Comparison of future fuels and technologies for shipping

Frauke Wiese
DTU MAN
System Analysis
90% of world trade is transported by ship

Shipping Emissions

- 2-3% of global greenhouse gas emissions [IMO 2015]
- Growth rates of 4% per year

- Predicted increase by 2050: 50% - 250% [IMO 2015]
- If unregulated, by 2050: 20% of global greenhouse gas emissions

⇒ Shipping is not on track to reach a 1.5 - 2°C climate goal
Shipping Emission Reduction Scenarios

Annual CO₂ emissions from the global shipping fleet, distinguished by business-as-usual and reduction scenario pathways.

Source: Boumann et al. 2017
Emission Reduction Measures: up to 75% by existing technologies

Source: Boumann et al. 2017
Current and upcoming regulation

CURRENT:
• Emission Control Areas
• Efficiency Standards
• Shipping outside UN Paris Agreement
• IMO 2016: Data Collection

FUTURE:
• EU 2018: Reporting for large ships using EU ports
• IMO 2018: Initial CO$_2$ reduction commitments to be agreed on

Source:
IMO / Andersson and Salzar 2015
Denmark – Role of Shipping

Ship Movements 31.October 2017 - 09:30
Source: Marine Traffic : https://www.marinetraffic.com
## Danish Shipping?

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<td>Danish ships within</td>
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Source: Own calculations based on:
- Energistyrelsen 2015 – Transport – Søtransport
- Statistics Denmark 2015 ([ENE1HA](https://example.com/ENE1HA) 50000 Water transport)
## Danish Shipping?

<table>
<thead>
<tr>
<th>Description</th>
<th>Energy [PJ]</th>
<th>Emission [Mt CO2/year]</th>
<th>Danish Share [%]</th>
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<tr>
<td>Including half of int. voyages from/to Denmark</td>
<td>280</td>
<td>21.6</td>
<td>2.1</td>
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<td>Ships run by a Danish company [Mærsk 2016]</td>
<td>445</td>
<td>34.3</td>
<td>3.4</td>
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Source: Own calculations based on:
- Energistyrelsen 2015 – Transport – Søtransport
- Statistics Denmark 2015 ([ENE1HA](#)) 50000 Water transport
- Wisdom 2017, calculation based on data from Eurostat 2017
- Mærsk Sustainability Report 2016
Energy carriers and sources for shipping

FOCUS THIS PRESENTATION

Gaseous
- LNG – Liquefied Natural Gas
- LBG – Liquefied Biogas (Biomethane)

Liquid
- MeOH – Methanol
- bioMeOH – Bio-Methanol

Electric
- Batteries
- Hydrogen

Renewables
- Wind and Solar
Energy carriers and sources for shipping

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• Renewables
• Wind and Solar

OTHER:
• Liquefied Petroleum Gas (LPG) - mixture of propane and butane
• DME – Di-Methyl Ether
• Ethanol
• Biodiesel
• Vegetable Oil
• Synthetic Fuels
Emissions of marine fuels – Life Cycle

Sources: Bengtsson et al. 2011 / Andersson and Salazar 2015
LNG – LBG – MeOH - bioMeOH

Source: Brynolf et al. 2014 / Anderson and Salazar 2015
## Global Warming Potential

<table>
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<th>Emissions</th>
<th>Global warming potential for given time horizon</th>
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<tr>
<td></td>
<td>20 years</td>
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<tr>
<td>CO₂</td>
<td>1</td>
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<td>CH₄</td>
<td>72</td>
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<tr>
<td>N₂O</td>
<td>289</td>
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Source: Chryssakis 2014
LNG – MeOH – LBG – BioMeOH

Source: Brynolf et al. 2014
# Methane Slip

<table>
<thead>
<tr>
<th>Methane Slip from Operation</th>
<th>GWP Life Cycle Emissions compared to HFO [%]</th>
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<td>8 %</td>
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<td>4 %</td>
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<td>2.3 %</td>
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Source: Own rough calculation based on data from Brynolf et al. 2014
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Source: Own rough calculation based on data from Brynolf et al. 2014

## Methane Slip Operation [%]

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<th>2010</th>
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<tr>
<td>Dual-fuel engines</td>
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<tr>
<td>Dedicated gas engines</td>
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<tr>
<td>High Pressure Direct Injection HDPI</td>
<td>0.4</td>
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</table>

Sources: Calculation from Dejene Assefa Hagos based on Stenersen and Thonstad 2017 / Corbett et al. 2015
Aspects to consider for future marine fuels and technologies

Source: Brynolf et al. 2014
Liquefied Natural Gas – LNG
Liquefied Biogas/Biomethane - LBG

+ Mature technology
+ Fuel costs competitive (LNG)
+ Local air pollution reduction

- High infrastructure cost
- Reduced cargo capacity
- Global Warming Potential (LNG)
- Uncertainty about methane leakage

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**LNG - Examples**

Norwegian MF Glutra
- 1st LNG gas ferry 2000

Fjord Line
- Two Cruise Ferries
- Denmark – Norway
- 1.5 PJ/year

Cargo Ships
- Ordered
- Mostly dual-fuel

Source: Schnack and Krüger 2015
**Methanol – MeOH**
**bioMethanol - bioMeOH**

+ Similar to bunkering fuels today
+ Lower infrastructure and retrofit costs
+ Local air pollution reduction
+ Components are of mature technology

+/- Fuel cost differ locally

- Global Warming Potential (MeOH)
- Higher primary energy input
- Reduced cargo capacity
- Safety barriers

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Installations new-built Methanol Ship

Source: MAN 2015, Andersson and Salzar 2015
Methanol - Examples

Stena Germanica
- 24MW Retrofit
- Four engines on methanol
- Göteborg – Kiel

Source: Andersson and Salzar 2015

MS Innogy
- 5 kW - 7 modules fuel cell
- Fuel generated with CO₂ capture

Source: Ing.dk - Ingeniøren 2017
Electric - Batteries

+ Proven technology
+ Low operating costs
+ Less noise and vibration
+ No emissions during operation
+ Efficiency during load variations
+ Hybrid solutions

+/- Global Warming Potential depends on the electricity fuel mix

- Resource intensity of batteries
- High investment costs
- Low energy density – restricted range

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Electric Batteries and Hybrid - Examples

Ampere
- Full electric 0.9 MW engine
- 1 MWh battery capacity
- 20min – 6km crossing

Helsingør-Helsingborg
- Full electric
- 4.16 MWh battery capacity
- 4km crossing

Scandlines
- 6 Hybrid ferries
- Aiming at full electric:
  - Puttgarden-Rødby: 20km – 45min

Danish inland ferries:
- 1PJ could be electric

Source: ABB.com
Source: Siemens.com
Source: Wikimedia commons
Electric - H2 – Fuel Cell

+ Proven performance in marine environment
+ No emissions during operation
+ No noise and vibration

+/- Costs expected to fall
+/- Global Warming Potential depends on the generation of the H2

- High density only at high pressure and cryogenic storage
- Low expected lifetime of fuel cell
- High investment costs for transport, storage, fuel cell
- Dimension and weight of fuel cells

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Electric – H2 Fuel Cell Examples

Viking Lady
- Dual-fuel LNG/diesel Electric
- Fuel cell 320kW

Alsterwasser
- 2010 Hamburg
- Full electric / fuel cell powered
- 100kW engine
- 14 knots

Viking Cruise
- Planned: 2021
- Cruise ship
- 1400 persons – 230m long
- Hydrogen at 700bar -253degree

Wind and Solar

+ Proven performance
+ No fuel costs
+ No emissions during operation

+/- Auxiliary propulsion

- Weather dependency
- Dimension/Weight
- Logistics

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Wind - Solar Examples

Ecoliner
- Panamax
- Sails + Diesel electric

E-SHIP 1
- 2010
- Flettner Rotor
- 15-25% fuel savings

TESO
- 150kW solar panels
- 40% of hotel load

Sources: fairtransport.eu
kaæstn Disk/Cat - CC BY-SA 3.0 de Wikipedia/shipsmonthly.com
# Main Uncertainties

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Main Uncertainty:
- Methane Slip
- Safety
- Range
- Capacity
- Weather
- Size
- Costs
### Conclusion

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#### Today
- Operational Efficiencies
- Transition Fuels
- Short Distan ces
- Hybrid Solutions
- Electro-Fuels
- New Ship Designs

#### 2050
- Hull Design
- On-shore charging
- Auxiliary Power
- Small Scale
- Auxiliary Power

### Way forward

Addressing climate emissions by regulation - CO₂ and CH₄
Scandinavia as frontrunner in Sustainable Shipping
Mange tak for opmerksomhæden

Density of Ship Movements 2016
Sources I

• Danmark Statistik, 2015, Table ENE1HA: 50000 Water transport / Table ENE3H: 03000 Fishing
• Mærsk, Sustainability Report 2016. Available online: https://www.maerskline.com/about/sustainability
Sources II