# Can electrofuels in combustion engines be cost-competitive to hydrogen in fuel cells?

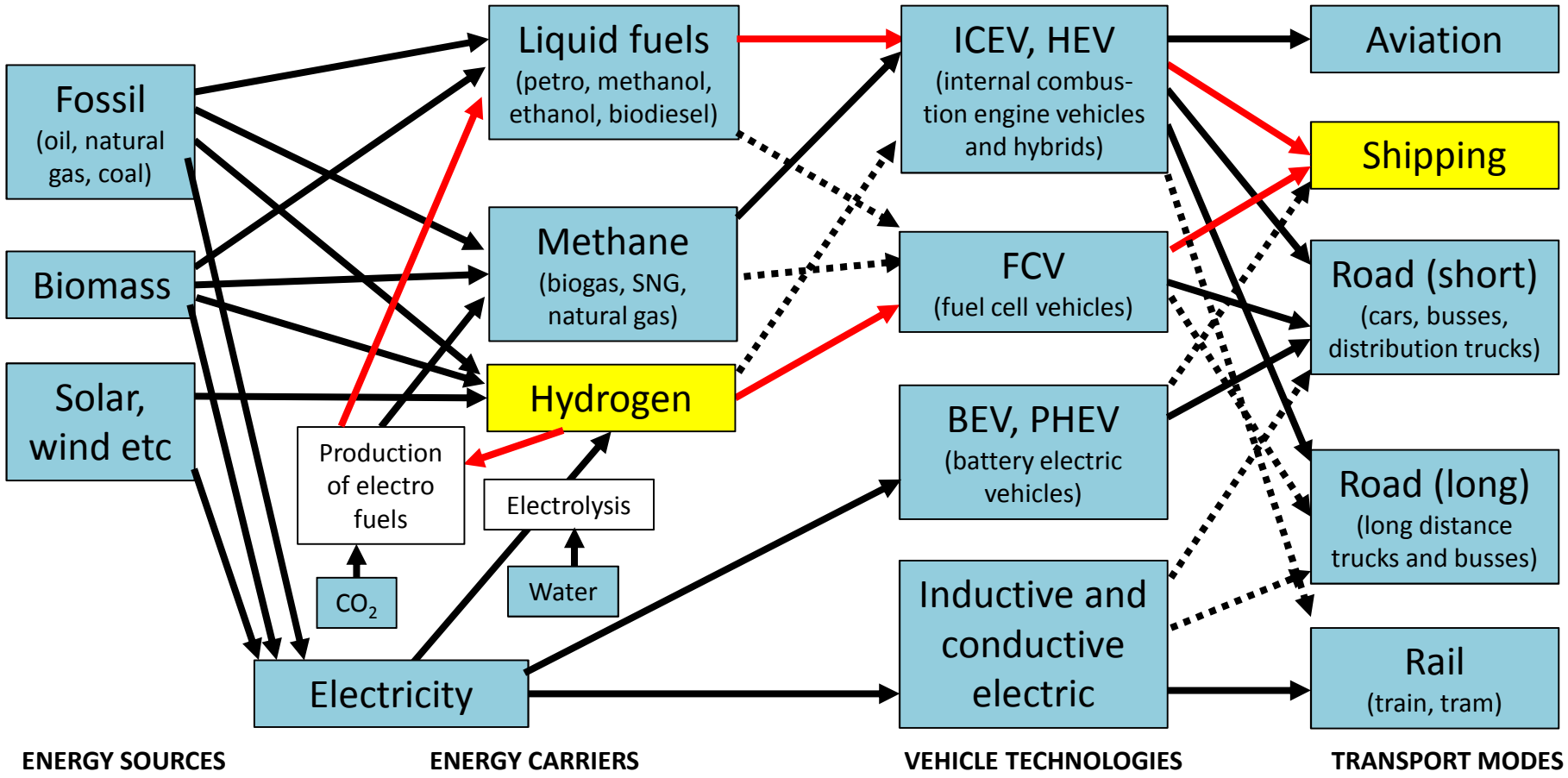
Maria Grahn, Selma Brynolf, Maria Taljegård

Division of Physical Resource Theory, Dept of Space, Earth and Environment,
**Chalmers University of Technology,**
Sweden

# Background

# Different fuels and vehicle technology options are differently well suited for different transport modes

Biofuels and electrofuels are suitable for all transportation modes

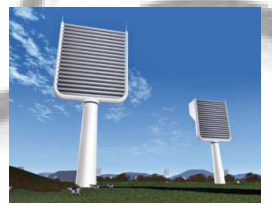


# Production of electro-fuels

Water ($H_2O$)

Other hydro options (H

Carbon dioxide $CO_2$



El

Electro-lysis

400-3700 $€_{2015}/kW_{elec}$

Hydrogen ($H_2$)

$CO_2$ from air and seawater

$CO_2$ from combustion

150-1250 €/$tCO_2$

20-60 €/$tCO_2$

Heat

$H_2$

Synthesis reactor (e.g. Sabatier, Fischer-Tropsch)

30-2100 $€_{2015}/kW_{fuel}$

5-10 €/$tCO_2$

$CO_2$

Biofuel production

Biomass ($C_6H_{10}O_5$)

Electrofuels

Biofuels

Methane ($CH_4$)

Methanol ($CH_3OH$)

DME ($CH_3OCH_3$)

Higher alcohols, e.g., Ethanol ($C_2H_5OH$)

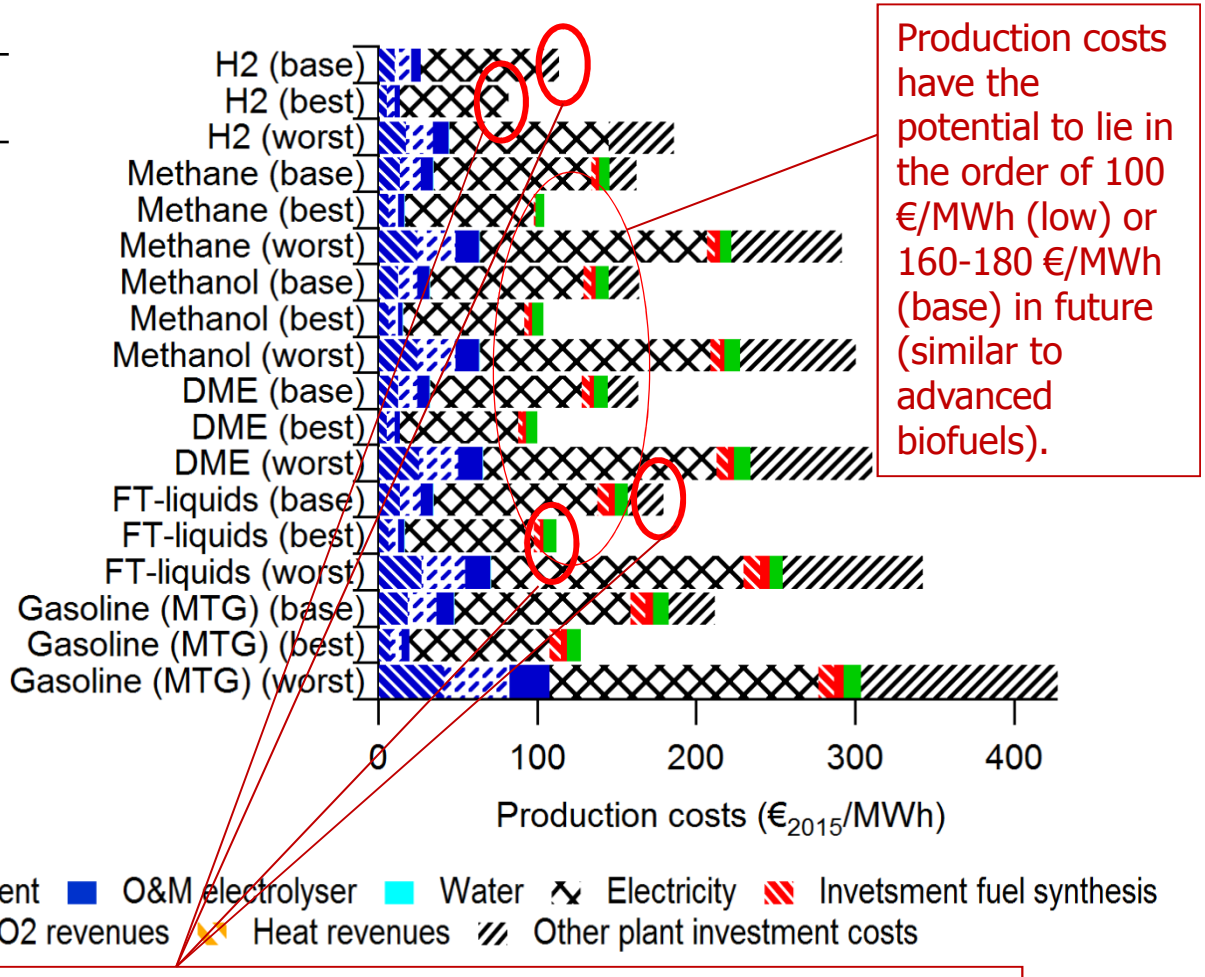
Higher hydrocarbons, e.g., Gasoline ($C_8H_{18}$)

# Production costs of electrofuels

# Production cost different electrofuels, 2030

## assuming most optimistic (low), least optimistic (high) and median values (base)

| **Parameters assumed for 2030, 50 MW reactor, CF 80%.** | |
|---|---|
| Interest rate | 5% |
| Economic lifetime | 25 years |
| Investment costs: | |
| Alkaline electrolyzers €/kW$_{elec}$ | 700 (400-900) |
| Methane reactor €/kW$_{fuel}$ | 300 (50-500) |
| Methanol reactor €/kW$_{fuel}$ | 500 (300-600) |
| DME reactor €/kW$_{fuel}$ | 500 (300-700) |
| FT liquids reactor €/kW$_{fuel}$ | 700(400-1000) |
| Gasoline (via meoh) €/kW$_{fuel}$ | 900(700-1000) |
| Electrolyzer efficiency | 66 (50-74) % |
| Electricity price | 50 €/MWh$_{el}$ |
| $CO_2$ capture | 30 €/t$CO_2$ |
| O&M | 4% |
| Water | 1 €/m³ |




Production costs have the potential to lie in the order of 100 €/MWh (low) or 160-180 €/MWh (base) in future (similar to advanced biofuels).

Data used for this cost-comparison: FT electro-diesel base = 180 €/MWh (case ”low”= 112 €/MWh), hydrogen base = 116 €/MWh (case ”low”= 84 €/MWh).

Brynolf S, Taljegård M, Grahn M, Hansson J. (2017). Electrofuels for the transport sector: a review of production costs. *Renewable & Sustainable Energy Reviews*. In press

# Cost-comparison electrofuels vs hydrogen including vessel costs

## Fact

- Hydrogen, if used as a fuel itself (and not as feedstock for an electrofuel), is obviously less costly to produce than electrofuels.
- Hydrogen is preferably used in fuel cells, which have a higher vessel engines efficiency but also a higher cost compared to combustion engines.
- On annual basis the share “fuel cost” would be higher compared to the share “vessel enegine cost” the more the vessel is used.

## Questions

- Would the higher cost for fuel cells even out the higher fuel production cost of electrofuels?
- Is there a breaking point where total cost would shift between the two concepts electro-diesel in ICE vs hydrogen in FC?

The cost comparisons are made for generalized types of vessels (i.e., short sea, deep sea and container).

# Assumptions on currency, fuel production costs, life time and engine efficiency

| | |
|---|---|
| Interest rate [%] | 5 |
| Currency USD/EUR (Forex 2017-05-28) | 0.89 |
| Production cost electro-diesel [€/MWh] [1] Base/Low | 180/112 |
| Production cost $H_2$ (Alkaline electrolyzer) [€/MWh] [1] Base/Low | 113/81 |
| Additional cost $H_2$ liquefaction [€/MWh] [1] | 3 |
| Tot production cost $H_2$ (liquid) [€/MWh] [1] Base/Low | 116/84 |
| Life time fuel cell stack [hours] [1] | 65,000 |
| Average vessel engine load (factor of max capacity) [2] | 0.75 |
| Engine efficiency Diesel-IC [2] | 0.40 |
| Engine (fuel cell) efficiency $H_2$-FC [2] | 0.45 |

Will be tested in sensitivity analysis (fuel production cost from lower end in range)

[1] Brynolf S, Taljegård M, Grahn M, Hansson J. Electrofuels for the transport sector: a review of production costs. *Renewable & Sustainable Energy Reviews*. In press (2017).
[2] Taljegård M., Brynolf S., Grahn M., Andersson K., Jonsson H. Cost-Effective Choices of Marine Fuels in a Carbon-Constrained World: Results from a Global Energy Model. *Environmental Science and Technology* **48** (21) 12986-12993 (2014).

# Assumptions regarding vessels

The cost comparisons are made for three generalized types of vessels (short sea, deep sea and container).

| | Container vessel | Deep sea vessel | Short sea vessel |
|---|---|---|---|
| Engine power [kW] [2] | 23000 | 11000 | 2400 |
| Life time [years per vessel] [2] | 30 | 30 | 30 |
| Investment cost ICEV [1000 € per vessel] [2] | 113574 | 69163 | 15638 |
| Annuitized investment cost ICEV [1000 € per vessel per year] [2] | 7388 | 4499 | 1017 |
| Investment cost FC [1000 € per vessel] [2] | 201948 | 118309 | 23769 |
| Annuitized investment cost FC [1000 € per vessel per year] [2] | 13137 | 7696 | 1546 |
| Cost per fuel cell stack replacement [1000 €/replacement] | 2874 | 1599 | 264 |

[1] Brynolf S, Taljegård M, Grahn M, Hansson J. Electrofuels for the transport sector: a review of production costs. *Renewable & Sustainable Energy Reviews*. In press (2017).
[2] Taljegård M., Brynolf S., Grahn M., Andersson K., Jonsson H. Cost-Effective Choices of Marine Fuels in a Carbon-Constrained World: Results from a Global Energy Model. *Environmental Science and Technology* **48** (21) 12986-12993 (2014).

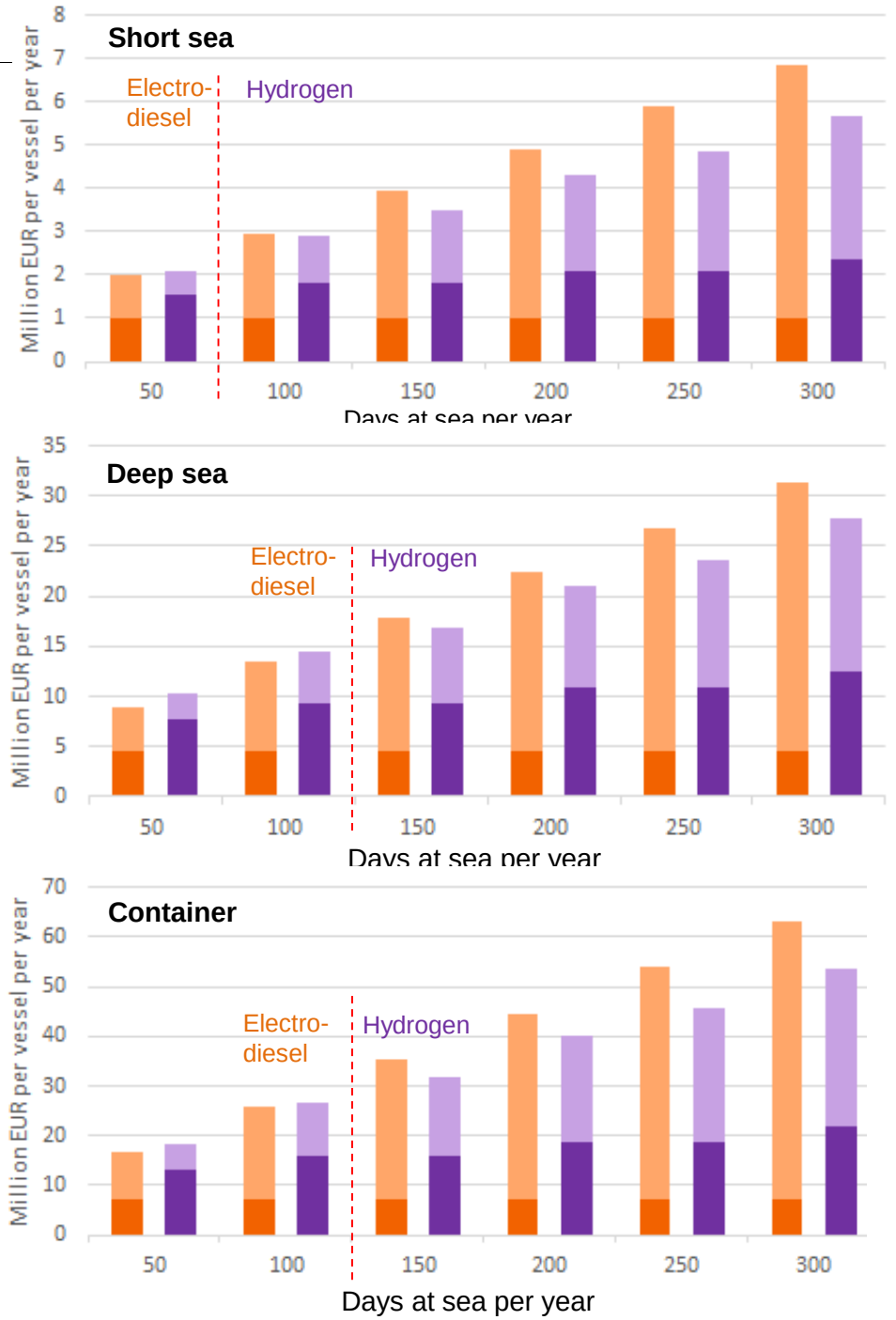
# Number of stack replacement during vessel life time

| Days/yr | 50 | 100 | 150 | 200 | 250 | 300 |
|---|---|---|---|---|---|---|
| Replacements | 0 | 1 | 1 | 2 | 2 | 3 |

# Results

## Annual cost electro-diesel in ICEVs (orange) vs hydrogen in FCs (purple)

- Hydrogen fuel prod cost (Euro/year)
- Fuel cell propulsion and H2 storage cost on vessel (Euro/year)
- Electro-diesel fuel production cost (Euro/year)
- Diesel propulsion and storage cost on vessel (Euro/year)




## Main findings

- Electro-diesel can be competitive when vessels are operated few days per year (less than 100-150 days/yr)
- Hydrogen has advantages when vessels are operated more days per year.
- Expensive investments dominates at low use, whereas expensive fuel dominates at large use.
- Stack replacements only minor post.

# Sensitivity analysis

Uncertainties connected to production cost of fuels. Now assuming values from lower end of range (case ”low”), i.e.

H2=84 €/MWh (base=116 €/MWh),

Electro-diesel=112 €/MWh (base=180 €/MWh)

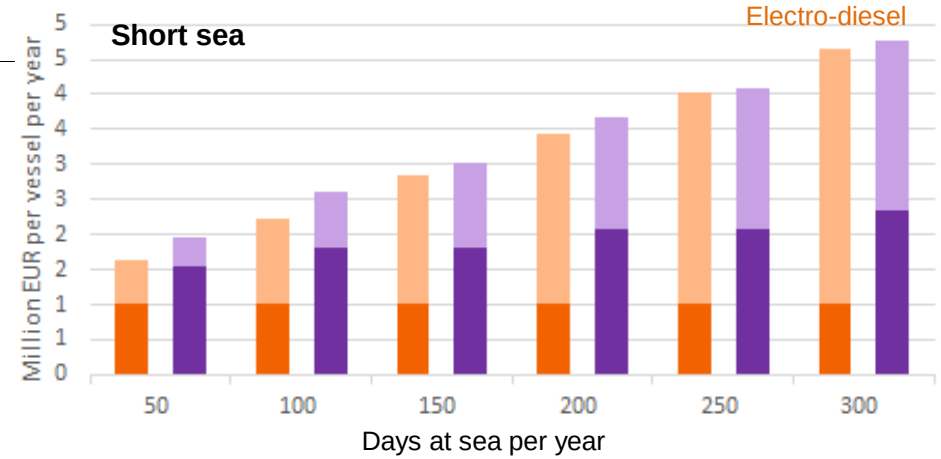
# Results assuming lower fuel production costs.

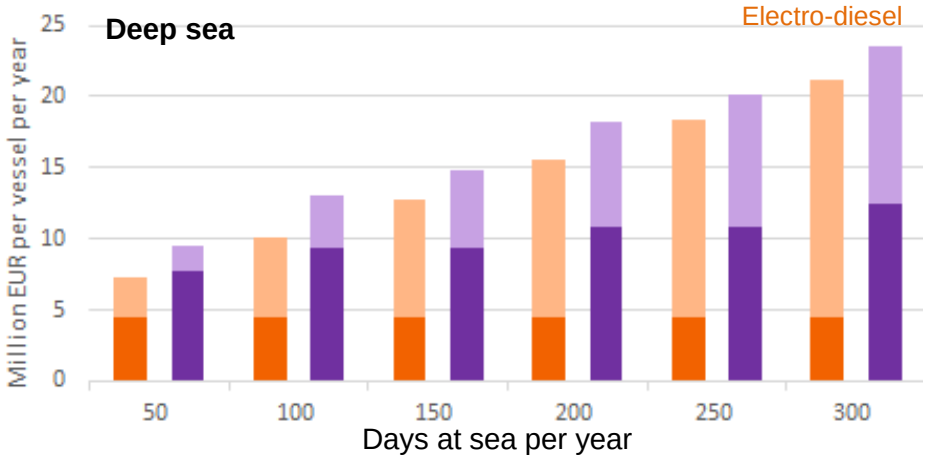
Annual cost electro-diesel in ICEVs (orange) vs hydrogen in FCs (purple) assuming
H2=84 €/MWh (base=116 €/MWh),
Electro-diesel=112 €/MWh (base=180 €/MWh)

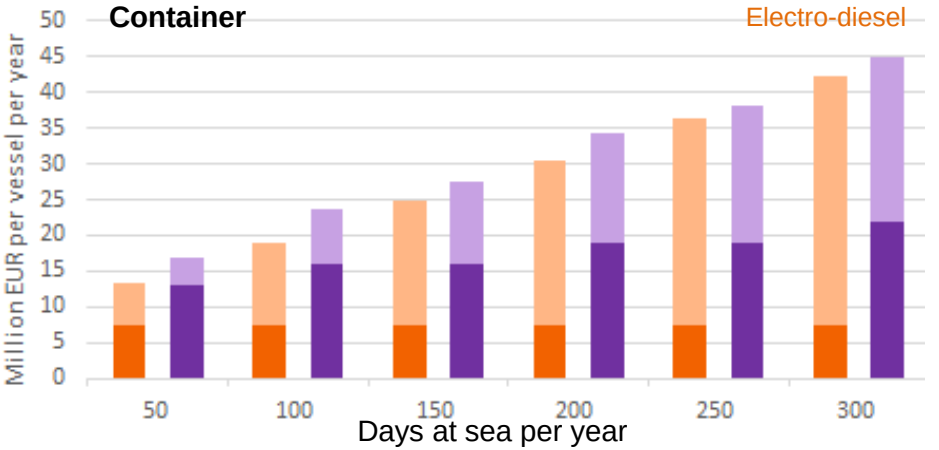
- Hydrogen fuel prod cost (Euro/year)
- Fuel cell propulsion and H2 storage cost on vessel (Euro/year)
- Electro-diesel fuel production cost (Euro/year)
- Diesel propulsion and storage cost on vessel (Euro/year)

## Main findings

- Results change when assuming lower fuel production costs.
- Now it seems more cost-efficient to operate the vessels on electro-diesel.
- Why? Electro-diesel production cost percentual higher reduction (112/180= 0.62, compared to hydrogen 84/116=0.72).
- Uncertainties in fuel production cost imply no clear winner between the two concept.



# Challenges to reflect on

- If electrofuels are used as drop-in fuels, although they may offer a solution for a fast transition away from fossil fuels, there is a risk that they may contribute to a prolonged era of fossil fuels.
  - Policy measures that continuously encourage increased shares of low-emitting drop-in fuels (up to finally 100%) would reduce this risk.
- Effects on human health from local emissions (e.g., NOx and soot), from combustion engines would remain if using electrofuels in conventional combustion engines
  - Local emissions would be slightly lower with electrofuels in the form of, e.g., e-dimethyl ether, e-methanol or e-methane, than with e-gasoline or e-diesel, however, never as low as with hydrogen used in fuel cells.
  - The majority of local emissions can, on the other hand, be reduced with exhaust after-treatment technologies.

# Conclusions

- There are breaking points where total cost would shift between the two concepts electro-diesel in ICE vs hydrogen in FC. Can be seen in base case for all three vessel types.
- Electro-diesel can be competitive to hydrogen when vessels operate only part time of the year.
- Hydrogen has advantages when vessels are used for longer distances over the year.
- Container is the category showing the most positive results on electro-diesel (however, similar to deep sea).
- The higher cost for fuel cells lies in the same size of order as the higher fuel production cost of electrofuels.
- Uncertainties in fuel production cost imply no clear winner between the two concept.

# The electrofuel team

Maria Grahn, Research leader
Energy and environment
Chalmers University of Technology
Email:
maria.grahn@chalmers.se

Selma Brynolf, Postdoc
Energy and environment
Chalmers University of Technology
Email:
selma.brynolf@chalmers.se

Julia Hansson, Postdoc
Energy and environment
Chalmers University of Technology
Email: julia.hansson@ivl.se

Maria Taljegård, PhD student
Energy and environment
Chalmers University of Technology
Email:
maria.taljegard@chalmers.se

Karin Andersson, Professor
Shipping and Marine Technology
Chalmers University of Technology
Email:
karin.andersson@chalmers.se

Sofia Poulikidou, Postdoc
Energy and environment
Chalmers University of Technology
Email: sofiapo@chalmers.se

Stefan Heyne, Researcher
CIT
Email:
stefan.heyne@cit.chalmers.se

Roman Hackl, Researcher
IVL
Email:
roman.hackl@ivl.se