Cold recovery System as part of SBCC Solution on LNG-driven ships

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Disclaimer

Preface

This publication presents some of the findings from the third work package (WP3) of the research project EverLoNG, which aims to expedite the adoption of ship-based carbon capture technology on commercial vessels. The EverLoNG project is part of the Accelerating CCS Technologies (ACT) program [1], which seeks to promote the emergence of CCUS through transnational funding, targeted research, and innovation. The EverLoNG project is supported by several organizations, including the Federal Ministry for Economic Affairs and Climate Action (Germany), the Research Council of Norway, the Ministry of Economic Affairs and Climate Policy (Netherlands), the Department for Business, Energy & Industrial Strategy (UK), and the U.S. Department of Energy, all of whom have provided funding for this project.

List of abbreviations

CO_2 - Carbon dioxide
GHG - Greenhouse gas, e.g., methane, nitrous oxide
IMO - International Maritime Organization
CCUS - Carbon Capture, Utilization and Storage
SBCC - Ship-Based Carbon Capture
EEDI - Energy Efficiency Design Index
EEXI - Energy Efficiency eXisting ship Index
TRL - Technology Readiness Level
WTW - Well to Wake (the sum of upstream and downstream emissions)
WTT - Well to Tank - Emission associated with e.g., Production, Transportation, Storage
TTW - Tank to Wake – Emission of processes like Combustion)
DF - Dual fuel (engine capable of running on methane and liquid fuel)
HFO - Heavy fuel oil
MeOH - Methanol
GWP - Global Warming Potential
ACT - Accelerating CCS Technologies
WP - Work Package
LNG - Liquefied natural gas
CCS - Carbon Capture and Storage
HMC - Heerema Marine Contractors
MJ - Megajoule
WG - Water-glycol
Barg - Bar Gauge
BOG - Boil-off Gas
KCl - Potassium chloride

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1 GHG emissions as a main challenge in the maritime industry

According to the Fourth Greenhouse Gas Study by the International Maritime Organization (IMO), the maritime industry was responsible for 3% of anthropogenic CO_2 emissions, accounting for 1000 million tons of CO_2 equivalents in 2018 [2]. As the world's population continues to grow and is expected to reach 8 billion in 2022, the demand for basic needs, including transportation, will increase, requiring a larger amount of energy to meet them. Population growth will lead to an increase in global maritime trade, projected to reach 42 billion metric tons in 2030 and 62 billion metric tons in 2050 [3].

The maritime industry is under pressure to reduce its carbon footprint, and the IMO has set a target to reduce absolute CO_2 emissions by at least 20-30% in 2030 and by 70-80% in 2040, compared to the level in 2008, reaching net zero around 2050 [3]. Achieving these targets will require innovative solutions to reduce emissions from ships.

Aside from switching to carbon-free or carbon-neutral fuels, one promising solution is carbon capture and storage (CCS) technology, which can capture CO_2 emissions from ships and store them underground. CCS technology has been used in various industries for years, and it has proved to be effective in reducing CO_2 emissions.

The installation of CCS technology on board LNG-driven vessels has the potential to significantly reduce their carbon footprint. LNG is currently considered a cleaner-burning fuel than traditional marine fuels such as heavy fuel oil (HFO) or marine gas oil (MGO), but it still emits CO_2. By implementing CCS technology, the CO_2 emitted by LNG-driven vessels can be captured and stored, thus reducing their overall carbon footprint.

However, implementing CCS technology on board LNG-driven vessels presents several challenges. One of the main challenges is the limited space available on board ships. CCS technology requires significant space for equipment such as compressors, pumps, pipes and CO_2 storage tanks. Additionally, the weight of the stored CO_2 and the equipment needed for CCS may affect the stability and performance of the ship. Therefore, it is important to consider the design and integration of CCS technology from the early stages of shipbuilding.

According to the Global Status of CCS 2022 Report published by the Global CCS Institute, attention to CCUS projects is growing, with 164 commercial CCS projects in the pipeline worldwide and 30 facilities currently in operation. The total operational facilities can capture and store approximately 40 million metric tons of CO_2 per year [5]. Since the IMO aims to reduce CO_2 emissions from the global fleet by at least 70% and to reduce GHG emissions from shipping by at least 50% by 2050, compared to 2008 levels, Ship-Based Carbon Capture (SBCC) represents one potential solution for retrofitting options to drastically reduce the CO_2 emissions of the maritime sector.

The increasing number of CCS projects around the world indicates its growing popularity and feasibility as a solution for reducing emissions. By implementing CCS technology on board LNG-driven vessels, the maritime industry can significantly reduce its carbon footprint and contribute to achieving the IMO's decarbonization targets.

MAN Energy Solutions, a leading provider of propulsion systems and engines for the maritime industry, has shown great interest in Ship-Based Carbon Capture (SBCC) as a potential solution for reducing carbon emissions. In fact, MAN Energy Solutions has recently announced its participation in the EverLoNG project through its Four-Stroke business section, which represents a flagship project aimed at encouraging the implementation of SBCC by demonstrating its use on LNG-fueled ships.

2 The EverLoNG Project

The EverLoNG project is a collaborative effort involving partners from various sectors of the maritime industry, including universities, research institutes, ship owners, port authorities, and technology providers, with the aim of promoting the implementation of Ship-Based Carbon Capture (SBCC) technology. By demonstrating the use of SBCC on LNG-fueled ships, the project aims to encourage widespread adoption of this technology as a viable solution for reducing carbon emissions.

The project is focused on developing and testing SBCC technology on board an LNG-fueled vessel. It covers general design considerations for the technology, as well as the heat integration system needed to use cold media from LNG to liquefy captured CO_2. The EverLoNG project is using an LNG carrier from Total and the semi-submersible crane vessel Sleipnir from Heerema Marine Contractors as case studies for the heat integration system.

Through the EverLoNG project, the partners are working towards developing a reliable and economically feasible SBCC technology that can be implemented on a larger scale in the maritime industry. The project's findings and results will be shared with the industry to promote further research and development of SBCC technology. By promoting the adoption of SBCC technology in the maritime industry, the EverLoNG project represents a significant step towards achieving the International Maritime Organization's decarbonization targets and addressing cli-mate change concerns.

EverLoNG aims to take ship-based carbon capture from TRL4 to TRL 7 on board commercial maritime vessels and intends to thereby fulfill the following objectives [2]:

- Develop strategies for reducing shipping's CO_2 emissions by at least 70%
- Demonstrate effectiveness of SBCC on LNG-fueled ships, comparing Life Cycle Assessment results against operation without the technology
- Evaluate impact of SBCC on ship infrastructure, stability and safety to guarantee technical feasibility of SBCC technology
- Demonstrate emission reduction potential of SBCC according to energy efficiency and design guidelines (EEDI and EEXI)
- Identify any major safety hazards associated with SBCC and highlight safeguards
- Improve cost-effectiveness of SBCC with CO_2 capture and onboard storage costs below €100 per metric ton by 2025 and €50 per metric ton for follow-up developments
- Evaluate cost of offloading, transport, utilization and/or storage in different CCUS chains
- Develop offloading strategies that guide onboard post-treatment of CO_2 and port infrastructure requirements
- Establish a CO_2 Shipping Interoperability Industry Group (CSIIG) and develop a scale for evaluating port CCUS readiness levels
- Propose a roadmap for a European offloading network

3 Case study

For this case study, the Sleipnir was chosen as the vessel of interest. This vessel, which was built in 2019, is owned by Heerema Marine Contractors (HMC) and is equipped with 12 51/60 MAN engines. The Sleipnir is a semi-submersible crane vessel that can perform heavy lifting operations and is capable of installing large structures in deep waters. It is also a highly advanced vessel that utilizes cutting-edge technology to maximize efficiency and minimize its environmental impact.

The main objective of the case study was to present a preliminary system layout of the cold recovery system for CO_2 condensation. This system is essential for the liquefaction of captured CO_2 onboard the vessel, which is a key component of the SBCC technology. The study provides an in-depth overview of the feasibility of utilizing the cold media generated from the usage of LNG for this purpose. This investigation aimed to provide an indicative evaluation of the CO_2 liquefaction potential when onboard CO_2 capture is assumed.

The study is a scientific approach to the analysis of the technical and operational aspects of the SBCC technology for the maritime industry. It examines the technical feasibility of integrating a cold recovery system for CO_2 handling into the LNG supply system on the Sleipnir and provides a detailed assessment of the potential impact of the technology on the vessel's infrastructure, stability, and safety.

Figure 1:SSCV Sleipnir [4]

3.1 Existing cold recovery system

The existing cold recovery system shown in Figure 2 is a closed loop that utilizes a water-glycol (WG) mixture to supply heat to LNG vaporizers and cooling power to the ship's chilled water system. WG2 is a secondary water-glycol circuit that supplies heat and is connected to the cold natural gas stream for superheating. If heating power from the chilled water system is lacking or reduced, WG2 compensates for this by maintaining the temperature of the WG circuit at a level suitable for LNG vaporization.

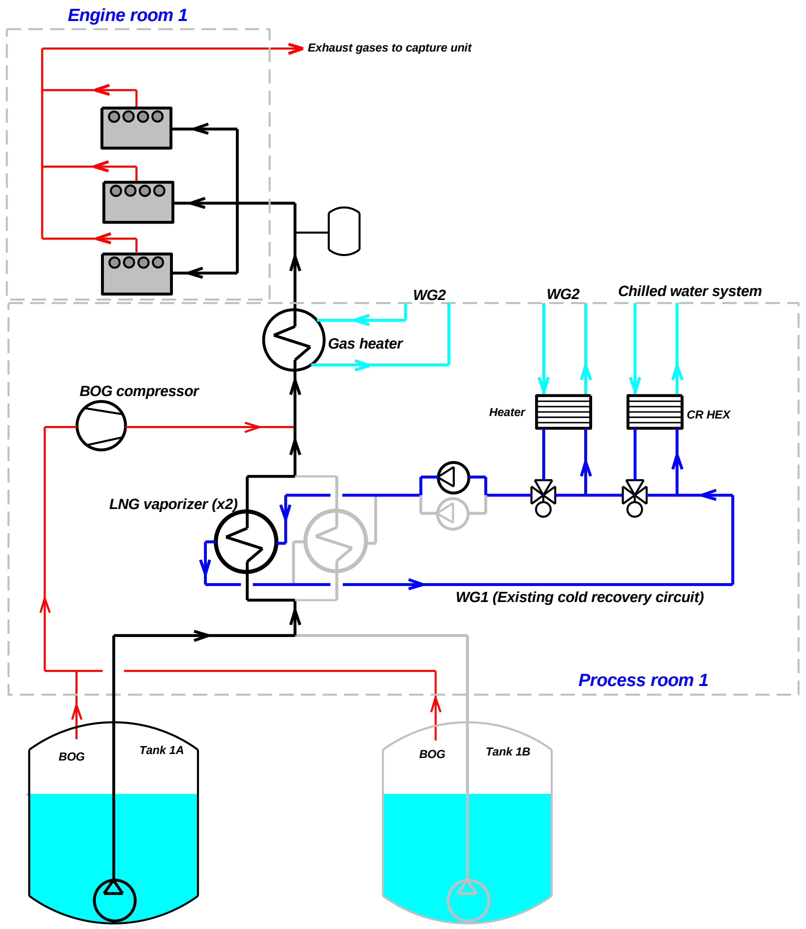

Figure 2: Existing cold recovery system WG1

3.2 Proposed new recovery system including CO_2 liquefaction

In order to satisfy the engineering requirements for CO_2 liquefaction, a secondary recovery circuit (Figure 3) is proposed. The purpose of this circuit is to gather cooling power from each process room through a heat exchanger and provide it to a condenser for the liquefaction of the CO_2 stream. A circulation pump will be used to maintain a constant flow rate throughout the circuit, but with the option to divert some of the flow through a separate line if necessary. The cooled media will be evenly distributed to each process room to collect more cooling power through the new heat exchangers as described in the previous sections. Depending on the load setup of each process room, the heat transfer media will vary in temperature. The returning streams will be mixed before being routed back through the pump into the condenser.

To add an additional cold recovery system for CO_2 condensation/liquefaction, an extra heat exchanger, typically of the plate-and-shell type, should be added to the WG1 circuit and connected in series with the other heat exchangers. The approach is to prioritize cold recovery for CO_2 condensation before the existing cold recovery for chilled water and therefore connect it first in series directly after the LNG vaporizer (Figure 3). A temperature control function should be implemented to ensure that temperatures remain warmer than the freezing point of the heat-transferring media and to prevent critical ice-plug formations inside the vaporizer. A margin of 10˚C to freezing point was chosen as the limiting point throughout the calculations.

When cold recovery from LNG vaporization is lacking, or when using only diesel fuel, additional cooling power has to be added to the condenser unit in order to be able to liquefy all incoming CO_2. The location of an external refrigeration circuit is shown in Figure 3 below. The main reason it is connected directly to the WG3 circuit, just before the condenser unit, is to facilitate a quicker response when requested.

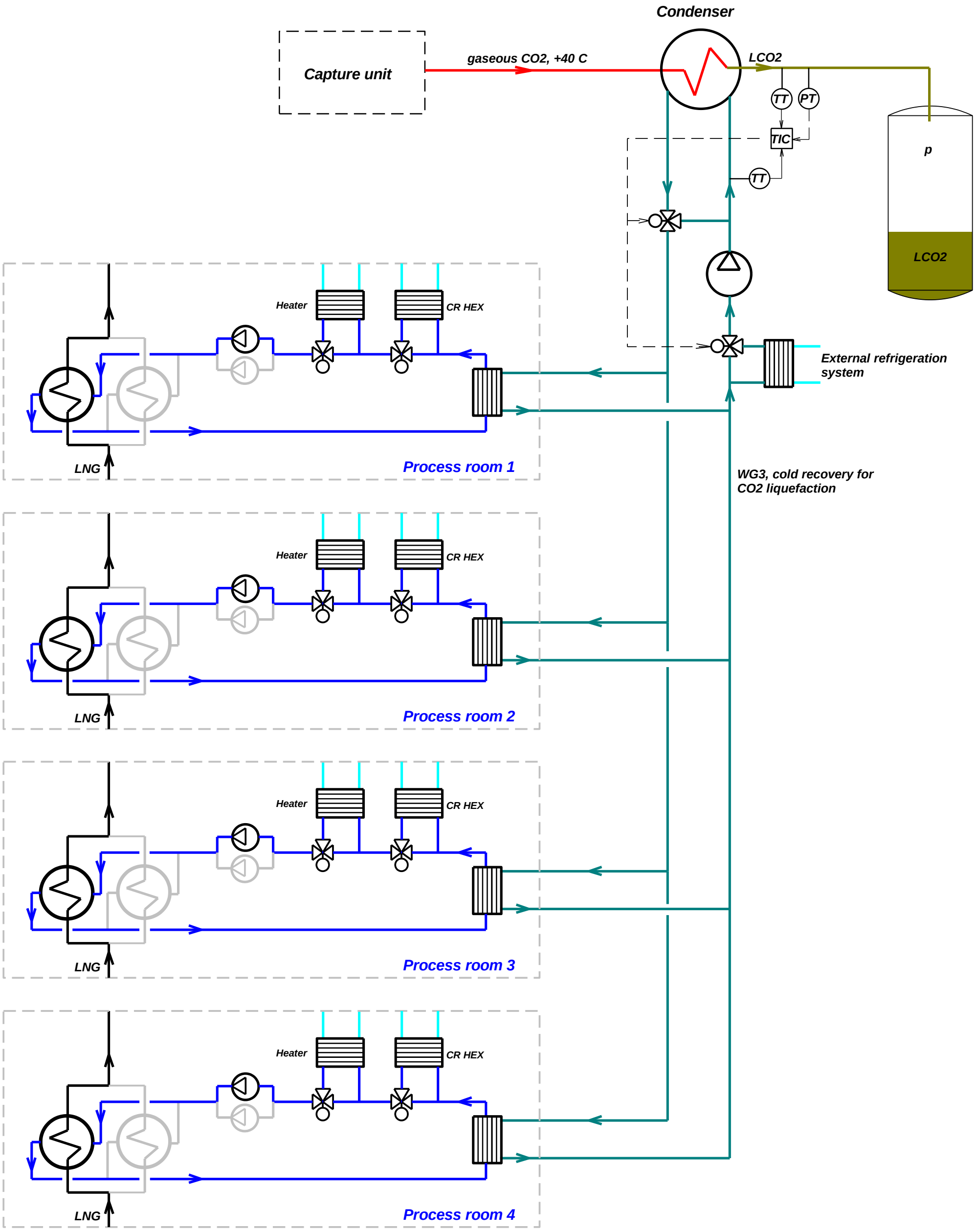

Figure 3: Proposed recovery system including CO_2 liquefaction and an external refrigeration circuit

3.3 Process simulations

Mass and heat balance calculations have been conducted to analyze various operational scenarios, considering different parameters that include engine power, CO_2 condensation pressure, LNG tank saturation pressure, the number of BOG compressors running, and the use of two different water mixtures in the recovery system with distinct freezing points.

The primary objective of these calculations was to determine the maximum mass flow rate of gaseous CO_2 that could be completely liquefied using the available cooling power from LNG vaporization and superheating. The focus is solely on CO_2 condensation, without any cold recovery to the existing chilled water system. However, in certain instances where the cooling media in the recovery system becomes excessively cold, additional heat may need to be supplemented from the existing chilled water system or a heater. This could lead to a loss of available cold recovery for CO_2 liquefaction, resulting in a reduced liquefaction ratio.

The liquefaction ratio is the main performance parameter, defined as the ratio of the mass flow rate of liquefied CO_2 to the mass flow rate of gaseous CO_2. Equation (1) represents the calculation of the liquefaction ratio:

$$[Liquefaction\ ratio] = \frac{[Mass\ flow\ of\ liquefied\ CO2]}{[Mass\ flow\ of\ CO2\ in\ engine\ exhaust]} \qquad (1)$$

For the calculations, a storage pressure of 19 barg was chosen as the reference state for CO_2 condensation, following the upper limit proposed in the Full Proposal for the EverLoNG project. The current system utilizes a water mixture with 60 wt-% ethylene-glycol and a freezing point of -52 ˚C. To expand the temperature range in the calculations, a potassium chloride (KCl)/water solution with a freezing point of -60 ˚C was used. However, the choice of either solution did not significantly impact the temperature distribution in the system or the liquefaction ratio.

4 Results

The first diagram, Figure 4, presents the achieved liquefaction ratio for a large number of different operational cases and engine loads ranging from 5% to 100% of rated capacity (96 MW). As can be seen, around 70% of total CO_2 coming from the engine exhaust gases could be liquefied by the recovery system. However, at lower engine loads the capacity decreases substantially when the tank boil-off compressors are running simultaneously.

Figure 5 shows the dependency of chosen condensation pressure on the liquefaction ratio. The cold recovery capacity clearly decreases with decreasing condensation pressure. These curves are ideal with no consideration of the current glycol-water mixture’s freezing point. Figure 6, on the other hand, accounts for the freezing point of the current glycol mixture, showing that the liquefaction ratio is heavily reduced at low condensation pressures. The glycol temperatures become too cold, which means additional heat must be added, which in turn means less recovery efficiency.

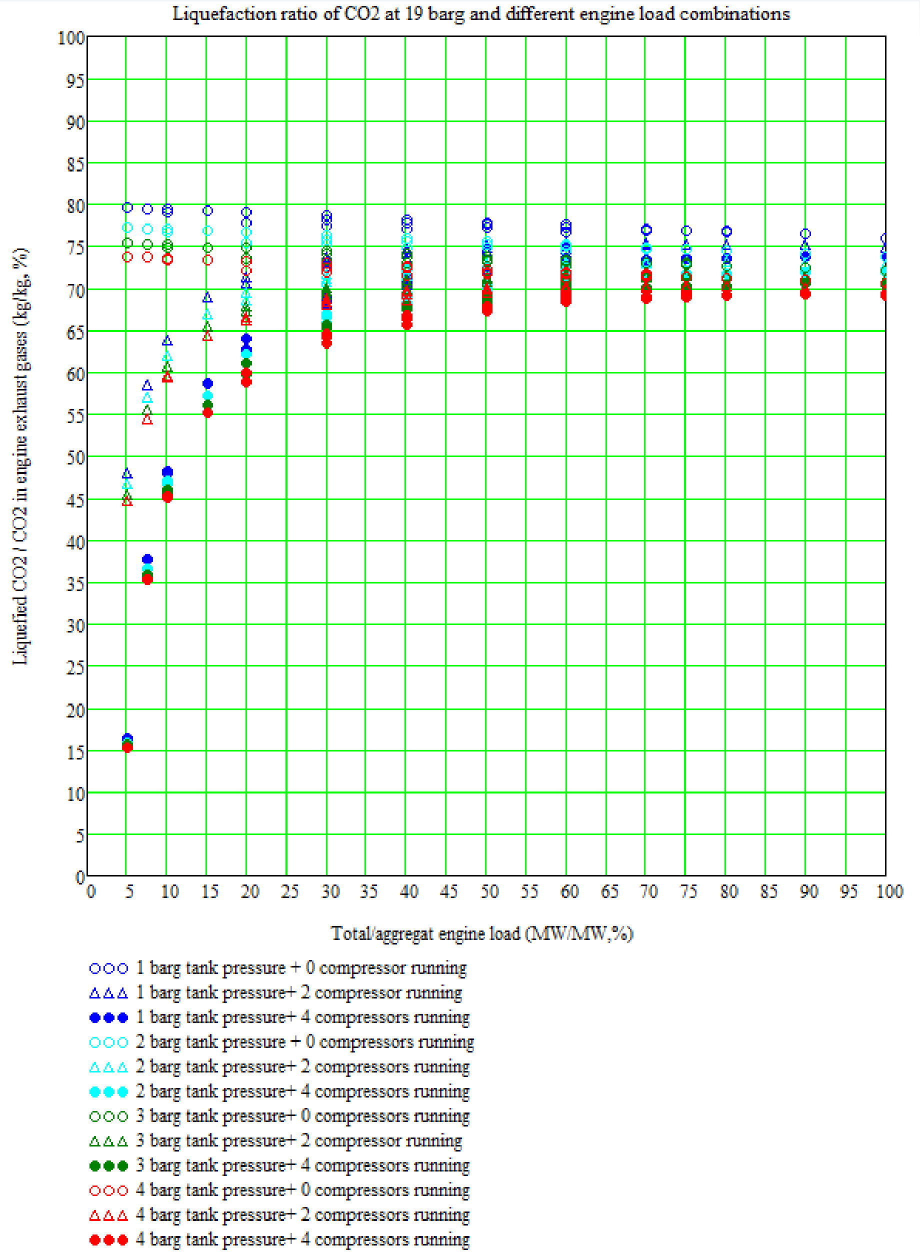

Figure 4: Liquefaction ratio of CO_2 with respect to total engine load where 96 MW corresponds to 100%

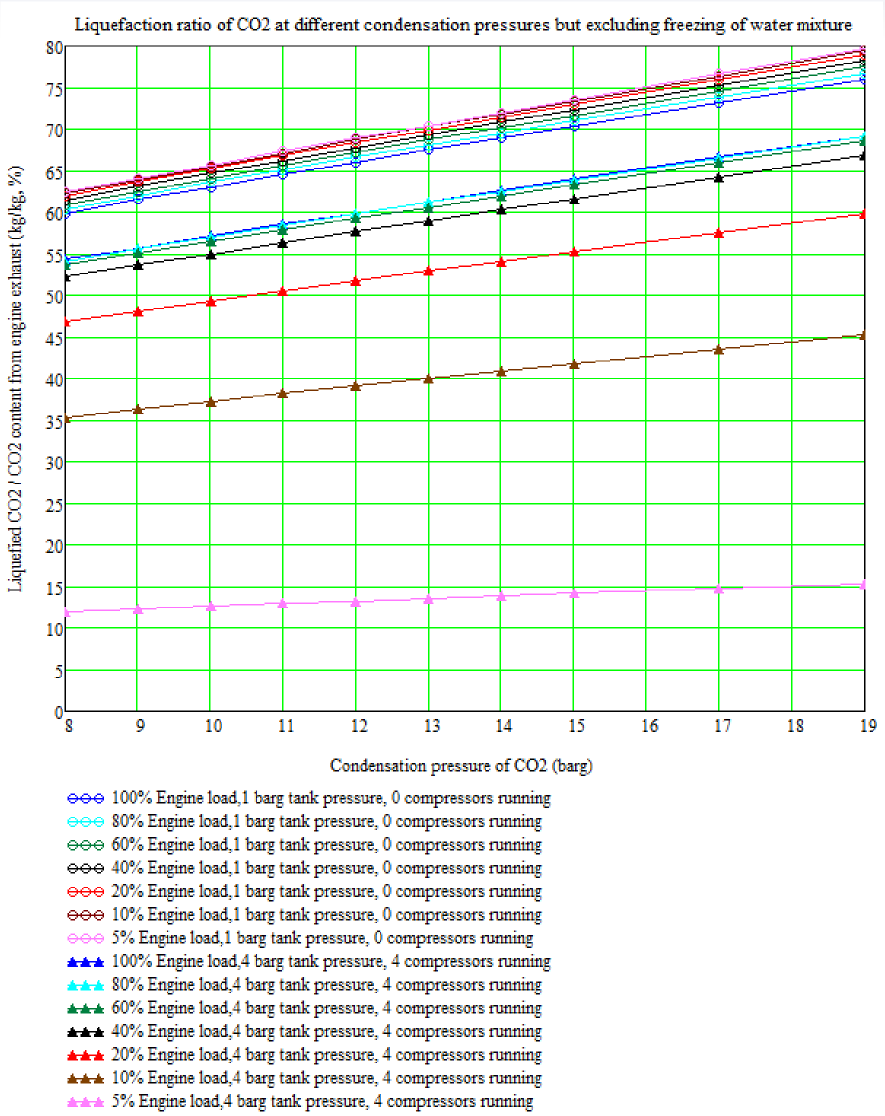

Figure 5: Liquefaction ratio of CO_2 with respect to condensation pressure. The glycol circuit's freezing point is not taken into account.

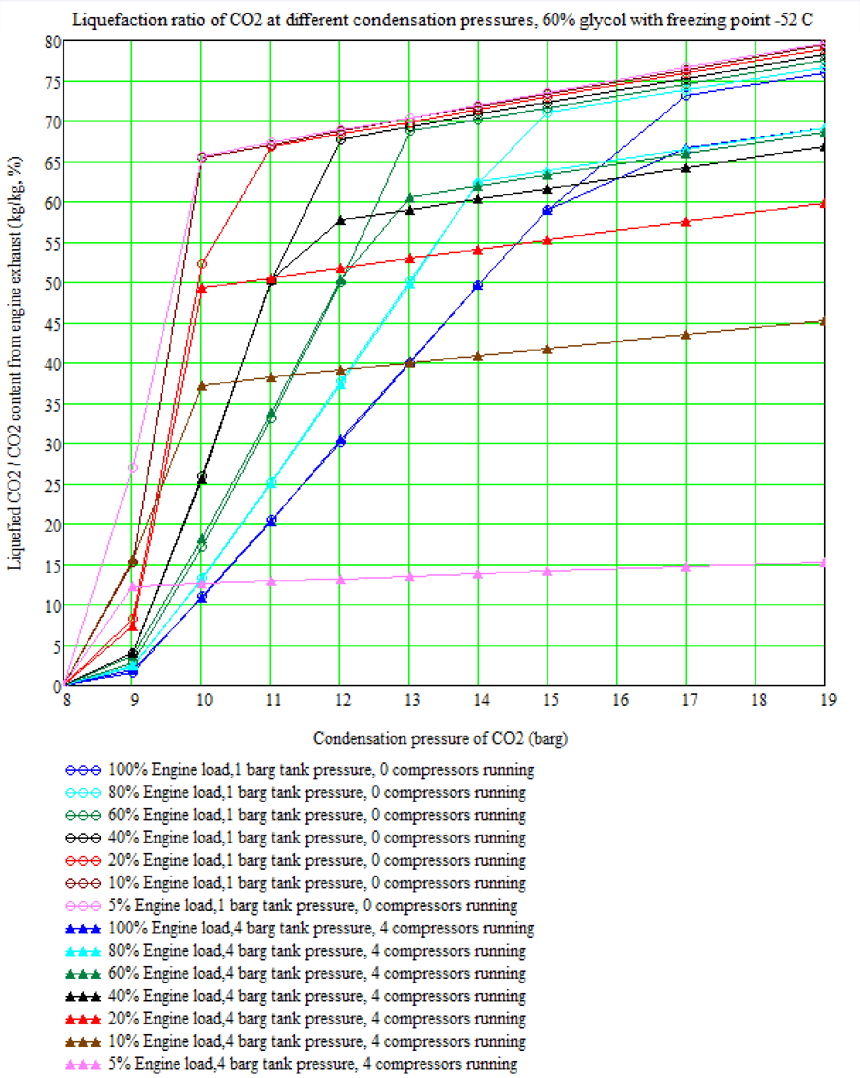

Figure 6: Liquefaction ratio of CO_2 with respect to condensation pressure and accounting for the glycol circuit’s freezing point

4.1 Amendment to the operational conditions on Sleipnir:

Based on the comprehensive evaluation of a wide range of engine loads (5% - 100%) and condensation pressures (8 barg – 19 barg), the operational conditions for Sleipnir have been revised. This decision was taken by the project members following recent operational data received from Sleipnir. The revised operational conditions are as follows:

Total engine load: The total engine load has been capped at a maximum of 40% (38 MW), considering the recent operational data. The CCS system has been specifically designed to accommodate a 15 MW engine load with 95% capture rate. Notably, the operational data indicated that diesel fuel was utilized for approximately 50% of the total operational time.

CO_2 liquefaction and storage pressure: It has been determined that the liquefaction and storage of CO_2 should be performed within the pressure range of 15-19 barg. For information, calculations were also performed for 10 and 8 barg respectively.

Table 1 below, representing 15 barg condensation pressure, presents the available cold recovery in the system and the cooling power needed for 100% liquefaction of the captured CO_2 at different engine loads, ranging from 5 MW to 40 MW. The cases A – C represent different fuels used by the engines, using either pure vaporized LNG, or only diesel, or a mixture of both. When cold recovery from LNG is not sufficient to liquefy all CO_2, the required cooling power from an external refrigeration circuit is presented. If more cold recovery is available than needed, the surplus is directed to the existing chilled water system.

Table 1: Required cooling power for CO_2 liquefaction at 15 barg condensation pressure and no BOG compressor operating. Existing glycol mixture used

Case	Total engine load	Fuel mixture		CCS		Required cooling power for CO_2 liquefaction**	Cold recovery from LNG vaporization	Cooling power from external refrigerator	Cooling power to Chilled water
		LNG *Kg/kg*	Diesel *Kg/kg*	Engine load covered by CCS	Mass flow rate CO_2^*				
A1	40 MW (41.7%)	100%	-	15 MW	1.66 Kg/s	616 kW	1 264 kW	-	**648** kW
A2	15 MW (15.6%)	100%	-	15 MW	1.66 Kg/s	616 kW	474 kW	142 kW	-
A2	10 MW (10.4%)	100%	-	10 MW	1.108 Kg/s	411 kW	317 kW	94 kW	-
A4	5 MW (5.2%)	100%	-	5 MW	0.554 Kg/s	206 kW	159 kW	47 kW	-
B1	40 MW (41.7%)	50%	50%	15 MW	1.867 Kg/s	693 kW	660 kW	33 kW	-
B2	15 MW (15.6%)	50%	50%	15 MW	1.867 Kg/s	693 kW	249 kW	444 kW	-
B3	10 MW (10.4%)	50%	50%	10 MW	1.242 Kg/s	461 kW	166 kW	295 kW	-
B4	5 MW (5.2%)	50%	50%	5.0 MW	0.621 Kg/s	230 kW	83 kW	147 kW	-
C1	40 MW (41.7%)	-	100%	15 MW	2.09 Kg/s	775 kW	0 kW	**775** kW	-
C2	15 MW (15.6%)	-	100%	15 MW	2.09 kg/s	775 kW	0 kW	**775** kW	-
C3	10 MW (10.4%)	-	100%	10 MW	1.39 Kg/s	516 kW	0 kW	416 kW	-
C4	5 MW (5.2%)	-	100%	5 MW	0.694 Kg/s	257 kW	0 kW	257 kW	-

* *Accounting for 95% capture rate*

** *Determined according to table 4.2 for 15 barg*

5 Recommendations

During favorable conditions on board LNG-driven ships with SBCC technology, between 60% to 80% of all CO_2 content in engine exhaust gases may be recondensed to liquid form by utilizing cold recovery from the LNG vaporization process. This holds when CO_2 is condensed between 19 to 12 barg and all fuel consumed by the engines is coming from vaporized LNG and not tank boil-off gases (BOG). A larger share of BOG due to insufficient LNG tank insulation will substantially reduce the recovered cooling capacity, especially in an idle ship. A freezing point around -60°C is also recommended for the recovery system in order to handle the low temperatures involved when CO_2 condensation pressures fall below about 12-15 barg. In such cases, it becomes very important to design the LNG vaporizers to prevent internal icing, and to design the heat exchangers and CO_2 condenser units in the recover circuit with overcapacity in order to minimize thermal resistance. A CO_2 condensation pressure below 8-9 barg seems unrealistic.

6 Summary and conclusion

This report presents a solution for implementing a cold recovery system using SBCC technology (Ship-Based Carbon Capture) on the LNG-fuelled crane vessel Sleipnir.

The primary objective was to determine the percentage of CO_2 in the engine exhaust gases that can be liquefied through cold recovery from LNG vaporization and superheating.

Based on the mass and heat balance calculations, the following conclusions were drawn:

- A higher condensation pressure results in a higher liquefaction ratio, reaching up to 80% at a condensation pressure of 19 barg under ideal operational conditions. The ratio decreases linearly to around 60% at a condensation pressure of 8 barg, without considering the freezing point of the water mixture in the recovery system.
- By using the current water-glycol mixture with a freezing point of -52˚C, a liquefaction ratio of 60% to 80% can be achieved for engine loadings up to 80% (77 MW), but only within the condensation pressure range of 15 to 19 barg and without any BOG compressors running. By using a potassium salt solution with a lower freezing point (-60˚C), a slightly wider range of condensation pressures (11 to 19 barg) can be accommodated.
- The liquefaction ratio is significantly reduced when running multiple BOG compressors simultaneously, especially at low engine loads. At 5 MW loading (5% of rated capacity), the ratio can be as low as 15% due to a reduced share of vaporized LNG available for cold recovery.
- The temperature level in the recovery system (WG1) drops significantly below its current operating conditions. It is recommended, if possible, to operate both existing vaporizers simultaneously in each process room and to increase the flow rate by utilizing the second WG pump. This approach reduces the load on the vaporizers and mitigates the risk of internal icing. However, a detailed evaluation with the supplier is advised.
- The capture unit is assumed to deliver gaseous CO_2 at a temperature of +40˚C to the condenser unit for liquefaction. Reducing the incoming temperature by 10˚C can result in a 1-2% increase in the liquefaction ratio.

Operational data obtained from Sleipnir over the past two years indicated significantly lower engine loads than evaluated in this report, mostly ranging from 10% to 20%, with occasional peaks up to 40% of the rated capacity. Additionally, approximately 50% of the fuel consumed was diesel fuel. Therefore, the decision was made by the project members to design the CCS system to accommodate exhaust gases up to a 15 MW engine load, with CO_2 being liquefied and stored at condensation pressures between 15 and 19 barg.

Based on these revised conditions, calculations demonstrated that engine loads below 15 MW require an additional refrigeration system to fully liquefy all captured CO_2. The maximum cooling power achievable from such a circuit was determined to be 870 kW when using only diesel fuel, without any cold recovery from LNG vaporization. If vaporized LNG alone is used for engine loads ranging from 15 to 40 MW, it can provide cooling power to the chilled water system, but at most approximately 700 kW.

The current glycol-water mixture can be used for condensation pressures down to around 10 barg, but only if the glycol heat exchangers and the condenser are designed with significant overcapacity.

Condensation pressures between 8 and 10 barg require a water mixture with a lower freezing point of around -60˚C. If the heat exchangers and condenser capacities are lower than what was evaluated in this report, it will result in lower cold recovery efficiency, requiring a larger share of cooling from an external refrigeration system. The next phase will involve optimizing the system and its components to better align with Sleipnir's operational profile.

7 Acknowledgements

The EverLoNG project is funded through the ACT programme (Accelerating CCS Technologies, Horizon2020 Project No 691712). Financial contributions have been made by the Ministry of Economic Affairs and Climate Policy, the Netherlands; the Federal Ministry for Economic Affairs and Climate Action, Germany; the Research Council of Norway; the Department for Business, Energy & Industrial Strategy, UK; and the U.S. Department of Energy. All funders are gratefully acknowledged.

8 Bibliography

[1] “Accelerating CCS Technologies,” accessed December 12, 2022, http://www.act-ccs.eu/.

[2] International Maritime Organization (IMO),"Fourth IMO Greenhouse Gas Study 2020” (2021).

[3] IMO, “REDUCTION OF GHG EMISSIONS FROM SHIPS: Report of the Working Group on Reduction of GHG Emissions from Ships”, MEPC 80, 06/2023.

[4] IMO, "ADOPTION OF THE INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS AND EXISTING IMO ACTIVITY RELATED TO REDUCING GHG EMISSIONS IN THE SHIPPING SECTOR" (2018).

[5] “EverLoNG", official EverLoNG project website, accessed December 12, 2022, https://everlongccus.eu/.

[6] "Heerema", official Heerema website, accessed December 12, 2022, https://www.heerema.com/.

Annex: MAN activities in CCUS

Having dedicated over three decades to research in CCUS, MAN Energy Solution has become a leading provider of compression technology for various CO_2 gas streams within the capture process. Their technology is integral in tasks such as CO_2 liquefaction or delivery to a pipeline for transportation. Their range of integrally geared compressors can handle suction flow rates of up to 500,000 m3/h and achieve a maximum discharge pressure of up to 250 bar. Through optimized impeller designs, tailored aerodynamics, and optimized pinion speeds, MAN Energy Solutions' compressors boast exceptional efficiency.

In addition to their cutting-edge technology, MAN Energy Solutions has also conducted extensive research and can offer modeling expertise in supercritical CO_2 behavior in compressors. They have a unique dedicated CO_2 test rig for components and solution optimization, allowing them to provide their clients with the best possible solutions.

MAN Energy Solutions is a leading provider of CO_2 compression solutions with a proven track record of more than 20 references for wet and dry CO_2 compression, accumulating over 1,000,000 operating hours and compressing approximately 200 million tons of CO_2. The company's state-of-the-art compression technology is designed to meet the growing demand for carbon capture, utilization, and storage (CCUS) projects worldwide.

Recently, MAN Energy Solutions in Berlin was awarded a prestigious contract for the engineering of three RG compressor trains for the Porthos project, a landmark carbon capture, utilization, and storage (CCUS) initiative in the Netherlands, jointly developed by the Port of Rotterdam Authority, Energie Beheer Nederland B.V. (EBN), and N.V. Nederlandse Gasunie. The project aims to establish a CO_2 transport hub and offshore storage facility in the Port of Rotterdam, one of Europe's largest and most important ports.

Through its advanced compression technology, MAN Energy Solutions is set to play a critical role in supporting the Porthos project's ambitions of reducing carbon emissions and achieving a more sustainable future. The company's innovative RG compressor trains are designed to deliver efficient, reliable, and high-performance compression of CO_2 gas, enabling its safe and secure transport and storage offshore. With its proven expertise and extensive experience in the field, MAN Energy Solutions is well positioned to support the Porthos project and other CCUS initiatives around the world.

Figure 4: MAN Energy Solutions is installing three compressors at a large-scale carbon capture project in the port area of Rotterdam, Netherlands. It is planned to store approximately 2.5 million tons of CO_2 per year under the North Sea

For more information, please visit our web page at www.man-es.com