1.31	Power supply / Input power for control systems and vacuum pump	V,A		Residential 200-230V/50/60Hz max 2.5 A	
4.1.32	Power draw	W		To be determined	< 7 kW

2.6. THERMO ELECTRIC ELEMENT (TEE)

Entry	Demand / requirement	Unit	Average value	Minimum value	Maximum value
5.1	TEE				
5.1.1	Number of TEE elements	Number	625		
5.1.2	Dimensions	mm	781 x 510 x 1160		
5.1.3	Weight	kg	110		
5.1.4	Temperature range coolant (direct)	°C	T _{in} = 95	75	99

5.1.5	Temperature range fluegas (indirect)	°C	T _{in} = 105	45	105
5.1.6	Thermal conversion efficiency	%	Up to 8		
5.1.7	Humidity range	%		5	99
5.1.8	Flow rate of coolant	m ³ /h	TBC	6.6	10.2
5.1.9	Power output	V		24 V DC	
5.1.10	Power generation	W	TBC	500	1500

2.7. SOFTWARE TOOL CATALOGUE

Entry	Demand / requirement	Unit	Average value	Minimum value	Maximum value
6.1	Software framework				
6.1.1	Opensource user friendly GUI with multiple visual interfaces. Approval rate from end user feedback	%		>80	
6.1.2	Development of high quality technical documentation. Approval rate from end user feedback Measurement of users ability to perform tasks after reading the documentation	%		>80 >70	
6.1.3	Approval rate from end user feedback (time spent on site and number of clicks)	Number of clicks and min.	Visit: 3, time: <10min, average clicks: < 30 Visit: 5, time: <5min, average clicks: < 20 Visit: 10, time: <2min, average clicks: < 15		
6.1.4	Organisation management configuration & administration features. Approval rate from Organisation Administrators configuration and features from user feedback	%		> 80%	
6.1.5	Usage of functionalities regarding Organisation management configuration & administration by Organisation Administrators	%		>70%	
6.1.6	Target uptime	%		M37-39: 90%	

				M40-48: 95%	
6.1.7	Simulations per month	Number		M37-39: 60 M40-42: 120 M43-48: 200	
6.1.8	Use case definition	Number		50 user stories 100 technical requirements	

3. CONCLUSIONS

The fourth version of this report is to document the necessary End System Requirements and KPIs under deliverable D4.4 of WP4 due on M36. This deliverable is a follow up of the first, second and third versions of D4.1 “First report: End System Requirements & KPI’s” (M1), D4.2 “Second report: End System Requirements & KPI’s” (M6) and D4.3 “Third report: End System Requirements & KPI’s” (M18). This document was 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)

This report is scheduled to be updated on 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.