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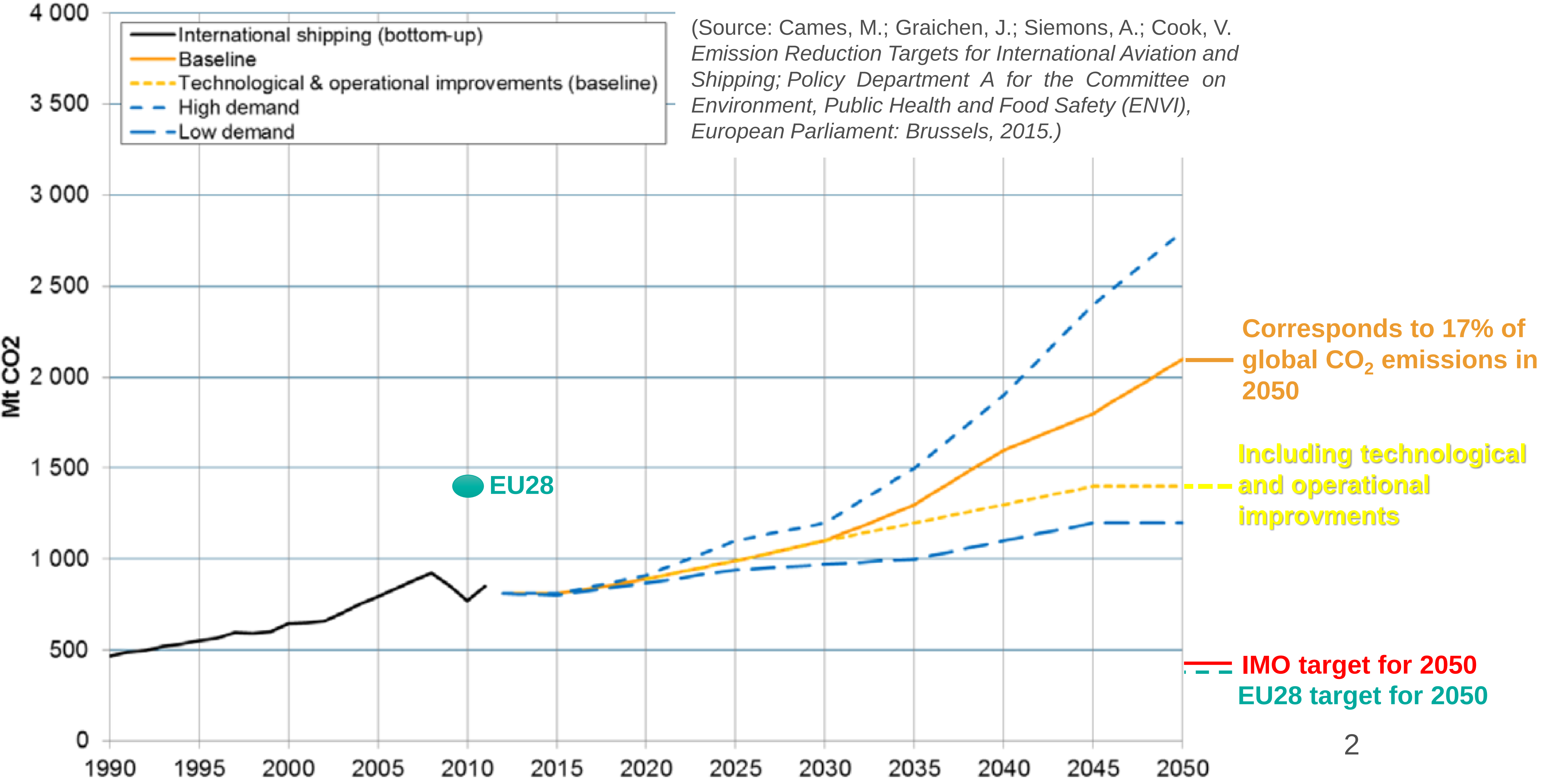
ELEKTROBRÄNSLENS ROLL SOM DRIVMEDEL

FRAMTIDENS SJÖFART

15 MAJ, NORRBOTTENS HANDELSKAMMARE, LULEÅ

SELMA BRYNOLF, MECHANICS AND MARITIME SCIENCES



(Source: Cames, M.; Graichen, J.; Siemons, A.; Cook, V. *Emission Reduction Targets for International Aviation and Shipping; Policy Department A for the Committee on Environment, Public Health and Food Safety (ENVI), European Parliament: Brussels, 2015.)*

GHG emissions from shipping (g CO_2 eq.)

- Shipping energy demand (MJ)
  - Energy demand per transported unit (MJ/unit km)
  - Transported units (unit km)
- GHGs/ energy unit (g CO_2 eq./MJ)

Reducing energy need

Hull design

1) Vessel size
2) Hull Shape
3) Lightweight material
4) Air lubrication
5) Hull coating
6) …

Power & propulsion systems

1) More efficient power & propulsion system (e.g. fuel cells, hybrid, fully electric)
2) Waste heat recovery
3) On board power demand (e.g. lighting)
4) 4…

Operational measures

1) Speed optimization
2) Capacity utilization
3) Voyage optimisation
4) …

Reducing energy GHG intensity

Alternative energy sources

1) Kites, sails/wings
2) Solar panels onboard
3) Shore power
4) …

Alternative energy carriers

1) Low carbon fuels (e.g. bio-methanol, biogas, HVO, electrofuels)
2) Ammonia
3) Hydrogen
4) Electricity
5) …

Emission abatement

1) Onboard carbon capture
2) …

WHAT FUTURE FUELS ARE AVAILABLE?

Near future | 2030 | 2050 | Beyond

Fossil fuels with increasing share of low carbon fuels

Low carbon fuels

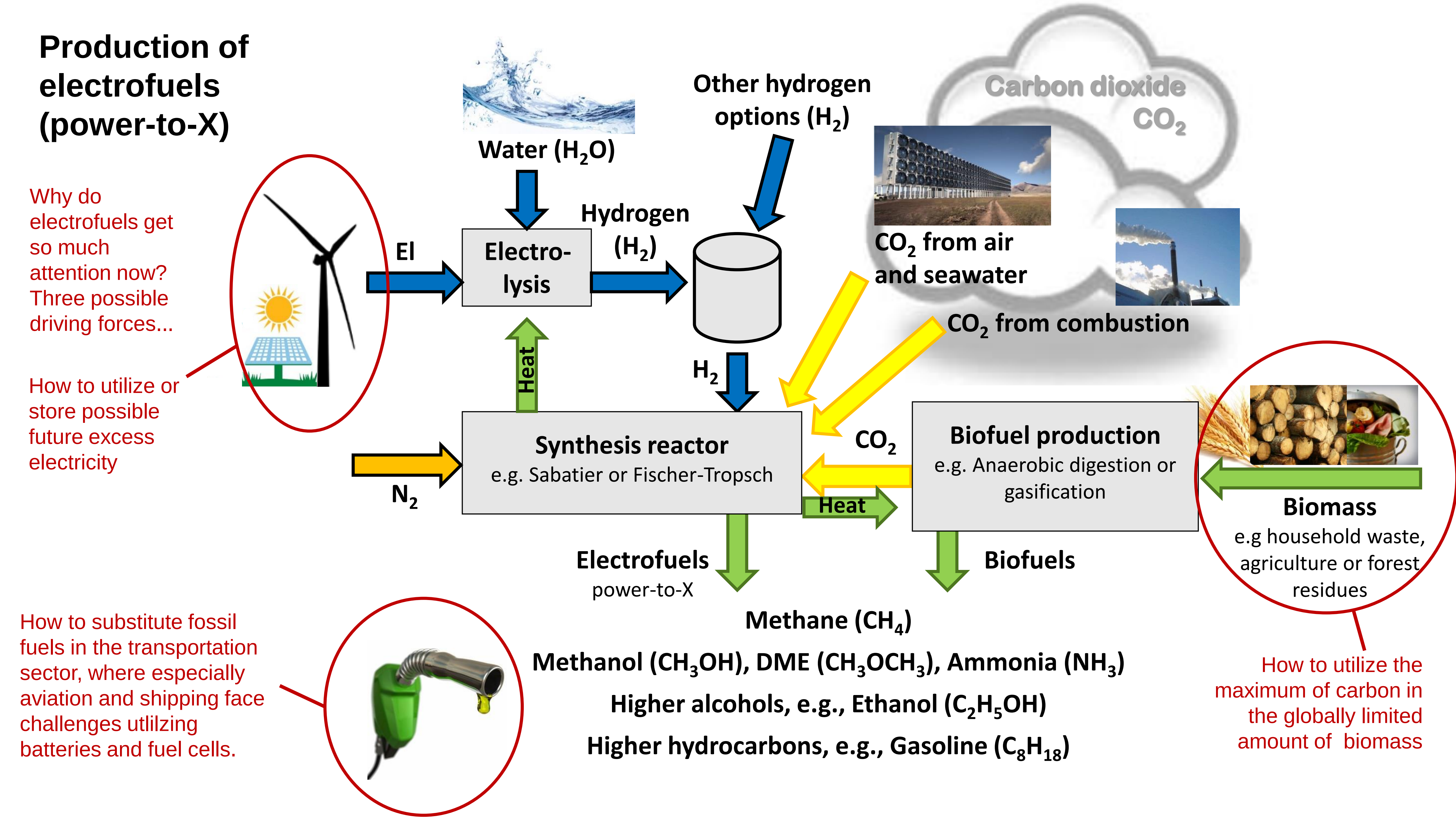
Energy carriers without carbon or carbon capture onboard

Increased electrification

Increase use of kites, sails, solar panels, etc

LOW CARBON FUELS

- Biofuels
  - Bio-oils
  - Hydrotreated vegetable oil
  - Bio-methanol
  - Liquified biogas
  - Synthetic diesel
  - Exotic fuels/chemicals as drop in
- Electrofuels

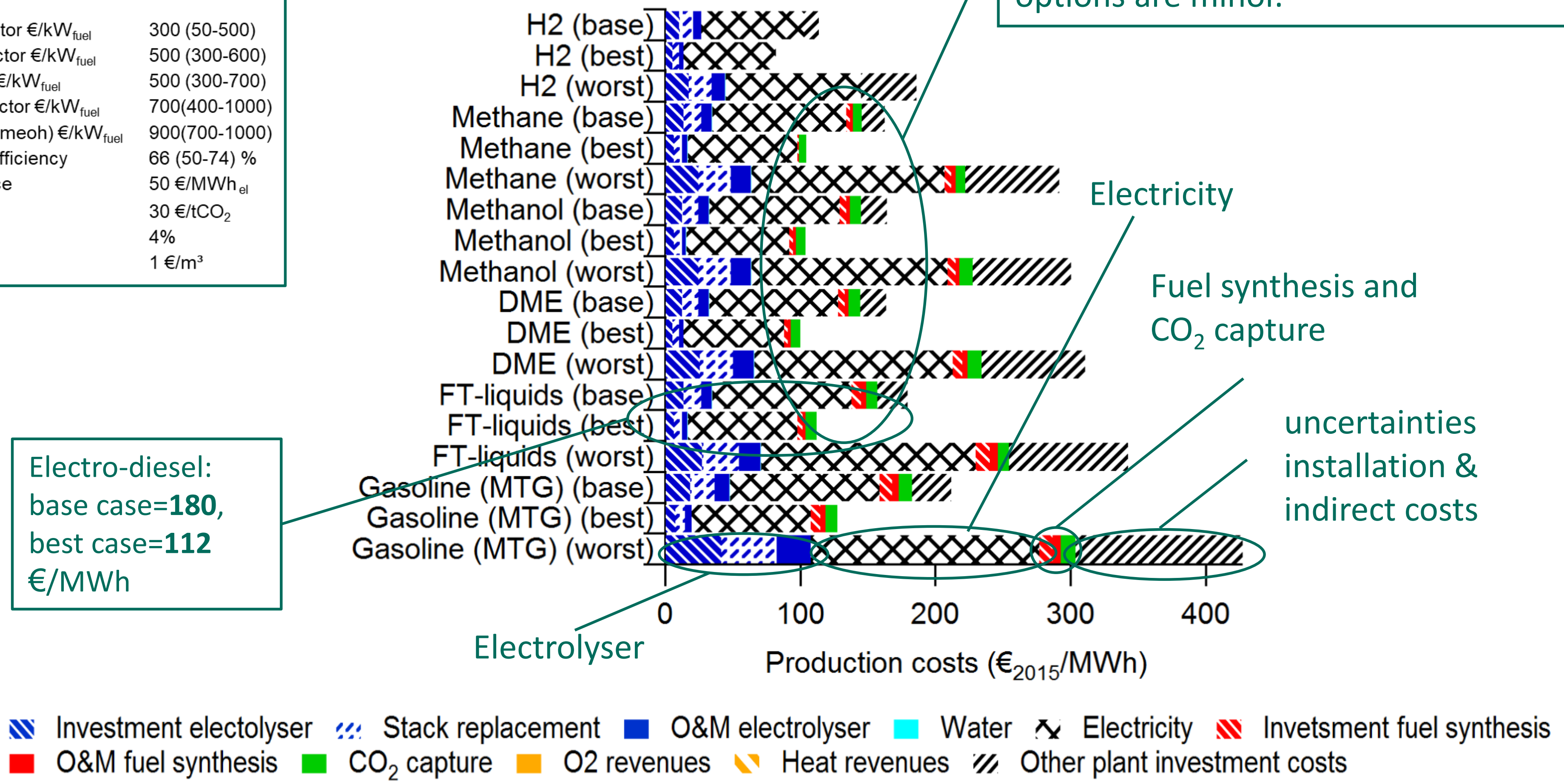


Production of electrofuels (power-to-X)
Why do electrofuels get so much attention now? Three possible driving forces...
How to utilize or store possible future excess electricity
Water (H_2O)
Other hydrogen options (H_2)
Carbon dioxide CO_2
El
Electro-lysis
Hydrogen (H_2)
CO_2 from air and seawater
CO_2 from combustion
Heat
H_2
Synthesis reactor
e.g. Sabatier or Fischer-Tropsch
N_2
CO_2
Biofuel production
e.g. Anaerobic digestion or gasification
Heat
Biomass
e.g household waste, agriculture or forest residues
Electrofuels
power-to-X
Biofuels
Methane (CH_4)
Methanol (CH_3OH), DME (CH_3OCH_3), Ammonia (NH_3)
Higher alcohols, e.g., Ethanol (C_2H_5OH)
Higher hydrocarbons, e.g., Gasoline (C_8H_{18})
How to substitute fossil fuels in the transportation sector, where especially aviation and shipping face challenges utlilzing batteries and fuel cells.
How to utilize the maximum of carbon in the globally limited amount of biomass

PRODUCTION COST 2030

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 €/tCO_2
O&M	4%
Water	1 €/m³

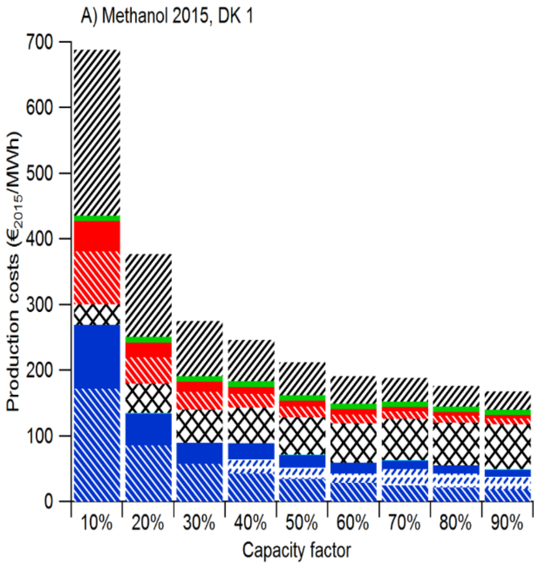
Insight: Many different approaches among authors.
Insight: When data is ”harmonized” between the fuel options (low compared to low etc) the differences between the fuel options are minor.



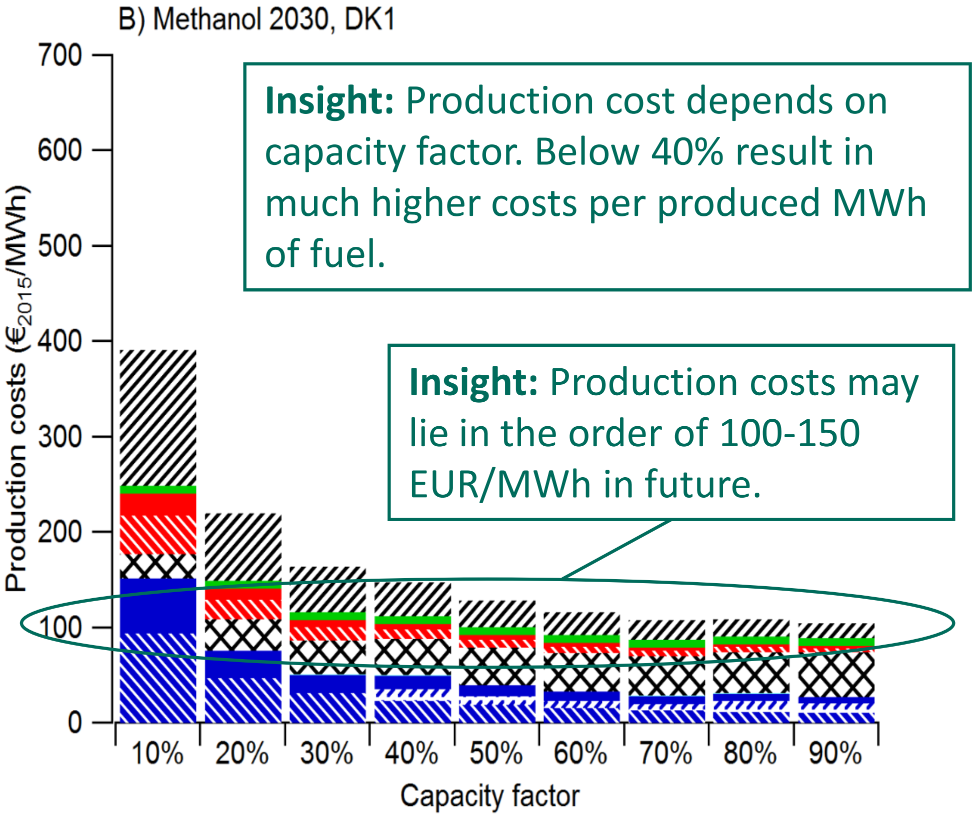
Electro-diesel:
base case=**180**,
best case=**112**
€/MWh

Insight: Costs for electrolyser and electricity dominates
Note. Currently we see a trend towards lower investment cost of electrolyzers (comes with an increased market). Some scenarios also point out a trend towards lower electricity prices in future (if increased variable electricity production).

Ref: Brynolf S, Taljegård M, Grahn M, Hansson J. (2018). Electrofuels for the transport sector: a review of production costs. *Renewable & Sustainable Energy Reviews* 81 (2) 1887-1905.



Assuming curent cost the production cost of electro-methanol may lie in the order of 200 EUR/MWh (if running the facility more than 40% of the year).



Insight: Production cost depends on capacity factor. Below 40% result in much higher costs per produced MWh of fuel.

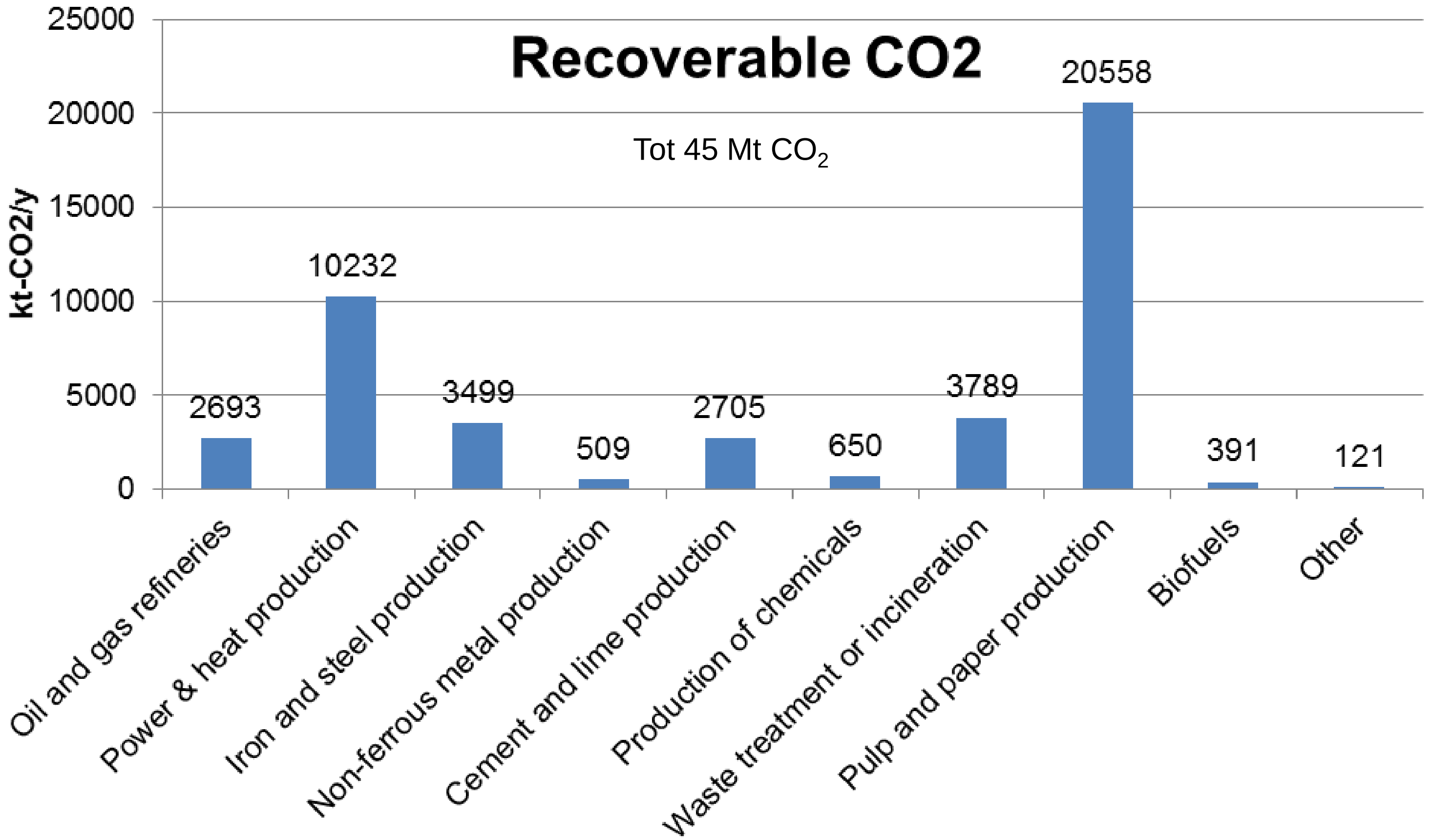
Insight: Production costs may lie in the order of 100-150 EUR/MWh in future.

Production costs found in literature	
Fossil fuels	40-140
Methane from anaerobic digestion	40-180
Methanol from gasification of lignocellulose	80-120
Ethanol from maize, sugarcane, wheat and waste	70-345
FAME from rapeseed, palm, waste oil	50-210
HVO from palm oil	134-185

Insight:. Future production of electrofuels have the potential to be cost-competitive to advanced biofuels.

Ref: Brynolf S, Taljegård M, Grahn M, Hansson J. (2018). Electrofuels for the transport sector: a review of production costs. *Renewable & Sustainable Energy Reviews* 81 (2) 1887-1905.

RESULTS ON AVAILABLE CO_2 SOURCES IN SWEDEN



How much fuel can be produced?

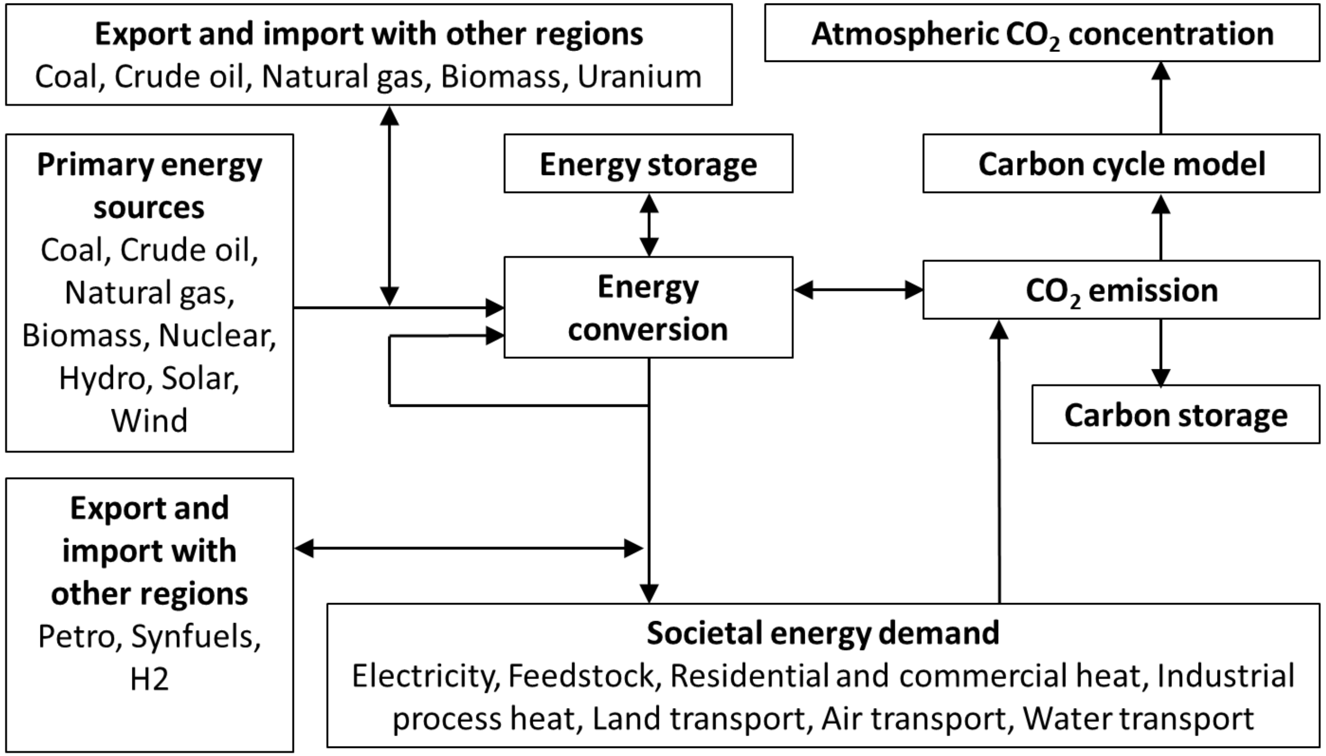
- 45 $MtCO_2$/yr (fossil+renewable)
- 30 $MtCO_2$/yr is recoverable from biogenic sources =>**110 TWh/yr electro-methanol**

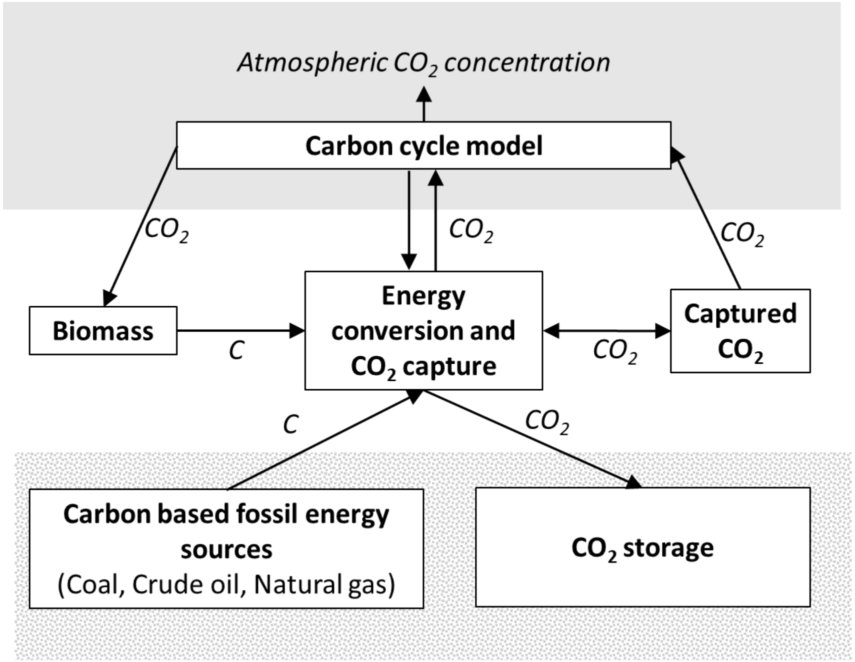
Insight: The amount of recoverable non-fossil CO_2 is not a limiting factor for a large scale production of electrofuels, in Sweden.
Note. The revised EU-directive on renewable fuels states that electrofuels is a "renewable liquid and gaseous transport fuels of non-biological origin" if the energy content is renewable (article 2.36). Electrofuels from fossil industrial CO_2 is defined as "recycled carbon fuels" (article 2.35) and not defined as renewable.

Ref: Hansson J, Hackl R, Taljegård M, Brynolf S and Grahn M (2017). The potential for electrofuels production in Sweden utilizing fossil and biogenic CO2 point sources. *Frontiers in Energy Research* 5:4. doi: 10.3389/fenrg.2017.00004 http://journal.frontiersin.org/article/10.3389/fenrg.2017.00004/full

ENERGY-ECONOMY MODEL GLOBAL ENERGY TRANSITION (GET)

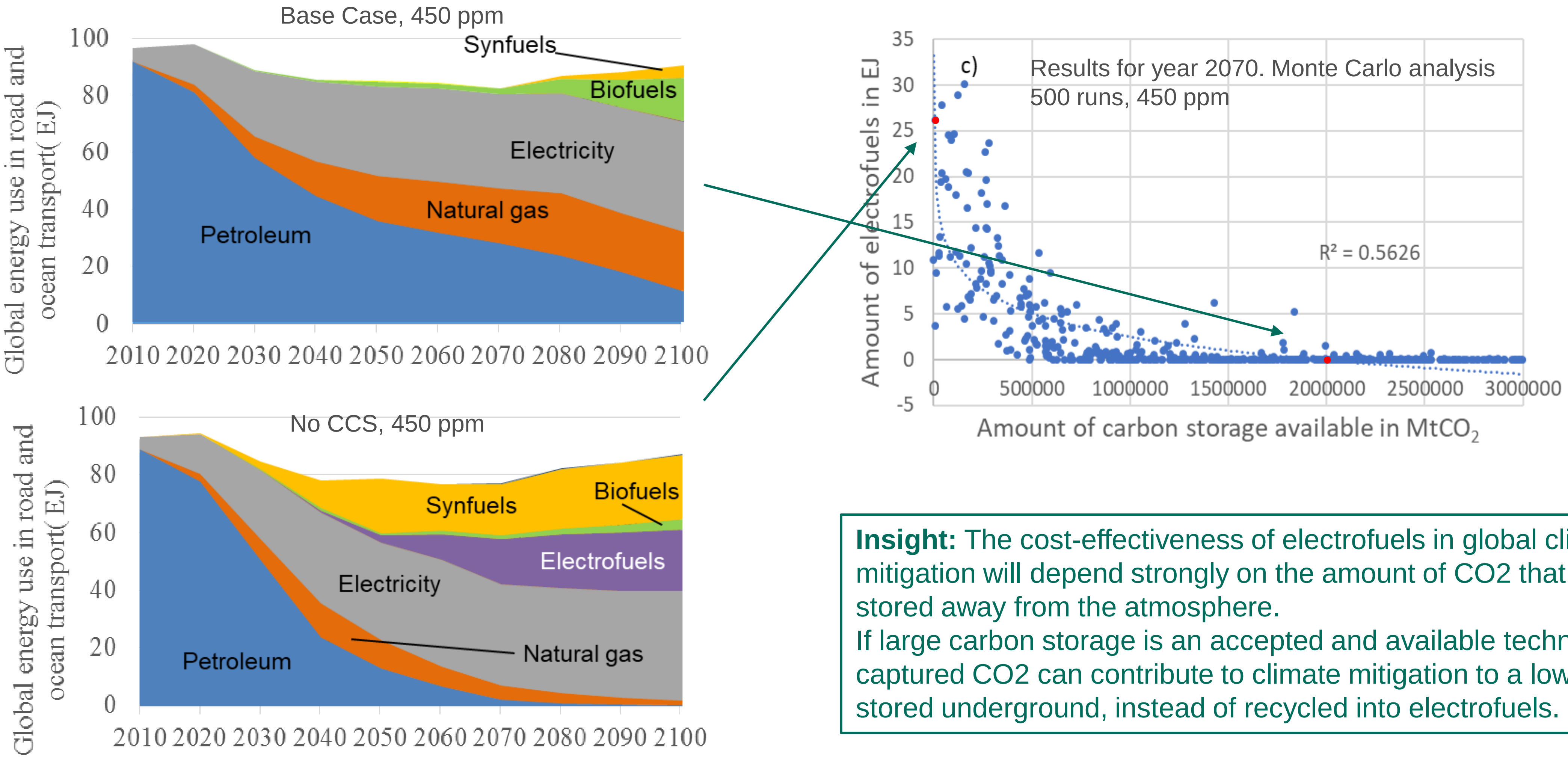
Linearly programmed energy systems cost-minimizing model. Generates the fuel and technology mix that meets the demand (subject to the constraints) at lowest global energy system cost





Ref: Lehtveer M., Brynolf S., Grahn. M. (2019). What Future for Electrofuels in Transport? Analysis of Cost Competitiveness in Global Climate Mitigation." Environmental Science & Technology 53(3): 1690-1697.

COST-COMPETITIVENESS IN A GLOBAL ENERGY SYSTEMS CONTEXT



Insight: The cost-effectiveness of electrofuels in global climate mitigation will depend strongly on the amount of CO2 that can be stored away from the atmosphere.
If large carbon storage is an accepted and available technology, the captured CO2 can contribute to climate mitigation to a lower cost if stored underground, instead of recycled into electrofuels.

Source: Lehtveer M., Brynolf S., Grahn. M. “What future for electrofuels in transport? – analysis of cost-competitiveness in global climate mitigation”. Accepted for publication in Journal Environmental Science and Technology. 2019.

ELECTROFUEL INSIGHTS

- Costs for electrolyser and electricity are dominating posts of the total electrofuels production cost.
- Production cost depends on capacity factor. Below 40% result in much higher costs per produced MWh of fuel. (However, from a global energy system model perspective, electrolysers can be beneficial for the energy system even at low load factors (10–30%))
- Production costs may lie in the order of 100-150 EUR/MWh in future.
- Future production of electrofuels have the potential to be cost-competitive to advanced biofuels.
- The amount of recoverable non-fossil CO2 is not a limiting factor for large scale production of electrofuels, in Sweden.
- The cost-effectiveness of electrofuels, in a global climate mitigation context, will depend strongly on the amount of CO_2 that can be stored away from the atmosphere.

WHAT FUTURE FUELS ARE AVAILABLE?

Near future | 2030 | 2050 | Beyond

Fossil fuels with increasing share of low carbon fuels

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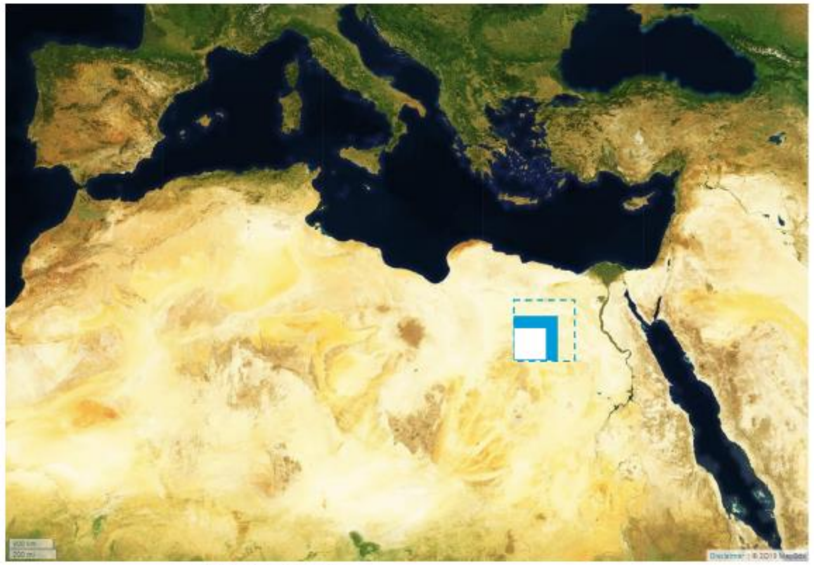
ZERO CARBON FUELS AND ABATEMENT TECHNOLOGIES

- Renewable electricity
- Hydrogen (from renewable electricity)
- Ammonia (from renewable hydrogen)
- Low carbon fuels with carbon capture

Source: N. Ash, T. Scarbrough, Sailing on solar: Could green ammonia decarbonise international shipping?, Environmental Defense Fund, London, 2019.

FIGURE 18:
Map showing land area required for solar electricity to produce green ammonia for the international shipping fleet in 2050



Satellite image from [12]

GREEN REVOLUTION ON THE HIGH SEA

-97%
EMISSIONS

HyMethShip:
on the way to zero-emission shipping

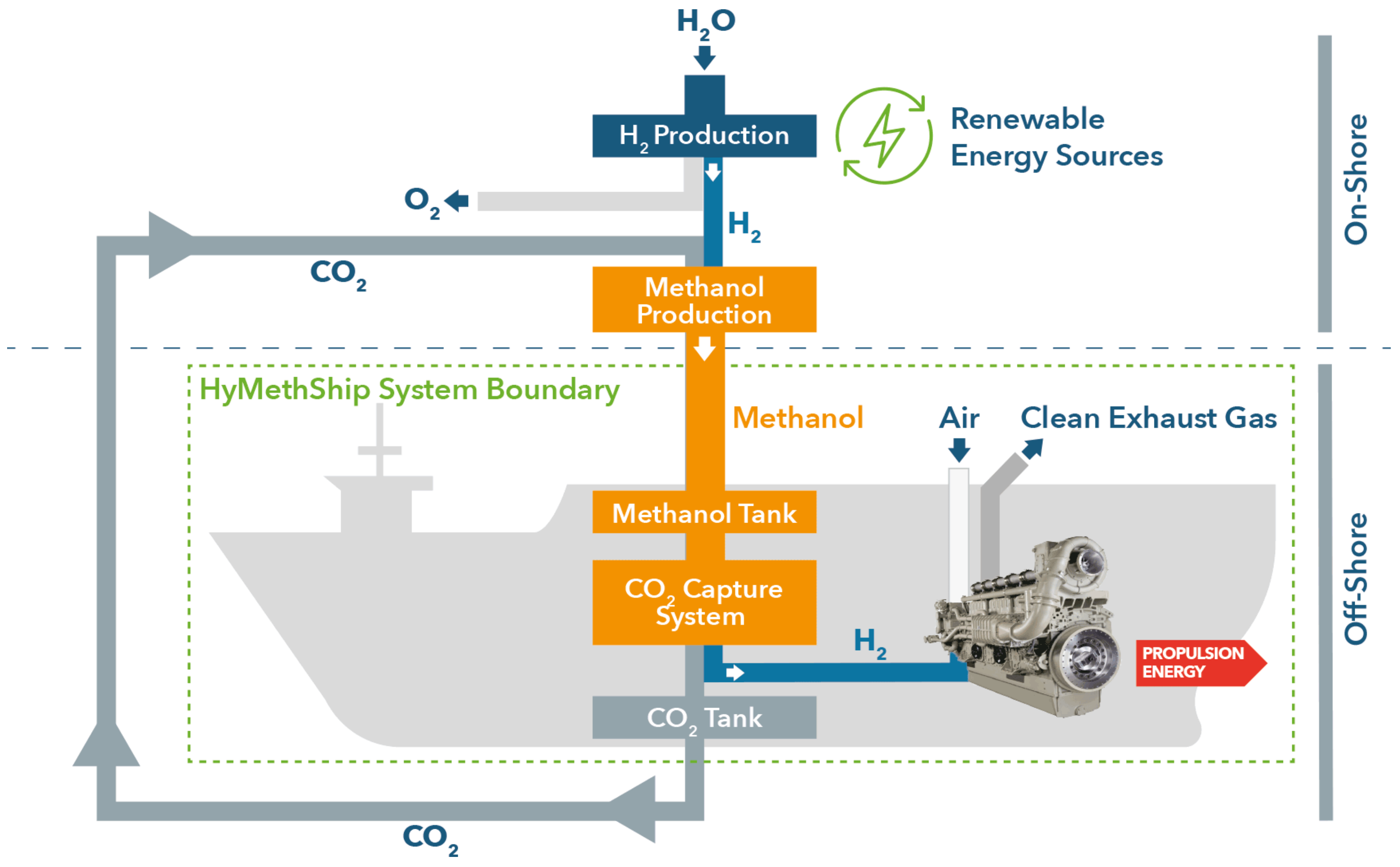
Presentation October, 2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768945

"Emission-free" Ship Propulsion

HyMethShip

The Concept



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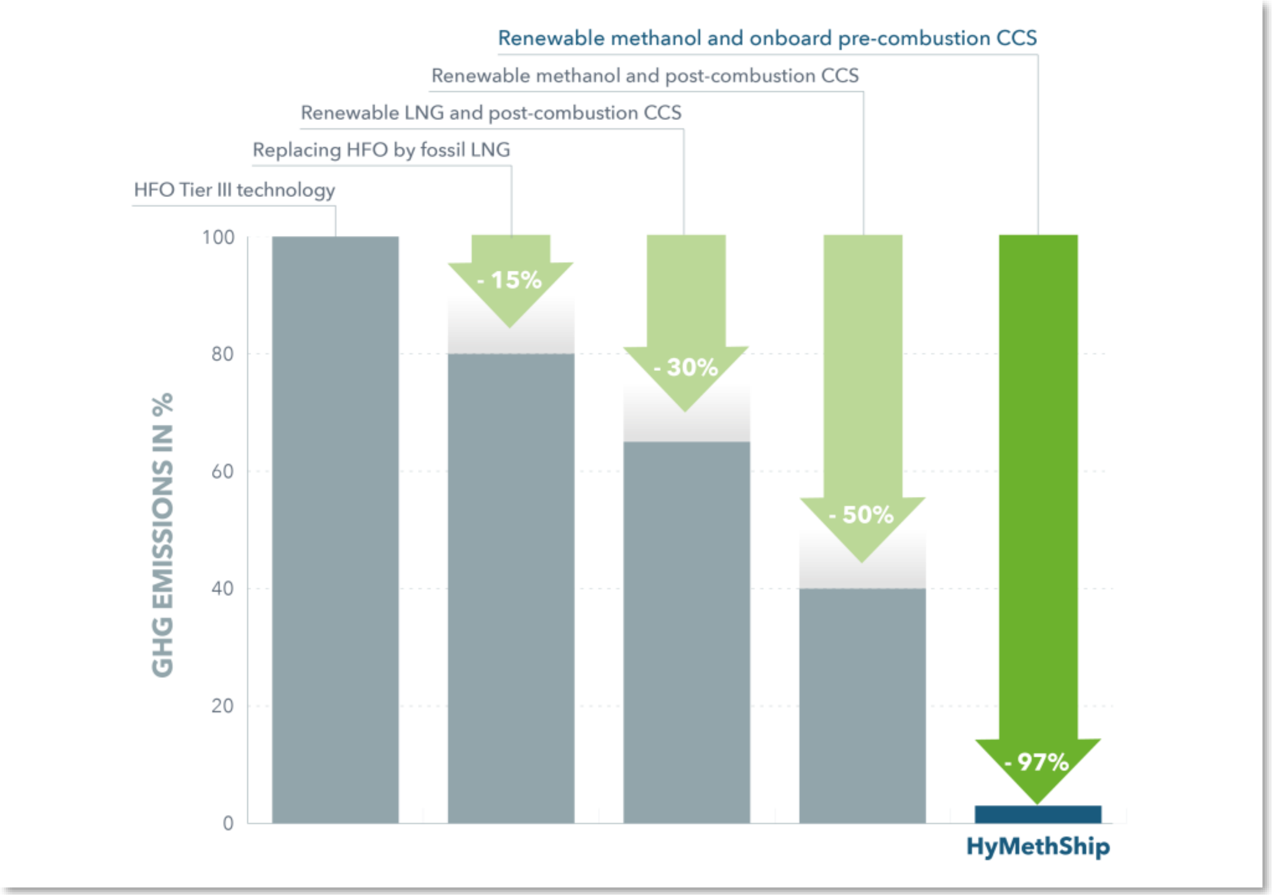
Goals and Objectives

Emissions reduction

- 97% reduction in GHG emissions
- Elimination of SO_x and PM emissions
- Minimization of NO_x emissions



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Near future — 2030 — 2050 — Beyond

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POSSIBLE PATHWAYS

Near future — 2030 — 2050 — Beyond

Fossil methanol with increasing share of bio-methanol

Bio-methanol or electro-methanol

Bio-methanol or electro-methanol with carbon capture onboard

LNG with increasing share of LBG

LBG or electro-methane

Hydrogen or ammonia

HFO/Diesel with increasing blend of bio-oils/biodiesel

Bio-oils/biodiesel or electro-diesel

Bio-oils/biodiesel or electro-diesel with carbon capture onboard

Increased electrification

Increase use of kites, sails, solar panels, etc

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THANK YOU FOR LISTENING!

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