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New Challenges, Onboard Carbon Capture and Storage OCCS for military ships

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Abstract. The concept of onboard carbon capture (OCC) is based on technology which captures the carbon on board the vessel before the CO_2 is emitted to the atmosphere through the exhaust. While it offers flexibility and retrofit potential, some significant engineering, logistical, and economic hurdles remain. Studies show that the technology can be applied safely on vessels, but it still needs to be further developed and optimized for maritime use and integration. Key factors that affect the technical feasibility of onboard carbon capture for a dedicated vessel are the size, operational profile and hull pattern, the machinery capacity for power and heat production, and the space available. This study explores these technologies for naval applications, specifically to reduce smoke emissions from exhaust systems.
Keywords: carbon capture; combustion, absorption, membrane separation, CO_2 desublimation, CO_2 anti-sublimation, cryogenic CO_2 separation

1. Introduction

The International Maritime Organization (IMO) has proposed requirements for international shipping to reduce carbon intensity by at least 20-30 percent by 2030 and 70 percent by 2050 from the 2008 values (International Maritime Organization, 2023), Figure 1.

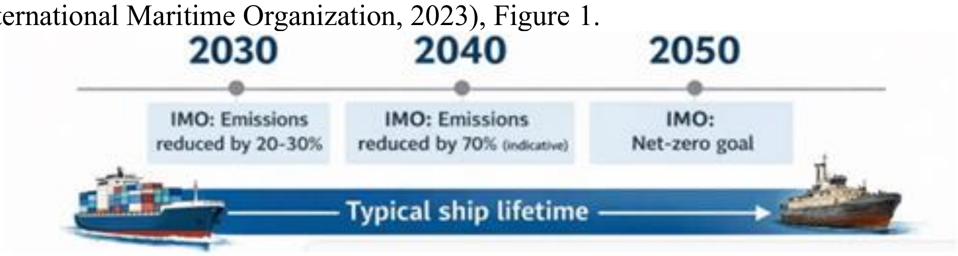

Figure 1 IMO and decarbonization

These major reduction goals are driving the maritime industry to pursue various feasibility pathways for zero- and low-carbon fuels together with decarbonization technologies including carbon capture and the supporting systems required to store, transport and utilize or permanently sequester captured carbon. While the topic of carbon capture, utilization and storage (CCUS) encompasses many industries and technologies, this document highlights insights into onboard carbon capture systems in more detail, focusing on post-combustion capture technologies, the storage of captured carbon on board and the energy requirements to operate the additional equipment for carbon capture. Instead of preventing carbon dioxide (CO_2) formation, onboard systems capture emissions directly from exhaust streams before they enter the atmosphere. While promising in theory, onboard carbon capture presents a unique set of technical, economic, and regulatory challenges. Global shipping traffic analysis indicates significant potential for emissions reduction through the implementation of carbon capture technologies across various vessel types (DNV, 2022). Below is a structured overview of the key considerations and obstacles.

The ISO Technical Committee ISO/TC 265 "Carbon dioxide capture, transportation and geological storage" publishes standards which historically have focused on industrial sectors such as power, cement, iron and steel production, where carbon capture is more mature than offshore applications (European Maritime Safety Agency, 2026). While onboard carbon capture may not be specifically referenced in the standards, they may apply to any post-combustion CO2 capture system, for example: ISO 27916:2019 Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO2 - EOR), Figure 2. Recent industry guidelines have been developed to standardize the implementation of onboard carbon capture systems, providing frameworks for safety and operational requirements (DNV, 2023c).

Figure 2. Stepwise process of the onboard capture value chain

For our application, we propose to retrofit an exhaust installation to store carbon dioxide in closed recipients (Popovici & Rusu, 2024), Figure 3. The main goal is reducing smoke from exhaust with applications in the navy.

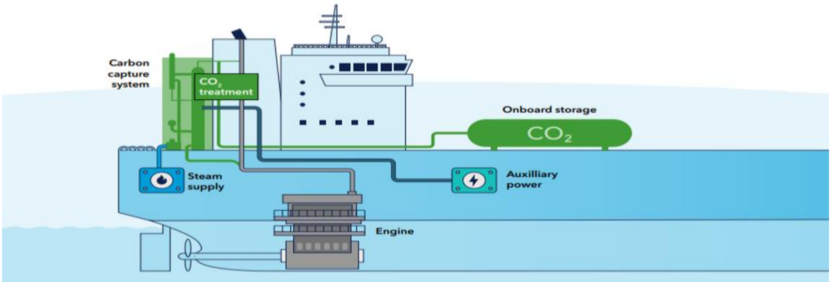

Figure 3. Storage the carbon on board

OCCS should not be understood as a single add-on box. It is an end-to-end chain that must operate reliably at sea and remain creditable when the CO_2 leaves the vessel.

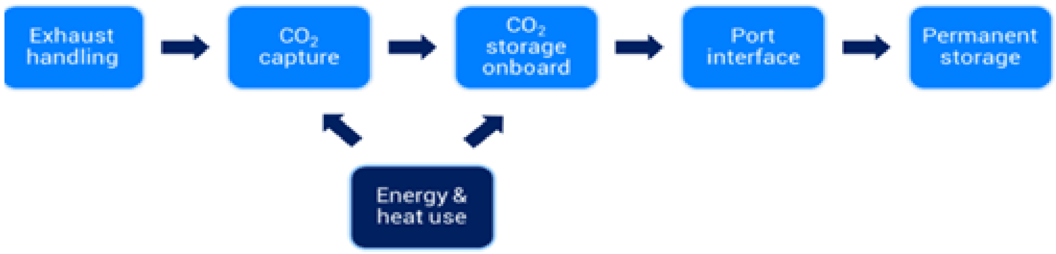

Figure 4 Chain of OCCS

In practice, the value of OCCS depends less on whether CO_2 can be separated from exhaust, and more on whether captured CO_2 can be measured, stored, transferred, and delivered to a verified permanent sink under a robust chain of custody, Figure 4.

2. Techniques and methods

There are many potential methods for the removal of carbon, shown in Figure 5. For onboard applications, pre-combustion and oxy-combustion carbon capture methods may be applied or considered to improve the effectiveness of post-combustion carbon capture methods. Further information on pre-combustion and oxy-combustion is available in the 2021 ABS publication Carbon Capture, Utilization and Storage (Sustainable Ships, 2023; European Maritime Safety Agency, 2026). For navy, post-combustion carbon capture on board ships involves cleaning exhaust gases before release, typically by installing equipment within or near the vessel exhaust stack. The methods for post-combustion shipboard carbon capture being considered by the maritime industry include chemical absorption, membrane separation and cryogenic carbon capture technologies. These can either be retrofitted on existing ships or fully integrated into new ship designs. While Figure 5 shows various types of carbon capture systems, the unique criteria for operating on ships may allow only a few types to be feasible.

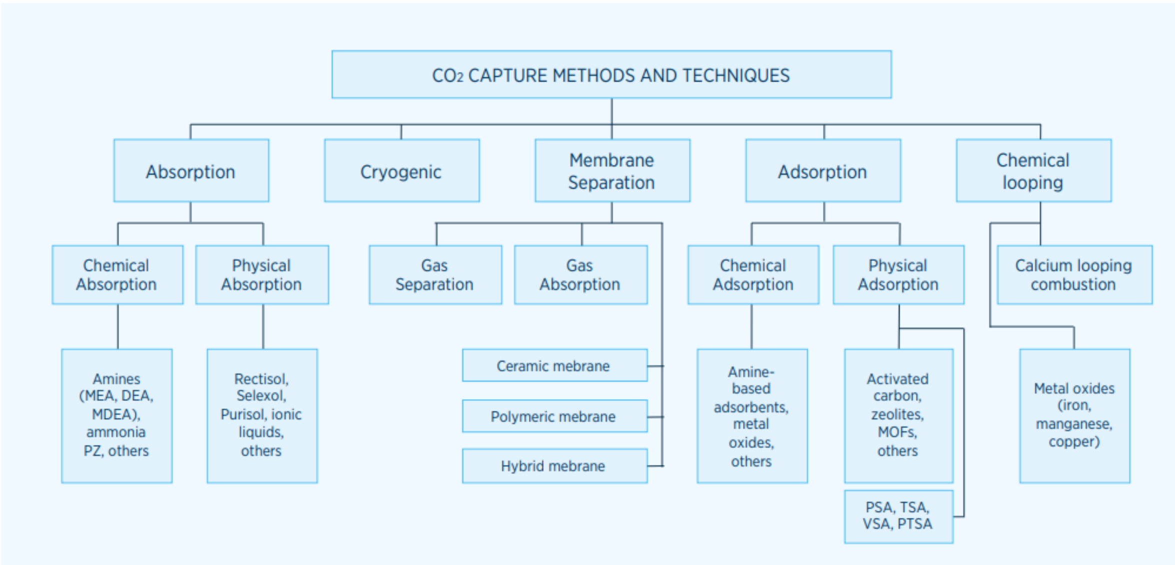

Figure 5. Methods of storage the carbon on board

In addition to cost considerations, when installed on board ships, the systems are also sensitive to size, weight and power limitations. The optimization of various onboard system architectures can result in more effective solutions. Carbon capture methods specifically discussed here include absorption, cryogenic separation chemical, membrane separation, adsorption and chemical looping. This technology may be adapted for the cleaning and cooling of exhaust gases prior to passing to the absorber and desorber parts of a chemical absorption carbon capture system. For general information about the installation of exhaust gas cleaning systems, see the ABS publication Practical Considerations for the Installations of Exhaust Gas Cleaning Systems.

Chemical absorption. Carbon capture using solvents depending on the fuel type and exhaust quality, the first step in many exhaust gas purifying systems for carbon capture is to reduce the impurities and gas species including SOx, Particulate Matter (PM), heavy metals, ash and nitrogen oxides (NOx) that may be present in the exhaust gas. Onboard carbon capture systems may utilize wet scrubbing in the exhaust gas quenching/cooling stage and then be arranged using an absorber unit where the solvent extracts CO2 from the exhaust stream. Commercial marine carbon capture systems based on chemical absorption are currently available from several manufacturers, offering modular solutions for retrofit applications (Wärtsilä, n.d.). The CO_2-rich solvent is then sent to a desorber, or stripping, unit to both separate CO_2 from the solvent and recover the solvent for reuse. Depending on the type of solvent used, they may degrade over time at various rates and require replenishment or replacement, while the spent solvent or residue requires proper handling and disposal. Supporting systems for the main process stages include water vapor removal, heat exchangers for temperature and constituent phase control, blowers or pumps for circulation, or other systems to achieve the desired quality of captured CO_2.

See Figure 6 for a generic onboard carbon capture and storage system using solvents. Various concept design arrangements of onboard carbon capture using monoethanolamide (MEA) solvent systems have been documented (DNV, 2023b; Sustainable Ships, 2023), showing 50 percent and 90 percent capture rates on bulk carriers, tankers and containerships, respectively. The arrangements conceptually show the estimated sizes of the carbon capture systems with explanatory information regarding ship routing, power requirements and system capacities.

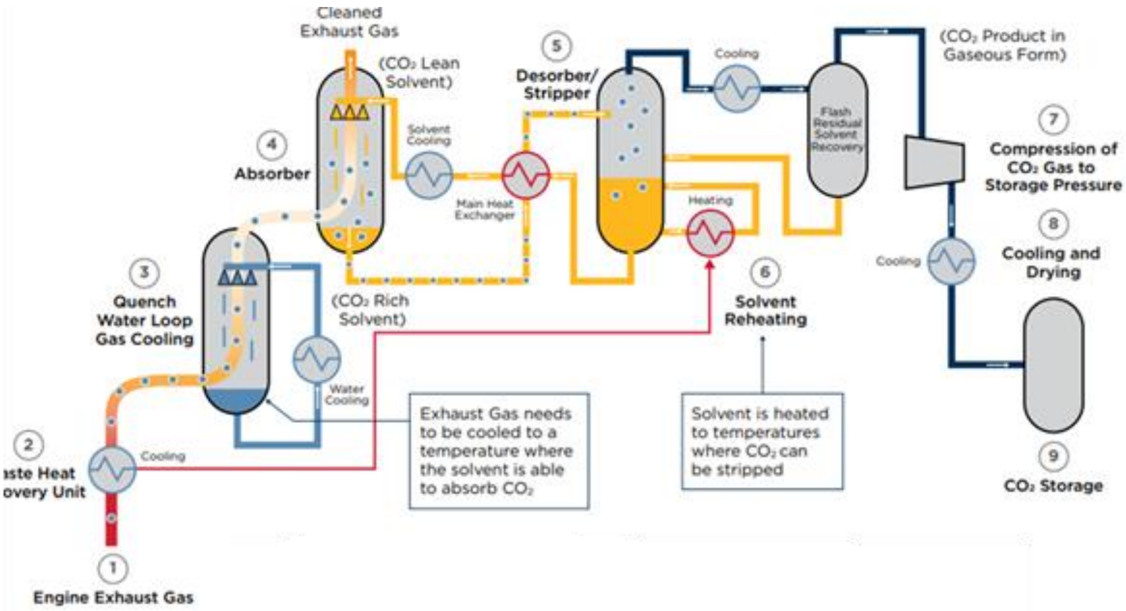

Figure 6 Absorption

Solvents work as aqueous carriers that absorb excess CO_2 molecules from the gas stream and can be composed of a combination of liquefied chemicals. Already used in land-based applications, the technical aspects of carbon absorption using solvents such as MEA, diethanolamine (DEA) and methyl diethanolamine (MDEA), commonly referred to as amines, are mature and well understood. These three amines exhibit similar characteristics and are generally referred to here simply as MEA. Although handling MEA on land is well understood, it can present a new challenge for handling and storing on board ships (Damartzis et al., 2022). Other solvents introduced here for chemical carbon absorption or direct carbon separation are aqueous ammonia, potassium hydroxide (KOH), sterically hindered amines, piperazine and ionic liquids. Based on the criteria for the system or operational constraints, various system architectures and solvent types can be used to achieve different carbon capture and energy efficiencies or size/ weight system optimizations. Typically for solvent systems, energy requirements are highest for the energy needed (heat of reaction) for CO_2 absorption, heating the CO_2-rich amine solution to the regenerator temperature, or producing steam needed for solvent regeneration.

Cryogenic. Cryogenic carbon capture is a method of separating and collecting CO2 directly from the exhaust gas stream by cooling it to a very low temperature (DNV, 2023a; Sustainable Ships, 2023). Also, is a process in which carbon is separated from exhaust gas by controlling phase changes via temperature and pressure (thermodynamic) modulations, Figure 7. The effectiveness of cryogenic carbon capture relies on the various chemicals found in the gas stream. The process involves cooling exhaust gas to the solidification point of CO_2 (-100 to -135° C). Where conventional distillation processes may prefer liquid products for ease of handling, it has been shown in various studies that vapor-to-solid separation can be more energy-effective. Using the CO_2 solidification extraction method to extract gases, including NOx and SOx, results in two exhaust gas streams; one consisting of pressurized pure CO_2 (99 percent or higher), and another comprised of the remaining contents in the original exhaust at ambient pressure, as shown in Figure 4. This system can be installed on existing ships with a relatively small footprint connected to an exhaust gas input and a power source. The extreme temperatures necessary for the cryogenic carbon capture process require the integration with other systems on board to optimize the heat exchange process. This method is achieved primarily by a network of heat exchangers, the specific architecture of which can significantly improve the energy efficiency of the installed system. It is estimated that this process can reduce the energy consumption of carbon capture by 50 percent when compared to solvent-based carbon capture systems. While cryogenic carbon capture systems appear to have promising advantages over other systems, research is still ongoing to develop, optimize and implement for application onboard ships. Due to the low temperature requirements for cryogenic carbon capture, they may be of interest to vessels carrying liquefied natural gas (LNG) (which is stored at temperatures as low as -163° C). There may be opportunities for the LNG cryogenic systems to work harmoniously with the cryogenic carbon capture systems to gain additional efficiencies.

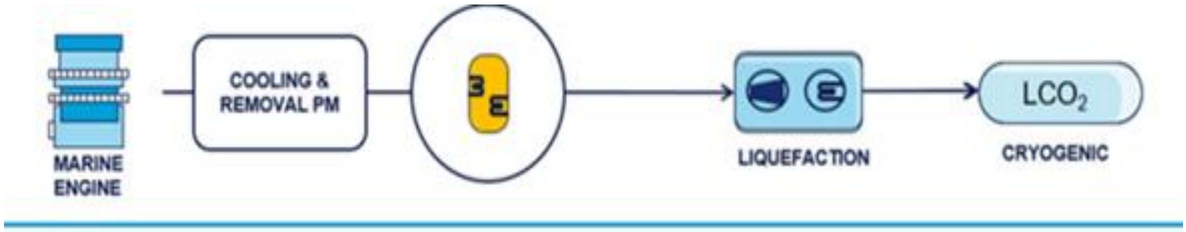

Figure 7 Cryogenic Carbon Capture process (source DNV)

Cryogenic OCCS includes the following steps: exhaust gas drying: in this stage, H_2O is removed from the exhaust gas by cooling; cooling of remaining gases: the remaining exhaust gas is further cooled; liquefaction of CO_2 - the dry exhaust gas is cooled and pressurized, causing the CO_2 to liquefy; capture of CO_2 - the liquefied CO_2 is stored onboard until disposal to port. Cryogenic separation, though still in early stages of maritime adaptation, has demonstrated the ability to achieve very high CO_2 purity levels (up to 99.99%), which supports efficient downstream storage or utilization (Popovici & Rusu, 2024). While the low CO_2 concentration in ship exhaust limits its standalone effectiveness, projects like the DNV LNG carrier study have explored its potential for vessels with cryogenic fuel systems (DNV, 2023a).

Membrane Separation. Membrane separation is a developing onboard carbon capture technology that has various advantages in the separation of mixed gases (Damartzis et al., 2022; European Maritime Safety Agency, 2026). Membranes can be implemented as a physical filtration system to absorb various impurities, including carbon gas, see Figure 8. Conventional membrane technology consists of filters specific to molecule sizes and can require significant input pressure. Gaseous membrane CO_2 filters are made of a semi-permeable fabric that allows selected molecules to pass through while restricting the flow of others. The efficiency of these systems is negatively affected by the presence of other gasses such as NOx and SOx groups, and moisture. Advanced membrane technology may also use solid carriers (sorbents) bonded to the surface of a filter to encourage chemical or electrical CO_2 separation. These are novel and emerging technologies which involve less commercially available systems but may show potential for the future of carbon capture on board ships.

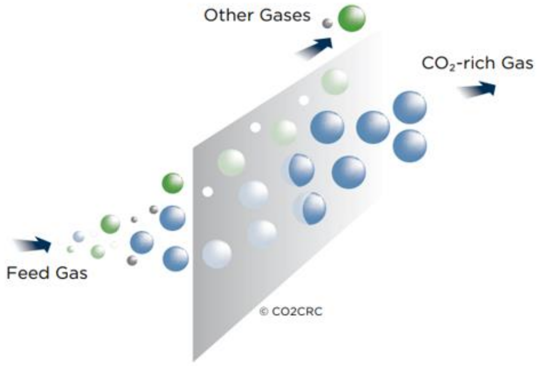

Figure 8 Membrane separation

Adsorption. Physical adsorption involves the use of materials that adsorb CO_2 through the creation of bonds, such as Van der Waals bonds. The process is particularly effective at high pressures. By altering pressure or temperature, the bonds are activated or deactivated, allowing CO_2 to be captured and then released as high-purity gas Figure 9.

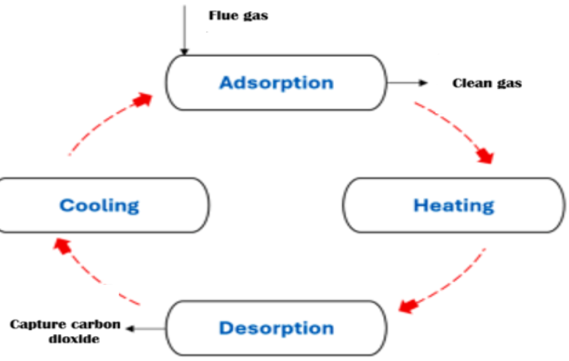

Figure 9 Schematic representation of TSA for carbon dioxide capture from flue gas

Variants of the process include Pressure Swing Adsorption (PSA) and Temperature Swing Adsorption (TSA). PSA achieves this by reducing pressure to release the captured CO_2, while TSA uses heat to desorb CO_2 from the adsorbent, (Karimi, Shirzad, & Silva, 2023), Figure 10.

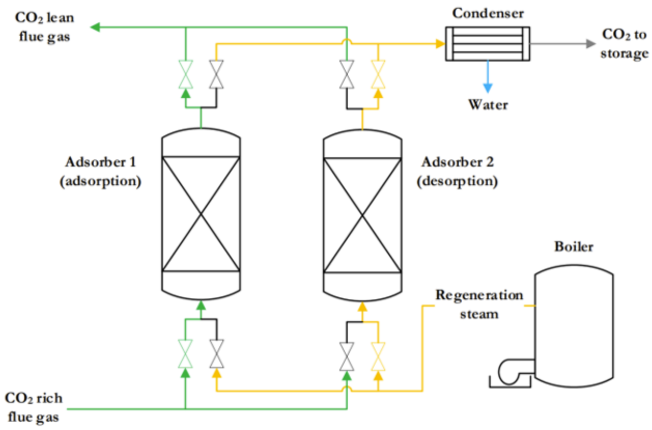

Figure10. Schematic of a fixed bed adsorber using TSA

Chemical looping. The CLC process is usually conducted in a system of two reactors Figure 11, which consists of the fuel reactor (FR), where combustion takes place, and the air reactor (AR), where oxygen carriers (OC) are regenerated (European Maritime Safety Agency, 2026). Thus, oxygen carriers are subjected to continuous oxidation and reduction (relations 1,2) while they circulate throughout the combined CLC unit. There are two crucial benefits of OCs employment in a power generation system, which are the elimination of conventional energy-consuming air separation units and the inherent separation of forming flue gases (mainly CO_2 and H_2O) from the air supplied to the combustion process. As a result, the flue gas that leaves the fuel reactor is free of atmospheric nitrogen and thus it becomes almost ready for geological sequestration—CCS (carbon capture and storage) and/or commercial utilization—CCU (carbon capture and utilization). Concurrently, the exhaust gas from the air reactor consists essentially of nitrogen and the remaining oxygen, which are both environmentally friendly gases, relation 3.

$$(2 \cdot n + m)Me_xO_{y-1} + (2 \cdot n + 0.5 \cdot m)O_2 \rightarrow (2 \cdot n + m)Me_xO_y \Delta H_0 \quad (1)$$

$$C_nH_{2m+}(2 \cdot n + m)Me_xO_y \rightarrow nCO_2 + mH_2O + (2 \cdot n + m)Me_xO_{y-1}\Delta H_r \quad (2)$$

$$C_nH_{2m} + (n + 0,5 \cdot m)O_2 \rightarrow nCO_2 + mH_2O\Delta H_c = \Delta H_0 + \Delta H_r \quad (3)$$

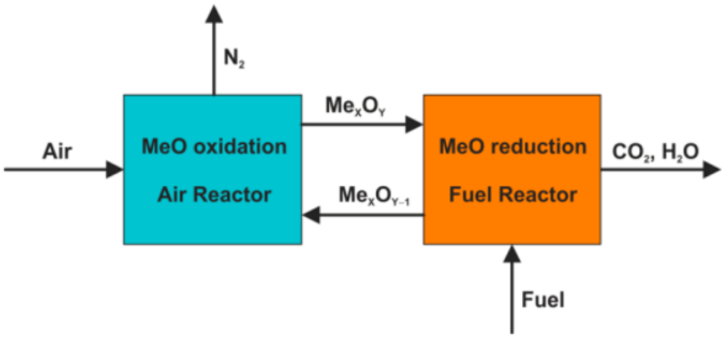

Figure 11. Chemical looping combustion concept

Calcium looping (CaL) technology removes acid gases and carbon dioxide (CO_2) from the flue gases using a calcium oxide (CaO) sorbent. The process relies on two reversible chemical reactions: carbonation and calcination.

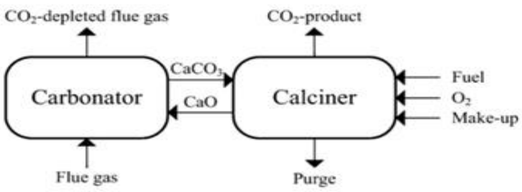

Figure 12. Calcium Looping technology

During carbonation, the sorbent reacts with the CO2 in the flue gas to form calcium carbonate ($CaCO_3$). The $CaCO_3$ is then fed into a calciner, where it is heated to about 600 - 900°C1, causing it to decompose into an almost pure CO2 gas stream and solid CaO. The CO2 is removed and further purified before being sent either for geological storage or onward use. The solid CaO can be sent back for reuse in the process to capture more CO2. This system not only captures CO2 but also produces additional heat and power by integrating with a subcritical steam cycle. Some of the sorbent must be purged to remove accumulated impurities. The purged material is calcined lime mixed with ash and minerals, which can be used as a by-product and renewable feedstock for the cement and lime industries.

Table 1. Comparative table for technology of OCCS

Technology of OCCS	Performance of reduction CO_2	Energy Penalty	Notes
Chemical absorption	30÷90 %	Heat 1.8÷4.0 GJ/t CO_2 *Fuel penalty 9÷30%*	Mature, high heat demand
Membrane separation	20÷80 %	Fuel penalty ~ 14%	Needs low temperature exhaust, sensitive to impurities
Cryogenic separation	High purity CO_2 up to 99.99%	Energy intense	Low CO_2 exhaust limits efficiency

These performance metrics reflect current technological capabilities in maritime carbon capture applications (DNV, 2023b; Sustainable Ships, 2023; Damartzis et al., 2022). Chemical absorption involves the use of liquid solvents, such as amines, to selectively absorb CO_2 from exhaust gas stream, with applications in both land-based and maritime industries. The CO_2 gas gets absorbed into the liquid solvent and bonded with the liquid chemical. The effluent is fed to specialized equipment to release the captured CO_2, by breaking it from the solvent through a regeneration process, allowing the solvent to be reused. This method is widely used in industrial applications due to their high removal efficiency, low vapour pressure and low cost, Table no 1.

3. Results and discussions for military ships

Carbon capture is a technique that can be divided into two main branches:

- Carbon Capture and Storage (CCS), the name under which several technologies are currently being developed that allow the capture of carbon dioxide from the gases resulting from the combustion of fossil fuels (Global CCS Institute, 2023; International Energy Agency, 2023).
- Direct Air Capture (DAC) refers to technologies for capturing carbon dioxide from the atmosphere (Lagemann & Lindstad, 2023). The concentration of carbon dioxide is about 300 times lower in the air than in the gases generated by the combustion of fossil fuels, which is why DAC technologies have a lower efficiency and are more expensive than CCS technologies.

Based on the analyses performed in section 2, for military ships equipped with diesel engines, gas treatment solutions based on the absorption process will be applied, see Figure 6. Thus, carbon dioxide will be captured from the exhaust gas and stored in cylinders on board the ship. Offshore CO2 transfer infrastructure is being developed to facilitate the offloading of captured carbon from vessels (Global Centre for Maritime Decarbonization, 2024; Popovici & Rusu, 2024), see Figure 13.

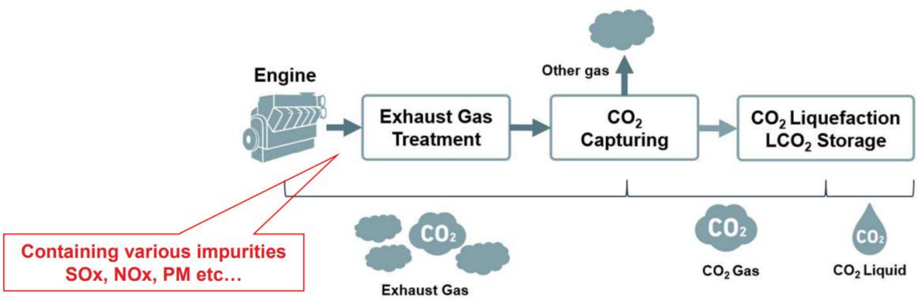

Figure 13. Retrofit concept for military ship

As an application and case study, we chose a corvette-type ship, equipped with 4 diesel engines and which emits impressive amounts of smoke, especially during manoeuvring. The corvettes are part of the Tetal-I class, in service with the Romanian Navy since 1983. The Romanian naval modernization strategy emphasizes environmental compliance and emissions reduction technologies (Ministerul Transporturilor și Infrastructurii, 2023).

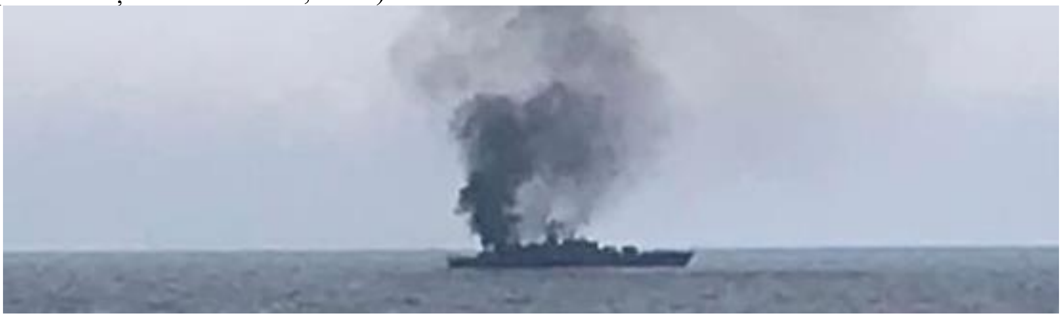

Figure 14. Corvette in maneuver mode.

With a displacement of approximately 1385-1590 tons and a length of 93 meters, they are equipped for anti-submarine missions, which often require low speed. Propulsion is provided by 4 ALCO 16R 251 FMA diesel engines, manufactured in Reșița, generating significant total power with considerable naval diesel consumption and exhaust gas emissions (see Figure 14). The 4 propulsion engines each provide 3,285 HP at a specific fuel consumption of 165 g/HPh. At nominal power, the fuel system must supply these engines with a minimum quantity of diesel fuel of $4 \times 3{,}285 \times 165 \times 10^{-6} = 2.2$ t/h, which also implies the production of approximately 7.9 t CO_2/h (assuming a conversion factor of 3.65 kg CO_2 per kg diesel fuel). At a carbon dioxide recovery rate of 50%, one hour of operation requires a storage capacity of approximately 4 cubic meters.

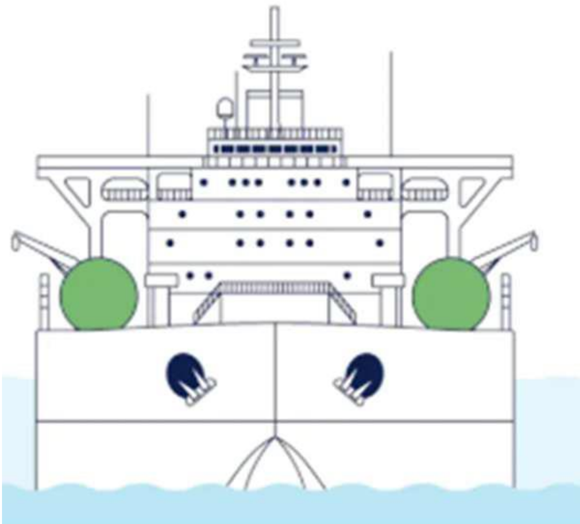

Figure 15. Tanks CO_2 for military ship

The capacity of the carbon dioxide storage tanks will be provided only for maneuvering cases, so to ensure 24-hour transient regimes and to prevent the appearance of smoke in excess exhaust gases, two tanks with a capacity of 48 cubic meters would be necessary, which would not cause major inconvenience on board, Figure 15.

4. Conclusions

These systems are categorized by the stage at which CO_2 is separated, post-combustion. Post-combustion methods, such as chemical absorption, physical adsorption, mineralization, membrane separation, cryogenic separation, and electrochemical separation, are widely explored for maritime use.

Pilot projects across the maritime sector have demonstrated OCCS feasibility under real-world marine environment conditions and chemical absorption systems have been tested on various vessel types, showing promising results in terms of capture efficiency and operational stability (Henderson et al., 2025), while mineralization pilots have validated the conversion of CO_2 into solid carbonates.

These pilots for military ships contribute with knowledge on system performance, integration challenges, and regulatory compliance, supporting the broader consideration of OCCS as a solution for decarbonization of shipping (Ricardo Energy & Environment & DNV, 2023; European Commission, 2024)

Finally, it is important to notice that although OCCS technologies are being demonstrated and further developed, the realization of this technology is dependent on the development of the downstream infrastructure for receival, transport and permanent storage or use of the CO_2 (Global CCS Institute, 2023; Clean Air Task Force, 2023). These reduction targets are also supported by European regulations, including the EU Emissions Trading System for maritime transport (European Union, 2023; European Commission, 2024).

Author contributions:

- Conceptualization: P.I.
- Methodology: P.I. and V.O.N.
- Investigation: C.D.
- Writing original draft: V.O.N. and P.I.
- Writing review and editing: V.O.N. and P.I.
- Supervision: P.I.

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References

1. European Maritime Safety Agency. (2026). Onboard carbon capture and storage systems study. EMSA.
2. Clean Air Task Force. (2023). Mapping the cost of carbon capture and storage in Europe. https://www.catf.us/2023/02/mapping-cost-carbon-capture-storage-europe
3. DNV. (2022). AIS analysis of Nordic ship traffic (Nordic Roadmap Publication No. 2-A/1/2022). https://futurefuelsnordic.com/ais-analysis-of-the-nordic-ship-traffic-and-energy-use
4. DNV. (2023a, September 4). Investigating carbon capture and storage for an LNG carrier. DNV Maritime Impact. https://www.dnv.com/expert-story/maritime-impact/investigating-carbon-capture-and-storage-for-an-lng-carrier
5. DNV. (2023b). Maritime forecast to 2050. https://www.dnv.com/maritime/publications/maritime-forecast-2023/download-the-report

6. DNV. (2023c, October 9). DNV has launched new guidelines for onboard carbon capture systems on board ships [Press release]. https://www.dnv.com/news/dnv-has-launched-new-guidelines-for-onboard-carbon-capture-systems-on-board-ships-247921
7. European Union. (2023, May 10). Directive (EU) 2023/959. Official Journal of the European Union. https://eur-lex.europa.eu/eli/dir/2023/959/oj
8. Popovici, J. S., & Rusu, C. (2024, April 7). Tehnologii navale si combustibili viitorului pe drumul decarbonizarii (CCN 98).
9. European Commission. (2024, March 19). FAQ – Maritime transport in EU Emissions Trading System (ETS). https://climate.ec.europa.eu/eu-action/transport/reducing-emissions-shipping-sector/faq-maritime-transport-eu-emissions-trading-system-ets_en#biofuels-and-other-alternative-fuels
10. Global CCS Institute. (2023). Global status of CCS 2023 – Scaling up through 2030.
11. Global Centre for Maritime Decarbonisation. (2024). Concept study to offload onboard captured CO_2.
12. International Energy Agency. (2023). Net zero roadmap - A global pathway to keep the 1.5°C goal in reach. https://www.iea.org
13. International Maritime Organization. (2023). 2023 IMO strategy on reduction of GHG emissions from ships. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf
14. Karimi, M., Shirzad, M., & Silva, J. A. C. (2023). Carbon dioxide separation and capture by adsorption: A review. Environmental Chemistry Letters, 21, 2041–2084. https://doi.org/10.1007/s10311-023-01589-z
15. Ricardo Energy & Environment, & DNV. (2023). Study on the readiness and availability of low- and zero-carbon ship technology and marine fuels (IMO Future Fuels and Technology Project). https://www.imo.org
16. Sustainable Ships. (2023). Ship-based carbon capture (SBCC): A techno-economic guide on the use of carbon capture and storage onboard your ship based on 11 case studies.
17. Damartzis, T., Fosbøl, P. L., Paschalidi, Z. M., Woodley, J. M., & Nassos, V. (2022). Solvents for membrane-based post-combustion CO_2 capture for potential application in the marine environment. Applied Sciences, 12(6100). MDPI.
18. Ministerul Transporturilor și Infrastructurii. (2023, December). Strategia de dezvoltare a transporturilor navale. Direcția Transport Naval.
19. Wärtsilä. (n.d.). Carbon capture and storage. https://www.wartsila.com/marine/products/exhaust-treatment/carbon-capture-and-storage
20. Henderson, N., Baskår, H. K., & Shepherd, L. (2025, February 19). Onboard carbon capture: A bridge to zero emission shipping?
21. Lagemann, B., & Lindstad, E. (2023, November 30). The importance of carbon capture (onboard) and DAC (onshore) for maritime transport to reach net zero by 2050 [Conference presentation]. Rotterdam, Netherlands.