Full chain cases for SBCC

Report D2.1.2

MS2.1.1 Full chain utilization cases defined.

MS2.1.4 Full chain storage cases defined.

Author: Kristian Aas, Ragnhild Skagestad, Anette Mathisen

Release Status: FINAL/

Dissemination level Public

Date: 24th June 2024

Filename and version: EverLoNG Project definition of full chain cases rev2

Document History

This document is stored in the following location:

Filename	D2.1.2 EverLoNG definition of full chain cases rev2
Location	

Revision History

This document has been through the following revisions:

Version No.	Revision Date	Filename	Brief Summary of Changes
V01	08.05.2024		For comment
V02	24.06.2024		Final

Authorisation

This document requires the following approvals:

AUTHORISATION	Name	Signature	Date
WP Leader	Ragnhild Skagestad	Ragnhild Skagestad	25/06/2024 DD/MM/YY
Project Coordinator	Marco Linders	Marco Linders Marco Linders (Jun 26, 2024 08:38 GMT+2)	26/06/2024 DD/MM/YY

Disclaimer

The information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of the Funders. Neither the Funders and bodies nor any person acting on their behalf may be held responsible for the use which may be made of the information contained therein.

Executive summary

This deliverable concentrates on the definition of full chain CCUS cases that will be evaluated in EverLoNG. Definition contains ship types, port location, sailing route, the Ship Based Carbon Capture (SBCC), onshore facilities for CO_2 handling and the transport of CO_2 to either storage or utilization.

The defined cases will be evaluated by life cycle analysis (LCA) and techno-economic assessments (TEA) in WP4.

In EverLoNG two ship types are considered for SBCC and will also be part of the full chain cases.

- The SSCV Sleipnir, the world's largest crane vessel (SSCV: Semi-Submersible Crane Vessel), operated by Heerema Marine Contractors
- A typical LNG tanker ship, operated by Total energies.

The specific ports selected are Port of Houston in Texas and Port of Rotterdam in The Netherlands. Both ports have closeness to infrastructure for CCS, which is identified in this project as the main selection criteria for enabling SBCC full chains. These Ports are also central for the regions.

The sailing route for the LNG tanker ship is defined by the route between Houston and Rotterdam. The sailing route for the SSCV Sleipnir is based on actual operation during an almost 2-year period.

Due to available capacity, the Northern Lights Project is chosen as a storage site in the full chain cases in EverLoNG. An Alternative to Northern Lights is the Aramis project that is planned during the coming years offshore the coast of Netherlands. Even if the Porthos project is located perfectly with respect to EverLoNG offloading of CO_2 in Rotterdam, it is not likely as storage site since it is already fully booked.

Production of methane or methanol, via catalytic processing of captured CO_2 and green hydrogen are chosen as the utilization cases in EverLoNG.

To summarize, four main cases have been suggested:

- Case 1: Sleipnir CO_2 storage pathway
- Case 2: Sleipnir CO_2 utilization pathway
- Case 3: LNG tanker CO_2 storage pathway
- Case 4: LNG tanker CO_2 utilization pathway

For all these cases, two different routes for storage or utilization have been identified. Storage is suggested in connection to the Northern Lights project and the Aramis project. For the cases with utilization pathways, production of methanol or methane has been proposed.

Table of Contents

Background

Ship-Based Carbon Capture (SBCC) is proposed as a low-cost alternative to decarbonize the maritime sector, as compared to zero-emission fuels (ammonia, hydrogen). The objective of the ''EverLoNG'' project is to accelerate the implementation of the SBCC technology by.

- Demonstrating SBCC on-board of LNG-fuelled ships.
- Optimizing SBCC integration to the existing ship infrastructure.
- Facilitating the development of SBCC-based full CCUS chains.
- Facilitating the regulatory framework for the technology.

This concentrates on the definition of full chain CCUS cases that will be evaluated in the project.

Definition contains ship types, port location, sailing route, the SBCC, onshore facilities for CO_2 handling and the transport of CO_2 to either storage or utilization.

The defined cases will be evaluated by life cycle analysis (LCA) and techno-economic assessments (TEA) in WP4. Port selection is included and will be aligned with task 2.2 "CO_2 shipping interoperability and port readiness". TotalEnergies and Heerema will advise on the ships' ports of call.

Figure 1, show the principle for the full chain in EverLoNG.

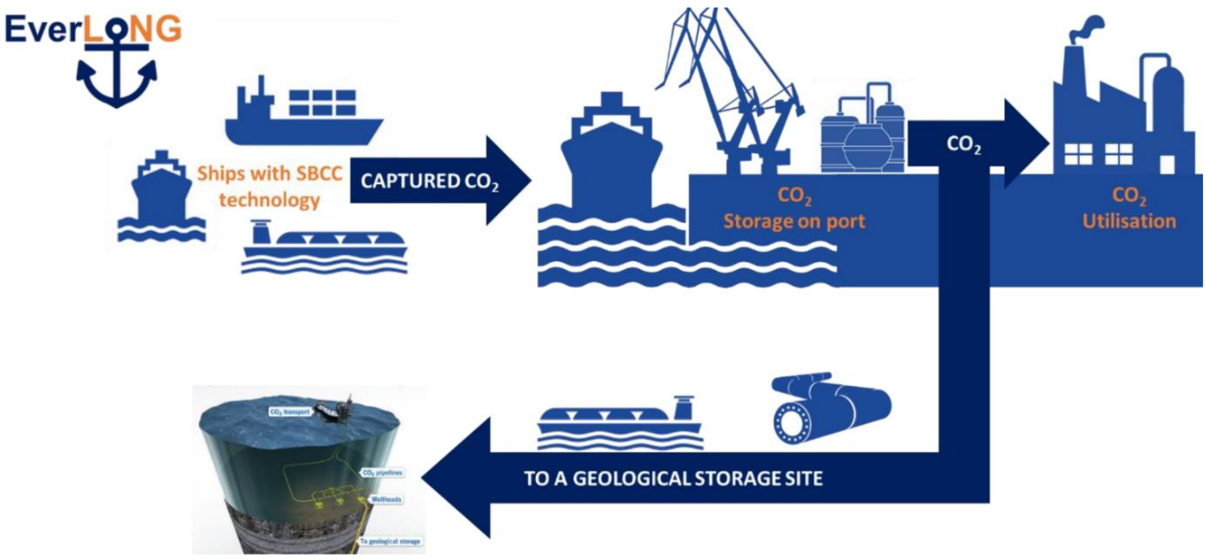


Figure 1: Principle for EverLoNG full chain [1].

Ships

In EverLoNG two ship types are considered for SBCC and will also be part of the full chain cases.

More specifically (see Figure 2):

- **The SSCV Sleipnir**, the world's largest crane vessel (SSCV: Semi-Submersible Crane Vessel), operated by Heerema Marine Contractors
- **A typical LNG tanker ship**, operated by Total energies.

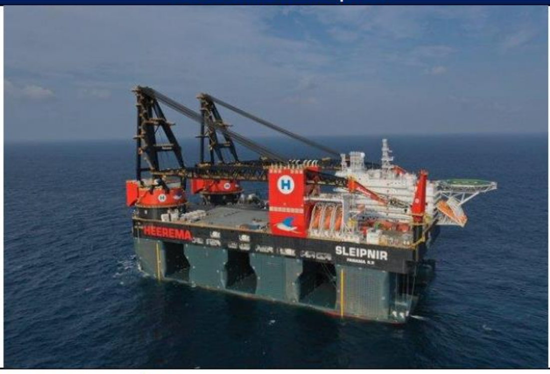
Heerema's Sleipnir	TOTAL's LNG carrier *
	
Type: crane ship Main Power: 96 MW total main power plant, consisting of 12 engines of 8 MW each, divided over four engine rooms (three engines per engine room). Fuel (dual): Low sulphur Marine Gas Oil (MGO) and Liquefied Natural gas (LNG)	Type: LNG tanker Total Main Power: 40MW (4 engines) Fuel (dual): Low sulphur Marine Gas Oil (MGO) and Liquefied Natural gas (LNG)

Figure 2: The two types of ships to be included in the full chain cases [1]

Sleipnir uses LNG from its bunker tanks as fuel. The LNG needs to be vaporized to be used as fuel. The LNG carrier tanker uses boil off gas from the LNG cargo tanks (no vaporization needed), but this limits the cooling capacity avaible on the ship.

The Sleipnir case is representative for many ship types fuelled by LNG, e.g. cruise ships, container ships etc. The Total case study concerns a hypothetical new-build LNG carrier. This LNG carrier tanker case represents the fleet of such tankers, that consist of many hundreds of ships. With existing ships (approx. 700) and ordered ships (approx. 370) the number of LNG carrier tankers will exceed 1000 in near future [2]. Total has supplied operational profile for a sister vessel spanning 2 years of operational data at a daily average frequency.

The Sleipnir cases do not have the same regular voyage pattern as an LNG tanker on a route between e.g. Houston and Rotterdam. The Sleipnir will have a variety of tasks around the world. In average Sleipnir is in a port 8-10 times per year for bunkering. The cases for Sleipnir will be based on real data from a period of almost two years. The Sleipnir and LNG carrier tanker are described in more detail under the case descriptions. The document "TEA and LCA case study framework document for EverLoNG" is giving more details about the technical assumptions and the methodology for the TEA and LCA work.

Ports

The selection of ports is a result of work in the WPs.

The LNG tanker cases are related to shipping of LNG from North America to Europe. The voyage back and forth is covered.

The specific Ports selected are **Port of Houston** in Texas, USA and **Port of Rotterdam** in the Netherlands. Both ports have closeness to infrastructure for CCS. These Ports are also central for the regions.

Port of Houston

By total tonnage the Port of Houston is ranked as number one in the USA, with total tonnage of 266 million short tons in 2021 [3]. A large fraction of the tonnage is related to import and export of petroleum products and natural gas. There is infrastructure for handling of containers as well as LNG [4]. The proximity to the "Denbury Green Pipeline", a pipeline for supply of CO_2 to Enhanced Oil Recovery (EOR), connecting the Houston area to oil fields in Louisiana and Mississippi is also of importance.

Figure 3: View of Houston ship Channel from Buffalo Bayou Toll Bridge, Port of Houston (Photo: SINTEF K. Aas)

Port of Rotterdam

The Port of Rotterdam is by far the largest port by total tonnage in Europe, with approx. 425 million tonnes of goods handled (2022). Close to 50% is liquid bulk goods [5]. Infrastructure for LNG is in place. "Gate terminal" is the LNG import terminal of Rotterdam with a storage capacity of 180 000 m^3 [6], and is located conveniently at the entrance or "gate" to the vast port area. Port of Rotterdam is also in the centre of the "Porthos project", a CO_2 storage project just offshore of Rotterdam [7]. Rotterdam is also relatively close to other possible storage sites within the North Sea including the Norwegian Northern Lights storage project and the planned Aramis project offshore the Netherlands. Among the CCU opportunities is the production of green methanol. Port of Rotterdam is the largest methanol hub in north-western Europe and the top bunkering port in Europe for methanol for ships.

On- shore Equipment

Port facilities is part of the full chain cases. It is assumed that the CO_2 will be captured, processed, and liquefied on the vessel and offloaded from the ship to the onshore facility, for intermediate storage and further processing. The deliverable D.2.1.1 “CO_2 offloading alternatives and guidelines” is describing the main facilities needed.

A drawing of the port's facilities that is needed for CO_2 and solvent handling is presented in Figure 4

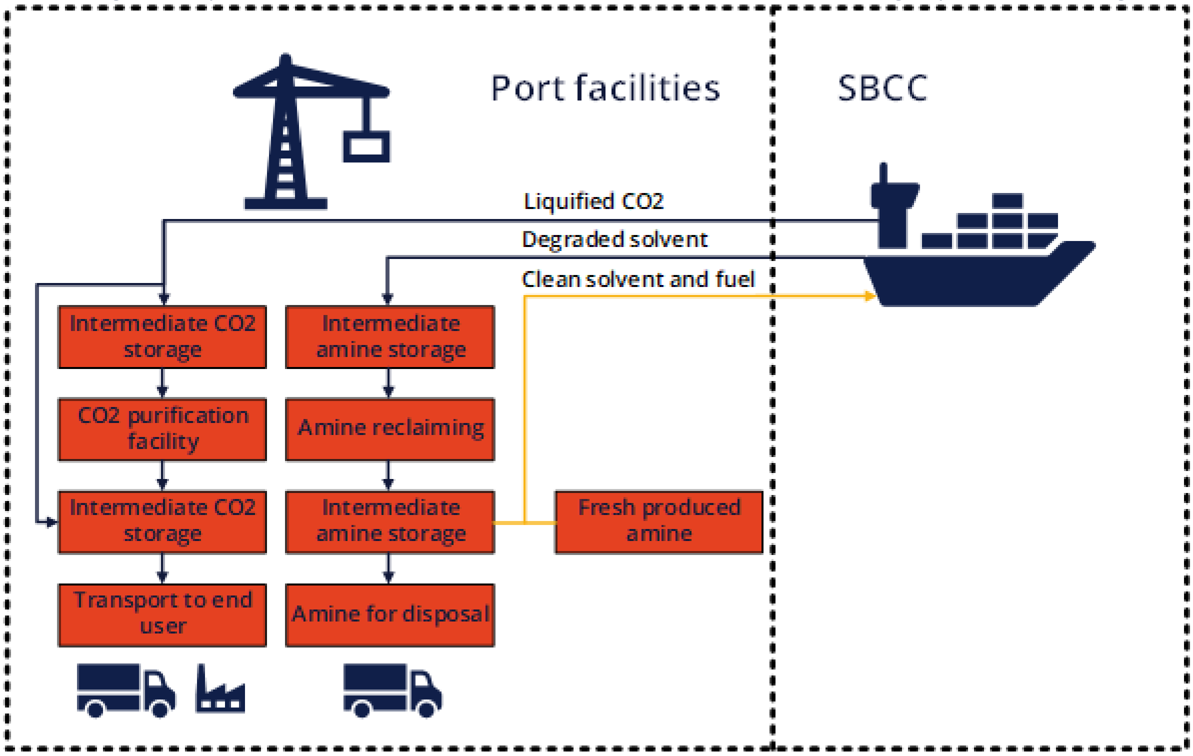


Figure 4: Proposed port infrastructure.

Storage site

Several storage permanent storage sites have been developed or are under development in the North Sea basin. Early movers are the Northern Lights project and the Porthos project. The Aramis project is also under development. Due to available capacity, the Northern Lights Project and Aramis project are chosen as the storage sites in the full chain cases in EverLoNG.

- The Northern lights project (Norway) [8] is establishing a CO_2 transport and storage infrastructure at the west coast of Norway. First of a kind – open for third parties. Funding is 80% from the Norwegian Government. In the first phase the storage capacity will be 1.5 million tonnes CO_2 per year. The infrastructure will open in 2024 and offer storage to emitters in Norway and elsewhere in Europe. The second phase planned started in 2025 increases the storage capacity to 5 million tonnes per year. Total storage capacity is expected to be minimum 100 million tonnes.[9]

  Recently (February 2024) the CO_2 specifications for storage at Northern lights has been adjusted. The changes are due to increased understanding of risks due to impurities [10]. The new specification can be found at Northern light web site (https://norlights.com/wp-content/uploads/2024/02/Northern-Lights-GS-co2-Spec2024.pdf). Main changes are much smaller tolerance for mercury (Hg) content and for nitrogen oxides (NOx). Further, a list of more than 10 elements, with limits, are added to the specification.

- Porthos is a similar project in The Netherlands. Porthos stands for Port of Rotterdam CO_2 Transport Hub and Offshore Storage. It will provide storage capacity in an empty gas field just 20 km offshore of Rotterdam for the Industries located in the Rotterdam Port area. Capacity is expected to be 2,5 million tonnes per year over a 15-year period. The systems are planned to be operational in 2026. Even if the Porthos project is located perfectly with respect EverLoNG offloading of CO_2 in Rotterdam it is not likely as storage site since it is already fully booked [11].

- Aramis CCS [20] is another project aiming to support large scale CO_2 transport and storage service. This project can be an alternative to Northern lights when established after 2030. The project is a collaboration between TotalEnergies, Shell, EBN and Gasunie. The location is Rotterdam due to the proximity to industries and transport corridors. The plan is to establish a storage in offshore depleted gas fields with a capacity of 22Mt CO_2 per year. According to planned timeline, startup will be in 2028 or 2029, followed by an expansion phase after 2030. The total storage capacity is expected to be 400 Mt CO_2.

- Enhanced Oil Recovery (EOR) in the Gulf Coast Region in USA (Texas, Louisiana, Mississippi and Alabama). EOR has been used for many decades to increase the amount of oil that can be produced (recovered) over the lifespan of an oilfield [21]. The CO_2 is pumped into the reservoir to increase the pressure and hence enable prolonged production from the field. The long-term climate effect is debated. CO_2 is stored in the ground due to the injection, and if this CO_2 is captured from an industrial source or a ship it will contribute positively with respect to climate emissions. At the same time more fossil fuel is produced leading to CO_2 emissions when combusted.

Utilization

The full chain utilization cases (case 2 a, b and 4 a, b) differ from the storage cases (case 1 a, b and 3 a, b) only by different routing of the CO_2 when offloaded in the European port selected, Rotterdam. Instead of being shipped to permanent storage through the Northern Lights project or Aramis project the captured CO_2 is transported to a plant where the CO_2 can be reused in a product that is offered to the market. Such recycling needs to be a climate viable alternative to the fossil-based product as well as having an economically potential. CCU might lower the net cost of CO_2 reduction to the atmosphere by offering a product to the market.

Several routes for utilizing of captured CO_2 can be outlined [12]. However, there are challenges associated with bringing CO_2 into the feedstock due to, high energy demand and price on renewable energy, lack of established market, technology challenges and lack of regulatory framework.

Synthetic fuels are among the products where CCU finds a potential. If fuels that are currently in use could be produced in a circular way by utilizing captured CO_2 and renewable energy sources, it will be a step towards carbon neutrality. Methane and Methanol are products that can be produced from CO_2 and hydrogen. The hydrogen needs to be "green hydrogen", that is produced with water electrolysis powered by renewable electricity. Methane and Methanol can both be used as fuel and as feedstock for products. Existing infrastructure for natural gas and methanol distribution can be utilized. Methane and methanol are versatile chemicals with numerous industrial applications. Methane can be used for heating, electricity generation, transportation, and as a feedstock for various chemical processes. Methanol is used in the production of plastics, paints, adhesives, and fuels. This versatility enhances the market potential of e-methane and e-methanol.

Methanol is among the most common industrial chemicals in the world with yearly production exceeding 100 million tonnes after year 2020 [15]. Methanol is used both as a material (70%) and an energy source/fuel (30%)[16] .

Methanol is among the products several sources mention as a viable for CCU. Several sources suggest MeOH targeted for the regulated transport market as the best pathway for short term opportunities for increasing the CO_2 demand in the CCU market. E-methanol produced by renewable energy has a higher cost of 18-25 €/GJ compared to a cost of 10-15 €/GJ for MeOH based on fossil fuel production[13].

The global marine fuel demand was estimated to be in the order of 500 000 000 ton/year [14] in 2020. Converting the CO_2 captured from the ships into E-methanol in a plant close to a port may form an interesting lifecycle opportunity as the shipping and logistics company Maersk among others investigates the opportunity for E-methanol production for ship fuel.

Current methanol production methods

There are several processes and raw materials available for the production methanol. Most commonly is steam reforming of natural gas to create synthesis gas. The synthesis gas is fed into a reactor with a catalyst, resulting in production of methanol and water [17]. Feedstocks may also come from biomass or coal. In a life cycle perspective, the carbon footprint of methanol varies very much with feedstock and production pathway. The resulting carbon footprint can result in negative carbon emissions (-50 to -100 g CO_2eq/MJ) for feedstocks from biomethane (anaerobe digestion of cow and pig manure). Fossil feedstocks result currently in emissions in the range of approx. 100 g CO_2eq/MJ (from natural gas) to as high as 300 g CO_2eq/MJ (from coal)[18][19].

E-methanol is based on green hydrogen (hydrogen from water electrolysis with renewable electricity) and captured CO_2, can have a low carbon footprint ,provided the electricity comes from renewable sources (PV, wind, hydro)[18][19].

The defined full chain cases

The cases from ship type and operation to CO_2 storage or utilization are summarized graphically in Figure 5 to Figure 12.

- Case 1: Sleipnir CO_2 storage pathway
- Case 2: Sleipnir CO_2 utilization pathway
- Case 3: LNG tanker CO_2 storage pathway
- Case 4: LNG tanker CO_2 utilization pathway

Sleipnir cases

The Sleipnir cases, storage or utilization are equal during the vessel's operation at sea and SBCC is ongoing. The difference between cases, Case 1 and Case 2 is that the captured CO_2 is routed differently when offloaded on Port and transported to its destination either for permanent storage or for CCU The CO_2 volume captured for each trip (6 weeks) is expected to be approx. 4500 tCO_2.

LNG tanker cases

It is assumed that this LNG tanker ship will transport LNG from port of Houston to the port of Rotterdam, and the journey takes 11 days one way. CO_2 is captured during the transport and offloaded when in port. The difference between cases, Case 3 and Case 4, is that the captured CO_2 is routed differently when offloaded in port in Europe, either for permanent storage or for CCU. The CO_2 volume captured for each trip from US to Europe is expected to be approx. 2500 tCO_2 and 2400 tCO_2 on the return journey.

Case 1: Sleipnir CO_2 Storage Pathways.

Case 1a. Sleipnir SBCC Operation to CO_2 Storage Pathway, Northern Lights.

The ship will be offshore for 6 weeks, before it will enter the Port of Rotterdam. Then the CO_2 will be offloaded by flexible hoses and stored in intermediate tanks at the port. The CO_2 will be loaded into CO_2 ships that will transport the CO_2 to the Northern Lights terminal at Øygarden before the CO_2 is transported in pipelines to the final storage place in the North Sea.

- Sleipnir operation 6 weeks – with SBCC – average approx. 4500 tCO_2/voyage captured.
- Unloading of the CO_2 in Rotterdam.
- Treatment (if any) and intermediate storage in Rotterdam.
- Export and transport by ship to, Øygarden, Norway.
- Pipeline transportation.
- CO_2 storage in the formations in the North Sea (**Northern Lights project**)

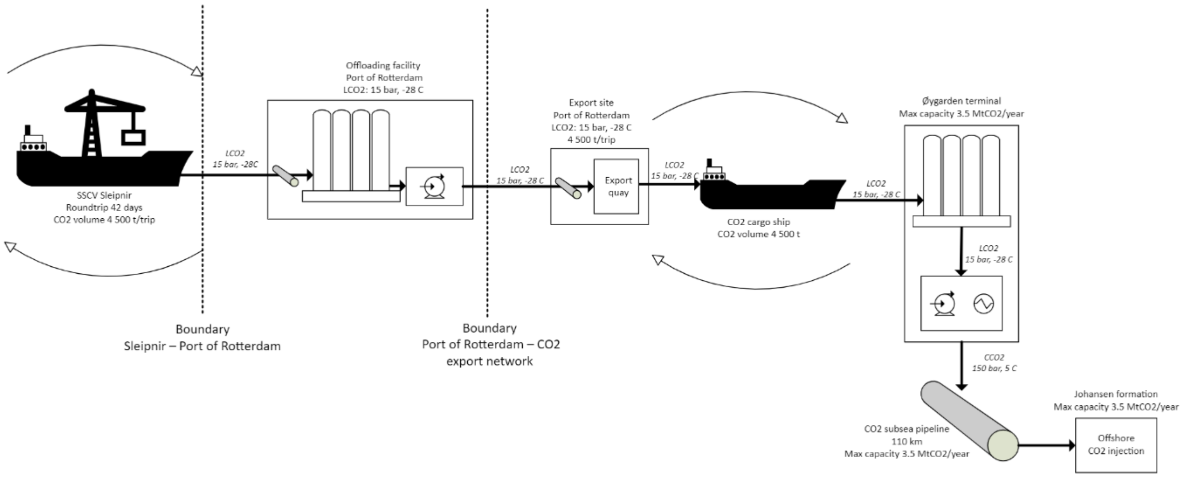


Figure 5 : Case 1a. Sleipnir SBCC Operation to CO_2 Storage Pathway, Northern Lights.

Case 1b. Sleipnir SBCC Operation to CO_2 Storage Pathway, Aramis.

The ship will be offshore for 6 weeks, before it will enter the Port of Rotterdam. Then the CO_2 will be offloaded by flexible hoses and stored in intermediate tanks at the port. Thereafter it will be transferred to the Aramis collection hub, before the CO_2 is transported in pipelines to the final storage place in the North Sea.

- Sleipnir operation 6 weeks – with SBCC – average approx. 4500 tCO_2/voyage captured.
- Unloading of the CO_2 in Rotterdam.
- Export to **Aramis** collection hub.
- Transport by subsea pipeline offshore.
- CO_2 storage in the formations in the North Sea (**Aramis**)

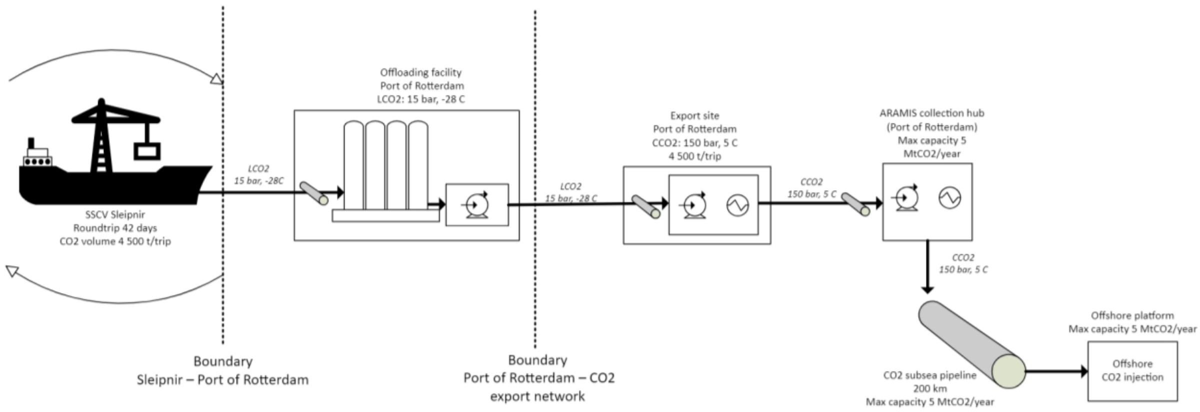


Figure 6: Case 1b. Sleipnir SBCC Operation to CO_2 Storage Pathway, Aramis.

Case 2a. Sleipnir SBCC Operation to CO_2 Utilization Pathway, Methanol.

The ship will be offshore for 6 weeks, before it will enter the Port of Rotterdam. Then the CO_2 will be offloaded by flexible hoses and stored in intermediate tanks at the port. The CO_2 will be transported by pipeline, train or truck to a **methanol** plant located in Port of Rotterdam area

- Sleipnir operation 6 weeks – with SBCC – average approx. 4500 tCO_2/voyage captured.
- Unloading of the CO_2 in Rotterdam.
- Treatment (if any) and intermediate storage in Rotterdam.
- Transport by pipeline or truck to a **methanol** plant located in Port of Rotterdam area.

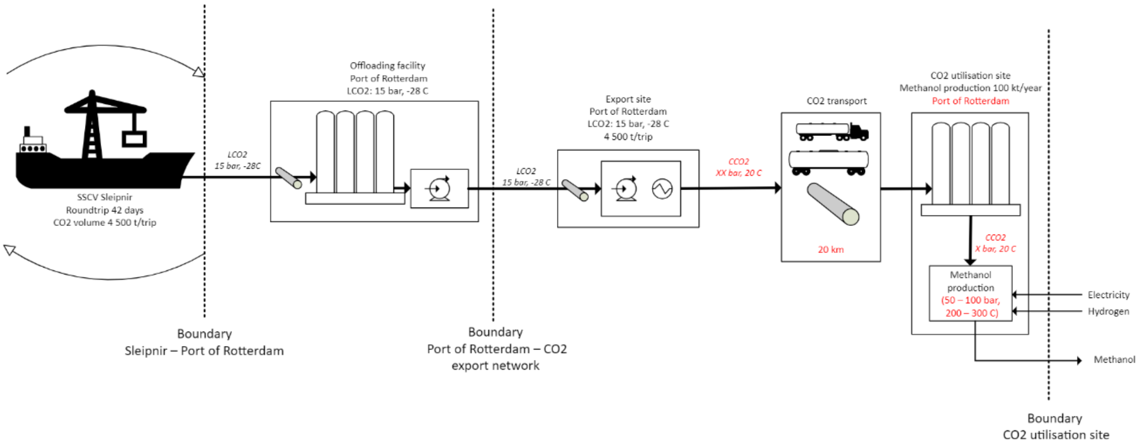


Figure 7: Case 2a. Sleipnir SBCC Operation to CO_2 Utilization Pathway, Methanol.

Case 2b. Sleipnir SBCC Operation to CO_2 Utilization Pathway, Methane.

The ship will be offshore for 6 weeks, before it will enter the Port of Rotterdam. Then the CO_2 will be offloaded by flexible hoses and stored in intermediate tanks at the port. The CO_2 will be transported by pipeline, train or truck to a **methane** plant located in Port of Rotterdam area.

- Sleipnir operation 6 weeks – with SBCC – average approx. 4500 tCO_2/voyage captured.
- Unloading of the CO_2 in Rotterdam
- Treatment (if any) and intermediate storage in Rotterdam
- Transport by pipeline or truck to a **methane** plant located in Port of Rotterdam area.

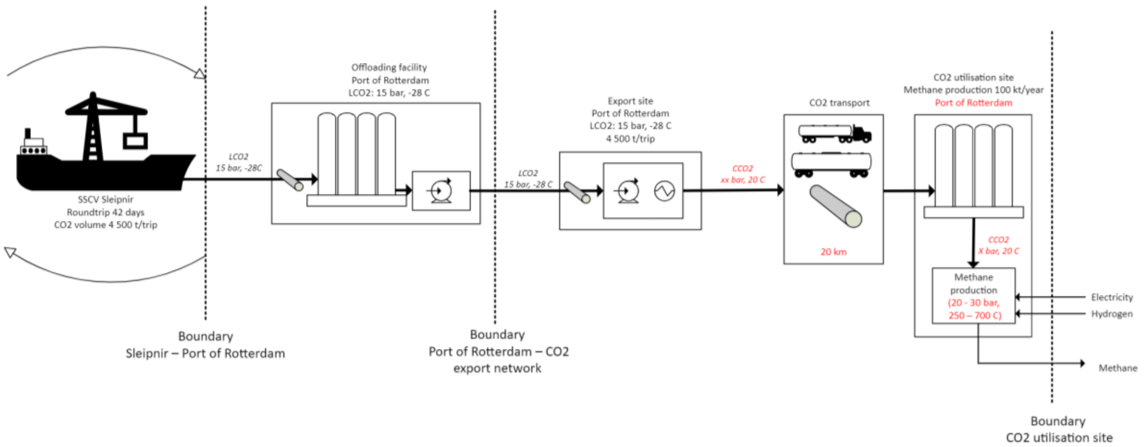


Figure 8: Case 2b. Sleipnir SBCC Operation to CO_2 Utilization Pathway, Methane.

Case 3: LNG tanker CO_2 Storage Pathways.

Case 3a. LNG Tanker SBCC Operation to CO_2 Storage Pathway, Northern Lights.

The CO_2 captured on the ship during transport to the port of Rotterdam will be offloaded there by flexible hoses. The CO_2 is stored intermediate in tanks at the port before the CO_2 is transported by ship to Øygarden for further pipeline transport to the reservoir in the North Sea.

After the return trip CO_2 is offloaded by flexible hoses at Port of Houston and stored in intermediate storage tanks before it is compressed and transported by pipeline to an EOR reservoir.

- LNG transport from Houston 11 days – with SBCC – average approx. 2500 tCO_2/voyage captured.
- Unloading of the CO_2 in Rotterdam
- Treatment (if any) and intermediate storage in Rotterdam
- Transport by ship to, Øygarden, Norway
- Pipeline transportation.
- CO_2 storage in the formations in the North Sea (Northern Lights project)

- LNG ship return to Houston (empty) 11 days -with SBCC average approx. 2400 tCO_2/voyage captured.
- Unloading of the CO_2 in Houston
- Intermediate storage
- Transport by pipeline to EOR reservoir

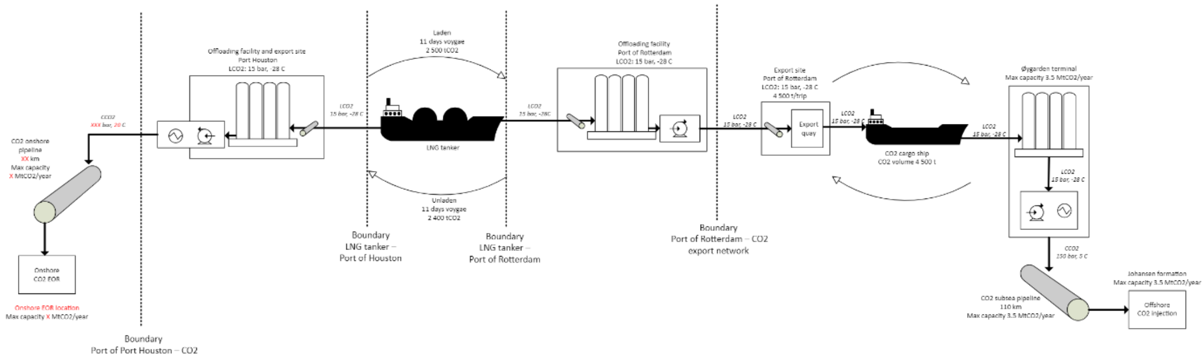


Figure 9: Case 3a. LNG Tanker SBCC Operation to CO_2 Storage Pathway, Northern Lights.

Case 3b. LNG Tanker SBCC Operation to CO_2 Storage Pathway, Aramis.

The CO_2 captured on the ship during transport to the port of Rotterdam will be offloaded there by flexible hoses. The CO_2 is stored intermediate in tanks at the port before the CO_2 is transported by to Aramis collection hub, for further pipeline transport to the reservoir in the North Sea.

After the return trip CO_2 is offloaded by flexible hoses at Port of Houston and stored in intermediate storage tanks before it is compressed and transported by pipeline to an EOR reservoir.

- LNG transport from Houston 11 days – with SBCC – average approx. 2500 tCO_2/voyage captured.
- Unloading of the CO_2 in Rotterdam
- Treatment (if any) and intermediate storage in Rotterdam
- Transfer to **Aramis** Collection HUB
- Pipeline transportation.
- CO_2 storage in the formations in the North Sea (**Aramis)**

- LNG ship return to Houston (empty) 11 days -with SBCC average approx. 2400 tCO_2/voyage captured.
- Unloading of the CO_2 in Houston
- Intermediate storage
- Transport by pipeline to EOR reservoir

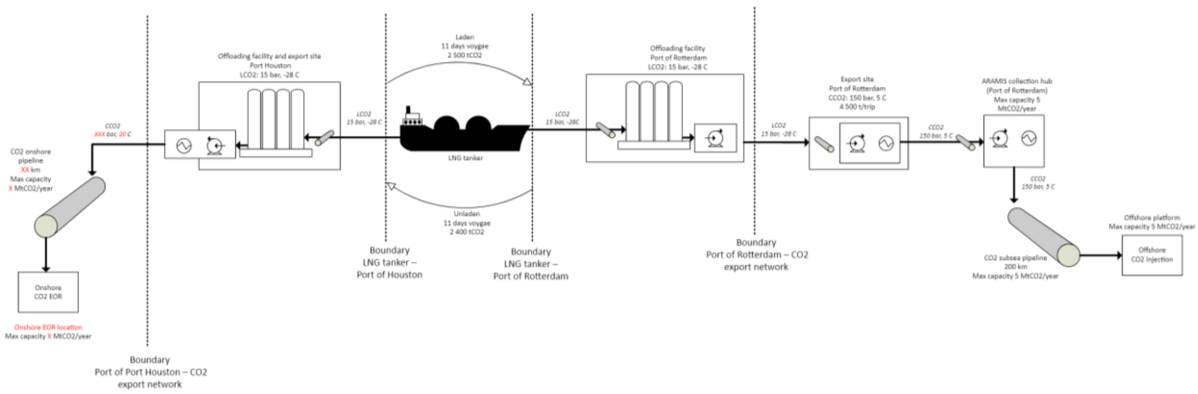


Figure 10: Case 3b. LNG Tanker SBCC Operation to CO_2 Storage Pathway, Aramis.

Case 4: LNG tanker CO_2 Utilization Pathways.

Case 4a. LNG Tanker SBCC Operation to CO_2 Utilization Pathway, Methanol.

The CO_2 captured on the ship during transport to the port of Rotterdam will be offloaded there by flexible hoses. The CO_2 is stored intermediate in tanks at the port before pipeline, train or truck transport to a **methanol** plant located in Port of Rotterdam area.

After the return trip the CO_2 is offloaded by flexible hoses at Port of Houston and stored in intermediate storage tanks before it is compressed and transported by pipeline to an EOR reservoir.

- LNG transport from Houston 11 days – with SBCC – average approx. 2500 tCO_2/voyage captured.
- Unloading of the CO_2 in Rotterdam
- Treatment (if any) and intermediate storage in Rotterdam
- Transport by pipeline or truck to a **methanol** plant located in Port of Rotterdam area.

- LNG ship return to Houston (empty) 11 days -with SBCC average approx. 2400 tCO_2/voyage captured.
- Unloading of the CO_2 in Houston
- Intermediate storage
- Transport by pipeline to EOR reservoir

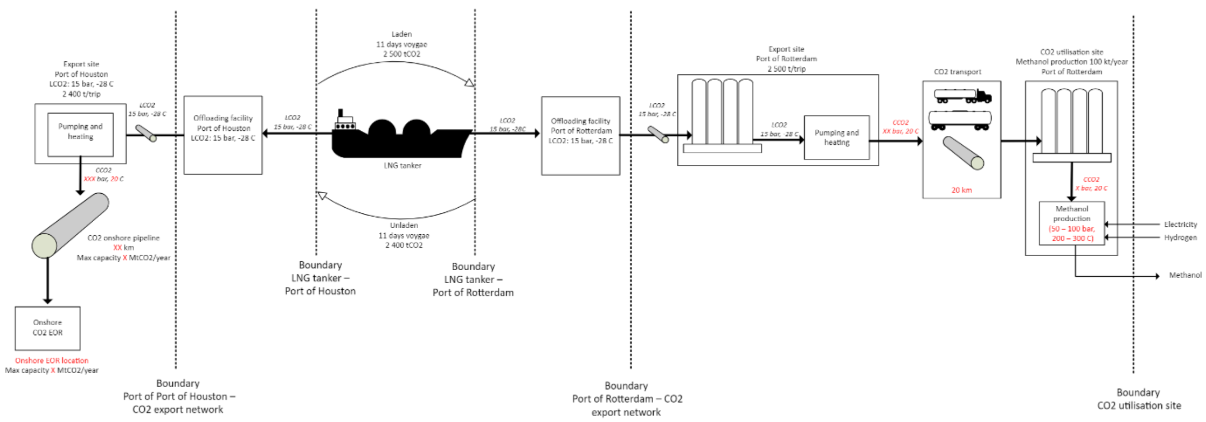


Figure 11: Case 4a. LNG Tanker SBCC Operation to CO_2 Utilization Pathway, Methanol.

Case 4b. LNG Tanker SBCC Operation to CO_2 Utilization Pathway, Methane.

The CO_2 captured on the ship during transport to the port of Rotterdam will be offloaded there by flexible hoses. The CO_2 is stored intermediate in tanks at the port before transport by pipeline, train or truck to a **methane** plant located in Port of Rotterdam area.

After the return trip the CO_2 is offloaded by flexible hoses at Port of Houston and stored in intermediate storage tanks before it is compressed and transported by pipeline to an EOR reservoir.

- LNG transport from Houston 11 days – with SBCC – average approx. 2500 tCO_2/voyage captured.
- Unloading of the CO_2 in Rotterdam
- Treatment (if any) and intermediate storage in Rotterdam
- Transport by pipeline or truck to a **methane** plant located in Port of Rotterdam area.

- LNG ship return to Houston (empty) 11 days -with SBCC average approx. 2400 tCO_2/voyage captured.
- Unloading of the CO_2 in Houston
- Intermediate storage
- Transport by pipeline to EOR reservoir

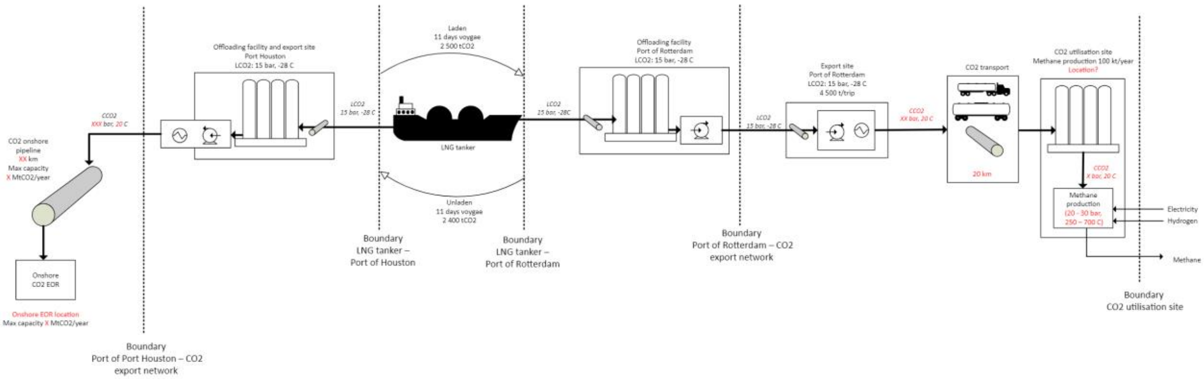


Figure 12: Case 4b. LNG Tanker SBCC Operation to CO_2 Utilization Pathway, Methane.

Conclusion

Full chain cases are defined and described above.

- Case 1a and 1b: Sleipnir CO_2 storage pathways
- Case 2a and 2b: Sleipnir CO_2 utilization pathways
- Case 3a and 3b: LNG tanker CO_2 storage pathways
- Case 4a and 4b: LNG tanker CO_2 utilization pathways

The defined cases will be evaluated by life cycle analysis (LCA) and techno-economic assessments (TEA) in WP4

References

[1] Application: ACT3 Demonstration of ship-based carbon capture on LNG fuelled ships (EverLoNG)
[2] Riviera Maritime Media, LNG fleet hitting the big numbers in 2023, 29 Dec 2023 by Craig Jallal, https://www.rivieramm.com/news-content-hub/news-content-hub/editors-choice-2023--lng-fleet-hitting-the-big-numbers-in-2023-78711
[3] U.S department of Transportation, Bureau of Transportation Statistics, Tonnage of Top 50 U.S. Water Ports, Ranked by Total Tons https://www.bts.gov/content/tonnage-top-50-us-water-ports-ranked-total-tons
[4] https://www.searates.com/blog/post/a-comprehensive-guide-to-shipping-to-houston-everything-you-need-to-know
[5] Eurostat Statistics explained. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Seaborne_transport_of_freight_between_main_ports_in_the_reporting_country_and_their_partner_ports_grouped_by_main_geographical_areas,_2022.png
[6] https://www.portofrotterdam.com/en/logistics/cargo/lng/lng-terminal (08.03.2024)
[7] https://www.portofrotterdam.com/en/news-and-press-releases/first-co2-storage-project-in-the-netherlands-is-launched
[8] https://norlights.com/
[9] https://ccushub.ogci.com/focus_hubs/northern-lights/
[10] https://norlights.com/wp-content/uploads/2024/02/Northern-Lights-GS-co2-Spec2024.pdf
[11] https://www.porthosco2.nl/en/customers/
[12] D. Roberts, "These uses of CO2 could cut emissions — and make trillions of dollars," 2019. [Online]. Available: https://www.vox.com/energy-and-environment/2019/11/13/20839531/climate-change-industry-co2-carbon-capture-utilization-storage-ccu.
[13] R. Gresser, October 2019. [Online]. Available: https://www.slideshare.net/RobertGresser/carbon-capture-and-utilization-outlook.
[14] "Hellenic Shipping News," November 2021. [Online]. Available: https://www.hellenicshippingnews.com/e-methanol-missing-piece-to-shippings-decarbonization-puzzle/.
[15] https://www.statista.com/statistics/1323406/methanol-production-worldwide/
[16] https://bse-methanol.com/en/about-methanol/
[17] https://afdc.energy.gov/fuels/emerging_methanol.html
[18] Methanol Institute, "Carbon footprint of methanol" White paper.
[19] C. Hepburn et.al. "The technological and economic prospects for CO_2 utilization and removal," Nature, Vol 575, 7th Nov. 2019. (https://www.nature.com/articles/s41586-019-1681-6)
[20] https://www.aramis-ccs.com/project/
[21] https://www.vox.com/energy-and-environment/2019/10/2/20838646/climate-change-carbon-capture-enhanced-oil-recovery-eor

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 Energy, 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.