CHALMERS
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Elektrobränslens roll som drivmedel

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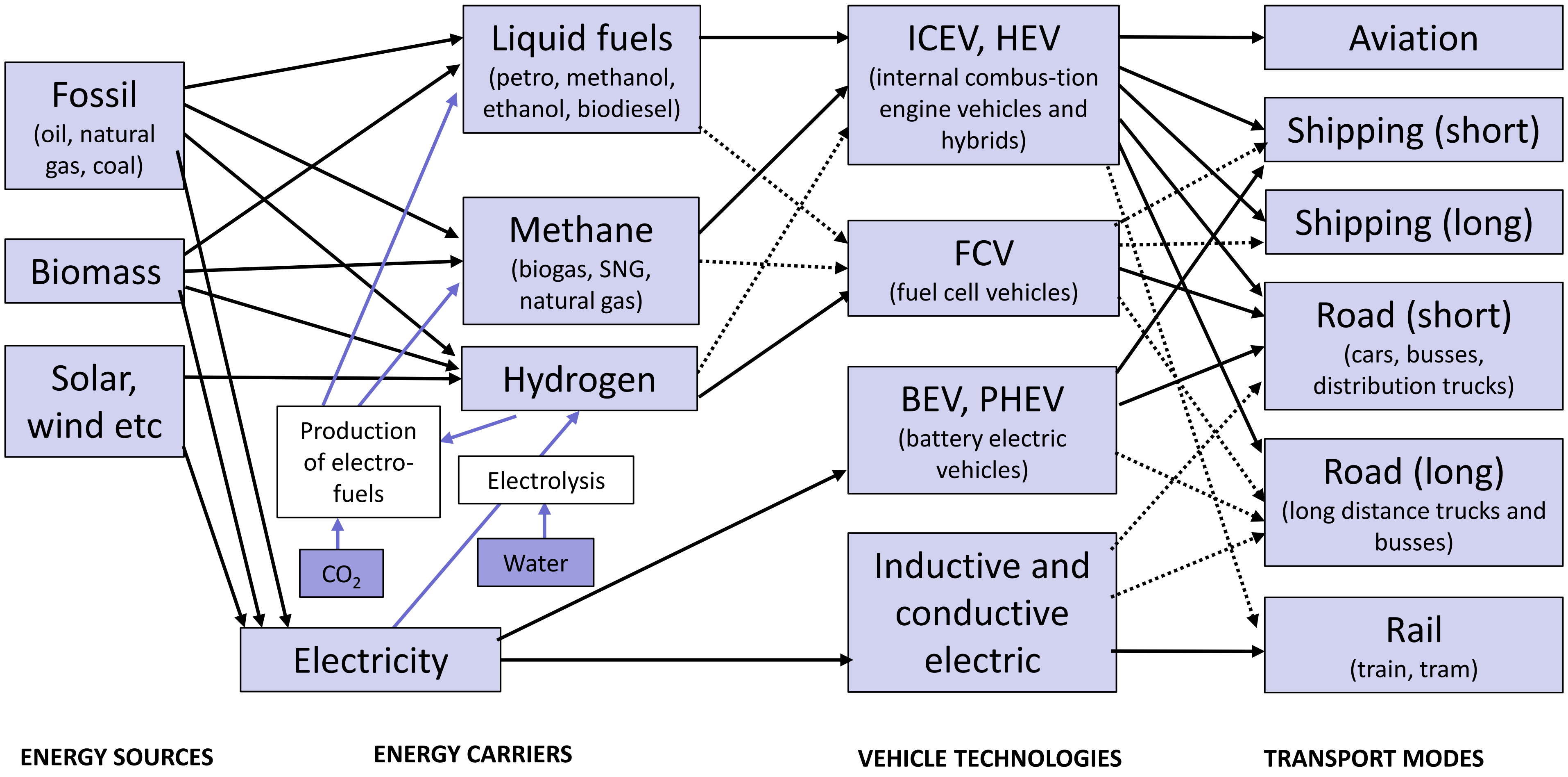
IVL och Chalmers med inkind-bidrag från Scania

22 November 2018

Avstamp från resultat inom projekt nr 39121-1 inom ramarna för samverkansprogrammet ”Förnybara drivmedel och system”. Projektet har finansierats av Energimyndigheten och f3 – Svenskt kunskapscentrum för förnybara drivmedel.

Different fuels and vehicle technology options in different transport modes?

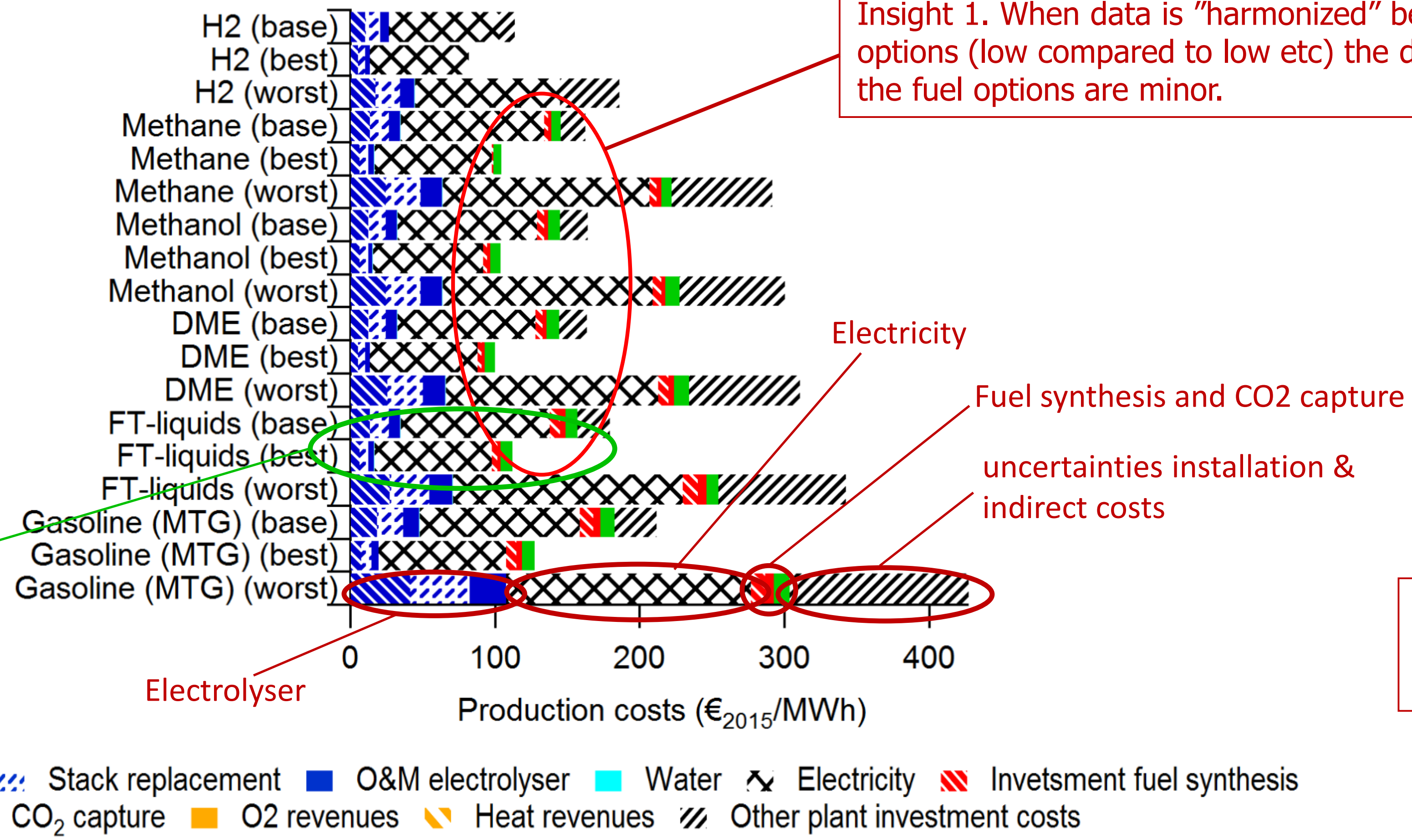


Main results and insights

Literature review, data differs. Production cost 2030 (mature costs) different electrofuel options

assuming most optimistic (low/best), least optimistic (high/worst) 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 €/tCO_2
O&M	4%
Water	1 €/m³



Insight 1. When data is ”harmonized” between the fuel options (low compared to low etc) the differences between the fuel options are minor.

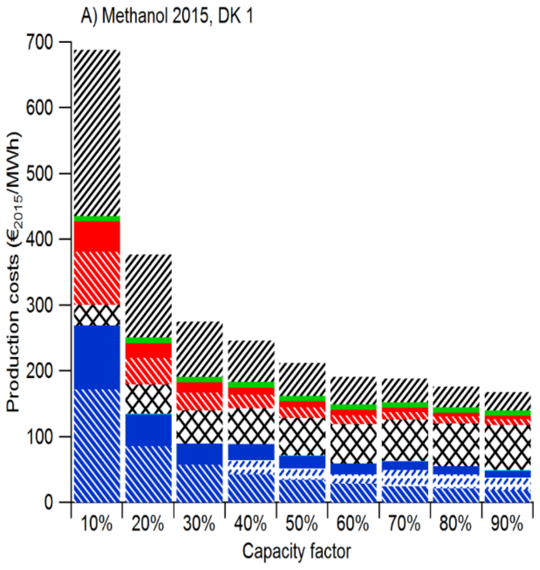
Electro-diesel:
base case=**180**,
best case=**112**
€/MWh

Insight 2: Costs for electrolyser and electricity dominates

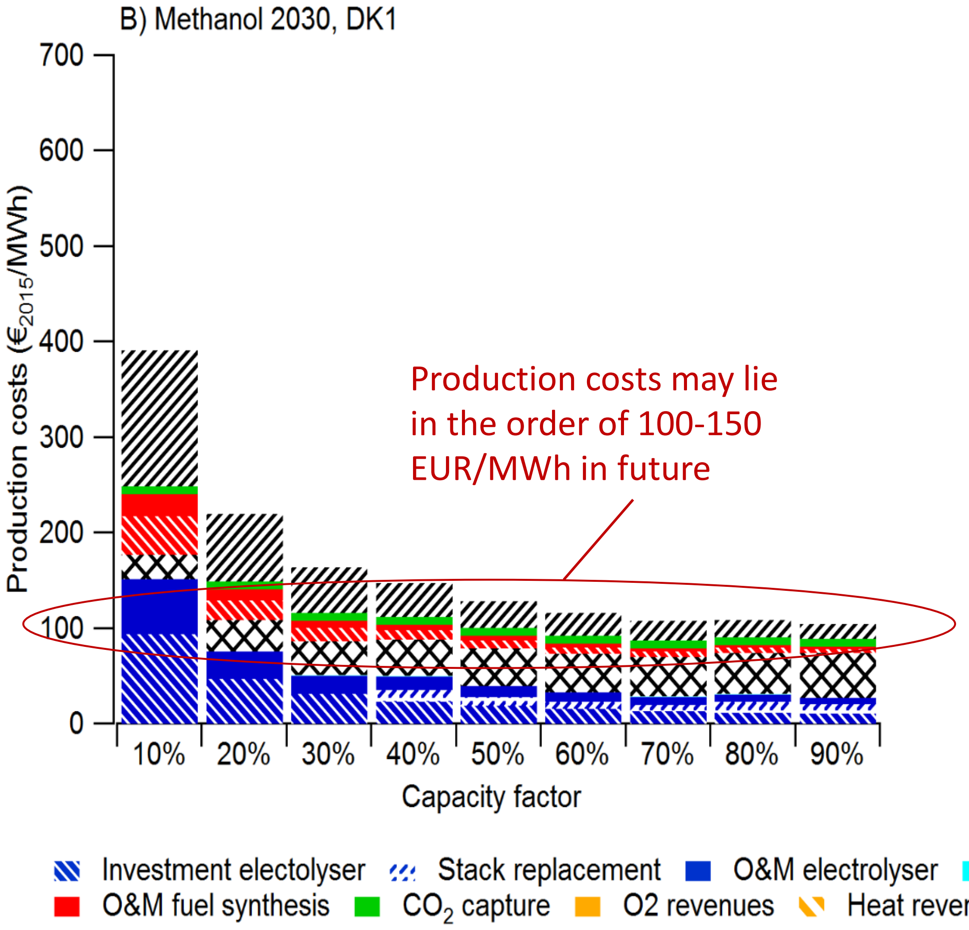
Source: Brynolf S, Taljegård M, Grahn M, Hansson J. (2018). Electrofuels for the transport sector: a review of production costs. *Renewable & Sustainable Energy Reviews* 81 (2) 1887-1905.

Production cost depends on capacity factor

below 40% result in much higher costs



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).

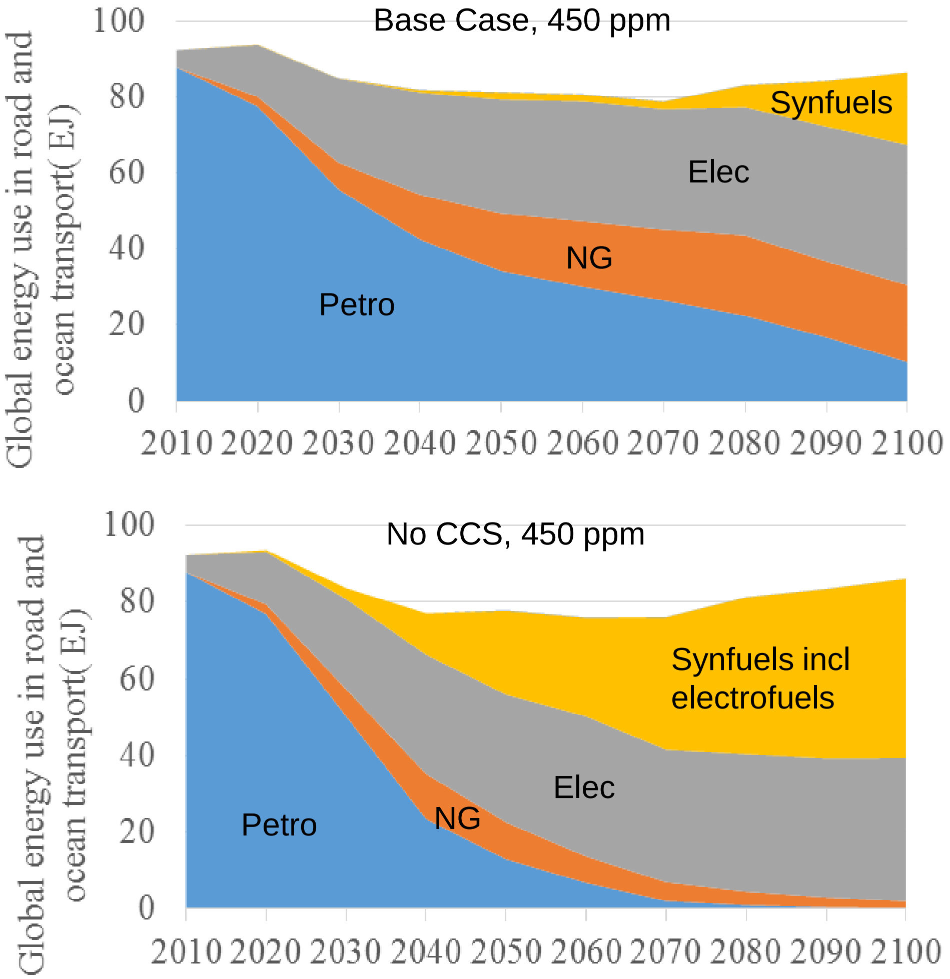


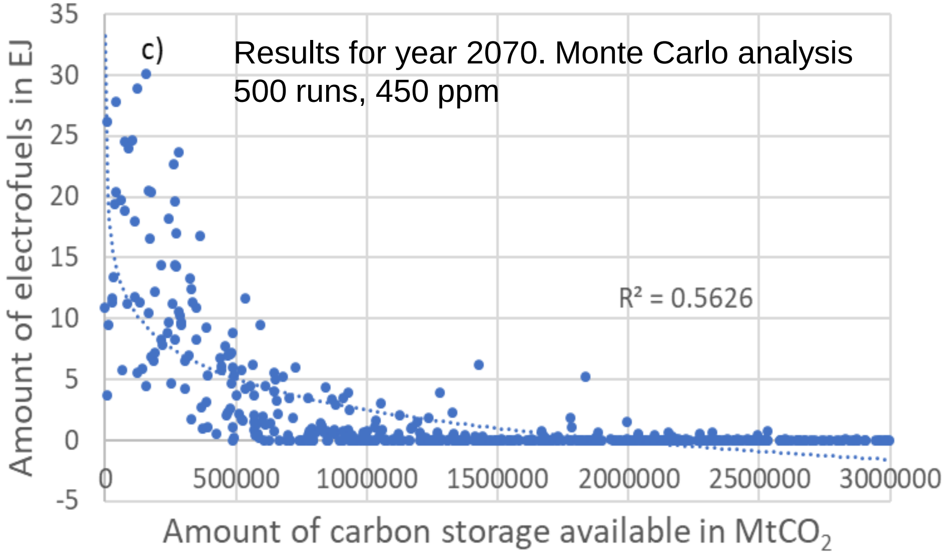
Production cost found in literature	
Fossil fuels	40-140
Methane from anaerobic digestion	40-180
Methane from gasification of lignocellulose	70-90
Methanol from gasification of lignocellulose	80-120
DME from gasification of lignocellulose	90-110
Ethanol from maize, sugarcane, wheat and waste	70-345
FAME from rapeseed, palm, waste oil	50-210
HVO from palm oil	134-185
Synthetic biodiesel from gasification of lignocellulose	120-655
Synthetic biogasoline from gasification of lignocellulose	90

Future production of electrofuels have the potential to be cost-competitive to the most expensive 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.

Cost-competitiveness in a global energy systems context





Main insight: The amount of electrofuels in the future fuel mix for road and ocean transport sector depend to a large extent on the amount of CO_2 that will be stored away from the atmosphere. A result connected to the acceptance of CCS.

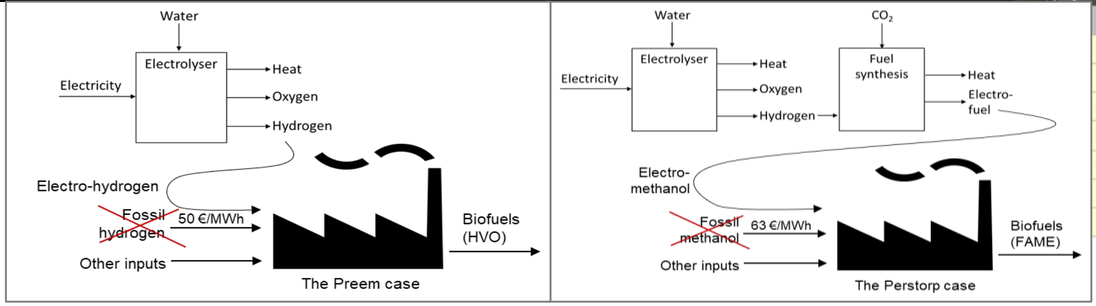
Source: Lehtveer M., Brynolf S., Grahn. M. "What future for electrofuels in transport? – analysis of cost-competitiveness in global climate mitigation". submitted to Journal Environmental Science and Technology. Supporting Information. Sept 2018.

Hur kan slutsatserna från våra projekt bidra till den fortsatta utvecklingen i Sverige?

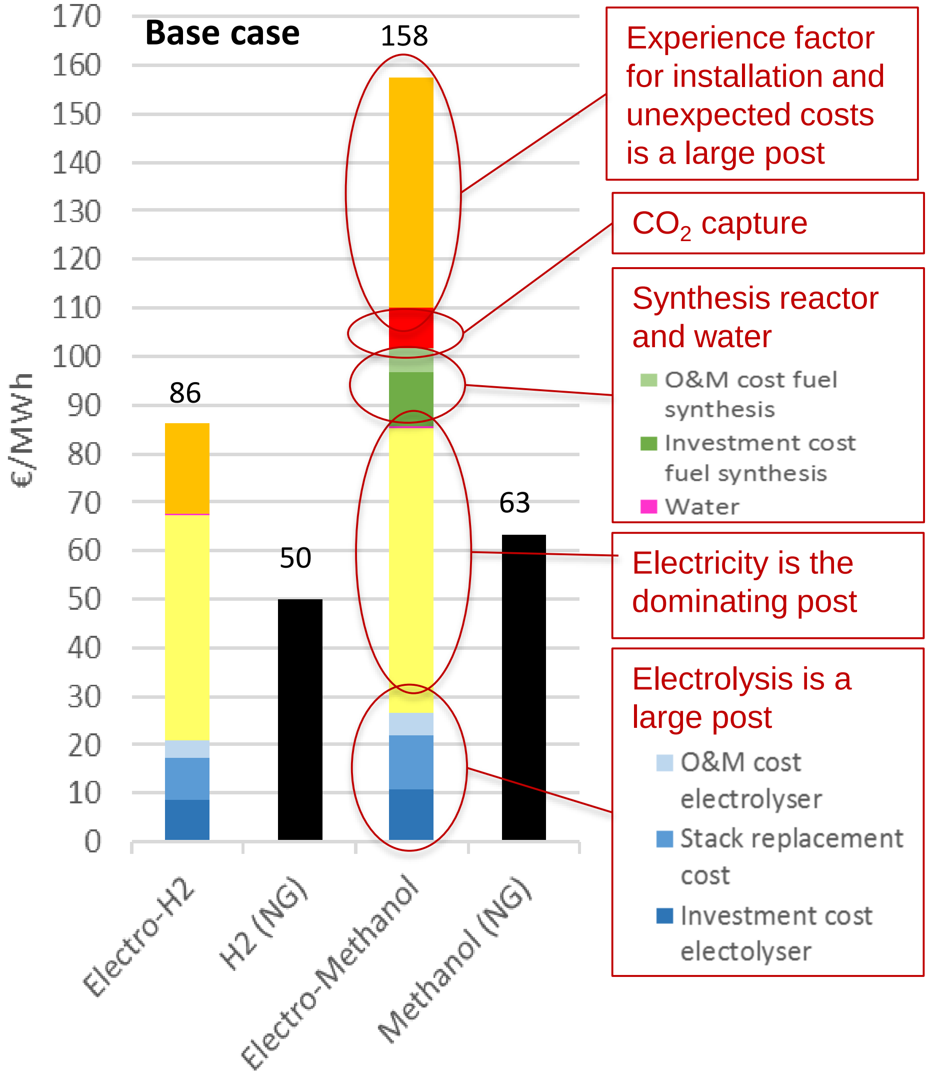
Underlag för beslutsfattande i drivmedelsindustrin, och aktörer inom väg-, flyg- och sjöfartsektorn

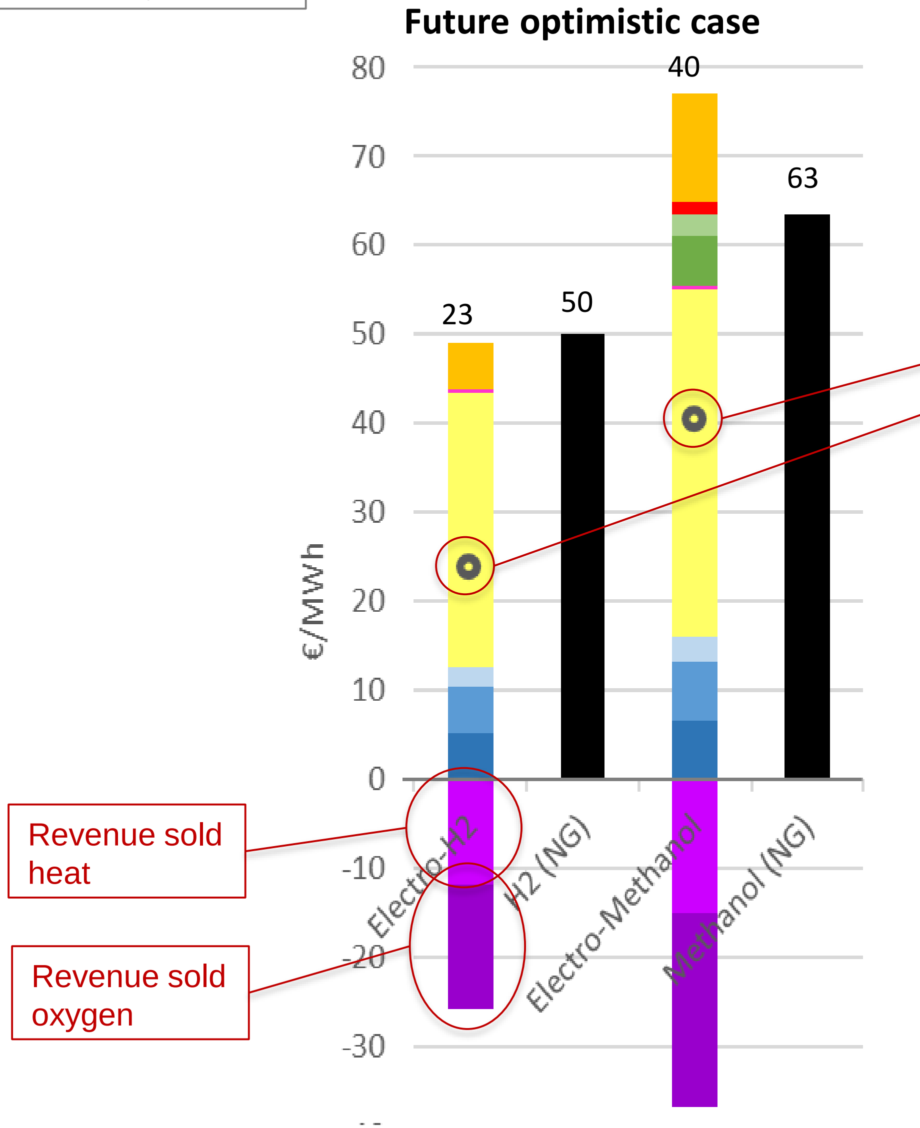
Industrial perspective.

Production cost electrofuels compared to market price for fossil options



		Base case	Future case
Investment cost electrolyser (alkaline)	[€/kW_{el}]	500	300
Heat revenue	[€/MWh_{heat}]	0	30
Oxygen revenue	[€/ton_{O2}]	0	50
Investment cost methanol synthesis reactor (base:5 MW, future: 50 MW)	[€/MW_{MeOH}]	1000	500
Cost for CO_2 capture (10–50% concentration)	[€/ton_{CO2}]	30	5
Electricity price	[€/MWh_{el}]	30	20
Experience factor for indirect investment costs		3.14	2





In a future optimistic case the production cost could be competitive to fossil option

Source: Grahn M, A-K Jannasch (2018). What electricity price would make electrofuels cost-competitive? 6th TMFB, Tailor-Made Fuels from Production to Propulsion Aachen, Germany. 19-21 June

Production cost of electro-methanol, for different electricity prices and different electrolyser investment cost, in the (a) base case and in a (b) future optimistic scenario

a) **Electro-methanol. Productions cost. Base case.**

Electrolyser €/kW$_{el}$	0 (CF: 10%)	10 (CF: 40%)	20 (CF: 95%)	30 (CF: 95%)	40 (CF: 95%)	50 (CF: 95%)
500	762	230	138	158	177	197
400	688	208	128	147	167	187
300	613	187	118	137	157	177
200	539	166	108	127	147	166
100	465	144	98	117	137	156

Electricity price €/MWh

b) **Electro-methanol. Productions cost. Optimistic case.**

Electrolyser €/kW$_{el}$	0 (CF: 10%)	10 (CF: 40%)	20 (CF: 95%)	30 (CF: 95%)	40 (CF: 95%)	50 (CF: 95%)
500	348	93	55	75	94	114
400	297	78	48	67	87	106
300	247	63	40	60	79	99
200	196	47	33	52	72	91
100	145	32	25	45	64	84

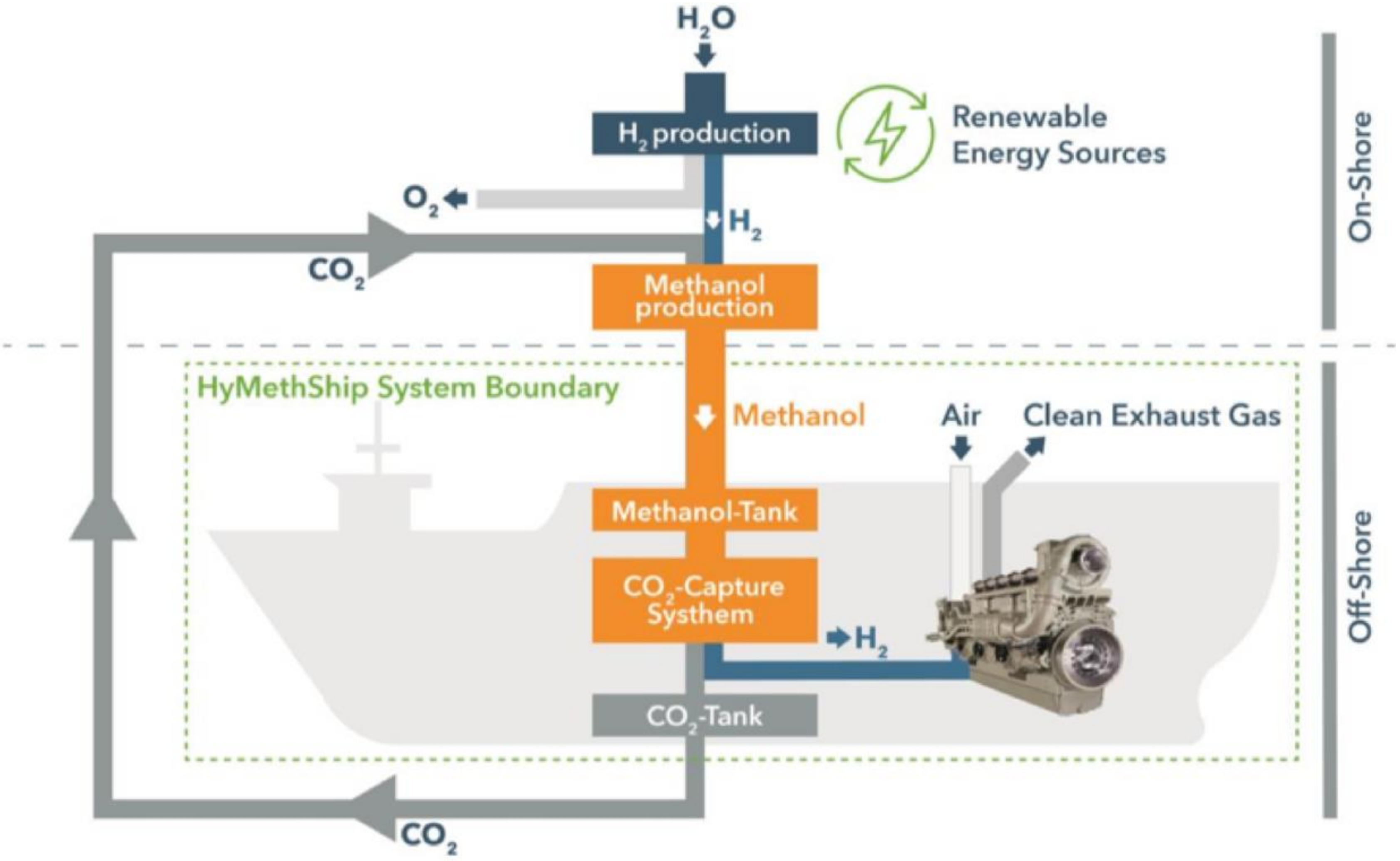
Electricity price €/MWh

- Green-marked results indicate a production cost that is equal or below what the industries' pay for fossil methanol (63 €/MWh).
- Yellow-marked results indicate a production cost that is equal or below double the market price of fossil methanol (126 €/MWh).
- Red-marked results indicate a production cost that is higher than double the market price of fossil methanol, i.e. difficult to see business opportunities (>126 €/MWh).

Source: Grahn M, A-K Jannasch (2018). What electricity price would make electrofuels cost-competitive? 6th TMFB, Tailor-Made Fuels from Production to Propulsion Aachen, Germany. 19-21 June

Project HyMeth

- The HyMeth Ship system combines a membrane reactor, a CO_2 capture system, a storage system for CO_2 and methanol, as well as a hydrogen-fuelled combustion engine into one system.
- The new concept allows for a closed CO_2 loop ship propulsion system while maintaining the reliability of well-established marine engine technology.
- The system will be demonstrated onshore at full scale.
- Our research group will analyze environmental and techno-economic aspects.



General insights on future fuels

- Three types of energy carriers have the potential to substantially reduce the fossil CO_2 emissions from the transportation sector: **carbon based fuels (biofuels/electrofuels)**, **electricity** and **hydrogen**.
- Fuels that have an advantage are those that
  - can be blended in conventional fuels (drop-in, alcohols, biodiesel, efuels).
  - already have a wide-spread fuel infrastructure (ethanol, methane, EV charging poles).
  - EU have decided to focus on (electricity, methane, hydrogen).
- It is most likely that parallel solutions will be developed, e.g.
  - There are many advantages for electric solutions in cities. Aspects like a reduction of NOx, soot, and noise. Most likely different electric solutions in cities (electric buses, cars, delivery trucks, trams, metro etc).
  - There are several challenges for electrifying long-distance transport (especially ships and aircrafts). Electrofuels may complement biofuels for these transport modes.
- Irrespective of fuel type, CO_2 emissions can be reduced by more energy efficient vehicles and measurements towards reduced transport demand.




Our research group, future fuels incl electrofuels

All studies trying to shed some light to the larger research question
”Under what circumstances could electrofuels become an interesting option in the fuel mix of the transportation sector?”

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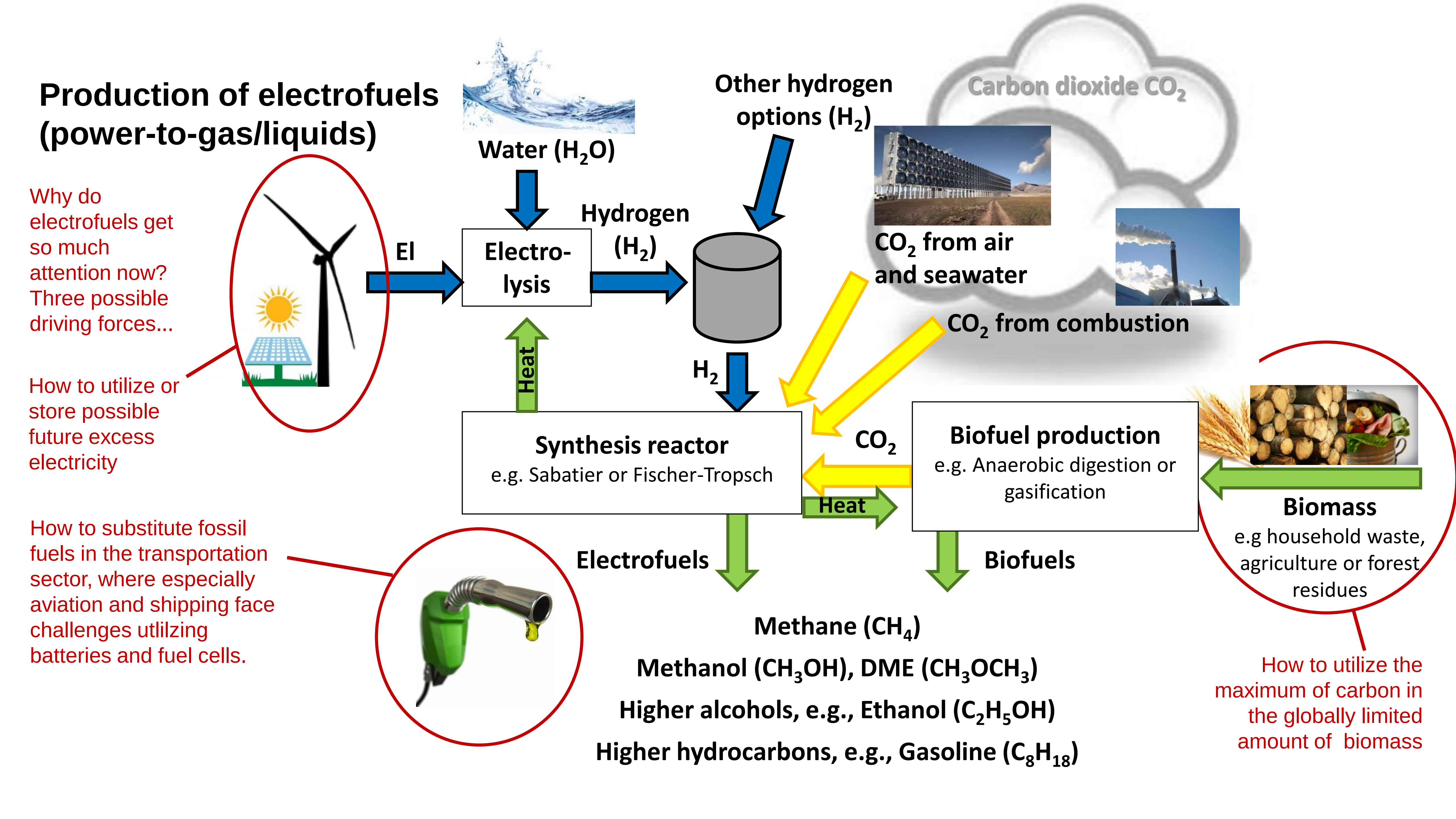
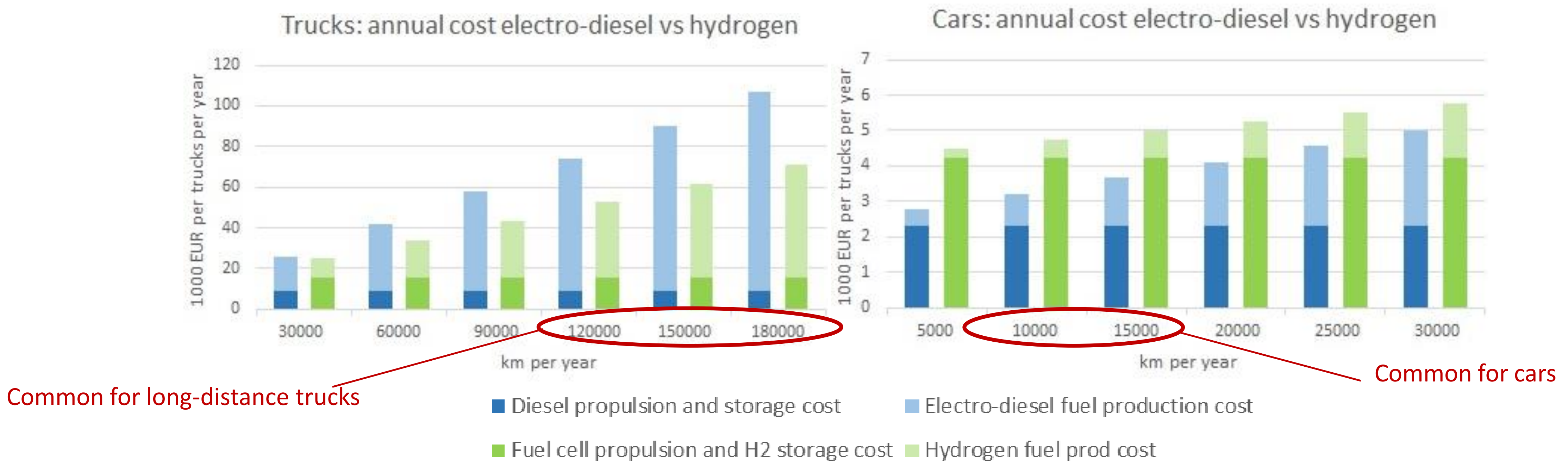
Extra



Production of electrofuels
(power-to-gas/liquids)
Water (H_2O)
Other hydrogen options (H_2)
Carbon dioxide CO_2
Why do electrofuels get so much attention now? Three possible driving forces...
El
Electro-lysis
Hydrogen (H_2)
CO_2 from air and seawater
CO_2 from combustion
Heat
H_2
How to utilize or store possible future excess electricity
Synthesis reactor
e.g. Sabatier or Fischer-Tropsch
CO_2
Biofuel production
e.g. Anaerobic digestion or gasification
Heat
Biomass
e.g household waste, agriculture or forest residues
How to substitute fossil fuels in the transportation sector, where especially aviation and shipping face challenges utlilzing batteries and fuel cells.
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})
How to utilize the maximum of carbon in the globally limited amount of biomass

Cost comparison electro-diesel in ICEV vs hydrogen in FC



Results: The concept of electro-diesel in ICEVs seems competitive, compared to hydrogen-FC, for all analyzed driving distances in the car sector (the opposite in the trucks sector).

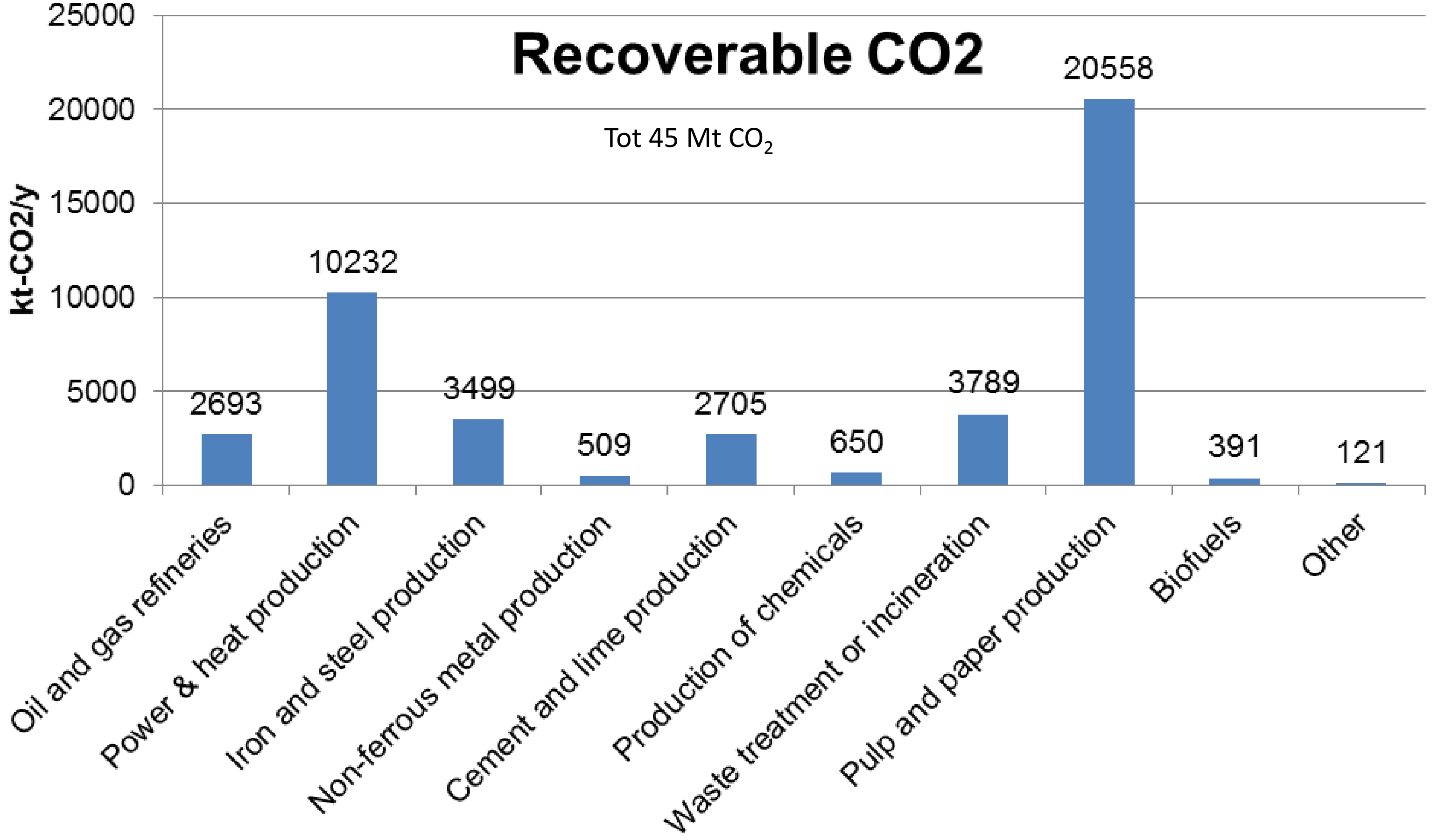
Insight: Electro-diesel can be competitive when vehicles has a short driving range per year, whereas hydrogen has advantages when vehicles has long driving distances per year. That is, expensive investments dominates at low use, whereas expensive fuel dominates at large use.

Source: Grahn . M. (2017) Can electrofuels in combustion engines be cost-competitive to hydrogen in fuel cells? Conference proceedings, TMFB, Aachen, 20-22 June.

Are there enough non-fossil CO_2?

Yes, in Sweden we have biogenic CO2 enough for approx 110 TWh electrofuels per year.

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**

	Sweden
Assuming replacing all bunker fuel (TWh)	22
Electricity demand (TWh)	42
Carbon dioxide (Mton)	6
Current electricity use in Sweden (TWh)	*140*
RE generation goal 2020 (TWh)	*30*


frontiers in Energy Research

The Potential for Electrofuels Production in Sweden Utilizing Fossil and Biogenic CO_2 Point Sources

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

Production cost of electro-hydrogen, for different electricity prices and different electrolyser investment cost, in the (a) base case and in a (b) future optimistic scenario

a) **Electro-hydrogen. Productions cost. Base case.**

Electrolyser €/kW$_{el}$	0	10	20	30	40	50
500	294	100	71	86	102	117
400	235	83	63	78	94	109
300	177	66	55	70	86	101
200	118	49	47	63	78	93
100	59	33	39	55	70	85
CF:	10%	40%	95%	95%	95%	95%

Electricity price €/MWh

b) **Electro-hydrogen. Productions cost. Optimistic case.**

Electrolyser €/kW$_{el}$	0	10	20	30	40	50
500	174	50	35	51	66	81
400	135	38	29	45	60	75
300	95	26	23	39	54	70
200	55	14	17	33	48	64
100	15	2	12	27	42	58
CF:	10%	40%	95%	95%	95%	95%

Electricity price €/MWh

Green-marked results indicate a production cost that is equal or below what the industries' pay for fossil hydrogen (50 €/MWh).

Yellow-marked results indicate a production cost that is equal or below double the market price of fossil hydrogen (100 €/MWh).

Red-marked results indicate a production cost that is higher than double the market price of fossil hydrogen i.e. difficult to see business opportunities (>100 €/MWh).

Source: Grahn M, A-K Jannasch (2018). What electricity price would make electrofuels cost-competitive? 6th TMFB, Tailor-Made Fuels from Production to Propulsion Aachen, Germany. 19-21 June