Ship-based Carbon Capture (SBCC)

Green Deal Validation

Netherlands Maritime Technology | IRO · TNO innovation for life · MARIN · Koninklijke Vereniging van Nederlandse Reders · Ministerie van Infrastructuur en Waterstaat · Ministerie van Economische Zaken en Klimaat

Description

Ship-based carbon capture (SBCC) is a technology that captures CO_2 from the exhaust gas and temporarily stores this on board in separate CO_2 tanks. The CO_2 can be unloaded in ports and used as a feedstock for e-fuels, permanently stored underground, or bound to other products in e.g. the plastics industry, or traded as a commodity. The technology potentially offers the opportunity of up to 90% CO_2eq emission reduction on ships.

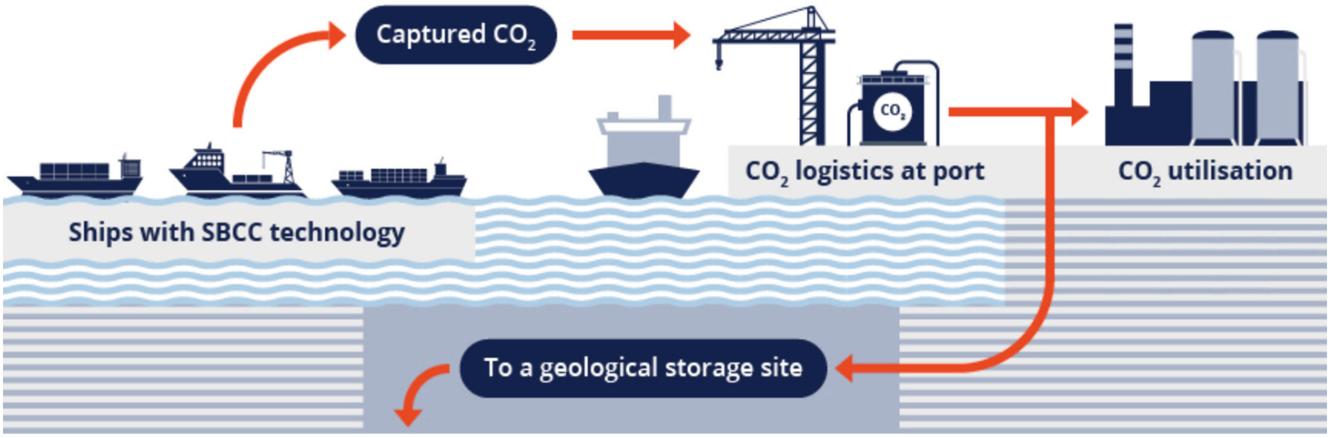

Figure 1: Example of a full SBCC chain[1]

Market readiness & availability

Status quo

International research projects cover the capture, storage, and offloading of up to 90% CO_2 emitted during the operational phase of the ship, including demonstration of the complete value chain from off-loading to shore and geological storage onshore or utilisation in industrial activities[1].

Technology & Infrastructure

SBCC technology is currently taking steps towards modular standardisation and upscaling via full-scale pilots (TRL7-8) [1,2,3]. International Original Equipment Manufacturers (OEM) such as Value Maritime, Wärtsila, VDL AEC, Mitsubishi Shipbuilding, and more perform both commercial feasibility assessments and technology pilots. However, one of the main concerns is the limited CO_2 handling infrastructure, which depends on projects such as Porthos and Northern Lights[4].

Regulation

Considering regulation, the research's first results show no major safety impediments to implementing SBCC[5]. Currently, the focus is on crediting the well-to-wake CO_2 reduction within international regulation. CO_2 accounting is essential to improve the technology business case and is currently addressed in the EU and IMO.

[1] Everlong, "Demonstrating Carbon Capture on LNG-Fuelled ships,", 2023, Available: https://everlongccus.eu/.
[2] OGCI, „Project to demonstrate end-to-end shipboard carbon capture," Available: https://www.ogci.com/news/project-to-demonstrate-end-to-end-shipboard-carbon-capture.
[3] "K" Line Successfully Captures CO_2 in Shipboard Trial," 20 October 2021. [Online]. Available: https://maritime-executive.com/article/k-line-successfully-captures-co2-wartsila-plans-co2-capture-pilot.
[4] Northern Lights Project, "Who we are", 2024. Available: https://norlights.com/who-we-are/
[5] J. A. Ros et al., "Advancements in ship-based carbon capture technology on board of LNG-fuelled ships," Int. J. Greenh. Gas Control, vol. 114, 2022, doi: 10.1016/j.ijggc.2021.103575

Applicability for reference ships

In principle, the SBCC technology can be applied to the exhaust gases of all carbon-based marine fuels. However, certain differences between fuels can be identified. LNG has advantages over other fuels, as the fuel is relatively clean and has heat/cold integration benefits. An example is the engine waste heat, which can be used for CO_2 capture process. In addition the 'cold' available from LNG can be used for liquefying the CO_2 for onboard storage (see Figure 2). For other fuels like MGO or heavy fuel oil, it is expected that the amount of impurities, such as particulate matter, SO_x, and NO_x, will have a significant impact on the long-term durability of the capture solvent, the CO_2 transport onboard, and therefore operational cost. This effect has not yet been quantified.

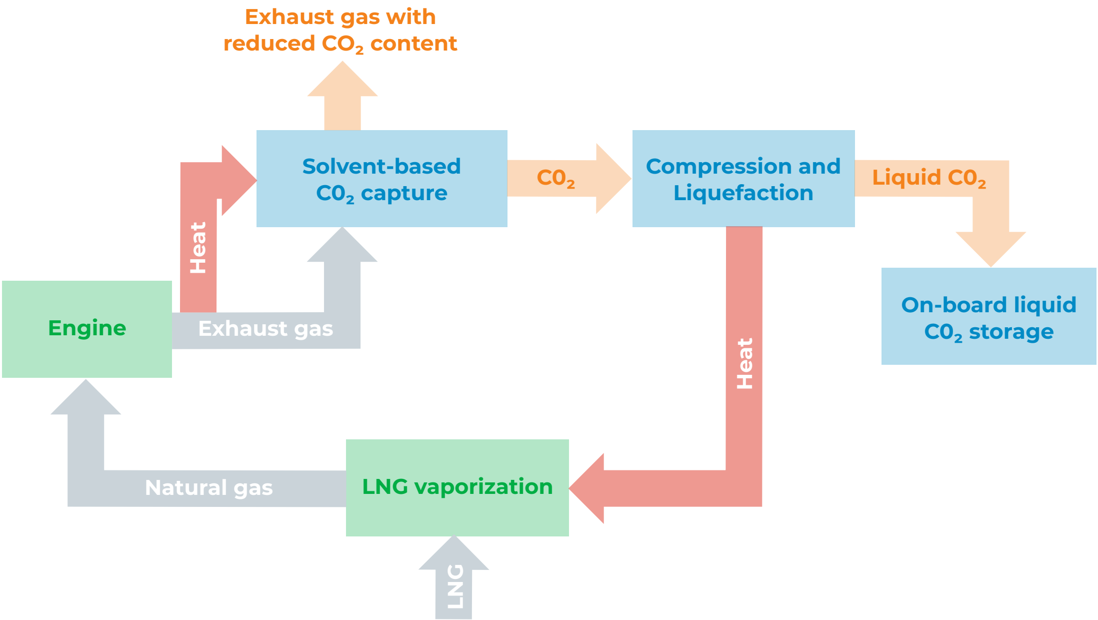

Figure 2: Concept heat integration for LNG-powered vessel with SBCC[1].

The main limitation on board is the large footprint of the SBCC installation, both for the capture plant and the storage tanks. Depending on the design and whether it concerns newbuild or retrofitting, an additional volume of up to 15% is required for the complete installation[6]. In practice, energy-efficiency and therefore economic considerations are paramount. The footprint makes SBCC mostly suitable for larger ships (see Table 1).

International shipping			Dutch shipbuilding and shipping key segments					
Tanker	Bulk carrier	Container ship	General cargo	Tug boat	Offshore supply	Crew tender catamaran	Dredger vessel	Super yacht
+	+	+	+	-	-	-	+/-	-

Table 1: Feasibility of SBCC for different sizes of ships[7]

[6] MMMCZCS, "The Role of Onboard Carbon Capture in Maritime Decarbonisation", 2022
[7] Netherlands Enterprise Agency, "Roadmap brandstoftransitie in de Zeevaart", 2024, available: https://www.rvo.nl/sites/default/files/2024-07/Roadmap%20Brandstoftransitie%20in%20de%20zeevaart.pdf

Emission reduction effectiveness

It is important to note that the CO_2 net removal rate and fuel penalty are highly dependent on the ship and waste heat/cold availability. Therefore, correct integration and availability of waste heat results in a significant lowering of the fuel penalty. The net CO_2 removal can be as high as 60-70% for retrofit vessels, and as high has 90% for newbuild.

Based on recent findings, the first insights are presented in Figure 3. Figure 3 shows an estimate of the additional energy that is needed for the SBCC system (the "fuel penalty") and the resulting net CO_2 removal (including the additional CO_2 from the fuel use of the SBCC system). The graph shows this for MGO/HFO and LNG in different vessel types. Example 1 (yellow line) represents a retrofit case in which a capture plant is installed that treats all exhaust gases downstream of the existing SO_x scrubber. Since not all the exhaust lines are connected to the SO_x scrubber (e.g., auxiliary engines running on MGO), the maximum CO_2 capture rate is limited to 63%. Example 2 (grey line) represents a situation for the same vessel in which the capacity of the carbon capture plant is smaller, thus limiting the required investment. The sizing of the plant for this system was based on meeting the IMO 2030 target of 40% CO_2 emission reduction in combination with other measures. All the dots in Figure 3 (green, gray, yellow) refer to retrofit cases. The "generic" cases added are taken from a literature study in which hypothetical cases are proposed. These are taken as examples of what could be achieved in new built systems.

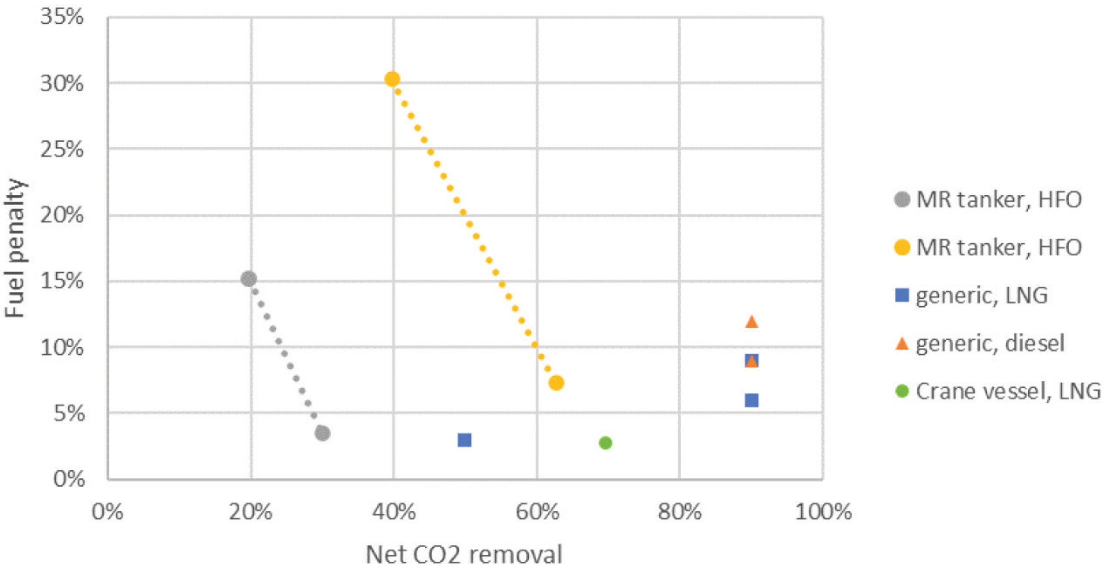

Figure 3: Example insights for net CO_2 removal via SBCC vs. the fuel penalty[8]

For both lines, the upper point represents the worst-case scenario, in which no heat can be retrieved from the vessel systems and needs to be supplied by burning extra fuel, leading to a higher fuel penalty and (thus) a lower net CO_2 removal. As we move down the lines, an increasing amount of heat is assumed to be recovered. The lower point in the lines represents the situation in which 100% of the heat can be retrieved from the vessel systems. Note that the availability of heat for the SBCC system differs per vessel and depends on several factors, such as engine type, fuel type, and how much heat is already being used onboard for other purposes.

[8] Juliana Monteiro, "Memo on the Feasibility of Ship Based Carbon Capture", 2023

Captured CO_2 from SBCC systems is currently expected to be mostly from fossil sources. Geological storage and utilisation routes are explored and considered but should always be accompanied by elaborate calculations of net CO_2 reduction, and LCA impacts to showcase the overall CO_2 reduction efficiency of the SBCC system connected to these utilisation options. The quality of the CO_2 is expected to be (close to) food-grade quality, with impurities like O_2 and N_2 in ppm levels.

Operation and safety

The solvent that is currently most advanced for SBCC application is mono-ethanolamine (MEA), which is a solvent that has been used for around 100 years in acid gas treatment systems [9,10]. Many more modern solvents contain Piperazine (PZ), which is considered a more dangerous solvent than MEA in terms of (eco-) toxicity [3,11]. This impact needs to be quantified and minimized in case of calamities.

Other safety concerns are the potential harm from any concentrated CO_2 release by the SBCC system. The harm correlates to the number of individuals present, the CO_2's capacity to disperse, and adherence to safety distances. CO_2 release only poses a threat when people are around, and the concentration is high enough.

Therefore, the impact of CO_2 release is significantly different for indoor or outdoor complications. Safety recommendations that are made involve: set safety distances, mechanical ventilation in enclosed spaces containing risk of CO_2 leak, CO_2 detectors located in ventilation paths, and limitation of CO_2 accumulation in piping and equipment.

Costs

Ultimately, the applicability of Ship Based Carbon Capture strongly depends on its economic feasibility. Current estimates show significant variations in CO_2 abatement cost (from \$130 to \$290 per ton CO_2) with current technology[7,9]. A large share of these costs are capex-related costs of the SBCC system. Because of the capex dominance of the costs, economy of scale is a crucial cost element. The smaller the vessel, the more expensive SBCC will be (on a cost-per-ton basis). To mitigate this effect, standardisation and modularisation of SBCC systems are actively under investigation.

Development prospect

Like all technologies, SBCC will only get off the ground if a sufficiently feasible business case exists. The investment costs for an SBCC system are relatively high. Standardisation and a modular structure should lead to scaling up and, thus, cost reduction. Furthermore, SBCC requires, similar to the alternative of using alternative energy carriers, the development of infrastructure. Finally, the business case must align with the regulatory developments considering CO_2 accounting and proof that the systems perform according to specification. Overall, the timeline of alignment of technological, economic, and regulatory developments is crucial.

[9] OGCI and Stena Bulk, "IS CARBON CAPTURE ON SHIPS FEASIBLE?," 2021. [Online]. Available: https://www.ogci.com/wp-content/uploads/2021/11/OGCI_STENA_MCC_November_2021.pdf.

[10] Rochelle G.T., "Amine scrubbing for CO_2 capture," Science (80-.)., vol. 325, pp. 1652–1655, 2009, doi: 10.2139/ssrn.2379600.

[11] Carvalho & Daniel, Regulatory review and CO_2 hazards," Everlong Report, 2023.