CO2ASTS
CO2 ABFANG, SPEICHERUNG UND TRANSFER IN DER SCHIFFFAHRT

CO_2ASTS – carbon capture, storage and transfer in shipping

A technical and economic feasibility study:

Public Concise Report

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1. The CO_2ASTS project and concept

The project “CO2 capture, storage and transfer in shipping” (CO2ASTS) was developed with a consortium of German and Dutch companies and knowledge institutions in order to develop and establish technologies for more environmentally friendly and less CO2-intensive shipping technologies that could be established on the market in relatively short-term.

The CO2ASTS technology concerns post-combustion carbon capture and storage on LNG fuelled ships. This includes CO2 absorption by an aqueous solution containing a chemically active amine (30wt% monoethanolamine) and subsequent liquefaction and storage on board. The liquefied stored CO2 could then be transferred in the port and sold to potential end users, especially for production of renewable fuels (E-Fuels). A comparable system of this kind is currently not available for shipping worldwide.

The project supports the transition to more sustainable and sustainable shipping through cross-border cooperation, thereby implementing the environmental and transport policy goals of Germany, the Netherlands and the EU in the shipping sector and contributing to achieving the climate goals of the Paris Agreement 2015.

2. How does it work?

The general concept of the CO_2 capture unit includes the items shown in Figure 1. In an amine-based CO_2 capture unit, the flue gas is introduced in an absorber column where the MEA reacts with CO_2 to form carbamates. These species are regenerated back to free amine and free CO_2 by applying heat, in the reboiler of a stripper column. The free amine is circulated back to the absorber column, and the process is repeated. The free CO_2 is produced at condenser at the top of the stripper column with a purity of ca. 98%. The main impurity is water. CO_2 is compressed to 7 bar, dried, and then liquefied at around -50ºC. The liquid CO_2 is stored in tanks.

LNG-fuelled ships integrate perfectly with carbon capture and liquefaction, as the heat of the exhaust gas and the cold of the LNG vaporization can be utilized in the process, greatly reducing the operational costs of the process. The heat is applied in the solvent regeneration step, whereas the cold is applied in the CO_2 liquefaction step.

The equipment involved in the process (packed columns, pumps, heat exchangers, compressors, etc.) are standard and are therefore available in the market.

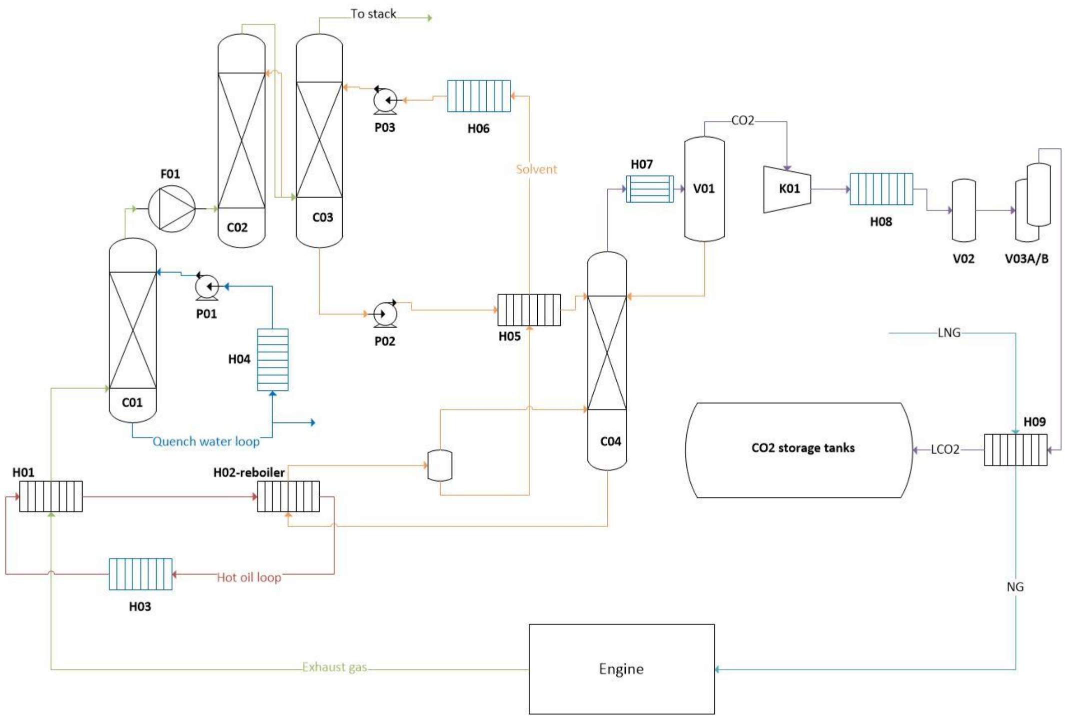

Figure 1. Schematic representation of the CO_2ASTS concept (as developed for case I).

3. Three use cases

3.1. Use case I: Reference sea-river vessel (1050 kW)

The smallest use case is a concept sea-river vessel design developed by Conoship International. The vessel is based on a modular LNG-electric propulsion plant: three Sandfirden GLA 821C gas generator sets fitted into one 20-feet ISO container provides the power required for propulsion, as well as the auxiliary power. Total maximum output is 1050 kW.

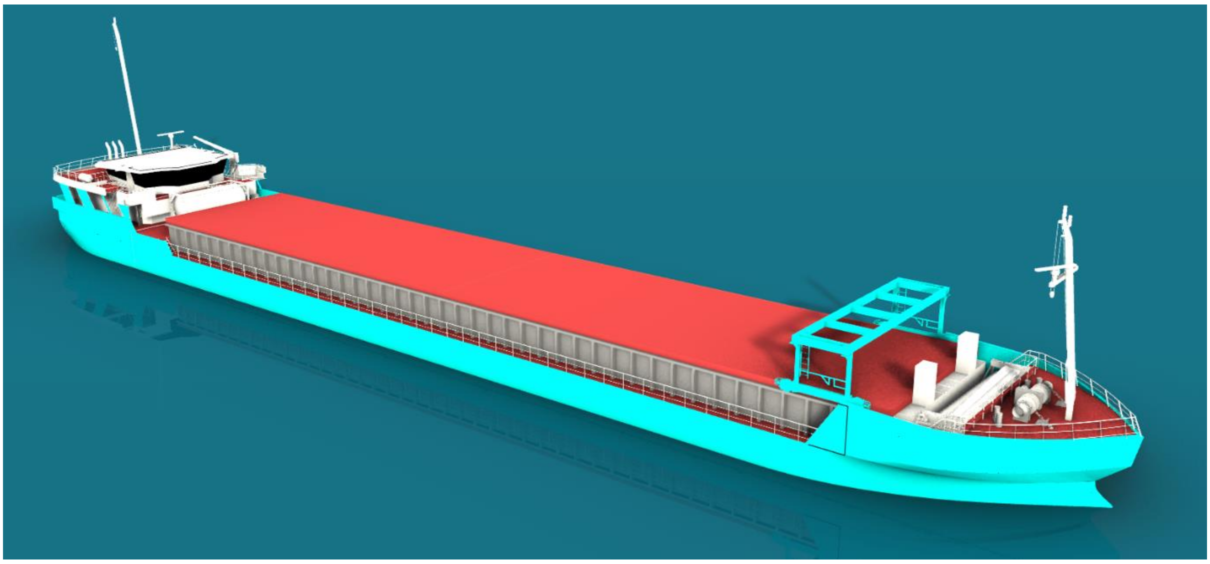

Figure 2. Use case 1 sea-river vessel (source: Conoship International)

Fuel is stored in one or more tank containers. Fuel capacity can thus be altered, depending on the demand. For this reason, the capture and storage systems will also be placed on a 20-foot ISO container footprint; if occasionally an increased fuel capacity is required, the capture plant and/or CO_2 storage tanks can be replaced by fuel containers.

Main dimensions and installed power of the vessel for this case are typical for sea-river vessels. The total installed power is also similar to that of large inland freighters, so the system developed for this use case can be extrapolated to a fairly broad range of vessels. As the system developed for this use case is based on a 20-foot ISO footprint, a 'standard' unit like this could be produced in series for a large number of vessels, reducing the cost per unit.

Main dimensions of this vessel cannot be increased, as that would make the vessel too large for some inland waterways (locks, bridges etc.). Hence, any volume required for the capture system and CO_2 storage will have to be found within the main dimensions of the benchmark design. The challenge is to fit the system on board while losing as little hold volume as possible. Same thing goes for weight: all weight that is added will be at the expense of deadweight capacity.

Main dimensions:

- Length over all: 89 m
- Breadth moulded: 13.4 m
- Depth moulded: 6.5 m
- Draught abt. 4.5 m
- Deadweight: abt. 3300 tonnes

3.1.1. Results of use case I

In case I, there is a good balance between the heat available in the exhaust gas and the cold available from LNG vaporisation. Based on the LNG storage temperature (-160 ºC at 1,1 bar), on the engines consumption, the exhaust gas flowrate and temperature, and on the pre-defined conditions for the CO_2 storage (7bar, -48 ºC), a maximum flowrate of 232 kg/h of CO_2 can be liquified, corresponding to a **capture rate of 75% at design conditions**.

Assuming that the captured CO_2 is offloaded every time the vessel bunkers, the CO_2 storage capacity should correspond with the vessel's fuel capacity. The vessel has a nominal fuel capacity of 44 m^3 (19.8 tonnes) LNG, leading to a required storage capacity is 40.5 tonnes CO_2 (ca. 38 m^3).

The total required power is 13 kW. The amount of cooling water that is needed is 28,6 m^3/h. The total weight, including the solvent inventory and liquid CO_2 is estimated at 97 ton. The CO_2 storage tanks require a total volume of 42 m^3, estimated on a period of 14 days operating with the specified sailing profile. The storage tanks can hold approximately 47 ton of CO_2.

Vessel layout

Based on the designed CO_2 capture liquefaction and storage plant, a possible layout of a capture module is made. Following the design of the fuel tanks and power plant, the capture system is also based on a 20 ft. container footprint, and CO_2 storage tanks are 20 ft. tank containers. Although the footprint of the system is small, it does require quite some height to be available: the top of the quench tower and of the absorber and stripper columns are at 10.5 metres above the skid's base. Because of the nature of the vessel (low air draught to fit under bridges), the capture module should not be any higher than this. It should be noticed that the absorber column was split in two, to accommodate this design constraint.

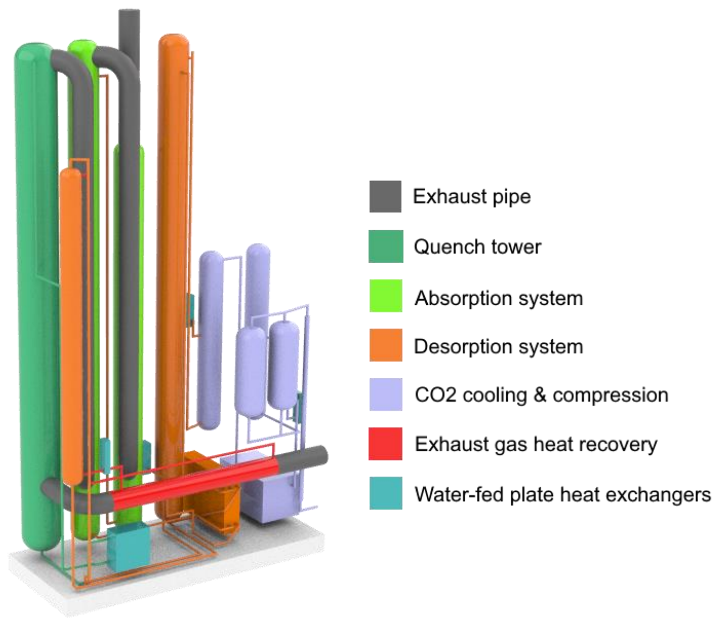

Figure 3. Concept layout capture plant use case I with 20ft container footprint

The original ship design has a ‘container bay’ between the hold and the accommodation for the propulsion unit and the fuel tanks. The propulsion container (or engine room) is separated from the fuel tanks by means of a (removable) floor.

To accommodate for the capture module, an additional bay is added in front of the existing one, at the expense of hold length. Because of the height of the capture module, it must be placed at the tank top. The height of the double bottom is reduced to a minimum (800 mm a.b.). This creates just enough height so that visibility from the bridge is not severely impacted by the capture module. The new layout of the vessel is shown in the figure below.

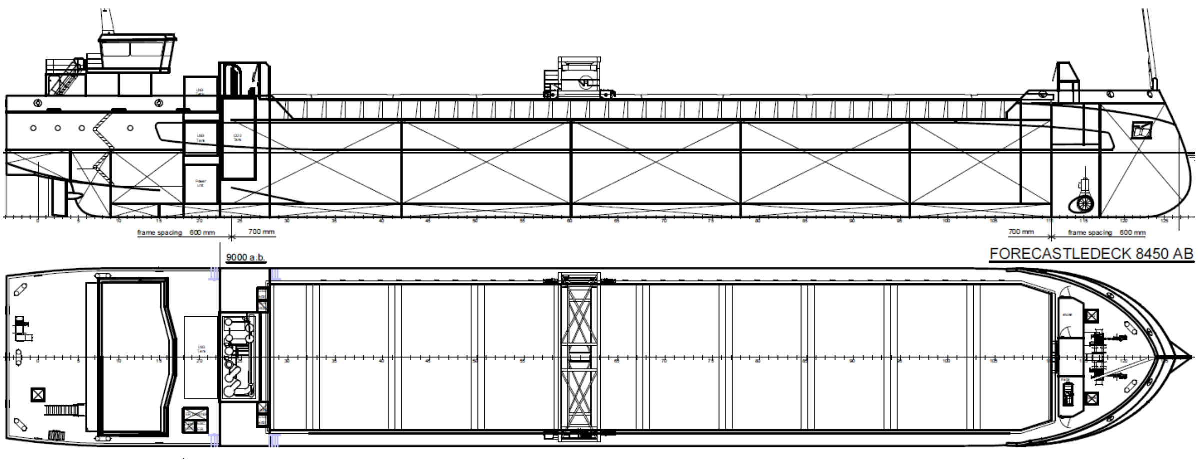

Figure 4. Use case I layout with carbon capture system

To compensate for the reduced length of the hold, the hold is heightened by 350 mm, so that the hold volume remains equal to that of the original vessel.

Two 20 ft. CO_2 tank containers (22 m^3 each) are vertically placed on either side of the capture module to store the CO_2. Vertical tank containers are a non-standard solution (most tank containers are always placed horizontally), but in this case are necessary to reduce the system’s footprint as much as possible. Total CO_2 storage capacity is 44 m^3, which is in balance with the ship's fuel capacity and the capture rate of the capture system. The transverse section in the figure below shows the arrangement of the capture system and storage tanks on the vessel.

Stability calculations were done and show that the stability of the vessel is not severely impacted by the increased height of the hold and the added weight of the capture system and storage tanks. The trim of the vessel is also not changed a lot.

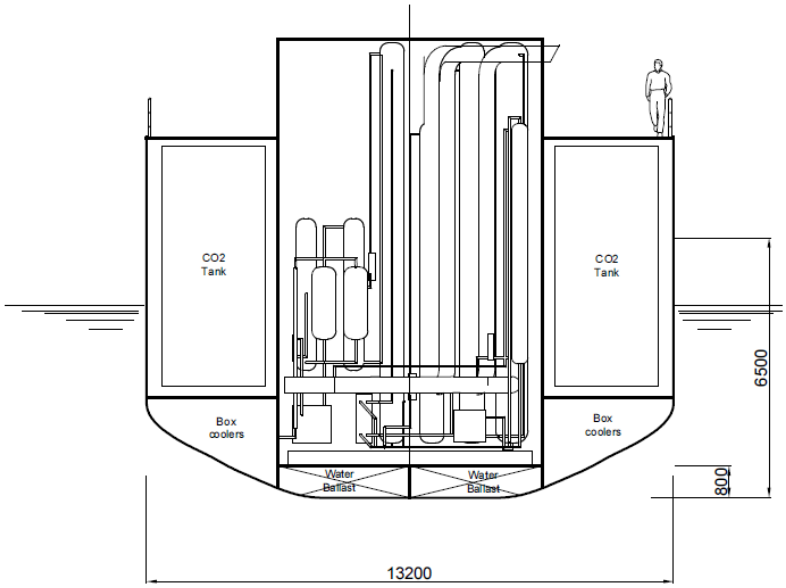

Figure 5. Use case I transverse section showing the capture system and storage tanks

Economic feasibility

In contrast to the hold volume, the weight added to the vessel cannot be compensated, so the weight added by the capture system is at the expense of deadweight capacity.

Total loss of cargo capacity is thus 94.5 tonnes. Typical day rates of a 3000 tonne deadweight general cargo vessel are around € 0.72 per tonne deadweight (calculation based on Norbroker Short Sea Market Report [1]). Based on these figures the reduced deadweight will result in a decrease in earnings of around € 25,000 per year.

The estimated CAPEX for the CO_2 capture, liquefaction and storage system is of 2,67 M€, while the levelised CO_2 capture cost amounted to 301 €/ton, already taking into consideration the lost income, cost of utilities, labour, maintenance, use of chemicals, etc. Annualised CAPEX corresponds to 67% of this cost.

What is not quantified in this study, but might be very relevant: the significant decrease in CO_2-emissions might deliver the vessel a competitive edge over other vessels: it might be that a vessel that emits less than half the greenhouse gases of its conventional competitors, is chartered at significantly higher dayrates than these competitors. This could be stimulated by governments and ports; for example, the port of Rotterdam offers LNG-fueled vessels reduced port tariffs because of the environmental benefits of these vessels compared to conventional diesel fueled vessels. A similar discount is not unlikely to be implemented for vessels that have significantly lower CO_2 emissions than conventional vessels.

3.2. Use case II: Reference dredger (7600 kW)

The LNG-fueled dredger Ecodelta was selected as second use case. The Ecodelta is a trailing suction hopper dredger designed by Conoship International, built by Barkmeijer Shipyards in Stroobos and operated by dredging company Van Der Kamp from Zwolle.

Figure 6. Use case 2 Ecodelta (source: Conoship International)

Main power is provided by four Dual fuel ABC 12DZD generator sets of 1900 kW each, giving a total power of 7600 kW. Additionally, there are two auxiliary gensets: one 500 kW Sandfirden OL 821 F diesel generator set and one 232 Sandfirden GL 820 C gas generator set.

As the Ecodelta is an existing vessel, the carbon capture plant will be designed as a retrofit. The design allows for installation of both the capture system and the CO_2 storage tanks on deck, so the hopper volume is not affected by the capture system. Stability and deadweight capacity will be affected by the added weight on deck. The consequences of this for vessel operations are investigated in this use case.

Main dimensions:

- Length over all: 134 m
- Breadth moulded: 21.4 m
- Depth moulded: 8.4 m
- Draught: abt. 6.6 m
- Hopper volume: abt. 6000 m^3

3.2.1. Results of use case II

Due to the fuel mix that is used (dual fuel engine running on LNG and diesel), in this case the CO_2 capture rate is limited by the amount of cold available from LNG evaporation. Therefore, a maximum capture rate of 54% can be achieved, and this value is used in the system design.

Considering the operational profile of the dredger, it is decided that the vessel should have enough CO_2 storage capacity for 6 continuous days of operation. The amount of CO_2 captured varies between 0.94 and 1.40 tonne/hour, depending on the specific operation. A total of 174 tonnes (163 m^3) CO_2 per week is estimated to be captured. Thus, a CO_2 storage capacity of 163 m^3 is required.

The total power is 95,2 kW. The amount of cooling water that is needed is 460 m^3/hr. The total weight, including the solvent inventory and liquid CO_2 is estimated at 371 ton. The CO_2 storage tanks have a total volume of 178 m^3 and can approximately hold 187 ton of CO_2.

Retrofit considerations

The Ecodelta currently has no waste heat recovery system for the exhaust gases of its four main generating sets. The exhaust gases are routed to the air through a silencer. Each engine has its own exhaust and silencer. In the capture system retrofit, these silencers are replaced by exhaust gas economizers which also act as silencers. The economizers provide the heat required for the capture process. This way, the heat recovery system requires minimal extra space.

After the economizers, the exhaust gases are diverted from the stack to the capture system by means of a diverter valve. After the diverter valves, the exhaust gas lines from all four engines are combined and routed to the capture system. The diverter valves ensure that each separate engine can run independently of the capture system.

Currently, the LNG from the vessel's fuel tank is vaporized in the tank connection space using a water-glycol mixture. In order to cool the captured CO_2 using the cold from the LNG, the LNG is to be routed through an additional heat exchanger that uses the captured CO_2 as heating medium. The existing vaporizer is not to be removed, as the vessel's engine should be able to run without the capture system in operation. Moreover, even if the capture system is in operation, there could be an imbalance between the cold required for CO_2 liquefaction and the heat required for fuel vaporization. The existing vaporizer can be used for compensating for this imbalance.

Because both CO_2 and NG are hazardous gases, the heat exchanger is to be enclosed in a gas-tight compartment. To keep cryogenic lines as short as possible, the heat exchanger is to be placed close to both the LNG tank and the CO_2 tanks.

The cooling capacity required for the intercooling between compression stages can be provided by the existing aft rack cooler.

Vessel layout

The liquefaction and storage of the captured CO_2 should be located close to the LNG tank. On this vessel, the engines are located in the forward part of the vessel and the LNG tank is located in the aft part of the vessel. The capture equipment is placed near the funnels in front of the hopper, whilst the CO_2 tanks and the liquefaction plant are placed aft of the hopper. The captured CO_2 is thus routed in gaseous form from the capture plant to the liquefaction plant.

The net weight increase of the vessel due to the capture system and the captured CO_2 amounts to around 217 tonnes. This is a relatively small weight compared to the vessel's displacement and does not severely impact the vessel's stability.

The system required for the capture process consists, among other things, of several columns with a height of more than 8 metres. These columns should be placed so that the navigation bridge visibility is not limited too much. Hence, the columns are placed forward of the portside funnel increasing the blind sector to around 2°, which is well within the limits specified by SOLAS regulations.

The existing silencers are replaced by exhaust gas economizers which double as silencers. After the economizers, diverter valves rout the exhaust gases to the capture plant.

The rack cooler (required mainly for the quench column) as well as all other equipment required for the capture process is located in a newly constructed enclosed room on the forecastle deck, next to the portside funnel. The general layout of the forward part of the capture system is shown in figure 7.

Economic feasibility

The loss in cargo capacity is estimated at 178 ton or about 102m^3. Based on a volume price of 2.50 €/m^3 this implies lost income of 255€ per dredging trip - when the volume is limiting (which is in about 30% of the trips the case). Assuming 27 trips per week, 47 operational weeks per year and 30% of those volume-constraint, this would result in an income loss of 100 k€/a.

The estimated CAPEX for the CO_2 capture, liquefaction and storage system is of 5,85 M€, while the levelised CO_2 capture cost amounted to 115 €/ton, already taking into consideration the lost income, cost of utilities, labour, maintenance, use of chemicals, etc. Annualized CAPEX corresponds to 58% of this cost.

The CO_2 storage tanks are placed on the main deck, between the accommodation and the hopper. This is directly above the tank space. In the tank space, ample room is available for the CO_2 liquefaction plant. Because the CO_2 tanks are located so close to the LNG tanks, the length of the cryogenic lines can be kept to a minimum.

The tank space is already provided with forced ventilation of 5 air changes per hour. On deck, there is space for 4 20-feet tankcontainers and 2 40-feet tankcontainers (stacks of 2), providing for a capacity of around 175 m^3. Deck strength should be evaluated. Figure 8 shows how the CO_2 tanks could be arranged on deck.

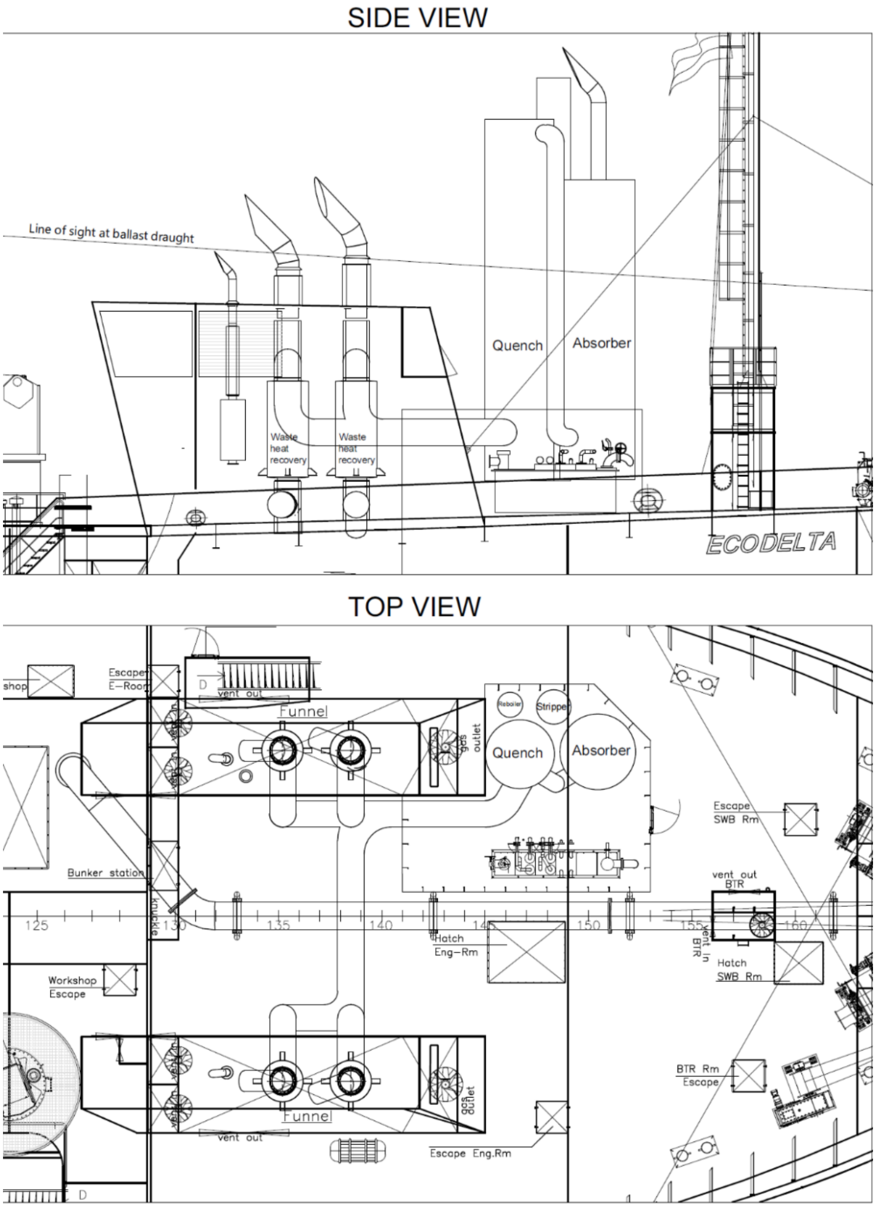

Figure 7. Layout forward part capture system

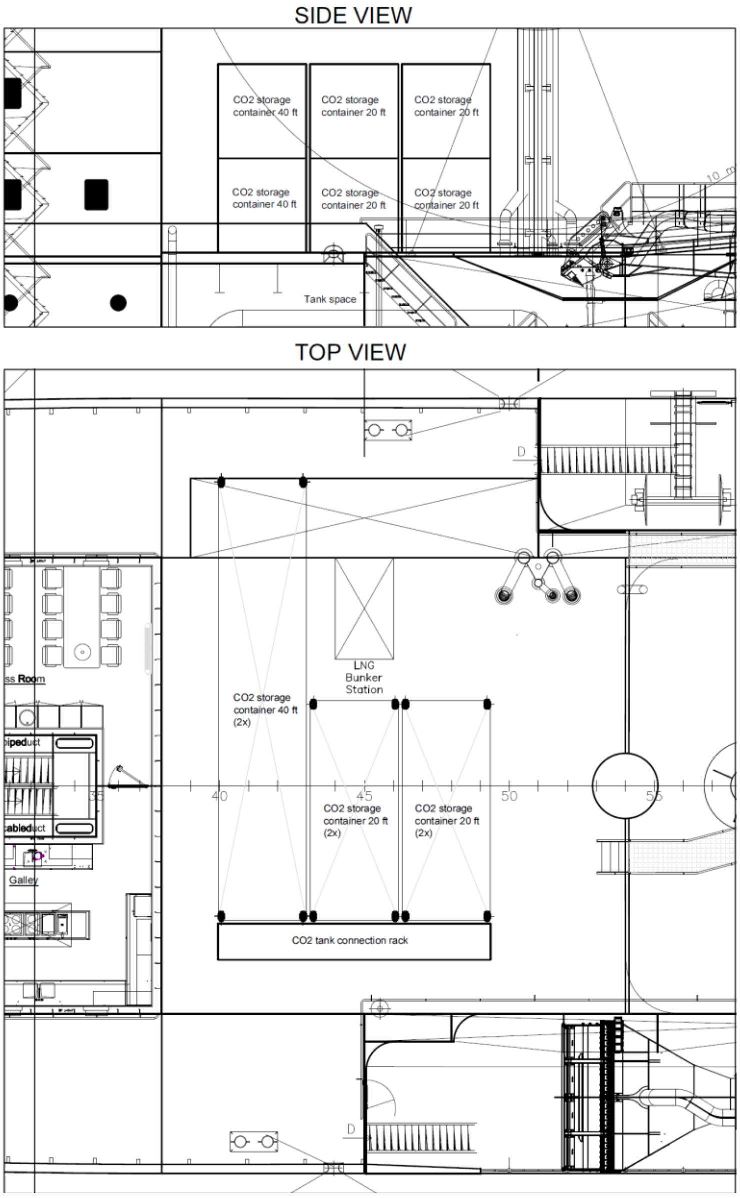

Figure 8. Aft layout CO2 storage

3.3. Use case III: Reference cruise ship (36000 kW)

MEYER WERFT is working on several research projects regarding the energy supply of ships. Most of them have severe impact on the ships design, especially on the general arrangement due to higher space consumption.

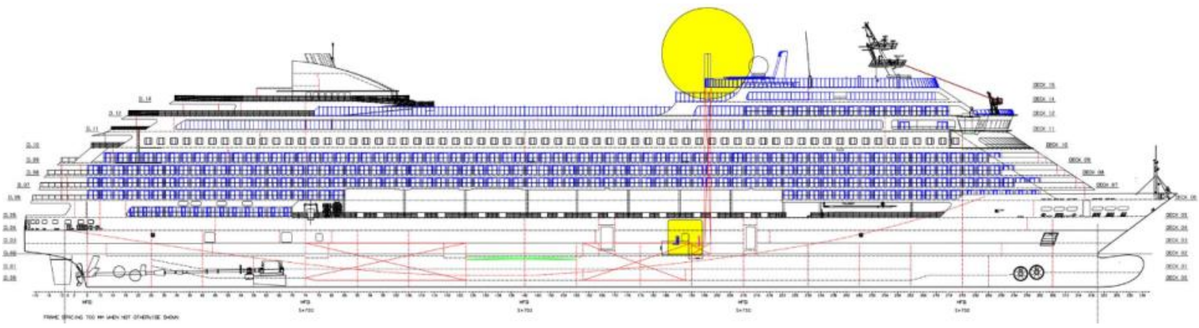

Figure 9. Use case 3 cruise ship (source: Meyer Werft)

The project ship is a generic, typical ship as built several times by MEYER WERFT. It is a typical panamax size cruise ship. Wherever possible, the same project ship is used for all research activities. That enables to compare different solutions.

- B 32,2m; L 250m
- 2500 Passengers
- 70 000 GT
- 4 x 9MW Dual Fuel engines (LNG fuelled)

3.3.1. Results of use case III

In this case, the limitation of the capture rate is on the availability of the cold coming from the vaporization of the LNG. The engines are arranged in two engine rooms (two engines per room). Two capture plants are designed: one per engine room, and each capture plant is only in service when both engines in the respective room are running. At low and usual speeds at sea, one capture plant will be running. At high speed at sea, both capture plants will be running. In port, or other situations when only one engine is running, the capture plants are off service. A maximum of 6840 kg/hr of CO_2 can be captured, corresponding to 69% of the CO_2 present in the flue gas.

A conventional steam cycle system (170 °C at 8 bar) is normally considered for the cruise ship, as this is convenient for heating of different purposes onboard. This relatively high temperature is required to avoid condensation of sulphurous acid. However, for LNG fuelled ships, this is not a concern, and the steam cycle can be redesigned at a lower pressure (and therefore temperature; 4 bar at ca. 145 °C). By doing so, the usable thermal exhaust gas energy is sufficient for running the capture plant. Moreover, the lower steam temperature avoids thermal degradation of the solvent.

Meyerwerft suggests a CO_2 storage capacity equal to 7 days of sailing. Given the design constraints, this means that the CO_2 storage tanks need to be able to handle 585 ton of CO_2.

The total power consumption is 396 kW. The amount of cooling water that is needed is 871 m^3/hr. The total weight, including the solvent inventory and liquid CO_2 is estimated at 1176 ton. The CO_2 storage tanks require a total volume of 548 m^3, based on a period of 7 days operating at the specified sailing profile. The storage tanks can approximately hold 585 ton of CO_2. The expected power consumption is 1,74 GWh/year.

Vessel layout

For the general arrangement it was decided to split the plant into two rooms: the absorber column that requires a big height is located in the engine casing (funnel). The rest of the equipment is located in the engine room (limited height) where it can be arranged space optimised.

The arrangement in the engine casing requires a larger casing that leads to loss of 15 cabins. LNG is stored in cylindrical tanks. That enables overpressure and eases insulation. Both is necessary for liquid CO_2 tanks, too. The usual arrangement of the tanks includes two big tanks with 1.500m^3 each and one small tank with 530m^3. The full capacity is used for long distances transatlantic cruise only. In normal service, the required range does not require the third tank. With minor modifications the small LNG tank can be used as a CO_2 tank. In normal operation the small tank could be used for storage of captured CO_2. For transatlantic cruise, initially the small tank would be filled with LNG. After the small tank is emptied first, the capture plant can be started and the captured CO_2 stored in the empty small tank. Solutions for ensuring no contamination of the liquid CO_2 must be developed.

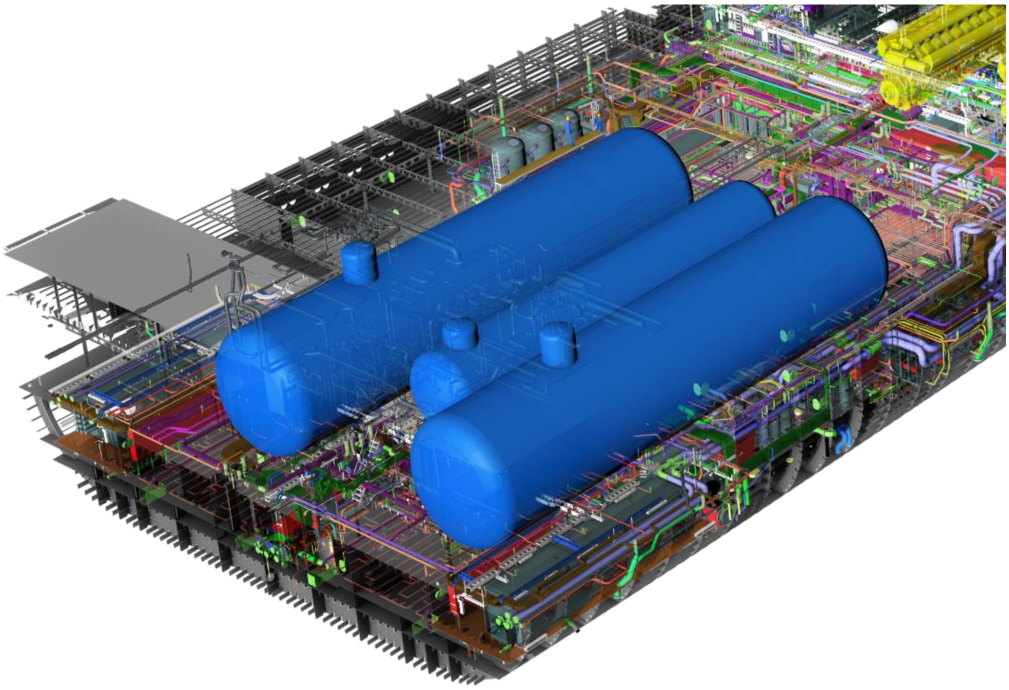

Figure 10. Arrangements of LNG tanks

Economic feasibility

For a cruise-ship one could expect a loss of 15 passenger cabins. It is assumed that this leads to a loss in EBITDA (income) of 100€/cabin/day. Based on utilisation of 360 days per annum the lost income would amount to about 550 k€/a.

The estimated CAPEX for the CO_2 capture, liquefaction and storage system is of 13,32 M€, while the levelized CO_2 capture cost amounted to 154 €/ton, already taking into consideration the lost income, cost of utilities, labour, maintenance, use of chemicals, etc. Annualized CAPEX corresponds to 52% of this cost, whereas the lost income amounts to 30%.

4. Port and Logistics

4.1. Law & regulation

Liquid CO_2 is a product with a number of very specific properties when it comes to transport. It is non-toxic or flammable but suffocating and falls under transport of hazardous substances, ADR (road transport) or ADN (transport by water), depending on which mode of transport is chosen. The product is transported under cryogenic conditions (-47ºC at 7 bar or -25/-30ºC at 18 bar), which means that there are also special requirements for the tanks. In order to guarantee the maximum flexibility of the ship/transport, the HACCP (requirements for the transport of foodstuffs) regulations are used. The pressure is more or less normal and when using the right tanks there is no need for extra cooling during transport.

CO_2 transport over inland waterways is an unknown action, because there is a lack of clarity about the way in which it is transported. The shipping company Anthony Veder has been transporting liquid CO_2 since 1999 and since 2015 Yara (fertilizer manufacturer) has a fleet of 3 ships that transport food-grade CO2 (including sea shipping). The innovation that comes together with the transport and the regulations for inland shipping that has to be adapted or tested for this is so innovative that a project like this is necessary. This is also faced in the development of the receiving and transmitting installation. The design of an installation to load and/or unload the vessel shall be compatible with the ship's design. For example, for pumping the liquid CO_2, a pump can be used at the vessel or a pump in the "on shore installation".

4.2. Transshipment

Starting point of the design should be the use of identical solutions at different positions. This means that the method of transshipment at the different unloading points must be identical. For example, this could be an installation with an unloading arm, see figure below.

Figure 11. CO_2 loading and unloading arm

For the choice of transshipment there are a limited number of possibilities. This is caused by the fact that a ship moves relative to the shore side during loading and unloading in height, but also horizontally by the influence of passing ships. The most obvious variant is the use of hoses, which are also used for the loading and unloading of trucks. However, these hoses are not resistant to the movements of the ship. A loading/unloading arm is. This is a technique specially developed for the shipping industry, which absorbs the movements and does not cause any tension in the various parts of the installation. Because of the cryogenic nature of the liquid, it is still possible to use a combination of both techniques.

4.3. Safety and implementation

During installation, it is important and practical that the gas and liquid phase connections move evenly, so that there are no additional moving parts when connecting. The two connections are necessary. Fluid has to be transported from the ship to the shore storage facility and the pressure in the tanks has to be regulated and controlled so that a gas pipe to the storage facility is also necessary. In addition to the loading arm, an emergency shut down (ESD) system is required. This system ensures that the pipelines on board the ship and in the shore-based installation are sealed off in case of an emergency situation. A fence shall be fitted around the unloading installation so that no unauthorized persons have access to it. During unloading, both on board the ship and at the shore-based installation, there shall be a person able to be present or be able to intervene in case of an emergency. These regulations are described in the ADN (transport of dangerous goods on inland waterways) and in applicable PHS guidelines. One (or two) pump(s) of the ship will be used to unload the ship. This ensures that that not every unloading bay needs to be equipped with a pumping system. For the loading of the vessel, the same device may be used except that it is practical to use a pump at the onshore facility. This prevents double piping on board of the ship (thermal insulated).

5. How does it compare to other technologies?

A Lloyd's Register study [2] has summarized seven Zero Emission Vessel (ZEV) routes that should help reduce CO_2 emission in the shipping industry in absolute terms by 50% by 2050.

Table 1. ZEV-routes according [2]

Type	Requirements
Electric	Batteries; Electric engine
Hybrid Hydrogen	H2 Storage; batteries; fuel-cell; electric engine
Hydrogen Fuel cell	H2 storage; fuel cell; electric engine
Hydrogen +ICE	H2 storage; HFO tank; dual fuel IC Engine
Ammonia Fuel cell	Ammonia storage; reformer; fuel cell; electric engine
Ammonia + ICE	Ammonia storage; HFO tank; dual fuel ICE
Biofuel	Biofuel tank; ICE

Such ZEV's need to be produced from 2030 onwards and – with the exception of biofuels – require a major change in the powerline (which is not required for the CO_2 capture installation). The same report also quotes shipping stakeholders saying that CO_2 reduction-costs should not exceed 50 €/tCO_2 and extra vessel costs should not exceed 10%. This proves to be a difficult constraint to meet.

In this evaluation none of the seven evaluated technologies, under any evaluated scenario, will be profitable when compared to the benchmark (HFO) as alternative, hence leaving this to market will be ineffective for adoption. The best option for all investigated vessel-types and scenarios is the use of bio-fuels.

The study further shows that the most cost-effective of the evaluated zero-emission options only becomes competitive (compared to conventional propulsion) for **CO_2 prices in the order of $250-300/t.** Even at this price point – which is way higher than the worst case expectation of a carbon tax of 150 €/t CO_2 – only the biofuel vessel would become competitive relative to a conventionally propelled ship. The synthetic fuel options (ammonia/hydrogen) become competitive at approximately $500/t, even in a low cost of capital scenario. The fuel cell/electric engine options would require still higher CO_2 prices. A lower cost of capital (lower interest rate) does reduce the carbon price at which several of the zero-emission technologies become competitive somewhat. It, however, only has a minor impact on the competitiveness of the biofuel and ammonia with ICE options. For these options involving alternative fuels, the competitiveness with a conventionally propelled ship is dominated by the difference between prices for ammonia/biofuel vs fossil fuel.

Compared to the above evaluation, the CO_2ASTS project addresses an alternative solution for ships with a conventional power train. In that sense it is difficult to compare with above options as these require, apart from the bio-fuel option, from-scratch new built vessel design and construction. It aims at reducing CO_2 emission with an add-on installation that captures the CO_2 and can be retrofitted in existing vessels. It is important to emphasize that the technology is already mature and used in other industrial sectors, which means that decarbonization can be achieved in the short-term.

The capture rates, determined for the reference cases studied in this project, are likely to be between 50 and 89%, so the solution proposed here does not lead to zero emission. It is, however, economically competitive at lower CO_2 prices than the proposed ZEV. Scale plays an important role in the levelized cost of CO_2 for the cases studied: while small ships (herein represented by the reference sea-river vessel 1050 kW) might be quite expensive to decarbonize, larger ships may already present a business case in a scenario of high carbon tax (150 €/ton). Achieving the target cost of 50€/ton set by shipping stakeholders in the Lloyd's Register study would be hard, but significantly lowering the costs by means of lowering the CAPEX is a possibility, which is investigated by members of the CO_2ASTS consortium in follow-up projects.

6. References

[1] Norbroker Shipping & Trading A/S. *Short Sea Market Report Issue 08/2017.* 2017

[2] "Zero Emission Vessels. How do we get there?" Lloyd's Register/UMAS report (2017) info.lr.org/zev2030; www.u-mas.co.uk