MCC – MARITIME CARBON CAPTURE

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WHY?

Around **90% of world trade** is carried by the international shipping industry

<table>
<thead>
<tr>
<th>Emissions</th>
<th>2012</th>
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<tbody>
<tr>
<td>CO₂</td>
<td>2.2%</td>
</tr>
<tr>
<td>NOx</td>
<td>30%</td>
</tr>
<tr>
<td>SOx</td>
<td>9%</td>
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Source: https://www.shipmap.org
MCC – DESIGN BASIS

Cargo ship with a 3000 kW Wärtsila 6L34DF engine

Fueled by LNG

+ CO₂ capture and storage

Is it technically feasible?
How much does it cost?
MCC – DESIGN BASIS

120 m

8000 TDW
DESIGN BASIS
LNG-FUELED SHIP BASICS

LNG storage tank
-160°C

Vaporizer 30°C

Engine 380°C

LNG

Exhaust gas
LNG-FUELLED SHIP BASICS

Heat sink

LNG storage tank

-160°C

Vaporizer

30°C

Engine

380°C

4.6 kg/s total
4.8 mol% CO₂

Heat source

LNG

Exhaust gas
CARBON CAPTURE AND LIQUEFACTION

- CO₂ capture by amines
  - Heat demand at ca. 120ºC (reboiler)

- CO₂ compression and liquefaction
  - Electricity demand
  - Cooling demand at ca. -20ºC
HEAT INTEGRATION PHILOSOPHY

- **LNG evaporation**
  - From -160°C to 0-30°C

- **CO₂ liquefaction**
  - From 40°C to -20°C

- **Exhaust cooling**
  - From 380°C to 40°C

- **Amine regeneration**
  - At 120°C
MCC – MARITIME CARBON CAPTURE

LNG storage tank
-160°C
-16°C

Vaporizer
30°C

Engine
380°C

Absorber
40°C

DCC
40°C

Reboiler
170°C

Lean-RichHX
100°C

Stripper

Dryer
40°C

DCC
150°C

CO₂ compressor
40°C

CO₂ storage tank
40°C

LNG

CO₂
Exhaust gas
Rich amine
Lean amine

07 June 2017
HEAT AND MASS BALANCES

Capture unit
Compression unit
Quench unit
Vaporizer
AVAILABLE HEAT: REBOILER

![Graph showing reboiler duty and available duty at different capture rates]

- **Reboiler duty, MW**
  - 381 max
  - 370 max
  - 350 max

- **Available duty, MW**
  - 0.6
  - 0.7
  - 0.8
  - 0.9
  - 1.0

- **Capture rate**
  - 60%
  - 65%
  - 70%
  - 75%
  - 80%
  - 85%
  - 90%
  - 95%
  - 100%

- **Design**
  - 90%
AVAILABLE HEAT: VAPORIZER

ΔT = 10°C

Heat duty, kW

Temperature, °C

LNG vaporization

CO2 liquefaction

Liquid CO2

CO2 cooling

NG heating

Dew point

Bubble point
SHIP RE-DESIGN

CO2 capture onboard LNG-fired ships
ADDED WEIGHT

- Equipment + amine + CO$_2$ storage tanks = 110 tonnes
  - 3% of ship capacity

- CO$_2$ weight depends on trip duration
  - At 90% capture rate:
    - CO$_2$ weight gain = 27 ton/day (44 g/mol)
    - LNG weight loss = 10.5 ton/day (17 g/mol)
    - Weight gain = 16.5 ton/day
  - For a 1 week trip: 115 tonnes gain
COST ESTIMATE – CCS

- Cost of CO$_2$ captured = 79 €/tonne CO$_2$
  - CAPEX = 75 €/tonne CO$_2$
  - OPEX = 4 €/tonne CO$_2$

- CAPEX = 8 million Euros

- 8000 TDW vessel ca. 10-12 million Euros

- Shipping cost: + 40% (with CCS)
CONCLUSIONS

- CO₂ capture on board of an LNG fuelled cargo vessel is **technically feasible**

- **Volume** and **weight** of equipment and CO₂ vessels are acceptable

- **Cost** is the major challenge
  - Lowering costs → focus on CAPEX
    - ✓ High pressure stripping
    - ✓ Cheaper materials of construction (lighter)

- LNG + CO₂ capture is a **promising** solution for the shipping industry
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More information on MCC?
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