Large Engines Competence Center

Carbon Capture on board a ship

June 20, 2023 • **Nicole Wermuth** / Igor Sauperl / Andreas Wimmer

Agenda

- Pre-combustion carbon capture
  → EU Horizon2020 project "HyMethShip"

- Post-combustion carbon capture
  → FVV-project "CCS on Ships"

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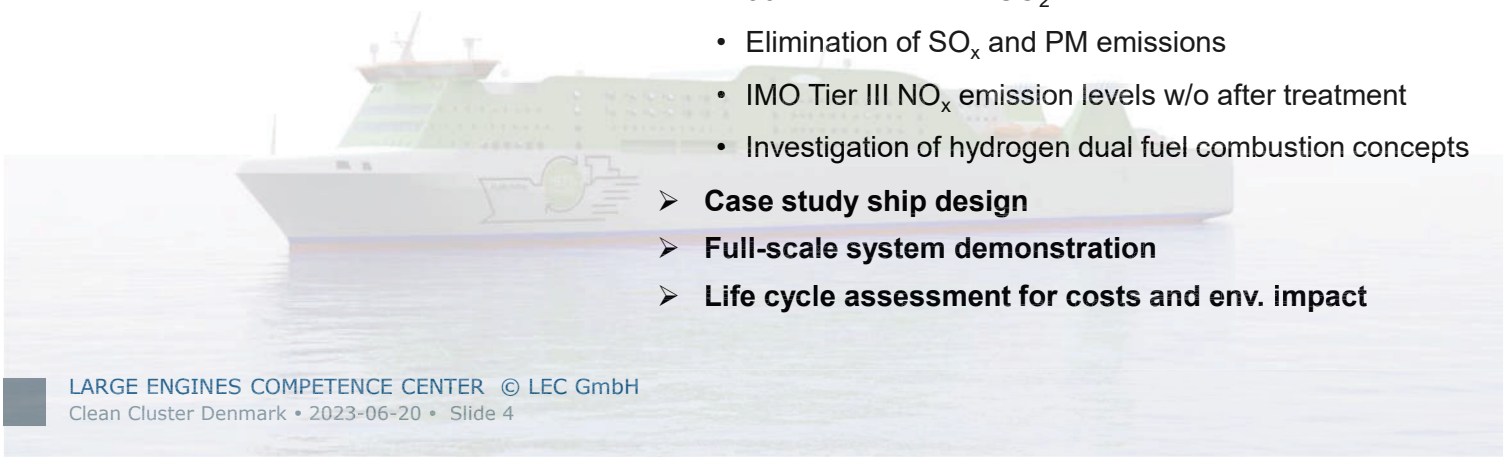
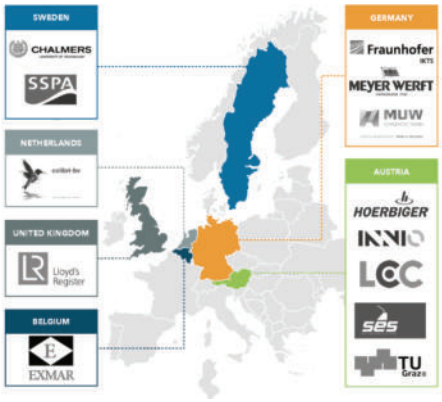
The Goals & Path

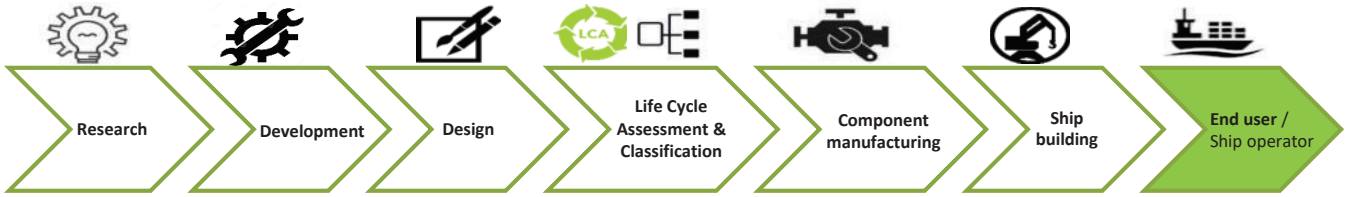
HyMethShip Project

- **Funded from the European Union's Horizon 2020 research and innovation program under grant agreement No 768945**
- **Emissions reduction goals**
  - 90+ % reduction in CO_2 emissions
  - Elimination of SO_x and PM emissions
  - IMO Tier III NO_x emission levels w/o after treatment
  - Investigation of hydrogen dual fuel combustion concepts
- **Case study ship design**
- **Full-scale system demonstration**
- **Life cycle assessment for costs and env. impact**

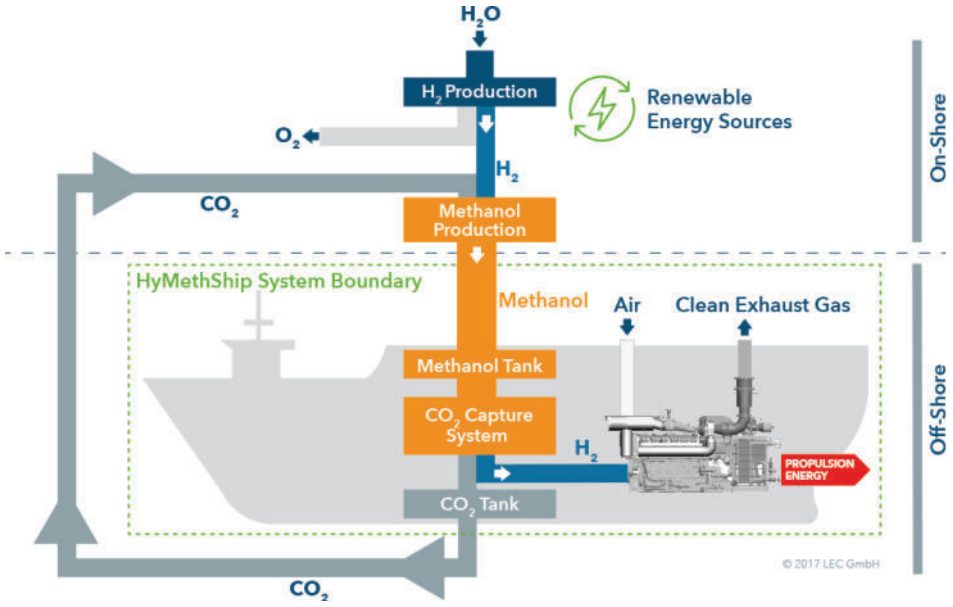


Project Consortium:
6 countries, 13 organizations

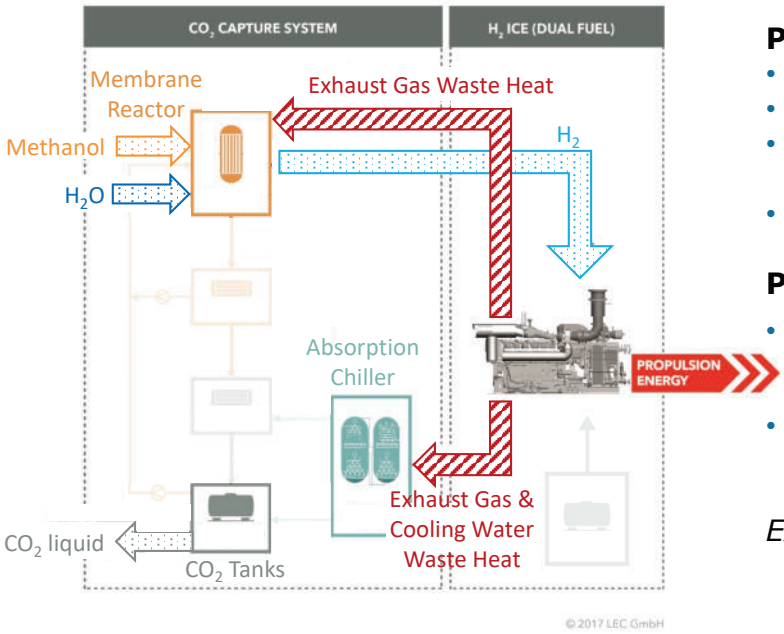




The Concept



On-board Setup



Pre-combustion carbon capture system

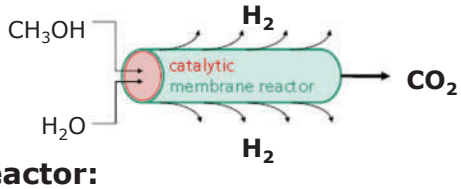
- Receiving liquid methanol & water
- Producing hydrogen fuel using waste heat
- Liquefying CO2 w. cooling driven by waste heat
- Feeding liquid CO2 to tanks

Propulsion engine

- Consuming hydrogen fuel
  - Methanol used as back-up fuel
- Supplying waste heat for reformation and carbon capture

Exhaust gas temperature > 400 °C !

Methanol Reformer



Two processes in the same reactor:

- Catalytic methanol reforming ($CH_3OH + H_2O \rightarrow CO_2 + 3H_2$)
- H_2 separation via membrane permeation

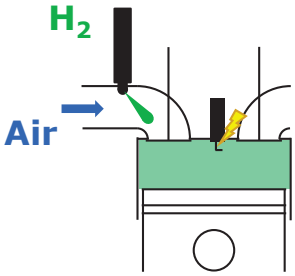
Ceramic-based carbon membrane technology

- Free of precious metals
- Reaction pressures up to 50 bar
- H_2 pressures 10-20 bar
- Low risk of poisoning (e.g. from CO)
- Membrane tubes stacked together working in parallel in pressure vessel

Photo by LEC GmbH

Photo by MUW Screentec GmbH

Dual-Fuel Engine – H_2 or MeOH operation

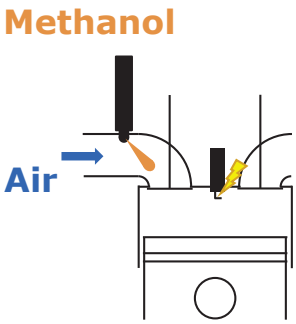


Standard operation

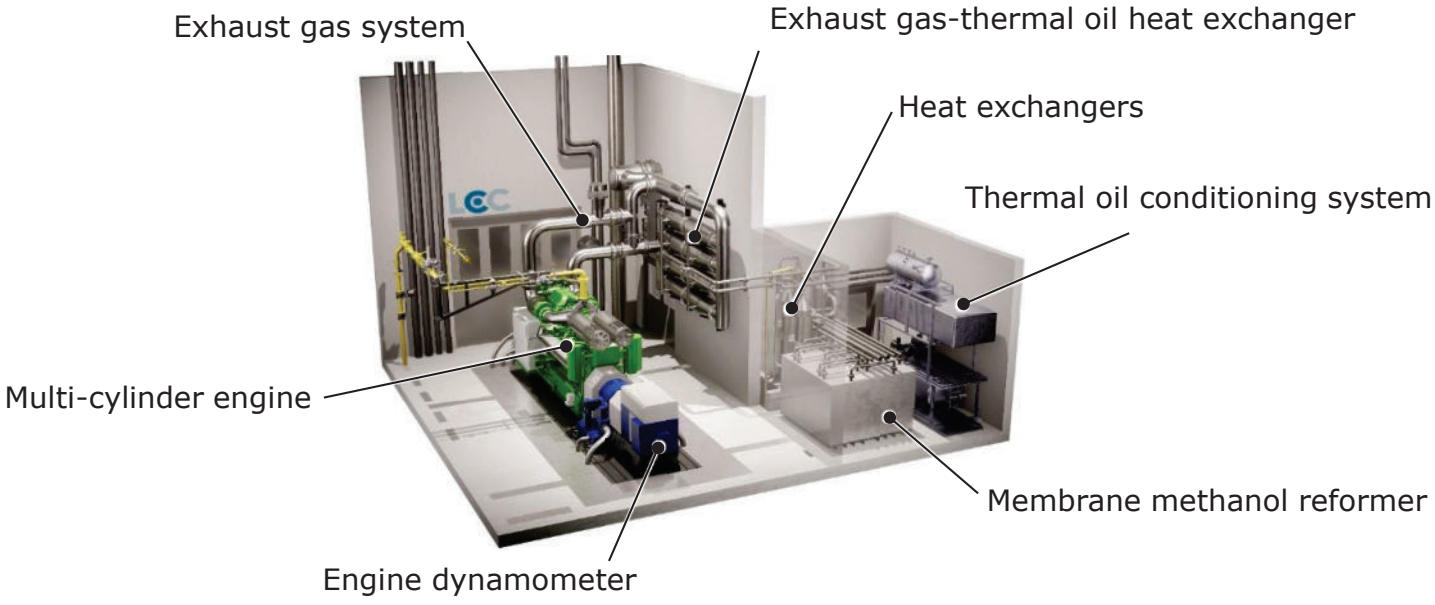
Hydrogen combustion – medium pressure port fuel injection & spark ignition.

Redundancy / back-up operation

Methanol combustion - spark ignition system for hydrogen as well as for methanol combustion. Reduced emissions, no diesel fuel systems required



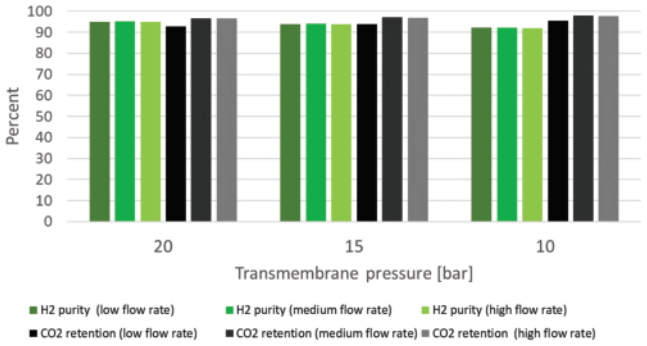
Technology demonstration



Membrane separation performance

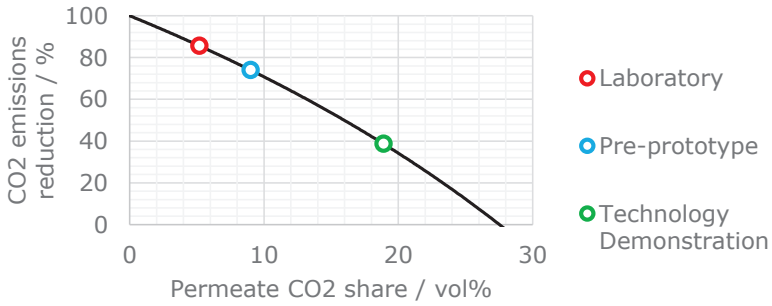
Membrane performance in laboratory environment at IKTS

- Hydrogen purity in permeate stream > 90 %
- CO_2 retention in retentate > 95 %



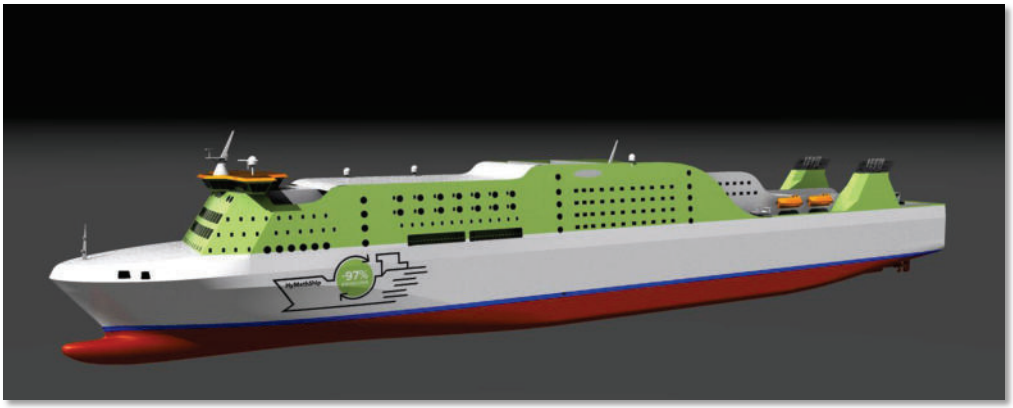
Membrane performance in reformer environment shows lower selectivity than in laboratory environment

- Operating conditions under investigation
- Next generation membrane technology in development



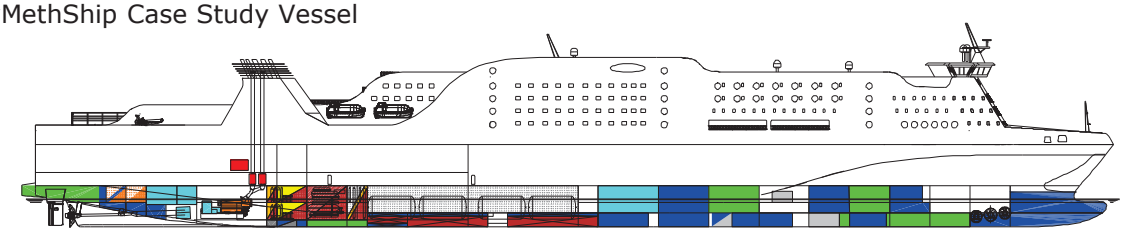
Case Study Vessel

- RoPax ferry with fixed operating route Gothenburg-Kiel: 236 nautical miles one way
- Electrical generation power 4 x 5 MW (+2.3 MW emergency generator)
- Propulsion power ≈ 18 MW
- Vessel model for detailed design of system integration and use in HazId/HazOp

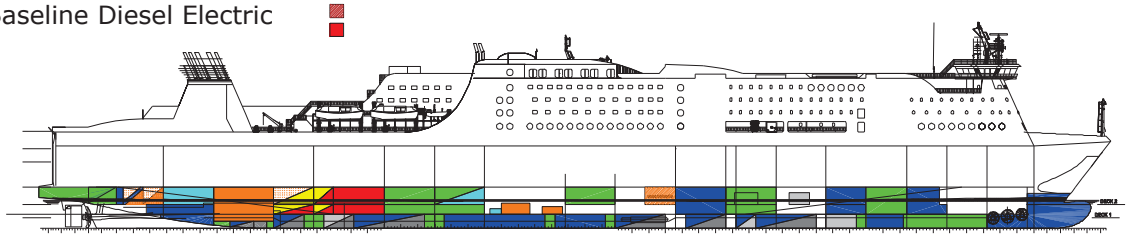


Placement of main systems - comparison

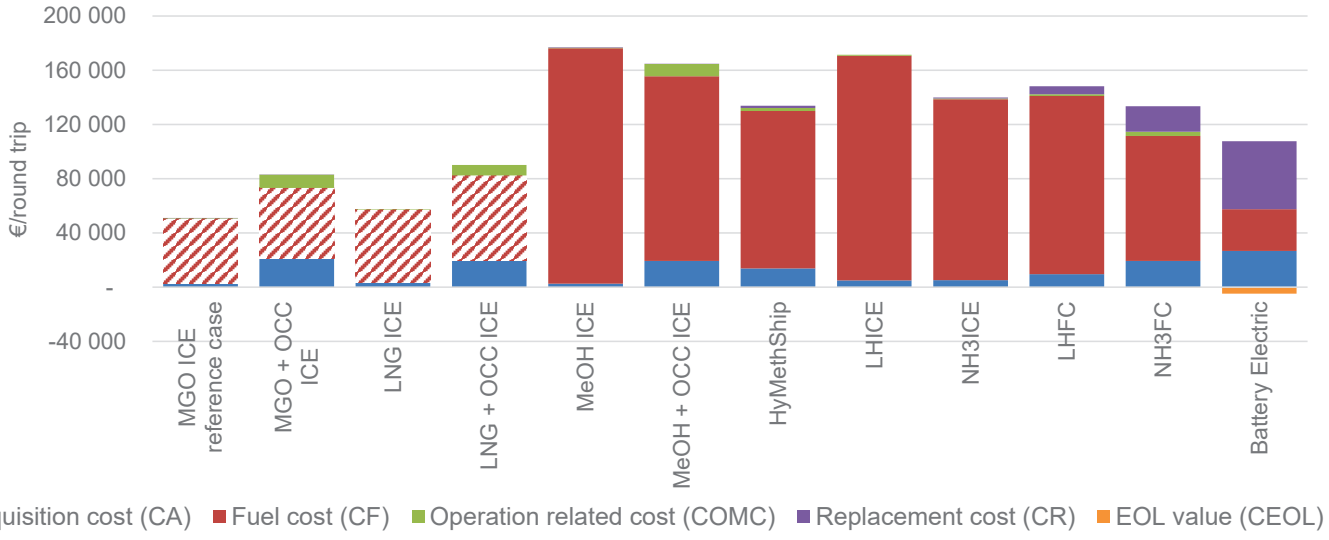
HyMethShip Case Study Vessel



Baseline Diesel Electric

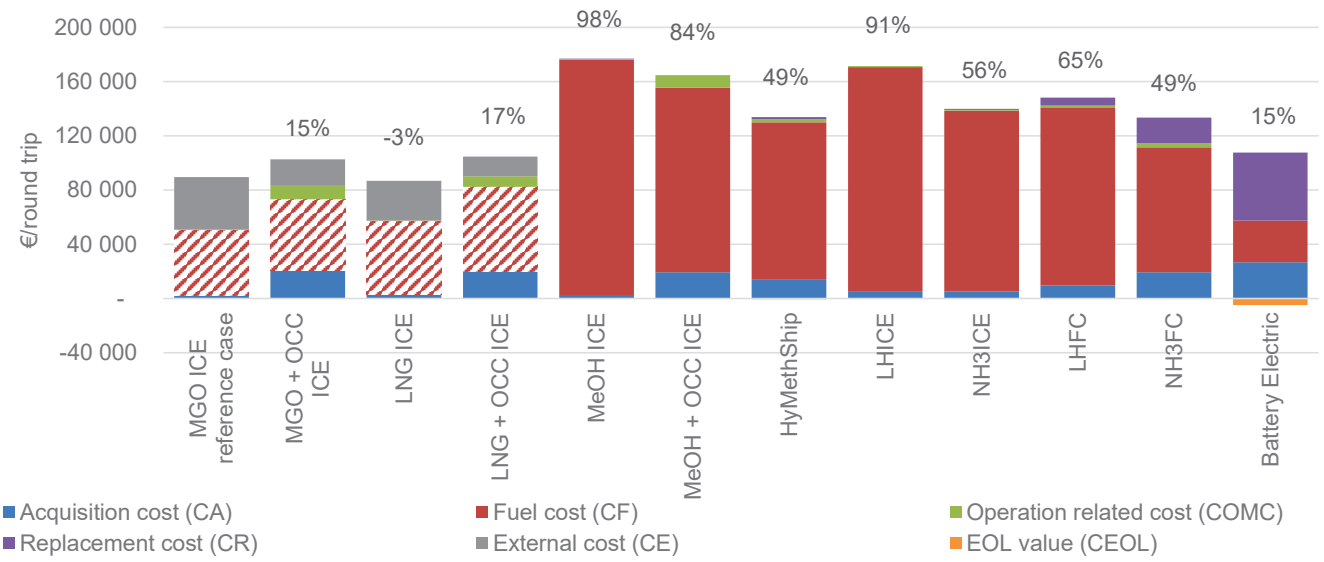


Life cycle cost of low carbon options



Source: Kanchiralla et al. (2021)

Life cycle cost of low carbon options



Example of the impact of a carbon tax of 150 Euro/tonne CO_2

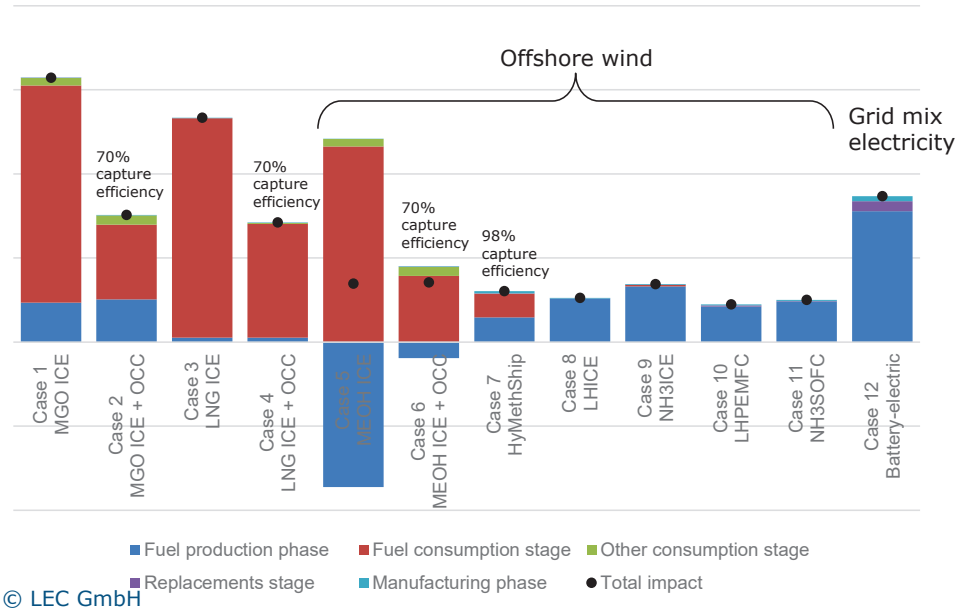
Source: Kanchiralla et al. (2021)

Life cycle climate impact

Global warming potential 100-year time perspective

Source: Kanchiralla et al. (work in progress)

- The HyMethShip system reduced climate impact with about 80% in a life cycle perspective
- Climate impact in the same order of magnitude as hydrogen and ammonia propulsion systems



The Wrap-up of HMS

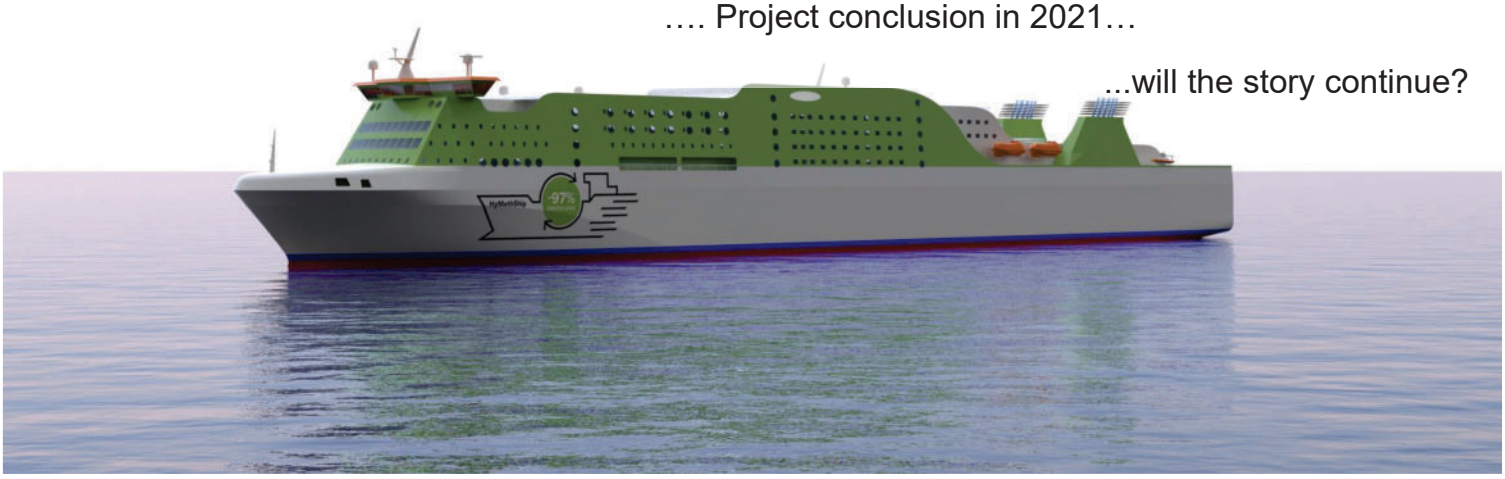
High H_2 / CO_2 selectivity of membranes

Full scale engine operation with 100 % hydrogen

Onshore system demonstration complete

…. Project conclusion in 2021…

...will the story continue?



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LEC ENERsim

A versatile simulation platform for the optimization of sustainable energy systems

Features

- Energy flexibility: electricity, heat, fuels (H_2, CH_4, ...)
- Energy storages
- Energy markets
- Sector coupling
- Data driven controls

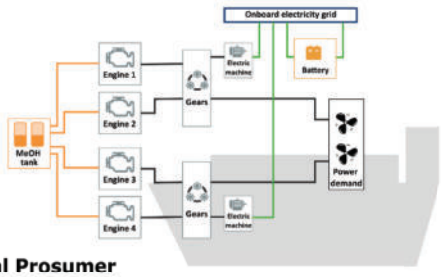
Applications

- Power plants (industrial or utility)
- Maritime systems / shipping
- Microgrids
- Supraregional energy systems

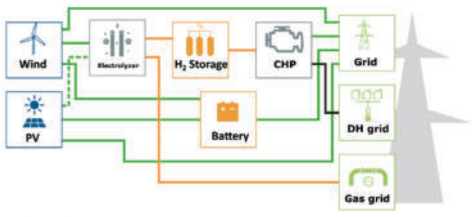
LEC ENERsim application examples

Energy source
Energy Storage
Energy Grid
Energy Converter
Energy Demand

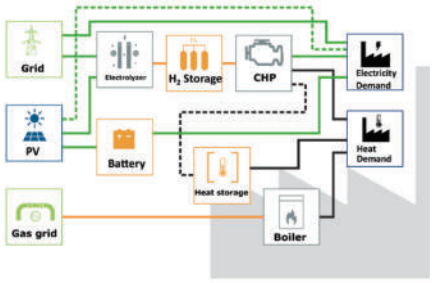
Maritime energy system



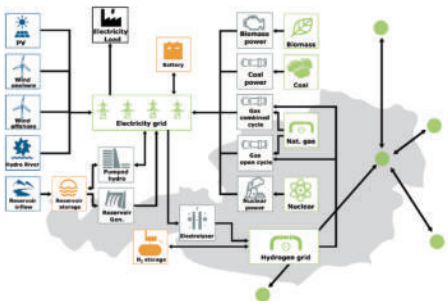
Renewable energy power plant



Industrial Prosumer

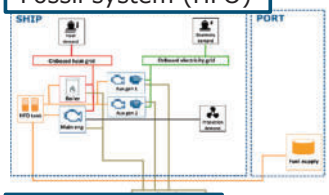


National energy system

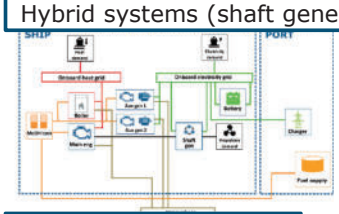


LEC ENERsim example: ship systems

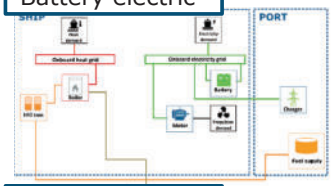
Fossil system (HFO)



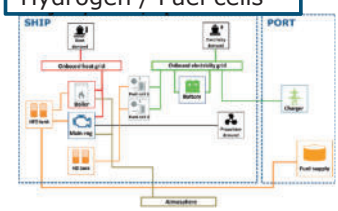
Hybrid systems (shaft generator)



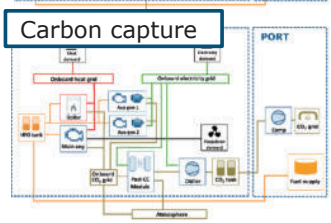
Battery electric

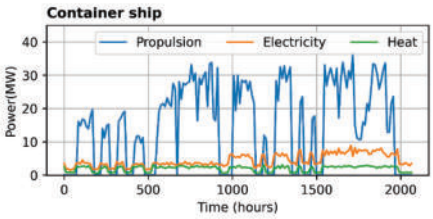


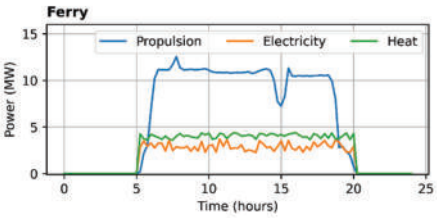
Hydrogen / Fuel cells



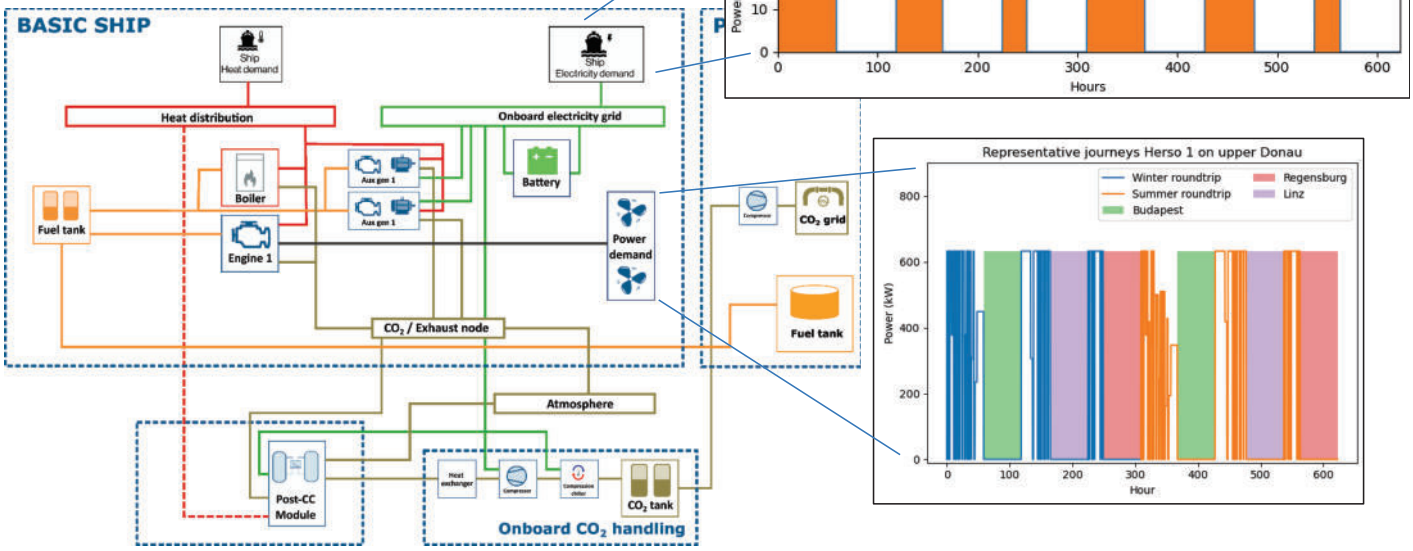
Carbon capture







System simulation: postCC setup



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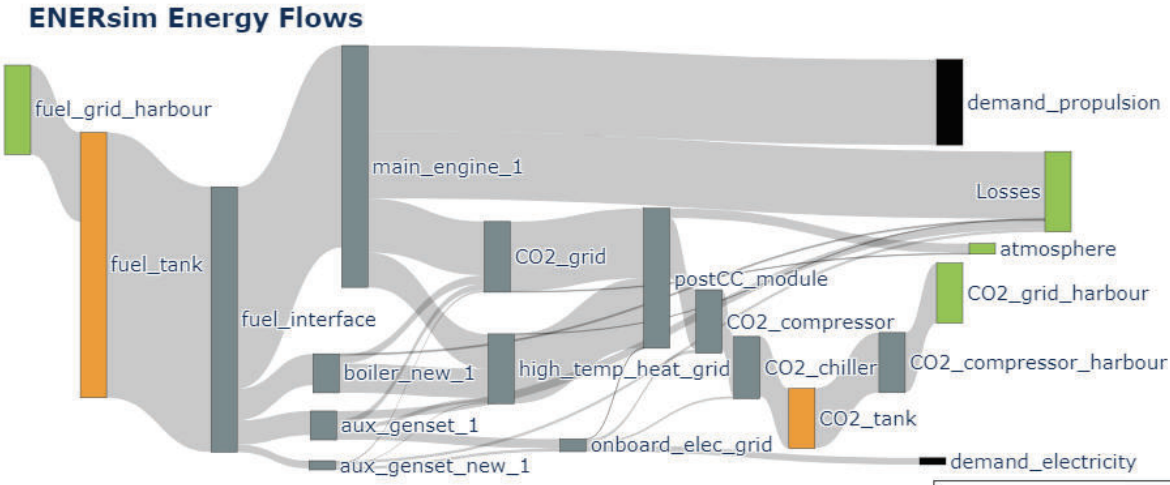
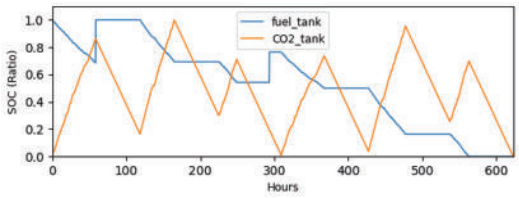
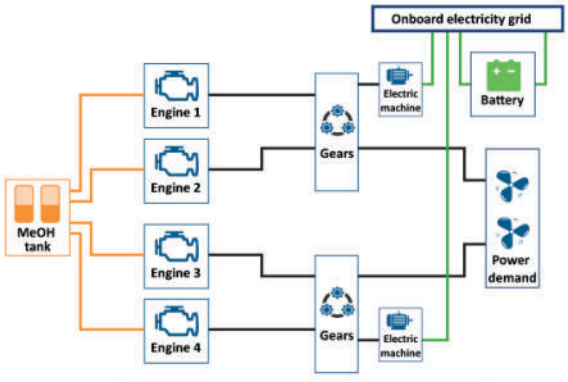


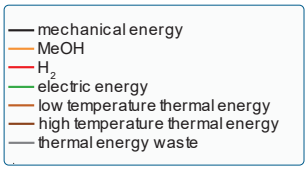


*Energy demand CC: 4.17 GJ/t_CO2 (170°C); Capture efficiency: 85.6%

LEC ENERsim | Propulsion Concept 1

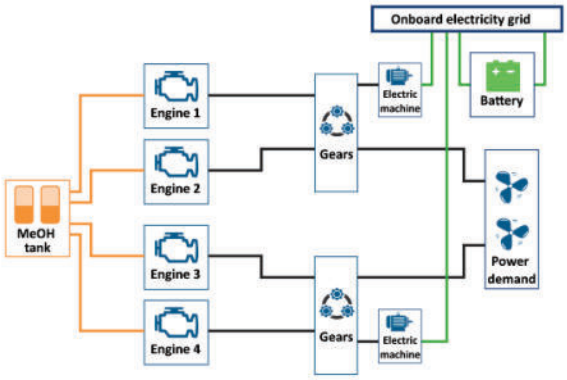
Concept 1



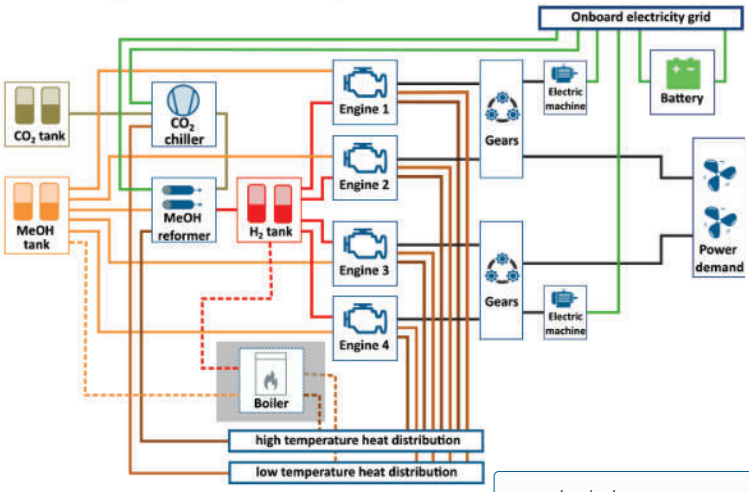


LEC ENERsim | Propulsion Concept 1, 2 & 3

Concept 1

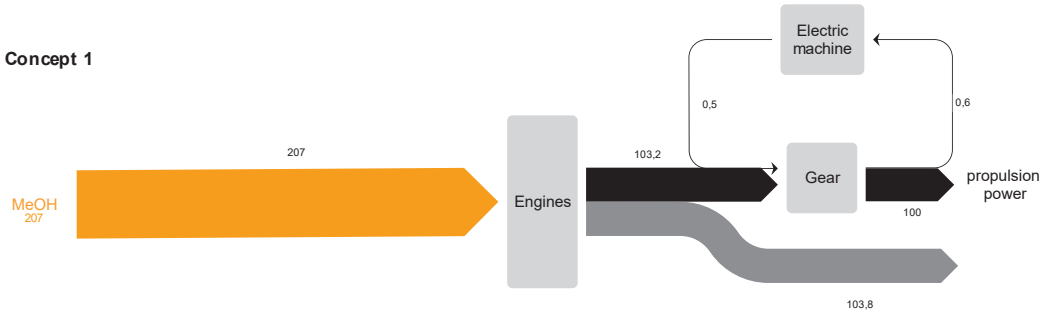


Concept 2 / Concept 3



- mechanical energy
- MeOH
- H_2
- electric energy
- low temperature thermal energy
- high temperature thermal energy
- thermal energy waste

Energy Flows | Concept 1 @ 100 % load



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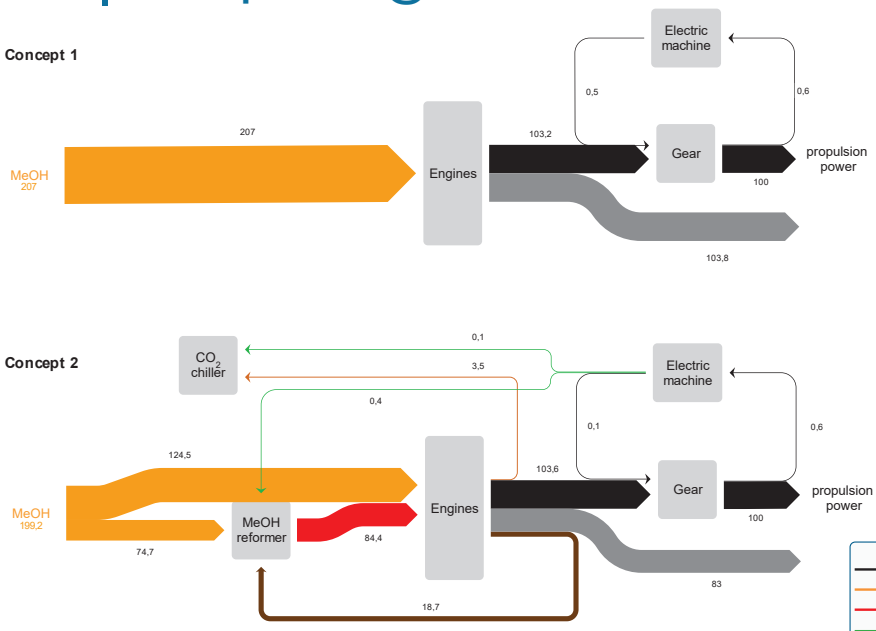
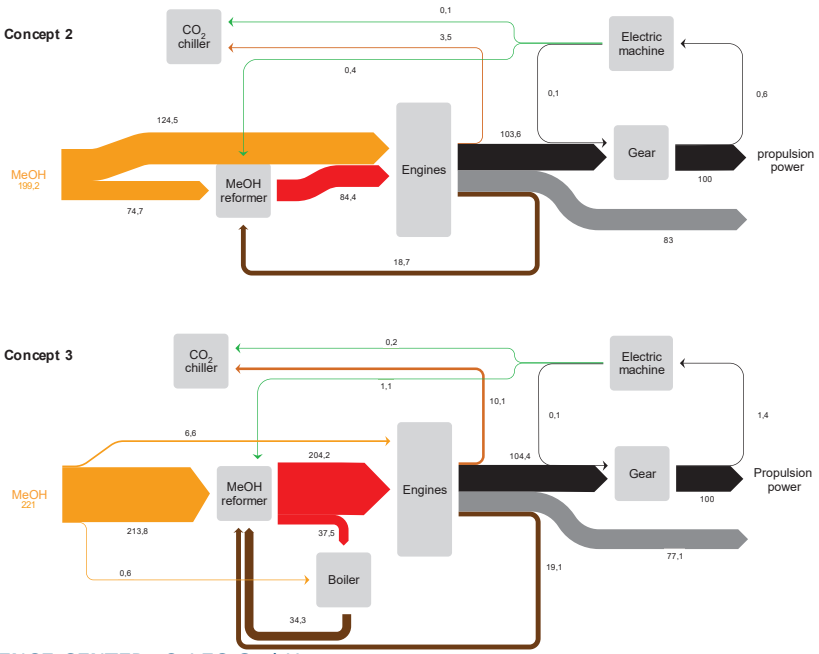
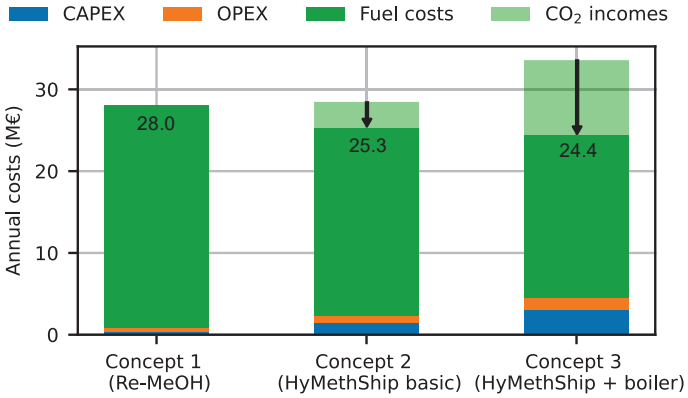
Energy Flows | Concept 1 & 2 @ 100 % load

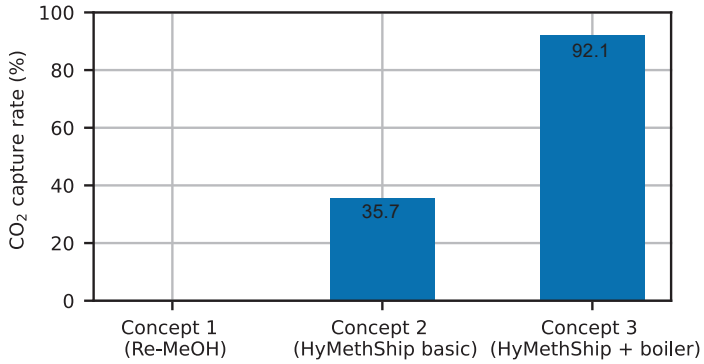


Energy Flows | Concept 2 & 3 @ 100 % load



Concept Comparison | Annual Costs & CO_2 Capture Rates





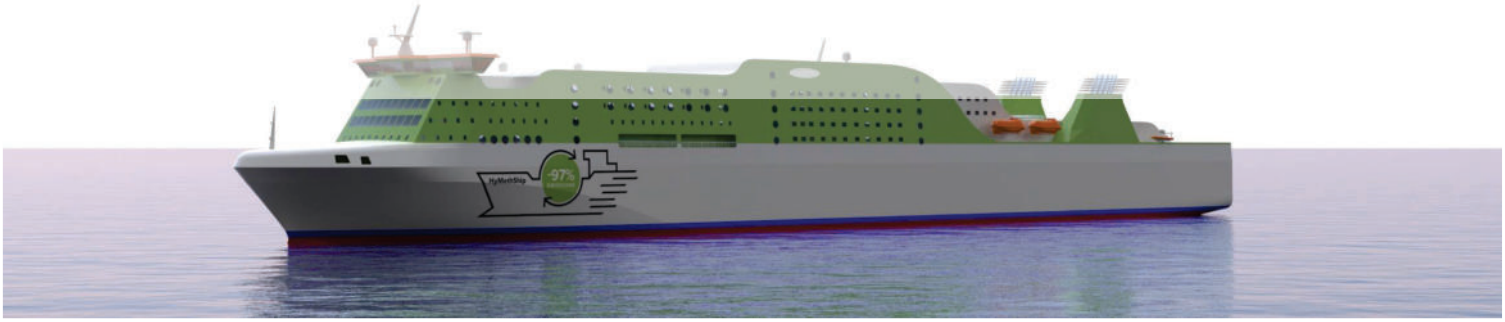
Summary

Carbon capture on board a ship is feasible with pre-combustion and post-combustion concepts

Application of simulation platform LEC ENERsim to ship propulsion concept

Post-combustion: Assessment in progress

Pre-combustion: Cost advantage of pre-combustion carbon capture over pure methanol propulsion; integration of an additional boiler significantly improves carbon capture rates and further decreases annual net costs



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Thank you for your attention!



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