Retrofitting towards climate neutrality

D6.5a First Exploitation Report

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Acronym Table	
CCM	Carbon Capture Machine
CCUS	Carbon Capture, Utilisation and Storage
CO_2	Carbon Dioxide
CRL	Commercial Readiness Level
HVAC	Heating, Ventilating and Air conditioning
IP	Intellectual Property
IPR	Intellectual Property Rights
IRR	Internal Rate of Return
NPV	Net Present Value
ROI	Return on Investment
TEE	Thermoelectric element
TRL	Technical Readiness Level
WP	Work Package
WPS	Wind Plus Sonne
W2E	Waste-to-Energy

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Executive Summary

This document is deliverable "D6.5a First Exploitation Report" 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 a summary of the exploitation strategies on a per technological solution route basis. More specifically, four innovation routes are distinguished:

- Carbon Capture Route (led by CCM)
- Air Ventilation Route (led by SMP)
- Thermoelectric Element Route (led by SMP)
- Software Catalogue Route (led by PDM)

The deliverable mainly targets the physical and software technology providers of the consortium. The goal is to provide a rigorous basis for research and development activities and to further guide technological development by revealing the probable exploitation plans of the respective innovation routes. The deliverable is a public one and as such it also aims to bring clarity to the general public regarding the key exploitable results stemming from the Green Marine project.

The report provides an overview of the exploitation outlooks of all Green Marine technologies and a list of the exploitation outputs. It then drafts the scope of the ensuing exploitation assessments and differentiates between four different exploitation roadmaps. Based on the information collected so far, only one exploitation route is described in sufficient detail in this 1st exploitation report - the air ventilation route. Yet, the potential of all four routes is evaluated and data collection activities have been commenced.

Ultimately, it is crucial to note that this deliverable is understood to be a "living" document and as such – results are not definite even within the project scope. The deliverable is scheduled to be updated and submitted in month 24 (Second Exploitation Report – D6.11) and month 47 (Third Exploitation Report – D6.12) with information continuously generated by the project. The current version of this deliverable, is at a very preliminary stage in many sections such as the TEE, CCM and software catalogue, due to the ongoing development and scale-up activities of the various Green Marine technologies under WP3.

1. INTRODUCTION

1.1. PROJECT DESCRIPTION

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 CO_2 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 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.

1.2. CONSORTIA HIGHLIGHTS

The consortium as a whole is formed by 10 partners from 7 different countries, including 4 research organisations, 1 industrial End User (Ferry line operator), 5 SMEs (of which 3 are technology providers, 2 service providers). With a majority of the participants being technology providers and end users – in addition to a pronounced research component – a strong industrial push/pull is clearly demonstrated. Green Marine covers a vast area in Europe from geographical, economic and regulation point of view, including participation from South Europe (Portugal, Italy, Cyprus), Central Europe (Germany, The Netherlands) and Northern Europe (Norway), and the United Kingdom. The consortium also covers the whole value chain of innovation from technology providers (creators and manufacturers), ships (end users), research centers for analytics and testing, software building and technical services. Key aspects supporting the exploitation activities are, amongst others, the operation of a fleet of approximately 35 vessels across the west side of Scotland by CalMac and the available and ready for scale-up inhouse manufacturing capabilities of SMP.

1.3. PURPOSE OF THE DOCUMENT

The objectives of "D6.5a – 1st Exploitation Report" are to:

- Identify key exploitable project outputs and translate them into innovation routes.
- Outline an exploitation roadmap for the two most promising innovation routes. The roadmap must consist of:

    - Business model
    - Financing plan
    - IP management strategy
- Devise the overall strategy for the joint exploitation of results by the different partners and the consortium as a whole.

These are carefully aligned with the objectives of WP6, which are:

- Implement the strategy for knowledge and IPR management and protection.
- Develop the business models and business plans for commercializing the technologies after the project period.
- Disseminate project results, initiate joint activities and increase CCUS awareness and readiness.

The aim of the ensuing exploitation strategy is to ensure the uptake of project results by a maximum of concerned stakeholders. The overall methodology of this report is presented on Figure 1. It is a stepwise approach aimed at gradually reducing the scope to only the most economically feasible and suitable for exploitation results.

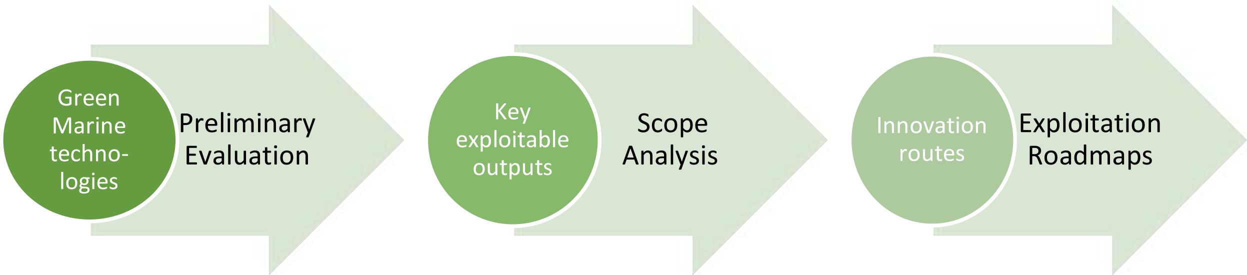

Figure 1. Overall Methodology

1.4. Document structure

Chapter 1 provides some background information about the project and the document.

Chapter 2 lists the technologies as part of the Green Marine project.

Chapter 3 outlines the conception of the key exploitable outputs via a preliminary evaluation.

Chapter 4 presents the translation from key exploitable outputs to innovation routes.

Chapter 5 elaborates on the different exploitation strategies per innovation route.

Chapter 6 describes the overall joint exploitation strategy of Green Marine.

Chapter 7 summarizes the conclusions of this report.

2. Summary of Technologies

2.1. Carbon Capture Machine

In short, the CCM process captures gaseous CO_2 from process flue gas and converts it to stable and insoluble mineral solids. The process operates at ambient temperature and pressure. The proprietary sequential precipitation process can operate continuously to yield scrubbed flue gas and carbonates. Depleted brine, the third output, can be disposed of, re-injected to ground or water, or post-processed for other uses.

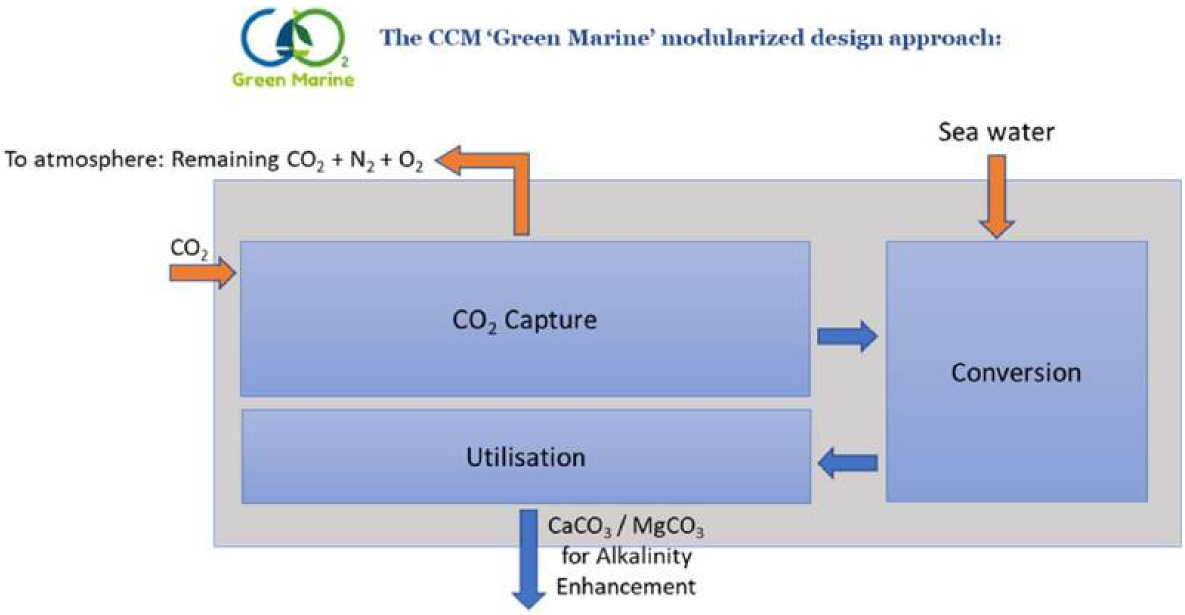

Figure 2. Carbon Capture Machine principle of operation and key components

2.2. SEPARAPTOR

The SepaRaptor agglomerates small particles into larger particles (agglomeration of nanoparticles (5-300nm) to microparticles (2-6µm)). In the case of use with the exhaust gases, the SepaRaptor will agglomerate and ultra-fines (less than 2.5PMs). For the HVAC system, the SepaRaptor will be used to agglomerate viruses and/or bacteria. Together with the use of UV light to destroy viruses and/or bacteria, the air can be reused.

The principle of operation is as follows. Electricity is used to power the piezos that generate high frequency sound waves. A standing wave is formed between the piezos (distance 6-8 cm), this is an open structure allowing air to flow through without any restriction. Where the nodes meet, the pressure is zero and agglomeration of nanoparticles occurs. Nanoparticles act like a gas, and not as a particle, and under these circumstances they will remain situated in this node (pressure is zero). 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 µm)1. These agglomerated particles do not breakdown into smaller particles after assimilation. So once assimilated the size can be larger than 2 µm.

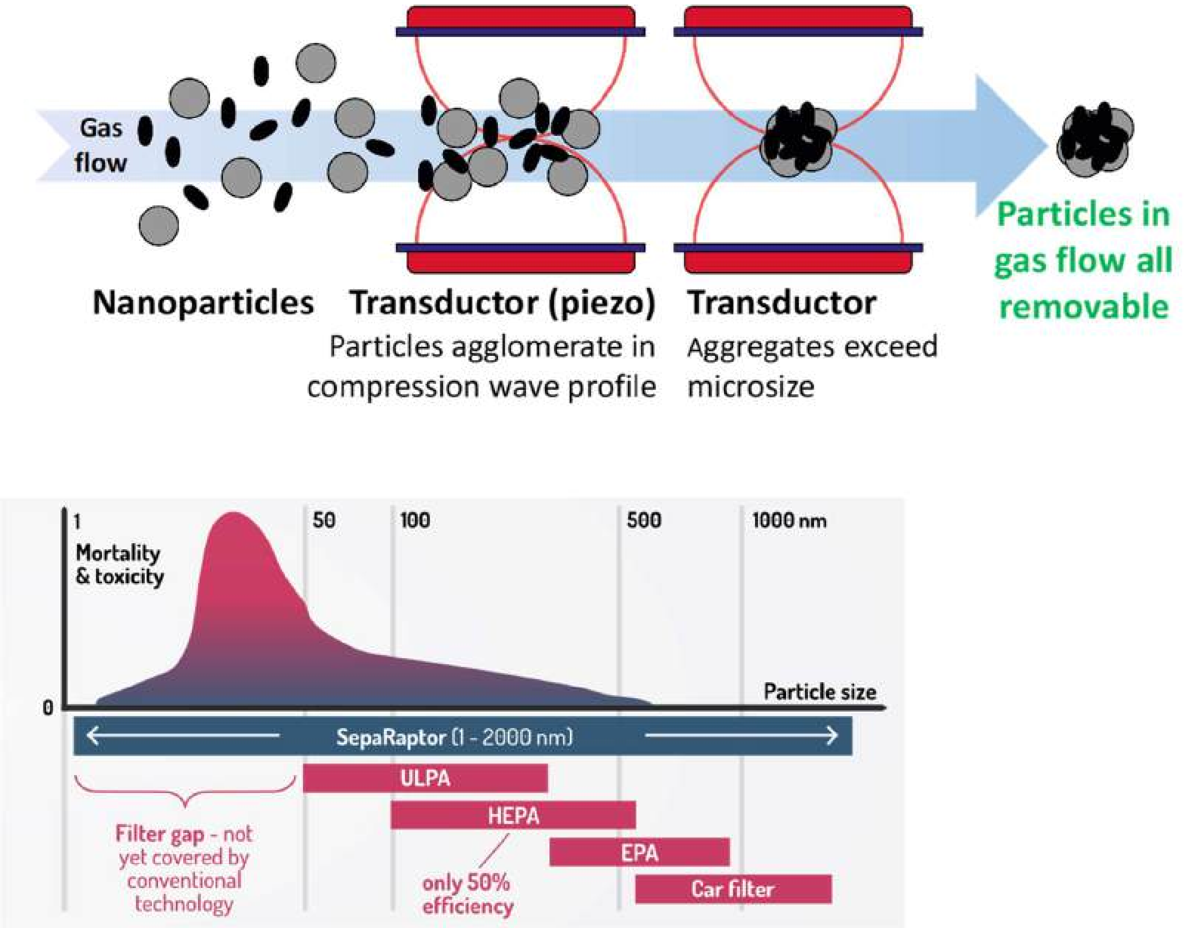

Figure 3. SepaRaptor principle of operation (top) and filter gap with standard filters (bottom)

2.3. THERMOELECTRIC ELEMENT

Based on the Peltier principle Thermoelectric elements (TEEs) transform the thermal energy, i.e., use waste heat from an engine into electricity. Two avenues are considered within the Green Marine project.

TEE option 1 – combined loop of flue gas 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. The approach is to 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, two separate TEE loops can be created. For this, the engine coolant and flue gas loops will have separate TEEs.

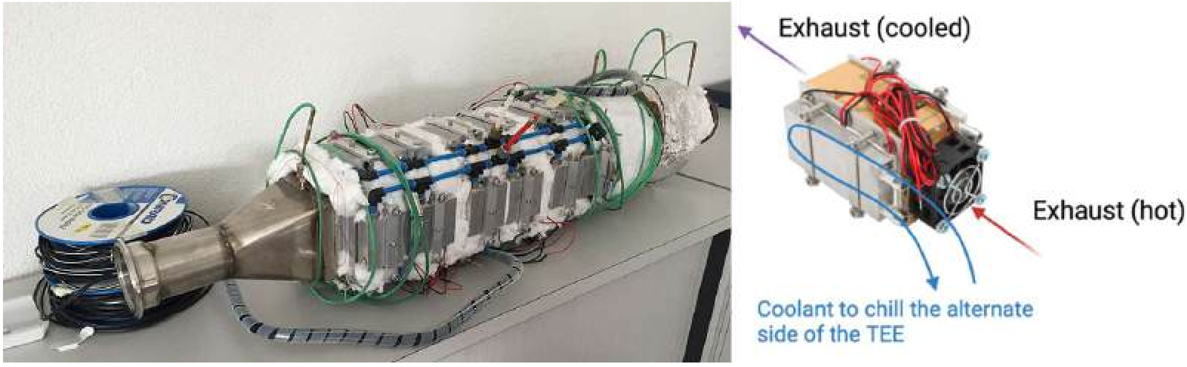

Figure 4. TEE principle of operation

2.4. PROTON EXCHANGE MEMBRANES (PEM)

As depicted in Figure 4, Proton exchange membranes can be utilized to produce hydrogen through water electrolysis. The principle of operation is that due to sufficient amounts of energy (that can come in the form of green electricity), the water molecule breaks down into hydrogen and oxygen, which can be recouped. Though not innovative by nature, the utilization of these membranes in a waterborne vessel setting provides a different techno-economic challenge and implies a different approach towards exploitation.

Water electrolysis via PEM is currently under technical feasibility study and evaluation. All Green Marine partners will decide on its eventual use within the project's scheduled activities. Information will be provided in upcoming reports.

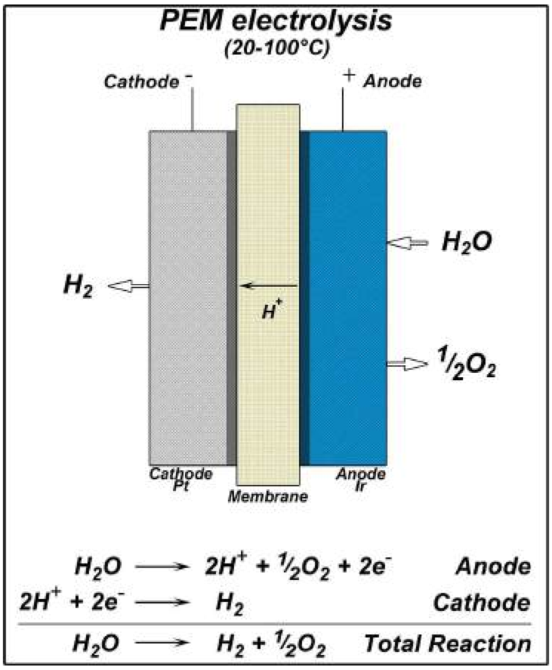

Figure 5. PEM water electrolysis

2.5. THORSPIN UNIT

The ThorSpin relies on the mechanochemistry principle. It is a mobile equipment, with a modular, plug and play setup, making it easy to manoeuvre and install on-site. Any material will be either sorted or not depending on the requirements of the final product. In Green Marine this will allow the recovery of precious metals (Ir and Pt).

The material enters a "ball pit" where rotating wings collide with special material balls (diameter 1–5 mm). The rotating wings are powered by a cooled electro-motor with sophisticated software control. The wings move at about 1/3 of the speed of sound and through continuous collisions ("snowball-effect"), the balls are propelled to 6–9 times the speed of sound. The collision forces are enormous with localized temperatures reaching 1000–10,000 °C while the temperature of the casing and wings, through cooling, remain ambient. With these high speeds and torsion, the balls will destruct materials to elementary atoms and allow formation of new molecules. Typically, a very fine black powder exits the ThorSpin.

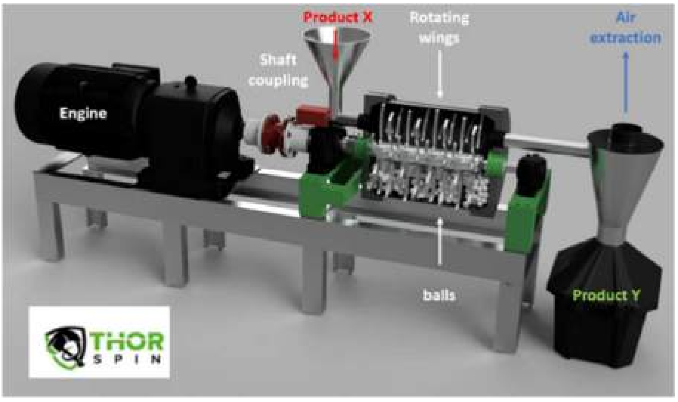

Figure 6. Depiction of ThorSpin unit

2.6. CO_2 MEMBRANES

The general principle of operation of membranes is to serve as a permselective barrier between two phases. A simple representation of a membrane is shown on Figure 7. When it comes to the CO_2 capture membranes in Green Marine, either a one-stage or two-stage process is in consideration. Depending on number of stages CO_2 content can reach up to 80% or over 95 %, as required for transport and storage in CCUS.

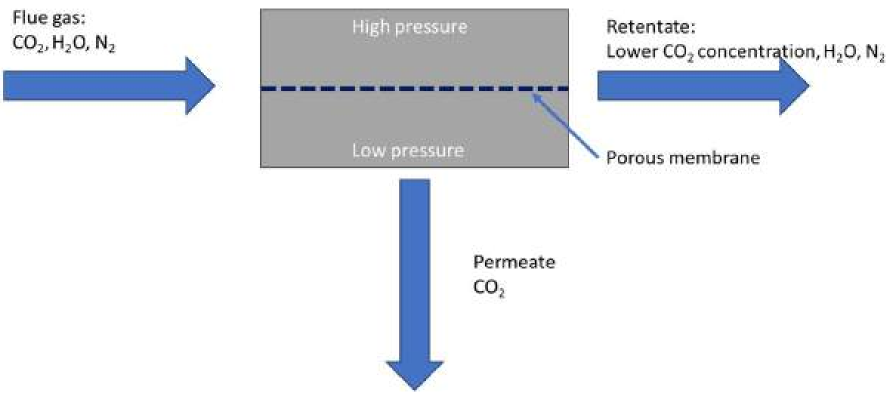

Figure 7. Membranes principle of operation

2.7. SYNGAS PRODUCTION AND RE-INJECTION

The exact composition of syngas depends on the production method and feedstock used. Preliminarily, Green Marine will use Catalytic CO_2 hydrogeneration reaction. The production of syngas on-board can be achieved through the catalytic reverse water gas-shift (RWGS) reaction and methanation.

Syngas is currently under technical feasibility study and evaluation. All Green Marine partners will decide on its eventual use within the project's scheduled activities. Information will be provided in upcoming reports. This also includes the PEM.

2.8. Software Catalogue Tool

The principle of operation of the software catalogue tool is to utilize a variety of data generated within Green Marine in order to aid decision makers in optimising the different technological processes. Here, different processes include engine air ventilation, on-board carbon capture and utilization, engine retrofitting through waste heat utilization, etc. Both available and tailored software tools are incorporated and deployed to validate and process the data. Software tools like Artificial Intelligence and big data analytics also aid the predictions.

3. Preliminary Evaluation

3.1. Assessment

3.1.1. Exploitation Criteria

The exploitation criteria described in this section aims at encompassing the status of each project technology in order to objectively operationalize the respective exploitation outlooks. Although not a fully comprehensive one, the criteria consist of four categories that roughly summarize the current advances and future impact of the technologies as it pertains to the Green Marine project. No weights are introduced to the criteria since the aim is not to rank the technologies but to differentiate between their levels of maturity, commercial readiness, and likely exploitation roadmaps. The four criteria categories are as follows:

***Technical Readiness Level (TRL)** – The technical maturity of a technology as set by the EC*[i]*.*

***Scale** – The targeted scope/stakeholders of technological outcomes and impacts.*

***Significance** – The importance of technological outcomes and impacts for the relevant scope.*

***IP protection** – The level of access to background knowledge and information.*

3.1.2. Exploitation Outlooks

Note all land-based activities under WP2 will be used to obtain relevant reports, permissions and re-assurances as to the operation of the said Green Marine technologies for CalMac, Lloyd's Register (since MV Coruisk is under LR) and the allocated classification society subcontractor for WP2.

Table 1. Exploitation Outlooks per technology.

Technology	TRL in marine environment	Scale	Significance	IP protection
Carbon Capture Machine	6 to 8	Ships with CO_2 rich flue gas	Recuperation of >50% of flue gas CO_2 and >85% conversion to mineral solids	Relevant patents obtained while background

				knowledge currently being generated
SepaRaptor	6 to 7	Ships with HVAC recirculation aims	Reduction of HVAC electric consumption by 15 – 20 %	Patents obtained
Thermoelectric element	6 to 7	Ships with large amounts of engine waste heat	Recuperation of 5-30% of waste heat and conversion to electric energy	System patents obtained while building blocks commercially available
Proton exchange membranes	6 to 7	Ships with excess electricity and availability to utilize hydrogen	Utilizing 60 – 80 % of excess energy via hydrogen	Commercially available
ThorSpin	7 (not onboard)	Ships generating precious metals waste	The 95 – 99 % recovery of precious metals	Patents obtained
CO_2 membranes	6 to 7	Ships with CO_2 rich flue gas	CO_2 extraction of close to 80% (one-stage) or more than 95% (two-stage)	Relevant patents obtained while certain units commercially available
Syngas handling	4 to 6	Ships where RWGS and methanation are possible	Utilization of > 50% CO_2 in the production of syngas	Commercially available modules. Entire system not patented
Software catalogue tool	5-6 to 8	All ship builders and ship operators	Optimization of vessel design and performance: 30 – 40 % less carbon footprint	Trademark on key functionalities secured, data sets to be protected. N.A. for code

23.2. KEY EXPLOITABLE OUTPUTS

The key exploitable outputs stemming from Green Marine are yet to evolve as the project unfolds. In any case, major outputs – suitable for exploitation – have already been generated and will serve as the backbone for the exploitation roadmaps. Namely:

- A prototype, outside Green Marine, of the carbon capture machine has been built and demonstrated in a laboratory and in a semi-relevant working environment.
- The SepaRaptor coupling with UV light for bacteria/virus removal has been duly tested and demonstrated as successful in a land-based context, outside Green Marine.
- Coordinated engine retrofit efforts have taken place to identify the most impactful yet feasible solutions for decarbonising the engine operations to be performed during WP2 activities.
- The framework of the software catalogue tool and the basic functionalities will be defined, engineered and preliminary tests will be carried out.

4. SCOPE

To focus and substantiate the exploitation efforts a clear scope with regards to the project technologies and the associated relevant outputs has to be established. In other words, the exploitation strategy must serve to guide further project actions and calibrate research efforts in an attempt to maximise future project impact. This is only achieved by prudently drafting the Green Marine scope of each technological development.

CCM. Carbon Capture Machine shows great potential as a means for recouping CO_2 and decarbonising marine vessel operations. Although key techno-economic issues regarding the transport and weight of raw materials and the size of the CCM unit remain, further research is likely to address those. From a business case point of view, the challenge pertains to the value and subsequent handling of the resulting output minerals. Two scenarios are identified – selling upon harbour arrival and discharging to de-acidify the seas. Albeit the economical soundness of either of these scenarios seems dubious, further optimizations and governmental or EU incentives are likely to change that. Hence, the possible exploitation pathways are to be examined in this report.

SepaRaptor. The high TRL and versatility of the SepaRaptor technology make it one of the easiest Green Marine technologies to exploit. As such, additional research efforts must focus primarily on different HVAC integration options to allow potential off takers greater flexibility in terms of price and efficiency. This combined with a standalone unit running on batteries, a first of its kind. This is to reflect the needs of the shipping industry where mass production gives way to customization. In any case, the exploitation avenue of this technology remains clear and will be elaborated in more detail in this document.

TEE. Despite the low TRL, the utility of the Thermoelectric element -from an exploitation point of view- remains vital. This is due to its unique, first-of-its-kind nature allowing for the recuperation of excess engine heat and the consequent generation of electricity. Though further Green Marine research should aim to achieve as optimal efficiency rates as possible, the relationship between technical parameters (heat recuperation, electricity conversion) and financial parameters (ROI, PP) is yet to be examined. Regardless, the possibility of utilizing even a small percentage of the otherwise wasted heat is in principle a solid enough reason to pursue further exploitation.

PEM for H_2 production and syngas use (depending on feasibility assessment under Subtask 3.3.3). However, the same cannot be said about the current Green Marine option in consideration for handling the resulting electricity – Proton Exchange Membranes. Although theoretically possible (and commercially available), the likelihood is that the introduction of a “mini electrolyser” on board to convert electricity to hydrogen will be impractical and unnecessarily costly solution. Even for vessels able to directly employ the alternative fuel in their engines, utilizing the possibly small amounts of electricity for immediate needs or potentially storing it in a battery seems to be a more realistic approach. Introducing a separate system to carry the hydrogen is also techno-economically infeasible. As an auxiliary, the on-board operation of a ThorSpin unit to process the PEM (or any other) precious metals is also deemed as futile from an exploitation point of view. Therefore, though further project research or external findings could improve the exploitation potential of these two technologies in a marine vessel setting, they are yet to prove their place within the scope of this exploitation report.

Membranes. Even though CO_2 membranes have been around for a considerable amount of time, their application in a marine vessel setting presents a unique set of challenges. Though project research is likely to optimise their workings, major functional overlaps with the CCM provides opportunities for cross cutting innovation. Of course, CO_2 capture via the two different means can be complemented but what's more the CO_2 gathered via the membranes can be utilized in the CCM for the production of carbides – resolving one of the main issues related to the treatment of membrane collected CO_2. Therefore, the exploitation of the membranes is of interest and will be examined in parallel with the exploitation of the CCM.

The production of syngas and the subsequent re-utilization in a marine vessel engine is a unique approach towards the reduction of overall carbon footprint. Yet, much like the introduction of an on- board PEM system, it lacks in techno-economic viability. This is largely due to the envisaged initial investment, small scale of operations and envisaged efficiency loss. All those factors ultimately impact key KPIs such as ROI and reduce the exploitation potential. A separate (technical) deliverable on the feasibility of producing and utilizing syngas has already been circulated for evaluation by the project partners. The outcome of this feasibility confirms the unlikelihood of its adoption. Though additional research might greatly shift the perspective on marine vessel syngas production, as by this report, it falls outside the scope of exploitation activities.

Software tool. Lastly, the software catalogue tool is a quintessential addition to the set of physical tools used for decarbonisation. The utility it presents makes it possible to greatly enhance the overall sustainability of a ship by selecting the most optimal combination of physical decarbonisation solutions. The future exploitation of such a tool is a necessity as it is likely to have a profound impact on the industry by enabling decarbonisation and connecting key stakeholders such as ship builders and ship operators with the most fitting solutions for achieving their sustainability targets. Hence, the exploitation of the tool is well within the scope of this report.

5. EXPLOITATION ROADMAPS

To adequately address the exploitation strategy within the scope of GreenMarine, the relevant technologies listed in chapter 2 are assessed and key exploitable outputs are identified. After being subject to scope analysis the technologies and the outputs are translated into four innovation routes that are set to be presented to potential end users. Subsequently, an elaboration on the respective exploitation roadmap is provided for each innovation route. The routes are as follows:

- Carbon Capture Route
- Air Ventilation Route
- Thermoelectric Element Route
- Software Catalogue Route

For the sake of clarity and pertinence the following definition for exploitation is embraced within Green Marine: "Exploitation is making the most of a projects' results by ensuring their uptake by a maximum of concerned stakeholders (e.g. potential end users) after the end of the project." Hereby, the exploitation strategy per innovation route.

5.1. CARBON CAPTURE ROUTE

5.1.1. Business model

5.1.1.1. Value proposition

The business behind the CCM solution revolves around the successful and efficient capture of CO_2 from gases and the subsequent production into valuable carbonates. To achieve this a proprietary multi-stage precipitation technology is used to selectively separate and produce nearly insoluble Ca and Mg carbonate minerals that have useful properties, and hence commercial value in existing established and new markets.

5.1.1.2. CRL assessment

CCM's solution is being demonstrated and commercialized through the NRG COSIA Carbon XPrize competition. This is for a land-based solution. Here CO_2 from flue gas is dissolved directly into slightly alkaline water, that is then faced with a suitable brine source containing dissolved Ca and Mg (and other) ions as found in connate formation, produced, and other abundantly available waters.

5.1.1.3. Market analysis

The Calcium Carbonate Market is projected to be worth USD 63.87 Billion by 2028, registering a CAGR of 4.20% during the forecast period (2021 - 2028), The market was valued at USD 49,502 Million in 2020 (REF).

Calcium Carbonate is a white insoluble mineral comprising more than 4% of the earth's crust and occurring naturally as limestone, chalk, calcite, marble, and forming mollusk shells. It is commonly used in the manufacturing of lime and Portland cement and as a gastric antacid. The growth of the market is driven mainly by the growing consumption of calcium carbonate in various end-use industries, including paints and coatings, paper, and plastics. The demand is also supported owing to its wide availability and low cost. The global calcium carbonate market has been segmented on the basis of product type, end-use industry, and region.

The product type segment in the global calcium carbonate market has been categorized into ground calcium carbonate (GCC) and precipitated calcium carbonate (PCC). Among these, ground calcium carbonate dominated the product type segment, accounting for more than 70% in 2020. Ground calcium carbonate is commonly used as an industrial mineral. It is used in paints and coatings, paper, and plastic fillers. GCC also finds application in cement and can be converted into calcium oxide (quick-lime) and calcium hydroxide (slaked lime). It increases the pH in soils or water and can be used to neutralize combustion vapors. Hence, various advantageous properties of GCC drive the growth of product type segment. Precipitated calcium carbonate (PCC) is projected to register the highest CAGR of over 4%. The different shape of PCC allows them to act as a functional additive in adhesives, sealants, rubber, plastic, inks, paper, pharmaceutical, and nutraceutical, aiding the growth of this segment.

With the assumption of a commercial vessel engine size that emits 1.5 kTon of CO_2 per year, the CCM solution would yield approximately 1 kTon/year of CO_2 capture (emission reduction costing between 3-5 MLN €), yielding approximately 2.3 kTon/ year of Calcium Carbonate or Magnesium Carbonate. At a market price of €280 per metric ton for PCC and over €750 per metric ton for specific PMCs, the CCM equipment will yield saleable PCC/PMC products with a market value of €466k - €1.4 million per year when accounting for incoming material consumption. Over a 20-year useful life of the equipment, this yields over €9-33 million in marketable products. The additional potential for carbon offsets could yield an additional €1 million or more depending on market pricing and final LCA calculations. The anticipated Return on Investment would be about 5 years, with the above assumptions. For ferry's travelling to remote areas and islands that require these building materials (shipped to the island) this can be a viable model. This would help introduce the solution in the industry. Investigating the benefits of deacidification would identify the opportunities for large freight vessels.

5.1.1.4. Competitors

The names of some competitors in the report on marine vessels sector are as follows: 1) Kawasaki Kisen Kaisha Ltd (Japan), 2) Mitsubishi Heavy Industries, Ltd. (Japan), 3) Wah Kwong Maritime Transport Holdings Ltd (China), and 4) likely Samsung Heavy Industries Co. Ltd. (Japan) and 5) Fincantieri S.P.A. (Italy).

Understanding competitors' market positions, technological advances and recent developments will provide insight and opportunity into potential areas of cooperation or differentiation.

5.1.1.5. Market penetration strategy

While it is premature to describe a market penetration strategy. A viably sound approach is to target the ferry's travelling to remote areas and islands that require these building materials (shipped to the island). Once the technology is established (optimized) it can then be utilized in other markets (ships).

5.1.1.6. Growth strategy and sales forecast

To be determined in later deliverables / not provided by CCM.

5.1.2. Financing plan

5.1.2.1. CAPEX and OPEX

The cost of a larger-scale CCM solution can be approximated in the \$3-5 million range with nominal annual costs for maintenance, electricity consumption, and related material storage and handling included. Over the product lifetime the OPEX is ~\$2.5 million consisting of the raw input materials and electricity and Capex ~\$1.5 million with very little maintenance. However, current OPEX projections don't consider the costs related to carrying the additional input materials on board as well as the costs of carrying the carbonate products. The volume as well as the weight (of the inputs and the outputs) could greatly impact the commercial competitiveness of the technology.

5.1.2.2. Revenues

On the revenue side, sales of useable products and carbon offsets are estimated at 14-20 MLN euro. Based on that it is reasonable to anticipate a complete RoI within 5 years of initial investment.

5.1.2.3. Financial indicators

To be determined in later deliverables / not provided by CCM.

5.1.2.4. Sensitivity analysis

To be determined in later deliverables / not provided by CCM.

5.1.2.5. SWOT analysis

To be determined in later deliverables / not provided by CCM.

5.1.2.6. Risk analysis

To be determined in later deliverables / not provided by CCM.

5.1.3. IP Management

To be determined in later deliverables / not provided by CCM.

5.2. AIR VENTILATION ROUTE

5.2.1. Business model

5.2.1.1. Value proposition

Before the COVID-19 pandemic, cruise lines had invested considerable resources to develop and implement air recirculation on their ships. Keeping the temperature of air constant and on the right level of humidity inside, HVAC systems can account to as much as 15% of fuel consumption. Under this assumption, reducing the HVAC contribution by one third would reduce the total consumption of the vessel by 5%. To be more specific, energy savings of 15-25% in a typical cruise vessel cabin (in tropical conditions) by recirculating air with fan coil units can translate to a yearly saving of 500-700 kWh. Alone for the cabins the yearly saving potential in a vessel with 2,000 cabins would be 1 to 1.4 million kWh. However, these energy savings can only be achieved if a reliable, safe, and scalable method for removing contaminants and thus enabling the recirculation of air is available.

The SepaRaptor technology enables just that. Although during the pandemic the use of fresh outside air was preferred to energy savings, this proved to be a difficult challenge for all HVAC categories besides cabins. Also, the industry cannot ignore the costly energy aspect anymore and is thus looking for a solution that would strike a medium. Thus, preparation for epidemics/pandemics and reduction of energy consumption are both of high priority now, and the SepaRaptor solution can help to achieve both. The SepaRaptor technology (with the cube version and adapted units) can be applied to each and all of the four area categories of HVAC: cabins, public spaces, service areas like galleys and laundries, and stairs – enabling recirculation and thus resulting in overall energy savings.

5.2.1.2. CRL assessment

Currently, the parental technology of the SepaRaptor is exploited in individual units by Atmofizer and are sold in North America and in the UK. Atmofizer is shifting focus from individual units to HVAC-based systems. However, for this exploitation report, we are still focusing on the single, stand-alone units with a power cord. Further development is ongoing to introduce the SepaRaptor technology into HVAC systems, which is planned for year 2 and 3 of this project. With this information given, the CRL of the stand-alone SepaRaptor unit can be considered level 6 or 7.

5.2.1.3. Market analysis

In contrast to other areas of the report, in this paragraph we focus on the application of the SepaRaptor, for both HVAC as well as a stand-alone unit. With that in mind, we do believe that we can aim well beyond (only) maritime applications with the HVAC systems, which will be identified in later versions of the Exploitation Report. Yet, for the sake of consistency and scope only the maritime application is elaborated on in the following paragraphs.

The global impact of Covid-19 on the shipping and cruise line industry has been unprecedented and staggering, with marine vessels witnessing a negative demand shock across all regions amid the pandemic. Based on analyses (REF) the global market had shown a decline of 17.2 % in 2020 as compared to the average year-on-year growth during 2017-2019. The market is projected to grow from USD 170.75 billion in 2021 to USD 188.57 billion at CAGR of 1.43% in the 2021-2028 period. Europe is estimated to be the second-largest market for marine vessels. The European shipbuilding industry is a leader in innovation and sustains its position as a technology provider, cleaner and safer ship provider. With its diverse fleet of commercial vessels, the European Union (EU) shipping industry contributes USD 165 billion to the EU's annual GDP growth.

Marine Emission control market

Emission reduction technology market for recreational, offshore, commercial, and navy applications, is a 11,18 billion USD global market[ii].

While the SepaRaptor does not actively reduce emissions of marine vessels, it indirectly contributes to a reduced demand in power needed on vessels. Therefore, we do believe that the SepaRaptor will fall into this market. The market is rapidly developing and growing (CAGR of 8,5% expected between 2023 and 2032) and projects such as, Green Marine may contribute to that growth.

Marine HVAC market

A sector containing: Marine Ventilation Systems, Marine Air Conditioning, Marine Heating Systems, and Marine Refrigeration Systems, is a 2,33 billion USD global market[iii, iv].

An alternative market that we can enter is the Marine HVAC market. A smaller, but growing market, with a CAGR > 3,5 % and in some regions >8 %. We aim to enter the market by 1) collaboration with companies that are currently established in the Marine HVAC market. Or 2) develop HVAC systems that can be installed in the venting systems by ship manufacturers or to upgrade existing HVAC systems in vessels. A realistic share would be less than 1% in the first 5 years, more likely less than 0,5%. This represents a revenue of < 67,55 million USD.

5.2.1.4. Competitors

Currently, no technologies like the SepaRaptor are offered by any (known) competitors. However, competitors may become actual current and prospective partners as the SepaRaptor tech may be integrated into HVAC technologies directly.

In addition, applying the SepaRaptor can be compared with filtration technology, such as HEPA filters, which they may replace as a whole. Competitors in the HEPA filters field include:

- Daikin Industries, Ltd.
- Dometic Group AB (publ)
- Marcotex - Engineers & Consultants
- Johnson Controls International plc
- Heinen & Hopman Engineering BV
- Carrier Global Corporation

5.2.1.5. Market penetration strategy

The overall strategy is to collaborate with HVAC/AC/vent companies to introduce the SepaRaptor tech in cruise Lines, ferries, and perhaps commercial vessels. Many cruise lines have retrofitted some of their ships with HEPA filter systems after the COVID-19 pandemic started. However, COVID-19 viral envelopes are small enough to pass through these and can be considered ineffective. Moreover, the SepaRaptor has very limited energy consumption (Watts) versus the pressure drop caused by HEPA filters which needs to be compensated by the air ventilation units. Unlike HEPA filters the SepaRaptor will not lose its performance and/or require replacing. Therefore, we aim to show the effectiveness of the SepaRaptor technology to convince ferries and cruise lines to adopt our technology.

Green Marine will act as a real-world test run on a CalMac ferry (MV Coruisk), based in Scotland. However, implementing this on cruise ships will have a much more profound effect as the passengers are more densely clustered, while also spending more continuous time on the vessel. Therefore, the belief is that the Green Marine tests will be a good step up to implementing it into cruise ships.

Moreover, SMP will leverage on the ties to Atmofizer, in an attempt to enter the market from both sides of the Atlantic region, as Atmofizer is based in North America. Often, Caribbean-based cruise Lines use their fleet in both Europe, as well as the Americas. Therefore, CO_2 reduction can be ensured in both areas. For example, assuming the air-circulation in ships, low ETS prices (50 EUR/ton), this transcends to 16 kEUR/annum for a 200-person vessel and 160 kEUR/annum for a 2000-person vessel. Yet, it is clear that the business case around air-reuse is not the CO_2 credits but the vessel's ability to save energy and allow more passengers in times of pandemic.

Different business models are considered when it comes to the future sales of the product.

Individual product sales: The primary business model is to sell individual SepaRaptor units at ~1000 € a piece. For a small passenger ship (200 person) this would mean the purchase of approximately 100 units and 10x as much or more for large cruise ships. Although this seems to be a safe and profitable investment route, it is plausible that this strategy may not be able to penetrate the market quickly enough. Hence, alternative business models are also thought out, namely as a service provider or perhaps as a leasing constructor.

Service provider: The SepaRaptor, software tools, and sensors are sold as part of total service package towards ship owners. Here the stand-alone SepaRaptor units can be easily replaced or repositioned in the ship. They can be connected to the platform to track performance, use and location. While the other services aim to reduce infection spread and monitor it. The services are to be commercially sold by a new legal entity to the multinationals of the cruise industry.

Lease construction: Currently SMP licensees in EU and USA lease a single unit to hotels for about 1 EUR/day (per hotel room). After a 5-year lease period the customer can purchase the solution (at 40 % value of 500 k€ for individual large scale integrated solutions, as they can be removed if a vessel/cruise line becomes bankrupt – fixed assets like the integrated solution will be considered part of the asset). Its Pay-Out time are between 1–2 years. The customer would own 76 % of the solution. While this approach demonstrates commitment by partners (24 % ownership) towards the solution and their customers, it is riskier than just selling the unit or adopting a service provider solution. It has the advantage to realize quicker market penetration.

Market penetration is essential for it would enable manufacturing of scale to be reached and the unit operations to improve over time (optimized energy consumption, stand-alone operation). We are convinced the solution price can potentially drop significantly to about half at least. This is common practice for semi-conductor products. As more units can be installed on a ship or plane, or elsewhere it can be manufactured at large scale, then licensee arrangements can be made. Here the European partners would provide the knowhow to other manufacturers globally, the predictive maintenance and operation software will have an annual fee for each unit.

5.2.1.6. Growth strategy and sales forecast

Our strategy for growth is as follows:

- Pick and place systems and assembly are available in the Netherlands at SMP that can produce 15 units per day.

- Assembly line is up and running in North America and can produce 100 per hour.

This will meet our expected requirement of increased demand.

As far as sales are concerned, the estimation is approximately one SepaRaptor unit for every 2 people on any given ship. This averages one unit in every cabin, as well as units in public spaces. Since approximately 840k people (crew + passengers) can fit on the fleet of all active cruise Lines (323 ships), this results in about 420k units to be sold in the first 5 years if all cruise lines accommodate the SepaRaptor. If a few major cruise Lines adopt our technology, we aim to a more realistic sales number of 75k units in the first 5 years post Green Marine completion. Of course, smaller ferries are also a major part of the business – especially in the beginning. Taking into account only the production capacity within the Netherlands this translates to approximately 12 000 EU manufactured units (for EU or globally sold). As the aim is to sell each unit for about € 1000 (base price) and for € 800 - € 900 (with a discount), the estimated revenue stream is of € 10 million in the first 5 years. For larger orders, providing discounts as a package deal for a single ship is conceived. Hereby, an estimation of the SMP sales volumes in the first 5 years after green marine and ultimately reaching the estimated production capacity of ~ 5000 units per year.

Table 3. Envisaged sales of SepaRaptor

Year		**2026**	**2027**	**2028**	**2029**	**2030**
Sales	***Units***	*500*	*1000*	*2000*	*3500*	*5000*

45.2.2. Financing plan

5.2.2.1. CAPEX and OPEX

The ensuing CAPEX and OPEX figures are just for manufacturing and distribution of stand-alone SepaRaptor units at the production site in the Netherlands and don't account for the production of HVAC-integrated systems.

Capital Expenditures

- SepaRaptor Assembly line:
    - Total Cost (excl VAT): € 346.396,14
    - Funded by Green Marine project: € 155.878,29 (total * 60% (funding ratio) + 15% for overheads)

- Residual expenses: € 190.517,85

- Antistatic flooring: € 100.000
- Manufacturing hall purchase and renovation: € 140.000

Total CAPEX outstanding = € 430.517.85

Operational Expenditures

- Raw materials and shipping costs to the Netherlands. Approximately € 100 per SepaRaptor unit.
- Labor costs – salaries for 5-7 staff. Approximately € 350.000 per annum.
- Utilities. Approximately € 15 per SepaRaptor unit.
- Office overheads. Approximately 10% of total forecasted revenue: rent, benefits, profession fees, website, phone, inventory, shipping + handling, storage, supplies.

Total OPEX (fixed) = € 350.000

Total OPEX (variable) = € 115 per unite + 15% of total revenue

5.2.2.2. Revenues

To properly analyze the revenue streams from the distribution and sale of the SepaRaptor units an overview of the annual sales, associated revenues and costs is presented on Table 3.

Table 5. Overview of revenues and profits

Year		2026	2027	2028	2029	2030
Sales	*Units*	500	1000	2000	3500	5000
Revenue	*Euro*	500 000	1 000 000	1 900 000	3 100 000	4 300 000
Total OPEX	*Euro*	482 500	615 000	865 000	1 217 500	1 570 000
Profit	*Euro*	17 500	385 000	1 035 000	1 882 500	2 730 000

65.2.2.3. Financial indicators

The ensuing financial indicators have been calculated assuming the CAPEX, OPEX and growth and sales forecast described in the previous section. They are not meant to provide a rigorous basis for conclusions with regards to exploitation but to collectively summarize the overall financial prospects of the exploitation roadmap.

Table 7. Key financial indicators

Net Present Value (NPV):	3 374 157.30
Internal Rate of Return (IRR):	100.93%
Profitability Index (PI):	7.8374
Payback Period (PP):	3 years

8The analysis shows that the breakeven point is reached in year 3 with IRR of 100.93 % and an NPV at year 5 at about 3.374 MLN EUR. The profitability index is at 7.8374. The overall evolution of NPV_5 is also depicted on Figure 8.

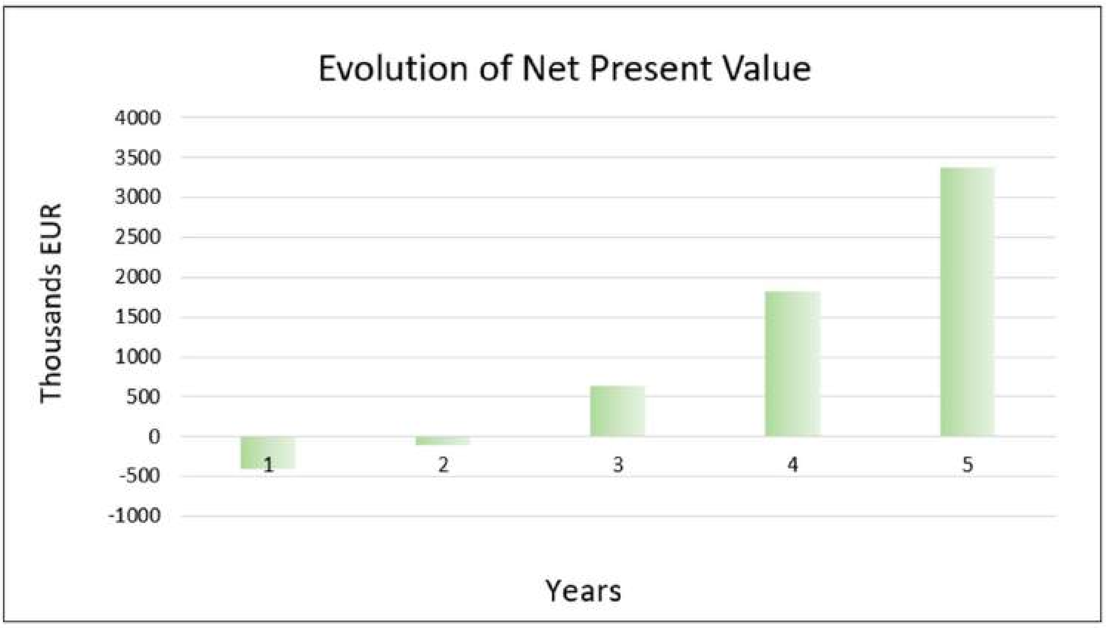

Figure 8. Evolution of NPV

5.2.2.4. Sensitivity analysis

To determine the impact of each cost or revenue stream on the financial outlook a sensitivity analysis is carried out. The sensitivity analysis as part of this section of the report has two stages – first one depicting the overarching separation between CAPEX, OPEX and Revenues and a second one depicting the subcomponents of CAPEX and OPEX in more detail. Notably, the sensitivity analysis is again applied to NPV_5. Stage one of the analysis is presented on Figure 9.

As anticipated, revenues greatly outweigh costs, with CAPEX playing a very marginal role (3%) as compared to OPEX (28%). Overall, this implies that the initial investment is a relatively minor one and that subsequent income streams are likely to exceed the costs in a swift manner. As a result, the manufacturing equipment necessary for the large-scale production of the technology is in principle a sound investment.

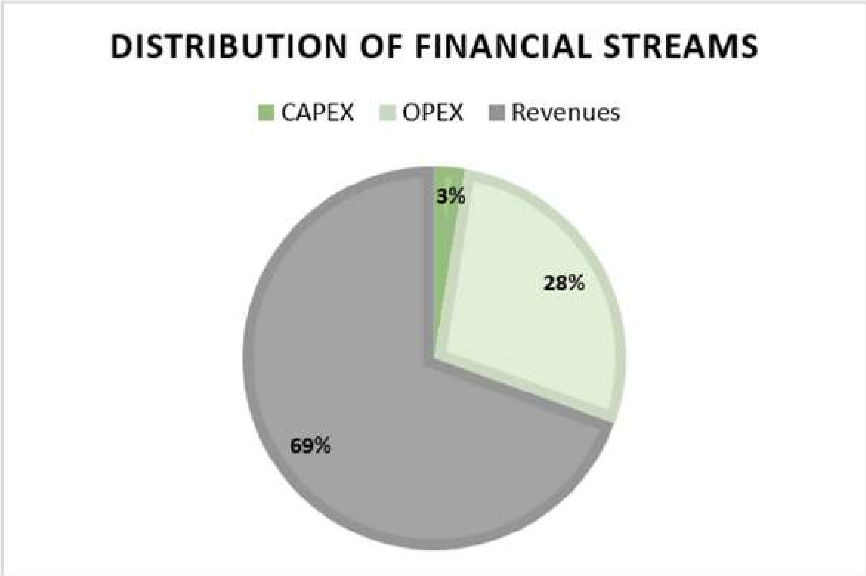

Figure 9. Distribution of costs

Stage 2 of the sensitivity analysis is presented on Figure 10. Evidently, the biggest cost contributors are related to labor, raw materials, shipping, and storage. In general, the NPV effect of the ongoing OPEX is quite considerably as compared to the one of the CAPEX – where the biggest cost driver is the Assembly Line.

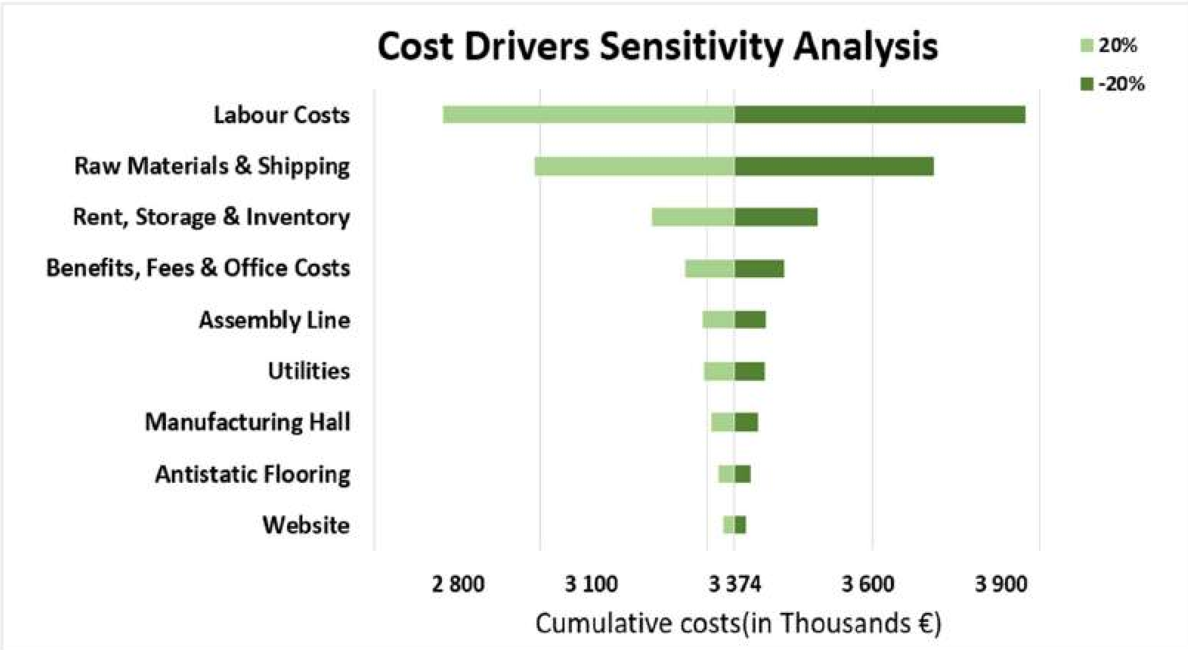

Figure 10. Advanced Sensitivity Analysis of costs

All in all, the results clearly show that careful budgeting should be implemented to manage labor costs and that supply chain optimization with regards to raw materials, shipping and storage is quintessential for effective cost saving strategy.

Within GreenMarine these assumptions will be verified and if new parameters arise that impact the sensitivity analysis they will be investigated as well.

Also, within GreenMarine financial data will be gathered for the ship owners. With that data a sensitivity analysis will be made as well.

5.2.2.5. SWOT analysis

Table 9. SWOT analysis table

Strengths	Weaknesses
• Availability of large price margin • Product flexibility and versatility in terms of size and integration • Critical infrastructure already established	• Returns depend heavily on HVAC recirculation in place • Effectiveness diminishes if not fully implemented on a vessel
Opportunities	**Threats**
• Post COVID attention to air quality and viral spread • Global as well as EU decarbonisation targets	• Advancements in filter technologies (HEPA or others) • Socio-economic acceptance of ultrasound and UV technologies

5.2.2.6. Risk analysis

The following risks – Table 6 – have been identified as primary when it comes to the exploitation of the SepaRaptor technology as it pertains to Green Marine. It is important to note that the list is not an exhaustive one and it includes only risks that could potentially impact the exploitation activities. The grading scores are based on discussions with the technology developers, and literature and market research.

Table 10. Risk table

Major Exploitation Risks **P = Probability, I = Impact, R = Risk = Probability * Impact. Grading Scale (1-10)**					
№	Risk	P	I	R	Explanation
1	Social acceptance of tech	7	7	49	Poor social acceptance of the technology – especially in combination with UV light – due to healthcare concerns.
2	Failure to secure funds	6	8	48	Failure to secure the necessary funding during years 1 and 2 of production/operation until a positive ROI is achieved.
3	Failure to secure labor force	6	7	42	Difficulty in ensuring sufficiently big and skilled labor force to meet sales and growth targets.
4	No demonstration	6	6	36	Inability to showcase solution effectiveness unless holistically implemented on a vessel.
5	No relevant demonstrations	5	6	30	Failure to achieve the desired design modularity so as to enable integration into different not only small but also large-scale systems.
6	Pricing inaccurate	4	6	24	Incorrect pricing strategy in terms of predicted market value of the product/s. Despite bringing clear energy savings and virus reduction benefits, the price might be deemed too high.
7	Transition to no HVAC systems	2	9	18	Global industry transition to no recirculation HVAC systems.
8	Competitors	8	2	16	Advancements in filter technologies (HEPA, etc.) or other competing technologies.

9	Supply chain challenges	5	3	15	Supply chain challenges with key (semi-conductor) materials and components.

115.2.3. IP Management

To ensure the proper management of IP, Smart Material Printing and Wind Plus Sonne have taken a proactive approach already outside the Green Marine project. More specifically, all relevant patents as well as rights to background information have been secured by Smart Material Printing and Wind Plus Sonne. As it pertains to Green Marine, they remain the sole owner of the technology and any results generated from relevant project work activities. Licensing of the technology has been proven as a working and mutually beneficial business strategy via the successful collaboration with the US based Atmophizer. As such, it remains a possible approach for further exploitation. Still, the primary efforts will be to keep knowledge as well as manufacturing means and relevant know-how in the EU and in the Netherlands.

5.3. THERMOELECTRIC ELEMENT ROUTE

To be prepared for next deliverable

5.3.1. Business model

To be prepared for next deliverable

5.3.1.1. Value proposition

To be prepared for next deliverable

5.3.1.2. CRL assessment

To be prepared for next deliverable

5.3.1.3. Market analysis

To be prepared for next deliverable

5.3.1.4. Competitors

To be prepared for next deliverable

5.3.1.5. Market penetration strategy

To be prepared for next deliverable

5.3.1.6. Growth strategy and sales forecast

To be prepared for next deliverable

5.3.2. Financing plan

To be prepared for next deliverable

5.3.2.1. CAPEX and OPEX

To be prepared for next deliverable

5.3.2.2. Revenues

To be prepared for next deliverable

5.3.2.3. Financial indicators

To be prepared for next deliverable

5.3.2.4. Sensitivity analysis
To be prepared for next deliverable

5.3.2.5. SWOT analysis
To be prepared for next deliverable

5.3.2.6. Risk analysis
To be prepared for next deliverable

5.3.3. IP Management
To be prepared for next deliverable

5.4. SOFTWARE CATALOGUE ROUTE
To be prepared for next deliverable

5.4.1. Business model
To be prepared for next deliverable

5.4.1.1. Value proposition
To be prepared for next deliverable

5.4.1.2. CRL assessment
To be prepared for next deliverable

5.4.1.3. Market analysis
To be prepared for next deliverable

5.4.1.4. Competitors
To be prepared for next deliverable

5.4.1.5. Market penetration strategy
To be prepared for next deliverable

5.4.1.6. Growth strategy and sales forecast
To be prepared for next deliverable

5.4.2. Financing plan
5.4.2.1. CAPEX and OPEX
The running costs of the platform is ~1000 € per month after the project period, as most of the costs are made during the project. With only about 2–3 software sales-engineers to continue marketing the platform and individual. This is an additional 10-15k EUR per month for personal costs and 2-3k EUR per month for other direct costs. PDMs ventures subsidiary would be willing to take that role after the project period allowing future exploitation.
The costs to maintain the individual simulation tools of the individual partners (or 3rd parties) should not be considered a future cost of the platform. Some of these individual simulation tools have a negligible cost to maintain, or they may require expensive licensees, CPU time or large data storage. If the platform is requested to host and support specific simulation tools, and therefore incurring a cost, that cost would be offset by the revenue provided by the customers and/or developers of such simulation tools. To ensure that the partners generate a revenue from the tool, an automated accounting system will be developed to appropriately

reward the partners when their simulation tool (and the platform itself) is used or subscribed too. Expensive storage or CPU time can also be offered by the platform for a fee. This is not uncommon as demonstrated by IBM, Amazon and others. During the project, and thereafter, the focus would be to target marine research institutes to gather more simulation tools and data, while also informing other users like emitters and utilizers of the advantages of the platform. Other simulation tools can, for a fee, easily be integrated to the platform by following the API-requirements developed in WP6. And it is very likely that the other parties will be keen to connect to the platform as it contains other simulation tools and data, strengthening their own simulation tool. The platform will not only generate revenues for the individual partners but also to these new parties. Revenue can be generated through fee's (integration, CPU time, storage, etc.) or monthly subscriptions for use of: CPU time, data it generates or stores, simulation runs etc. As with other software solutions there are many different business models possible (see Figure 17) and this requires an in-depth investigation by the consortia members. In 5 years', time, the platform could employ up to 20 people directly and more at other software developers or simulation tool providers.

5.4.2.2. Revenues

The possible revenue streams like fees and subscriptions between stakeholders is shown in Figure 17. Here data and modelling tool providers can earn income through the automated accounting system of the platform. This will stimulate the platform's further growth (with data and users).

5.4.2.3. Financial indicators

To be prepared for next deliverable

5.4.2.4. Sensitivity analysis

To be prepared for next deliverable

5.4.2.5. SWOT analysis

To be prepared for next deliverable

5.4.2.6. Risk analysis

To be prepared for next deliverable

5.4.3. IP Management

To be prepared for next deliverable

6. JOINT EXPLOITATION STRATEGY

To be prepared for next deliverable

6.1. COORDINATION OF EFFORTS

To be prepared for next deliverable

6.2. IPR PROTECTION STRATEGY

To be prepared for next deliverable

7. CONCLUSION

This is an initial deliverable aimed at gaining insight in the financial exploitation opportunities and risks of the technologies that are furthest up the TRL ladder (after 6 months of the project). The exercise has been helpful for at least one of the technology providers.

More development time and validation in the demonstrations is needed to provide proper conclusions and recommendations.

8. REFERENCES

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