Retrofitting towards climate neutrality

D6.11 2nd Exploitation Report with first business plans

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Acronym Table	
CCM	Carbon Capture Machine
CCUS	Carbon Capture, Utilization 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

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EXECUTIVE SUMMARY

This document is deliverable "D6.11 – 2nd Exploitation Report" of the European Union project "Retrofitting towards climate neutrality" (herein referred to as "**Green Marine**"), with **grant agreement No. 101096522**. UK participants in Horizon Europe Project Green Marine are supported by UKRI grant numbers 10064539 (University of Strathclyde), 10068477 (CalMac Ltd) and 10064666 (CCM).

The current version of this report contains a summary of the exploitation strategies on a per technological solution route basis. More specifically, five innovation routes are distinguished:

- Carbon Capture Route (led by CCM)
- Carbon Capture Route (led by SINTEF)
- 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. As the current technologies have not reached to the demonstration level, only initial business models are provided without detailed financial analysis.

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 final version of the deliverable is scheduled to be updated with the final version of the business models and a plan for the exploitation roadmap after the project period and will be submitted in M47 with information continuously generated by the project.

1. INTRODUCTION

Over the past decades, global reliance on fossil fuels in the maritime sector has contributed to significant environmental challenges, including greenhouse gas (GHG) emissions and marine pollution. The International Maritime Organization (IMO) reports that shipping accounts for nearly 3% of global CO_2 emissions, a figure expected to rise if proactive measures are not implemented. With approximately 90% of global trade carried by sea, the industry faces mounting pressure to transition to sustainable practices. This shift is underscored by stringent international and regional regulations, such as the IMO 2030 and 2050 decarbonization targets and the European Union's Fit for 55 framework. The Green Marine project aims to address these challenges by innovating and demonstrating retrofitting technologies that reduce emissions, increase energy efficiency, and enhance environmental performance in the maritime sector. By targeting existing fleets, the project enables shipowners and operators to meet decarbonization targets without investing in costly new builds. Green Marine's solutions include retrofitting protocols, carbon capture systems, energy-saving technologies, and advanced decision-support tools for optimal integration and operations. These innovations are complemented by a holistic sustainability framework, ensuring that technical advancements align with environmental and economic goals. At the heart of Green Marine's exploitation strategy is the integration of its pioneering technologies into commercial and regulatory frameworks. This involves leveraging partnerships with shipowners, operators, port authorities, and regulatory bodies to ensure widespread adoption. The project also evaluates the potential for scaling solutions within existing organizations.

This document presents the second version of the exploitation plan, updated to reflect the progress and lessons learned in the two years since the Green Marine project was launched. It provides refined business plans for each of the key exploitable outcomes, incorporating technological advances achieved to date, feedback from partners and evolving market trends. These updates highlight the alignment of Green Marine solutions with emerging regulatory requirements, industry demands and sustainability goals. In addition, individual partner plans have been expanded to highlight their unique roles and aspirations in driving the commercialisation and adoption of project outcomes.

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, carbon and water capture with membranes, an ultrasound technology tailored to operate as pre-treatment enhancing a membrane carbon capture process, and a thermoelectric element to convert the waste heat to electricity. 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 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.

1.2. CONSORTIA HIGHLIGHTS

The consortium as a whole is formed by 10 partners from 7 different countries, including 4 research organizations, 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

This document, "D6.11 – 2nd Exploitation Report," serves as a comprehensive guide to the exploitation strategy for the Green Marine project, reflecting the progress made over two years and aligning the project outcomes with market needs and industry demands. It builds on previous findings and incorporates insights from ongoing activities, pilot studies, and stakeholder feedback to ensure the effective deployment of Green Marine's innovations.

The objectives of "D6.11 – 2nd Exploitation Report" are to:

- **Chapter 1 Provides information about the document structure.**
- **Chapter 2 outlines the technology improvements within the first 24 months of the project.**
- **Chapter 3 provides an overview of the current market analysis and regulatory compliance needs:** This includes assessing the competitive landscape, identifying emerging market opportunities, and aligning Green Marine technologies with international maritime regulations.
- **Chapter 4 Outlines the business models for the possible key exploitable results (KERs) of Green Marine technologies and propose preliminary business plans:** Detailed plans are provided for each KER, showcasing their commercialization potential and alignment with industry requirements.
- **Chapter 5 provides conclusion and next steps.**

2. UPDATES ON KEY EXPLOITABLE OUTPUTS (KEOS)

2.1. CURRENT STATUS OF TECHNOLOGICAL DEVELOPMENTS

Following the first reporting period, a few of the pre-determined key exploitable results provided in the first version of this deliverable was not seen feasible for further scale-up within the project timeline. The use of catalyst to produce CO from CO_2 (originating from the exhaust flue gases) as well as the use of the TEE to produce H2 from water with electrolysis (water originating from exhaust flue gases) and eventual combination of envisioned CO and H_2 to produce syngas on-board has been extensively evaluated and assessed in a desktop analysis under WP_2 and WP3. Our assessments showed that this path does not result in energy savings. Instead, the electricity from the TEE harvesting is used directly, secondly, the catalyst for syngas production will be recycled in the lab (onshore). The lab-scale investigations will continue. Reinjection of syngas in marine genset will not be further investigated at land-based tests and will not go further for the approval procedures based on the initial evaluations as shown in D2.1 "Preliminary report on results of land-based testing..

By M24, the following technologies are selected as the Key exploitable results that Green Marine will work on and continue with the land-based tests and class approval procedures:

- Air Filtration Control Solutions: SepaRaptor with UV
- Carbon Capture Route
    - Membranes for CO_2/H_2O separation
    - Carbon Capture Machine for carbon capture and utilization
- Thermoelectric element for waste heat utilization
- Software catalogue tool

2.1.1 Air filtration Solutions

According to WPS/SMP significant progress was made in the development and testing of the SepaRaptor with UV technology. The technology was established, and detailed specifications were defined. Lab-based testing demonstrated that the system effectively agglomerates particles. The SepaRaptor with UV sterilized over 99% of three tested microbes, which are surrogates for viruses such as coronavirus, Ebola, and influenza. These results position the SepaRaptor with UV as a promising solution for marine vessels, enabling cabin air recirculation and reducing the need for additional heating. The system was optimized for different configurations, including integration inside ventilation systems and use as wired stand-alone units. Power bank solutions were found impractical for continuous operation, as simultaneous charging of multiple units posed logistical challenges. Instead, a wired connection was deemed feasible when sufficient power sockets were available in corresponding rooms on vessels. Due to the special conditions on the MV Coruisk (no HVAC system with air recirculation), the plans were adapted so that stand-alone units would be used in the crew areas and on the bridge.Based on the discussions, SepaRaptor with UV technology will be a standalone unit operating in a cabin crew or bridge (location and number of standalone units to be determined in following reporting period). Discussions with CalMac, UoS and CMMI involved the determination where the stand-alone unit can best be included on-board MV Coruisk. After a certain period, it will also be evaluated whether the crew members felt healthier overall or were less ill. To this end, crew members can also request SepaRaptor devices for their days off, which they can set up in their private rooms at home. In parallel, an external immunity study will be conducted (lab and physician) to test the effect on sterile immunity = Pilot study for larger ships (cruise ships). Note that, before on-board demonstrations, the technology must be compliant by a Portable Appliance Testing (PAT) and appropriately has a CE certificate. In this regard, WPS/SMP with the aid of CMMI and CalMac have created a three-pager document to convince crew members of the benefits of this technology for on-board demonstrations.

Figure 1. SepaRaptor with UV technology, and three-page brochure targeting the MV Coruisk crew members for on-board WP1 demonstrations.

2.1.2 Membranes for CO_2 and H_2O capture

SINTEF has successfully developed, optimized, and scaled up gas separation membranes tailored to meet the project performance requirements. The main activities so far included the selection and optimization of polymer membranes, upscaling from bench-scale to pilot-scale modules, and the preparation of flat sheet and hollow fiber geometries. Innovations such as amine grafting and enzyme-polyacrylic acid coating have significantly enhanced CO_2 selectivity, supporting the development of high-performance membranes tailored for the maritime industry. Testing confirmed that optimized membranes can achieve CO_2 permeance and selectivity metrics suitable for capturing CO_2 under marine exhaust conditions, providing a reliable basis for pilot-scale deployment. SINTEF also advanced the pilot design to accommodate both single and two-stage membrane processes. The single-stage process produces medium-purity CO_2 (~75 vol%), suitable for short-term storage or further processing. The two-stage configuration achieves high-purity CO_2 (>95 vol%), enabling direct liquefaction and onboard storage. However, the associated energy demands for high-purity production highlighted the need for optimization to minimize operational costs and emissions impact. The membranes which are applied in this project are selective towards transport of water as well as CO2. The selectivity for water with respect to nitrogen will typically be of the same order of magnitude as for CO2. Thus the membranes may also have an application for water removal from humid gas. This is however outside of the scope for this project.

Pre-treatment with SepaRaptor: SMP has been working on a solution for treating flue gas using SepaRaptor technology and a bypass. Work has been carried out to modify the technology for use in the flue gas duct (rearrangement of SepaRaptor modules, design and material of bypass, discussion of most suitable location within the flue gas system). The SepaRaptor unit in this scenario, will be mounted as an auxiliary tool for the membranes. SMPs technology will be an in-line, auxiliary technology which low to no effect on the flue gas air flow (speaking of pressure drops or speed), either if it is turned on or off.

2.1.3 Thermoelectric element

The Thermoelectric Element (TEE) system will be used for waste heat recovery. According to WPS/SMP system modeling has been completed to define input and output values and determine the optimal length and capacity for the TEE unit. Following this, the assembly of components was successfully achieved, and a fully functional prototype was built and tested, demonstrating promising performance in initial trials. While partial tests have shown successful results, full-scale unit testing is currently underway, marking a critical step toward validating the system's operational capabilities and readiness for practical application.

2.1.4 Carbon Capture Machine

The system design has been refined and ongoing work on a detailed Piping and Instrumentation Diagram (PID). Initial pilot-scale testing using flue gas and synthetic seawater (brine from seawater) concentrate has demonstrated the feasibility of the process, supporting further design optimizations and experimental campaigns planned for Cyprus. Key components, including gas-liquid contactors, heat exchangers, and storage tanks, have been identified and integrated into the system. Advanced simulations using tools like Aspen are underway to predict system performance and explore various process configurations.

2.1.5 Software Catalogue tool

The development of the software catalogue tool is progressing steadily, focusing on consolidating literature related to GHG emissions, monitoring, control, and mitigation measures, with valuable inputs from the assessment tasks (LCA, TEA, SEA etc.). Efforts are underway to identify additional ships for assessing the tool’s functionality, aiming to demonstrate its value and convince ship owners and managers to adopt it for informed decision-making. The portal interface is also customized to appeal to external users, offering privileged access to advanced tools and features, ensuring user engagement and facilitating widespread adoption.

2.2. SUMMARY OF THE EXPLOITATION ACTIVITIES FOR THE FIRST 24 MONTHS OF GREEN MARINE PROJECT

The Green Marine project has actively engaged in dissemination and exploitation activities to maximize the visibility and impact of its innovations. The consortium has strategically utilized high-impact journals, global conferences, workshops, and stakeholder forums to showcase its technological advancements and their relevance to maritime decarbonization. In particular, the LinkedIn project website enjoyed 500+ followers and nearly 21,000+ impressions, exceeding our targets significantly These efforts have helped the consortium establish itself as a leader in green shipping solutions and foster collaborations with key stakeholders. Details are provided in Deliverable 6.2 Second Revision of the Dissemination and Communication Plan.

The consortium has collaborated with classification societies like DNV, Lloyd's Register, and Bureau Veritas, as well as port authorities such as Rotterdam (Rotterdam Port Authority)[1], Antwerp (Port of Antwerp Brudges)[2], and Hamburg[3] etc, to align its solutions with industry standards and operational requirements. Workshops such as the *BioCH4-to-Market Open Day, BioCNG-to-CI Workshop and Open Day* and the *Peer-to-Peer Green Energy Sharing Platform* have fostered dialogue with stakeholders, including regulatory bodies, academia, and industry representatives, ensuring that Green Marine's innovations are practical and aligned with market needs.

Innovative technologies like digital twins, onboard carbon capture, and retrofitting tools have been showcased using interactive demonstrations, including 360° VR videos from vessel engine rooms. These efforts have highlighted the real-world applicability of Green Marine solutions, helping stakeholders visualize their implementation and impact on decarbonization goals.

3. UPDATED MARKET ANALYSIS

The maritime industry, a cornerstone of global trade, faces increasing pressure to decarbonize in response to international regulations, public demand, and environmental concerns. With over 90% of global trade transported by sea, reducing emissions in this sector is crucial for achieving global climate targets. Ship retrofitting, particularly for carbon capture and utilization (CCU), offers a viable pathway for reducing greenhouse gas (GHG) emissions without replacing existing fleets. According to Lloyd's Register Maritime Decarbonisation Hub's report, "Onboard Carbon Capture Utilisation and Storage (OCCUS): A Readiness Assessment for the Shipping Industry" (April 2023)[4], CCUS technologies represent a promising transitional solution for reducing carbon emissions in the shipping sector. These technologies are particularly suited for existing vessels where retrofitting for zero-carbon fuels is economically unfeasible. While the Technology Readiness Level (TRL) is relatively high (6–8) due to proven applications in non-maritime contexts, the Investment Readiness Level (IRL) and Community Readiness Level (CRL) remain significantly lower (2–3). These discrepancies are attributed to economic uncertainties, regulatory gaps, and limited real-world performance validation. The alignment between the maritime industry's pressing need for decarbonization and the promising potential of CCUS technologies highlights the critical role of targeted initiatives like the Green Marine. By bridging the gap between high technology readiness and the challenges of investment and community acceptance, Green Marine aims to address the barriers with a well defined exploitation strategy.

The following section aims to provide insights into the state of the art in the maritime industry that are relevant to shaping the deployment plan of Green Marine technologies and, more broadly, the future of decarbonisation in the maritime industry.

3.1 MARKET DRIVERS

The demand for retrofitting solutions in the maritime industry is driven by a combination of regulatory, economic, and environmental factors. These drivers create significant incentives for shipping companies to adopt advanced technologies that enhance efficiency and reduce emissions.

3.1.1 Regulatory Drivers play a critical role in shaping the market demand for retrofitting solutions. Compliance with the International Maritime Organization (IMO) regulations, including the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) metrics, is now mandatory for ship operators. These standards require vessels to meet strict benchmarks for fuel efficiency and carbon emissions, prompting many operators to consider retrofitting as a practical solution. Additionally, the European Union has introduced measures such as the inclusion of maritime emissions in the EU Emissions Trading System (ETS). This regulation effectively places a price on carbon emissions, creating a strong regulatory incentive for retrofitting technologies like carbon capture and energy efficiency systems.

The EU maritime sector comprises over 25,000 ships, including cargo, passenger, and service vessels. It accounts for approximately 13.5% of the EU's total transport emissions. The industry is subject to stringent regulations from the International Maritime Organization (IMO) and the European Union, including:

- IMO’s Initial Strategy on GHG Reduction (50% reduction by 2050 compared to 2008 levels).
- EU’s Fit for 55 package (55% reduction in emissions by 2030).
- Emission Control Areas (ECAs) in the Baltic and North Seas, enforcing stricter limits on sulphur and nitrogen oxides.

In July 2023, the IMO revised its GHG reduction strategy aiming to reach net-zero GHG emissions by 2050. The revised strategy aims to significantly curb GHG emissions from international shipping. The new targets include a 20% reduction in emissions by 2030, a 70% reduction by 2040 (compared to 2008 levels), and the ultimate goal of achieving net-zero emissions by 2050. The strategy now also addresses lifecycle GHG emissions from shipping, with the overall objective of reducing GHG emissions within the boundaries of the energy system of international shipping and preventing a shift of emissions to other sectors. To ensure that shipping reaches these ambitions, the IMO has decided to implement a basket of regulatory measures. **The measures will, according to the agreed timeline, be adopted in 2025 and enter into force in around mid-2027[5].**

According to “*REGULATION (EU) 2023/1805 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC”,* from 2025, shipping companies will report energy used on board their ships and their emissions through THETIS-MRV, operated and maintained by the European Maritime Safety Agency (EMSA). This system will act as a one-stop shop for companies, as shipping companies already report ships' emission data through THETIS-MRV for the EU ETS[6]. The targets for reducing the GHG intensity start small for 2025 with an overall reduction of - 2%, but then the targets become increasingly stringent up to an 80% reduction target in 2050.

Both sets of regulations are valid and ships operating in EU waters must comply with both, FuelEU Maritime includes additional requirements such as on-shore power supply use and financial penalties for non-compliance. The coexistence of these regulations highlights the complex regulatory landscape in maritime emissions reduction, with regional and global initiatives working in parallel to address climate change.

Detailed information on the regulatory framework for ship emissions is provided in deliverable *"D1.1 Engineering and Preparations for Retrofitting"* and shared with the Green Marine consortium.

3.1.2 Economic Drivers

One of the main reasons why marine industry is experiencing a shift towards retrofitting, is that it is a key strategy to overcome the economic challenges. This trend is driven by a few economic factors, including the need to reduce fuel costs by 10-30% through improved efficiency[7], compliance with stringent regulations like IMO's Energy Efficiency Existing Ship Index (EEXI)[8], and the potential to extend vessel lifespans[9]. The European market alone presents a substantial opportunity, with approximately 28,000 ships eligible for retrofits and an annual sector turnover of about 4 BLN EUR. Retrofitting enables shipowners to adapt to alternative fuels, potentially reducing long-term operational costs and improving environmental performance[10]. Additionally, upgraded vessels with enhanced sustainability features can command higher charter rates and attract environmentally conscious clients. As the industry progresses towards the IMO's ambitious net-zero emissions target by 2050, engine retrofitting is becoming a crucial element in the transition to a more sustainable future, with a projected 9,000-12,900 large merchant vessels identified as candidates for retrofitting by 2030[11].

3.1.3 Environmental Drivers

IMO forecasts that maritime trade could increase between 40% and 115% by 2050 in comparison to 2020 levels. About 99% of energy demand from the international shipping sector is met by fossil fuels, with fuel oil and marine gas oil comprising as much as 95% of total demand (IMO, 2020a). IMO warned that in the absence of suitable mitigation policies, GHG emissions associated with the shipping sector could grow between 50% and 250% by 2050. As mentioned earlier, this broad range presented by IMO illustrates the level of uncertainty in terms of how the sector will evolve over the next 30 years, but even the lower band increase would undermine efforts to limit global warming. To reduce the level of uncertainty, it is critical to plan in advance and analyse pathways to decarbonise the international shipping sector by 2050. In 2023 major decisions have been made regarding GHG ambitions and regulations. The IMO has revised its GHG Strategy, strengthening the ambitions for international shipping. The new targets include a 20% reduction in emissions by 2030, a 70% reduction by 2040 (compared with 2008 levels), and the ultimate goal of achieving net-zero emissions by 2050. New regulations are expected to enter into force around mid-2027. The EU has also agreed to include shipping in its Emission Trading Scheme (EU ETS) from 2024 and on setting requirements on well-to-wake GHG emissions (FuelEU Maritime) from 2025[12].

At last but not least, recently the COVID-19 has brought significant impacts on maritime industries since early 2020. First, the operators (e.g. shipowners, exporters, importers, terminal operators, shipping carriers, etc.) of these industries have faced operational losses and inconvenience due to health and safety consideration. For example, seafarers or passengers who entered or departed from international ports must be detected and received mandatory investigation and/or strictly quarantined for 14 days due to incubation of virus. These restrictions and regulations have inevitably affected the freight rates, charter rates, revenues and earnings as well as the utilisation of facilities and human resources. In particular, the cruise industries have faced huge losses since the cabins, nearly closed space, might increase the risk of infections. Strategies to mitigate these risks involve among others of limiting the air circulation within ships. This results in increased energy consumption, costs and increased emissions. It is like driving with your car window open with the air-conditioning on.

3.2 OVERVIEW OF THE RETROFIT MARKET

3.2.1 Ship Sizes and Their Retrofitting Potential The retrofitting potential varies according to ship size, and the technologies would be more efficient for some sizes, or the partners would be willing to focus the exploitation activities on a specific type of ship. For example, based on initial discussions conducted for the mid exploitation report to prepare the initial business models, partner CCM is more interested providing their services to large vessels for the potential future business case (more CO_2, available space, easy of retrofit etc.). Thus, the commercialisation plans will definitely take ship sizes into account. For this reason, the current market figures for the scale of EU maritime cluster, based on the ship sizes and ages are important for identifying the market opportunities. The following chart provides an overview of global ship registrations by flag, highlighting the number of vessels and their total deadweight tonnage (DWT) and gross tonnage (GT) across different jurisdictions[1].

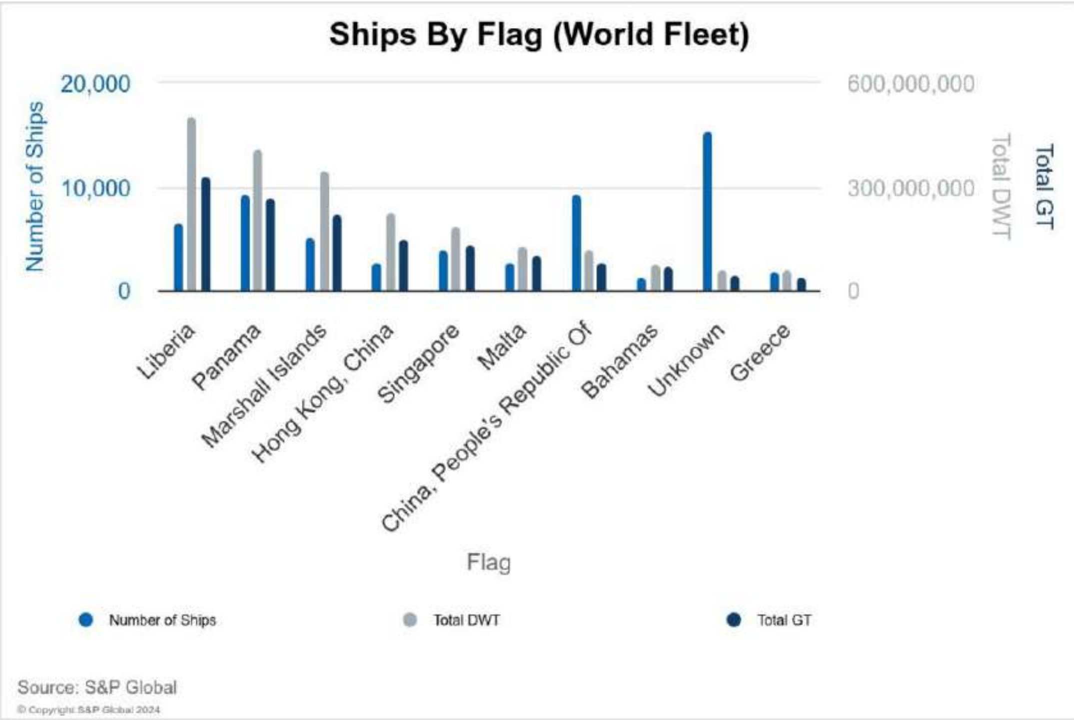

Figure 2. Number of ships registered under various national flags and their corresponding total deadweight tonnage (DWT) and gross tonnage (GT).

The EU member state flagged fleet represents a significant portion of the world's fleet [13]:

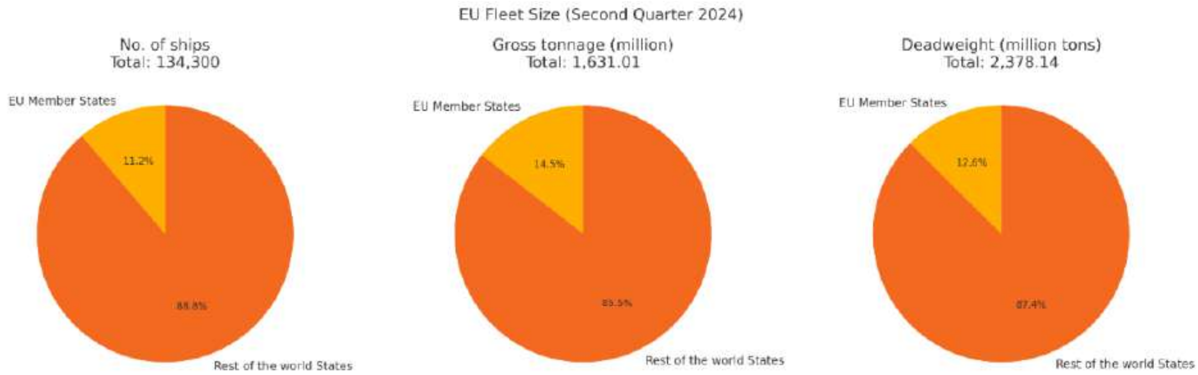

Figure 3. EU fleet size in the second quarter of 2024 (Source EMSA service data)

[1] Data obtained by CMMI by utilizing access to HIS Markit database (Reference: IHS Markit Global Sarl. SeaWeb; S&P Global Maritime & Trade. 2024. Available online: https://maritime.ihs.com/Account2/Index (accessed on 16 December 2024).) Green Marine would like to thank IHS Markit for providing raw access data of vessel characteristics

Among these, the flagged fleet encompasses a wide variety of vessel types, reflecting the diverse needs and operations of the European maritime sector. The following graph illustrates the distribution of ships by size (Small, Medium, Large, Very Large) and their age groups (0-4 years, 5-14 years, 15-24 years, and 25+ years). The distribution of ship sizes and their corresponding age groups is presented below.

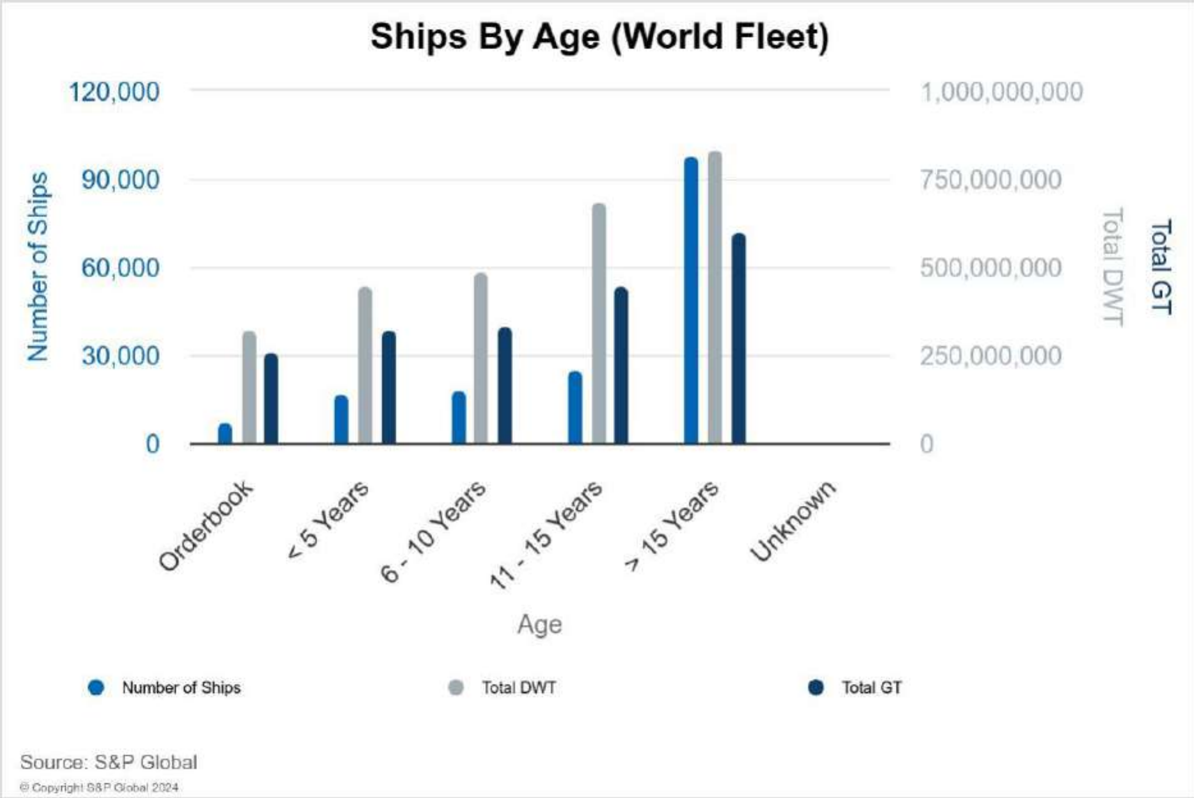

Figure 4.Ships by age (World Fleet)[1] above

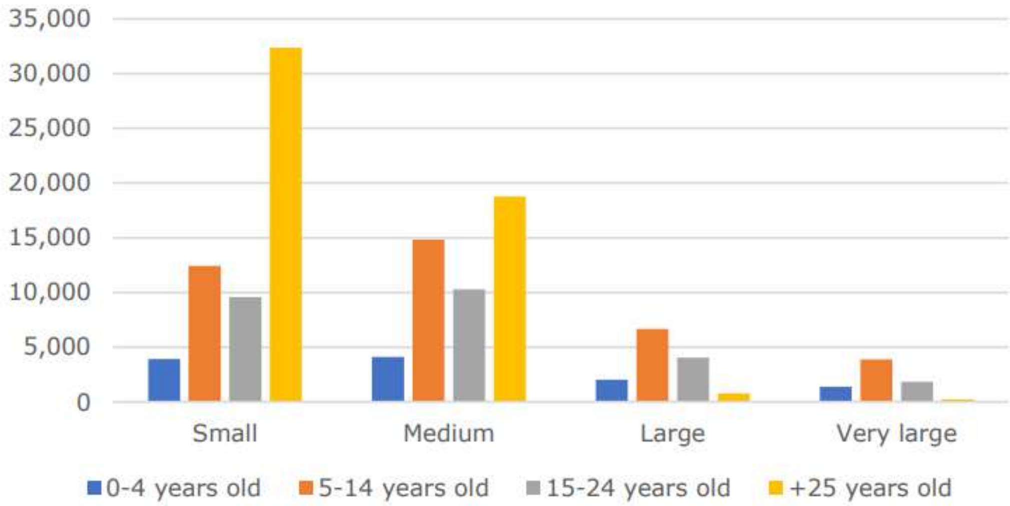

Figure 5. World wide distribution of ship size and age (Source EMSA service data)

From a retrofitting perspective, the following key insights are:

Older Ships (+25 Years):

- The largest proportion of older ships is concentrated in the Small and Medium categories, with over 30,000 Medium ships being 25+ years old. It needs to be determined if the business case is attractive for both ship owners/operators and the technology providers (i.e. CCM prefers to target the larger ships).

- Older vessels are ideal candidates for retrofitting, as they are likely operating with outdated technology, higher emissions, and less energy efficiency. Retrofitting these vessels with modern solutions like carbon capture systems, thermoelectric energy recovery, or air filtration technologies could significantly improve compliance with environmental regulations.

Mid-Aged Ships (15-24 Years):

- Medium and Large ships dominate in this category, with notable numbers in the 15-24 years range.
- Retrofitting for this group can help extend their operational lifespan while meeting stricter International Maritime Organization (IMO) regulations. Investments in retrofitting at this stage can reduce operational costs and improve fuel efficiency.

Newer Ships (0-4 and 5-14 Years):

- These ships show lower counts across all size categories, indicating fewer immediate retrofitting opportunities.
- However, they could benefit from modular or incremental retrofitting strategies, such as adding carbon capture membranes or energy recovery systems to keep up with future regulatory demands. Here the business case must be attractive for the ship owner/operator.

Small Vessels (<5,000 GT (Gross Tonnage))

Small vessels, those under 5,000 GT, include coastal ferries, small cargo ships, and fishing vessels. While these ships contribute only a minor share of total maritime emissions, their role in localized operations makes them important targets for retrofitting in specific regions. **However, limited onboard space presents significant challenges for installing carbon capture systems or other large retrofitting solutions. Additionally, the operators of small vessels often lack the capital for high-cost investments, which further restricts the scope of retrofitting.** Despite these limitations, the market potential for small vessels is moderate, particularly in Emission Control Areas (ECAs) where strict environmental regulations drive demand for lightweight and space-efficient retrofitting solutions, such as energy-efficient HVAC systems or solar panel integration.

It is important to note that small vessels will be subject to new EU regulations starting from January 2025. Specifically, the EU reporting and Validation (MRV) regulations will extend to general cargo vessels with a gross tonnage of 400 to 5000 and the offshore vessels of 400 GT and above[14,15].

While their numbers are significant in older categories, the ROI (Return on Investment) for retrofitting small ships may be lower due to limited operational capacity and lower emissions compared to larger vessels. Retrofitting efforts could focus on cost-effective technologies, like air filtration or lightweight components.

Within Green Marine the Calmac MV Coruisk is a 1600 GT vessel without HVAC[16]. By targeting this vessel the consortium is investigating the viability of the most challenging category of ship sizes in techno-economic terms.

Medium-Sized Vessels (5,000–20,000 GT)

Medium-sized vessels, which range from 5,000 to 20,000 GT, include regional ferries, container feeders, and bulk carriers. These ships are significant contributors to emissions, especially in coastal and short-sea shipping routes. Their larger size provides more flexibility for retrofitting, allowing the adoption of modular solutions such as Carbon Capture and Utilization (CCU) systems. This category of vessels also has the capacity to integrate advanced technologies like membrane-based CO_2 capture and waste heat recovery systems, making them highly feasible for retrofitting. The market potential for medium-sized vessels is high, driven by their prevalence in regional trade routes and the pressure to comply with European Union regulations and emissions trading schemes.

With the highest number of older vessels, retrofitting efforts could focus on this category, targeting technologies that significantly improve efficiency and emissions control.

Large Vessels (>20,000 GT)

Large vessels, which exceed 20,000 GT, include the biggest players in maritime transport such as large container ships, tankers, and cruise ships. These vessels are the largest emitters due to their immense fuel consumption, with some large container ships emitting as much CO_2 as millions of cars annually. However, their size provides ample space for advanced retrofitting solutions. Carbon Capture Utilization (CCU) technologies and thermoelectric systems for waste heat recovery are particularly effective for these vessels. Additionally, technologies like ultrasound air-reuse systems for HVAC and syngas production for fuel savings can be implemented to significantly reduce emissions. The economies of scale associated with retrofitting large vessels make these upgrades cost-effective, offering the greatest potential for impactful decarbonization. These vessels dominate transcontinental trade routes and face intense regulatory and consumer pressure to adopt sustainable technologies, which makes their market potential exceptionally high**. These vessels, though fewer in number, offer higher retrofitting potential due to their scale and operational footprint. The focus should be on impactful technologies, such as comprehensive carbon capture and energy recovery systems.**

The graph below illustrates the trends in vessel decommissioning over the past decade, highlighting fluctuations in the number of ships retired annually and their corresponding total deadweight tonnage (DWT) and gross tonnage (GT).

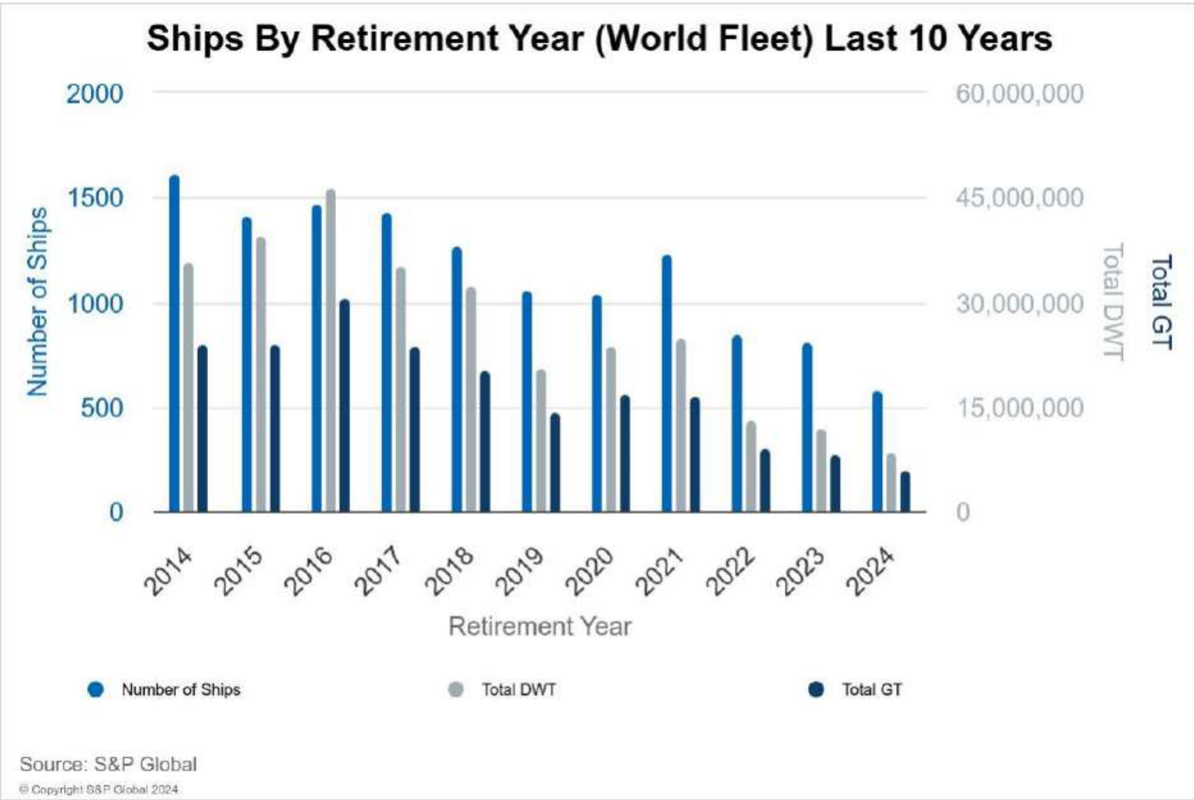

Figure 6. Ships by retirement year last 10 years [1]

The data shows a peak in retirements between 2014 and 2017, followed by a decline in later years, with a particularly sharp drop in 2023 and 2024. This trend suggests that shipowners are increasingly opting to extend the operational lifespan of vessels through retrofitting rather than retiring them outright. From a retrofitting perspective, the decline in ship retirements post-2021 indicates that many shipowners are choosing to upgrade existing vessels rather than invest in new builds. As new retrofitting solutions have become more cost-effective, shipowners now appear more willing to invest in them. The sharp decline in retirements in 2023 and 2024 may also reflect strategic decision-making within the industry, as shipowners anticipate further technological advancements in zero-carbon solutions and seek to align their fleet investments with the IMO's 2050 decarbonization roadmap. Additionally, supply chain disruptions in shipbuilding, high new-build costs, and uncertain fuel pricing may have discouraged fleet renewal, further reinforcing the need for cost-effective retrofitting options. These insights present a significant opportunity for Green Marine technologies to position themselves as key players in the sustainable transformation of the maritime sector.

3.2.2 Competitive Landscape

The competitive landscape of maritime decarbonization has intensified recently as the industry approaches key regulatory milestones. Shipowners and operators are increasingly investing in cleaner technologies and fuels to meet stringent emissions targets set by the IMO and the European Union. Companies are exploring a range of solutions, including more efficient engines, cleaner fuels. Like biofuels and bridging fuels such as LNG. Also, innovative technologies such as wind-assisted propulsion and air lubrication systems[17]. The market is seeing a shift towards greener vessels, with charterers and cargo owners favouring ships with lower emissions, creating a competitive advantage for early adopters. Additionally, there's a growing focus on developing green shipping corridors, with major ports and shipping companies collaborating to establish routes for vessels running on zero-emission fuels[18]. The industry is also witnessing increased demand aggregation efforts, such as the Zero Emission Maritime Buyers Alliance, which aims to drive the adoption of zero-emission vessels through collaborative procurement[19]. As the 2025 deadline for the FuelEU Maritime Regulation approaches, companies are strategizing to meet the initial 2% reduction in greenhouse gas intensity, with some analysts suggesting that existing fuel mixes may satisfy up to 90% of the needed reductions for that year[20].

3.2.2.1 Decarbonisation efforts

Several key technologies are currently driving maritime decarbonization efforts as the industry strives to meet ambitious emissions reduction targets. According to DNV's "Maritime Forecast 2050", the competing key decarbonisation technologies include[12]:

- Alternative Fuels: Shipowners are exploring cleaner fuel options such as liquefied natural gas (LNG), methanol, ammonia, and hydrogen. Ammonia and methanol engines are among the most cost-effective options for decarbonizing merchant marine ships [21].
- Wind-Assisted Propulsion: This technology has already generated annual fuel savings of 5% to 9% for certain ships, with the potential to reach 25% savings.
- Air Lubrication Systems: These systems are used to reduce hull friction, improving fuel efficiency and reducing emission. ALS is reported to reduce fuel consumption and associated CO_2 emissions by 5-10% in most cases [22].
- Onboard Carbon Capture (OCC): This technology is considered potentially the most effective way to decarbonize, as it enables the continued use of conventional fuels while capturing emissions.
- Solid Oxide Fuel Cells: These can convert fuels like ammonia, LNG, methanol, and hydrogen into electricity with significant energy efficiency potential.(electrical efficiencies of up to 60%,

SOFCs running on natural gas can achieve CO_2 reductions of approximately 30-56% compared to conventional grid electricity or diesel-based systems[23])

- Digital Fleet Management Systems: Technologies like Smart Ship Viewer use satellite communication to optimize navigation, weather monitoring, and route planning, leading to improved fuel efficiency.
- Waste Heat Recovery: These units capture heat from ship engines to power auxiliary equipment or generate electricity, reducing overall fuel consumption[24].
- Improved Ship Design: Enhancing vessel design for better hydrodynamics and energy efficiency is a key focus area.
- Shore Power and Electrification: Providing electric power to ships while docked can reduce emissions from onboard generators, potentially cutting the 7% of total energy consumption that ships use in ports. Vessels at anchorage are usually located some distance offshore and are not physically connected to port infrastructure. This makes it challenging to provide shore power to these ships using conventional methods. To address emissions from anchored vessels, alternative solutions are needed.
- Digital Twin Technology: This technology uses onboard and environmental data to provide fuel efficiency advice, potentially delivering reduced emissions and cost-effective vessel energy management.

A closer look at the carbon capture and utilisation is crucial for the analysis of the competitive landscape of Green Marine solutions.

3.2.2.2 Carbon Capture and Utilization

Carbon capture technologies are in nascent stages within the maritime sector but show significant promise. The EU Emissions Trading System is currently the only regulatory framework incentivizing onboard carbon capture, though not including a verifiable method to measure and monitor the derogated emissions. The International Maritime Organization (IMO) is planning to include onboard carbon capture in its Lifecycle Assessment (LCA) Guidelines. In March 2024, MEPC 81 established a group to develop a regulatory framework for using onboard carbon capture systems[25].

Key technologies include:

1) Membrane-Based Carbon Capture

Membrane-based carbon capture systems rely on selective membranes to separate CO_2 from exhaust gases. These systems are compact and lightweight, making them highly suitable for retrofitting existing vessels where space is often limited. Pilot projects in the European Union have demonstrated the potential of these technologies, particularly on medium and large vessels. However, the high cost and complexity of integration remain significant barriers to widespread adoption.

As of 2024, membrane-based carbon capture processes for marine decarbonization are still in the development and testing phase, rather than in widespread commercial use. However, significant progress has been made in this area:

- A feasibility study and conceptual design of an onboard carbon capture and storage system using membrane technology was conducted from July 2024 to April 2025 by Zenith Purification LLC, in collaboration with Lamar University and The Ohio State University[26].The proposed system combines a new generation of polymeric CO_2-removal membranes with commercially available gas cleaning systems, aiming to capture 95% CO_2, reduce 99% of SOx, and 90% of NO_x emissions.
- Membrane contactors are being explored as a potential solution for maritime CO_2 capture due to their modular nature and smaller size compared to traditional packed separation columns, which is advantageous in the space-constrained environment of ships[27].

While membrane-based systems for carbon capture are being researched, they are currently seen to have a large footprint and are energy-intensive, which poses challenges for practical implementation in marine environments[28].

A project called MemCCSea, aimed at developing hyper-compact membrane systems for flexible and cost-effective post-combustion CO_2 capture at sea, has been proposed[29]. A study has proposed an onboard membrane carbon capture and liquefaction system specifically for LNG-fuelled ships to meet the IMO's 2050 greenhouse gas reduction targets[30].

Despite these developments, membrane-based carbon capture technologies for marine applications are not yet in widespread commercial use. The industry is still working on optimizing these systems for the unique challenges posed by the maritime environment, such as space constraints, energy efficiency, and durability in harsh conditions.

Error! Reference source not found. illustrates that in this region, CO_2 will be in the gaseous phase. Liquefaction of compressed CO_2 is more challenging, especially on-board confined spaces since the temperature must decrease and/or the pressure must increase. Thus, requiring advanced CO_2 liquefaction cycles.

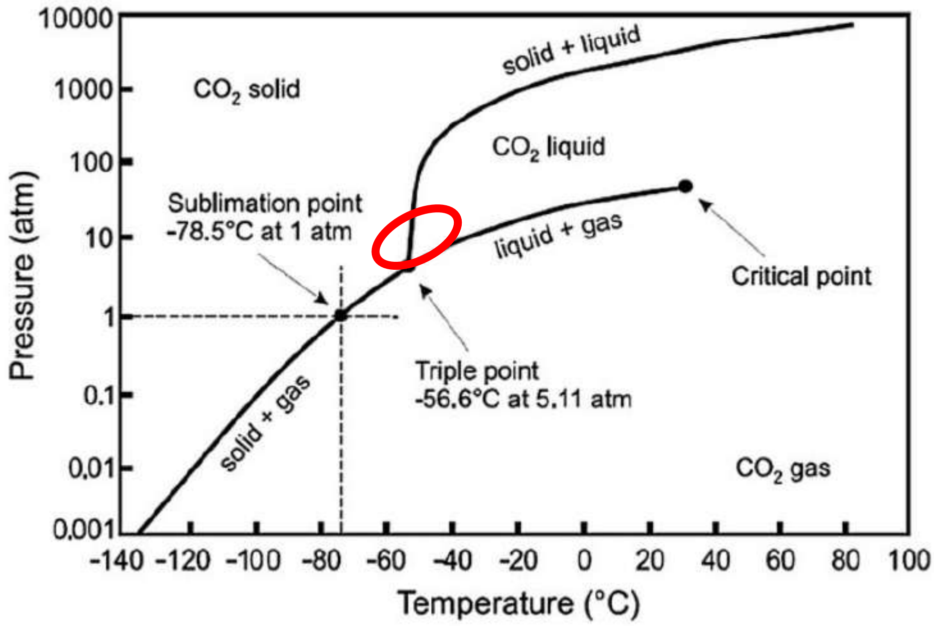

Figure 7 CO_2 phase diagram, obtained from study by Kvamsdal et. al, which was adapted from MAN[31]. Typical operating envelope of compressed/liquefied CO_2 on-board vessels is shown in red. The envelope includes liquefaction of CO_2.

Kvamsdal, et al. (2016) in their modelling[32] mention that additional drying is needed to reach a water content of lower than 50ppmv. Thus, flash separation is included to cool the mixture and also remove condensation. Due to low water concentrations specialised equipment in drying are used by Kvamsdal et. al, however on-board a vessel with limited space etc specialised equipment are not considered in this case study. Usually a multi-stage compressor with intercooling is needed. For example, an optimised multi-stage compression of CO_2 is depicted below. The minimum temperature after intercooling must ensure that CO_2 is in the superheated state.

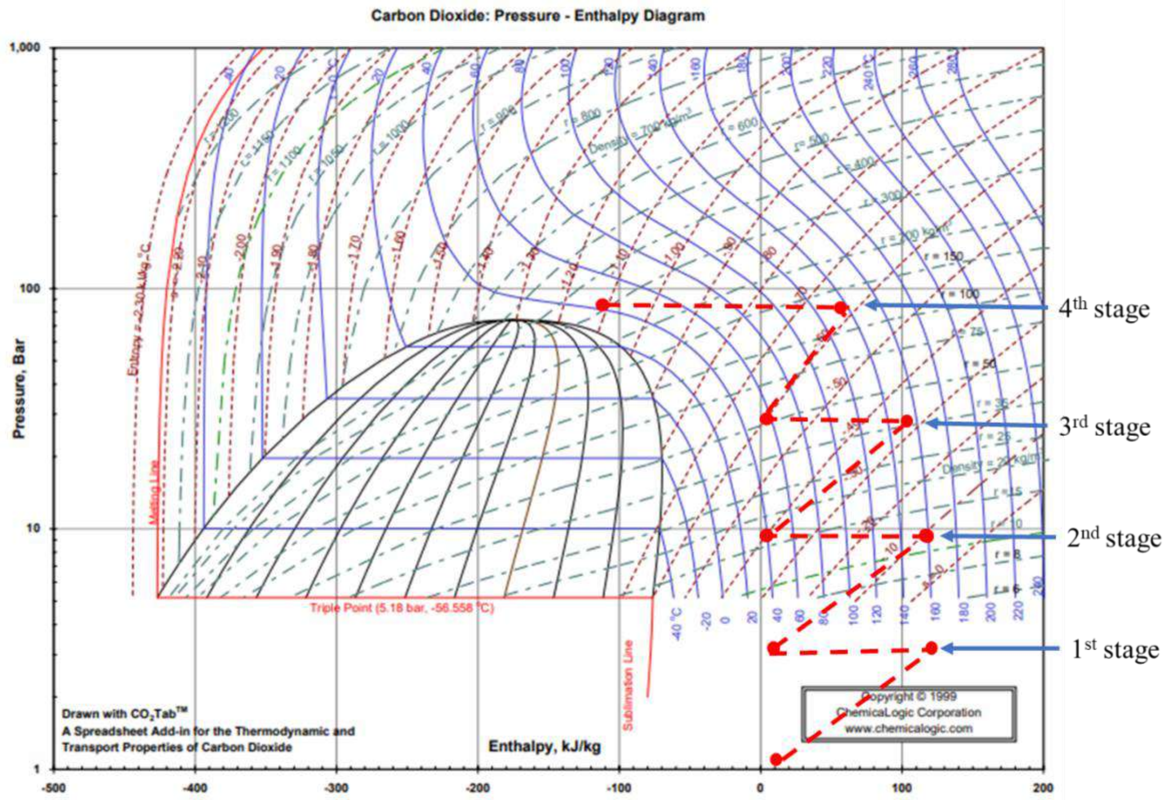

Figure 8. CO_2 Mollier diagram illustrating multi-compression stage[33].

2) Amine-Based Scrubbing

Amine-based scrubbing technology utilizes amine solutions to absorb CO_2 from flue gases, a method already proven in other industrial applications. Its primary advantage lies in its high capture efficiency, which makes it an effective tool for substantial emission reductions. However, adoption within the EU maritime sector has been limited due to the technology's weight and space requirements, which make it less suitable for vessels with size constraints. Additional challenges include corrosion risks and the high energy consumption needed to regenerate the amine solution, which can impact the overall efficiency of the system

3) Cryogenic Carbon Capture

Cryogenic carbon capture involves chilling exhaust gases to condense and separate CO_2, producing a high-purity output. This technology shows promise for applications requiring clean CO_2 streams, such as carbon utilization or storage. Early-stage testing is underway in the EU, but the high energy demands and the large size of the required equipment pose challenges to its implementation, particularly on smaller vessels or those with limited power availability.

4) Adsorption Technologies

Adsorption technologies use solid materials to adsorb CO_2 from exhaust gases. These systems benefit from regenerable adsorbents, which can be reused multiple times, and their scalability makes them a flexible option for retrofitting vessels of varying sizes. However, these technologies are still in experimental stages within the EU, with durability being a primary concern. Maritime environments can be harsh, and ensuring the long-term performance of adsorbents remains a technical hurdle.

5) Hybrid Systems

Hybrid systems combine two or more carbon capture technologies to optimize performance and overcome the limitations of individual methods. For example, a system might integrate membrane technology with cryogenic capture to balance efficiency and energy demands. Hybrid systems are flexible and adaptable, making them a promising option for future retrofitting. However, adoption remains limited due to the high costs associated with development and operation, as well as the complexity of integrating multiple technologies into a single system.

Trade-offs – The energy paradox: Following the discussion of onboard carbon capture methods, it is essential to assess their feasibility and the trade-offs involved in their implementation. Onboard carbon capture systems require energy—typically heat and electricity—to operate, leading to increased fuel consumption, known as a "fuel penalty." Balancing emissions reduction with this penalty is a critical challenge, as systems with higher capture rates may achieve significant emissions reductions but often demand substantial energy, impacting their operational and economic viability (*and their emissions*). Current pilot projects worldwide aim to address knowledge gaps and optimize these technologies for maritime use. Research confirms their safety for shipboard application, but further development is needed to improve integration and efficiency. DNV provides a guideline (**DNV-CG-0667[34]**) with a comprehensive framework for the safe implementation of Onboard Carbon Capture and Storage (OCCS) systems on ships, addressing the growing need to reduce GHG emissions in the maritime industry. As alternative fuels may not be feasible for all vessels, DNV sees OCCS is emerging as a potential solution to meet IMO and national emission reduction goals. According to DNV's analysis[35], onboard carbon capture could become commercially viable if high capture rates, low fuel penalties, and affordable CO_2 storage costs are achieved, especially under regulatory frameworks and market mechanisms like carbon pricing.

The marine retrofitting market for decarbonization is experiencing significant growth and the competitive landscape is characterized by a mix of established industry leaders and mid-sized companies. Commercial marine retrofitting solutions for decarbonization are becoming increasingly important as the shipping industry strives to meet stringent environmental regulations and sustainability goals. Several companies are at the forefront of providing these solutions:

- MAN Energy Solutions: Offers dual-fuel engine retrofits, allowing ships to run on greener fuels like methanol. Provides retrofit solutions for converting existing engines to run on synthetic fuels, both gaseous and liquid.
- Wärtsilä: Offers onboard carbon capture technology for both retrofit installations and newbuilds.

3.2.3 Barriers to Market Entry: The marine retrofitting market for decarbonization faces several significant barriers to entry, which can hinder the widespread adoption of green technologies and solutions. These barriers present challenges for both new entrants and existing players in the market.

High Costs: One of the primary barriers to market entry is the substantial financial investment required for retrofitting vessels.

Initial Investment: The cost of retrofitting is a major obstacle, with 45% of respondents in a UK Chamber of Shipping study identifying it as a significant barrier. This high upfront cost can deter shipowners from pursuing retrofitting options.

Operational Expenses: The use of alternative fuels like renewable methanol or ammonia can significantly increase fuel costs, in some cases more than doubling expenses for vessels across all segments.

Technical Challenges: Integrating new technologies with existing ship architectures presents complex technical hurdles such as system Integration and design modifications.

Regulatory compliance: The evolving regulatory landscape as well as the unique standards of specific vessel types creates uncertainty for market penetration.

Within Green Marine, the above barriers/market entry constraints are investigated. Green Marine has initiated the process to demonstrate its technologies on CalMac **MV Coruisk** with the aim to determine the technical and other challenges, to verify the technology in-principle and consider class certification. The above will be conducted with close follow up from the regulatory bodies (UK MCA), Classification Society (LR) and ship operator to ensure all stakeholders requirements are met. All Green Marine technologies, whether selected for demonstration or not, will undergo the Approval in Principle (AiP)[36] procedure. This process provides an initial validation of their feasibility for installation on board a vessel. Obtaining AiP certification can enhance credibility and support efforts to secure funding, investment, and loans by demonstrating the technology's potential viability.

4. EXPLOITATION PLANS FOR KEY EXPLOITABLE TECHNOLOGIES OF GREEN MARINE

As part of the Green Marine 2nd exploitation report, we have mainly adopted the Business Model Canvas approach to systematically evaluate and outline the commercial potential of our key technologies, including the software tools. This approach allows for a comprehensive analysis of each component of the business model, such as value propositions, customer segments, key activities, and revenue streams. While this structured methodology provides a clear framework for commercial strategy, it is important to note that detailed financial projections are not yet available due to the current development stage of the technologies. The absence of validated cost data and market pricing limits the depth of our financial analysis at this time. The following sections present the outcomes of our work using the Canvas methodology. Each component of the business model has been analysed based on the current status of the technology, existing partnerships, and industry needs. The subsequent explanations provide a detailed breakdown of our approach to market entry, customer engagement, revenue generation, and scalability strategies for the technologies with a preliminary market penetration strategy.

However, it is important to note that, given the current low Commercial Readiness Level (CRL) of the technologies and the fact that demonstration tests are still pending, this business models represent a preliminary approach. They have been developed based on input provided by project partners through discussions and questionnaires. Each section of the business models reflects the feedback from the technology providers, who contributed insights into their respective areas of specialization. The information presented here is therefore derived directly from their responses and is intended as a foundational framework to guide future exploitation activities as the technologies progress toward higher readiness levels and market validation.

4.1. Air filtration Solutions - SepaRaptor with UV

4.1.1 Updated Business model

1) Key Partnerships and Development Activities

The success of the SepaRaptor system relies on establishing partnerships with UV technology providers, filtration manufacturers, shipbuilders, and R&D institutions. These collaborations are essential for developing advanced components, ensuring seamless integration with HVAC systems, and driving innovation. Close coordination with regulatory bodies and maritime associations is also critical to align the system with future air quality standards. Development activities include prototyping, performance testing, and microbial removal validation to optimize the system for various vessel configurations. In parallel, plans are being developed to provide customer support services, including training, installation guidance, and after-sales assistance. Marketing strategies will focus on showcasing the technology's potential through targeted outreach, trade shows, and industry engagement.

Key partners for the SepaRaptor technology will first include UV technology providers, as UV sterilization is one of the main components of this dual-function system. Collaborations with UV tech suppliers ensure access to high-quality components that meet the durability and efficiency requirements of maritime environments. Shipyards and retrofit firms will also play a critical role, as they are essential for integrating the SepaRaptor system into existing vessels during retrofitting operations. Partnerships with regulatory authorities like the IMO and EU agencies will ensure the technology's certification and compliance with emission standards, helping to facilitate market entry. Additionally, industry associations such as maritime trade bodies will help raise awareness and promote adoption of the technology across the shipping sector.

2) Key activities

Key activities for the SepaRaptor include research and development focused on optimising the efficiency and durability of the system to cope with the challenging conditions of marine operations. Pilot tests will be carried out on shore and, if the technology is selected for on-board demonstration. Separaptor technology involves two approaches:

- The SepaRaptor with UV technology for air ventilation:
- In combination with the membranes as pre-treatment

The effectiveness of the technologies should be approved in principle. Therefore, certification processes in collaboration with regulatory bodies are crucial not only to build customer confidence and market acceptance, but also to meet the regulatory requirements to enable the technology to be installed on board. Manufacturing and supply chain management activities will ensure timely production and delivery of the system. Additionally, marketing and stakeholder engagement are the key activities that will promote the system to ship operators and retrofit firms.

3) Value Proposition and Market Potential

According to partner SMP, the novelty and the value preposition of SepaRaptor with UV technology is described below:

Competitiveness and the unique value: For all common filters three retention principles apply as illustrated in the picture below:

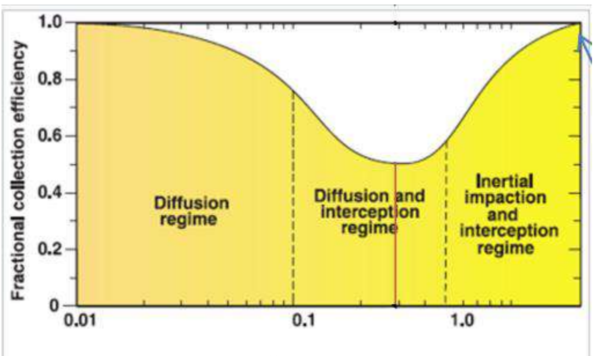

Figure 9. Particle Collection Efficiency as a Function of Particle Size

For particle with size from 0,01 µm to around 0,1 µm the diffusion regime operates in the fractional collection efficiency (FCE) of particles, with an efficiency range from 70 to 100 %. From 0,1 µm to around 1,0 µm the diffusion and interception regime overlap, generating the lowest FCE of filters of around 50%. With increasing particle size, from 1,0 µm the FCE is still low at around 60%, it increases up to 100% where the inertial impaction and interception regime operates until total interception of particles is guaranteed by the filter. The red line in the graph is the most penetrating particle size (MPPS). Which is the particle size by which filter classes are judged. True HEPA filters significantly improve the FCE, up to 99,97 %. But these are not the units being installed in HVAC systems due to its high cost and high energy demand. While other filters have significant lower efficiencies, their CADR can be much higher (commercial HVAC units have a volume flow of around 5000 m3/h) also filtering out the MPPS by repetition. And this is where the SepaRaptor can be an in-line improvement to existing systems, by which through agglomeration, as illustrated by independent testing in the Picture below, the MPPS are filtered out by agglomeration and therefore removed from the air cycle.

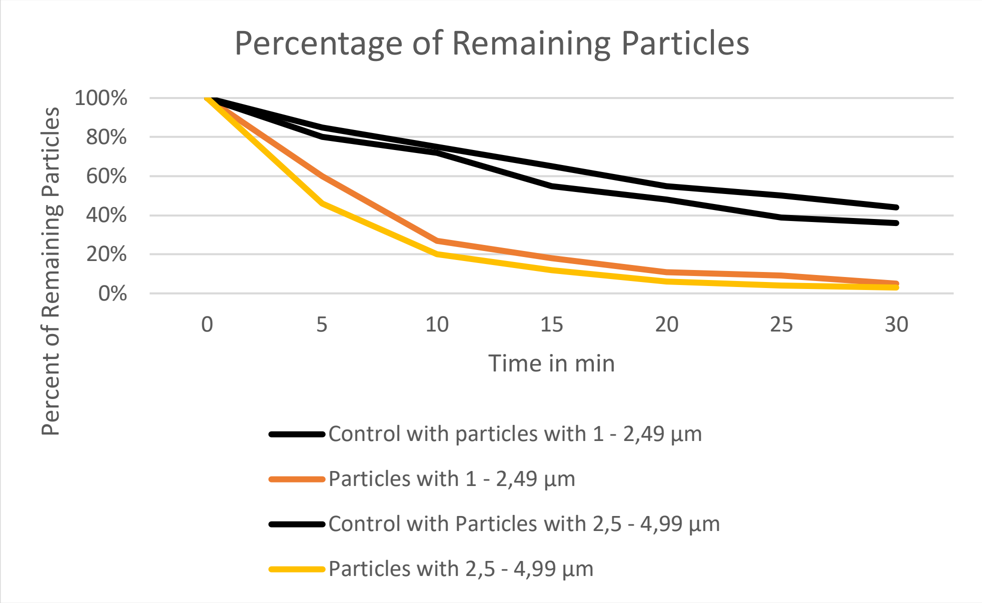

Figure 10. Percentage of Remaining Particles Over Time: Comparison of Control and Test Samples for Different Particle Size Ranges

The unique value therefore lays in cheap in-line implementation of a very low power consumption device with minimal resistance to the ventilation system and significant improvement of > 60 % for PM 2,5 particles for the usually used MERV filters.

The Separaptor with UV is an industrial solution designed for integration into HVAC systems, differentiating it significantly from commercially available small-scale devices like the Atmofizer. While the Atmofizer is a standalone household device with a volume flow of ~80 m³/h, the Separaptor is built to handle significantly larger flows—leveraging the 60-times higher volume flow of existing HVAC systems. This results in a 40% higher clean air delivery rate (CADR) for hazardous PM2.5 particle sizes with less than a 1% increase in power consumption. By operating in-stream within HVAC systems, the Separaptor could potentially achieve an overall CADR increase of up to 60 times, delivering clean air at industrial scales without the need for excessive energy use.

The Separaptor system is expected to deliver significant value to the maritime industry by addressing key challenges related to onboard air quality. Its anticipated benefits include:

- Improved air hygiene: Removes airborne microbes, allergens and harmful particles to promote health on board. The dual-function system has been experimentally proven to reduce aerosols and sterilise the air, creating a healthier atmosphere for crew members.
- Health and Safety Compliance: Alignment with future international air quality standards to reduce risks associated with airborne diseases. The Separaptor will need to ensure compliance with stringent ECA and IMO air quality standards, enabling operators to avoid penalties.
- Energy Efficiency: A low-energy design to support maritime sustainability goals.
- Ease of Integration: Compact and adaptable for retrofitting into existing HVAC systems with minimal modifications. The system is planned to be modular and space-efficient, making it suitable for retrofitting older vessels with limited space.

As there is no HVAC system and no HEPA filter on board of the MV Coruisk the consortium plans to carry out a pilot test, which can serve as a reference for larger ships (e.g. cruise ships). To this end, the SepaRaptor units are to be set up in the crew rooms and the bridge of the vessel. Crew members should also be persuaded to take the devices home and install them there. A clinical study together with an external laboratory and physician will be performed to assess the results and performance of the standalone system.

The initial target market for the technology could include commercial shipping operators, cruise lines, naval and military fleets, and offshore platforms. Additional opportunities exist with shipbuilders and retrofitting companies seeking to incorporate advanced air purification systems into new builds or retrofits. As the technology increases it commercial readiness level, promotion activities through B2B meetings can already be started.

4) Revenue Potential and Cost Structure

According to SMP, although the technology is not yet commercially available, the preliminary revenue model anticipates income from system sales, subscription-based maintenance and component replacement, and retrofitting services. This financial projections on the CAPEX and OPEX values are given separately below. According to the pre-liminary business plan projections, future revenue opportunities may include training and certification programs as well as licensing agreements for broader adoption of the technology. The cost structure will include expenses for research and development, prototype production, regulatory compliance efforts, and marketing initiatives. Initial operational costs will cover technical support and field validation activities. Land based and on board demonstrations with detailed TEA is not yet available. Therefore, additional details on the cost structure will be provided in the next report which will be prepared at the end of the project period.

The Potential revenue streams are:

- **Direct Sales:** Revenue will primarily come from selling Separaptor units tailored for HVAC systems in industrial and commercial settings.
- **Maintenance and Predictive Support:** Additional income streams from maintenance contracts and predictive maintenance services, ensuring optimal performance and reduced downtime.
- **Partnership Licensing:** Collaboration with HVAC manufacturers to integrate Separaptor technology directly into new systems, generating licensing fees.
- **Retrofitting Packages:** Tailored packages for retrofitting existing HVAC systems, targeting industries and regions with strict air quality regulations.

5) Channels and Competitive Position

The Separaptor system can be promoted through direct client engagement, an online platform, trade shows, and publications in maritime industry journals. Early demonstration projects will play a pivotal role in building credibility and showcasing the system's capabilities to potential adopters.

The system is positioned to offer a competitive edge through its innovative UV-based microbial removal technology, low-energy consumption, and flexibility for retrofitting. This combination is expected to make the Separaptor an attractive solution for addressing growing health and regulatory demands in the maritime sector.

Key differences of Separaptor with UV technology with the existing alternatives:

1. **Scale and Efficiency:** Unlike localized air purifiers, the Separaptor operates at industrial scales, addressing the needs of large spaces like commercial buildings, hospitals, and transportation hubs.
2. **Integration with Existing Systems:** The system integrates seamlessly into HVAC units, minimizing installation complexity and leveraging existing infrastructure to reduce costs.

3. **Energy Efficiency:** Agglomerates particles before filtration, reducing clogging and lowering energy consumption by reducing fan and ventilator workload.
4. **Improved ROI Metrics:** Offers long-term benefits such as reduced employee sick days, better air quality, and increased filter longevity, which justify the initial investment.

Business Model Canvas

Designed For : Separaptor with UV

Designed by: A Secer & L.Daal

Date: 24.01.2025

Version:0.2

Key Partners

- •Piezo and UV tech providers
- •Air filtration manufacturers
- •Shipbuilders and HVAC companies
- •Maritime health safety regulators

Key Activities

- •System Development and Testing
- •Regulatory Compliance
- • Regular tests & validation- removal effectiveness
- •Manufacture of key parts
- •Customer Support: Providing training, installation guidance, and technical assistance
- •Marketing and Industry Outreach

Key Resources

- **UV and Filtration Technology**: Core components of the Separaptor system.
- **Testing Facilities**: Infrastructure for microbial removal validation and performance testing.
- Technical expertise, IP

Value Propositions

- Enhanced Air Quality
- Health and Safety
- Energy Efficiency: UV and filtration technologies designed to operate with minimal energy consumption.
- Regulatory Compliance: Ensures compliance with international air quality and health regulations.
- Compact and Adaptable Design: Easy integration into existing HVAC systems without major modifications.

Customer Relationship

- •Ongoing technical and operational support through helpdesks and field technicians.
- •**Feedback Loops**: Collecting customer feedback for continuous product improvement.
- •**Long-Term Partnerships**: Building trust with clients through performance guarantees and reliable after-sales service.

Channel

Direct Sales

-Online Platform: Cloud-based software accessible via subscription.

-Trade Shows and Conferences: Showcasing the tool at maritime industry events

-Online advertising, webinars, and email campaigns targeting maritime professionals

Industry Publications: Feature articles and advertisements in maritime journals.

Customer Segments

Regional :

- EU

Industrial:

- Shipyards & Retrofit service providers
- Ship owners,
- ship operators
- Governmental and regulatory organizations

Cost Structure

- •**R&D Costs**: Expenses for system development, testing, and microbial removal validation.
- •**Manufacturing Costs**: Production of UV components, filters, and supporting hardware.
- •**Regulatory and Certification Costs**: Expenses for compliance testing and certification.
- •**Personnel Costs**: Salaries for engineers, microbiologists, and support staff.
- •**Marketing**
- •**After sales support:** Maintenance, repair, and customer service costs.

Revenue Stream

-Direct Sales: One-time revenue from selling the Separaptor system. Recurring revenue for maintenance and replacement parts (e.g., UV lamps and filters).

Retrofitting Services: Additional revenue from system installation and retrofitting.

Licensing Fees: Revenue from licensing the technology to third parties. ?

Figure 11. Business Model Canvas- SepaRaptor with

4.1.2 Risks and Mitigation

Partner SMP identifies the following risks:

Market acceptance: Because filter technologies are hard to understand / invisible and represent an investment with no immediate ROI, while improved parameters are expected to result in fewer sick days and longevity gains as better air with reduced inhalation of hazardous particles. The decision to implement lies with business managers who must invest in future benefits with potentially difficult to measure KPI's. In the long term, higher filter efficiency with less filter clogging (and therefore lower fan/ventilator power consumption) is expected, as the agglomeration of particles occurs before the filter, so the amount of PM 2.5 particles is reduced by agglomeration, increasing the particle size. This applies to all nano- and microparticle sizes.

Mitigation Strategies: Evaluate whether a built-in particle size distribution sensor, similar to those used in DYSON vacuum cleaners, is integrated into the machine. However, these sensors are known for their inaccuracy, which could limit their reliability. A trial is currently underway with CalMac to assess whether the SepaRaptor contributes to a measurable reduction in sickness-related absences. To effectively communicate the impact to C-level executives and management, a clear and easily measurable KPIs must be identified.

4.1.3 Financial Projections

CAPEX (Capital Expenditures):

The current values for the breakdown of the costs for CAPEX are provided by partner SMP as below:

	WPS/SMP	Green Marine Business plan	Separaptor lifetime [years]			5
ESTIMATED CAPEX FOR THE SEPARAPTOR WITH UV						
Group ID	**Subgroup ID**	**Costs group**	**Cost**	**Subgroup costs**	**Estimated lifespan**	**Annual CapEx estimate**
1		HARDWARE COSTS				
	a	Separaptor unit and components	500,00 €		5	100,00 €
	b	Instrumentation and controls	- €		5	- €
Subgroup costs				500,00 €		
2		SOFTWARE COSTS				
	a	Control and automation software	- €		5	- €
Subgroup costs				- €		
3		ENGINEERING AND DESIGN				
	a	System Design and Engineering	160,00 €		5	32,00 €
	b	Compliance and Permitting	160,00 €		5	32,00 €
Subgroup costs				320,00 €		
4		INSTALLATION AND COMISSIONING				
	a	Installation	100,00 €		5	20,00 €
	b	Testing and comissioning	- €		5	- €
Subgroup costs				100,00 €		
Total Costs			920,00 €			184,00 €

Figure 12. Estimated CAPEX for the SepaRaptor Unit

OPEX (Operational Expenditures)

The current values for the breakdown of the costs for CAPEX are provided by partner SMP as below:

	WPS/SMP	Green Marine Business plan	Separaptor lifetime [years]			5
ESTIMATED OPEX FOR THE SEPARAPTOR WITH UV						
Group ID	**Subgroup ID**	**Costs group**	**Cost**	**Subgroup costs**	**Estimated lifespan**	**Annual OpEx estimate**
1		ENERGY COSTS				
	a	Separaptor operation	77,00 €		1	77,00 €
	b	Control system and sensors	- €		1	- €
Subgroup costs				77,00 €		
2		MAINTENANCE AND CONSUMABLES				
	a	Duct cleaning	- €		2	- €
	b	Consumables	- €		5	- €
Subgroup costs				- €		
3		LABOR COSTS				
	a	Technician salaries	- €			
	b	Monitoring and Operations	70,00 €		1	70,00 €
Subgroup costs				70,00 €		
4		COMPLIANCE AND TESTING				
	a	Performance testing and certification	10,00 €		5	2,00 €
	b	Environmental monitoring	- €		1	- €
	c	Audits and Inspections	150,00 €		1	150,00 €
Subgroup costs				160,00 €		
5		SOFTWARE AND LICENSING				
	a	Software Updates and Support	- €		5	- €
	b	Data Analytics and IoT Integration	20,00 €		1	20,00 €
Subgroup costs				20,00 €		
6		CONTINGENGY AND MISCELLANEOUS				
	a	Emergency repairs	20,00 €		3	6,67 €
	b	Spare Parts Inventory	500,00 €		5	100,00 €
Subgroup costs				520,00 €		
Total Costs			**847,00 €**			**425,67 €**

Figure 13. Estimated OPEX for the SepaRaptor Unit

Although the cost breakdowns for the CAPEX and OPEX are provided, it is currently not feasible to conduct a comprehensive financial analysis, such as sensitivity analysis or return on investment (ROI) calculations. This limitation arises because the technologies involved have not yet reached their final target TRLs (TRL 7/TRL 8) making certain financial assumptions and projections unreliable at this stage. Therefore, we will limit the analysis to presenting a current overview of the cost data provided by the partners, acknowledging that these figures may evolve as the technology advances toward commercialization.

4.1.4 Commercial Readiness Level

Current CRL Level: According to partner SMP, the technology is currently reported at CRL 2. While addressing workplace infection risks offers significant benefits, especially given the increased exposure in social workplace environments, the precise quantification of these benefits remains a challenge. This limits the current CRL. According to SMP the devices being developed under the Green Marine Project are purpose-built for this initiative and are not commercially available outside the project. The immediate goal is to reach CRL 3 by the end of the project. This will involve gathering initial market feedback and quantifying the technology's benefits, which are currently challenging to measure. With scalability built into the design, significant improvements in readiness can follow steeply after CRL 3 is achieved. For now, demonstrating the device's efficacy and scalability remains the priority milestone for partner SMP.

4.1.5 Updated Market Penetration Strategy (Product pricing)

To successfully penetrate the market for the SepaRaptor with UV, Partner SMP can focus on regions with stringent air quality regulations, such as the EUs emission control areas. Collaborations with shipyards and retrofit firms will streamline the integration process, particularly for passenger ships for a healthier environment and also the medium and large vessels, making the technology highly attractive for retrofitting older fleets. Green Marine's ongoing dissemination and communication efforts already target industrial associations and maritime expos to showcase the unique capabilities of its solutions. As the technology advances from R&D to commercial readiness, these activities will be tailored to emphasize the specific benefits of each solution, aligning with market needs and industry demand.

Updates on the pricing of the units will only be available once the technology has matured and evolved to a commercial level because accurate pricing depends on several key factors that are currently under development. These include the final production costs, scalability of manufacturing processes etc. Additionally, the integration of feedback from the techno economical analysis of the demo tests will influence the optimization of design and materials, which directly impacts cost structures. The assessments will therefore need the finalization of the TEA studies. Market readiness and demand analysis will also further shape pricing strategies, ensuring that the units are competitively positioned while maintaining affordability for target customers. Until these elements are fully assessed, precise pricing details remain subject to refinement

4.2. CARBON CAPTURE ROUTE

4.2.1. Membranes

4.2.1.1 Updated Business model

1) Key Partnerships

Key partners for the Carbon Capture Route with membranes should first include **membrane manufacturers**. Given that SINTEF is an R&D organization and does not manufacture membranes, collaboration with specialized suppliers is critical. Below a potential list for the manufacturers, who are already involved in carbon capture. This makes collaboration easier:

- Parker, CUT, Evonik, and DeltaMem, will ensure access to advanced hollow fibre and flat sheet membranes and modules tailored for maritime applications, offering high selectivity and durability.

In addition to membrane manufacturers, partnerships with **engineering firms** specializing in retrofitting solutions will be beneficial to facilitate the seamless integration of the system into existing vessels. These partners will be the step to utilize and adapt the technology to various ship designs and operational profile.

Partnerships with classification societies, including DNV, Lloyd's Register, RINA, and Bureau Veritas, is crucial to facilitate certification and compliance with international maritime regulations, enhancing the technology's market readiness.

Engagement with port authorities, such as the Ports of Rotterdam, Antwerp, and Hamburg, as well as Baltic Sea Ports, will enable the integration of the technology into green corridors and support its adoption in key maritime hubs.

Regulatory bodies like the IMO, EU-ETS, and national maritime authorities will play a pivotal role in aligning the technology with emissions reduction targets and securing incentives for early adopters. Additionally, collaborations with shipyards and retrofit providers, including Damen, Fincantieri, and Navantia, will streamline the retrofitting process and ensure scalability.

Finally, Green Marine's integration partners will contribute expertise in system testing, software development, and pilot projects, ensuring the seamless deployment of the technology.

2) Key activities and resources

As per the current plans of partner SINTEF, key activities will include optimizing membrane performance to enhance scalability and cost efficiency and providing technical support for manufacturing and integration to ensure seamless adoption.

Key resources for the membrane-based carbon capture technology include intellectual property (IP), such as patents, process designs, and manufacturing trade secrets, which safeguard the innovation and provide a competitive edge. Licensing agreements are crucial to facilitating partnerships and generating revenue. Legal support ensures smooth contract negotiation, licensing enforcement, and IP protection, maintaining compliance and securing market trust. Additionally, specialized knowledge in membrane development and optimization is vital for enhancing performance and adapting the technology to diverse maritime applications.

IP protection is essential to safeguard innovations, while licensing management will streamline agreements and secure revenue. Focused marketing and promotion, including industry events and targeted outreach, will build awareness and drive adoption in the maritime sector.

3) Value Proposition and Competitive Position

The Green Marine membrane-based carbon capture system provides a pioneering solution for the maritime industry, addressing critical environmental and operational challenges through innovative design and performance. Unlike other CO_2 capture solutions, such as solvent-based systems, it offers **modularity**, **low footprint and weight**, **operational flexibility**, and **freedom from toxic chemicals**, making it particularly suitable for maritime applications. These features make the technology ideal for deployment in scenarios where **variable flow rates and CO_2 content feeds**, **tight space and weight limitations**, and **environmental safety concerns** are prevalent, such as on ships, offshore platforms, and in densely populated areas.

According to partner Sintef, the novelty and the value preposition of Green Marine technology is described below:

<u>Advantages Over Competing Technologies</u>

- ***Compact and Modular Design:*** The system is scalable, allowing for easy adaptation to vessels of different sizes and engine loads, making it particularly suitable for the maritime industry's variable flow rates and low CO_2 content in diesel exhaust (3–8% CO_2).
- ***Low Environmental Risk:*** Unlike solvent-based systems, the membrane technology eliminates the use of dangerous and potentially carcinogenic chemicals. This significantly **de-risks pollution probability**, mitigating concerns about accidental chemical spills in sensitive environments such as seas, oceans, or near populated areas.
- ***Operational Efficiency:*** *The* membranes maintain **similar CO_2 permeability** as other systems but offer **increased CO_2/N_2 selectivity** (above 30–50, compared to 15–20 for PPO membranes). This high selectivity ensures efficient capture of low CO_2 content feeds, a common characteristic of diesel exhaust, reducing CAPEX requirements by minimizing the need for large membrane areas.
- ***Water Recovery and Circularity:*** The system allows for the recovery of **clean water** as a by-product of the capture process, contributing to circular economy principles and offsetting some operational costs. Unlike other membrane types, such as PPO, Green Marine's membranes are unaffected by water vapor, eliminating the need for energy-intensive drying processes and reducing OPEX.

- ***Flexibility and Adaptability:*** The modular and lightweight nature of the system makes it suitable for environments with **space and weight constraints**, such as ships and offshore platforms, where traditional capture systems would be challenging to deploy.

Currently, no membrane systems are installed on ships for diesel exhaust CO_2 capture. This positions Green Marine as a leader in **pioneering work** in the maritime industry, filling a significant technological gap and providing a first-mover advantage.

Critical Performance Parameters

- ***CO_2 Permeability:*** Critical for maintaining high capture rates. Low permeability would require larger membrane areas, increasing CAPEX. Green Marine's membranes are optimized for moderate-to-high permeability, ensuring cost-effective scaling.

- ***CO_2/N_2 Selectivity:*** A selectivity of over 30–50 is targeted, which is higher than the 15–20 reported for PPO membranes. This improved selectivity is vital for capturing CO_2 from low-concentration feeds like diesel exhaust, enhancing system efficiency.

- ***Durability:*** Long-lasting membranes reduce replacement frequency, lowering OPEX and ensuring reliability in maritime environments.

Comparison with Chemical Sorption Systems

While chemical sorption systems achieve higher CO_2 purity, they come with notable disadvantages, including the use of toxic chemicals, larger footprints, and higher risks of environmental contamination. Membrane systems, in contrast, provide:

- ***Lower Weight and Compact Design:*** Suitable for space-limited environments like ships and offshore platforms.

- ***Safer Operations:*** No toxic chemicals involved, reducing environmental risks and easing compliance with stringent safety standards.

- ***Energy Efficiency*:** Techno-economic studies suggest that membrane systems have **lower or similar energy consumption** compared to chemical sorption methods, particularly for applications involving variable flow rates and CO_2 concentrations.

- ***Cost Savings:*** Lower energy demands and the absence of chemical handling equipment reduce both CAPEX and OPEX, making membranes more cost-competitive in the long term.

However, there are disadvantages and SINTEF is confident that those can be mitigated. The primary disadvantage of membrane systems is the need for a **2–3 stage configuration** to achieve the same CO_2 purity levels as chemical sorption systems. Green Marine membrane technologies mitigates this limitation through:

- ***Techno-Economic Assessment:*** Conducting detailed modelling and analysis to optimize membrane performance and lifecycle costs.

- ***Pilot Demonstrations:*** Showcasing results from real-world applications to validate efficiency and ROI, building confidence among stakeholders.

- ***Enhanced Design*:** Maintaining high CO_2 permeability while increasing selectivity ensures system performance remains competitive with existing technologies.

Competitive position

Green Marine's membrane technology is uniquely positioned to stand out in the market:

- ***Improved Selectivity for Diesel Exhaust:*** Higher CO_2/N_2 selectivity ensures efficient capture of low-concentration CO_2 feeds, outperforming alternatives like PPO membranes.
- ***No Drying Requirements:*** The technology is unaffected by water vapor in exhaust gases, unlike other membranes, eliminating the need for energy-intensive drying processes.
- ***Sustainability:*** Water recovery capabilities enhance circularity, reducing operational costs and contributing to broader environmental goals.
- ***First-to-Market Advantage:*** As the first membrane-based CO_2 capture system designed for maritime diesel exhaust, it positions Green Marine as a leader in maritime decarbonization.

4) Customer Relationship and Channels

To effectively reach target customers and ensure widespread adoption of the membrane-based carbon capture technology, a multichannel approach is needed:

- Direct licencing agreements are of interest for monetization allowing manufacturers, integrators, and shipowners to implement the technology while generating a steady revenue stream. Licensing agreements will streamline the adoption process by providing access to the membrane system, including necessary certifications and support for integration. The membranes used in the Green Marine project are protected by granted patents, ensuring the technology's exclusivity and competitive advantage in the market. Additionally, there is the potential for new intellectual property (IP) to be generated as the project progresses.
- Strategic partnerships are important. Joint market campaigns with manufacturers like PARKER, CUT, Evonik etc. will strengthen the value of the membranes aligning their existing customer database. Collaborative marketing efforts with shipyards are also foreseen. This is crucial to position the membrane technology as a preferred retrofitting option tailored to meet user needs.
- Throughout the project period, partner SINTEF is already actively participating in technical conferences and events as per the dissemination and communication plan of Green Marine project. This approach is valid for the marketing of the membrane based capture solutions for marine retrofitting industry. Participation in global maritime industry events and trade shows will provide visibility and networking opportunities with key stakeholders. These platforms are crucial to showcase the real-world applications and pilot results as well as the demonstration of the system's compliance with regulatory standards. Direct communication is also possible with shipowners, operators, and policymakers to build trust and credibility on the new market environment.

5) Target customer segments

As the membrane based capture system can provide modular solutions, a wide range of ship types can be targeted. Its modular, lightweight, and compact design makes it ideal for vessels with space and weight constraints, such as ferries, tankers, offshore vessels, and cruise ships. It is also well-suited for high-emission vessels like large container ships and bulk carriers, offering significant reductions in CO_2 emissions and aligning with international regulatory requirements, particularly in emission control areas. The system's ability to handle variable exhaust flow rates and low CO_2 concentrations, common in diesel engines, ensures operational flexibility and efficiency. Additionally, the absence of toxic chemicals minimizes environmental risks, making it a safe and sustainable option for shipowners. By targeting diverse ship categories, the technology provides a scalable pathway for reducing emissions, enhancing compliance, and supporting the maritime industry's transition to sustainability.

The primary regional market is the European Union, which is at the forefront of maritime decarbonization due to stringent regulations, such as the EU-ETS and compliance requirements within

Emission Control Areas (ECAs). The EU's progressive policies on emissions reduction provide an ideal environment for deploying the technology, offering significant opportunities for partnerships and early adoption. One of the direct customers of the membrane technology would be the membrane manufacturers. These partners play a critical role in producing high-performance membranes tailored for carbon capture applications. Shipyards and retrofit companies are also essential for integrating the carbon capture system into existing vessels. They act as direct intermediaries between the technology provider and shipowners, ensuring smooth installation and scaling across the maritime industry. System integrators are pivotal in incorporating the membrane technology into comprehensive solutions for ship retrofitting and emission control, ensuring compatibility and performance optimization.

For the indirect customer segments, ship owners and operators can be considered. These are the end users who directly benefit from the technology's emissions reduction capabilities, enabling compliance with international regulations and reducing operational costs such as EU-ETS fees. Their adoption is driven by the economic and regulatory advantages of the technology. Organizations such as classification societies and regulatory bodies (LR, DNV) ensure that the membrane technology meets maritime standards and compliance requirements. Their approval is essential for market entry and widespread adoption. Entities such as Innovation Norway and Enova are instrumental in providing financial support for the development, demonstration, and early adoption of the technology. These organizations play a vital role in de-risking investment and accelerating market penetration.

6) Revenue Potential and Cost Structure

As a non-commercial technology, the preliminary revenue model envisions income through direct system sales, leasing options, and maintenance subscriptions for membrane replacement and operational support. Licensing the technology to third-party manufacturers may provide an additional revenue stream. The cost structure includes R&D expenditures for developing advanced membranes and system prototypes, manufacturing costs for hardware and integration components, and regulatory certification expenses. Initial marketing efforts will focus on raising awareness and establishing credibility among maritime stakeholders.

4.2.1.2 Risks and Mitigation

The membrane-based carbon capture technology faces several risks that require strategic mitigation to ensure successful development and market adoption.

One key technical risk is the potential for reduced performance in upscaled membrane modules compared to lab-scale versions. This can result from challenges like pressure drops, ineffective gas flow patterns, or membrane area usage inefficiencies. To address this, pilot testing will be conducted to identify and resolve these issues, ensuring optimal performance at larger scales.

Differentiation from competitors is another challenge, as limited data exists on membranes specifically designed for diesel exhaust on ships. However, the system's higher CO_2/N_2 selectivity and chemical-free operation provide a significant advantage. A comprehensive techno-economic assessment, supported by modeling and pilot results, will showcase these benefits, building credibility and demonstrating the system's unique value.

Regulatory challenges also pose a market risk, as strict maritime regulations can make implementation costly and complex. Engaging directly with shipowners and involving them financially in the process can help mitigate this issue. Open discussions with regulators will further ensure alignment with compliance requirements, simplifying the adoption process.

Finally, there is a business risk that large membrane manufacturers may view this technology as competition, choosing to prioritize their own products. Early discussions with commercial producers and the presentation of strong pilot results will highlight opportunities for collaboration, positioning the technology as a complementary innovation rather than a competitor.

4.2.1.3 Financial Projections

The detailed capital (CAPEX) and operational (OPEX) expenditure estimates for the membrane-based carbon capture system are not yet finalized, as testing and validation are still underway. While preliminary modeling and assessments have provided some insights, accurate data will only become available after the completion of ongoing pilot tests and system evaluations.

CAPEX estimates, including costs for hardware, software, engineering, and commissioning, will be determined once the system's design and scalability are fully validated. Similarly, OPEX figures, such as maintenance costs, membrane replacement intervals, predictive maintenance requirements, energy consumption, and consumables, will be clarified as real-world operational data is gathered.

Additionally, metrics like total costs and percentage breakdowns for capturing 1 tonne of CO_2 per hour or day will be established after more comprehensive testing. These results will enable a precise understanding of the system's economic performance and competitiveness in the maritime market. Further updates will provide complete and accurate cost analyses as testing progresses.

4.2.1.4 Current CRL Level

The membrane-based carbon capture technology is currently at an early CRL with no fully commercial systems available for the maritime industry. While some membrane providers, such as MTR, have initiated large-scale pilots for CO_2 capture in other industries, these systems have not been adapted or validated for maritime applications. The Green Marine project is conducting groundbreaking work, representing the first effort to deploy and test membrane technology specifically for maritime CO_2 capture. This pioneering initiative aims to address the unique challenges of the maritime sector, including space constraints, variable engine loads, and environmental regulations.

Advancing the CRL of the membrane system requires achieving critical milestones through systematic testing and validation. The first step involves land-based testing in controlled environments to optimize membrane performance, scalability, and integration with existing systems. These tests will provide crucial data on the system’s efficiency, energy consumption, and reliability under simulated conditions. Following successful land-based trials, the next major milestone will be onboard testing, where the membrane system will be piloted on actual vessels operating in real-world maritime conditions. This phase will validate the technology’s performance under varying operational scenarios, including engine loads and exhaust compositions, and will demonstrate its compliance with maritime regulations. These milestones are essential to transition the technology from its current developmental stage to commercial readiness, enabling its adoption across the maritime sector.

4.2.1.5 Market Penetration Strategy

Given the current low CRL and the lack of validation in real-world environments, the market penetration strategy must prioritize technology development, stakeholder confidence-building, and gradual commercialization. Since the project timeline already includes validating the technology in controlled environments and onboard pilot demonstrations, the market penetration strategy will focus on leveraging these results to build industry trust and accelerate adoption. The land-based testing and onboard pilot demonstrations will provide the foundation for showcasing the system’s performance and scalability. Tangible metrics from these activities—such as quantified reductions in CO_2 emissions, improved energy efficiency, and operational cost savings—will be used to create compelling case studies and technical documentation. These materials will serve as critical tools for engaging with potential customers, partners, and regulators, ensuring that the technology's value proposition is clearly demonstrated and effectively communicated. Furthermore, comprehensive techno-economic assessments will be done to demonstrate the technology’s cost-effectiveness, modularity, and environmental safety as per the scope of the Green Marine project.   These assessments are crucial to secure partnerships and attract early adopters. As the technology is validated through pilot projects, SINTEF should refine business models to reduce adoption barriers and maximize market impact. The strategy will prioritize licensing agreements with shipyards, retrofit providers, and system integrators, generating upfront fees and recurring revenue while enabling seamless integration into maritime operations. Milestone payments tied to key achievements such as certification, deployment, and performance validation will help build stakeholder confidence and accelerate commercialization. Strategic partnerships with membrane manufacturers like Parker and DeltaMem, along with shipyards such as Damen and Fincantieri, should be leveraged to scale production and streamline retrofitting workflows. Initial efforts should focus on targeting small and medium vessels and ships operating in Emission Control Areas, where the technology's compact and modular design offers a competitive advantage. It is also crucial to build awareness and trust through educational outreach, including workshops, industry conferences, and technical publications as well as attending and disseminating the results via industrial events targeting decarbonization of marine industry.

Business Model Canvas

Designed For:Sintef Membranes

Designed by: A Secer & L.Daal

Date: 11 Dec 24

Version:0.1

Key Partners

Membrane manufactuers:
Potential partners:
HF: Parker, CUT, Evonik, others
Flat Sheet: DeltaMem, others

-***Classification societies:*** DNV, LR, RINA, Bureau Veritas...

-***Port Authorities and Green corridors:*** Port of Rotterdam, Port of Antwerp, Port of Hamburg, Baltic Sea Ports...
-***Regulatory bodies and governmental agencies:*** IMO, EU-ETS, National maritime authorities (i.e UK Maritime&Coastguard Agency)
Shipyards & Retrofit service providers ? Like Damen, Fincantieri, and Navantia to integrate
GreenMarine integration partners: CMMI, UoS, PDM for the software tool.

Key Activities

- Further membrane development and optimisation
- technical support to membrane manufacturing and **integration**
- IP protection
- Licensing management- negotiations and management
- marketing & promotion

Key Resources

- Intellectual Property (Patents, process design, Manufacture Trade Secrets)
- Licensing agreements
- Legal support- contract negotiation, licensing enforcement, IP protection
- Knowledge of membrane development and optimization

Value Propositions

- Compact & modular (scalable)-
- produces Clean water
- Access to Certified CO2 Capture Technology - Pre-certified for regulatory compliance
- Fast Market Entry - Ready-to-use design for shipbuilders, shipyards, and retrofitters
- Cost Savings for Licensee regulatory certifications included
- Compliance with marine standards
- Reduction of CO2 Emissions - Helps shipowners reduce EU ETS costs and port fees.
- Based on lab results some numbers were provided by Torbjørn in terms of energy consumption/ membrane area

Customer Relationship

- Technical support for membrane manufacturing
- Technical Support - Assistance during integration
- Knowledge Sharing

Channel

- Direct Licensing - Contract agreements
- Strategic Partnerships - Joint marketing with membrane manufacturers-
- joint marketing shipyards and retrofit service providers
- Industry Events & Trade Shows
- Digital Marketing - Industry publications, technical white papers, and online articles

Customer Segments

Regional :
- EU

Industrial:
- Different ship sizes can be targeted as per the modular system
- Membrane manufacturers
- Shipyards & Retrofit service providers
- System integrators (OEM)

Indirectly:
- Ship owners,
- ship operators
- Regulatory certification / compliance companies
- Governmental funding bodies (Innovation Norway, Enova, ...)

Cost Structure

- IP Protection Costs - Patent filings, design registrations, and trade secret management
- Legal & Licensing Fees - Contract negotiation, legal support, and enforcement costs
- Certification & Compliance Costs - Fees for DNV, ABS, and Lloyd Register approvals etc. (might be the cost of the licensee)
- Marketing & Sales - Participation in maritime industry events and conferences
- Administrative Costs - Staff salaries, software, office expenses for licensing management
- Costs for R&D work for implementation

Revenue Stream

- Upfront License Fees - Paid at the start of licensing agreements
- Milestone Payments - Paid when certification, deployment, or other milestones are achieved
- Royalties - Recurring payments from each CCU system sold, retrofitted, or installed OR Yearly payment of produced (dependent on license agreement achieved).
- Annual License Renewal Fees - Recurring fees for continued licensing rights
- Consulting & training Services - Revenue from training, technical support, and certification support for licensees

Figure 14. Business model canvas- Membranes

4.2.2. Carbon Capture Machine

4.2.2.1 Updated Business model

1) Key Partners: The successful development and deployment of the carbon capture machine technology require collaboration with a range of strategic partners across various sectors. Material suppliers are critical for providing the necessary chemicals and components required for the carbon capture and carbonate production systems. These partnerships ensure the availability and quality of materials for the system's efficient operation.

Collaboration with classification societies such as DNV, Lloyd's Register (LR), RINA, and Bureau Veritas is essential to ensure that the technology complies with industry standards and regulatory requirements, streamlining market entry and certification processes. Port authorities and green corridors like the Port of Rotterdam, Port of Antwerp, Port of Hamburg, and Baltic Sea Ports are important partners in facilitating the adoption of the technology within sustainable maritime logistics and emission reduction initiatives.

Close engagement with regulatory bodies and governmental agencies, including the International Maritime Organization (IMO), EU-ETS authorities, and national maritime agencies such as the UK Maritime & Coastguard Agency, is vital for regulatory compliance and alignment with emissions reduction policies.

Shipyards and retrofit service providers, including Damen, Fincantieri, and Navantia, are crucial for integrating the *carbon capture machine* into existing vessels, enabling its efficient deployment and scaling. Additionally, partnerships with non-governmental organizations (NGOs) and environmental agencies will enhance credibility and support for the technology by highlighting its contribution to global decarbonization efforts.

2) Key activities and resources: Key activities focus on optimizing performance, validating functionality, and driving commercialization. The optimization of the CCM system is critical for achieving efficient CO_2 capture and carbonate production, ensuring its competitiveness in the maritime industry. Land-based and onboard pilot demonstrations will validate the technology's efficiency and scalability under real-world conditions, paving the way for broader market adoption. Providing technical support for manufacturing and integration is essential to ensure seamless deployment of the CCM system in various ship designs. Additionally, intellectual IP protection will safeguard patents and trade secrets, while licensing management will involve negotiating and overseeing agreements with partners and manufacturers. Finally, marketing and promotion efforts will focus on building awareness and showcasing the system's benefits through targeted outreach and industry engagement. CCM is in preparation of a new utility patent application. This patent will comprehensively detail how the invention functions and operates specifically onboard vessels, emphasizing its unique contribution to maritime carbon capture and compliance with industry standards. The target timeline for the submission of this patent application is by the end of 2025

The successful development and deployment of the CCM technology rely on several critical resources. IP, including patents and trade secrets, secures the competitive edge of the CCM process. Pilot systems serve as the foundation for validating the technology, enabling land-based and onboard testing. R&D expertise, particularly in carbon capture, chemical engineering, and process optimization, ensures continuous innovation and technical advancement. Regulatory approvals from organizations such as DNV, ABS, and Lloyd's Register establish compliance with industry standards, facilitating smooth market entry. Lastly, industry partnerships with leading maritime and environmental stakeholders will provide valuable insights, resources, and collaboration opportunities to accelerate the commercialization of the CCM system.

3) Value Proposition and Competitive Position: CCM technology offers a range of unique benefits tailored to the maritime sector's decarbonization needs. It enables permanent CO_2 sequestration through carbonate production, directly contributing to the decarbonization goals set by the IMO and the EU. This process not only reduces greenhouse gas emissions but also has the potential to aid in the deacidification of marine environments, further enhancing its environmental impact when the participated minerals are dumped into the sea.

Besides, the CCM system delivers cost efficiency by eliminating the need for expensive chemical solvents and onshore CO_2 storage infrastructure, significantly reducing operational and capital expenses for shipowners. It provides access to certified CO_2 capture technology, ensuring compliance with stringent regulatory requirements, which streamlines market entry and reduces administrative burdens for users. CCM technology is already validated, through the NRG COSIA Carbon XPrize competition, but it is important to note that this technology is not tested for the flue gas decarbonisation yet.

4) Customer Relationship and Channels : Technical support will be a key offering, ensuring customers receive ongoing assistance for the installation, operation, and maintenance of the systems. This hands-on approach builds trust and ensures optimal system performance. Training programs will provide customers and partners with essential knowledge on system integration and certification processes, equipping them to efficiently implement and operate the technology. Additionally, knowledge sharing initiatives, such as webinars, workshops, and documentation, will help customers stay informed about advancements, best practices, and regulatory updates, fostering long-term engagement and satisfaction.

To effectively reach customers and promote the CCM technology, a multi-faceted channel strategy will be employed. Direct licensing agreements will form the foundation for collaborations, offering a straightforward path for customers to access the technology. Partnerships with shipyards and retrofit service providers will enable joint marketing efforts and facilitate seamless system integration during vessel retrofitting. Participation in industry events and trade shows will showcase the technology's capabilities and benefits, attracting a wide audience of stakeholders from the maritime sector. Lastly, digital marketing efforts, including the publication of technical white papers, industry articles, and online promotions, will amplify visibility and provide in-depth information to prospective customers.

5) Target customer segments: The primary geographic target for the CCM technology is the EU including UK, given the region's stringent decarbonization regulations and commitment to achieving net-zero emissions as explained for the other Green Marine technologies above.

CCM has plans to target bulk Carriers, container ships, tankers, and passenger ships as they are the major contributors to maritime emissions and operate in high-emission zones, making them key candidates for carbon capture retrofitting. Ongoing stakeholder mapping is underway to identify potential future collaborators from the maritime sector to help further develop the TRL and application areas.

As explained in the other Green Marine technologies above, the shipyards and service providers, ship owners and operators, governmental and environmental organisations are in scope. As the plan is to utilize the carbonates as marine deacidification solutions, environmental organisations are key.

6) Revenue Potential and Cost Structure: The precise numbers for the cost structure and revenue streams are not yet defined as the CCM technology is still in the development phase, and testing has not been performed. Key components such as R&D expenses, certification fees, pilot deployment costs, and operational expenses are currently being estimated based on preliminary designs and planning. Similarly, revenue projections for product sales, licensing fees, royalties, and consulting services are dependent on the outcomes of ongoing development and testing. With the assumption of a commercial vessel engine size that emits 1.5 kTon of CO2 per year, the CCM solution would yield approximately 1 kTon/year of CO_2 capture (emission reduction costing between 3-5 MLN €). Final figures will be determined as the technology progresses through validation and pilot demonstrations.

4.2.2.2 Risks and Mitigation

The potential risks associated with CCM's technology and their mitigation strategies are outlined below as provided by CCM:

- Brine Unsuitability for $CaCO_3$ Precipitation: The use of seawater brine for calcium carbonate precipitation may not be feasible due to its composition. To address this, alternative solutions such as NaCl-based artificial seawater can be explored. Modifications to the seawater evaporator may also be required, along with investigating additional chemical additives to enhance the precipitation process.
- Challenges in Deacidification: The process of deacidification using $Ca/MgCO_3$ may either fail to achieve desired outcomes or face regulatory challenges. To mitigate this risk, collaborations with research institutes like Scottish Association for Marine Science (SAMS) in Scotland are recommended, alongside seeking additional funding to expand the scope of work. If onboard implementation is not possible, storage and harbor discharge solutions should be considered.
- Unstable Column Operation: Ensuring stable column operation for the exhaust gas and NaOH solution interface is critical. This challenge can be mitigated by adopting improved design features such as better gas dispersion mechanisms or selecting alternative devices, including impinging jets, microfluidic systems, or other advanced fluidic technologies.
- Regulatory Approval Delays: Obtaining principal approval for new equipment like spargers and the CCM process can be a time-consuming process. To overcome this, detailed risk assessments and workshops should be conducted, working closely with classification societies such as Lloyd's Register. Additionally, engaging with engineering companies to streamline approvals can expedite the process.
- System Integration Challenges: Integrating the system onto CalMac vessels may face operational constraints and other limitations. This risk can be mitigated by conducting thorough data collection and making a go/no-go decision based on operational feasibility. If integration is deemed unfeasible, alternative vessels or partners can be identified, with a focus on obtaining approval-in-principle for future implementations.

4.2.2.3 Financial Projections

At this stage, detailed financial projections for CCM's technology are not available, as the system is still in development and has not been validated in a marine environment. Preliminary estimates from earlier reports suggest a potential cost range of $3–5 million for a larger-scale CCM solution that is for a commercial vessel engine size that emits 1.5 kTon of CO_2 per year . However, these figures remain speculative and subject to change as the technology advances and more data becomes available. While initial assumptions (provided in the first version of this report) estimate operational expenditures (OPEX) at approximately $2.5 million over the product lifetime, and capital expenditures (CAPEX) at around $1.5 million. These values are likely to differ in the marine context. The maritime environment introduces unique challenges, such as the costs associated with transporting input materials on board and handling carbonate products, which could have a substantial impact on the overall financial model. Given the novelty of this technology in the maritime sector, additional testing and validation are essential to provide accurate CAPEX and OPEX predictions. These efforts will help ensure that cost projections align with the operational realities of marine applications and support the development of a competitive and sustainable business model.

4.2.2.4 Current CRL Level

Currently, CCM reports the trial results together with the existing certifications in environments other than the marine sector. Adaptation and application of the technology in the maritime sector remain a significant step forward. Although the CCM system has prior validations and technical feasibility demonstrated in other industries, its implementation on board ships introduces new challenges, including integration with vessel systems, compliance with maritime regulations, and operational testing under marine conditions. These factors require additional validation and pilot demonstrations to progress the technology further along the CRL scale. To advance the CRL level, further testing in realistic maritime environments is necessary. This includes land-based trials tailored to marine specifications, followed by onboard pilot implementations to validate performance, reliability, and scalability in real-world maritime operations.

4.2.2.5 Market Penetration Strategy

Depending on the current CRL level, it is still premature to describe a market penetration strategy. A viably sound approach is to position the technology as a transformative dual solution for both carbon capture and ocean deacidification. By leveraging the dual benefits of CO_2 capture and its conversion into harmless mineralized forms that can be discharged into the sea to combat ocean acidification, CCM can appeal to shipowners looking to align with stringent IMO and EU decarbonization targets while contributing to environmental restoration. To address concerns around the use and handling of chemicals onboard, a clear focus on safety protocols, storage solutions, and cost-effective operations will be essential. The environmental co-benefits of ocean deacidification present a unique selling point that can differentiate CCM from traditional CO_2 capture solutions. This narrative should be amplified through participation in trade shows, industry publications, and collaborative workshops. Securing governmental funding and emphasizing the broader ecosystem benefits, such as reduced CO_2 emissions and improved ocean health.

Business Model Canvas

Designed For: CCM

Designed by: A Secer & L.Daal

Date: 30 Dec 24

Version:0.1

Key Partners

Material Suppliers: Providers of chemicals and components for carbon capture and carbonate production systems.

-***Classification societies:*** DNV, LR, RINA, Bureau Veritas...

-***Port Authorities and Green corridors:*** Port of Rotterdam, Port of Antwerp, Port of Hamburg, Baltic Sea Ports...

-***Regulatory bodies and governmental agencies:*** IMO, EU-ETS, National maritime authorities (i.e UK Maritime&Coastguard Agency)

Shipyards & Retrofit service providers ? Like Damen, Fincantieri, and Navantia to integrate??

NGOs: environmental agencies

GreenMarine integration partners: CMMI, UoS, PDM for the software tool

Key Activities

- Optimization of the CCM system for efficient CO_2 capture and carbonate production.
- Land-based and onboard pilot demonstrations to validate technology.
- technical support manufacturing and **integration**
- IP protection
- Licensing management-negotiations and management
- marketing & promotion

Key Resources

- Intellectual Property: Patents and trade secrets for the CCM process.
- Pilot Systems: Operational pilot systems for land and ship testing.
- R&D Expertise: Teams specializing in carbon capture, chemical engineering, and process optimization.
- Regulatory Approvals: Certifications from DNV, ABS, and Lloyd's Register.
- Industry Partnerships: Collaborations with leading maritime and environmental stakeholders.

Value Propositions

- Permanent CO_2 sequestration through carbonate production, contributing to IMO and EU decarbonization goals.
- Deacidification of seas (TO BE determined)
- Cost Efficiency: Eliminates the need for expensive chemical solvents and onshore CO_2 storage infrastructure.
- Access to Certified CO2 Capture Technology - Pre-certified for regulatory compliance
- Fast Market Entry - Ready-to-use design for shipbuilders, shipyards, and retrofitters
- Cost Savings for Licensees - No R&D costs, regulatory certifications included
- Compliance with marine standards
- **Reduction of CO2 Emissions - Helps shipowners reduce EU ETS costs and port fees?**

Customer Relationship

- **Technical Support - Ongoing support for installation, operation, and maintenance of CCM systems.**
- Training - on system integration and **certification processes**
- Knowledge Sharing

Channel

- Direct Licensing - Contract agreements
- joint marketing shipyards and retrofit service providers
- Industry Events & Trade Shows
- Digital Marketing - Industry publications, technical white papers, and online articles

Customer Segments

Regional :

- EU

Industrial:

- Medium to large sized vessels

- Shipyards & Retrofit service providers
- Ship owners,
- ship operators
- Governmental and regulatory organizations

Cost Structure

- R&D Expenses: Ongoing research for process optimization and scaling.
- Certification Costs: Fees for regulatory approvals and compliance testing.
- Pilot Deployment Costs: Operational expenses for land-based and onboard testing.
- Manufacturing and company operating costs: personnel, manufacturers, buyers, sales team..... To be determined
- Marketing & Outreach: Participation in exhibitions, publishing materials, and awareness campaigns.
- Legal & Licensing: Costs associated with IP protection and licensing management.

Revenue Stream

- TO BE DETERMINED: product sales versus service or leasing proposition
- Carbon Capture Product Sales: Revenue from selling CCM system to shipyards and/or ship owners.
- Carbonate Product sales: currently not foreseen (ETS fee? To be determined)
- Licensing Fees: One-time fees for the use of CCM technology (incorporated in product sales price).
- Royalties: Recurring revenue from installed systems based on operational metrics.
- Consulting & Support Services: Revenue from technical and regulatory consulting.

Figure 15. Business model canvas - Carbon Capture Machine

4.3 Software Catalogue Tool

4.3.1 Updated Business model

1) Key Partnerships : The success of the software tool relies on establishing strong partnerships with critical stakeholders in the maritime industry. Collaborations with third-party modelling and simulation providers are essential to integrate diverse retrofitting solutions into the tool, ensuring its functionality and relevance. Partnerships with regulatory bodies and certification organizations will help align the tool with maritime compliance standards, making it easier for customers to adopt the solution. Additionally, hardware providers specializing in parallel computing systems will support scalability by enabling efficient simulations. Collaborations with shipyards, shipowners, and retrofit providers will ensure the tool is grounded in real-world operational needs. Consultancy firms will also play a role by leveraging the tool to offer added value to their clients.

2) Key Activities and resources: The development of the software tool requires a series of focused activities to achieve commercial readiness. These include enhancing the tool to support diverse vessel types and retrofitting scenarios while ensuring scalability for future technologies and regulations. Meeting industry-specific certification requirements is another critical activity to gain customer trust and regulatory acceptance. Partnerships with third-party providers will be actively pursued to expand the range of simulations and overcome risks related to limited functionality. In addition, comprehensive customer training and ongoing support will help ensure smooth adoption and effective use of the tool. Marketing and outreach activities, such as participation in industry events and digital campaigns, will build awareness and demand for the tool.

The successful development and deployment of the software tool depend on several critical resources. These include technical expertise in software development, maritime engineering, and simulation modelling to ensure the tool's effectiveness and scalability. Intellectual property, such as proprietary algorithms and simulation techniques, will protect the tool's competitive advantage. Strong partnerships with third-party providers and hardware suppliers will enhance functionality and scalability. Access to a comprehensive database of ship data and retrofitting insights will enable the tool to deliver tailored solutions that meet specific customer needs.

3) Value Proposition and competitive position: The software tool provides significant value to its customers by helping them optimize retrofitting decisions, reduce costs, and enhance operational efficiency. By simulating various retrofitting solutions, the tool enables shipowners to make informed decisions that align with their compliance and financial goals. Its scalability ensures that it can accommodate a wide range of vessel types and future regulatory changes, offering long-term adaptability. The collaborative revenue model benefits third-party providers who contribute simulations, creating an ecosystem that enhances the tool's functionality. Additionally, the tool's ability to reduce emissions and comply with environmental regulations adds an essential sustainability dimension, making it a compelling offering for the maritime. The primary target markets for the tool include commercial shipping operators, cruise lines, shipbuilders, retrofitters, and consulting firms specializing in maritime sustainability. The competitive advantage lies in its comprehensive database, advanced evaluation capabilities, and user-friendly design. By combining these features, the tool differentiates itself from existing solutions, offering unparalleled support for retrofitting decisions in the maritime sector.

4) Customer Relationship and Channels : The software tool aims to establish long-term relationships with customers by providing robust support and value-added services. Technical support will ensure customers receive assistance for installation, operation, and troubleshooting, fostering trust and reliability. Training programs and detailed documentation will empower customers to use the tool effectively and maximize its potential. The tool will also leverage collaborative partnerships with third-party providers to enhance functionality, creating a mutually beneficial ecosystem that supports both customers and external contributors. Through these relationships, the tool will position itself as an indispensable resource for retrofitting optimization.

The tool will utilize a combination of direct and indirect channels to reach its target customers. Direct sales and licensing agreements will be the primary method of distribution, enabling close collaboration with shipyards, shipowners, and retrofit providers. Strategic partnerships with third-party modelling providers and marine technology integrators will enhance the tool's visibility and adoption. Participation in industry events, trade shows, and digital marketing campaigns will build awareness and credibility among potential users. A dedicated online platform will provide a central hub for licensing, subscriptions, and customer interactions, ensuring seamless access and support.

3) Revenue Potential and Cost Structure: The pricing strategy for the Software Catalogue Tool focuses on balancing affordability, scalability, and revenue generation while supporting the platform's continued growth and maintaining operational sustainability. The following outlines the possible strategy in detail:

- **Automated Accounting System:** A built-in accounting system automatically allocates revenue to data and simulation tool providers based on platform usage. This incentivizes providers to integrate their tools and ensures fair compensation for their contributions, fostering the platform’s growth in terms of both data and users.
- **Subscription Fees:** Monthly or annual subscription options are offered for accessing the platform’s features, such as data storage, simulation tools, and modelling capabilities. Subscriptions can be tiered, with pricing based on user needs (e.g., data access, simulation runs, or advanced analytics).
- **Pay-As-You-Go Model:** Users pay fees based on their consumption of high-demand resources, such as CPU time, advanced simulations, or large-scale data storage. This model ensures that costs are proportionate to usage, making it accessible for a wide range of users while covering operational expenses.
- **Integration Fees:** Third-party developers or simulation tool providers seeking to integrate their tools into the platform incur a one-time integration fee. This fee covers the costs of API compliance and platform hosting.
- **Storage and Computational Fees:** Expensive data storage or high CPU usage are charged at a competitive rate, similar to cloud service models used by providers like IBM and Amazon. This fee structure allows the platform to accommodate advanced simulations without incurring financial losses.
- **Licensing Fees:** Revenue to be generated through licensing agreements for proprietary simulation tools hosted on the platform, providing developers with an additional income stream while ensuring a steady revenue flow for the platform.

The possible cost structure consists of:

- **Development Costs**: Investments in software development, data integration, and user interface design.
- **Maintenance Costs**: Ongoing expenses for updating the database, adding new technologies, and customer support.
- **Marketing and Outreach**: Costs for promoting the tool through trade shows, digital platforms, and industry networks.

4.3.2 Risks and Mitigation

The primary risk for the software tool is the lack of diverse simulations, which could reduce market interest. To mitigate this, partnerships with multiple third-party providers will be pursued to expand the tool's capabilities and ensure its relevance. Certification challenges are another risk, as meeting maritime industry standards could delay deployment. Early engagement with regulatory bodies and certification organizations will address this issue. Adoption barriers, such as the customization required for different ships, will be mitigated by offering modular and flexible configurations. Additionally, demonstrating clear ROI through case studies and pilot projects will build customer confidence and encourage adoption. Through these strategies, the tool will address its risks and establish itself as a valuable solution in the maritime sector.

4.3.3 Financial Projections

Given the current Commercial Readiness Level (CRL) of the software tool, which remains at an early to moderate stage of development, it is not reasonable to provide accurate financial projections at this time. The tool is still undergoing validation and optimization, with critical milestones such as certification, scalability testing, and real-world deployment yet to be achieved. These steps are essential to determine the tool's full operational potential, market acceptance, and cost-effectiveness. While preliminary assessments can provide some insights, detailed financial projections would require data from completed pilot tests, regulatory approvals, and customer feedback to ensure accuracy and reliability. Until these milestones are reached, any financial estimations would carry a significant degree of uncertainty.

4.3.4 CRL Level

As the tool being under development, requiring validation through partnerships, certification, and deployment strategies the CRL is currently at a low to moderate level (likely CRL 3). This corresponds to a stage where:

- Concept Validation: The tool’s functionality and potential have been demonstrated in controlled settings (lab simulations or conceptual designs).
- Development Ongoing: The tool is still being optimized, with significant technical, regulatory, and market-related gaps needing to be addressed.
- Partnerships Required: Third-party integration and certification processes are necessary to advance the tool's readiness for commercial applications.

4.3.5 Market Penetration Strategy

The software tools are well-positioned for market penetration, with validation efforts, such as pilot projects and case studies, already underway as part of the Green Marine project. These efforts will be leveraged to demonstrate the tool’s ability to optimize retrofitting solutions, enhance compliance, and improve operational efficiency. Strategic partnerships with modeling providers, classification societies, and shipyards will ensure the tool remains versatile, compliant, and seamlessly integrated into retrofitting workflows. A subscription-based pricing model, coupled with consulting and training services, will make the tool accessible while creating recurring revenue streams. Marketing efforts, including participation in industry events, digital campaigns, and stakeholder workshops, will build awareness and confidence in the tool’s capabilities.

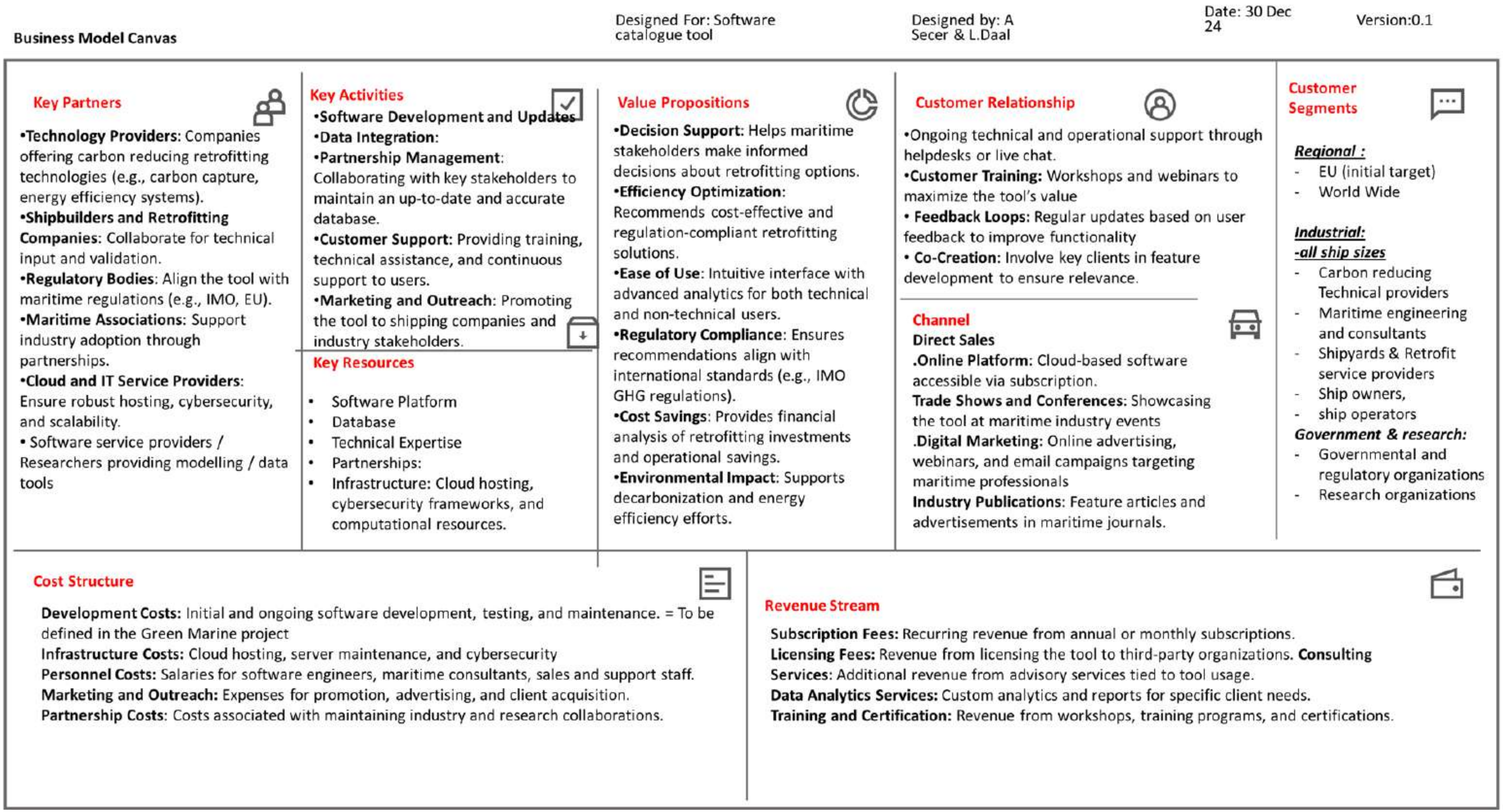

Figure 16. Business model canvas- Software Catalogue Tools

4.4 Thermoelectric element Route

4.4.1 Business Model

1) Key partners : The Thermoelectric Element (TEE) route relies on strong collaborations with various stakeholders to ensure successful development, certification, and commercialization. Key partners include shipbuilders and retrofit providers such as Damen, Fincantieri, and Navantia, who will assist in integrating TEE systems into existing ship systems for waste heat recovery. Partnerships with marine engine manufacturers like Wärtsilä and MAN Energy Solutions are critical to adapt TEE solutions to propulsion systems and auxiliary engines. Port operators will also play a significant role in facilitating land-based installations for port-related heat recovery projects. Partnerships with material suppliers are important, specializing in advanced thermoelectric components, as it will ensure the use of high-quality and efficient materials. Finally, regulatory bodies such as DNV, ABS, and Lloyd's Register will help certify and validate TEE systems for compliance with maritime standards.

2)Key Activities and resources: The commercialization of TEE technology focuses on delivering a market-ready system designed to integrate into maritime applications. As a product, the emphasis shifts from research and development to optimizing performance for real-world operational environments. Land-based and onboard demonstration results will be a pivotal resource in showcasing the system's scalability, efficiency, and value proposition to potential customers, including shipyards, shipowners, and operators.

To ensure its success in the market, technical support will be a cornerstone of the offering, enabling smooth integration into existing ship systems and designs. According to SMP protecting intellectual property through patents and trade secrets remains critical for maintaining competitive advantages and enabling licensing opportunities. Licensing agreements will allow for broader adoption while minimizing in-house production risks and expanding market reach.

Key activities will involve marketing and promotional activities will focus on positioning TEE as a cost-effective, energy-efficient, and regulatory-compliant solution for reducing CO_2 emissions and fuel consumption. Strategic outreach will target shipyards, retrofit service providers, and end-users through industry events, digital campaigns, and direct engagements. By establishing a robust customer support framework and delivering proven performance through pilot implementations, the TEE technology will transition from a concept to a fully commercialized product, driving value for stakeholders and accelerating maritime decarbonization efforts.

3) Value Proposition and Competitive Position: According to partner SMP, the TEE system offers a compelling value proposition by providing a net positive energy generation capability, making it a highly efficient solution for waste heat recovery. Unlike traditional systems such as Rankine or Organic Rankine Cycles (ORC), the TEE system leverages constant hot and cold sources to deliver consistent and reliable energy recovery. According to WPS/SMP, the excess energy generated by the TEE system can be used to charge batteries for powering energy-intensive devices or directly supply smaller devices with electricity consumption up to 0.5 kW/h, creating added value for end users, in this case the ship operators.

What sets the TEE system apart from conventional waste heat recovery technologies is its simplicity, modularity, and adaptability. Unlike ORC systems that rely on complex components, working fluids, and require frequent maintenance, TEE systems are solid-state devices with no moving parts. This design ensures low maintenance requirements, operational reliability, and a long lifespan. Additionally, the compact and modular structure of the TEE system makes it easy to install, even in space-constrained or remote environments, reducing both installation time and associated costs. While the efficiency of TEE systems may be lower compared to ORC systems, particularly in low-temperature gradient applications, their ability to provide a stable and steady energy supply offers a significant advantage.

The elimination of temperature fluctuations reduces thermal stress and enhances overall performance. Furthermore, the TEE system is environmentally friendly, with no need for complex fluids or infrastructure, making it suitable for diverse applications.

In terms of cost-effectiveness, the TEE system's durability and lack of intricate infrastructure result in lower lifecycle costs, despite higher initial material expenses. Its solid-state construction minimizes maintenance requirements, making it a reliable and economically attractive solution for small to medium-scale operations. The TEE system's simplicity, versatility, and scalability position it as an innovative and competitive technology for targeted waste heat recovery applications, particularly in maritime and other industrial sectors.

4) Customer relationship and channels: Following customer relationship routes are potential for SMP when the TEE is ready to be commercialized:

- Technical Support: Continuous support will be provided to shipbuilders, retrofit providers, and end-users for the installation, operation, and maintenance of TEE systems. This ensures a seamless integration process and minimizes downtime for the customer.
- Collaborative Development: Co-developing customized solutions with shipbuilders and marine engine manufacturers will enable the TEE system to meet specific operational needs, improving customer satisfaction and adoption rates.
- Performance Guarantees: Offering warranties and guarantees for the TEE system's performance and durability will build trust with shipowners and operators, helping to secure long-term partnerships.
- Training Programs: Tailored training sessions will be provided for customers to familiarize them with the integration process and ensure the effective operation of TEE systems.

The relationship to be achieved through the following channels:

- Direct Sales: Selling the TEE systems directly to shipbuilders, shipyards, and engine manufacturers will allow the company to establish a direct line of communication with key stakeholders, ensuring tailored solutions and immediate feedback.
- Strategic Partnerships: Collaborating with shipyards, retrofit service providers, and marine engine manufacturers will enable the company to tap into established networks, streamline integration processes, and enhance market penetration.
- Industry Events and Trade Shows: Participation in industry-specific exhibitions and trade shows will serve as a platform to showcase the TEE system's capabilities and build relationships with potential customers and partners.
- Digital Marketing: A comprehensive online marketing strategy, including technical white papers, case studies, webinars, and articles, will raise awareness about the TEE system's benefits and create demand among targeted customer segments.
- Joint Marketing Initiatives: Partnering with shipyards, retrofit providers, and marine technology integrators to promote the TEE system through co-branded campaigns, webinars, and technical showcases will expand its visibility in the maritime industry.

5) Target customer segments: Shipyards and retrofit service providers are crucial partners for integrating TEE systems into retrofitting and newbuild projects. These stakeholders, such as Damen, Fincantieri, and Navantia, can streamline the adoption of the technology through their expertise in vessel upgrades. Similarly, ship owners and operators, including commercial shipping companies and offshore platform managers, represent a core customer base due to their increasing need for cost-effective and compliant energy solutions. The focus will be on vessels like bulk carriers, container ships, tankers, and passenger ships that generate significant waste heat. Marine engine manufacturers, such as

Wärtsilä and MAN Energy Solutions, also serve as potential collaborators, allowing for the seamless integration of TEE systems with their propulsion units. Governmental and regulatory organizations, including the IMO, EU-ETS, and national maritime authorities, are influential in driving adoption through compliance requirements and financial incentives. Engaging these bodies will ensure alignment with maritime standards and de-risk adoption through potential funding programs. Cruise lines, facing increasing scrutiny for environmental compliance, and offshore platforms requiring optimized energy solutions represent promising growth areas. The TEE system's compact, reliable design makes it well-suited for these markets, offering additional pathways for expansion.

The relevant information is provided in Deliverable 6.6

4.4.2 Risks and Mitigation

According to the technology provider SMP, one primary risk is the high initial equipment cost relative to its efficiency. While thermoelectric elements (TEEs) have demonstrated the potential to achieve up to 15% efficiency, this may still be perceived as insufficient by end-users unless the device delivers a significant net positive electricity contribution. Achieving this would offset its initial costs over time, making it a compelling investment due to its low maintenance and constant operation advantages.

To mitigate these risks, several strategies have been implemented. According to SMP, on the technical front, material research and development are being prioritized to enhance efficiency and reduce costs. This includes exploring advanced thermoelectric materials such as nanostructured and hybrid materials. Additionally, four types of heat transfer paste have been evaluated to identify the optimal combination of cost and heat transfer performance, ensuring cost-effective and efficient operation. Efficient heat exchanger designs are also under development, considering material availability, supplier constraints, and cost conditions.

According to WPS/SMP, the modular design of the TEE system is another critical mitigation strategy. Scalability allows for cost reduction through economies of scale, making the system more appealing to end-users and improving return on investment (ROI). Furthermore, partnerships established within the Green Marine project play a vital role in advancing the TEE system's technological readiness level (TRL). Successful marine testing will validate the system's reliability and performance, opening new avenues for investor interest and applications beyond the maritime industry.

4.4.3 Financial Projections

The current values for the breakdown of the costs for CAPEX are provided by partner SMP as below:

	WPS/SMP	Green Marine Business plan	TEE unit lifetime [years]			20
ESTIMATED CAPEX FOR THE TEE UNIT						
Group ID	**Subgroup ID**	**Costs group**	**Cost**	**Subgroup costs**	**Estimated lifespan**	**Annual CapEx estimate**
1		HARDWARE COSTS				
	a	TEE unit and components	4.100,00 €		20	205,00 €
	b	Piping and valves	80,00 €		10	8,00 €
	c	Instrumentation and controls	- €		20	- €
Subgroup costs				4.180,00 €		
2		SOFTWARE COSTS				
	a	Control and automation software	- €		20	- €
Subgroup costs				- €		
3		ENGINEERING AND DESIGN				
	a	System Design and Engineering	2.400,00 €		20	120,00 €
	b	Compliance and Permitting	900,00 €		20	45,00 €
Subgroup costs				3.300,00 €		
4		INSTALLATION AND COMISSIONING				
	a	Installation	200,00 €		20	10,00 €
	b	Testing and comissioning	400,00 €		20	20,00 €
Subgroup costs				600,00 €		
Total Costs			**8.080,00 €**			**408,00 €**

Figure 17. Estimated CAPEX for the TEE unit

ESTIMATED OPEX FOR THE TEE UNIT						
Group ID	Subgroup ID	Costs group	Cost	Subgroup costs	Estimated lifespan	Annual OpEx estimate
1		ELECTRICITY CONVERSION GAINS				
	a	TEE operation	- 1.600,00 €		1	- 1.600,00 €
	b	Control system and sensors	50,00 €		1	50,00 €
Subgroup costs				- 1.550,00 €		
2		MAINTENANCE AND CONSUMABLES				
	a	Consumables	- €		2	- €
Subgroup costs				- €		
3		LABOR COSTS				
	a	Routine inspection and Maintenance	200,00 €		1	200,00 €
	b	Monitoring and Operations	10,00 €		1	10,00 €
Subgroup costs				210,00 €		
4		COMPLIANCE AND TESTING				
	a	Performance testing and certification	100,00 €		20	5,00 €
	b	Environmental monitoring	30,00 €		1	30,00 €
	c	Audits and Inspections	50,00 €		1	50,00 €
Subgroup costs				180,00 €		
5		SOFTWARE AND LICENSING				
	a	Software Updates and Support	- €		5	- €
	b	Data Analytics and IoT Integration	- €		1	- €
Subgroup costs				- €		
6		CONTINGENGY AND MISCELLANEOUS				
	a	Emergency repairs	150,00 €		1	150,00 €
	b	Spare Parts Inventory	150,00 €		5	30,00 €
Subgroup costs				300,00 €		
Total Costs			- 860,00 €			- 1.075,00 €
Negative value means value gain for the consumer						

Figure 18. Estimated OPEX for the TEE unit.

TEE efficiency ranges from 2 - 12 %. This is verified by calculating the heat flow across the TEE.

As the technology is not yet tested in the relevant environment including the land based tests, conducting a further financial analysis is not yet possible. A detailed financial analysis including ROI, NPV with product pricing strategies will be provided in the next, final report.

4.4.4 Current CRL Level

According to partner SMP, the current Commercial Readiness Level (CRL) of the TEE system is assessed at CRL 1, corresponding to an early-stage concept with a technology readiness level (TRL) of 4. According to SMP, this indicates that the core technological components of the system have been validated in a laboratory setting, but the system remains far from full-scale commercial deployment. At present, no components of the TEE system are externally commercially available. The device and its associated components are being specifically developed within the scope of the Green Marine project. To advance the CRL of the TEE system, a series of milestones have been planned. SMP reports that partial tests conducted thus far have demonstrated promising results, paving the way for further development. The goal is to elevate the technology from its current TRL 4 to TRL 7 by validating the system through rigorous testing in realistic operational environments, including both land-based and onboard demonstrations. Depending on the outcomes of these tests, there is potential to achieve a CRL 4 by the conclusion of the project. This would reflect a significant step toward commercialization, with initial pilot deployments and early market engagement strategies in place to drive adoption and investment. These efforts will establish the TEE system as a viable and competitive solution for waste heat recovery in maritime and other targeted applications.

4.4.5 Market Penetration Strategy

To successfully penetrate the market, the TEE system should prioritize demonstrating its value in niche applications, such as small to medium-scale vessels with constrained spaces and specific energy recovery needs. Starting with pilot deployments in controlled environments and onboard vessels will validate the system's performance and scalability, advancing its TRL and CRL levels. Partnering with shipyards, retrofit providers, and regulatory bodies will ensure compliance and streamline integration into existing systems. A focus on modular design and low maintenance requirements will appeal to cost-conscious shipowners and operators. Simultaneously, targeted marketing efforts, including industry events and technical publications, should highlight the system’s unique advantages, such as energy efficiency and environmental compliance, building credibility and creating demand within the maritime sector.

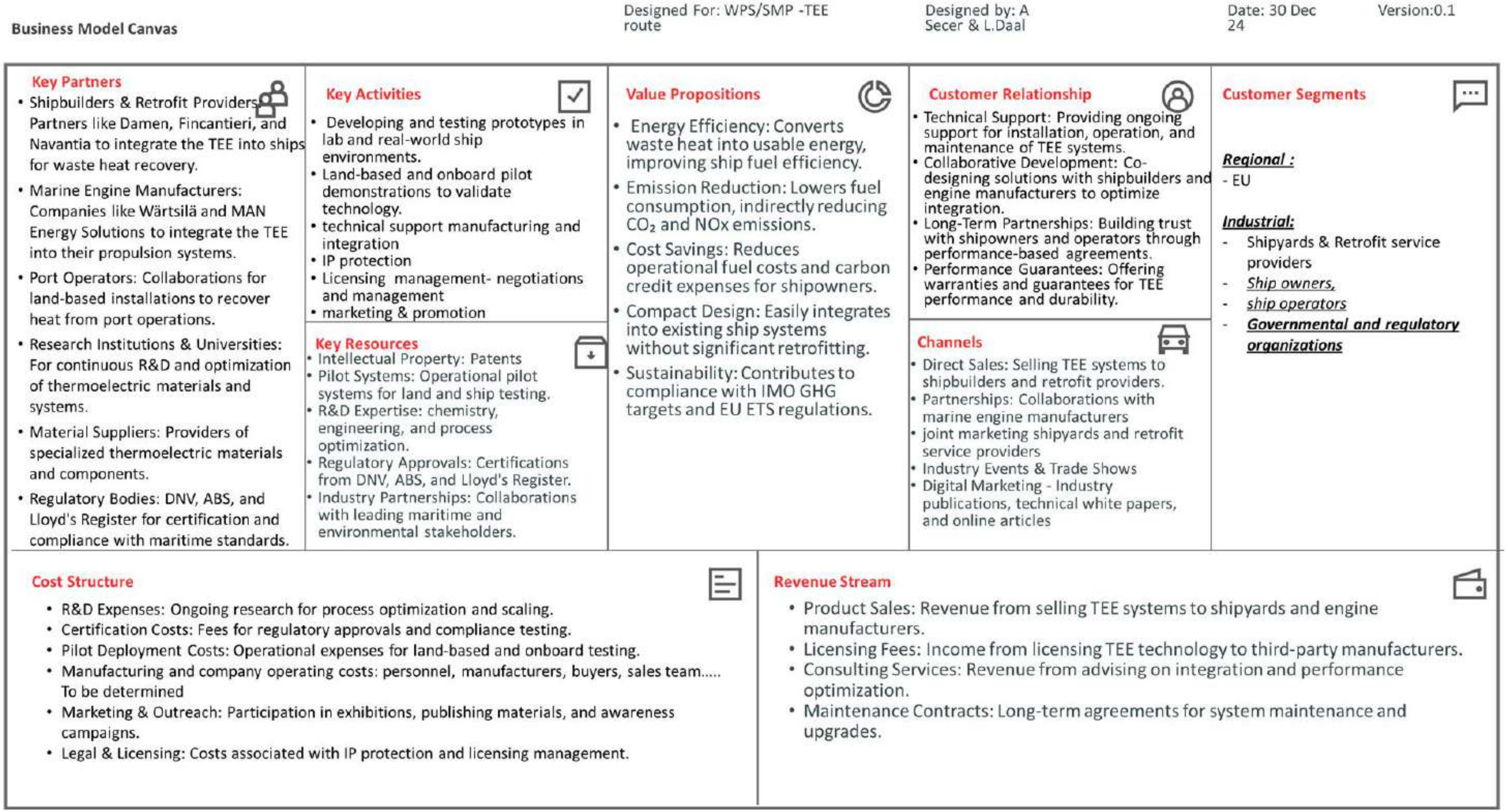

Figure 19. Business model canvas- Thermoelectric Elemet

5. CONCLUSIONS AND NEXT STEPS

The second version of Green Marine exploitation plan outlines the strategic framework for advancing and commercializing its key exploitable technologies, including the Separaptor with UV, Carbon Capture with Membranes, Carbon Capture Machine, Software Catalogue tools and Thermoelectric element. These technologies are designed to tackle critical challenges such as waste heat recovery, CO_2 capture, and emissions reduction, positioning the project as a leader in sustainable maritime innovation.

While currently, the technologies demonstrate strong potential, their readiness levels indicate the need for further validation and optimization to ensure successful market deployment. The next steps include land-based testing to optimize performance, obtaining class approvals and MCE approvals for onboard demonstrations, and pursuing an Approval in Principle (AiP) for pilot on-board demonstrations or AiP per technology process to align with regulatory and industry standards. The type of AiP will depend on several factors such as land-based tests, technical feasibility for on-board demonstrations, risk assessments and many more. These activities will generate critical data on scalability, forming the foundation for robust commercialization efforts. The results from the validation milestones, combined with techno-economic assessments (TEA), life cycle assessments (LCA), and social perception studies, will feed directly into the final version of the exploitation plan. This final report will include detailed financial analyses, SWOT and PESTLE analysis, a comprehensive business model, and validated cost structures, providing a clear pathway for market entry and long-term adoption. The preparation of the final exploitation report at the project's conclusion will consolidate all relevant data on costs, financial calculations, and market readiness, ensuring that the technologies are well-positioned for impactful adoption across the maritime sector.

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