Demonstration of ship-based carbon capture on LNG fuelled ships

Webinar, 13th March 2025

Marco Linders, TNO, Project Coordinator (marco.linders@tno.nl)

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.

Agenda

Introduction to EverLoNG - Marco Linders, EverLoNG Project Lead (TNO)

WP1 : Demonstrating onboard carbon capture - Juliana Monteiro. Jasper Ros (TNO)

WP2 : Onboard carbon capture in the full CCUS chain - Anette Mathisen (SINTEF)

WP3 : Impact of OCC on ship infrastructure - Joan van den Akker (Conoship)

WP4 : Environmental impact & techno-economic aspects - Lavinia Reitz (Forschungszentrum Jülich GmbH)

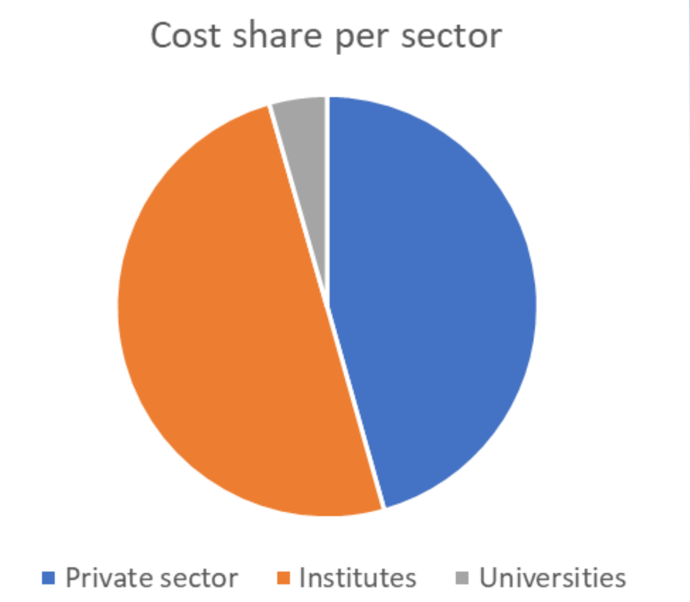
WP5 : Regulatory frameworks - Erik Vroegrijk (Lloyds Register)

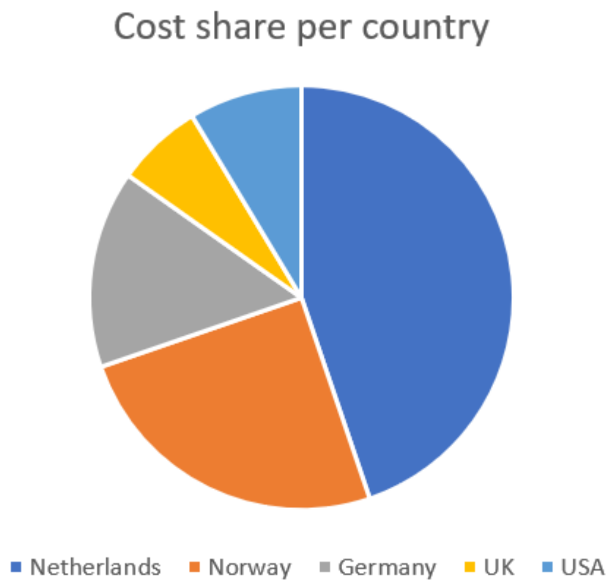
What next for EverLoNG, OCC and concluding remarks - Marco Linders, EverLoNG Project Lead (TNO)

Q&A

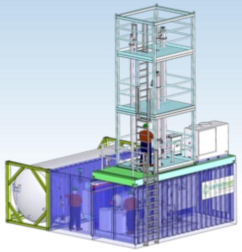
The EverLoNG project

- Accelerating CCS Technologies (ACT) project
- 16 partners from NL, NO, GE, UK, USA
- Total budget: € 4.903.098
- Total funding: € 3.484.653
- Industrial contribution >45%





Objectives



Objective of EverLoNG is to accelerate the implementation of Onboard Carbon Capture (OCC) by:

(i) demonstrating OCC on-board of two LNG-fuelled ships (WP1)

(ii) facilitating the development of OCC-based full CCUS chains (WP2)

(iii) optimising OCC integration to the existing ship infrastructure (WP3)

(iv) perform life cycle assessment and techno-economic evaluation: to show the impact of this technology, both from an economic viewpoint as from an environmental viewpoint (WP4)

(v) facilitating the regulatory framework for the technology (WP5)

These aspects will now be addressed in more detail

WP1 OCC Demonstration campaigns

WP1, Augsburg, 13/03/2025

Juliana Monteiro, TNO

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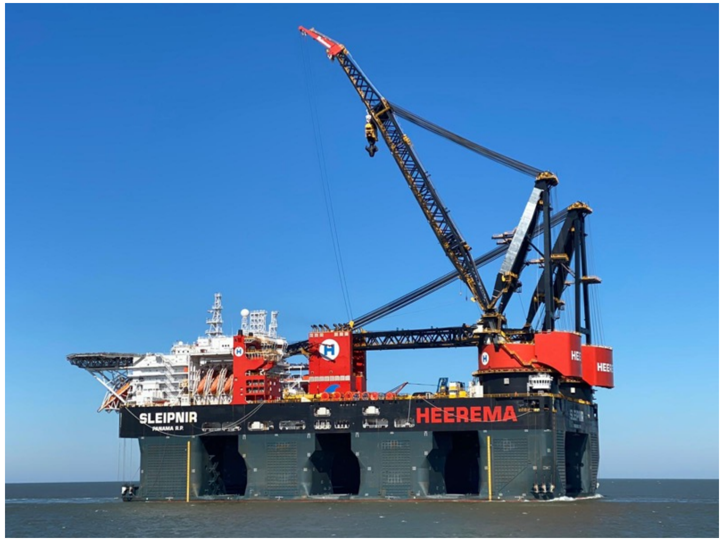
WP1 Objective

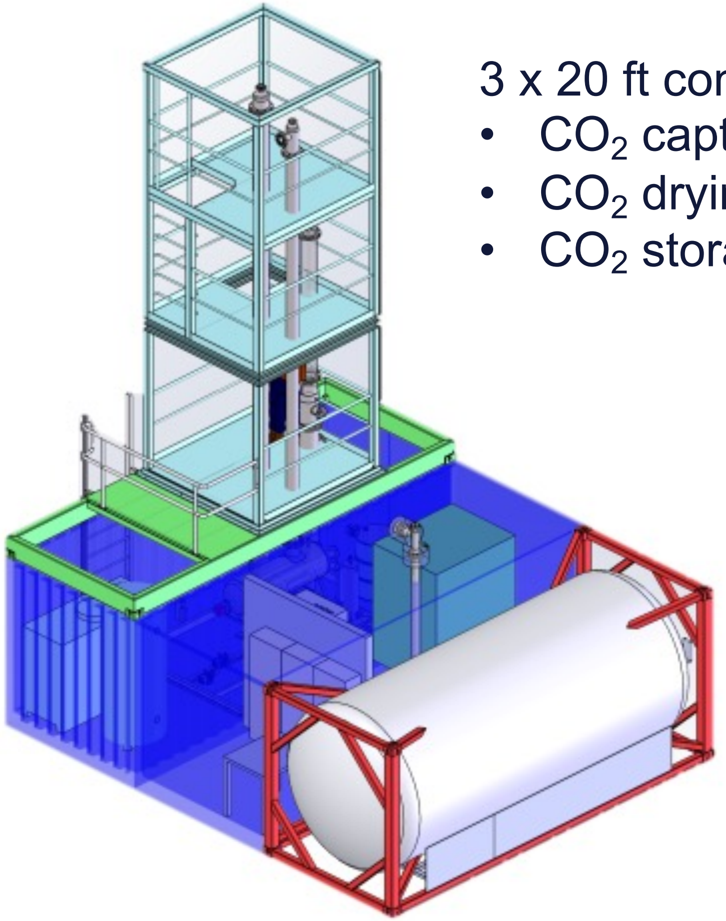
To demonstrate the onboard CO_2 capture (OCC) technology onboard 2 LNG-fuelled ships, bringing OCC to technology readiness level (TRL) 7

Seapeak Arwa (LNG carrier)



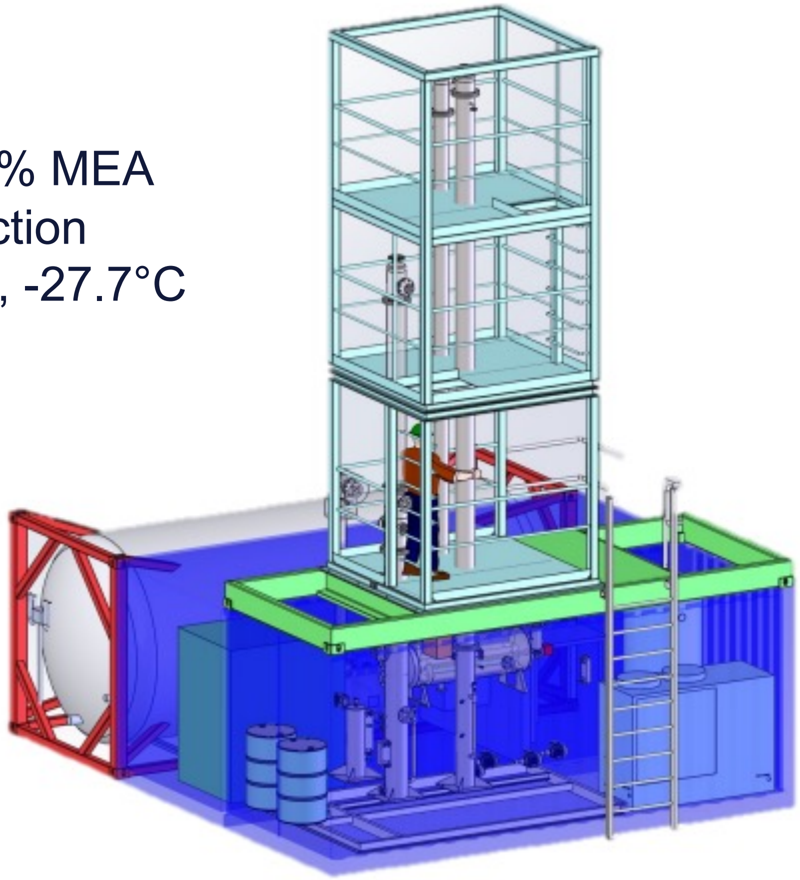
Heerema's Sleipnir (crane vessel)

WP1 OCC prototype

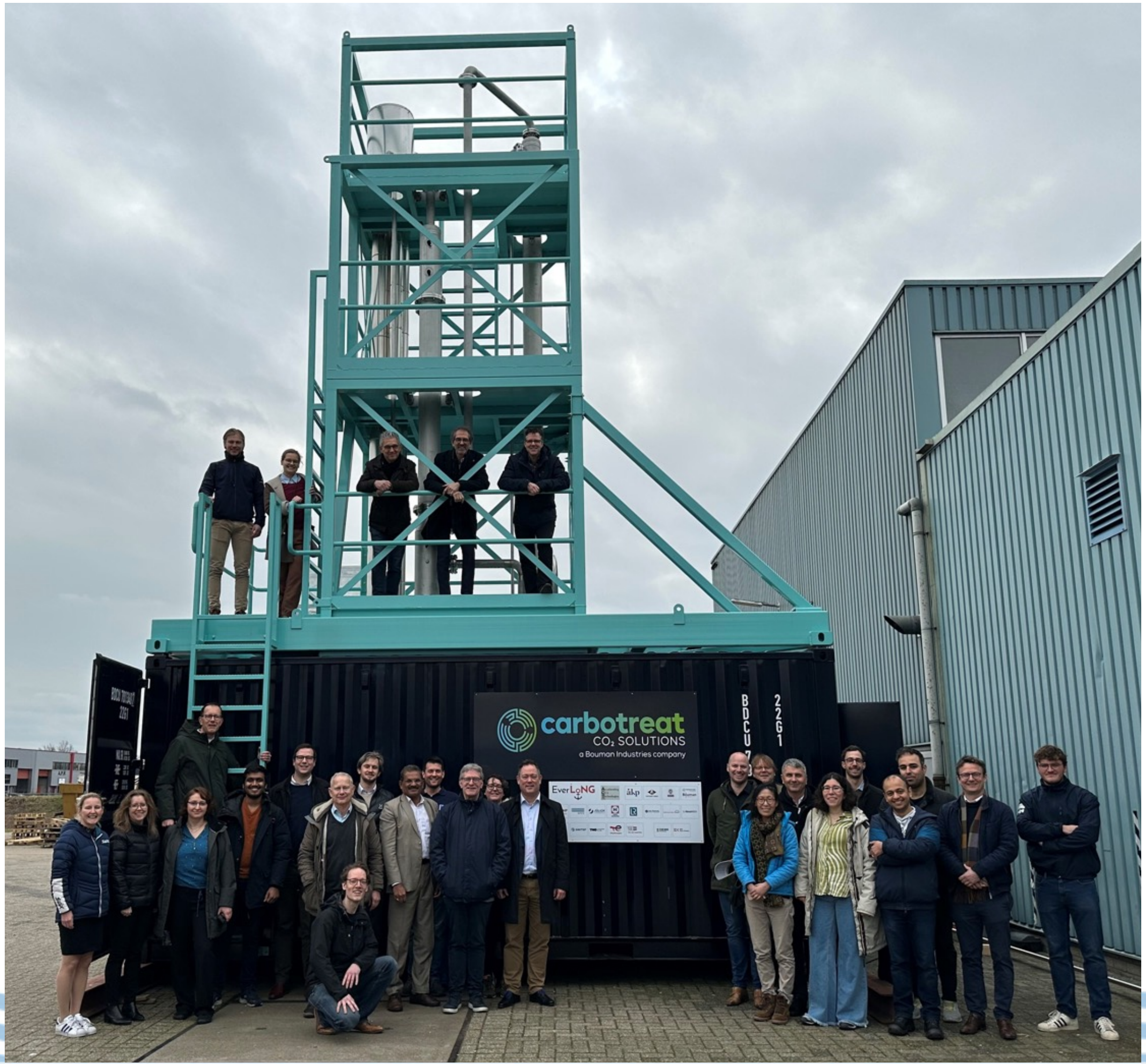


3 x 20 ft containers

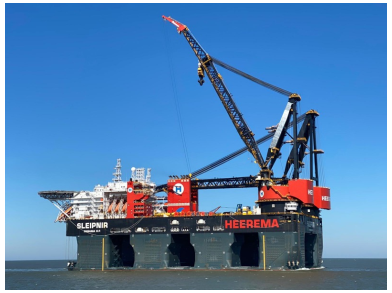
- CO_2 capture with 30 wt% MEA
- CO_2 drying and liquefaction
- CO_2 storage at 15 bara, -27.7°C



WP1 OCC prototype



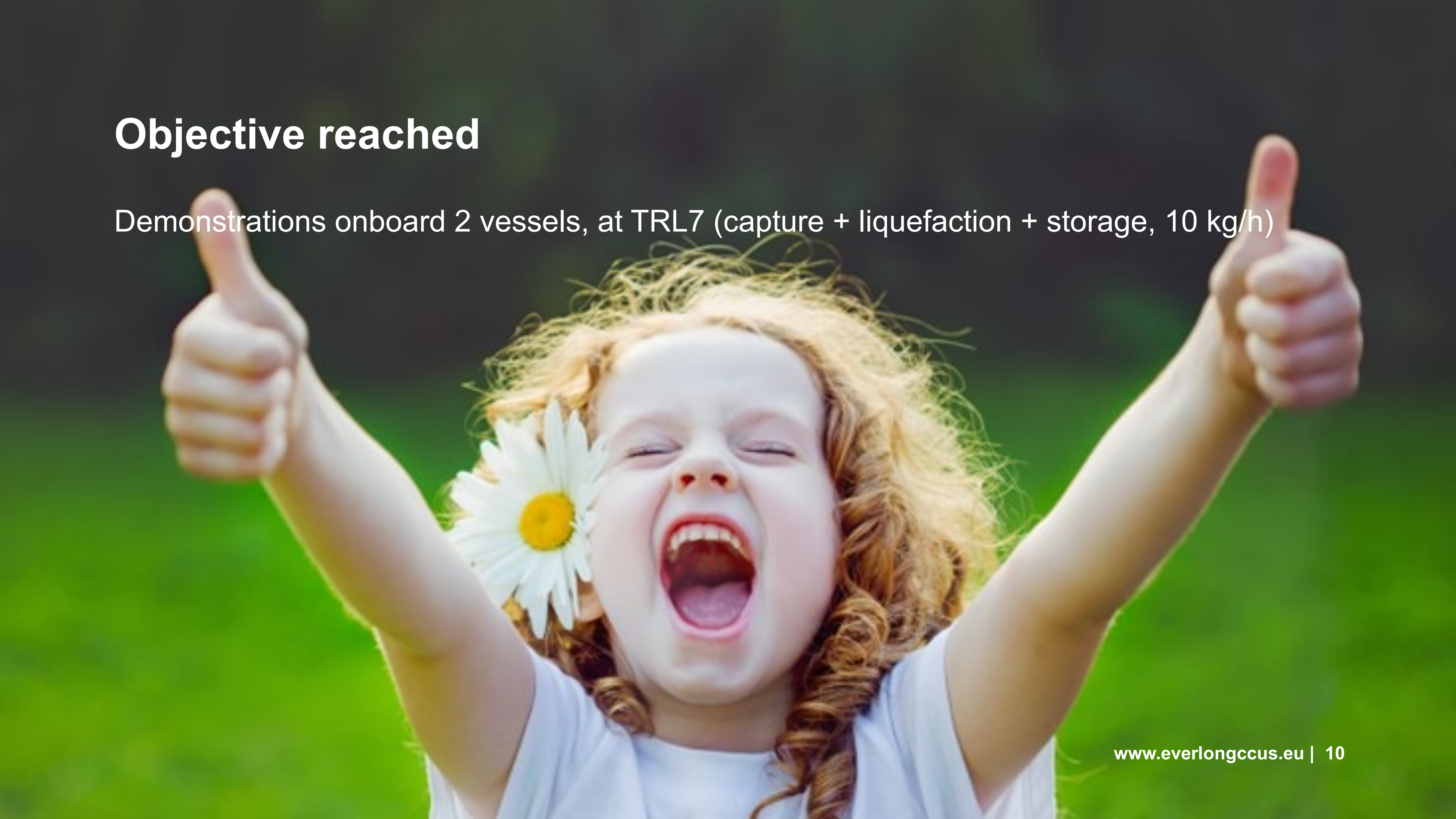
WP1 summary of demonstrations



	LNG carrier	Crane vessel
Engine	Wartsila 12V50DF (4-stroke)	MAN 8L51/60DF (4-stroke)
Operational hours	1539	418
Operation	Capture only	Capture + liquefaction
Fuel	LNG + pilot	LNG + pilot

Objective reached

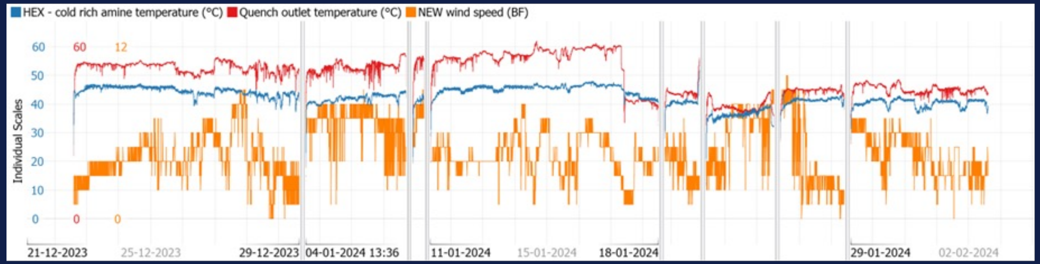
Demonstrations onboard 2 vessels, at TRL7 (capture + liquefaction + storage, 10 kg/h)

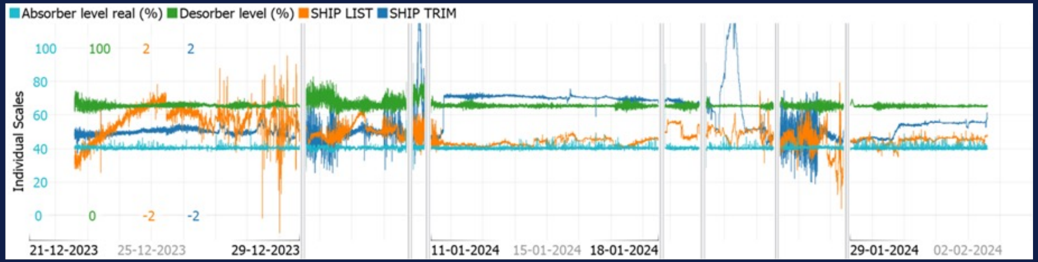


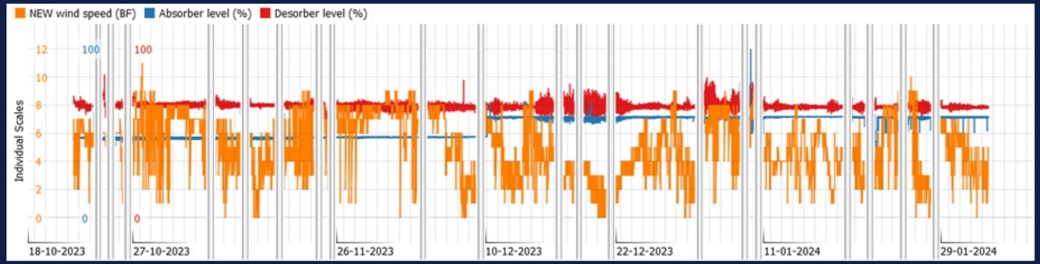
WP1 Lessons learned (1)

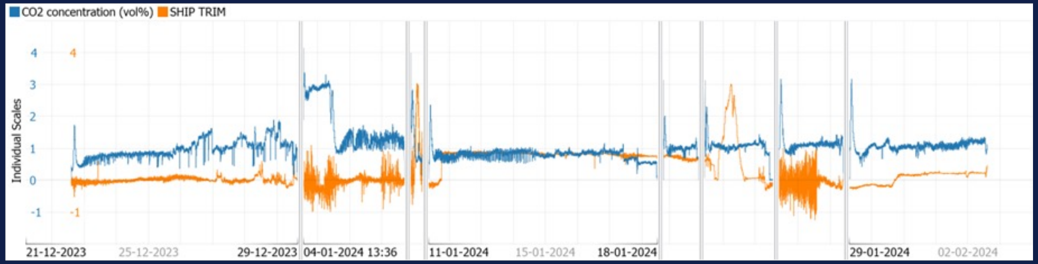
Ship motion doesn't seem to be a point of concern

Ship sea movement or rolling evaluated throughout the campaign
Periods with strong wind speed (up to Beaufort 10, or above 24.5 m/s)





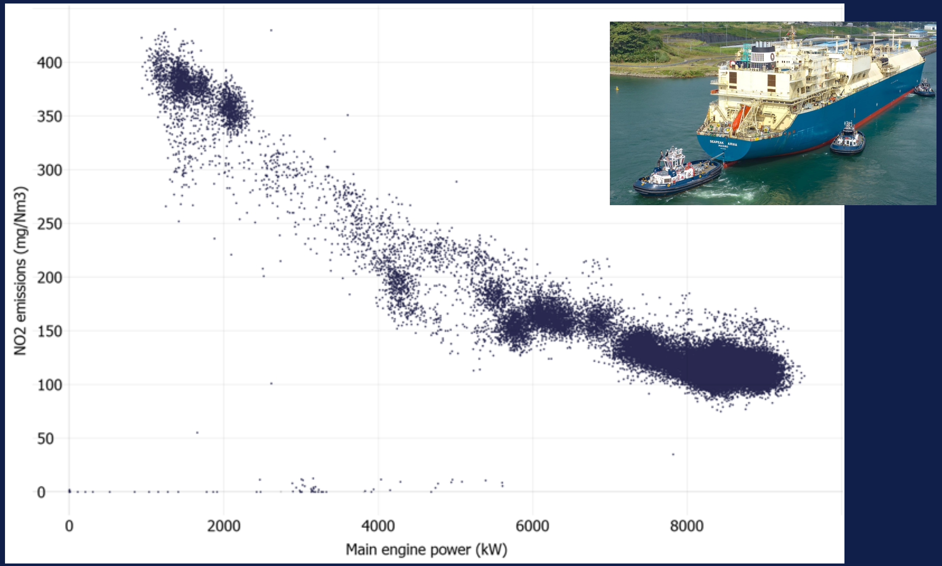




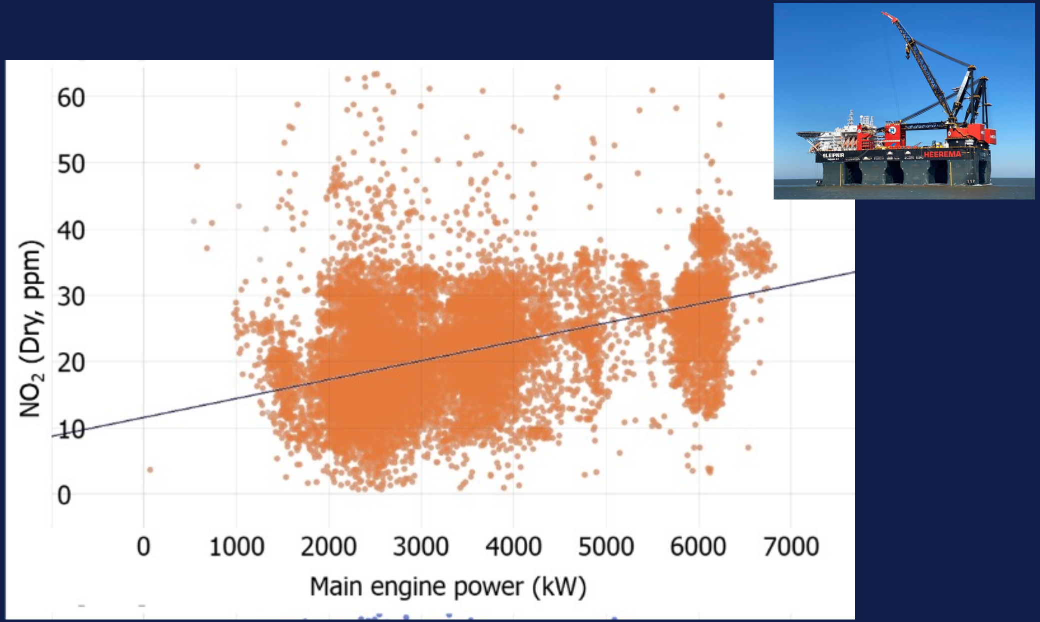
Ship motions had **no measurable effect** on CO_2 capture rate or other process parameters

WP1 Lessons learned (2)

High NO_2 content in exhaust gases



50-200 ppmv



10-30 ppmv

Onshore pilot references: below 5 ppmv

WP1 Lessons learned (2)

High NO_2 content in exhaust gases → high oxidative degradation rate

Component	Unit	TCM MEA	EverLoNG TotalEnergies
Formic acid	mg_L/Nm^3	2.0	6.2
Acetic acid	mg_L/Nm^3	0.3	2.9
Oxalic acid	mg_L/Nm^3	0.9	3.0

Onshore pilot benchmark

WP1 Lessons learned (2)

High NO_2 content in exhaust gases → high oxidative degradation rate

Component	Unit	TCM MEA	EverLoNG TotalEnergies	EverLoNG Sleipnir
Formic acid	mg_L/Nm^3	2.0	6.2	1.8
Acetic acid	mg_L/Nm^3	0.3	2.9	0.4
Oxalic acid	mg_L/Nm^3	0.9	3.0	0.5

NO_2 100% removed

WP1 Lessons learned (2)

High NO_2 content in exhaust gases → high oxidative degradation rate

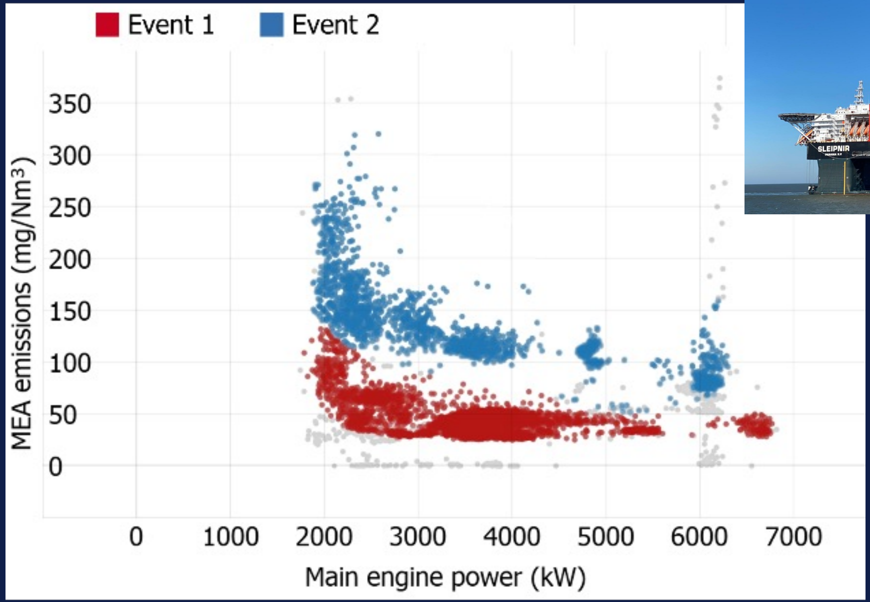
Component	Unit	TCM MEA	EverLoNG TotalEnergies	EverLoNG Sleipnir
Formic acid	mg_L/Nm^3	2.0	6.2	1.8
Acetic acid	mg_L/Nm^3	0.3	2.9	0.4
Oxalic acid	mg_L/Nm^3	0.9	3.0	0.5

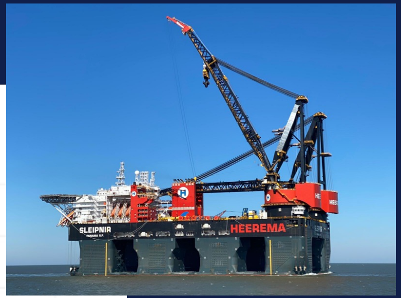
2 pathways: remove NOx (e.g. SCR) or allow higher degradation rate

WP1 Lessons learned (3)

Potential for aerosol-based emissions

Volatile emissions dominate
Average: 2.1 mg/Nm^3
Standard deviation: 14.8 mg/Nm^3





Aerosol emissions dominate

WP1 Lessons learned (3)

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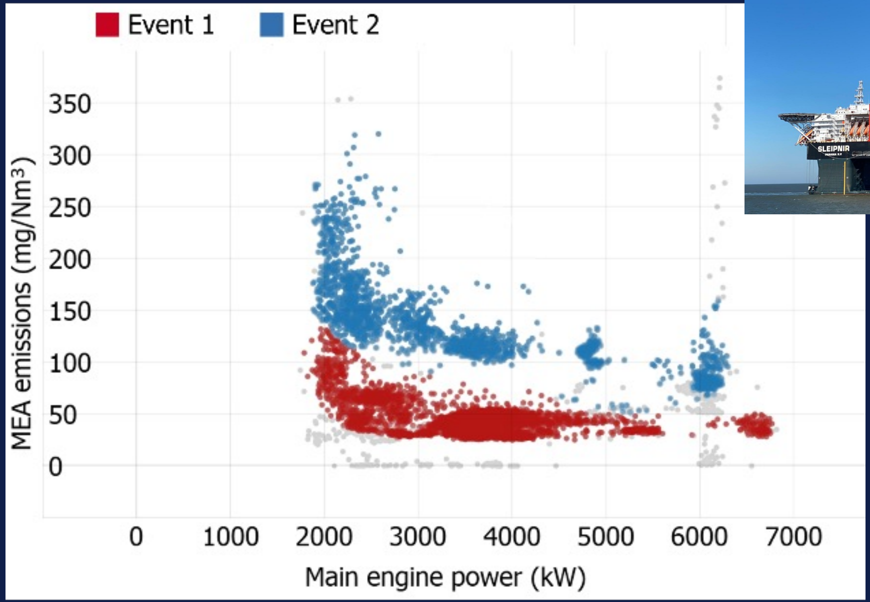

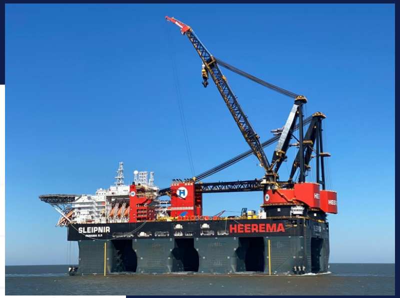

Aerosol emissions dominate

Particle measurements onboard & integrate countermeasure in OCC design

Main knowledge gaps

CO_2 quality in view of high NO_2 content and higher degradation rate

Engine + fuel + aftertreatment → NO_2 and particles (EverLoNG “sample” of 2 engines)

Thank you for listening

info@everlongccus.eu

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WP2 - Full CCUS chain integration

Webinar, March 13th 2025

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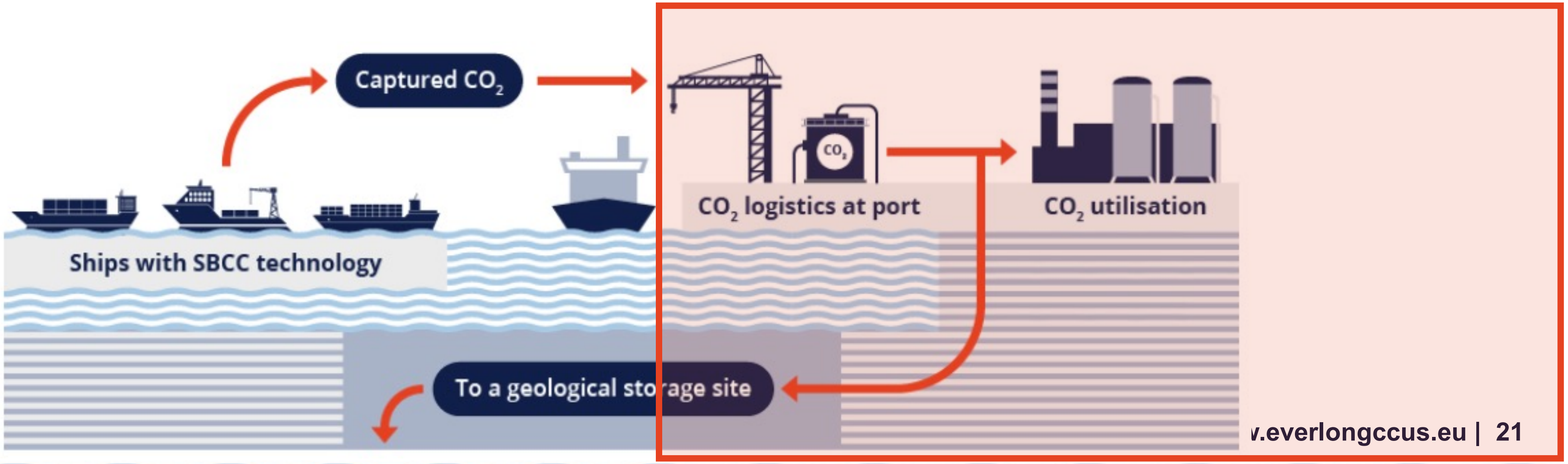
EverLoNG - not just capture

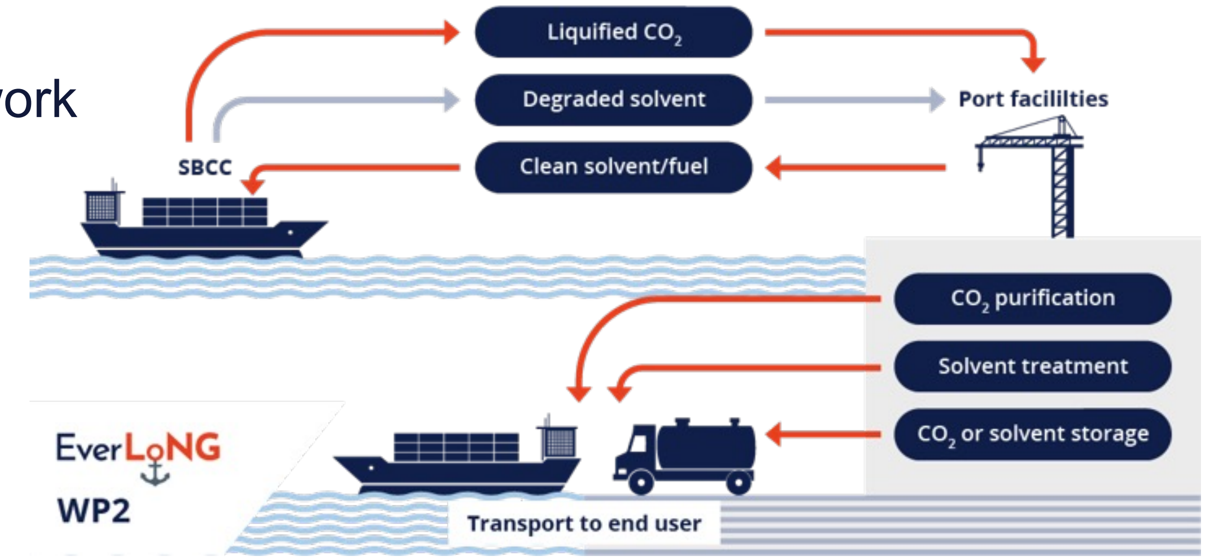
- After all the effort of capturing the CO_2 onboard the ship - it is paramount that the CO_2 remains captured and stored/utilised

- To enable this, a CO_2 handling infrastructure needs to be in place that can receive this CO_2 in such a way that it has little impact on the normal operation of the ship



Tasks

- Offloading strategies and chain integration
  - CO_2 and rich solvent offloading alternatives and integration into planned CO_2 infrastructure
  - Define full CCUS chain cases
  - Develop a process design package for port receival facility for CO_2
- CO_2 shipping interoperability and port readiness
  - Port readiness assessment tool
- Roadmap towards a European offloading network
- CO_2 quality in OCC context



CO_2 offloading and port integration

- There are several ways of unloading the captured CO_2 from a ship
- The main offloading options are
  - Ship to port
  - Ship to ship/barge
  - Jetty free transport
- The offloading can be done with flexible hoses, loading arms, and container swap
- Solvent handling
  - The spent solvent will be pumped to shore for regeneration and fresh/reclaimed solvent returned to the ship
  - It is not foreseen that this is done at every port call

Takeaways

➢ The offloading technology will ultimately depend on ship type and the port facilities

➢ A key factor is that the unloading should have as little impact on the normal ship operation as possible

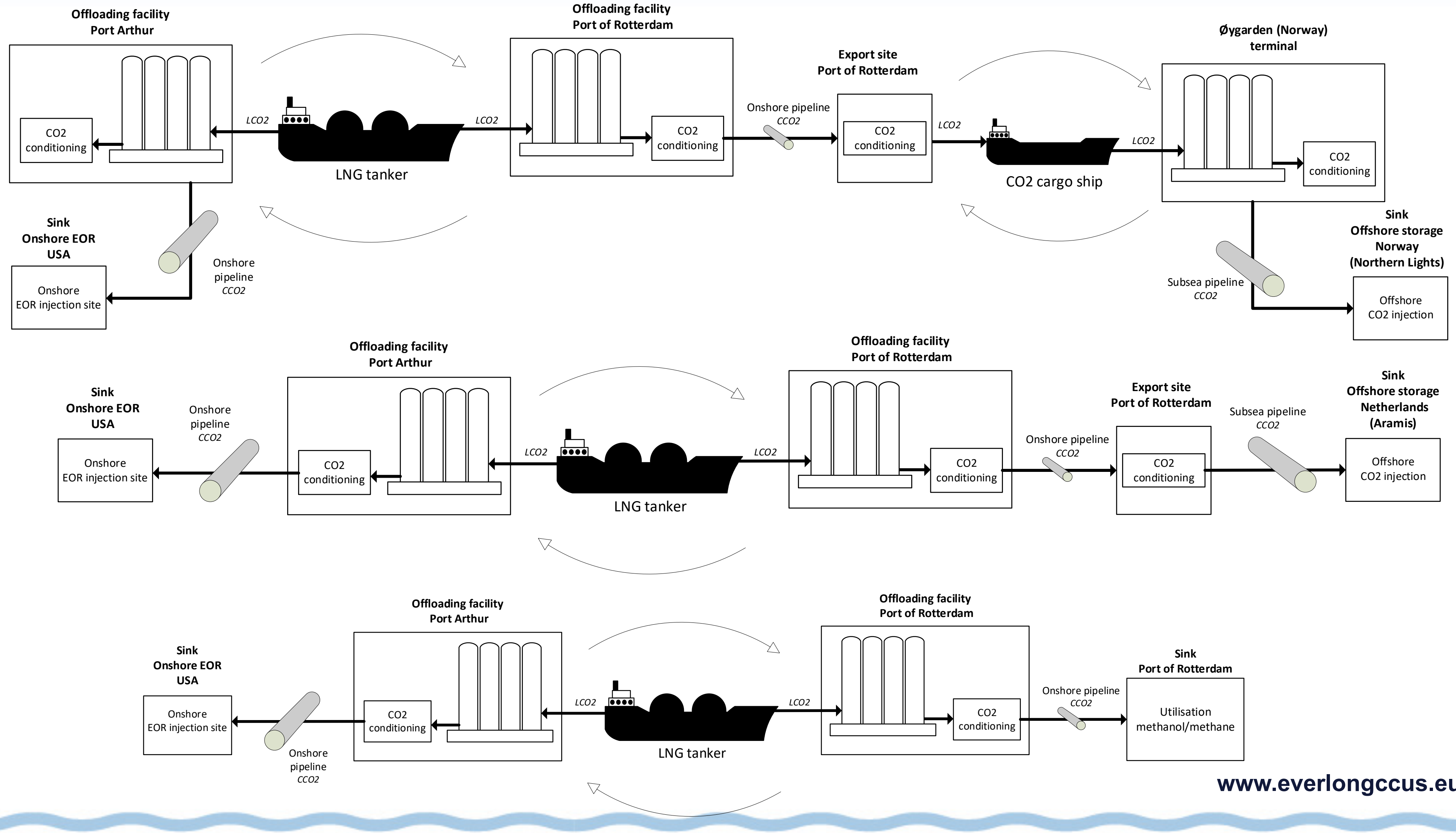
Port receival facility

- A portside receival facility for CO_2 (and solvent) has been designed
- The facility includes
  - CO_2 offloading equipment
  - Intermediate storage tanks including a BOG system
  - CO_2 conditioning
  - Solvent reclaiming

Takeaways

- ➢ The intermediate storage tanks constitute a substantial installation (and are cost intensive), alternatives should be explored at least in the implementation phase
- ➢ The final design will depend on integration with the transport and storage network

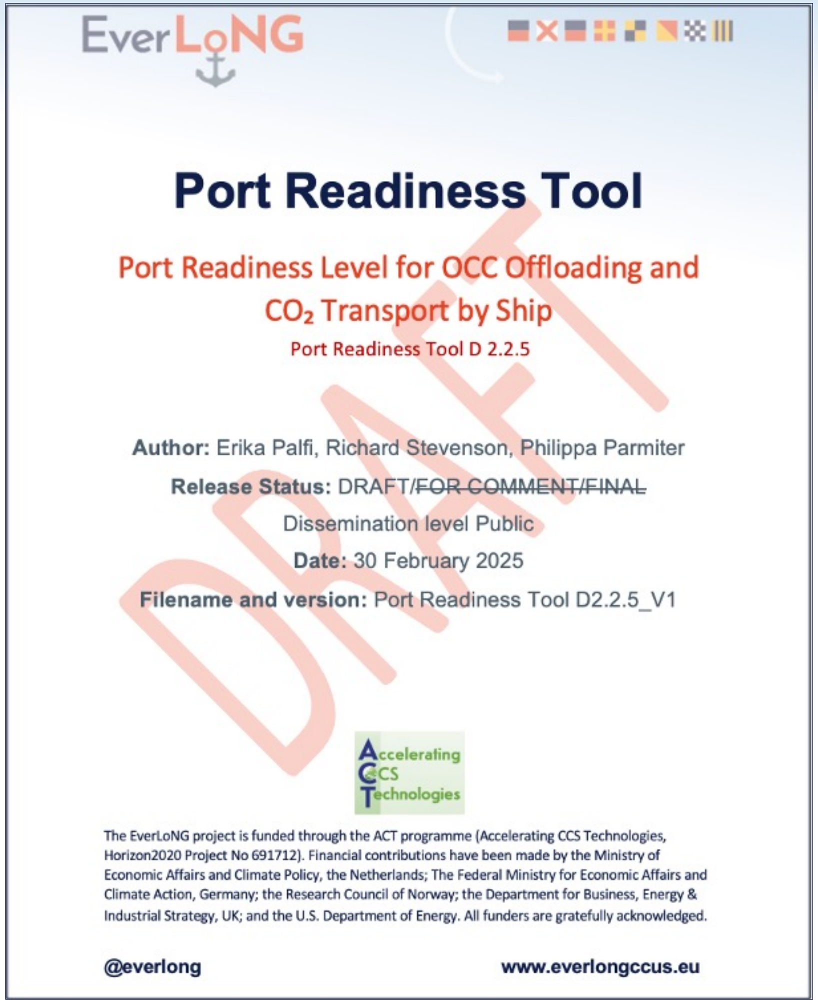
Several full-chain cases have been assessed



Port Readiness Tool

Takeaways

- Ports have an important dual role to play in facilitating CCUS networks and OCC for the purposes of decarbonising the wider economy and the maritime sector respectively
- For CO_2 handling at ports to become a central component of CCUS networks and general carbon management strategies, interoperability between ports, ships, and storage hubs is crucial
- The EverLoNG Port Readiness Tool for CO_2 (PRT-CO_2) is a structured, dual pathway framework to help port communities plan for and assess progress towards CO_2 handling preparedness
- The tool is based on the IAPH/WPCAP PRL-MF framework, and it is intended as a starting point for the sector to adopt and develop further
- Use of the PRT-CO_2 is expected to be a coordinated, collaborative exercise between key stakeholders led most likely by port authorities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Port Readiness Tool

Port Readiness Level for OCC Offloading and CO_2 Transport by Ship

Port Readiness Tool D 2.2.5

Author: Erika Palfi, Richard Stevenson, Philippa Parmiter

Release Status: DRAFT/~~FOR COMMENT/FINAL~~

Dissemination level Public

Date: 30 February 2025

Filename and version: Port Readiness Tool D2.2.5_V1

DRAFT

Accelerating CCS Technologies

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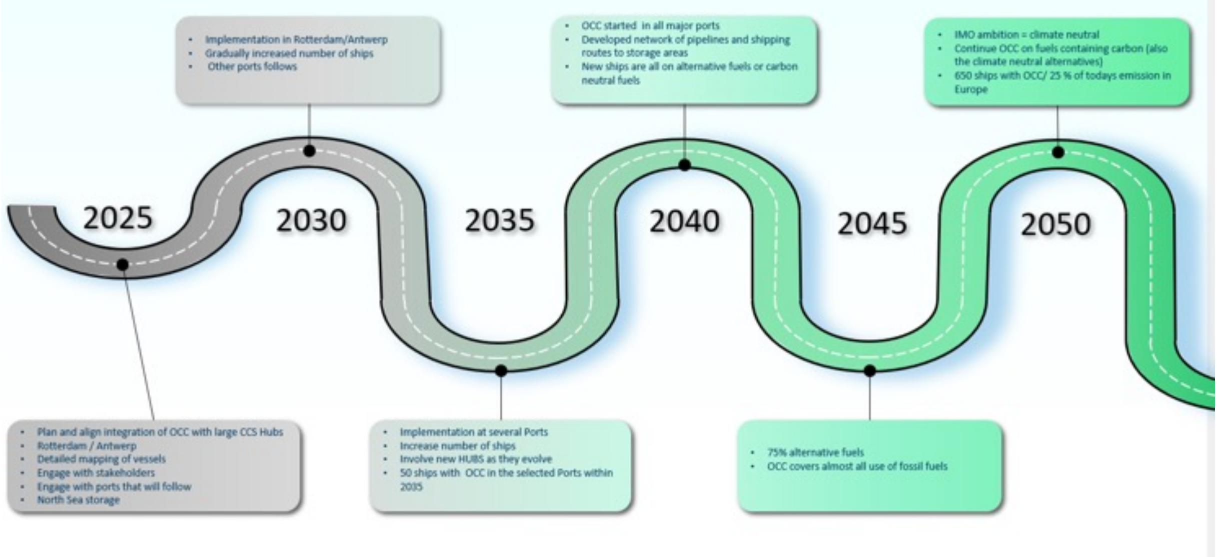
IAPH: International Association of Ports and Harbours
WPCAP: World Ports Climate Action Programme
PRL-MF: Port Readiness Level for Marine Fuels

Roadmap for OCC implementation in Europe towards 2050

- Developing a roadmap for OCC implementation is challenging
  - Individual ships will capture relatively low volumes annually which pose both technical and economic challenges
  - Flexible port infrastructure is need for receiving the CO_2 and facilitating for transport of the CO_2 to a suitable sink
  - Standardisation, regulations, and political incentives are needed to achieve large scale OCC
- Overall methodology for roadmap development
  - Start with the ports with the largest throughput with existing or potential infrastructure for CO_2 transport and storage
  - The basis of the roadmap is the IMO goal - 35 Mt CO_2 captured annually in 2050 by OCC



Takeaways

➢ OCC could contribute to net zero emissions in 2050

➢ ~ 700 ships with OCC could capture 35 Mt CO_2 in 2050

Key takeaways from full-chain OCC

- The relatively low volumes per ship/vessel annually combined with a relatively large volume unloaded per port call pose a challenge when developing CO_2 handling infrastructure
  - It is paramount to increase the utilisation degree of the OCC onshore infrastructure to reduce the cost
  - And to connect to other shared infrastructure at the earliest possible opportunity for transport of the CO_2 to a suitable sink
- No major technical obstacles identified, but implementation is not trivial at least not for the first movers
- Ports in collaboration with the shipping industry holds the key to OCC as a viable decarbonisation method for the industry

Work Package 3

EverLoNG final webinar

Joan van den Akker, Augsburg, March 13th, 2025

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WP3 overview

- Study of the conceptual design and shipboard integration of **full scale** SBCC systems

- Design of carbon capture system
- Onboard integration of systems
- Focus on optimisation between systems
  - Heat integration
- Target: >70% reduction of CO2 emissions (tank to wake)

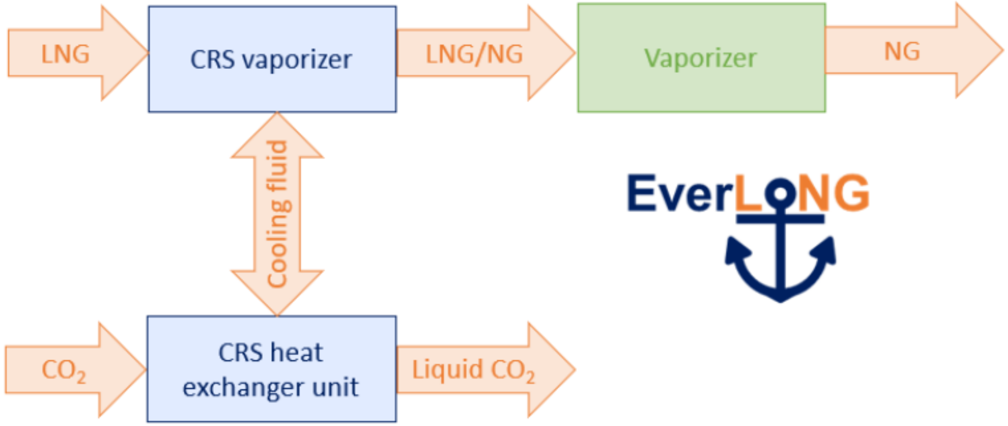
- Two cases:
  - Sleipnir (Heerema Marine Contractors)
  - LNG carrier (TotalEnergies chartered)

Focus areas

- Heat requirement for capture system
    - Exhaust gas heat recovery

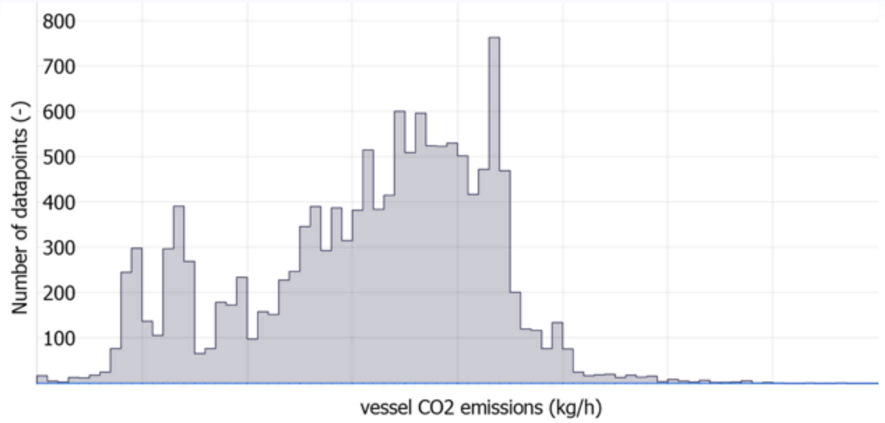
- Cooling requirement for CO2 liquefaction
    - Cold recovery system (CRS)
    - Use LNG vaporisation as heat sink

- Potential for standardisation

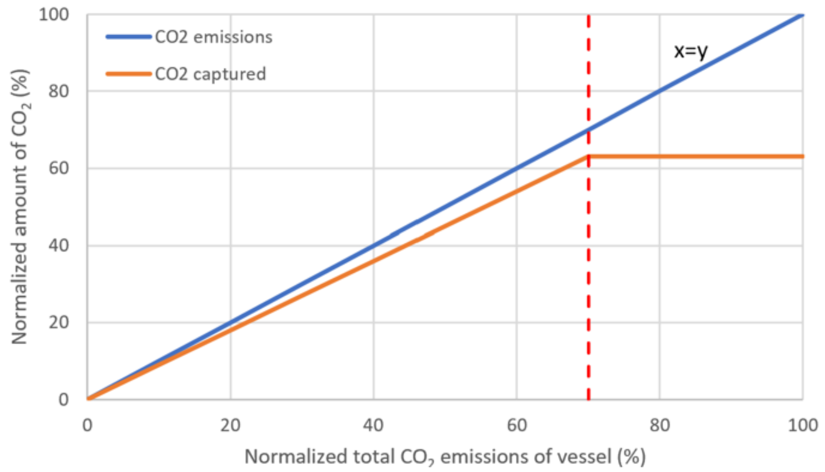


Capture system design

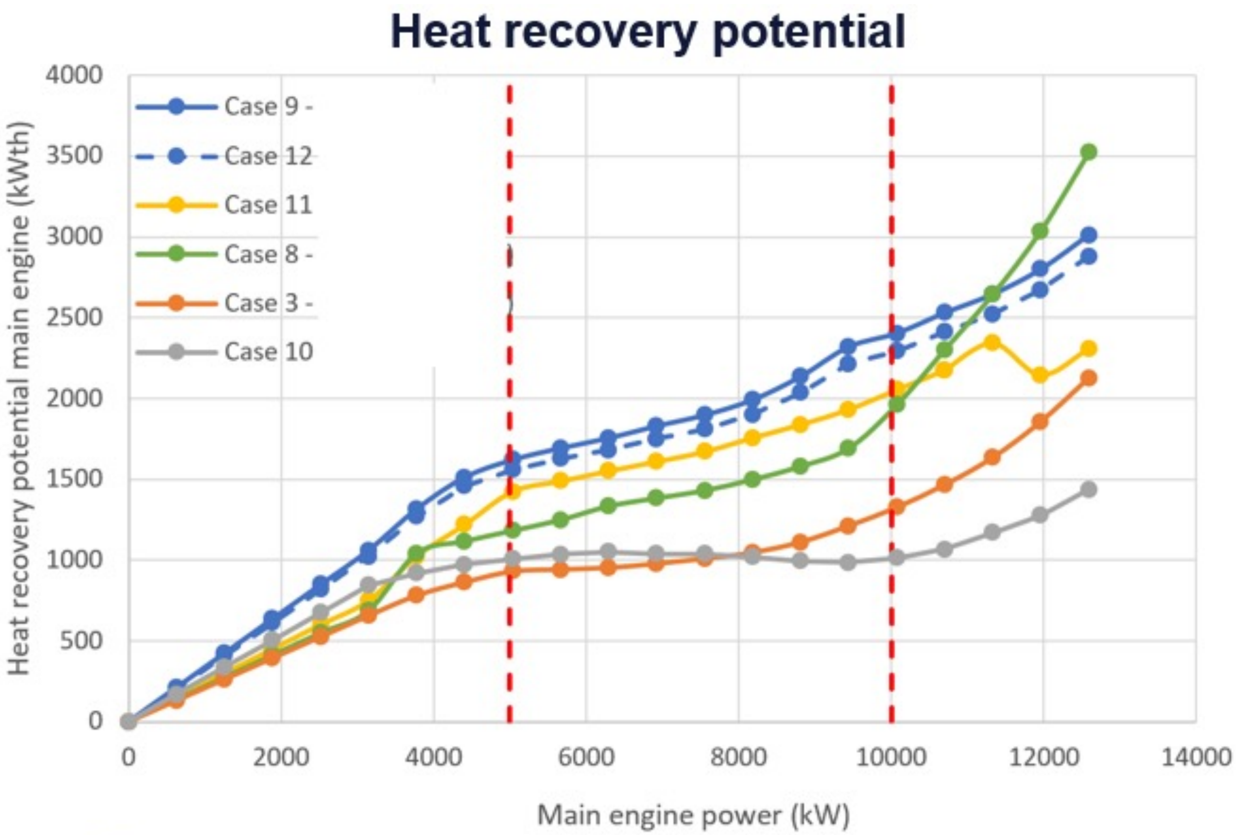
- Data analysis
  - Operational profile
  - Characteristics of different engine types
    - 4 stroke
    - Different types of 2-stroke engines
    - Gas operation vs. MGO operation
- Optimise sizing for the vessel's operational profile, taking into account amongst others:
  - >70% reduction target
  - Heat availability in exhaust gas
  - Heat requirement of other ship processes
  - Additional heat required and associated emissions
  - Electricity consumption of the capture system

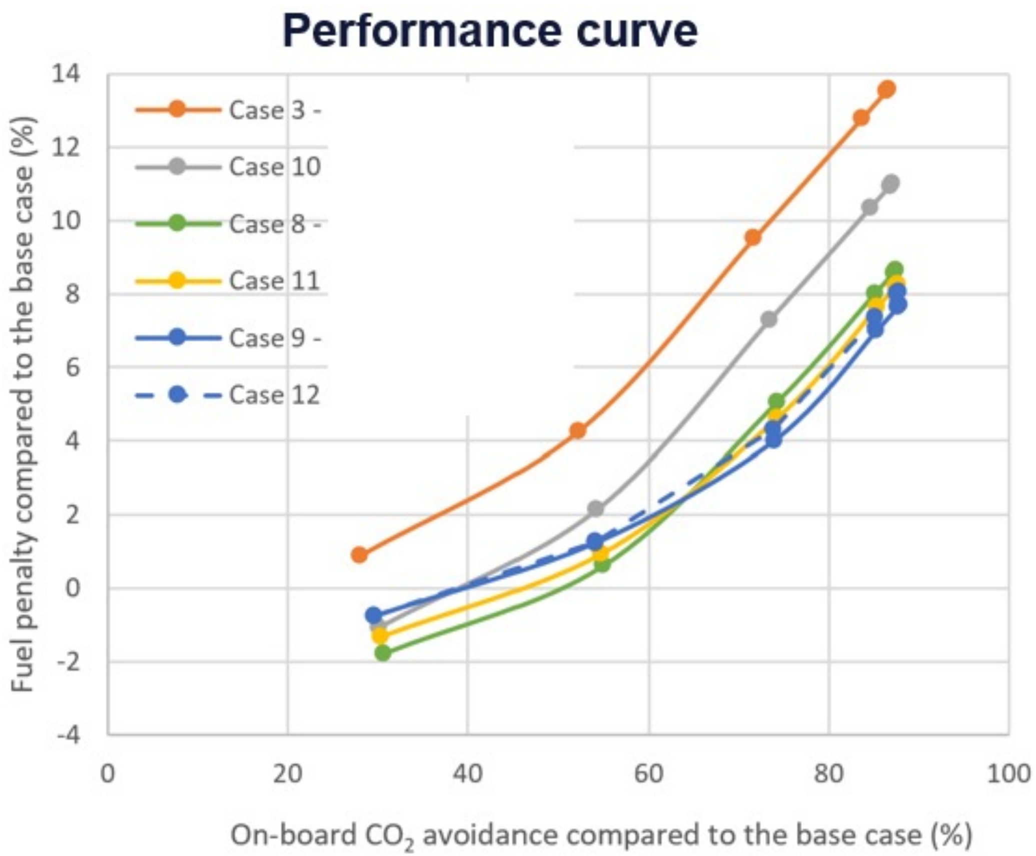


Visualisation of amount of CO_2 captured for a certain design point

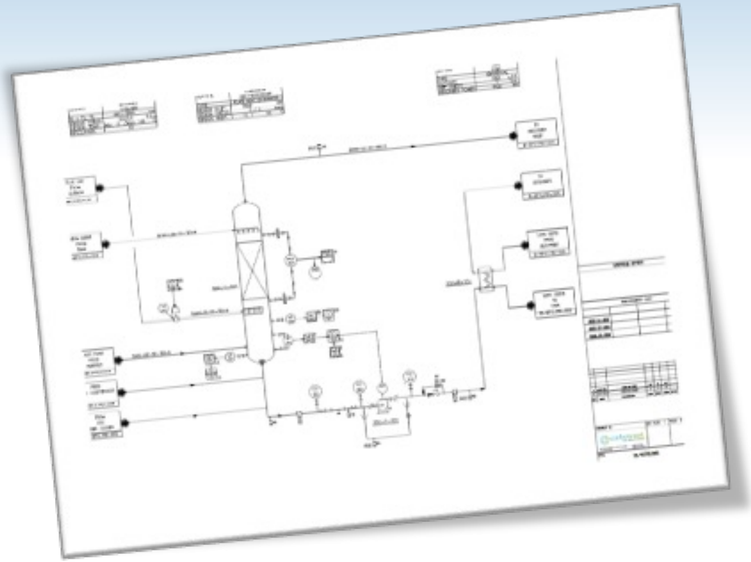


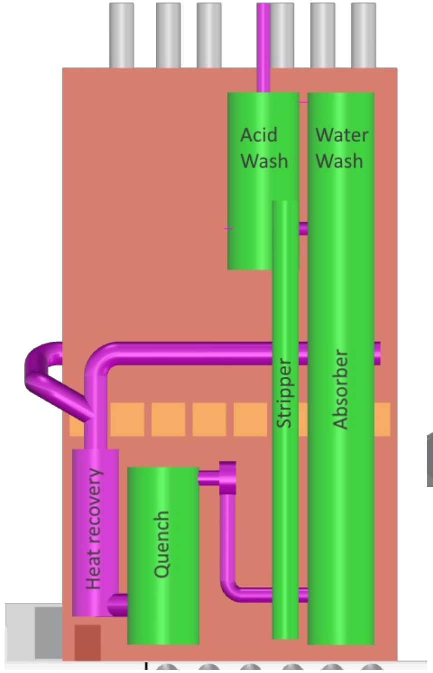
Data analysis and sizing examples

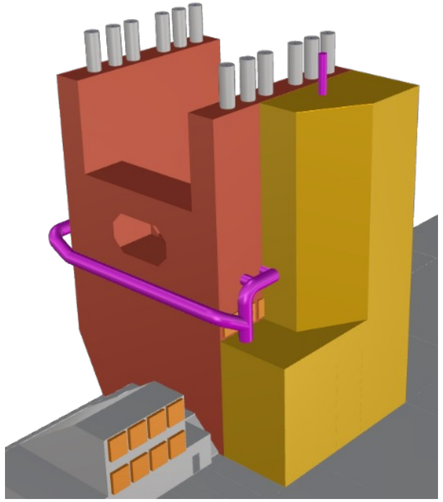


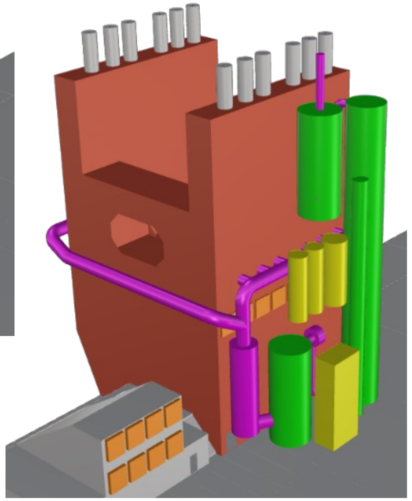


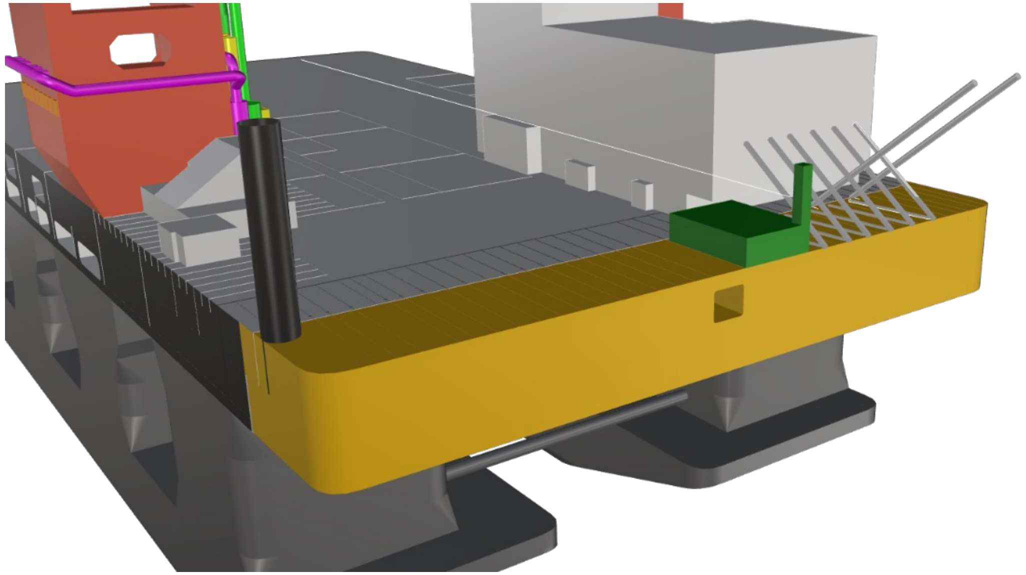
Sleipnir - design and integration results



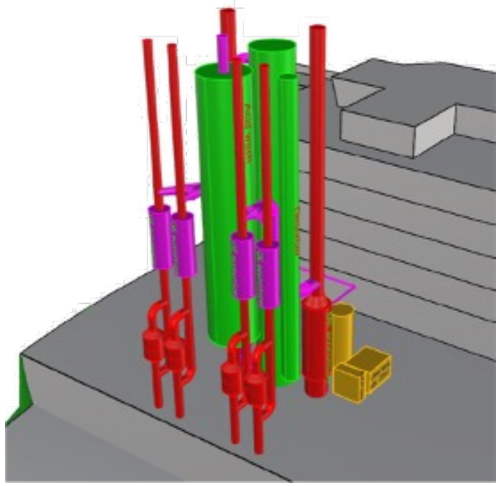


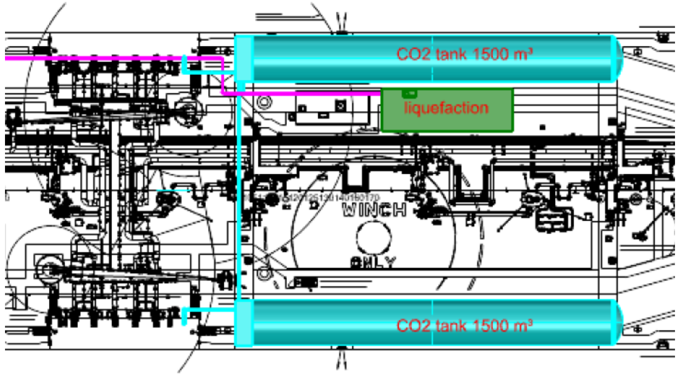


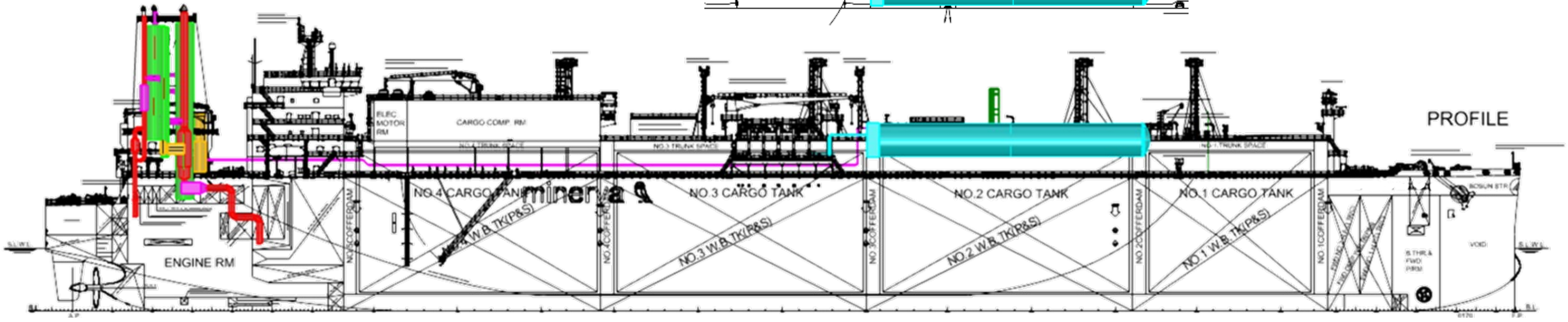




LNGC – design and integration results







General lessons: heat recovery

- Heat availability for four-stroke engines is typically sufficient for high capture rates (up to 95%)
- For two-stroke engines, this is a critical issue.
  - Additional heat is required to enable high capture rates
- Engine matching CAN provide important efficiency improvements
- Having HFO on board causes a high heat demand, not available for carbon capture: if possible, do not have HFO on board.
- Other heat recovery options to be further explored. E.g.: charge air cooling

General lessons: cold recovery

- Cold recovery from LNG vaporisation is challenging as a retrofit
- Cold recovery from LNG vaporisation is more feasible for vessels with a (relatively) small LNG tank vs. consumption.
- For vessels with a very large LNG tank, boiloff is typically too high to recover any cold from LNG vaporisation
- However, with large amounts of boil-off, the cold available in the already vaporised LNG becomes relevant.
- For an LNG carrier, the capture system could be sized for this cold availability in the boil-off, for a better energy efficiency.
- This will result in a lower CO2 capture/avoidance

General lessons: standardisation

- For high capture rates, a tailor-made design can provide significant benefits
- Standardisation becomes easier with a lower design rate (and smaller fraction of treated exhaust gas), providing a more predictable exhaust gas flow
- To what extent CAN we standardise?
    - Standardisation vs. optimisation
    - Mixing and matching of standardised components

Main takeaways

- When high capture rates (up to 95%) are aimed for, optimisation of ship systems with the capture system is very important
  - Engine matching enables significant improvements in heat integration
  - Cold recovery LNG vaporisation provides significant energy savings for newbuild vessels, for retrofits this is more challenging
- If optimisation options are limited, e.g. in retrofit situations for two-stroke engines, the fuel penalty is higher
  - Alternatively, adapt the sizing of the capture system to the availability of heat → lower CO2 avoidance
- Standardisation requires further consideration, especially for more ambitious capture rates
  - Designing for lower capture rates makes standardisation less challenging
- There is still room for improvement!

EverLoNG

Acknowledgements

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Thank you for listening

Joan van den Akker, joan@conoship.com

Life Cycle Assessment and Techno-economic Evaluation of SBCC

Webinar 2025

Lavinia Reitz, Jasper Ros, Anette Mathisen, Abhishek Subramani, Ragnhild Skagestad, Gabrielle Farrell, Megan Hellendall, Babul Patel, Prashant Sharan, Joan T. van den Akker, Petra Zapp

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.

Goals – Environmental Impacts and Costs:

Verify targets for full-scale SBCC (on-board)

- 70% **CO_2 emission reduction**, compared to same ship without SBCC
- **costs below 100€** per metric ton CO_2

Investigate the CO_2 handling via port and storage effect

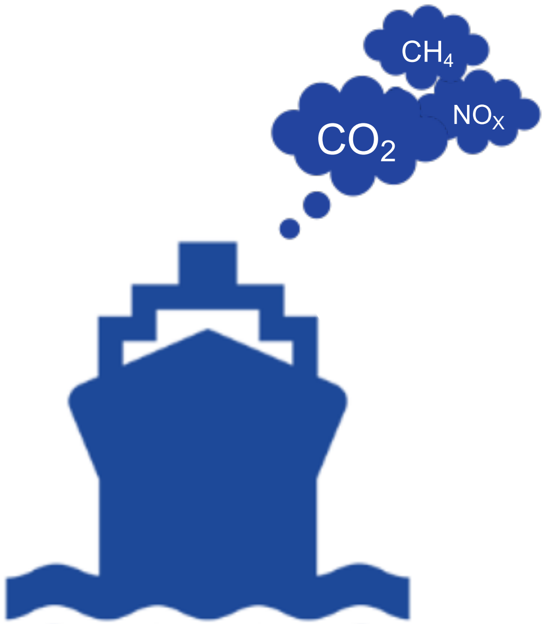
- on $CO_{2\text{-eq}}$ avoidance potential

→ including also upstream: fuel production, …
- on total costs

Identify drivers of benefits and trade-offs

- for $CO_{2\text{-eq}}$ avoidance potential

→ and other environmental impacts
- for total costs



Methods – LCA and TEA

LCA

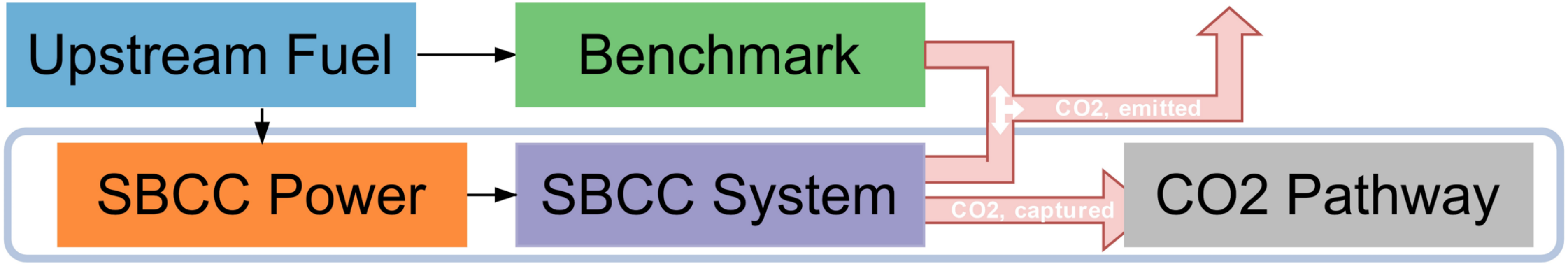
Emissions & resource use
~CO_2, CH_4

Impact on the Environment
- climate change
- resource depletion
- acidification, …

TEA

ETS: price €/t CO_2

Estimate CAPEX and OPEX
- total CAPEX
- variable OPEX
- cost per ton CO_2



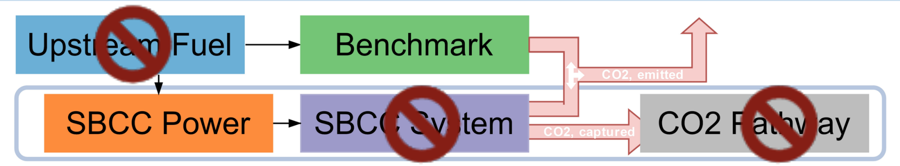
Capture System Design and Operation

- Benchmark: **Operational profile** (power demand over time)
  → Detailed modelling of the engine emissions
  - CO2, CH4, NOx, …*
- Amine degradation from Prototype measurements

Analyse for function:
6 weeks (Sleipnir)
& LNG delivery from US to NL (Tanker)

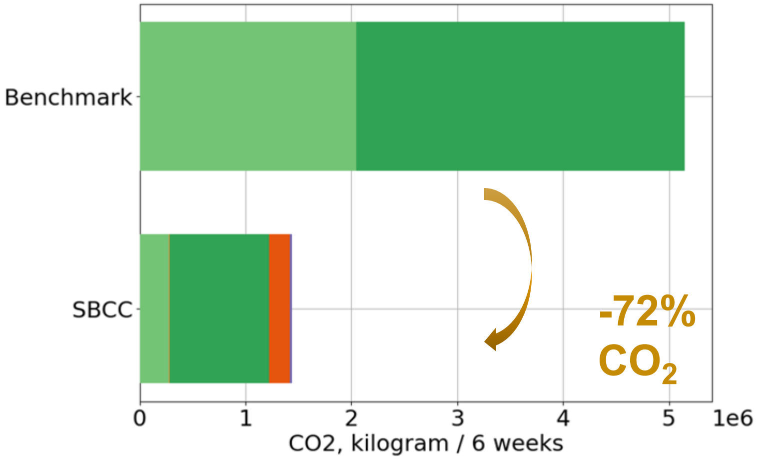
Specification			
Fuel Type	MGO	LNG + Pilot	LNG + Pilot

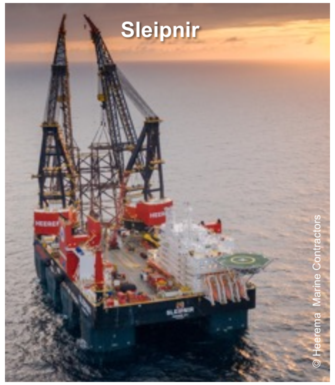
*IMO emission factors and engine data
** additional emissions from the capture plant are not captured in this case



On-ship operation - Sleipnir

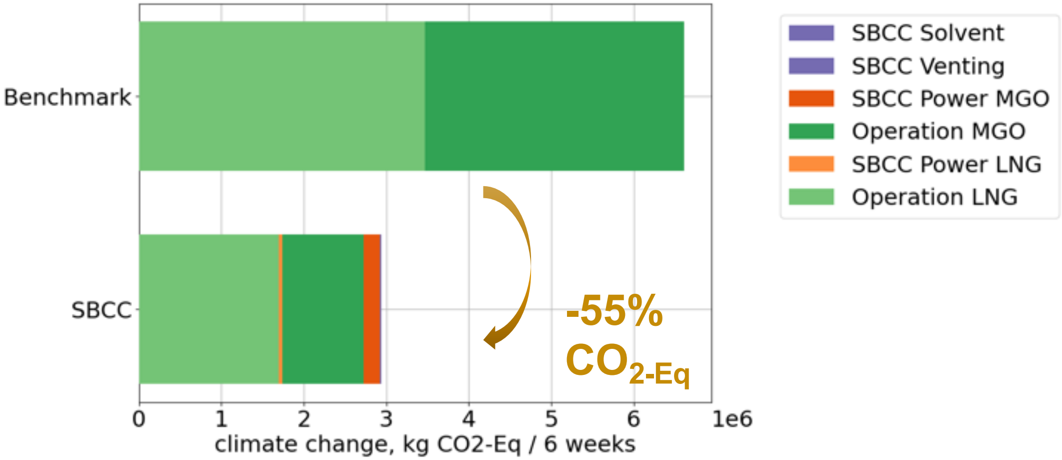
CO_2 Emissions





EF3.1 Climate Change

(CO_2, CH_4, …)



Methane slip during engine operation

✓ CO_2 reduction targets (70%) validated

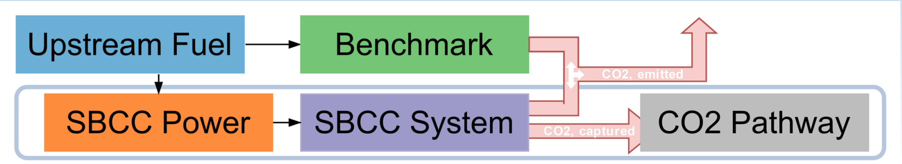
-84% CO_2

-75% $CO_{2\text{-Eq}}$

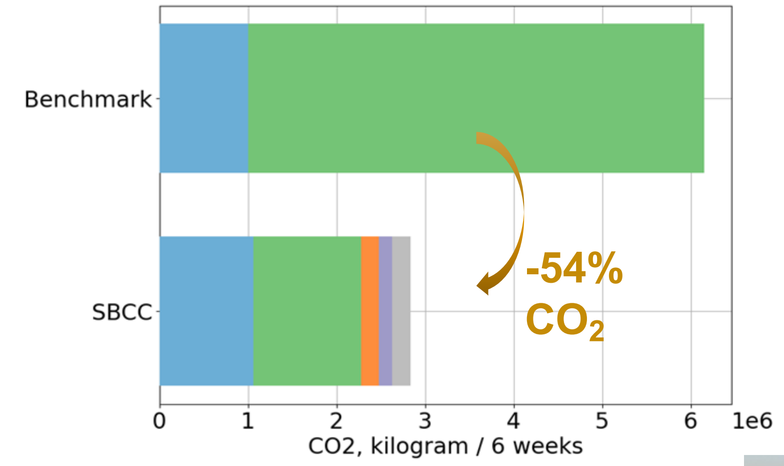
Note: Presented reduction shares are not directly comparable to decarbonisation targets

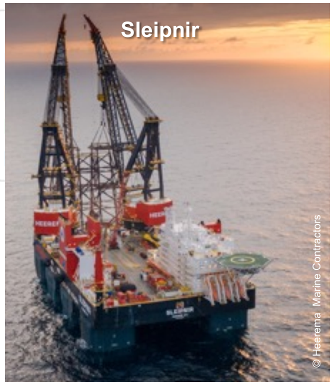
- **System Boundaries**
- **Benchmarking**
  (e.g. IMO would be against 2008 shipping fleet)

Full Life Cycle incl. CO_2 Pathway



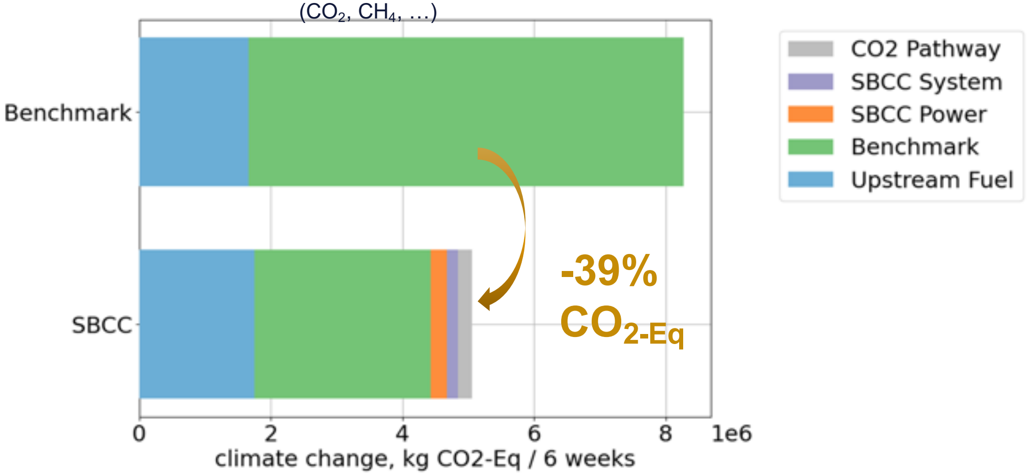
CO_2 Emissions

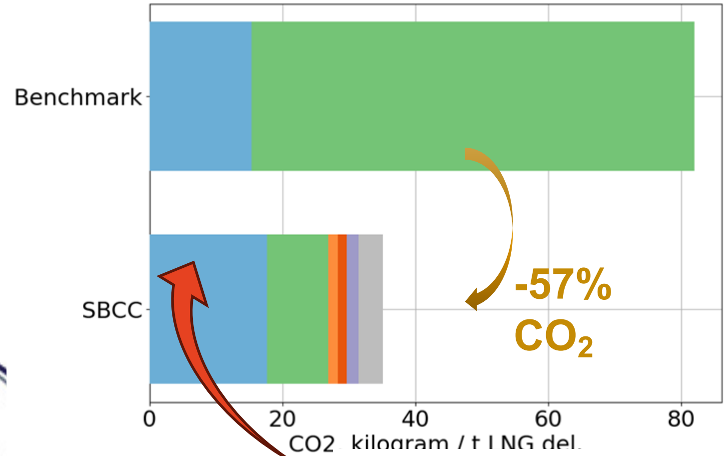


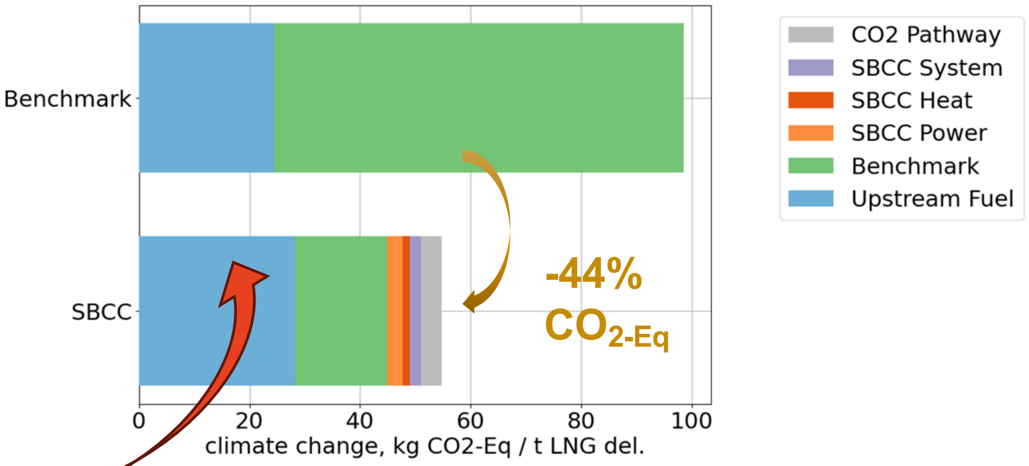


EF3.1 Climate Change

(CO_2, CH_4, …)

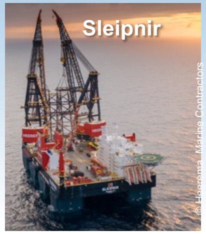


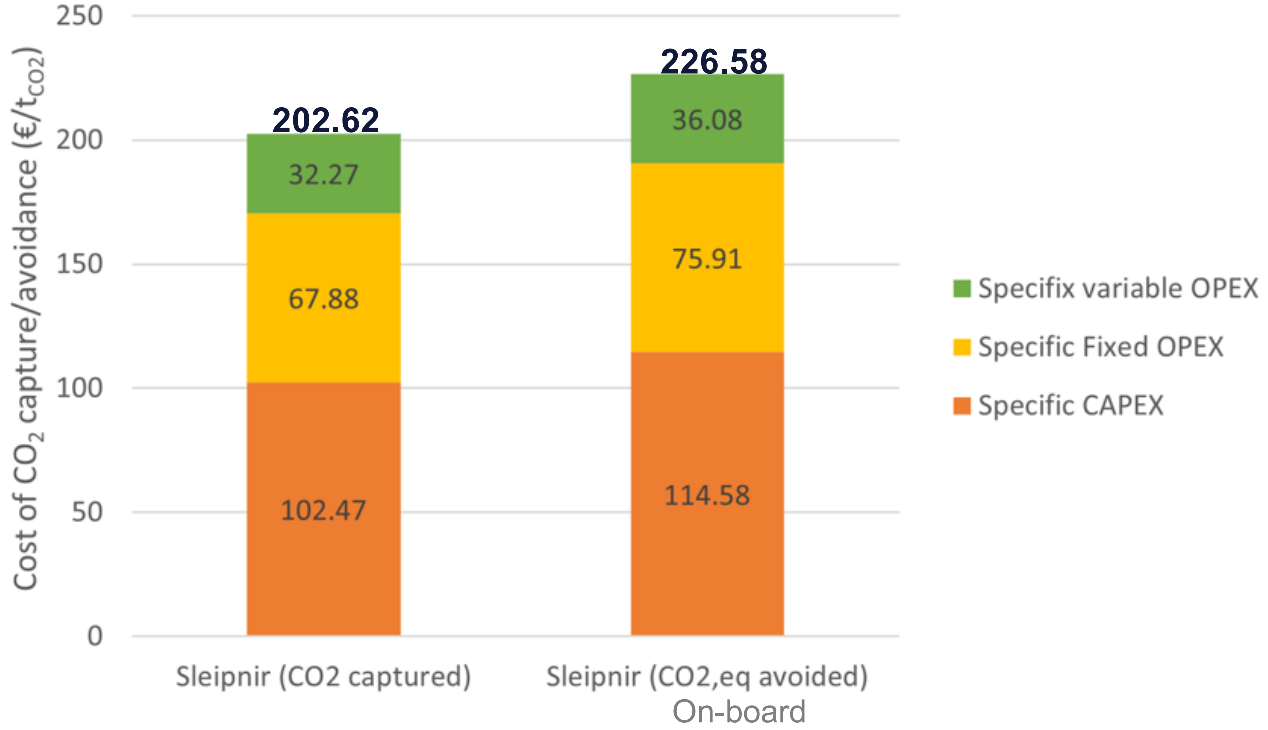


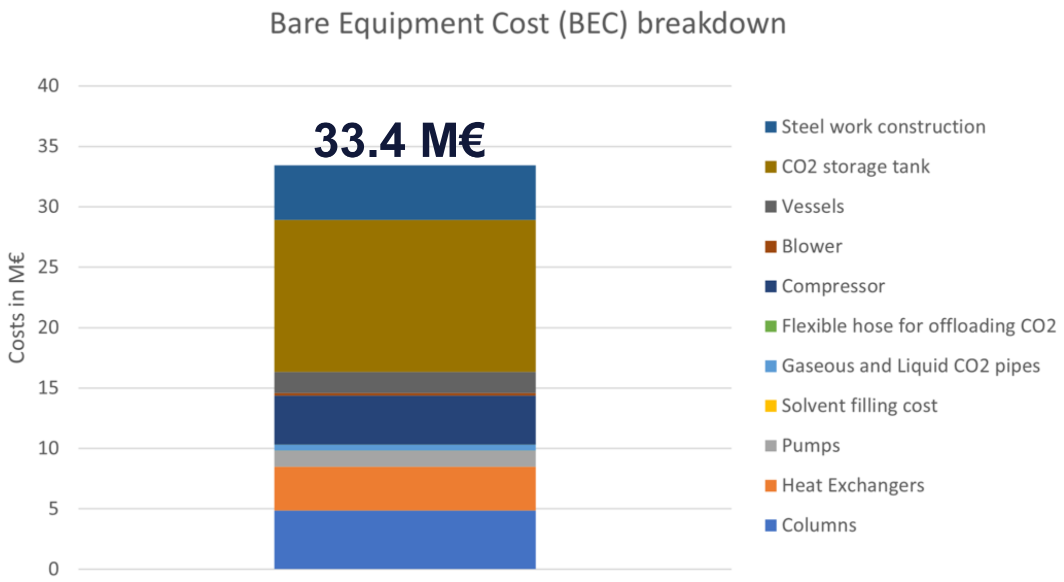


GHG emissions of fuel production

TEA - Sleipnir Case

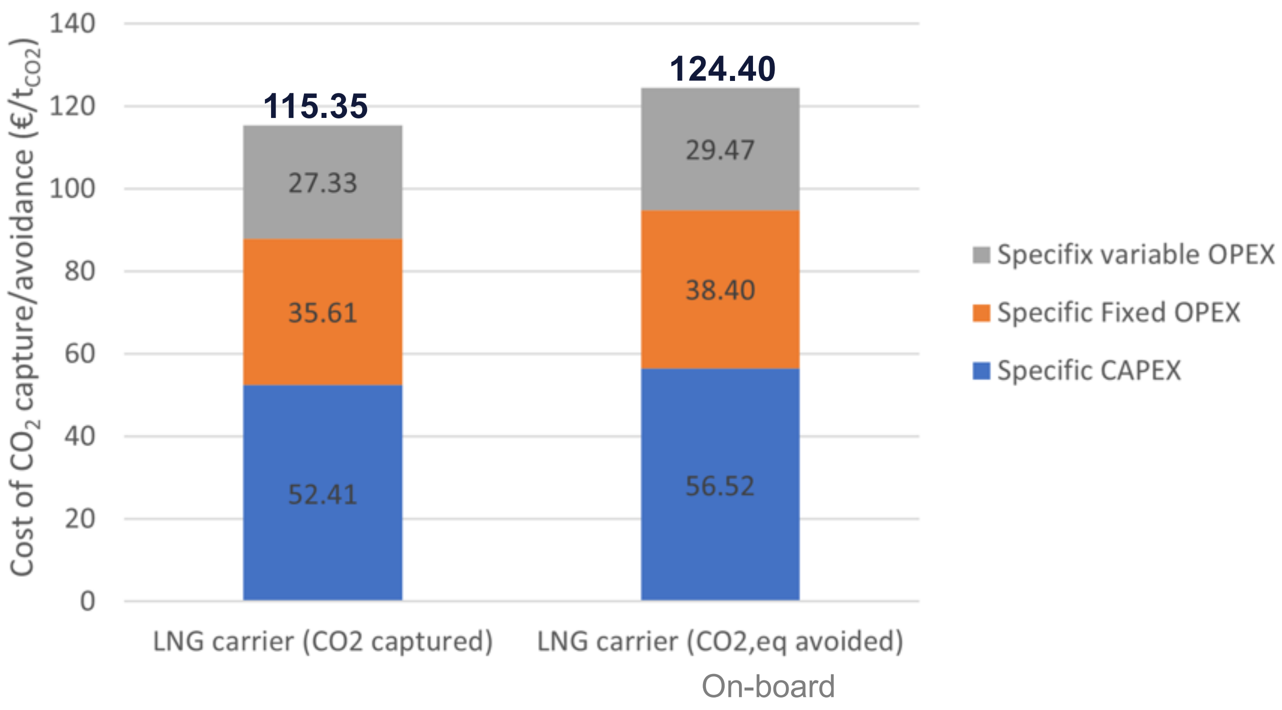


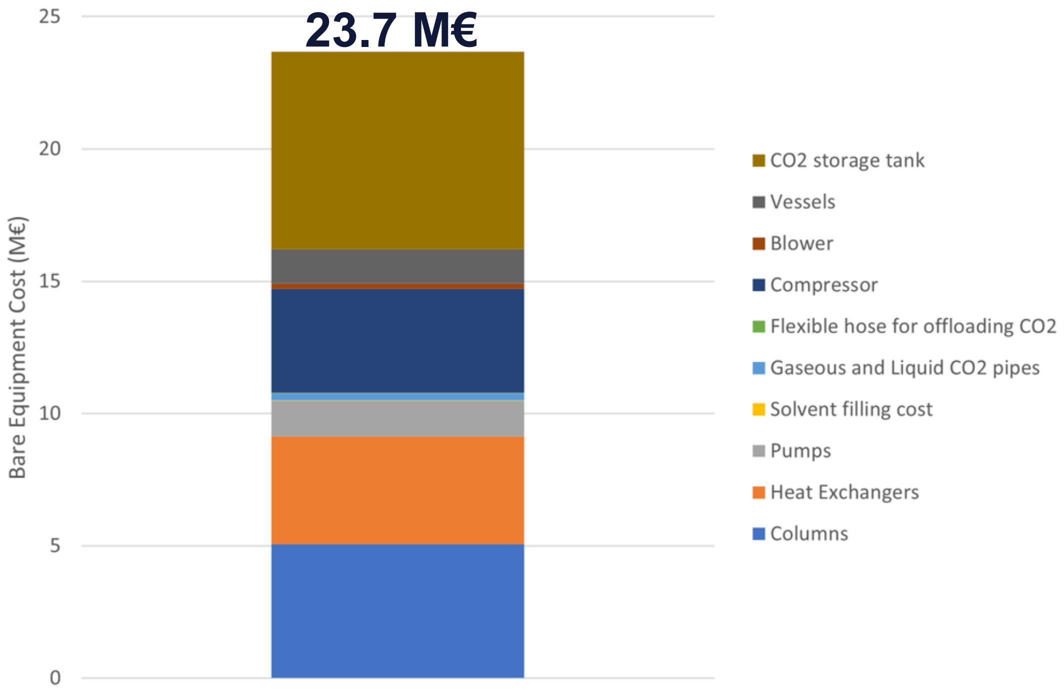




- **CO2 storage tank cost** is the major equipment cost driver.
- Since this is a retrofit case, steel work construction costs are considered.

TEA - Tanker Case

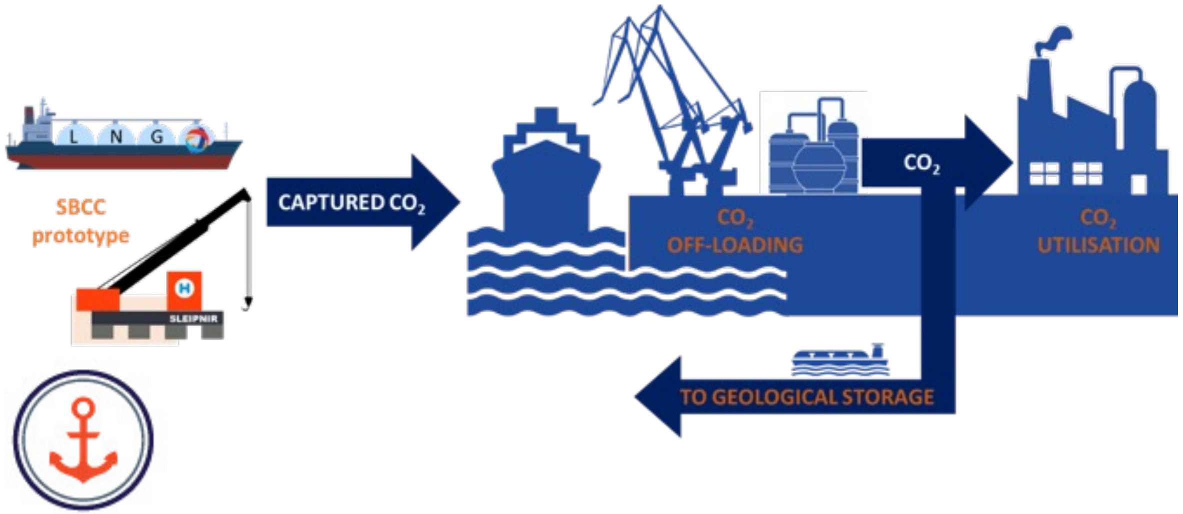




- CO2 storage tank cost is the major equipment cost driver but lower than Sleipnir.
- Since this is a **new-built case, steel work construction costs are NOT considered**.
- **The capacity factor of the capture system is higher** here thereby giving **lower specific total costs.**

Full-chain TEA – EUR/t captured CO2 (2023)

Cost element	Aramis, EUR/t
On-board carbon capture	200 | 115
Receival facility	20
Cost of transport, pipeline	20
Cost of storage	40
“Total”	**280 | 195**



Disclaimer

The results are only valid under the assumptions made

Take Home Message & Context

- **Upstream emissions** of the fuel and **methane slip** in the engines are identified as the most prominent hindrances for further reduction effects
    - With improving methane slip of ship engines in the future, increasing reduction potentials are projected
    - Attenuate fuel effects by improving designs further, e.g. on the heat recovery efficiency
    - Future potentials for **combination with e.g. biofuels** can be further explored
- **Burden shifting** to other environmental impacts, such as acidification due to higher fuel demand causing higher NOx emissions and Ammonia can be observed, though in expected range
- The TEA results show
    - **onboard costs**
        - are driven by **CAPEX**
        - good heat integration is possible, generating electricity is more expensive than on land-based systems.
        - **mainly determine total costs**
    - transport and storage costs are not negligible, **facilities need to be shared** among users
    - the current emissions penalties/subsidies are not sufficient, **new financial structures would be required for incentivization**

Take Home Message & Context

- **Effectiveness** of SBCC could be validated for full-scale on-board integration, including the **full Life Cycle** - at a total of **39 & 44% $CO_{2\text{-eq}}$ climate change impact reduction** compared to the benchmark ship without carbon capture.
- Contribute to means for comparison with alternative options for decarbonization of the maritime sector (e.g. green fuels)
- SBCC can serve as **one transition measure** in the efforts to decarbonize the shipping sector that could be **put into action promptly**, as part of the portfolio of measures needed to reduce climate change impacts.

Note: Presented reduction shares are not directly comparable to decarbonisation targets

- **System Boundaries**
- **Benchmarking**
  (e.g. IMO would be against 2008 shipping fleet)

EverLoNG

Acknowledgements

Accelerating CCS Technologies

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TNO innovation for life · CONOSHIP International innovative maritime solutions · Bouman Industries · carbotreat CO₂ SOLUTIONS · VDL AEC MARITIME · H MARINE CONTRACTORS · MAN Energy Solutions · JÜLICH Forschungszentrum · TotalEnergies

SINTEF · BUREAU VERITAS · akp · BLUE MARITIME CLUSTER · SCCS · Lloyd's Register · Los Alamos NATIONAL LABORATORY · NexantECA · DNV · ANTHONY VEDER

EverLoNG

Thank you for listening

Lavinia Reitz, l.reitz@fz-juelich.de

WP5: Regulatory framework for SBCC

Webinar, 13th March 2025, WP5

Erik Vroegrijk, Lloyd's Register EMEA

Partners: BV*, DNV*, HMC, TotalEnergies, Conoship, AV, TNO, Bouman, VDL, SCCS

* Report authors

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WP5: Objectives

- Analyze & review the Ship-Based Carbon Capture (SBCC) technology to determine **safety challenges** for the use cases identified in WP3.
- Address the **alternative design and arrangements** for the novel SBCC technologies on LNG fueled ships (EverLoNG) with the design process, see WP1, WP2 and WP3.
- **Disseminate** the insights created during this work package to the relevant international bodies to educate and inform the wider maritime industry of the SBCC technology.
- *Note: Class and Regulatory approvals were beyond the scope of this research project*

CO_2 pipeline rupture test by Dalian University of Technology in China. Source: https://www.youtube.com/watch?v=JCIbClPbrsU

WP5: Drivers

CO_2 concentrations and impact on life:

- **400 ppm** (0.04%) Typical indoor level
- **900 ppm** (0.09%) Highly congested urban areas
- **5,000 ppm** (0.5%) OSHA Permissible Exposure Limit (PEL) and ACGIH Threshold Limit Value (TLV) for 8-hour exposure. UK HSE long term exposure limit (8-hours).
- **10,000 ppm** (1.0%) Typically no effects, possible drowsiness
- **15,000 ppm** (1.5%) Mild respiratory stimulation for some people. UK HSE short term exposure limit (15 minutes)
- **30,000 ppm** (3.0%) Moderate respiratory stimulation, increased heart rate and blood pressure, ACGIH TLV-Short Term
- **40,000 ppm** (4.0%) Immediately Dangerous to Life or Health (IDLH)
- **50,000 ppm** (5.0%) Strong respiratory stimulation, dizziness, confusion, headache, shortness of breath
- **80,000 ppm** (8.0%) Dimmed sight, sweating, tremor, unconsciousness, and possible death

Source: FSIS Environmental, Safety and Health Group - Carbon Dioxide Health Hazard Information Sheet

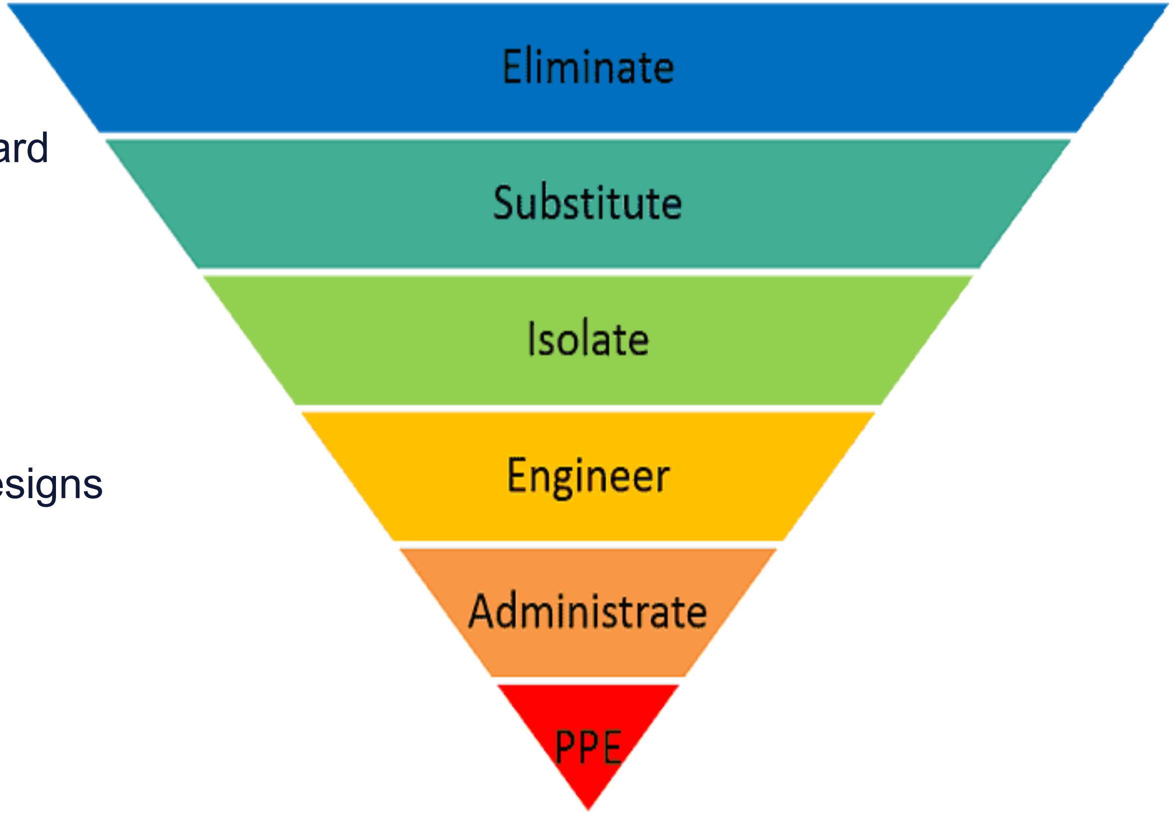
WP5: Drivers

Hit the ground running

- Active involvement in the risk assessments for the onboard demonstrator

Why?

- Risk and design are strongly interlinked
- Early identification = Easier Control = Inherently safer designs
- Risk reduction is a process and a mindset



WP5: Tasks

Task 5.1 Review of existing regulatory regime applicable to ship-based carbon capture

- Identify applicable safety and environmental standards and codes associated to SBCC
- Categorization of new technology
- Identify the major hazards of CO_2 loss of containment in the marine environment

Task 5.2 Risk assessment of the full-scale design use cases

- Perform a risk assessment(s) of the preliminary design
- Identify commonality safeguards from the risk assessments

Task 5.3 Disseminate SBCC among international regulatory regimes

WP5: Results – Task 5.1

Subtask 5.1.1 Identify applicable safety and environmental standards and codes associated to SBCC:

- System level
- Component level
- Regulations
- Rules (IACS and Class)
- Guidelines

CO2 storage sub-systems	Key components / risks	Risk	Regulations: Relevant regulations	Type	Existing (Y/N)	Reference	Link	Summary of scope and content	Comment
	Exhaust flue gas line	backpressure SOX/NOx content Asphixiation, High temperature unburnt fuel (methane,...)	Safety	International		IACS UR M78		Safety of Internal Combustion Engines Supplied with Low Pressure Gas - Rev.1 Feb 2021	special attention if manned space -- the carbon capture system built-up back pressure calculation shall be submitted: - the built-up back pressure in the carbon capture systems shall not exceed the fuel consumer allowable back pressure curve(s);
			Safety	International		IGC code or IGF		IGC code or IGF Code	special attention if manned space - carbon capture system back pressure calculation shall be submitted; - the built-up back pressure in the carbon capture systems shall not exceed the fuel consumer allowable back pressure curve(s);
									monitoring of pressure, exhaust bypass needed
									temperature monitoring with interlock
									liquid level monitoring or pressure monitoring Bilge alarms
								Safety measures against chemical treatment fluids used for exhaust gas cleaning systems and the residues which have hazardous properties - New Jan 2021	drip tray, spray protection
									crew training, appropriate PPE
									amount of water in exhaust gases may be high (2 mols H20 per 1 mol CH4)
								2021 Guidelines for exhaust gas cleaning systems	similar to scrubber (discharge requirement)
									all regulation on thermal oil systems

CO_2 systems	Specific component	Hazard category	Hazard	Category
1. Capture	After regeneration tower	LoC of CO_2	Asphyxiation / toxicity	Safety, Environmental
		ine	Flammability Chemical Pollution	Safety, Health, Environmental
		istic	Chemical	Health
		rmal oil	Flammability High temperature Pollution	Safety, Environmental
		ter	High temperature Pollution	Safety, Environmental
		al	Malfunction, poor operation	Safety, Operational
			Unburn fuel, SOx,	Environmental

Entity	Reference	Field	Scope	Applicable to:
IMO	SOLAS	Safety	Safety Of Life At Sea Convention	Part II-1 and II-2 gives generic requirements applicable to equipment regardless of their specificities as SBCC
	IGF CODE	Safety	Code of Safety for Ships using Gases or other Low-flashpoint Fuels	Guidelines as it is applicable to the use of tanks other than CO2 tanks
	IGC CODE	Safety	Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk	Guideline as it is applicable to the sea transportation of liquefied CO2 in bulk

WP5: Results – Task 5.1

Subtask 5.1.3 Categorization of new technology:

Technology used for	Application area	Technology status	Existing regulations
Flue gas quenching	Known	Proven	Class rules for exhaust gas scrubbers
CO_2 recovery	New	Proven	Class rules for piping systems and pressure vessels
Solvent regeneration	New	Proven	Class rules for piping systems and pressure vessels
CO_2 compression	Known	Proven	Class rules for Gas carriers
CO_2 liquefaction	Known	Proven	Class rules for Gas carriers, IGC Code Class Rules for fishing vessels using ammonia refrigerant
CO_2 storage	Known	Proven	Class rules for Gas carriers, IGF Code, IGC Code
CO_2 offloading	New	Proven	Class rules for Gas carriers, IGF Code, IGC Code

WP5: Results – Task 5.1

Subtask 5.1.2 Identify the major hazards of CO2 loss of containment in the marine environment:

Why?

- No matter how good systems are designed, build and maintained, there is always a residual risk of equipment and pipework failure

Aim:

- To deliver to designers, as well as reviewers, order of magnitude estimates for a wide range of CO_2 release scenarios

How?

- Engineering diagrams based on gas dispersion analyses

WP5: Results – Task 5.1

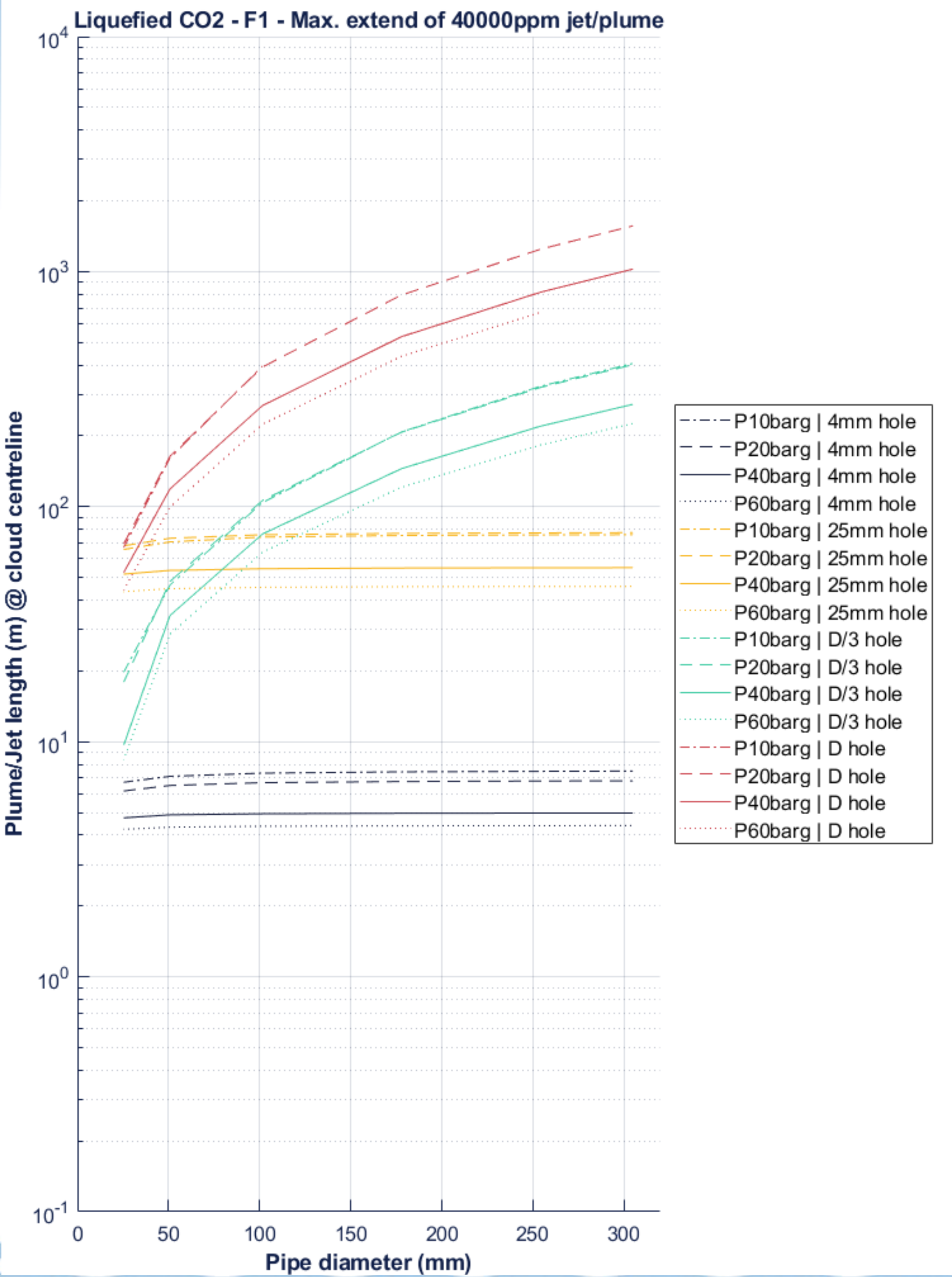
Subtask 5.1.2 Identify the major hazards of CO_2 loss of containment in the marine environment:

Results:

- Plume/Jet length vs. diameter
- Plume/Jet length vs. hole diameter
- Concentration vs. hole size
- Release rate vs. pipe diameter and hole size
- Expanded volumetric release

Based on:

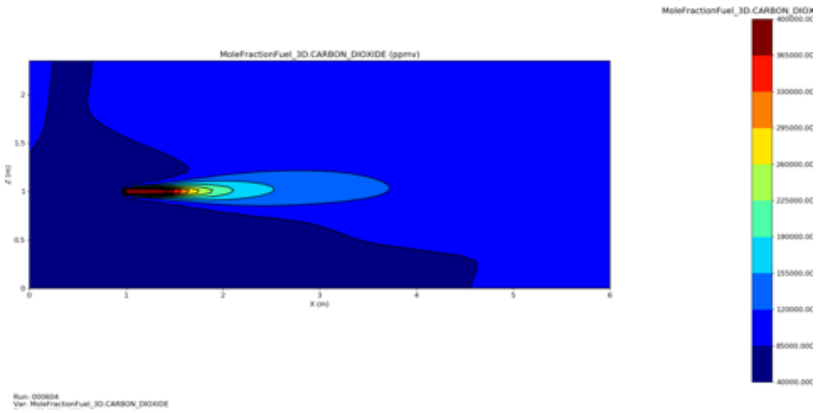
- Unified weather conditions for marine dispersion analyses for 54 ports around the world

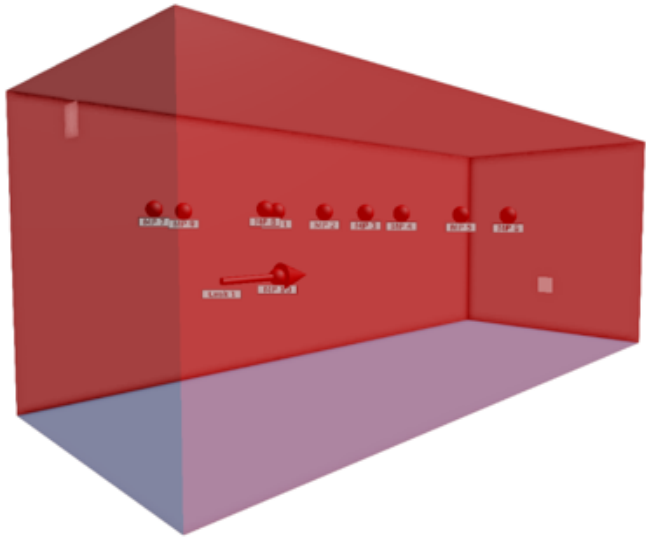


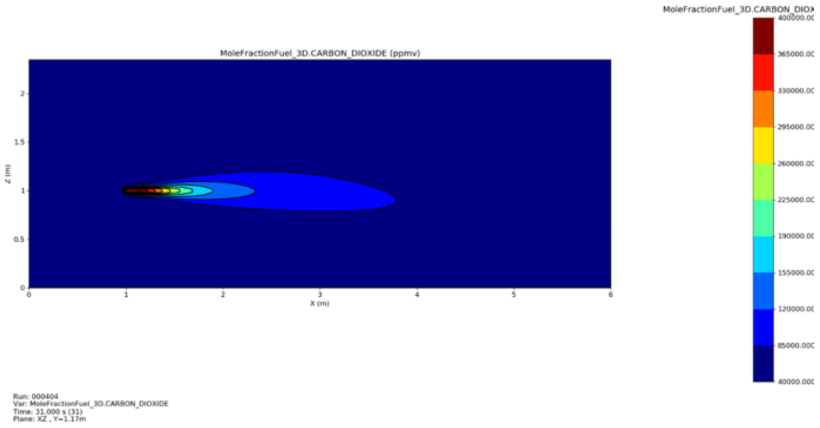
WP5: Results – Task 5.1

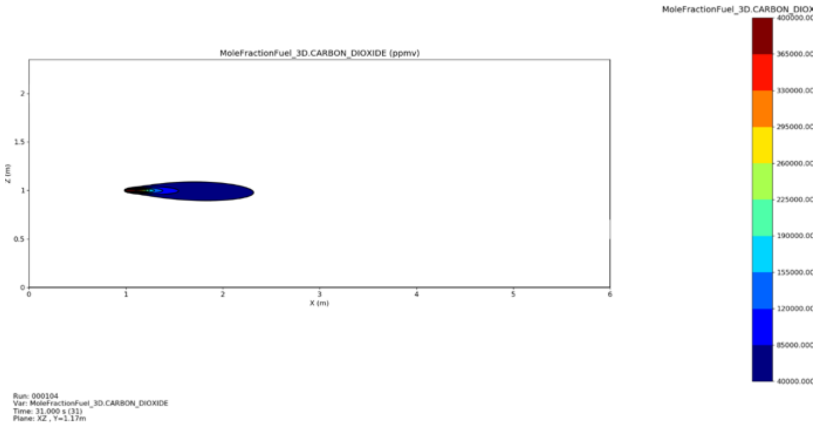
Subtask 5.1.2 Identify the major hazards of CO_2 loss of containment in the marine environment:

- Indoor (confined space) 20ft container
- 60, 40, 10 barg releases
- Reasonable match with concentration build-up from outdoor release rate









WP5: Results – Task 5.1

Conclusions:

- For the technologies used in Ship-Based Carbon Capture (SBCC) systems Regulatory and Class Rules frameworks exist that allow for their safe implementation onboard.
- Where prescriptive Rules and Regulations are missing, the alternative design assessment pathways are suitable and available, with knowledge gained from other parts of the shipping industry, i.e. LNG.
- The risks associated with SBCC installations are credible but well understood, with well-established safeguards and design principles available from other parts of the marine industry, like LNG-fuelled vessels.

- **In short, this technology can be implemented <u>today</u>**

- The full report for Task 5.1 is available to the public and be downloaded here: https://everlongccus.eu/about-the-project/results

WP5: Results – Task 5.2

Task 5.2: Risk assessments

- Full scale concept designs developed in WP3 for:
  - HMC - SSCV Sleipnir
  - TotalEnergies LNG Carrier
- Pre-HAZID meetings to further design
- Full HAZID workshops for both vessels with multidisciplinary SMEs

	Intolerable risk
	Tolerable risk - ALARP
	Broadly acceptable

				Consequence				
				C1	C2	C3	C4	C5
				Minor Injury	Major injury	One fatality or multiple major injuries	2-10 Fatalities	11+ Fatalities
Likelihood	L7	Extremely Likely	$\leq 10^{0}$ to $10^{-1}/_{y}$					
	L6	Very Likely	$\leq 10^{-1}$ to $10^{-2}/_{y}$					
	L5	Likely	$\leq 10^{-2}$ to $10^{-3}/_{y}$					
	L4	Unlikely	$\leq 10^{-3}$ to $10^{-4}/_{y}$					
	L3	Very Unlikely	$\leq 10^{-4}$ to $10^{-5}/_{y}$					
	L2	Extremely Unlikely	$\leq 10^{-5}$ to $10^{-6}/_{y}$					
	L1	Remote	$\leq 10^{-6}/_{y}$					

WP5: Results – Task 5.2

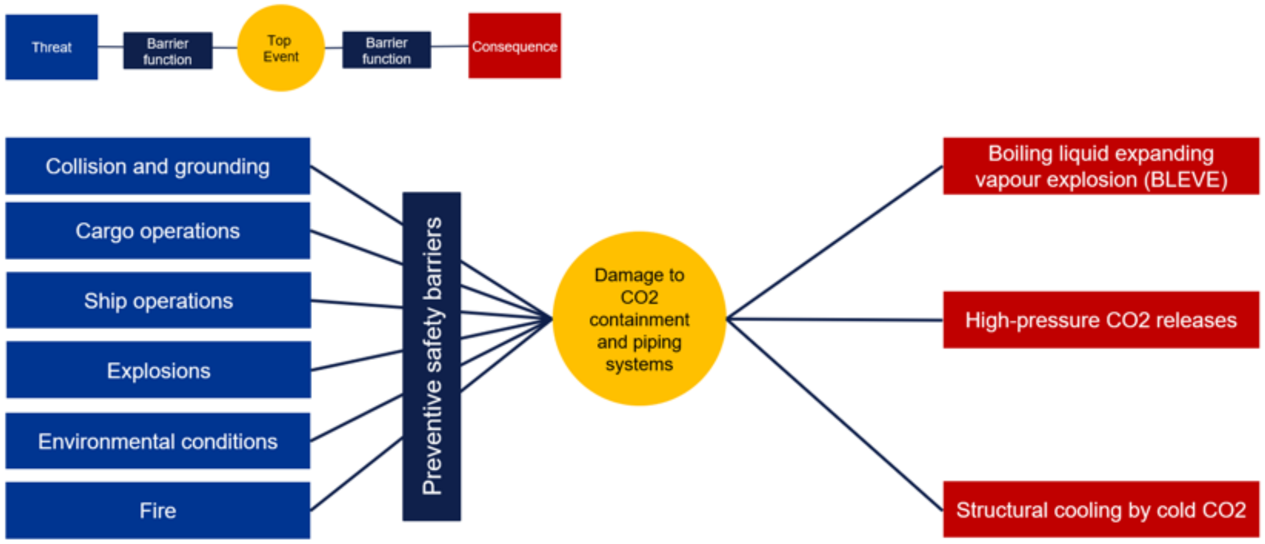
Generic recommendations:

- Consider **ship motions and vibrations** in the design, not only in terms of mechanical strength, but also in terms of sensor accuracy and reading frequency
- Consider **dropped objects** in the placement of equipment and pipework
- Carry out gas dispersion analyses for **credible release *(leak & vent)* scenarios**
- Consider **automatic leak detection** tests on suitable moments *(i.e. start-up / shut-down)*
- **Firefighting** medium to be appropriate for chemicals used
- Where practicable, use drip trays and spray guards to **control solvent *(MEA)* leakages**
- Setup and discuss with Class the **toxic area plan** as early as possible *(note: CO2 is considered toxic)*
- Consider the potential for **human failure** in the control and monitoring system design *(overwrites)*
- Safeguard against **trapped LCO_2 and CO_2** solidification by design
- Include the offloading of LCO2 in the **SIMOPS** risk assessments

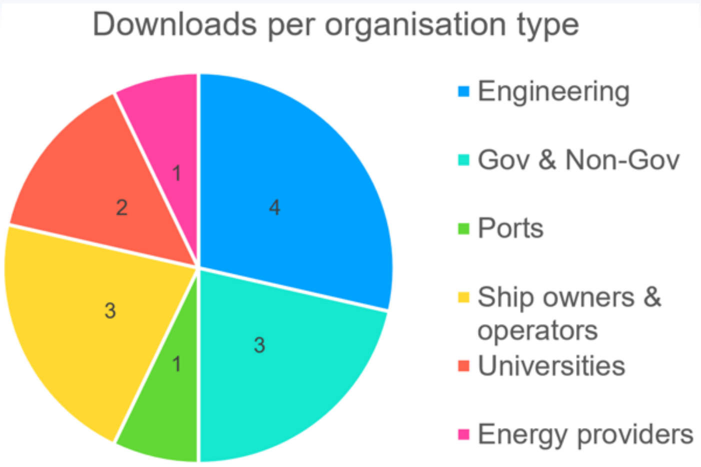
WP5: Results – Task 5.2

Generic safeguards:

- Derived from the full scale HAZID workshops
- Organised by SBCC safety risks and comprehensively explained
- Report on the generic safeguards is available to the public and be downloaded here: https://everlongccus.eu/about-the-project/results



WP5: Results – Task 5.3



Task 5.3: Dissemination

- Publication of the Task 5.1 report instead of keeping it confidential to the consortium
    - *Downloaded by 14 organisations outside consortium, not significantly more than in October 2023*
    - *Thanks for tracking Richard Lo Bianco (SCCS)*
- Presentation at the IMO CCC 9 on 20/09/2023
    - *Great feedback. Lots of interest for LCA and TEA.*
    - *Main question: Will CO_2 be considered waste or a product in the future?*
- Presentation to the IMO's *"Correspondence Group (CG) on Regulatory Framework for Ships Using New Technologies and Alternative Fuels"*, which will report to the Marine Safety Committee (MSC) 108
    - ***59 delegations present***

WP5: Food for thought

Open questions:

- Where to place the CO_2 vent masts?
  - *Due to the high density relative to air, it will likely be beneficial to place the vent masts low and pointing downward at an angle (i.e. 45 degrees). This way the release momentum is used to create a very low-level cloud on the sea surface, which will than naturally dissipate.*
- Can we standardise CO_2 offloading across the globe, i.e. storage pressures and temperatures?
  - *From a practicable point of view, full standardization most likely unfeasible and from an efficiency point of view perhaps not even desirable. The working assumption that there will be some form of gas processing on the LCO2 barge/carrier seems more reasonable.*
- How to fairly accredit SBCC in EEDI, EEXI, COI, Fuel EU, IMO LCA, etc.?
  - *The MEPC has started a working group on this topic. It will mostly be a political debate, noting that the "unit" for EEDI is grams of CO_2 per tonne-mile.*
- Is captured CO_2 a "product" or a "waste" and how should it be certified?
  - *Most likely outcome that CO_2 will be considered a "waste", with a future ratification of the London Protocol.*

WP5: Food for thought

Concluding:

- Why SBCC?
  - *Most mature technology available today to make a direct impact on the CO_2 emitted by shipping, which can not only be applied to newbuilds, but can also be retrofitted to existing vessels, therefore considerably increasing the potential CO_2 reduction.*

- Doesn’t SBCC delay the uptake of future fuels, like ammonia and hydrogen?
  - *On the contrary, SBCC in combination with LNG fuel is a credible long-term solution that can assist with achieving net zero faster. Experience with LNG fuel is a steppingstone for the implementation of future fuels, for they require levels of risk management that exceed those on LNG vessels and chemical tankers. Hence, future fuels not only require a change in equipment, but overall company management and culture, which takes time, training and dedication.*

Partners

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U.S. DEPARTMENT OF
ENERGY

Thank you for listening

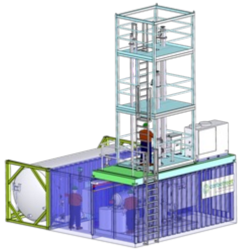
For questions, please contact:

Erik Vroegrijk, erik.vroegrijk@lr.org

info@everlongccus.eu **@everlongccus** **www.everlongccus.eu**

What next for EverLoNG, OCC and concluding remarks

- We have shown highlights of our journey from design to build to capture campaigns, as well as many results on infrastructure/logistic challenges, ship integration, LCA/techno-economics, and safety & regulations
- EverLoNG ends now but the website will be up and running for another 2.5 years, and public deliverables will be published soon !
- There is not a concrete follow-up with the full consortium, we are open for suggestions and new opportunities
- However, certain individual efforts are ongoing like Dutch partners investigating National opportunity for large and long-term demonstration



Q&A

Partners

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Thank you for listening

Marco Linders, marco.linders@tno.nl

info@everlongccus.eu **@everlongccus** **www.everlongccus.eu**