Grønt Skipsfartsprogram

Onboard carbon capture – Shuttle-tanker

MST
MARAN SHUTTLE TANKERS

Grønt Skipsfartsprogram

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Pilot partners

The Stella Maris CCS Project

Grønt Skipsfartsprogram

Executive Summary

As global efforts to decarbonize the maritime sector intensify, carbon capture and storage (CCS) is gaining traction as a promising solution to meet the ambitious targets set by the Paris Agreement, the IMO Initial GHG Strategy, EU fit for 55 and national goals such as those of Norway. This pilot study—initiated by Maran Shuttle Tankers (Altera Infrastructure at the time) and involving an impressive broad cross-section of stakeholders—was established to explore the end-to-end feasibility of onboard carbon capture (OCC) on a modern LNG-fueled shuttle tanker operating in Northern Europe.

The study aimed to assess both technical and economic viability—from CO_2 capture onboard, to intermediate storage, offloading, transport, and permanent sequestration. The Altera Wave, with its dual-fuel propulsion and energy-efficient design, was selected as the candidate vessel. The pilot design targeted a capture rate of up to 50 tons of CO_2 per day using post-combustion technologies such as amine absorption and membrane separation, with CO_2 stored in liquefied form and offloaded monthly. Engineering analyses confirmed that the retrofit would be feasible within the vessel's stability and space constraints, and no significant showstoppers were identified from a systems integration perspective.

However, despite these promising technical findings, the study ultimately concluded that the timing for a full-scale pilot installation was not viable. The vessel's upcoming dry dock window in 2026, combined with the long lead times for critical OCC system components and the required engineering, would necessitate an investment decision significantly earlier than Maran Shuttle Tankers (Altera Infrastructure at the time) was prepared to take. This decision was further influenced by uncertainty in two key areas: the timing and clarity of regulatory frameworks (notably under the IMO and EU regimes), and the availability of reliable downstream logistics and storage infrastructure.

These uncertainties significantly weakened the overall business case for the pilot, especially given the misalignment between technical readiness and the maturity of supporting external systems. While the EU ETS currently provides partial crediting for captured CO_2, other regulatory mechanisms such as FuelEU Maritime and IMO's lifecycle accounting frameworks are still under development. Similarly, CO_2 storage projects like Northern Lights and Stella Maris show great promise but are unlikely to be fully accessible for maritime OCC volumes until the latter part of the decade.

Nonetheless, the pilot study has provided a valuable knowledge base for the industry. It confirms that OCCS is technically viable and can be safely integrated on board shuttle tankers. More importantly, it has highlighted the critical enabling conditions that must be addressed to make onboard carbon capture a practical and scalable decarbonization option.

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1 Introduction

1.1 Background – why this pilot?

All measures to reduce emissions of greenhouse gases should be carefully considered to reach the targets defined in the Paris Agreement, the initial IMO GHG strategy and by the Norwegian Government.

Carbon capture and storage (CCS) of CO_2, both on land and onboard ships can play an important role in reaching the target of reducing GHG emissions. However, can CO_2 also be captured and stored onboard vessels? Many persisting preconceptions to onboard CCS systems exists; some of which relate to technology maturity, costs, energy consumption, space requirements for systems and CO_2 storage onboard.

Questions and concerns related to how captured CO_2 should be handled after off-loading from the vessel are currently unanswered. How should the onshore infrastructure and the infrastructure related to final storage be ensured? And overall – how to make sure the safety both on land and on the vessel is properly ensured? In light of UN and IMO ambitions for emission reduction, the appeal of CCS has led to extensive research and development on CCS technology and infrastructure in recent years. To investigate the current and future potential for onboard application of CCS, this GSP pilot study on CCS applied in a maritime setting has been started.

1.2 Goal of pilot project

Final implementation of this pilot:

The long-term goal is implementation of an onboard CCS system on one of Altera's shuttle tankers.

Aim of this pilot study:

To investigate the technical and economical applicability of an onboard CCS system for an end-to-end solution. From the first step onboard with the design solution for onboard carbon capture, to the offloading and transport of the captured CO_2 to permanent sequestration.

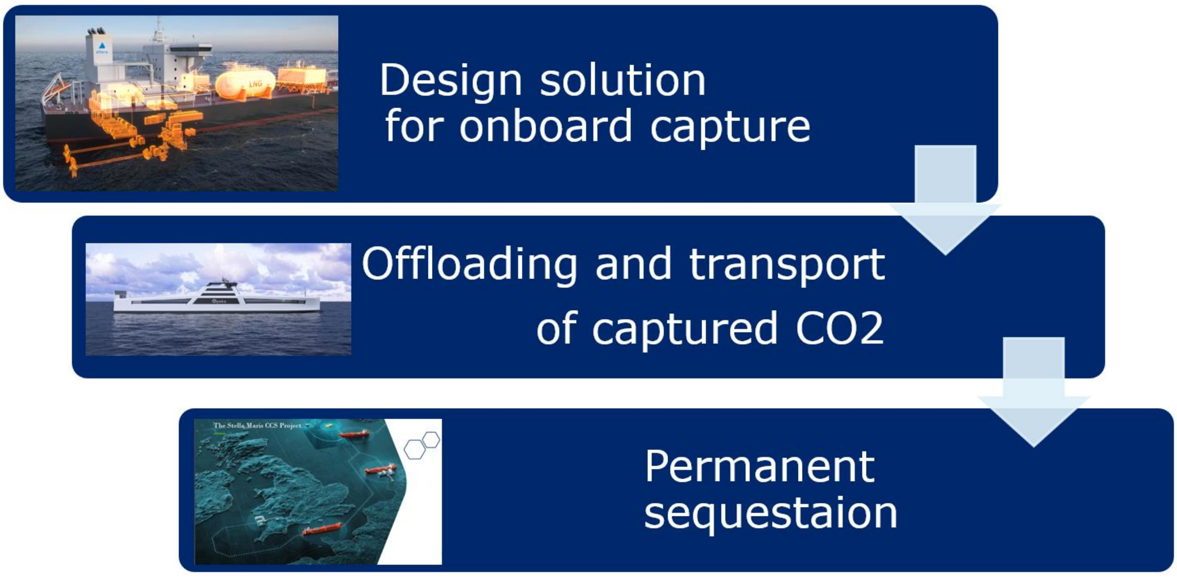


Figure 1-1: Technical and economical applicability for the end-to-end solution for onboard carbon capture technology.

1.3 Main activities

- A mapping of current onboard CCS initiatives, especially through discussion with suppliers and investigations of previous studies. This should result in descriptions of technologies and ongoing projects, maturity, applicability, safety aspects, and overview of the cost picture, rules and regulations, and possible support schemes. A high-level description of possible synergies with CCS value chains in other industries will also be elaborated.
- Develop an Altera-specific case based on E-shuttle propulsion design, but scalable for both the Altera Stella Maris CO_2 carrier and other liquid CO_2 ships for the CCS value chain.

1.4 Pilot participants

Maran Shuttle Tankers (MST) (Altera Infrastructure at the time) is the pilot owner in this study. Together with MST, it has been a large group involved in this pilot project from across the value chain. From shipowners, chartering and operations companies, Equinor, Total Energies, Wilhelmsen Shipmanagement and Color Line has been involved. The involved technology suppliers are Ionada, Wärtsilä and WE Tech. From the engineering side, Brevik Engineering has been heavily involved in the study. From the Finance and insurance side DNB and Skuld have been partners. DNV, the Norwegian Maritime Authority and the Norwegian Environment Agency has been involved from the regulation side. This large group has been essential for the work in this pilot study.

2 Literature/Desktop Study

Responsible: DNV

The goal of this work package is to give a high-level overview of the onboard carbon capture technology, what it is, how it works and setting the scene before going into the more details about onboard carbon capture on Altera's shuttle tanker. This chapter will also include ongoing CCS initiatives and projects for permanent storage, assess class/statutory safety requirements and the implications and applicability of onboard carbon capture for EEXI, CII, and how OCCS will be affected by EU ETS and FuelEU maritime.

2.1 Onboard carbon capture storage or utilization

Onboard carbon capture (OCC) is a technology that capture the CO_2-emissions onboard a vessel before it is released to the atmosphere. The captured carbon is then stored onboard for temporarily storage before it is offloaded the vessel and transported to the "end-destination". The captured carbon could either be stored permanent (Carbon capture and Storage – CCS), or utilized in other processes (Carbon capture and Utilization – CCU), the common term for carbon capture technology is CCUS. Figure 2-1 show the 5 steps of the onboard carbon capture value chain.

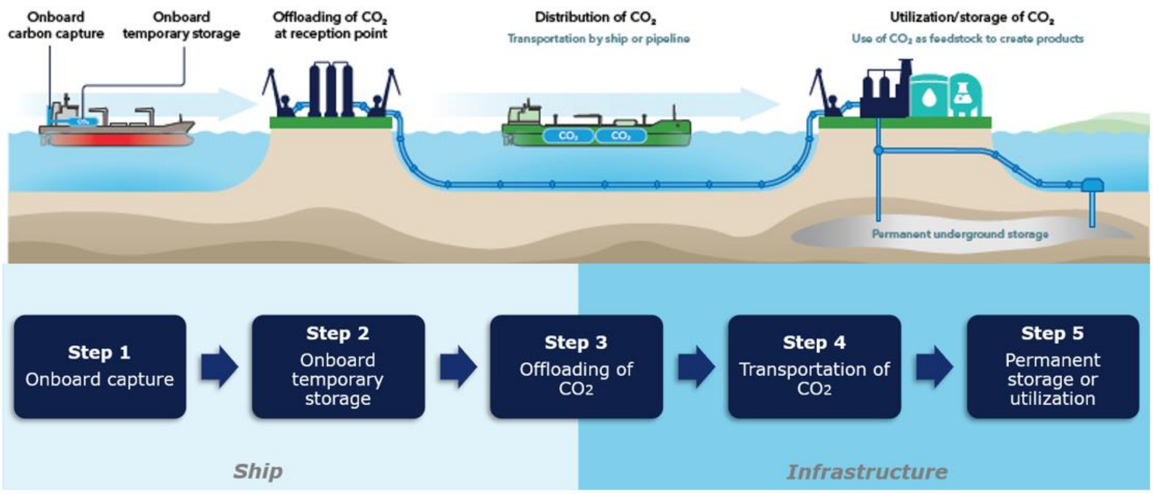


Figure 2-1: The stepwise process of the onboard carbon capture value chain (DNV, The Potential of Onboard Carbon Capture in Shipping - White paper, 2024).

Step 1 – Onboard Carbon Capture: The system that capture, removes and process the CO_2 from the exhaust to a state that can be stored onboard.

Step 2 – Onboard temporary Storage: The captured carbon needs to be temporarily stored onboard the vessel before offloaded onshore.

Step 3 - Offloading of CO_2: The ship will need to offload the captured CO_2, this will happen periodically either at the end of a voyage or additional port calls or offloading to CO_2 carrying vessels. The frequency of the offloading of CO_2 depends on the trade, storage capacity onboard and amount of captured CO_2.

Step 4 – Transportation of CO_2: After offloading, the CO_2 needs to be transported to the reception facility, either by ship, pipeline, trucks or train.

Step 5 – Permanent storage or utilization: The last step and the end of the onboard carbon capture value chain is either with permanent storage of the captured CO_2 (sequestration) as waste (the captured CO_2 is permanently stored in deep underground geological formations) or utilization.

2.1.1 Step 1 & 2 - Onboard carbon capture technology

The ship requires a capture system onboard that removes the CO_2 from the exhaust, and an after-treatment system that transforms the captured CO_2 to a state suitable for onboard storage. In addition, the ship requires CO_2 storage tanks and equipment for discharging the captured CO_2 to a reception facility.

The market is developing a wide range of onboard carbon capture concepts, which can be categorized by their effect on the ship energy converters in mainly three categories:

- **Pre-combustion:** When the carbon is removed from the fuel before combustion;
- **Oxy-fuel combustion:** If the CO_2 is released as a by-product from the combustion;
- **Post-combustion:** when the CO_2 is removed from the exhaust gas stream.

The post-combustion method does not affect the energy conversion system of the vessel and perform aftertreatment of the exhaust gas stream before is released to the atmosphere. Therefore, post-combustion methods are more relevant for conventional machinery, like internal combustion engines. These concepts can either be retrofitted on existing ships or implemented on newbuilds.

There are several post-combustion capturing methods, such as Chemical absorption, membrane separation, cryogenic separation and mineralization (or calcium looping). See Table 2-1 for a detailed description of the different methods (the table is extracted from DNV's white paper on the potential of onboard carbon capture in shipping).

Table 2-1: Overview of post-combustion capture methods from DNV's white paper on onboard carbon capture (DNV, The Potential of Onboard Carbon Capture in Shipping - White paper, 2024).

Chemical absorption	The exhaust gas stream is scrubbed by a liquid solution, comprising of a chemical agent and water, such as amines. CO_2 is selectively absorbed into the liquid, where it is bonded by the chemical compound and thus removed from the exhaust. The clean gas stream leaves the system, while the liquid solution saturated with CO_2 is either recirculated in the system or regenerated – to release CO_2 gas. The regeneration process is energy consuming, requiring significant amounts of heat, between 3–4 GJ/tCO_2 for conventional solvents. Novel solvents can achieve improved performance of 2 to 2.5 GJ/tCO_2 (T. Damartzis, 2022). When CO_2 gas is generated, proper treatment and handling is required for temporary onboard storage until discharge. The CO_2 gas can either be compressed and pressurized, or most often liquefied under medium or even low-pressure conditions. Onboard carbon capture involves cleaning of exhaust gases from CO_2, separating the CO_2 and storing it on board in various forms, depending on the technology (gas, liquid, or mineral), before offloading.
Membrane separation	The exhaust gas stream passes through membrane modules that selectively allow CO_2 to transport through their structure and become separated from the exhaust. The cleaned gas leaves the system, while the CO_2 stream is led to the treatment system, to become either compressed gas, or liquid. Some market concepts combine membranes and liquid absorption, to ensure increased mass transport efficiency, and reduced space requirement and regeneration energy demand on board.
Cryogenic separation	The exhaust stream is cooled down until CO_2 is separated into liquid and solid forms. As a result, CO_2 is separated from the gas constituents (e.g. nitrogen and oxygen) that require significantly lower temperatures to solidify. Impurities like water may separate out earlier than carbon dioxide. Effectively, the CO_2 product has high purity. The separation of phases is achieved by centrifuges, for example, and hence requires electric power for the cooling and compression unit.
Mineralization (calcium looping)	Depending on the concept design, the exhaust gas is passed through a reactor, where minerals are used to bond CO_2 into their structures, removing it from the exhaust gas. The saturated mineral is gathered as deposited sludge, which is offloaded at the port. The concept involves storage areas for both the mineral and the saturated product.

2.1.2 Step 3 - Offloading of CO_2

There are several ways to offload the captured CO_2 from the ship to a reception facility. The Global Centre for Maritime Decarbonization published a report in March 2024 "Concept Study to Offloading Onboard Captured CO_2" (GCMD, 2024). This study described four offloading concepts for offloading CO_2:

- Concept 1: Ship-to-liquid Bulk Terminal
- Concept 2: Ship-to-Floating CO_2 Storage with Intermediate LCO_2 Receiving Vessel

- Concept 3: Ship-to-Liquid Bulk Terminal with Intermediate LCO_2 Receiving Vessel
- Concept 4: Ship-to-Terminal with ISO Tank Containers

The study found that using an intermediate LCO_2 receiving vessel for both ship-to-ship and ship-to-sore transfers are the most promising methods for large-scale offloading of CO_2. Offloading of smaller volumes that require higher grades of CO_2 can be done by Ship-to-terminal transfer of captured CO_2 in ISO tank containers. For more details, read the report here.

2.1.3 Step 4 & 5 - Transportation of CO_2 and permanent storage/utilization

The captured carbon can be handled in two ways, either permanently store the captured carbon deep underground in geological formations or utilize the captured carbon and recycle the carbon for further use. Either way, the captured carbon will need to be transported from one site to another. The development of the infrastructure of maritime captured carbon will be highly dependent on the development of the land-based CCUS value chain. Shipping will need to integrate into this chain as a branch and take advantage of the expansion of CO_2 terminals near major ports. There are several gaps in the onboard CCS logistic value chain, and Altera, together with SinOceanic (another GSP pilot study on OCCS for a container vessel), decided to invite all important stakeholders to a workshop. In this workshop we discussed the onboard carbon capture value chain, and different challenges that needs to be overcome for onboard CCS to be a viable option with regards to the value chain. The key takeaways and findings from the workshop are described in Chapter 6.

2.2 Safety and regulatory status

If onboard carbon capture should be chosen as a decarbonization option, environmental and safety regulations must be in place to ensure that the emission reductions are credited in the environmental regulations and that the vessel complies with the safety requirements.

2.2.1 Environmental regulations

The only regulatory framework that incentives onboard carbon capture today is EU ETS, but there are ongoing discussions at the IMO to include OCCS in their regulations as well.

IMO: Today, there are no regulations that includes onboard carbon capture in MARPOL or other regulations. At MEPC 81 in March 2024, the IMO agreed to develop a detailed work plan for establishing a framework to regulate onboard carbon capture technologies.

EU ETS: Directive 2003/87/EC includes an exemption for emissions that are verified as captured and transported for permanent storage at a facility authorized under the CCS directive 2009/31/EC. In May 2023, the EU introduced a similar provision through Directive 2023/959, which applies to greenhouse gas emissions that are captured and utilized in a manner that permanently binds them chemically in a product, preventing their release into the atmosphere during normal operation. (EU, 2023)

FuelEU Maritime: Deducting captured carbon from ships when calculating the GHG intensity is not included in FuelEU maritime today. By 31 December 2027, the regulation will review new technologies, including onboard carbon capture depending on the availability of a verifiable method for monitoring and accounting of the captured carbon.

2.2.2 Safety regulations

IMO has not yet published any rules and regulations addressing possible safety implications for implementation of carbon capture and storage technology onboard ships. However, Class Societies have start developed guidelines and rules to ensure safe implementation of onboard carbon capture because of the interest from the industry.

In 2023, DNV published guidelines for safe installation of carbon capture systems on board ship. The guidelines are designed to help ship designers, builders, OCCS system manufacturers and ship owners, with safe implementation of onboard carbon capture systems onboard both newbuilds and retrofits. The guidelines cover all aspects for safe installation, including exhaust pre-treatment, absorption with the use of chemicals/amines, after-treatment systems, liquefaction processes, CO_2 storage, and transfer systems. The guidelines are based on DNV classification requirements additional technical or other requirements may be imposed by relevant flag-state administration.

DNV introduced its new OCCS notation in July 2024, which is a framework and requirements for the safe implementation of carbon capture systems onboard, including exhaust pre-treatment, absorption, after-treatment systems, liquefaction, CO_2 storage and transfer ashore. The publication of these new rules took place July 1st, and will enter into force on January 1st 2025 (DNV, 2024).

2.2.3 Regulatory overview

Table 2-2 present an overview of the regulatory landscape and status for onboard carbon capture from DNV's white paper on the potential of onboard carbon capture in shipping published in May 2024 (DNV, The Potential of Onboard Carbon Capture in Shipping - White paper, 2024).

Table 2-2: Status of environmental and safety regulations with regards to onboard carbon capture (DNV, The Potential of Onboard Carbon Capture in Shipping - White paper, 2024).

		Status	Challenges and uncertainties
Environment and GHG accounting	EEXI/EEDI & CII	Not yet included. Onboard carbon capture may be considered in future developments	How fuel penalty is going to be included. How to take into account potential carbon capture at design stage for EEDI/EEXI. How captured emissions will be derogated for CII e.g., based on direct measurements, custody transfers, or something else.
	Future IMO regulations	IMO plans to incorporate the application of onboard carbon capture in the IMO Lifecycle Assessment (LCA) Guidelines. MEPC 81 (March 2024) discussed the issue of onboard carbon capture and established a Correspondence Group to further discuss the matter and develop a working plan on the development of a regulatory framework for the use of onboard carbon capture systems.	How onboard carbon capture will be taken into account for well-to-wake emission factors. How captured emissions will be derogated e.g. based on direct measurements, custody transfers, or something else.
	EU MRV & EU ETS	Included	What terms and conditions will there be with regards to carbon utilization? A verifiable method for monitoring and ac-counting of the captured carbon is required.
	FuelEU Maritime	No current consideration in the EU's FuelEU Maritime package. Provision for review by 31 of December 2027.	How onboard carbon capture will be included in the emission factors.
Waste Handling	London Protocol	Amendment of Article 6 of the London Protocol was proposed by contracting parties in 2009 to allow for cross-border transportation of CO_2 for sub-seabed storage. To enter into force the amendment must be ratified by two thirds of contracting parties. This is as of today pending though an interim solution has been established.	How the London Protocol is to be managed when CO_2 is captured in various territorial and international waters remains uncertain.
Safety	SOLAS	Lack of regulations and guidelines on safety and procedures.	Procedures for offloading, custody transfers, technology risk, crew training and certification of components. Comments from Flag during onboard pilot testing.
	Class	Class guidelines, rules, and notations in place.	Exploitation of pilot examples to build experience and test rules.

Abbreviations: Carbon Intensity Indicator (CII); Energy Efficiency Design Index (EEDI); Energy Efficiency Existing Ship Index (EEXI); Emission Trading System (ETS); International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels (IGF); International Maritime Organization (IMO; The International Convention for the Prevention of Pollution from Ships (MARPOL); Marine Environment Protection Committee (MEPC); monitoring, reporting and verifying (MRV).

3 Candidate vessel, operational profile, and OCCS Design basis

3.1 Candidate Vessel

The Altera Wave was selected as the candidate vessel for this study as it is one of the most modern vessels in the MST fleet and is trading in Northern Europe,

Figure 3-1 - Altera Wave

Altera Wave – Main Particulars

- **Vessel Type**: DP2 Shuttle Tanker (Crude Oil Tanker)
- **IMO Number**: 9863558
- **Year Built**: 2021
- **Flag**: Bahamas
- **Length Overall**: 244.85 meters
- **Beam**: 43.84 meters
- **Gross Tonnage**: 67,383 GT
- **Deadweight Tonnage (approx.)**: 103,000 DWT
- **Draught**: ~8.6 meters
- **Hull Type**: Aframax (LR2)
- **Classification**: DNV
- **Propulsion Type**: Hybrid diesel/gas-electric system
- **Power Plant**: 4 x Wärtsila 8L34FD – 3.690kW
- **Fuel Types**: LNG and MGO
- **Battery Capacity**: 1,808 kWh

3.2 Operational Profile

To design an onboard carbon capture solution for a shuttle tanker, it is important to assess the operational profile of this type of vessel as it is quite different from other conventional oil tankers of similar sizes. The below shows the operational profile of the candidate vessel.

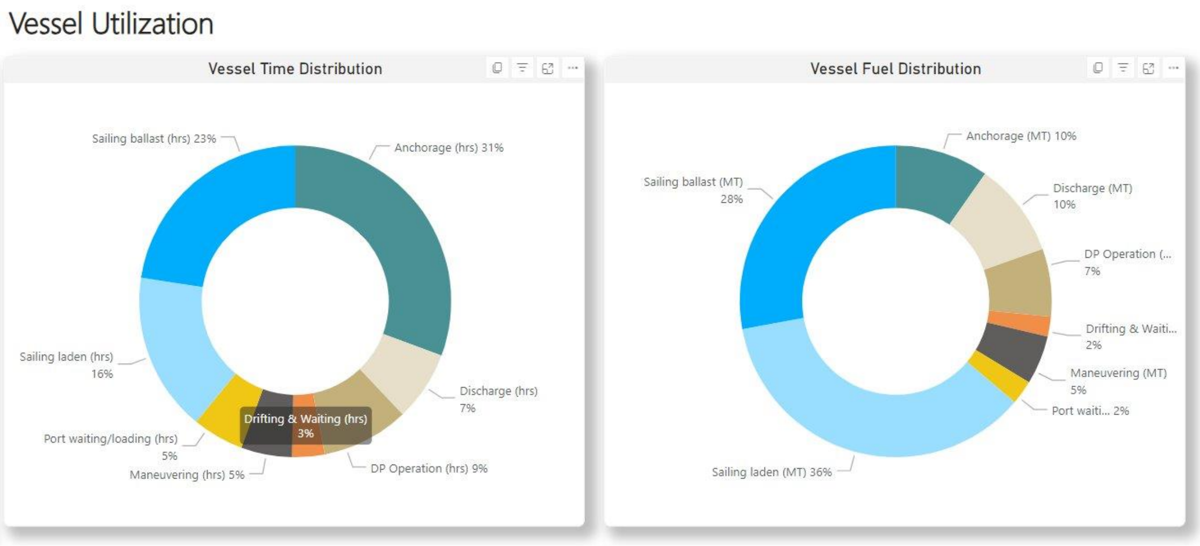


Figure 3-2 - Operational Profile

3.3 Design Basis

The design basis outlined below reflects key assumptions, boundary conditions, and performance targets that have guided the engineering development of the pilot system. These parameters have been selected to ensure compatibility with existing vessel architecture, regulatory frameworks, and operational profiles typical of shuttle tanker operations.

Category	Description/Specification	Design Basis	Additional info
Project Objective	Installation of a pilot onboard carbon capture system on an Aframax LNG-fueled dynamically positioned shuttle tanker.		
Vessel Type	Aframax Shuttle Tanker	Altera Wave	
Fuel Type	Liquefied Natural Gas (LNG) and MGO as backup	LNG	Approximately 6500 tons per year. Design primarily for lng, but describe operatoinal implications and potential additional system costs when running on mgo
System Capacity	Pilot Scale	Total of two units capturing 70-80% on one engine on each side of the DP2 redundancy sides	
Capture Technology	(Consider technologies such as amine absorption, membrane separation, or solid sorbents based on feasibility and suitability)	Amine absorpiton and Membrane Spearation	
CO2 Quality	Requirement to ultimately be able to meet NL/Stella Maris CO2 spec. It is important to prevent corrosion due to free water dissolving CO2 yielding carbonic acid ++	NL - spec for now. But an evaluation of potential risks (impurites, corrotion etc.) to be described.	

Storage and Offloading	Evaluate options for CO2 storage and offloading, considering safety, space, and operational constraints	Offloading monthly - dimensioing based on system capacity	Medium Pressure - 16bara - -26deg C
Energy Source for Capture System	Utilize waste heat recovery where possible; assess additional energy needs and sources	Minimum parasitic load	
Key utilities/ auxiliary systems	Cooling system to enable faster offloading by precooling system. Vent system as per class requirements. Provisions and scaling of Vapor Return. Discharge as per SIGTTO LPG standards	To be detailed in system integration workpackage	
Integration with Existing Systems	Ensure compatibility and optimization with existing vessel power systems and operations; consider impacts on vessel stability and dynamic positioning		
Safety and Risk Management	Conduct hazard and operability study (HAZOP), failure mode and effect analysis (FMEA), and risk assessments in line with industry best practices and regulations	Not part of GSP pilot study	
Regulatory Compliance	Ensure design complies with international and local maritime regulations, including but not limited to MARPOL, IMO, and classification societies	MED, ATEX, Hazardous area zone description.	
Monitoring and Control	Implement monitoring, control, and automation systems for efficient operation and performance evaluation	To be provided by Wärtsilä and Ionada. Standard solutions	Metering assumed handled on receiving terminal
Pilot Trial Duration	To be determined based on project objectives and stakeholder inputs	Altera Wave DD window 10/2025-01/2026 (Altera Wind DD window 12/2025-03/2026)	18 months prior to start up
Documentation and Reporting	Prepare comprehensive documentation for design, installation, operation, and performance evaluation; establish reporting protocols for regulatory and stakeholder communication		
Maintenance and Servicing	Develop maintenance plans, spare parts inventory, and servicing schedules; consider accessibility and modularity for maintenance activities	Ease of maintenance to be incorporated in design i.e. simple replacement of components and incorporation of condition based maintenance. Standardized spare parts where possible.	
Operational Philosophy	Prioritize safety and compliance with maritime regulations, ensuring that the system operates reliably under various sea conditions and does not compromise the vessel's integrity or maneuverability. The design should facilitate seamless integration with existing ship systems and operations, with a focus on optimizing energy use and minimizing operational disruptions. Furthermore, establish robust monitoring and maintenance procedures to continuously assess the system’s performance, ensuring that it meets emission reduction targets and allowing for necessary adjustments and optimizations throughout the pilot phase.		To be operated by normal maritime crew

4 Onboard carbon capture system

4.1 Chemical absoprtion - Wärtsila

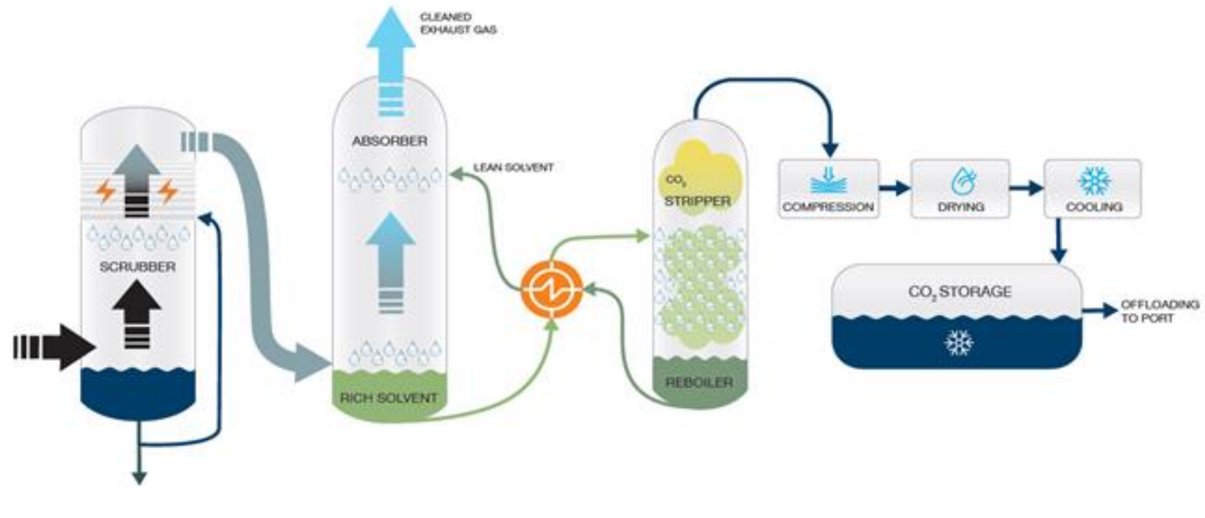


Figure 4-1: The capture technology Wärtsilä CCS is based on.

The Wärtsilä CCS System is based on CO_2 absorption from the exhaust gas using solvent. The exhaust gas is mixed with a circulating water-based solvent with high affinity to CO_2. The CO2 rich solvent is routed from the bottom of the absorber to a stripper tower via the rich solvent transfer pump. Before entering the upper section of the stripper tower, the solvent is heated in a rich-/lean solvent heat exchanger. An external solvent wash unit is installed after the absorber optimize solvent washing. This is illustrated in Figure 4-1.

In the stripper CO2 is separated from the solvent through addition of heat. The wet CO2 exits at the top of the column and is routed through a reflux condenser where water is condensed. CO2 is then routed from the condenser to the drying units before compression.

Compressed dried CO2 is liquefied by a low temperature refrigerant cycle and thereafter routed to the CO2 storage tank(s). The CCS system can be bypassed using the bypass damper arrangement.

The total exhaust gas and CO2 routed to the CCS system is as shown in Table 4-1.

Table 4-1: The total exhaust gas and CO2 routed to the CCS system.

Combustion Unit	#	Load (%)	Exhaust Gas Flow (kg/h)	CO_2 Flow (kg/h)	Total Exhaust Gas Flow (kg/h)	Total CO_2 Flow (kg/h)
Main Engines Wärtsilä 8L34DF	2	85	18 720	1 384	37 440	2 769

The CCS capture plant selected will have a capacity of max **50 ton/day**, corresponding to ~**75%** capture rate in gas mode.

4.1.1 Storage

System is designed based on liquefaction at 15.3 barg and -26 ºC. From liquefaction the LCO_2 is transferred with a pump to the storage tanks.

Boil off gas is returned to a Refrigeration skid in order to maintain a stable pressure in the tanks.

Parameter	Value/comment
Storage pressure (typical)	15-18 barg
Storage temperature (typical)	-26 to -21 °C

4.1.2 Utility Requirements

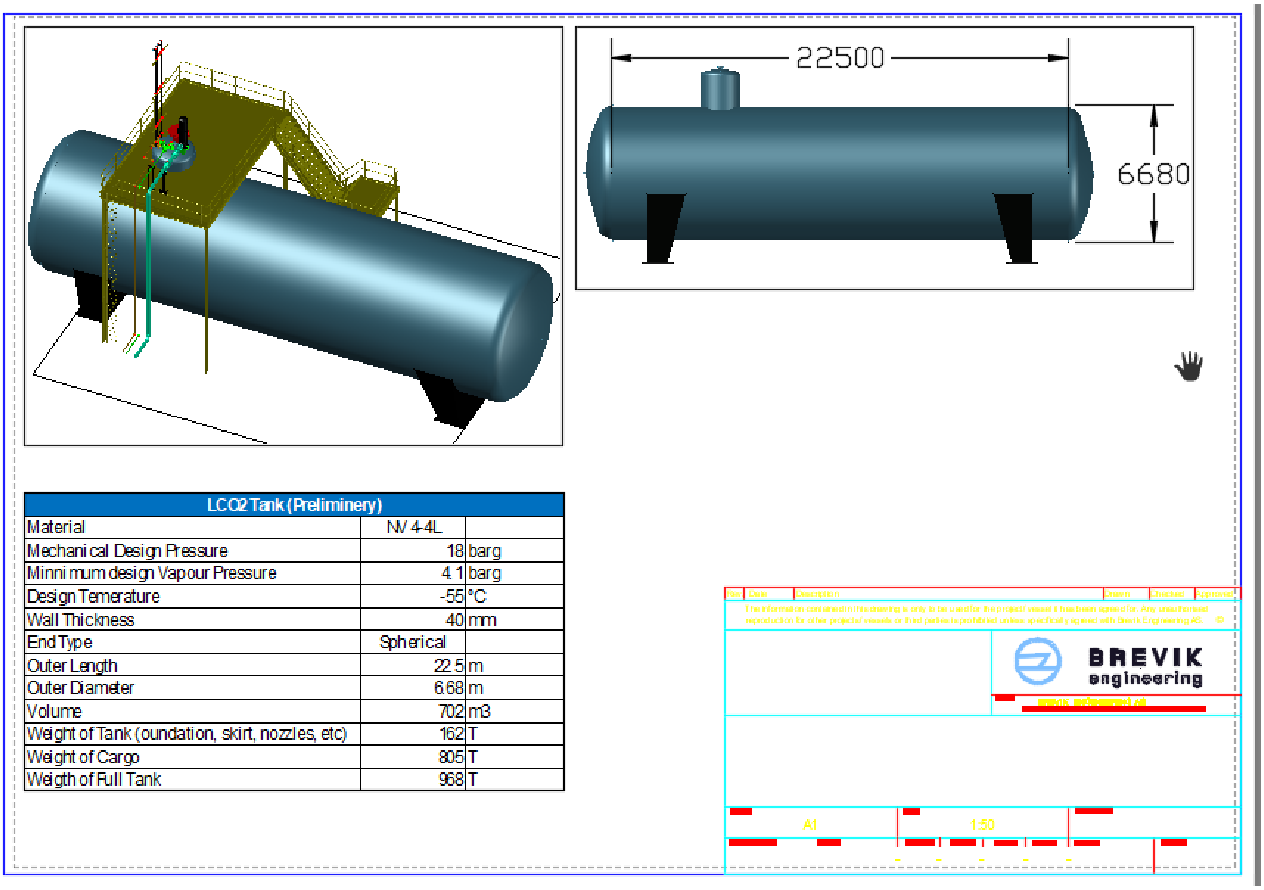
Utilities	Design Case
Cooling water supply	~386 m3/h
Power consumption	~600 kW
Heat input 3.5 barg steam @147 °C	~2315 kW

5 Onboard implementation

5.1 CO2 Tank size evaluation

For Altera Wave, we assumed a conservative estimate of 7000 tons of LNG consumption per year and a CO2 emission factor of 2,75 yielding 19 250 tons of CO2 per year.

Assuming an even spread of genset utilization, and OCC installation on two arbitrarily chosen genset (whichever is more practical wrt. space) and a capture rate assumption of 95% equals 9 144 tons of CO2 captured per year. Assuming monthly discharge, this would mean 762 tons of discharge per month. A C-type tank placed on deck is the chosen option with the following dimensions and location placement:



LCO2 Tank (Preliminery)		
Material	NV 4-4L	
Mechanical Design Pressure	18	barg
Minnimum design Vapour Pressure	4.1	barg
Design Temerature	-55	°C
Wall Thickness	40	mm
End Type	Spherical	
Outer Length	22.5	m
Outer Diameter	6.68	m
Volume	702	m3
Weight of Tank (oundation, skirt, nozzles, etc)	162	T
Weight of Cargo	805	T
Weigth of Full Tank	968	T

Figure 5-1 - CO2 tank dimensions

5.2 Stability and structural assessment

A separate report was done by Brevik Engineering to assess the feasibility of the retrofit with respect to stability and strength. The key findings are as follows:

Loading to the design draught (14.2 m): Retrofitting can be carried out with a very high probability that major adjustments will not be needed. Loading to the scantling/summer load line draught (15.0 m): Retrofitting is highly likely to be feasible without major adjustments. A reduction in the payload of between 636 t (dry weight of the retrofit) and 1500 t (operation weight of the retrofit) should be expected. Local reinforcement due to shear forces may be expected.

5.3 Location of key components

Due to confidentiality reasons, full detailed drawings can not be provided, but the below illustrations gives an overview of the feasible locations for the key equipment components required for the OCCS.

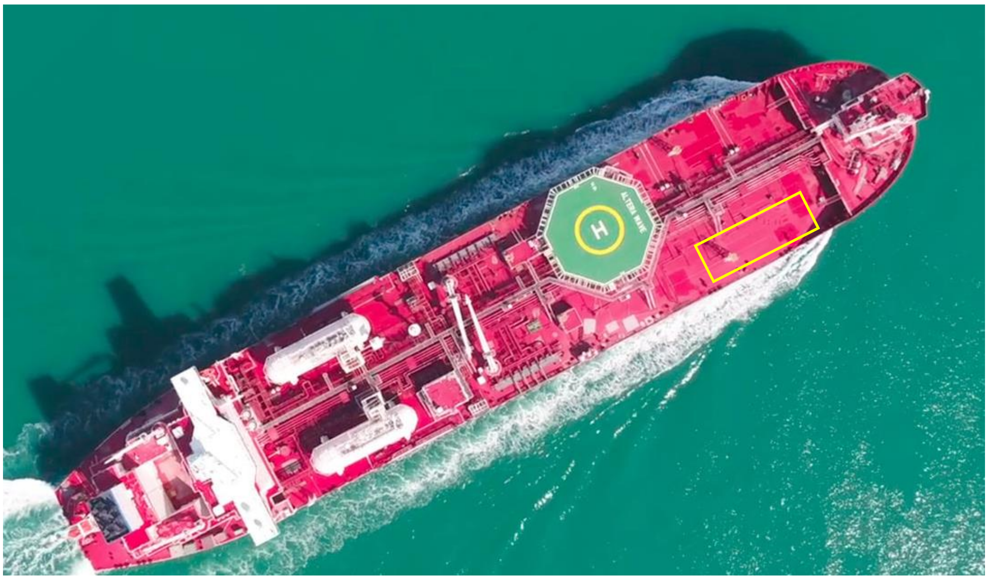


Figure 5-2- CO2 tank location marked in yellow rectangle

Figure 5-3 - CO2 tank location marked in yellow rectangle

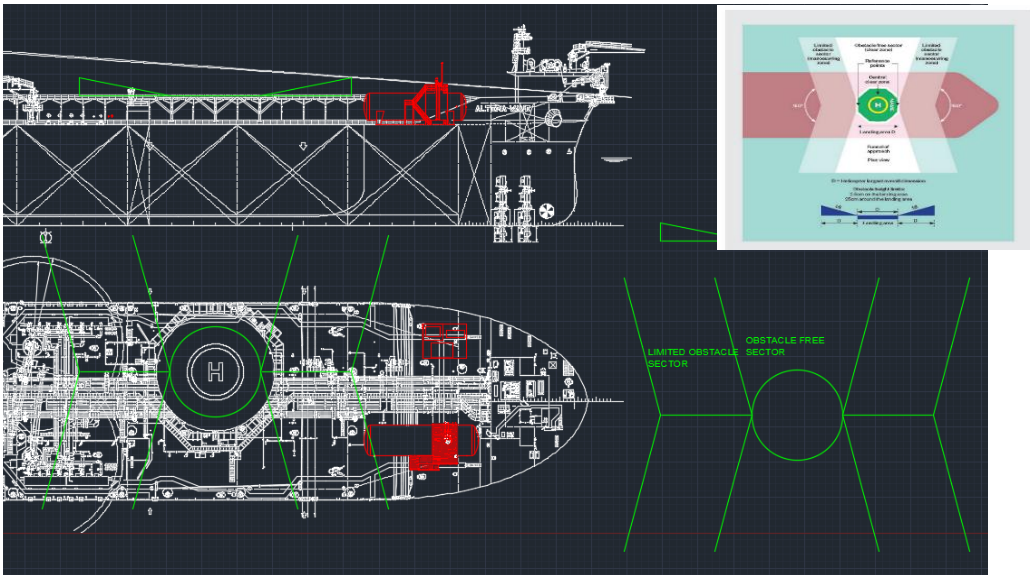


Figure 5-4 - Helideck flight path obstruction analysis

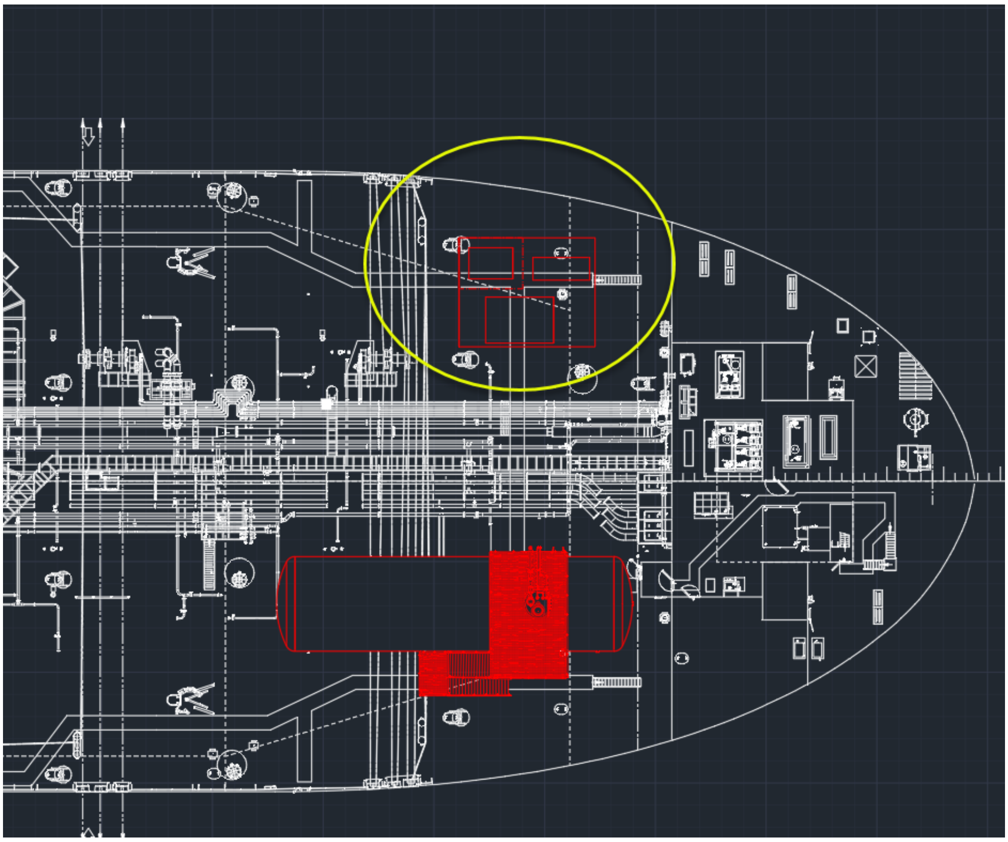


Figure 5-5 - Liquifaction system

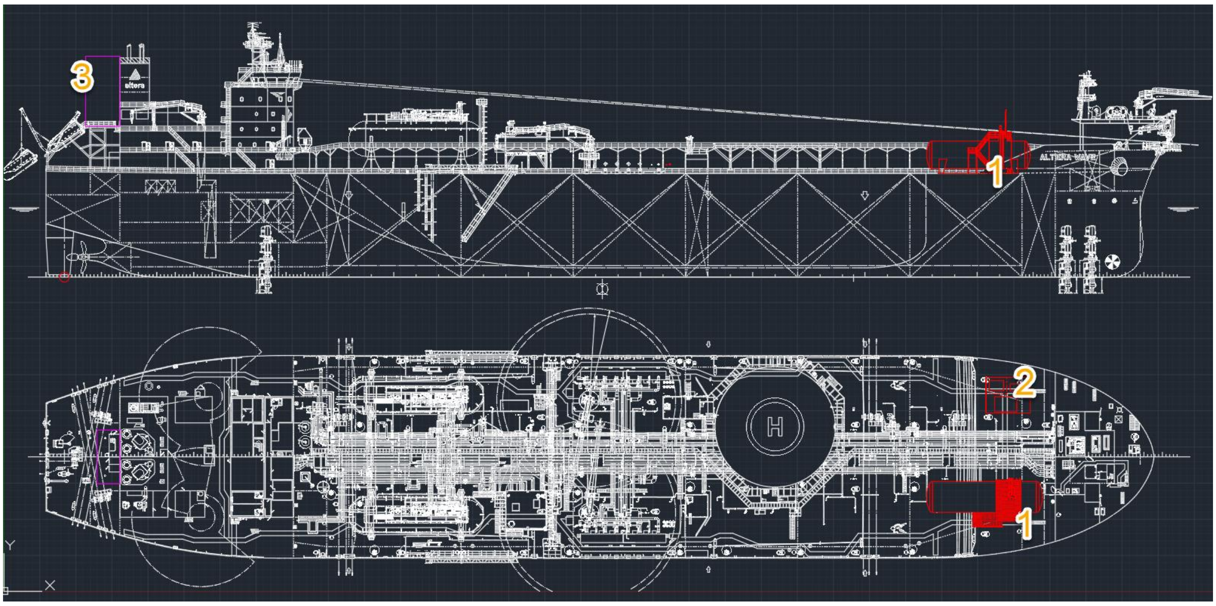


Figure 5-6 - 1. Tank, 2. Liquifaction, 3 Capture plant

5.4 Conclusion and further work for vessel integration

The study group conclude that no show stoppers have been identified wrt. Space requirements, stability or structural aspects.

To progress with this initiative further, a full yard specification should be developed to determine the costs and time required for such an installation. This will also provide important input to the overall business case.

6 Downstream OCC CO_2 logistics

Responsible: Altera

A major barrier for realizing OCC as an attractive means for decarbonizing the shipping industry is the establishment of cost-effective downstream infrastructure for the discharged CO_2 from ships, and a regulatory framework set up to support this. The two GSP OCCS pilot studies run by Altera Infrastructure and SinOceanic decided to join forces to discuss this important topic, and in June 2024 several stakeholders across the value chain were invited to a two-days workshop in Stavanger at Altera's headquarters to discuss this topic. Participants from DNV, Altera Infrastructure, SinOceanic, Stella Maris, Total Energies, Equinor, SINTEF, Norwegian Environmental Directorate, Norwegian Maritime Authorities, Brevik Engineering, Solvang and Bellona attended this workshop. The agenda is shown in the Appendix.

Although the conclusions are quite high-level, we hope they provide some insight important for shipping companies considering OCCS as a solution, plus provide some inspiration for further work to be done by the industry to make OCC a viable solution. This chapter summarizes the key findings from the workshop.

6.1 Regulatory Aspects for OCCS in the IMO and EU

We expect that by 2027, the regulatory frameworks in the EU will be fully developed to ensure the necessary credits in the EU ETS and FuelEU Maritime are obtainable. However, for the IMO, particularly the Carbon Intensity Indicator (CII), we anticipate that onboard carbon capture (OCC) will be included by 2028 or 2029.

Credits for captured CO2 will require demonstrable proof of permanent storage in suitable CCS sites to avoid payments for EU allowances. The process for complying with this principle is yet to be defined.

It is paramount that these regulations are established to provide the industry with a high degree of certainty regarding future EU and IMO compliance and business case calculations. **Now is the time for the industry to engage with regulators to ensure that the regulations are developed to be as practical and straightforward as possible while effectively stimulating the decarbonization of our industry.**

6.2 Storage Projects and Initiatives

There are several CCS storage projects on the horizon in Europe, with the Northern Lights project in the North Sea being the most advanced. Other notable projects include the Porthos and Aramis projects in the Netherlands, Project Greensands in Denmark, Altera Infrastructure and Wintershall DEA's Stella Maris project, and Equinor's Smeaheia project in the North Sea.

Although the start-up of these projects will commence with Northern Lights being the first in 2025, with the others becoming operational between 2025 and 2028, it does not mean that they will be ready to receive maritime OCC volumes immediately. These are large, complex industrial projects that heavily rely on achieving steady operations with their large-scale industrial anchor emitter customers. We expect this will be their focus before establishing additional reception facilities and infrastructure for the initial small volumes of CO2 from maritime OCC.

The GSP OCCS workshop participants hypothesize that maritime OCC CO2 volumes will realistically be able to deliver CO2 to these storage projects by 2028, with a more realistic expectation towards 2030. We hope this hypothesis can be proven wrong.

6.3 CO_2 Transportation from Vessel to Terminal

There will likely be a substantial business opportunity for maritime logistics entities to aggregate various maritime OCC volumes to leverage economies of scale, thereby reducing the "last mile" transportation cost from vessels to storage sites. This aggregation would also increase the likelihood of gaining access to storage sites, as presenting larger bulk volumes could be advantageous in negotiations with storage site operators.

Another key aspect to reducing costs and improving the business case for OCC is ensuring that CO2 discharge can be carried out during other in-port operations, such as cargo discharge or bunkering. Any deviation from these operations, resulting in off-hire costs for discharging CO2, would adversely affect the business case for OCC.

6.4 Cost Estimates for CO_2 Disposal

The most important driver for the adoption of OCC from ships is the overall business case when compared to alternative solutions for regulatory compliance. A decisive factor for this business case is the cost per ton for CO2 disposal. **Our literature study has shown a cost range between USD 20 to USD 80 per ton.** Scenarios where the discharge location is in immediate vicinity to the storage infrastructure, not requiring extensive "last mile" logistics, would entail costs closer to USD 20 per ton. Conversely, discharge locations far from the storage site would incur costs closer to USD 80 per ton. It is important to note that this does not include the onboard CAPEX or the OPEX of the OCCS itself.

6.5 Practical Design Considerations for Onboard CCS

There are many design considerations to be made when implementing OCCS, much of which will be regulated by upcoming rules from classification societies. Two practical design implications have been highlighted as important when considering downstream CO2 logistics from ships, vapor return systems and metering and purity.

6.5.1 Vapor Return Systems

It is crucial to consider the complexity, cost, and environmental impact of vapor return systems. One option is to accept the environmental and commercial penalties of venting CO2 instead of investing in vapor return systems.

6.5.2 Metering and Purity

Accurate measurement and control of CO2 quality and quantity are essential. Storage sites have strict specifications for injectable CO2, and OCCS system providers must guarantee that their systems deliver the required quality. Given the high cost and complexity of CO2 metering systems, the working group proposes that these metering systems be installed at the reception facilities rather than onboard ships.

6.6 CCUS and Utilization

It is important to stress that under the current regulatory status, CO2 must be permanently stored to avoid being considered emitted. Therefore, CCUS and utilized carbon are treated as emitted. Various uses of captured CO2, such as in greenhouses or the food and beverage industries, will not receive credit under EU regulations and likely not under forthcoming IMO regulations either. However, CO2 utilization can have interim value by generating revenue to support OCCS investments until full regulatory compliance and storage options are established.

Grønt Skipsfartsprogram

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