Övergripande om **elektrobränslen ur ett systemforskningsperspektiv**

utmaningar och möjligheter

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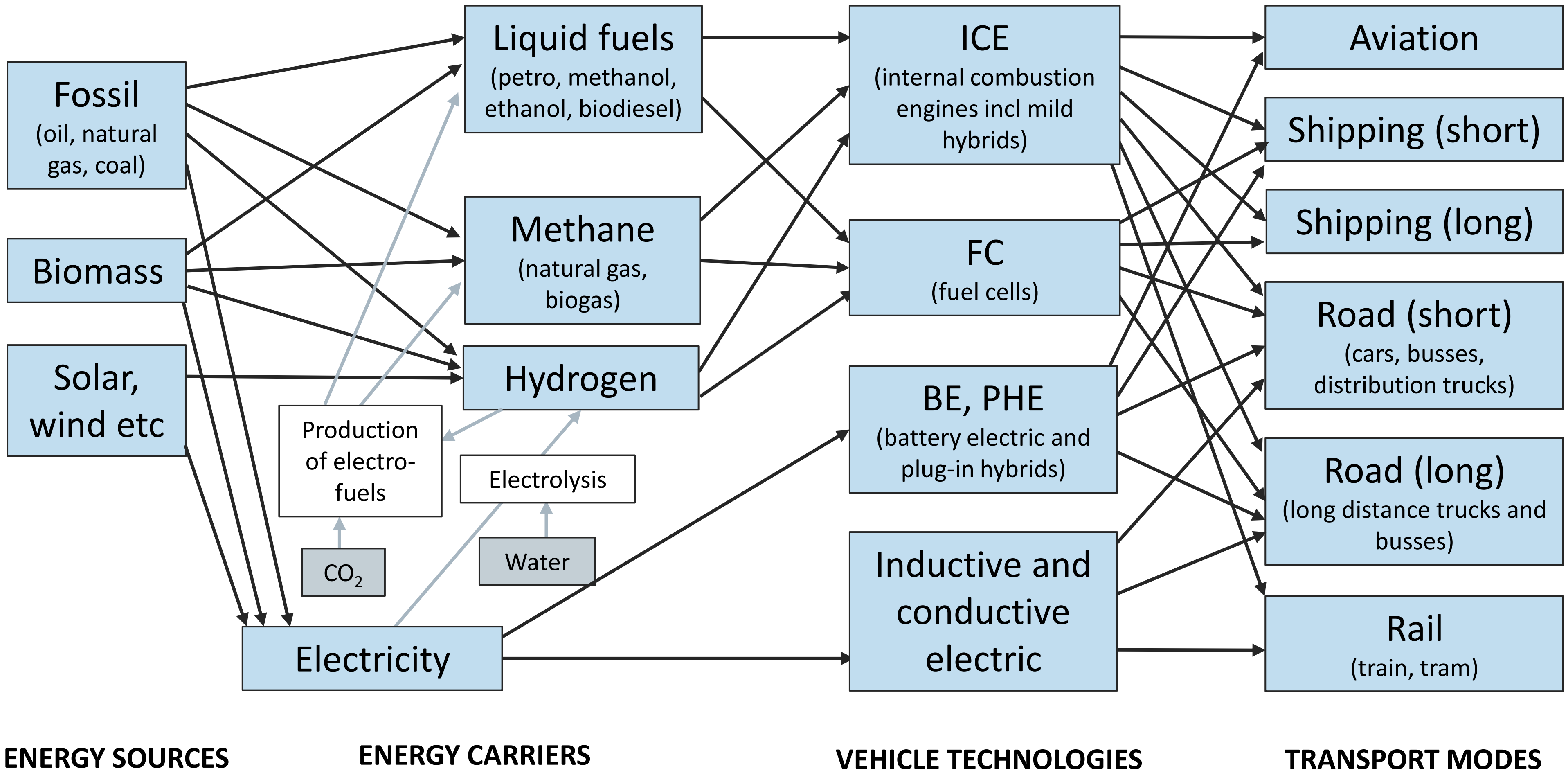
Different types of fuels and vehicle technology options for different transport modes?



Fossil
(oil, natural gas, coal)

Biomass

Solar, wind etc

Liquid fuels
(petro, methanol, ethanol, biodiesel)

Methane
(natural gas, biogas)

Hydrogen

Production of electro-fuels

Electrolysis

CO_2

Water

Electricity

ICE
(internal combustion engines incl mild hybrids)

FC
(fuel cells)

BE, PHE
(battery electric and plug-in hybrids)

Inductive and conductive electric

Aviation

Shipping (short)

Shipping (long)

Road (short)
(cars, busses, distribution trucks)

Road (long)
(long distance trucks and busses)

Rail
(train, tram)

ENERGY SOURCES

ENERGY CARRIERS

VEHICLE TECHNOLOGIES

TRANSPORT MODES

Production of electrofuels (power-to-gas/liquids)

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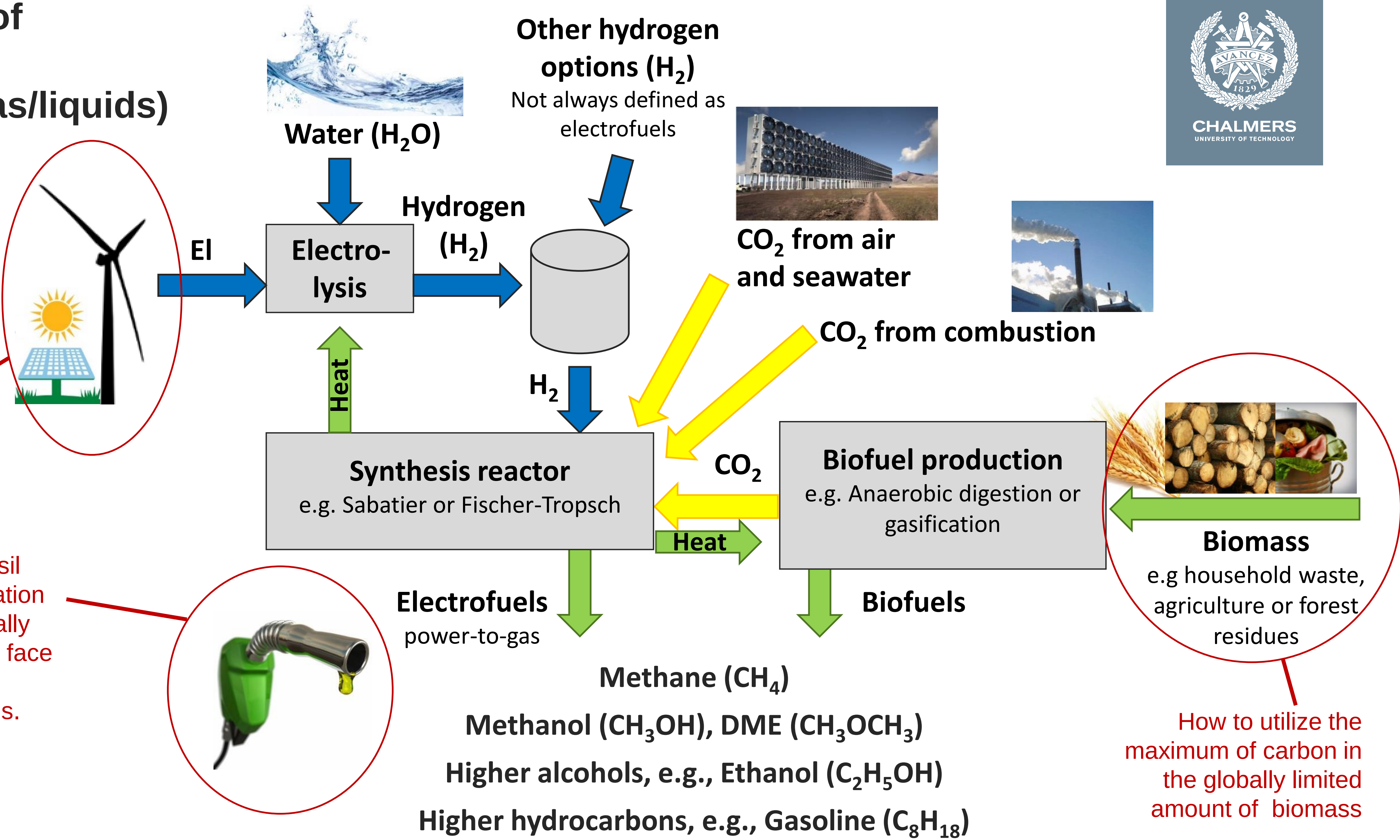
Why do electrofuels get so much attention now? Three possible driving forces...

How to utilize or store possible future excess electricity

How to substitute fossil fuels in the transportation sector, where especially aviation and shipping face challenges utlilizing batteries and fuel cells.



Water (H_2O)

Other hydrogen options (H_2)
Not always defined as electrofuels

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

CO_2

Heat

Biofuel production
e.g. Anaerobic digestion or gasification

Biomass
e.g household waste, agriculture or forest residues

Electrofuels
power-to-gas

Biofuels

Methane (CH_4)

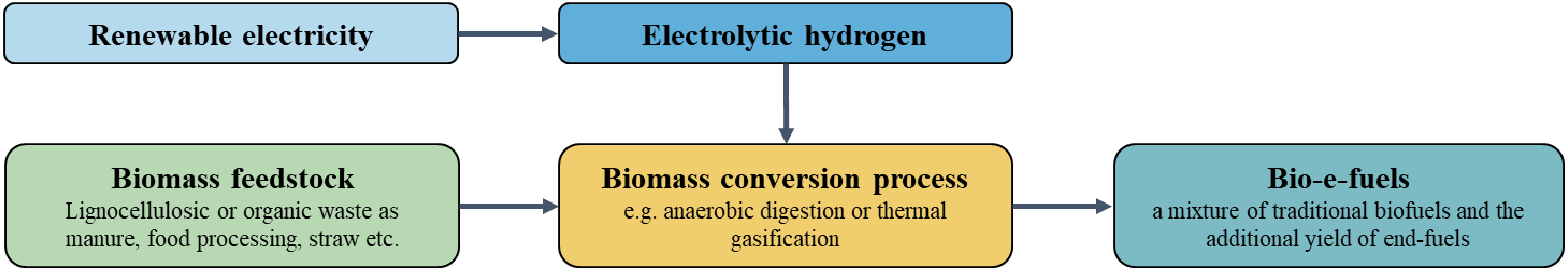
Methanol (CH_3OH), DME (CH_3OCH_3)

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

Introducing the term ”Bio-e-fuels”



Renewable electricity

Electrolytic hydrogen

Biomass feedstock
Lignocellulosic or organic waste as manure, food processing, straw etc.

Biomass conversion process
e.g. anaerobic digestion or thermal gasification

Bio-e-fuels
a mixture of traditional biofuels and the additional yield of end-fuels

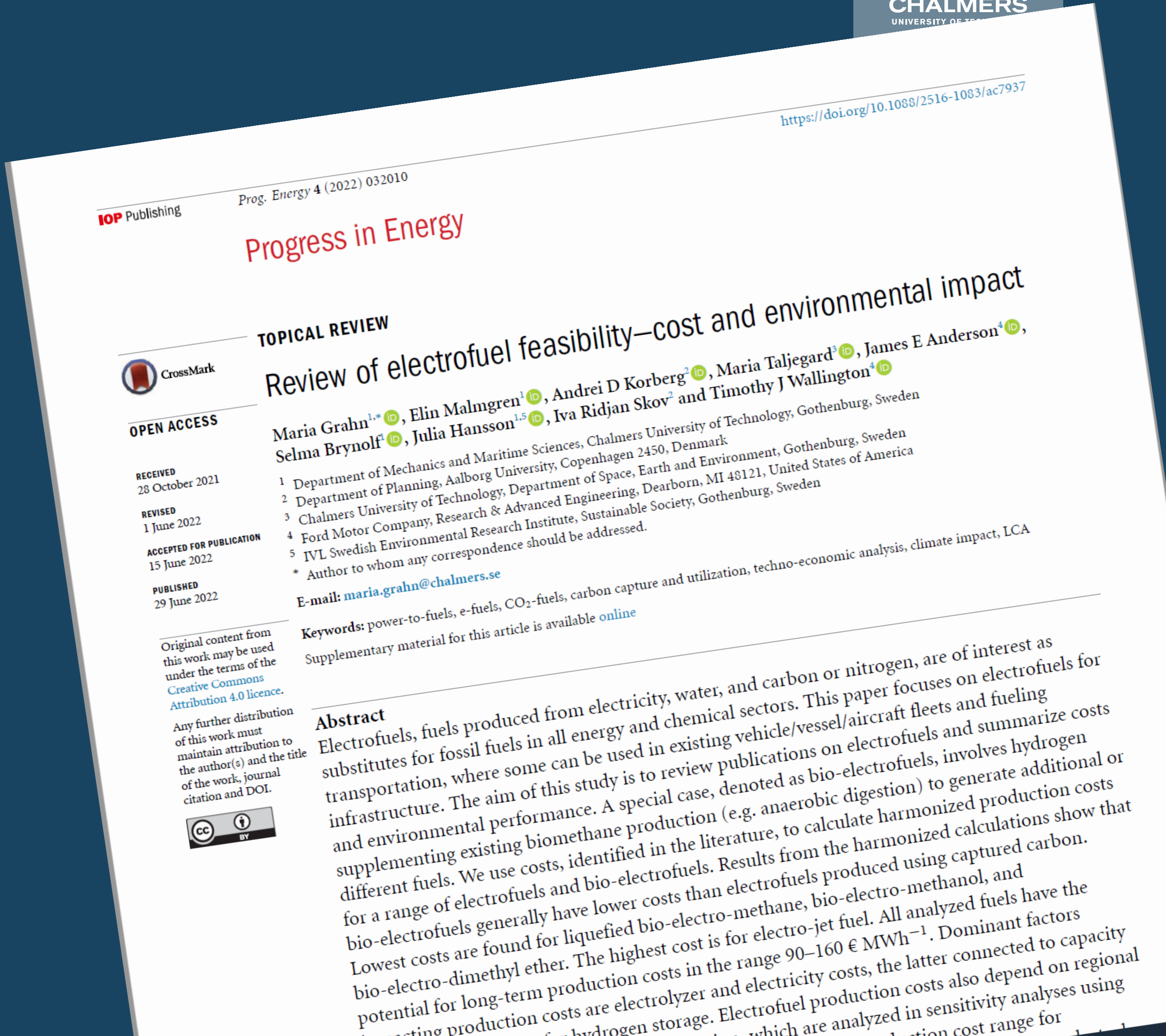
Bio-e-fuels are generated by adding electrolytic hydrogen to a biomass-based conversion process (such as anaerobic digestion or biomass gasification) to increase the production yields by utilizing the excess CO_2 or CO generated in the biomass conversion process.

This will generate additional fuel without the need for carbon capture.

Production cost for bio-e-fuels is built up by summing costs for electricity, biomass feedstock, and annuitized CAPEX for electrolyzer and the gasifier or anaerobic digester.

Costs are spread over the entire volume of fuel produced.

Production cost different electrofuels options



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TOPICAL REVIEW

Review of electrofuel feasibility—cost and environmental impact

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Supplementary material for this article is available online

Abstract

Electrofuels, fuels produced from electricity, water, and carbon or nitrogen, are of interest as substitutes for fossil fuels in all energy and chemical sectors. This paper focuses on electrofuels for transportation, where some can be used in existing vehicle/vessel/aircraft fleets and fueling infrastructure. The aim of this study is to review publications on electrofuels and summarize costs and environmental performance. A special case, denoted as bio-electrofuels, involves hydrogen supplementing existing biomethane production (e.g. anaerobic digestion) to generate additional or different fuels. We use costs, identified in the literature, to calculate harmonized production costs for a range of electrofuels and bio-electrofuels. Results from the harmonized calculations show that bio-electrofuels generally have lower costs than electrofuels produced using captured carbon. Lowest costs are found for liquefied bio-electro-methane, bio-electro-methanol, and bio-electro-dimethyl ether. The highest cost is for electro-jet fuel. All analyzed fuels have the potential for long-term production costs in the range 90–160 € MWh^{-1}. Dominant factors

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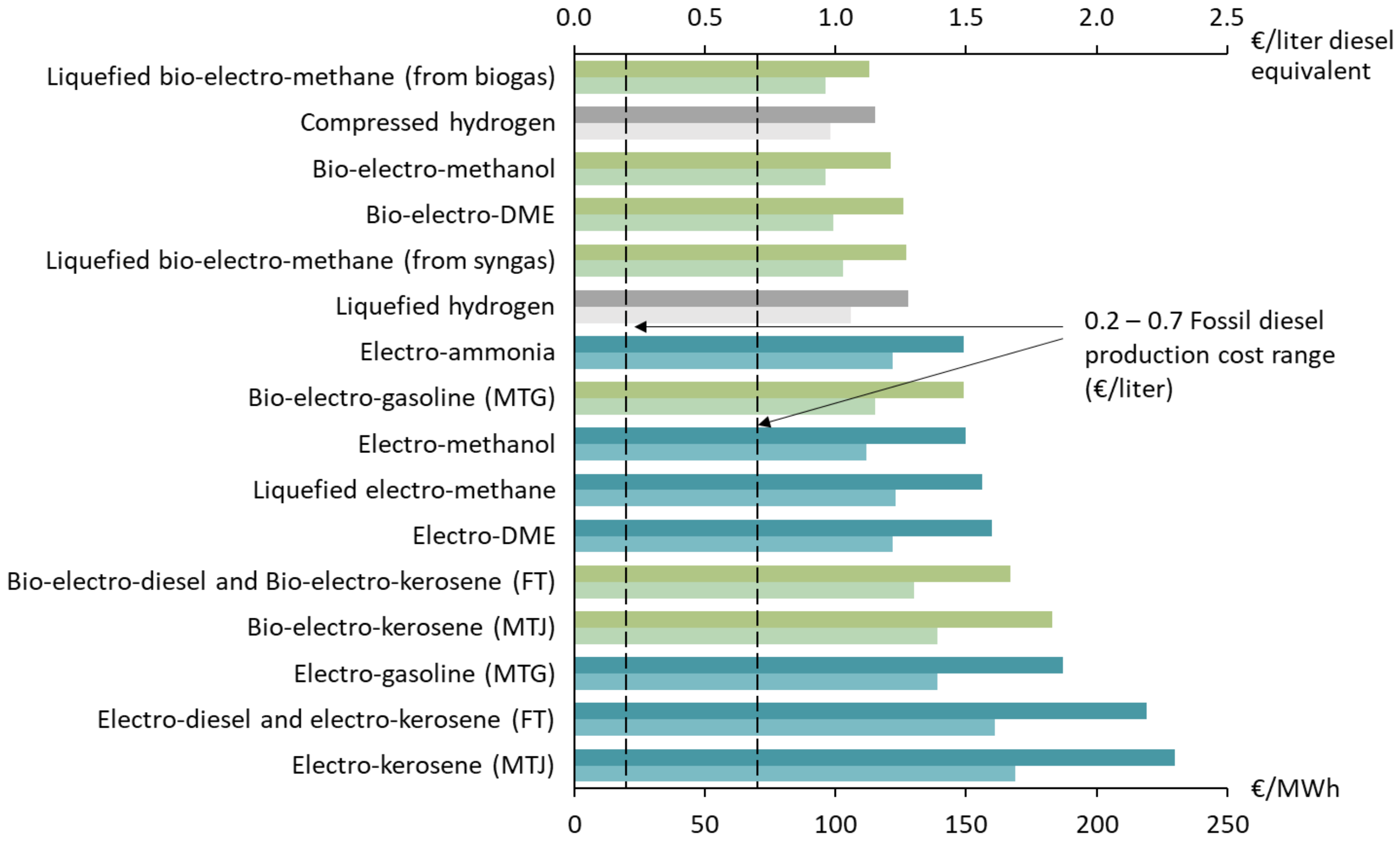
Production costs for electrolytic hydrogen, bio-e-fuels, and e-fuels



Dark colored bars: Near-term cost, approx. 5-10 years in future. **Results 110-230 €/MWh.**

Light colored bars: long-term cost, approx. 20-30 years in future. **Results 90-160 €/MWh.**

Black dotted lines illustrate a range of production costs of fossil gasoline/diesel/kerosene, corresponding to an oil price range of \$30–\$100/barrel.

Note: no cost for fuel infrastructure nor hydrogen storage, and no revenue for oxygen, are included.

Acronyms used:
DME: dimethyl ether;
MTG: methanol-to-gasoline;
MTJ: methanol-to-jet;
FT: Fischer-Tropsch.

Grahn et al (2022) Review of electrofuel feasibility: Cost and environmental impact. *Progress in Energy 4 (3)* 032010. doi.org/10.1088/2516-1083/ac7937.

Production cost e-methanol

depending on capacity factor and electrolyzer investment cost, 2050, **Reference case**

Hungary-Croatia-Slovenia

Electrolyser CAPEX (€/kWelec)										
900	567	222	158	135	123	116	112	108	107	106
750	499	199	144	125	116	110	106	104	103	103
600	431	177	131	115	108	104	101	99	99	99
450	363	154	117	105	100	98	96	95	95	96
300	295	131	104	96	93	91	91	90	91	92
150	227	109	90	86	85	85	85	86	87	88
Capacity factor (%)	5	15	25	35	45	55	65	75	85	95
Electricity price (€/MWh)	15	17	22	27	30	33	35	36	38	40
Hydrogen storage (€/MWh$_{H2}$)	11	11	8	8	7	6	6	6	5	5

Western Spain

Electrolyser CAPEX (€/kWelec)										
900	550	206	143	120	109	103	99	98	97	99
750	482	183	130	111	102	97	94	93	93	96
600	414	161	116	101	94	91	89	89	89	92
450	346	138	103	91	86	84	84	84	85	89
300	278	115	89	82	79	78	78	80	81	85
150	210	93	75	72	71	72	73	75	77	81
Capacity factor (%)	5	15	25	35	45	55	65	75	85	95
Electricity price (€/MWh)	3	6	11	16	20	23	26	29	32	34
Hydrogen storage (€/MWh$_{H2}$)	14	13	12	10	9	9	7	6	6	7

Using long-term values from the literature review and electricity prices as well as hydrogen storage costs from the eNODE model.

Ireland

Electrolyser CAPEX (€/kWelec)										
900	552	208	144	120	108	101	97	93	91	91
750	484	185	130	110	101	95	91	89	87	87
600	416	162	117	100	93	89	86	84	83	84
450	348	140	103	91	86	83	81	80	79	80
300	280	117	89	81	78	77	76	75	75	76
150	212	94	76	71	70	70	71	71	71	73
Capacity factor (%)	5	15	25	35	45	55	65	75	85	95
Electricity price (€/MWh)	5	11	15	18	22	24	26	28	29	30
Hydrogen storage (€/MWh$_{H2}$)	12	7	6	7	6	6	5	4	5	5

Southern Sweden

Electrolyser CAPEX (€/kWelec)										
900	559	218	153	129	117	109	104	101	99	100
750	491	195	140	119	109	103	99	97	95	96
600	423	172	126	110	102	97	94	92	91	92
450	355	150	112	100	94	91	89	87	87	89
300	287	127	99	90	86	85	84	83	83	85
150	219	104	85	80	79	78	78	78	79	82
Capacity factor (%)	5	15	25	35	45	55	65	75	85	95
Electricity price (€/MWh)	8	14	17	22	25	27	30	31	34	36
Hydrogen storage (€/MWh$_{H2}$)	15	12	11	9	9	8	7	7	5	5

Results (for electrolyzer CAPEX 300–450 €/kW and capacity factors 45–65%):

91–100 €/MWh for Hungary-Croatia-Slovenia

84–94 €/MWh for southern Sweden.

76–86 €/MWh for Ireland

78–86 €/MWh for western Spain

10-16% higher costs compared to Ireland and western Spain

Grahn et al (2022) Review of electrofuel feasibility: Cost and environmental impact. *Progress in Energy 4 (3)* 032010. doi.org/10.1088/2516-1083/ac7937.

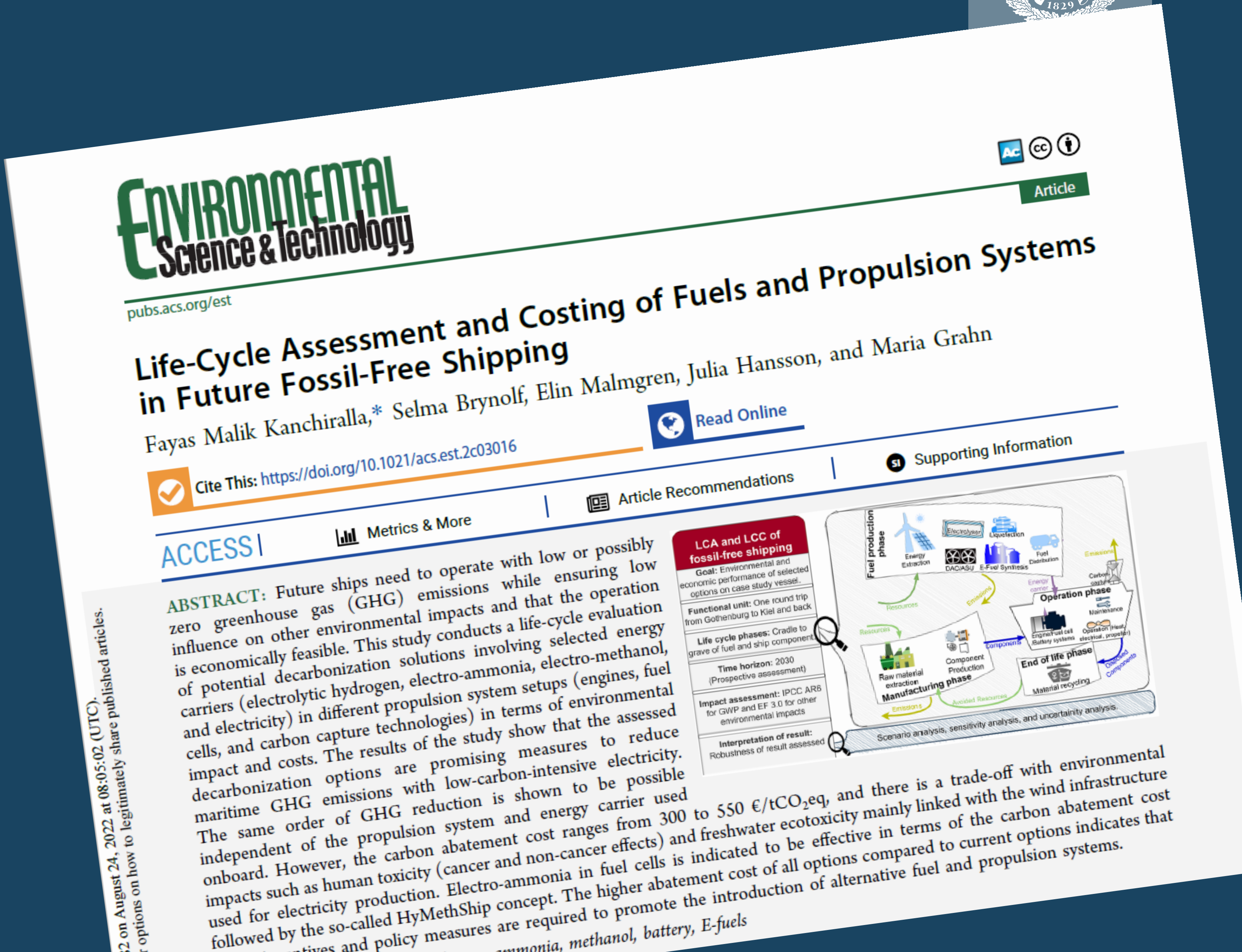
Case study:
Stena Germanica

Time horizon:
2030

Functional unit:
Round trip Gothenburg-Kiel-Gothenburg

Life cycle cost comparisons fuels, vehicles and fuel infrastructure

focusing on electrolytic hydrogen and electrofuels



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Article

Life-Cycle Assessment and Costing of Fuels and Propulsion Systems in Future Fossil-Free Shipping

Fayas Malik Kanchiralla,* Selma Brynolf, Elin Malmgren, Julia Hansson, and Maria Grahn

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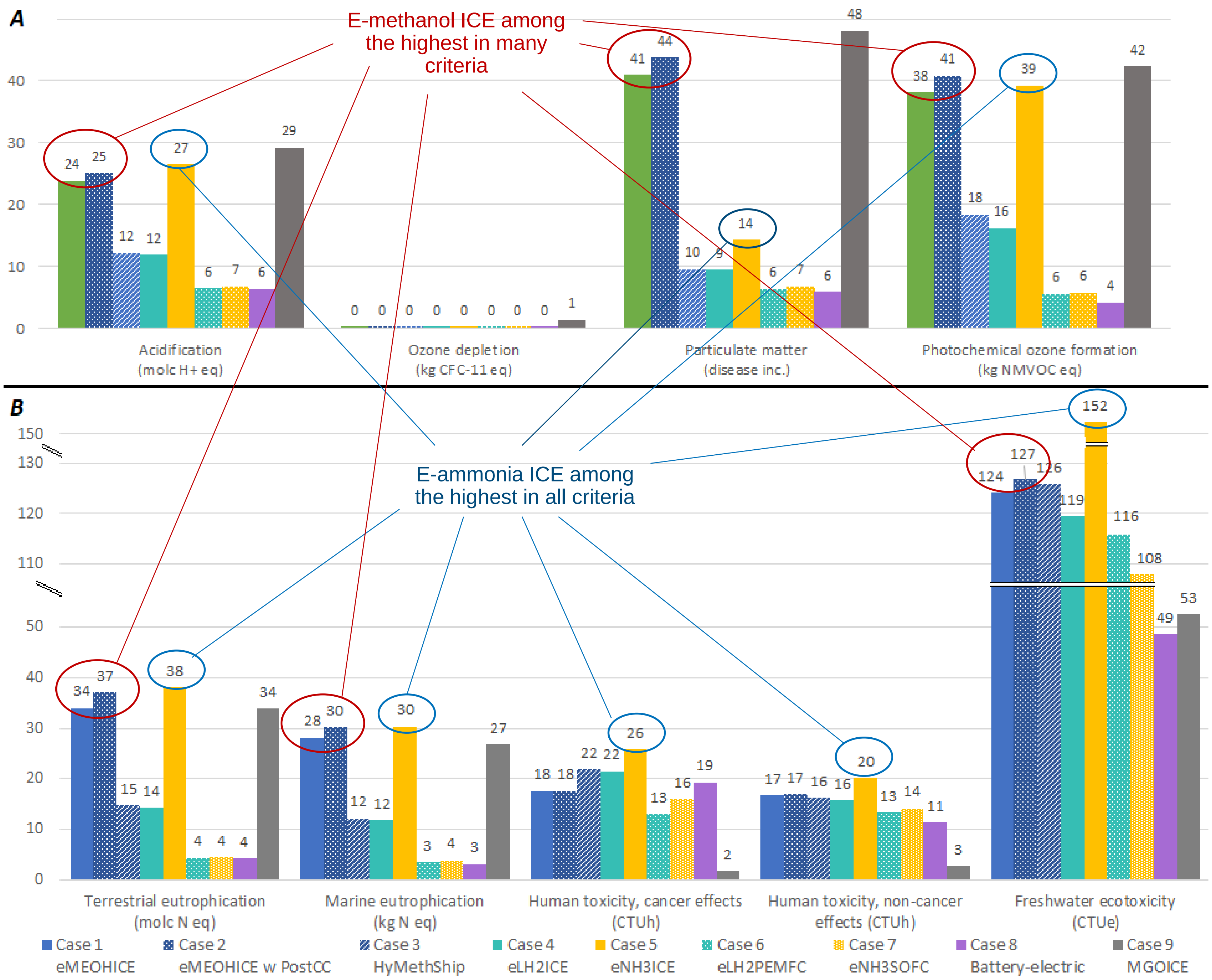
ABSTRACT: Future ships need to operate with low or possibly zero greenhouse gas (GHG) emissions while ensuring low influence on other environmental impacts and that the operation is economically feasible. This study conducts a life-cycle evaluation of potential decarbonization solutions involving selected energy carriers (electrolytic hydrogen, electro-ammonia, electro-methanol, and electricity) in different propulsion system setups (engines, fuel cells, and carbon capture technologies) in terms of environmental impact and costs. The results of the study show that the assessed decarbonization options are promising measures to reduce maritime GHG emissions with low-carbon-intensive electricity. The same order of GHG reduction is shown to be possible independent of the propulsion system and energy carrier used onboard. However, the carbon abatement cost ranges from 300 to 550 €/tCO_2eq, and there is a trade-off with environmental impacts such as human toxicity (cancer and non-cancer effects) and freshwater ecotoxicity mainly linked with the wind infrastructure used for electricity production. Electro-ammonia in fuel cells is indicated to be effective in terms of the carbon abatement cost followed by the so-called HyMethShip concept. The higher abatement cost of all options compared to current options indicates that tives and policy measures are required to promote the introduction of alternative fuel and propulsion systems.

mmonia, methanol, battery, E-fuels



E-methanol ICE among the highest in many criteria

E-ammonia ICE among the highest in all criteria

Environmental impacts of 9 fuel and propulsion options for shipping

Hydrogen and battery electric, typically perform the best.

Ammonia and methanol among the worst

Example of when trade-offs are needed

Acronyms used: **eMeOHICE**=electro-methanol in internal combustion engines, **eMeOHICE w PostCC**= electro-methanol in internal combustion engines with post carbon capture, **HyMethShip**= electro-methanol in ICE with pre-combustion carbon capture following the EU-project concept HyMethShip, **eLH2ICE**=liquefied electrolytic hydrogen used in internal combustion engines, **eNH3ICE**=electro-ammonia used in internal combustion engines, **eLH2PEMFC**= liquefied electrolytic hydrogen used in PEM fuel cells, **eNH3SOFC**= electro-ammonia used in solid oxide fuel cells, **BE**= battery electric operation, **MGOICE**= fossil oil-based marine gas oil used in combustion engines.

Ref. Kanchiralla, FM, Brynolf S, Malmgren E, Hansson J, Grahn M (2022) Life Cycle Assessment and Costing of Fuels and Propulsion Systems in Future Fossil-Free Shipping. Environmental Science and Technology 56(17), 12517-12531. https://doi.org/10.1021/acs.est.2c03016

General reflections on electrofuels

- Advantages are e.g.,
  - Liquid fuels are less complex to store and distribute, compared to hydrogen.
  - Can be used in all modes of transport. Particularly interesting for sectors as shipping and aviation where liquid fuels with high energy density are difficult to replace.
  - Some can be used in existing vehicles (less need for large investments in new distribution and tank infrastructure).
  - Address difficulties connected to behavior challenges (hydrogen fueling, battery charging etc).

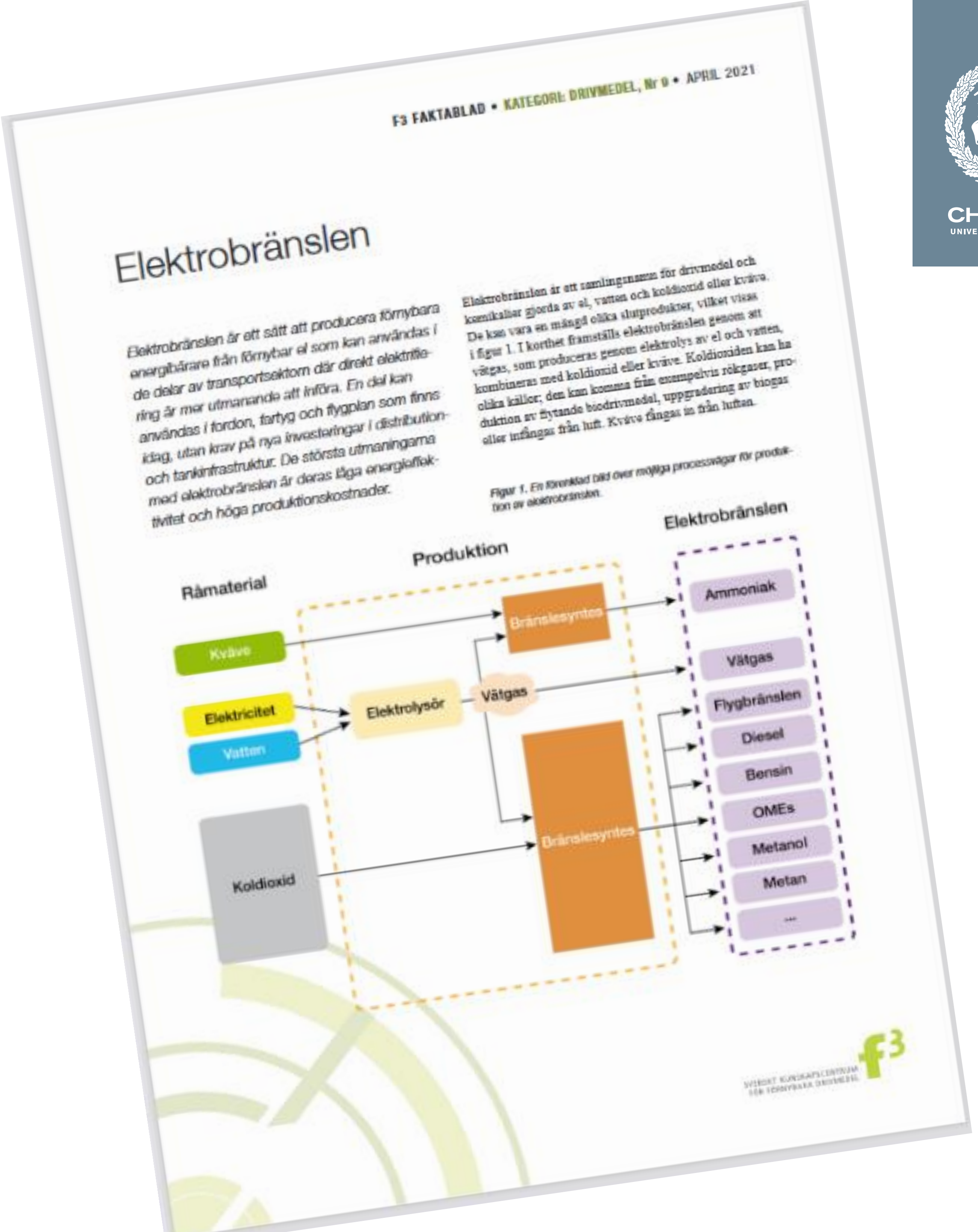
- Challenges are e.g.,
  - Low energy conversion efficiency. From the electricity grid to the wheels of a car, over 70% of the energy is retained if an electric car is used, while approximately 20-25% is retained for electrofuels used in internal combustion engines. That is, it make sense to use battery electric solutions when possible.
  - High production costs. Future costs are uncertain but likely higher than e.g., biofuels.

- It is most likely that parallel solutions will be developed, e.g.
  - There are many advantages for electric solutions in cities (Battery electric and hydrogen fuel cells). 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 aircraft). Electrofuels may complement biofuels for these transport modes.

Mer om elektrobränslen

Populärvetenskplig sammanfattning

https://f3centre.se/en/fact-sheets/electrofuels/



F3 FAKTABLAD • KATEGORI: DRIVMEDEL, Nr 9 • APRIL 2021

Elektrobränslen

Elektrobränslen är ett sätt att producera förnybara energibärare från förnybar el som kan användas i de delar av transportsektorn där direkt elektrifiering är mer utmanande att införa. En del kan användas i fordon, fartyg och flygplan som finns idag, utan krav på nya investeringar i distribution- och tankinfrastruktur. De största utmaningarna med elektrobränslen är deras låga energieffektivitet och höga produktionskostnader.

Elektrobränslen är ett samlingsnamn för drivmedel och kemikalier gjorda av el, vatten och koldioxid eller kväve. De kan vara en mängd olika slutprodukter, vilket visas i figur 1. I korthet framställs elektrobränslen genom att vätgas, som produceras genom elektrolys av el och vatten, kombineras med koldioxid eller kväve. Koldioxiden kan ha olika källor; den kan komma från exempelvis rökgaser, produktion av flytande biodrivmedel, uppgradering av biogas eller infångas från luft. Kväve fångas in från luften.

Figur 1. En förenklad bild över möjliga processvägar för produktion av elektrobränslen.

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