
LUT UNIVERSITY STRATEGY 2030 • TRAILBLAZERS – Science with a Purpose
SYSTEM
EARTH
AIR
Turning emissions into opportunities
BUSINESS
Sustainable renewal of business and industry
WATER
Refining sidestreams into value
ENERGY
Transition to carbon-neutral world
LUT University

LUT ELECTRICAL ENGINEERING 2024

LUT University

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- Prof. Olli Pyrhönen
- Prof. Pedro Nardelli
- Assistant prof. Niko Nevaranta

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- Prof. Pertti Kauranen (Kymenlaakso)
- Prof. Antti Kosonen

Solar Economy
- Prof. Christian Breyer

Industry prof. Jukka Ruusunen, Prof. Jarmo Partanen

FOCUS ON ENERGY SYSTEM ELECTRIFICATION

1. **Power-to-X Economy**
   - Energy system modelling
   - Wind and solar power generation
   - Electrochemical energy conversion and storage
   - Energy Efficiency
2. **Smart grids and Electricity Markets**
   - Smart grids
   - Sector integration and electricity grids
   - Electricity markets
   - IoT in energy systems
3. **Electric Power Conversion**
   - Electrified drivelines for different industrial and mobile applications
   - Electric transportation systems
   - Measurement, control, estimation, identification, optimization and communication methods
   - Power electronics: control, sensors, aging, design, optimization, diagnosis

Research staff (~170, summer 2024): 17 profs., 42 doctors, 62 post-graduate students, 51 research assistants, turnover ~13 M€

Head of Department
- Prof. Jero Ahola

Vice Head of Department
- Prof. Pertti Silventoinen

Head of Education
- Assoc. Prof. Katja Hynynen

Vice Head of Education
- Adjunct Prof. Janne Nerg

10.9.2024

Power-to-X Technologies – Status Update

Jero Ahola, D.Sc., Professor, Energy Efficiency, Head of the Department
Department of Electrical Engineering
LUT University
Email: jero.ahola@lut.fi
Tel: +358 40 529 8524
Twitter: @JeroAhola

Topics included in the presentation

- Power-to-x economy and key technologies in energy transition
- Direct and indirect electrification of transportation
- Applications of green hydrogen and production technologies

World greenhouse gas emissions

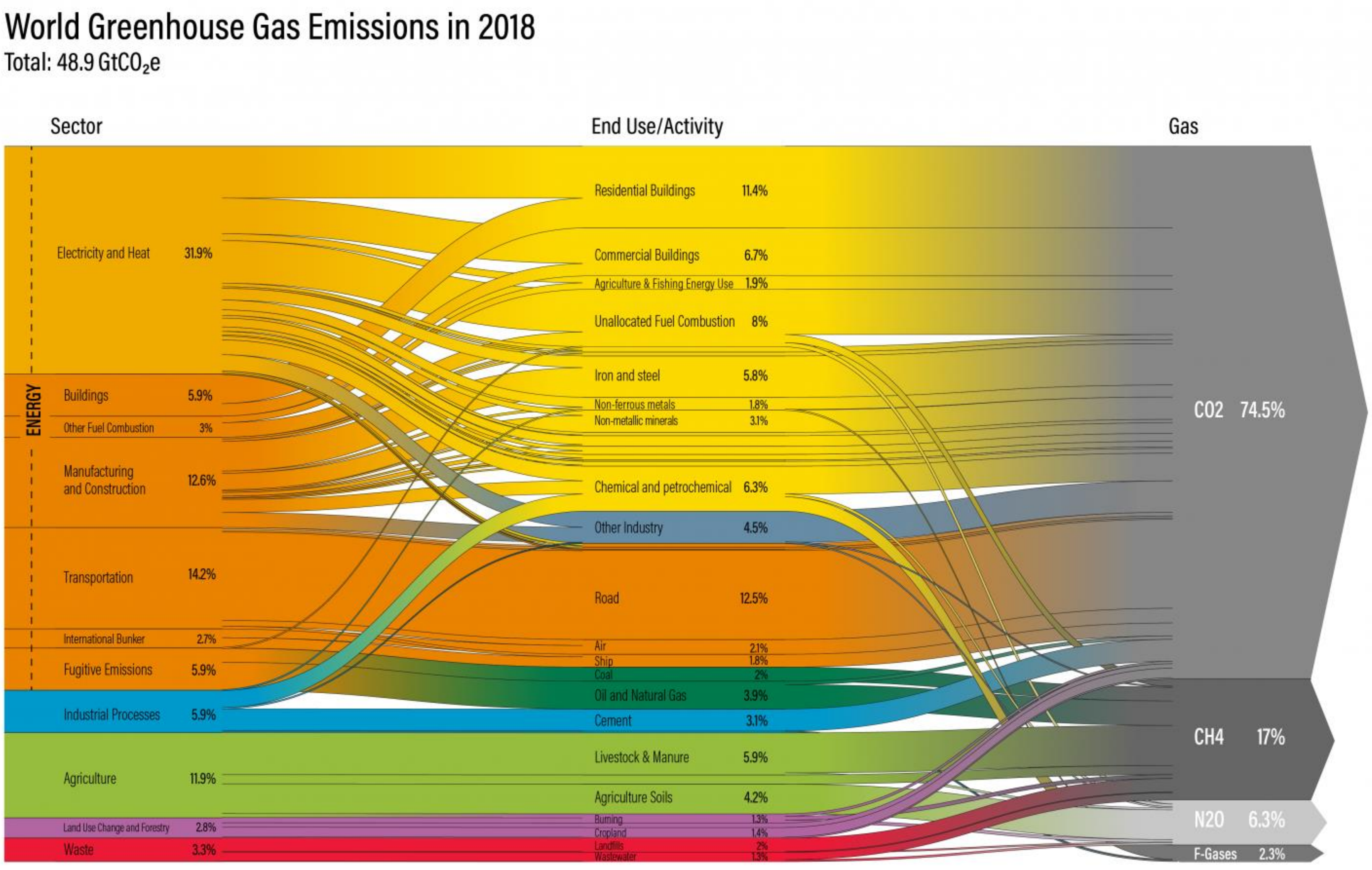
Electricity and heat (32%)

Industry (13%)

Transportation (14%)

Agriculture and land use change (15%)

ENERGY (73 %)

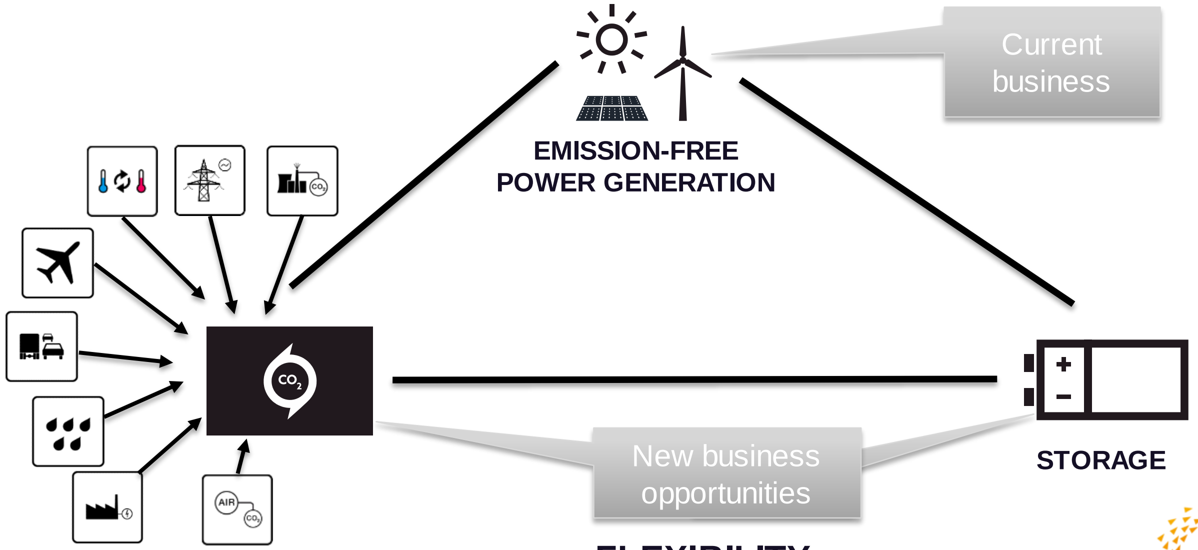


Source: Greenhouse gas emissions on Climate Watch. Available at: https://www.climatewatchdata.org

WORLD RESOURCES INSTITUTE

For < +2 ºC climate goal we have to have net-zero GHG emissions by 2050

Solution: Electrify everything either directly or indirectly!



http://www.neocarbonenergy.fi/library/reports/

NEO
CARBON
ENERGY

Many options available now in all sectors are estimated to offer substantial potential to reduce net emissions by 2030. Relative potentials and costs will vary across countries and in the longer term compared to 2030.

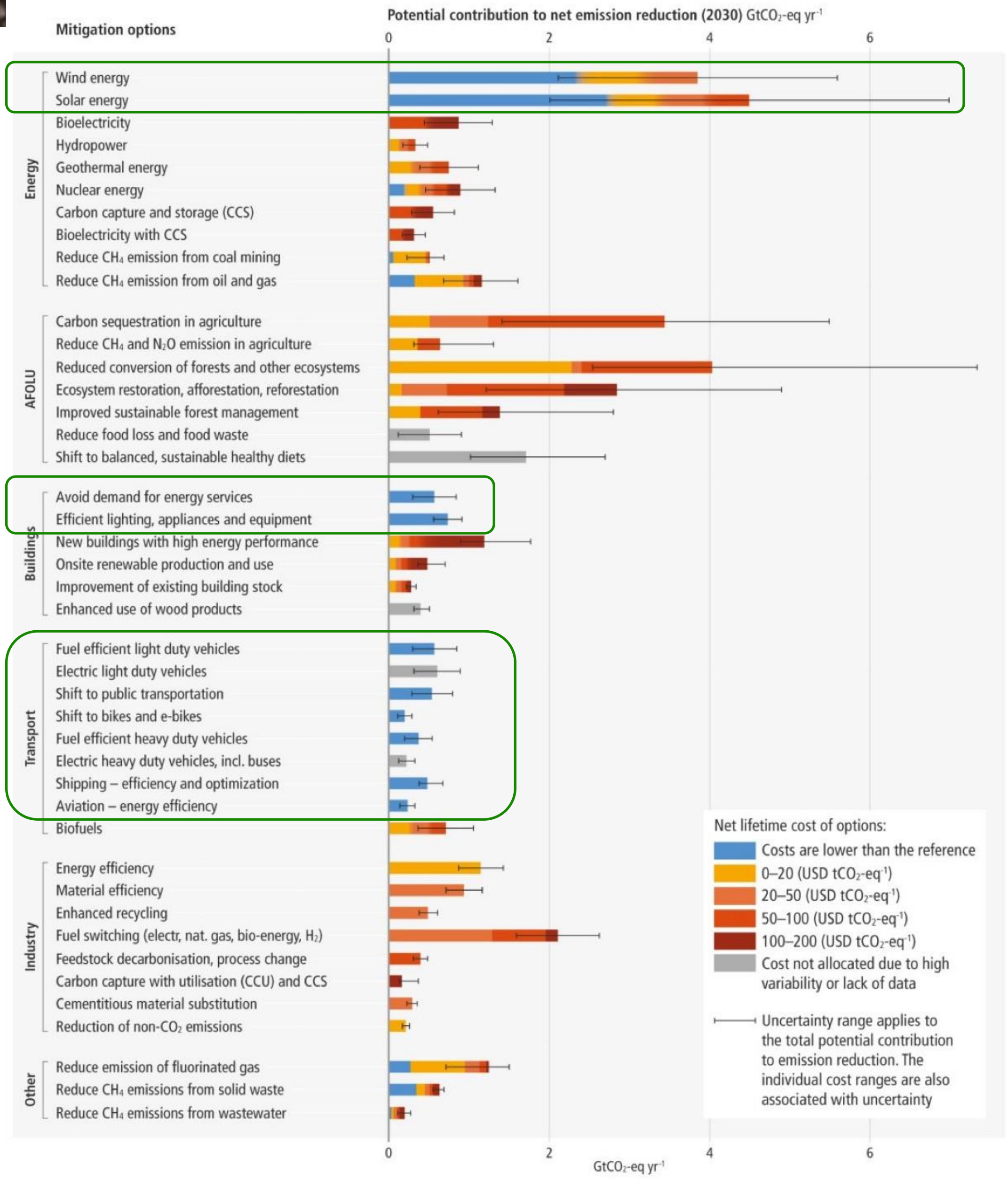


Figure SPM.7: Overview of mitigation options and their estimated ranges of costs and potentials in 2030.

Power-to-X economy – hydrogen will be an essential part of it

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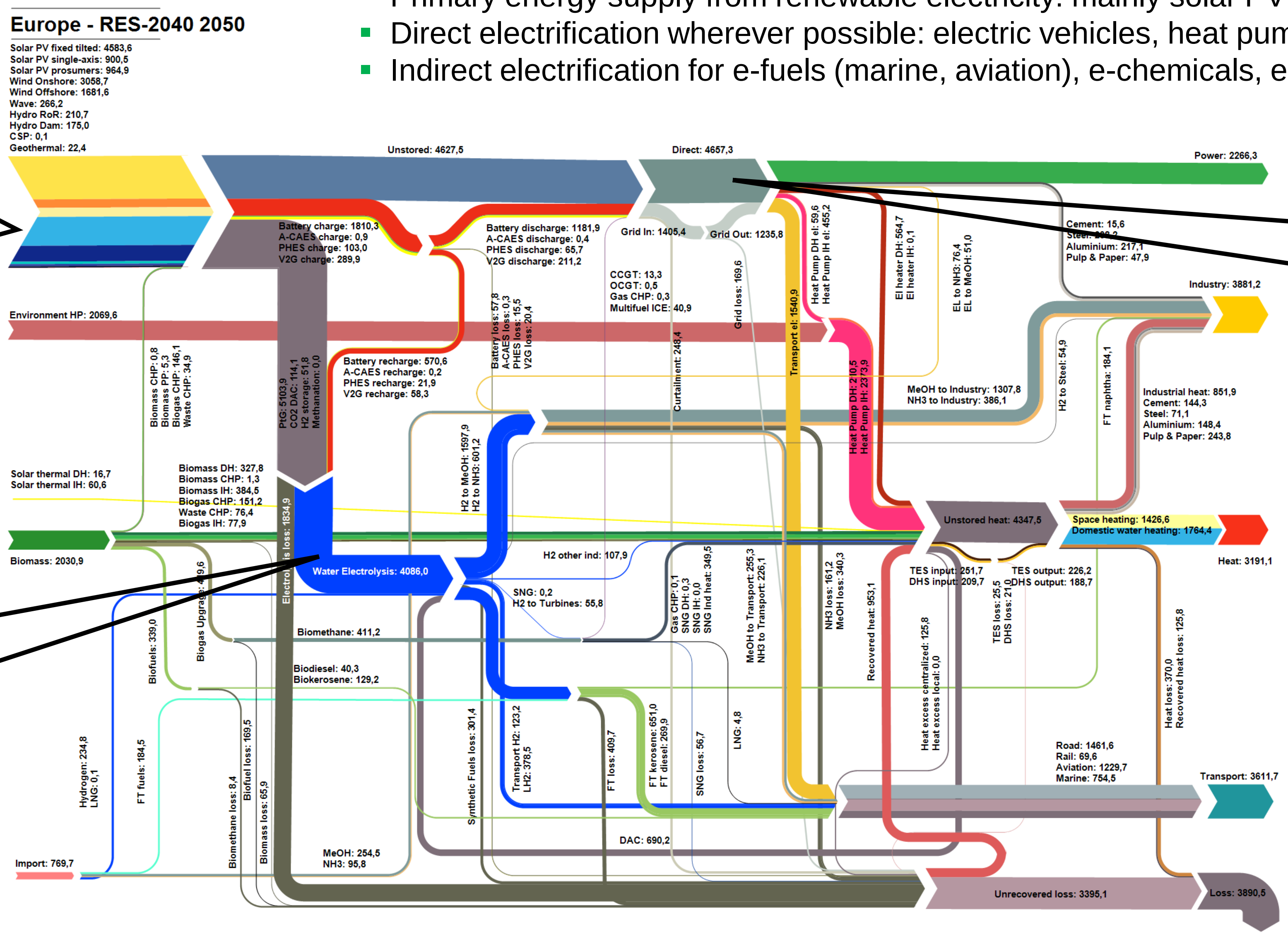
- Zero CO_2 emission low-cost energy system is based on electricity
- Core characteristic of energy in future: Power-to-X Economy
  - Primary energy supply from renewable electricity: mainly solar PV and wind power
  - Direct electrification wherever possible: electric vehicles, heat pumps, desalination, etc.
  - Indirect electrification for e-fuels (marine, aviation), e-chemicals, e-steel; power-to-hydrogen-to-X

Primary energy, electricity: Mostly solar & wind power



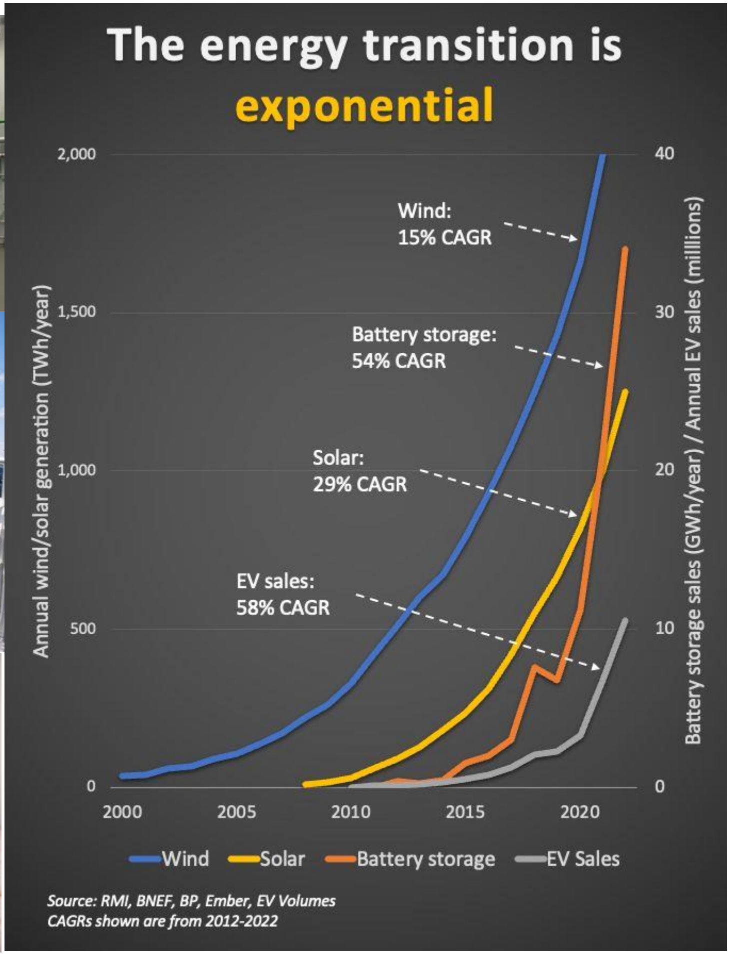
Priority 1: Direct electrification of energy end use

Priority 2: Indirect electrification, mostly with green hydrogen

Christian Breyer, Gabriel Lopez, Dmitrii Bogdanov, Petteri Laaksonen, The role of electricity-based hydrogen in the emerging power-to-X economy, International Journal of Hydrogen Energy, 2023, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2023.08.170.

Transition from the extraction fossil fuels to series-produced electric energy technologies

Age of fossil fuels:
Fossil fuels exploration extraction mining, refining, transportation, and burning



Past Present Future

Age of renewable electric energy technologies:
Series-produced wind, solar, batteries, electrolyzers, heat pumps, CO2 direct air capture, heat storages, etc. Electricity will be the primary energy source.

Learning curves of key renewable electric energy technologies

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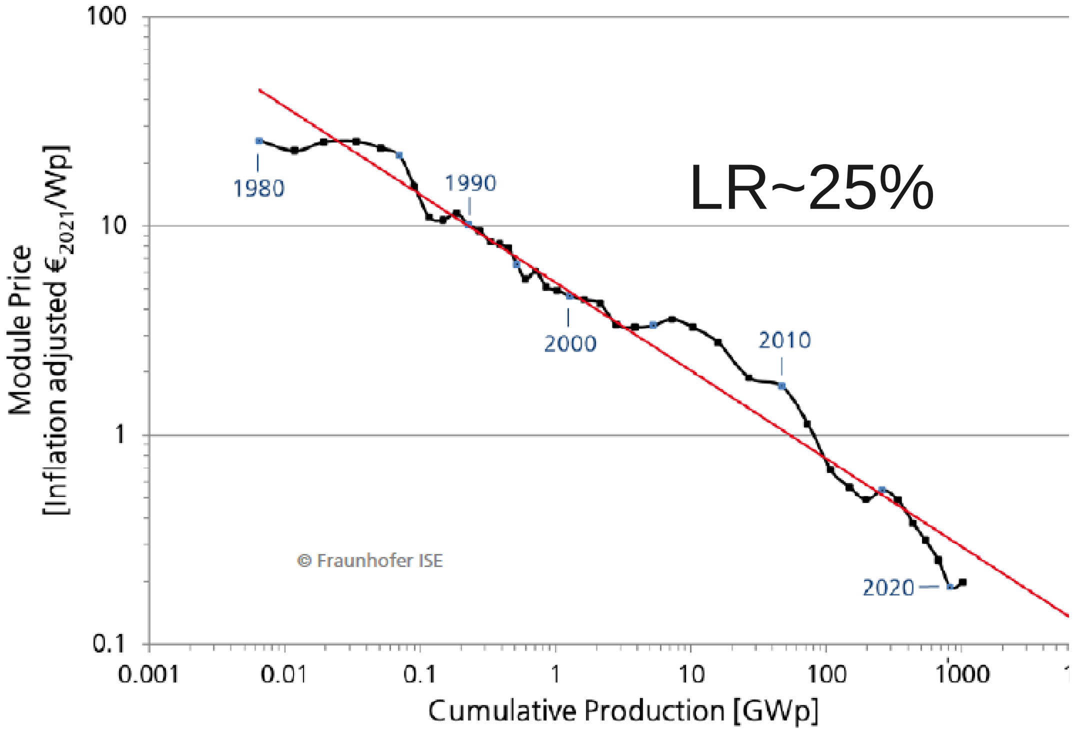
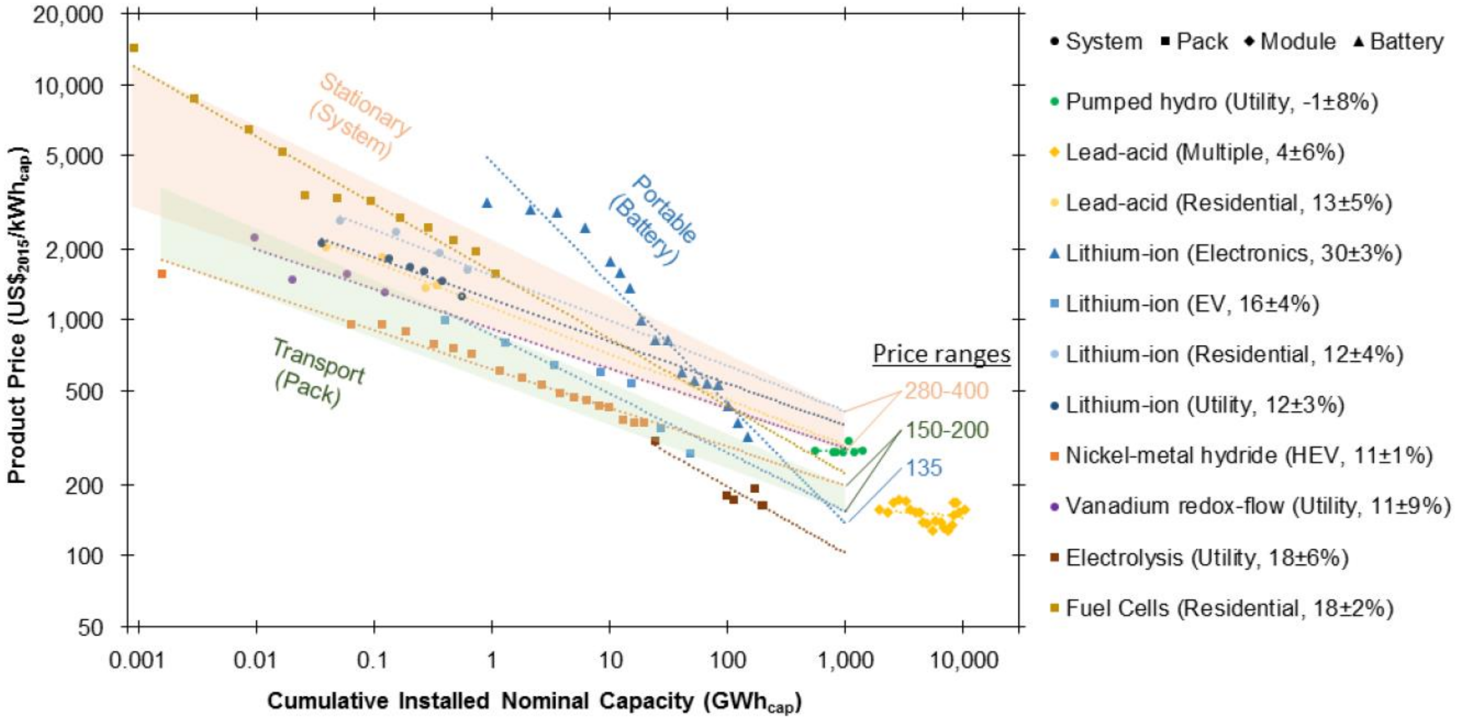
Solar PV module learning curve



Source: Photovoltaics Report, Fraunhofer-ISE, Germany, 22.8.2022
https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

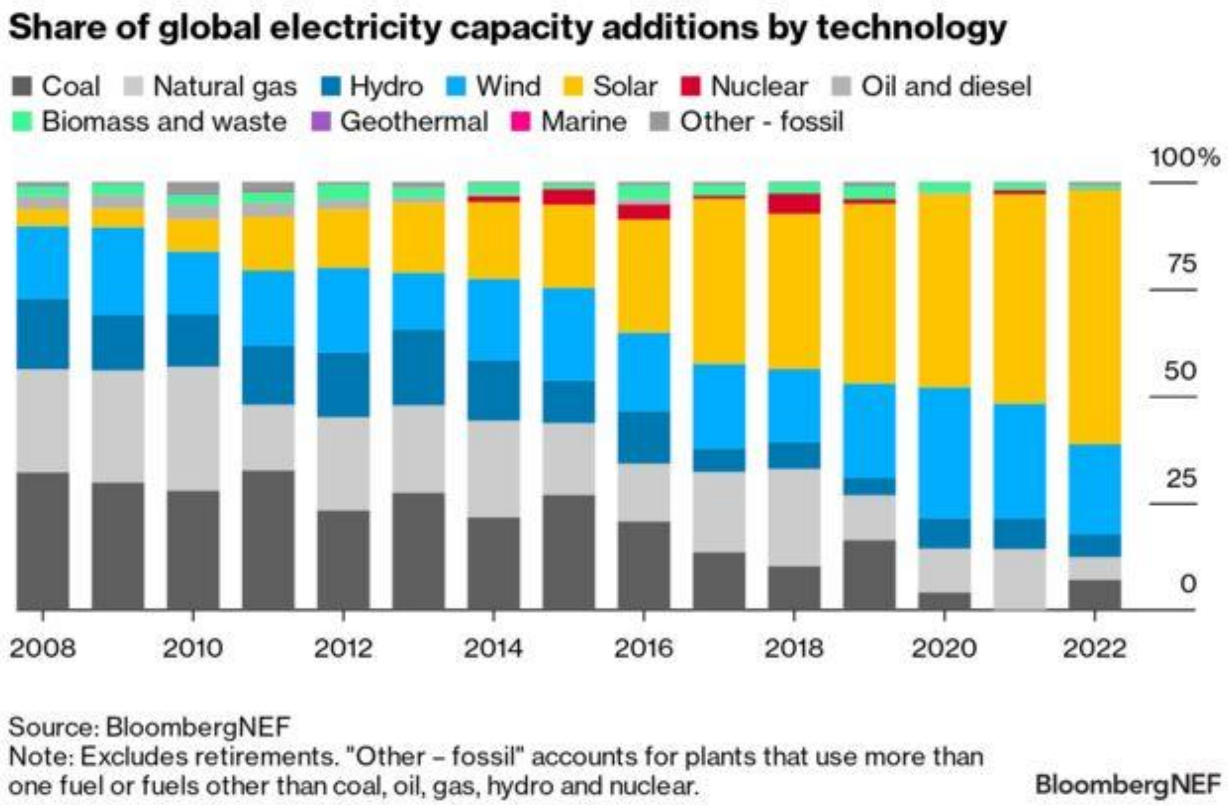
Electricity storage/conversion technology learning curves

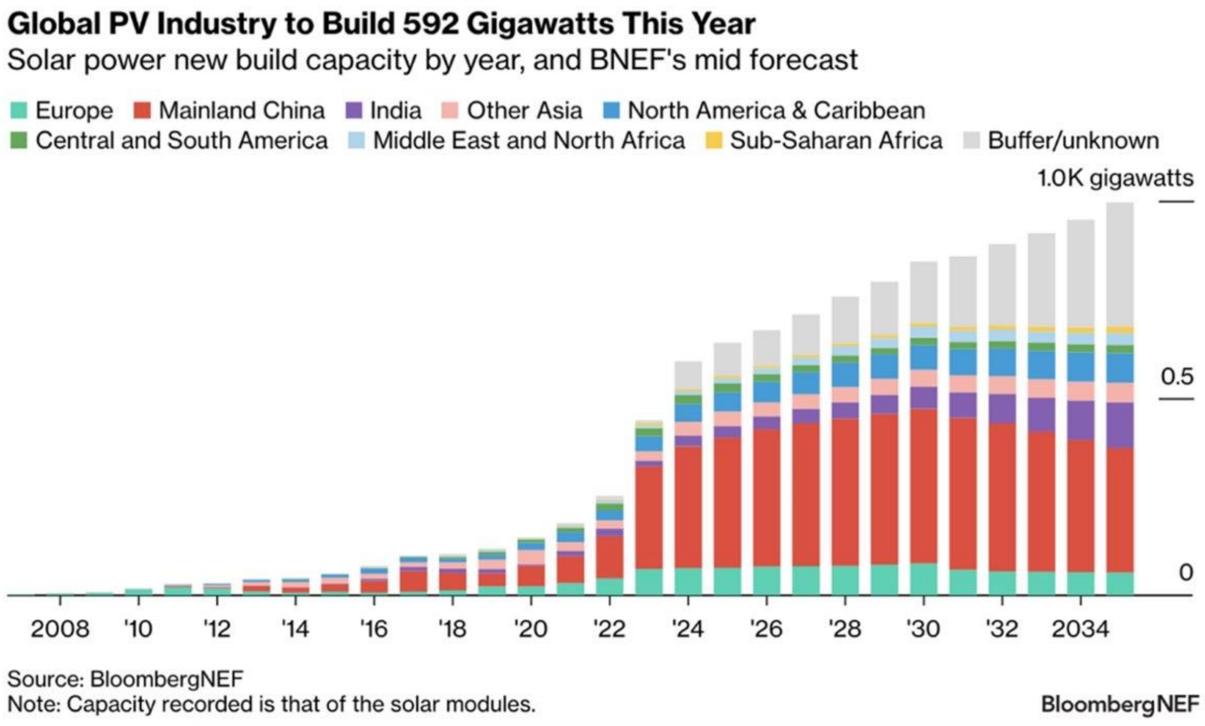


Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell, The future cost of electrical energy storage based on experience rates, Nature Energy volume 2, Article number: 17110 (2017)

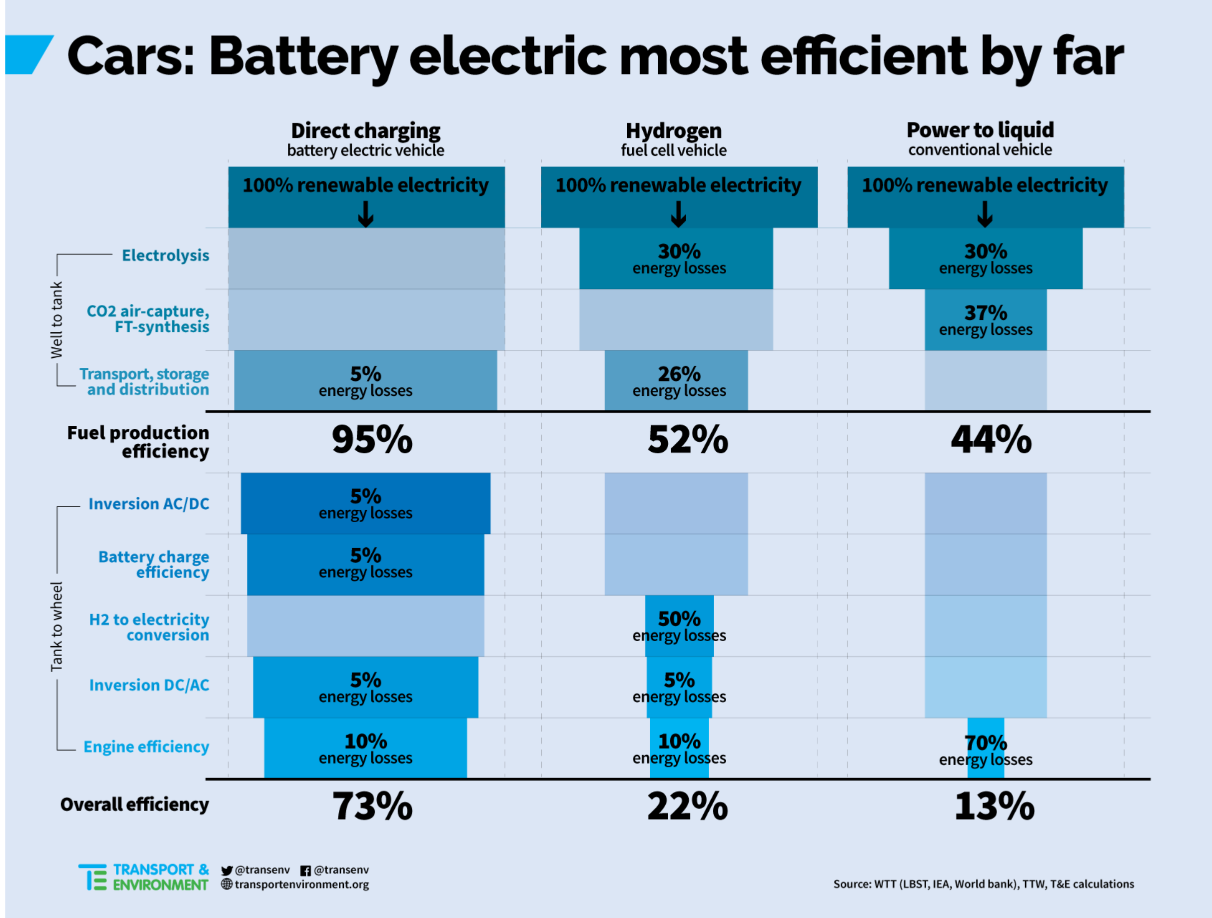
Solar and wind power-driven energy transition is ongoing without any doubts

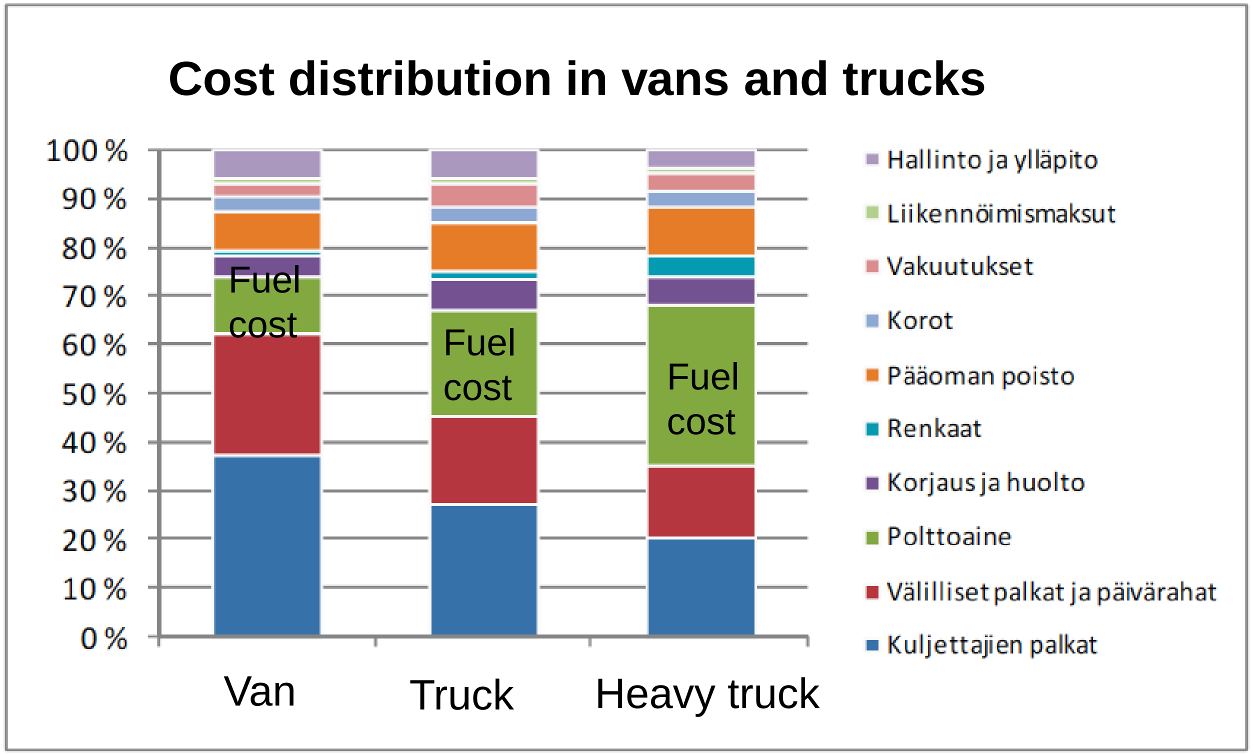
- Cumulative solar PV installations reached 1 TW in March 2022
- Based on IEA, in 2023 globally 349 GW of solar PV was installed, 56 GW in Europe
- During the next three years potentially additional 1 TW of solar PV capacity will be installed
- After 2025 global PV module manufacturing capacity will reach 1 TW/a





Example: Due to energy efficiency differences, the land-based transportation will be mainly electrified.

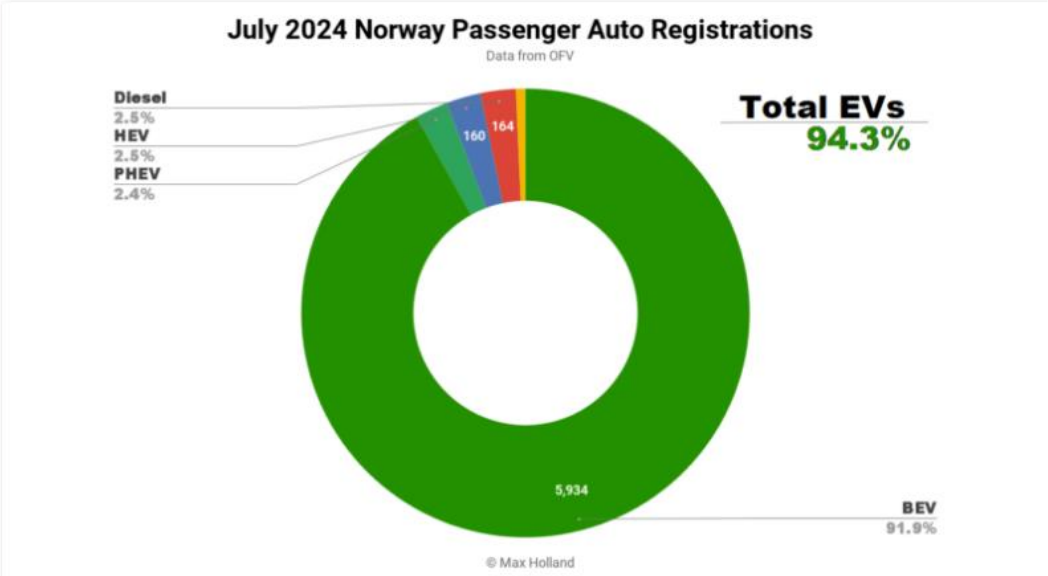




Lähde: Liikennemarkkinoiden nykytila, Liikenne- ja viestintäministeriö, 2009, https://julkaisut.valtioneuvosto.fi/handle/10024/78235

Transition from combustion engines to EV:s

NORWAY: global leader in electrification of cars

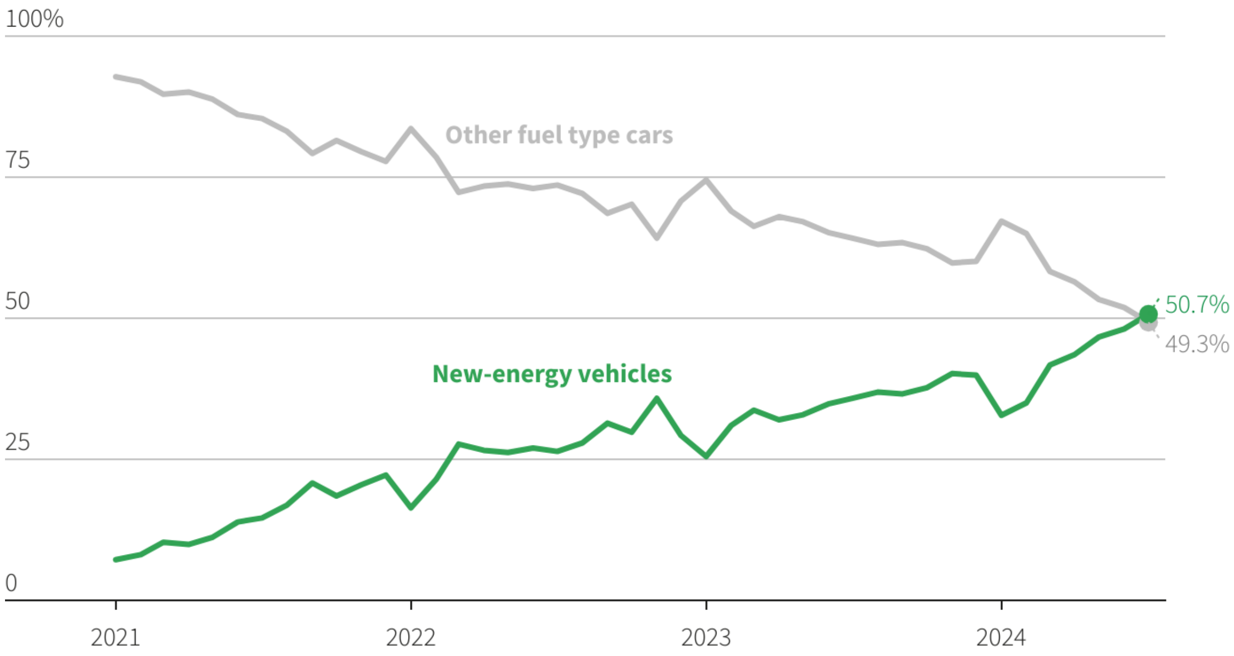


EVs Take 94.3% Share In Norway — New Record High

CHINA: the most important car market

NEV sales cross the halfway mark in July

New energy vehicle sales accounted for 50.7% of the total vehicle sales in China in July 2024, a record monthly high.



Source: CPCA | Reuters, Aug. 8, 2024 | By Sumanta Sen

- Global cars sales were ~80 million cars per year in 2023
- China was the largest car market with sales of 30 million cars in 2023

Battery-swapping for an electric truck

LUT study: Competitivity of battery swapping heavy transport

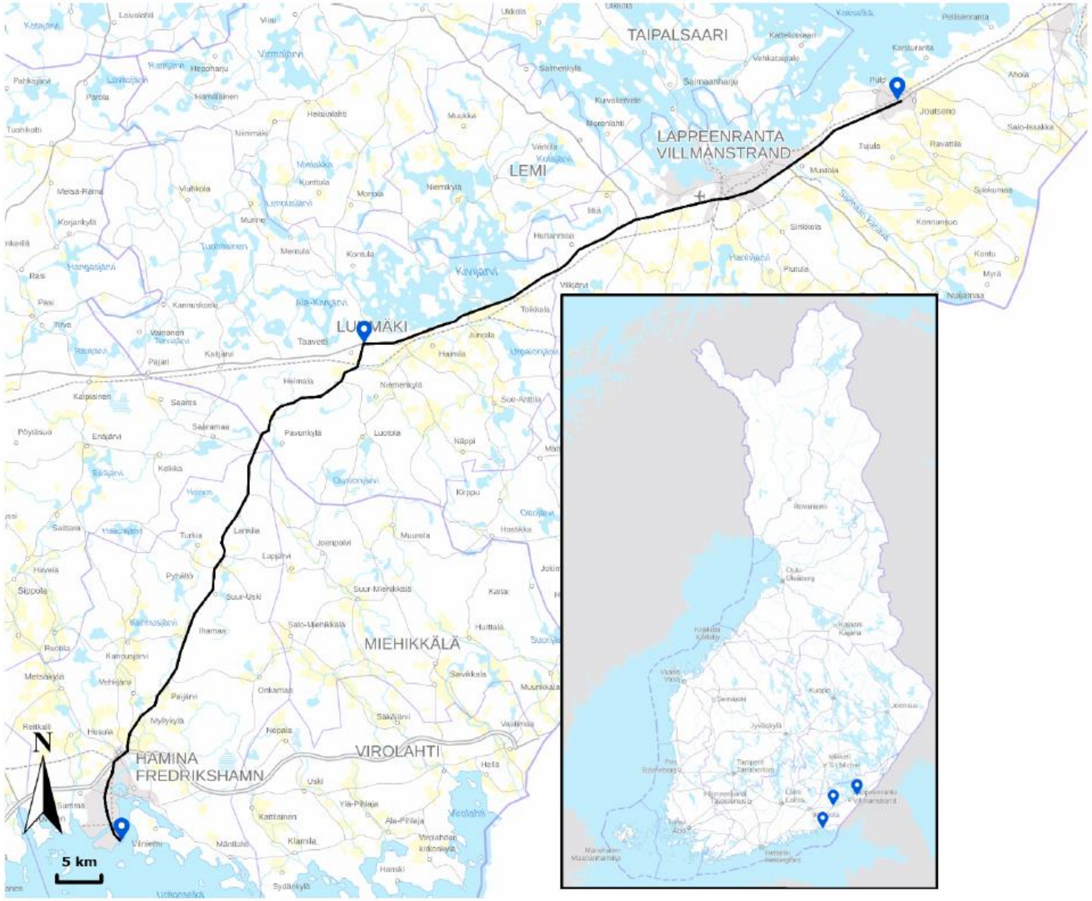


Fig. 2: Route of the case study. Background map (raster) contains data from the National Land Survey of Finland Topographic Database [47]

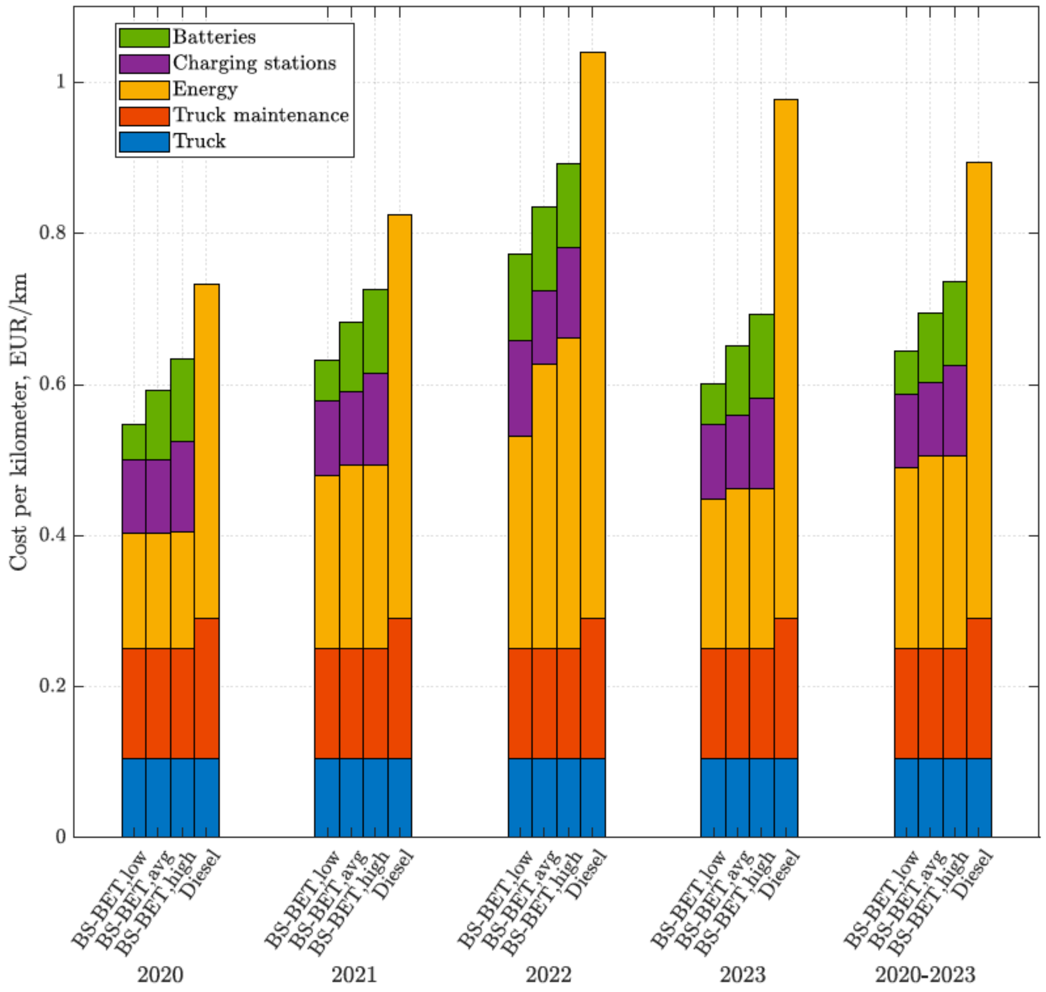


Fig. 4: Cost components for different scenarios with interest rate of 6 %. Low refers to low battery price (100 €/kWh), avg refers to average battery price (200 €/kWh), and high refers to high battery price (300 €/kWh).

Source:, Esa Tuviala, Altti Meriläainen, Teemu Hiltunen, Tuomo Lindh, Pertti Kauranen, Jero Ahola, Simulation tool to model the levelized cost of driving of battery swapping heavy duty vehicles, submitted to Transportation Research Part C: Emerging Technologies.

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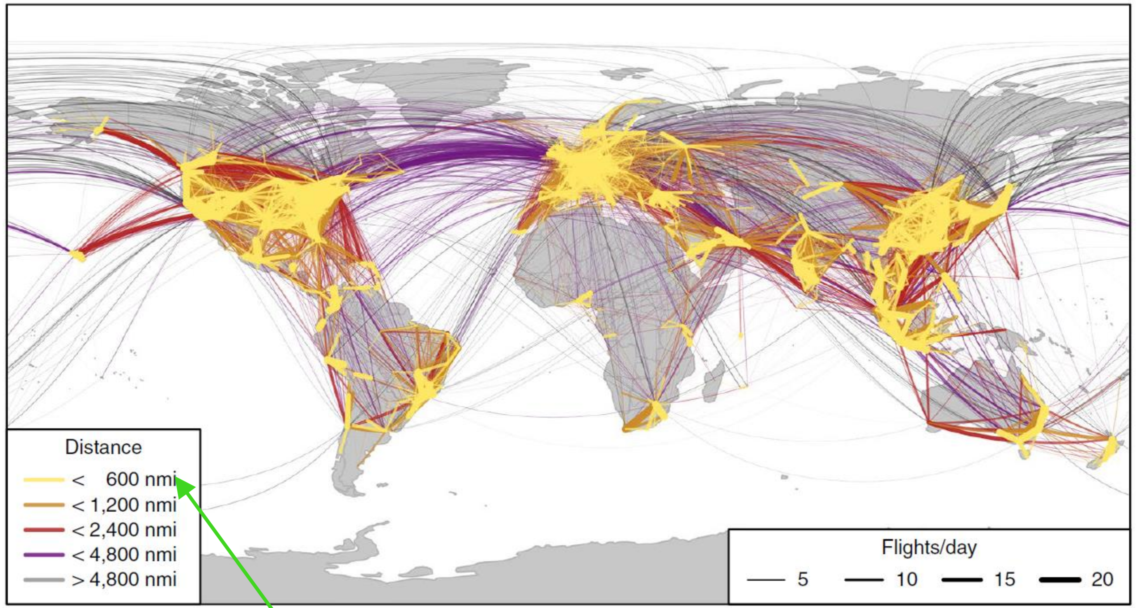
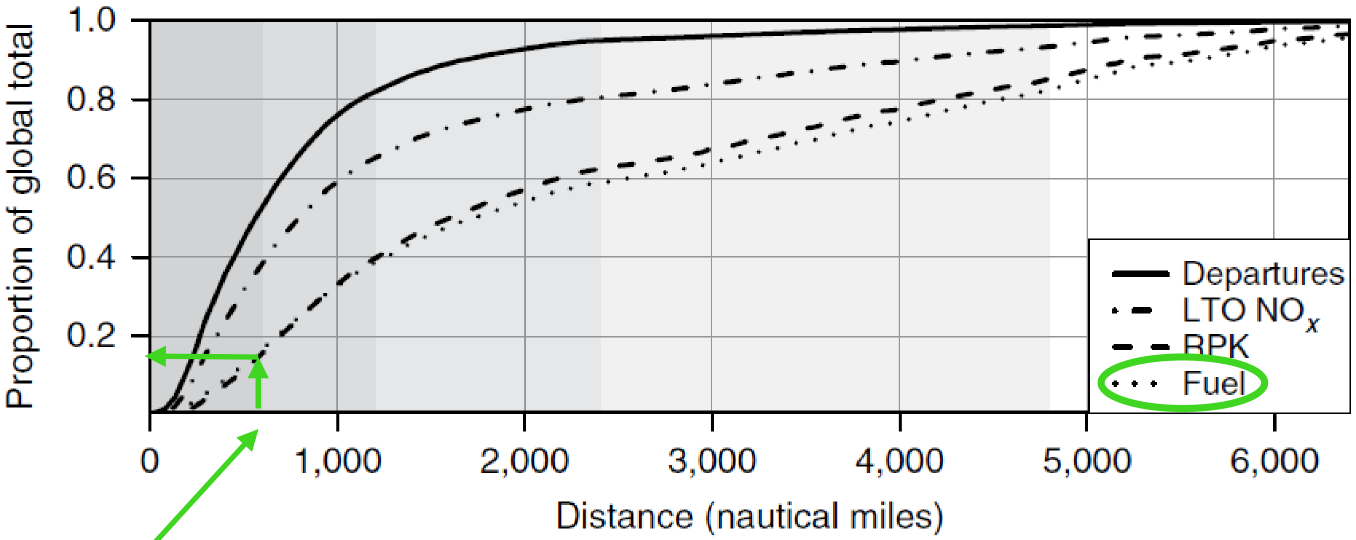
Despite of electrification and development of batteries, there will be plenty of need for electrofuels in aviation and in shipping

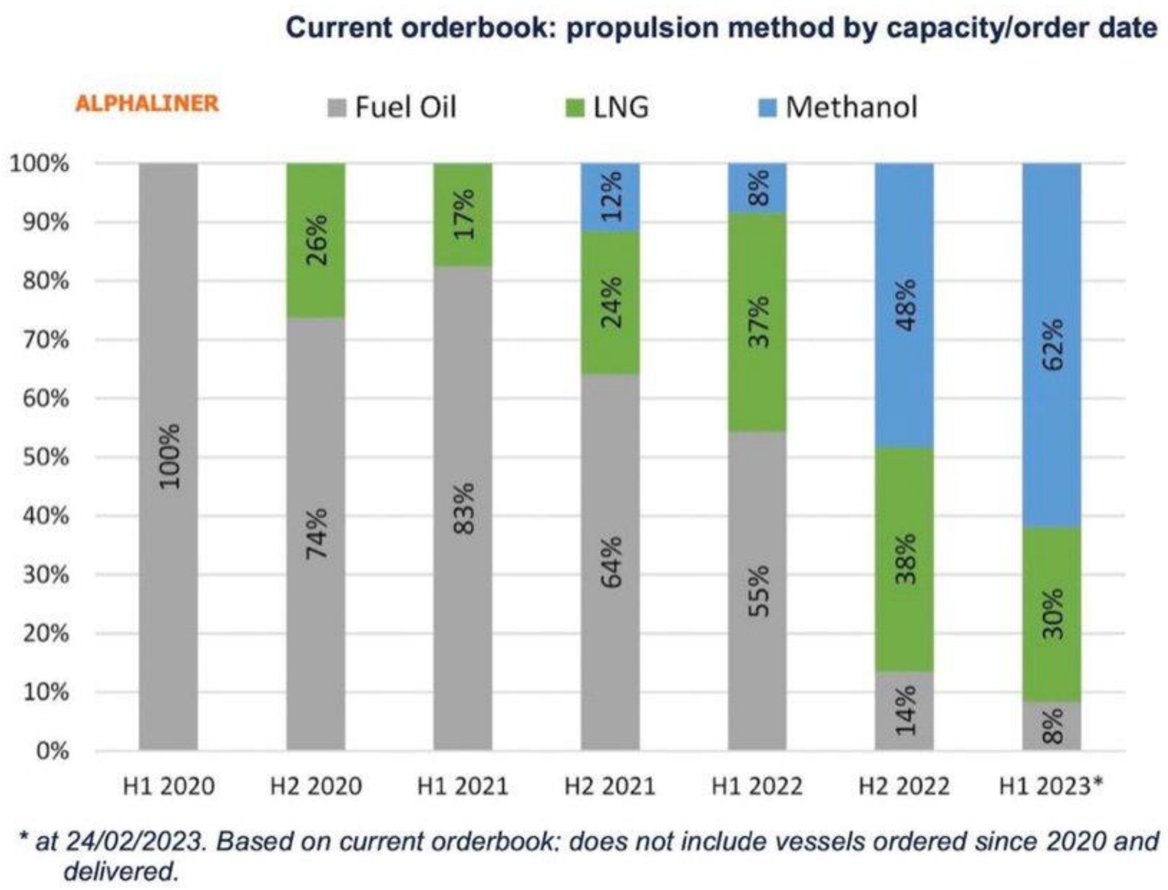




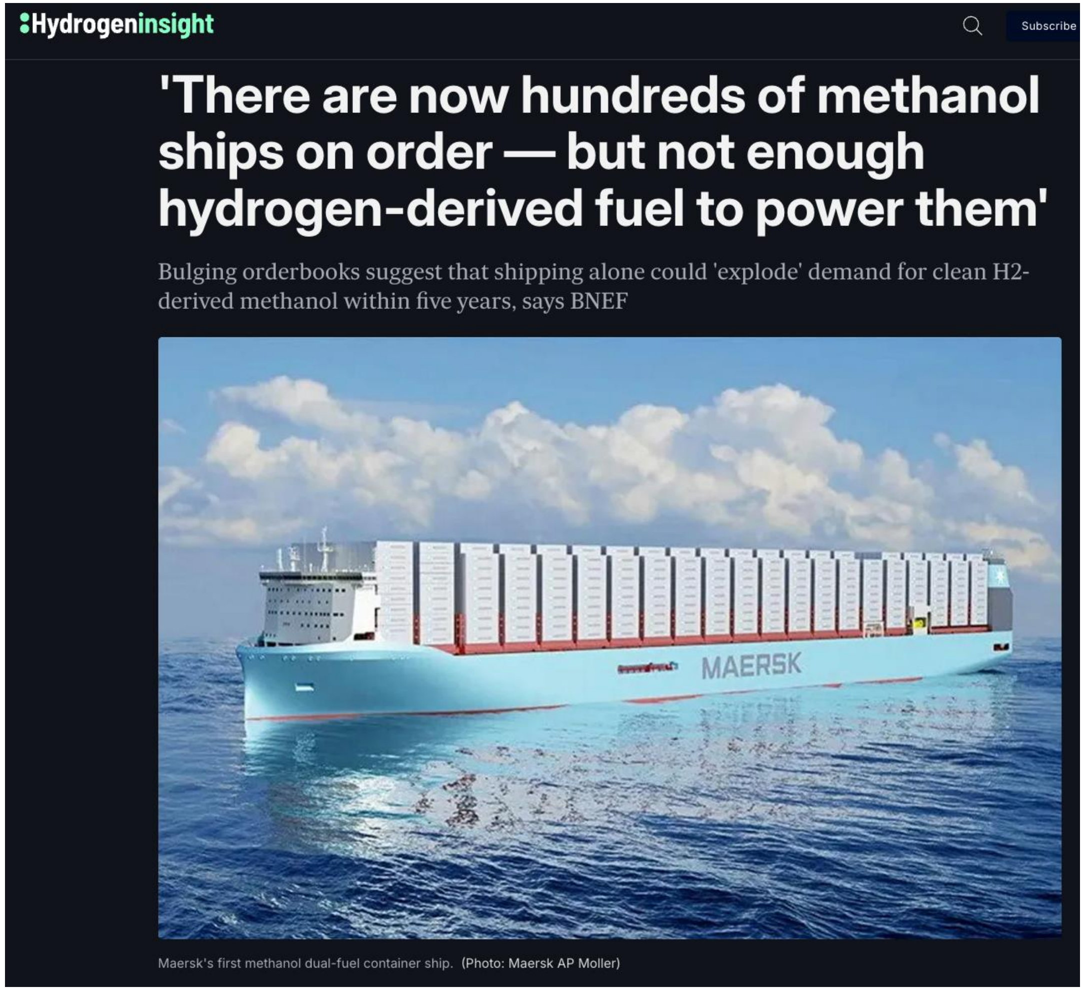
Electric flights at distances < 600 nmil (1100 km) ~15 % of total fuel consumption of battery energy density 800 Wh/kg will be reached

Source: Andreas W. Schäfer, et. Al., Technological, economic and environmental prospects of all electric aircraft, Nature Energy, Vol. 4, February 2019, pp. 160-166.

Methanol is becoming polular as a scalable carbon-neutral fuel in shipping



Source: https://splash247.com/methanol-boxship-orders-growing-more-rapidly-than-all-other-fuel-types/


Hydrogeninsight

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'There are now hundreds of methanol ships on order — but not enough hydrogen-derived fuel to power them'

Bulging orderbooks suggest that shipping alone could 'explode' demand for clean H2-derived methanol within five years, says BNEF

Maersk's first methanol dual-fuel container ship. (Photo: Maersk AP Moller)

Source: https://www.hydrogeninsight.com/transport/there-are-now-hundreds-of-methanol-ships-on-order-but-not-enough-hydrogen-derived-fuel-to-power-them/2-1-1666234

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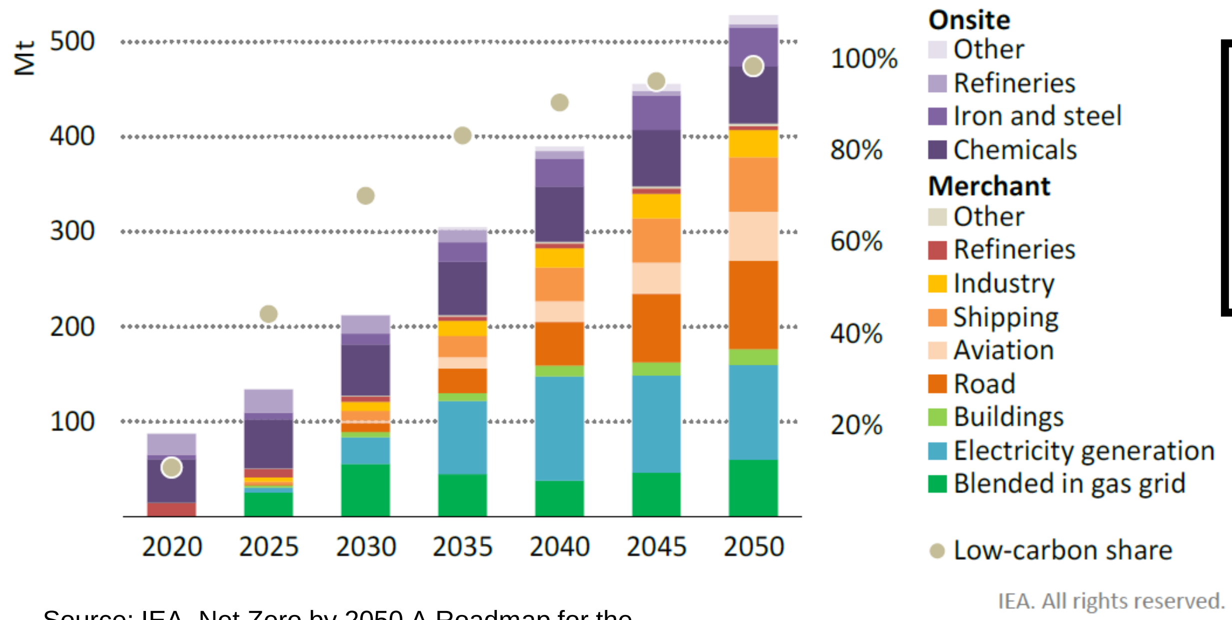
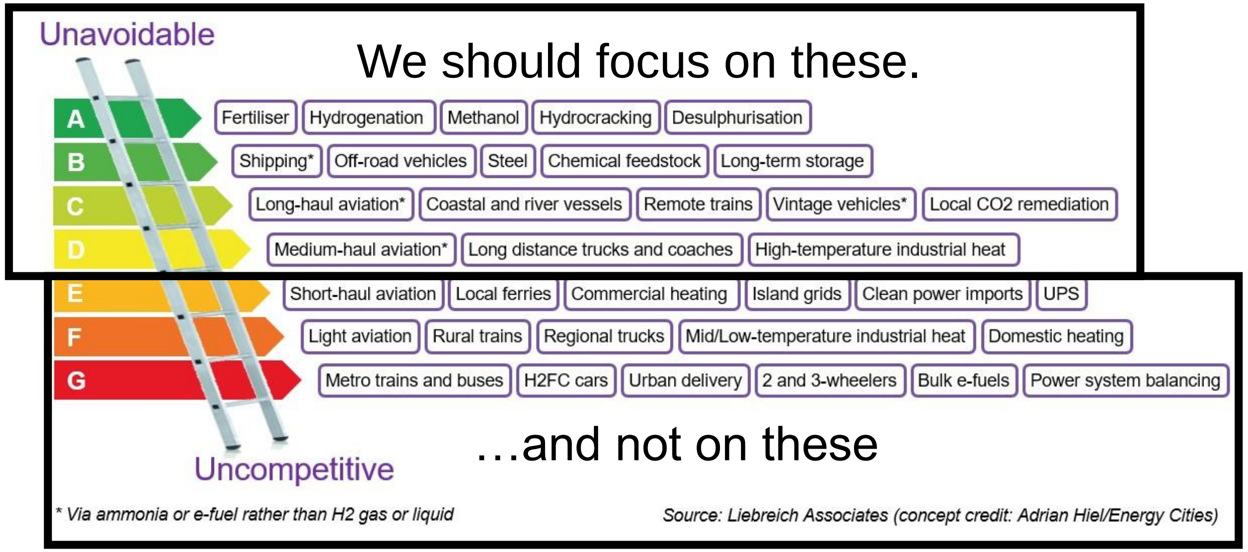
Applications of green hydrogen and production technologies

IEA Net Zero by 2050: Demand of clean hydrogen

Figure 2.19 ▷ Global hydrogen and hydrogen-based fuel use in the NZE



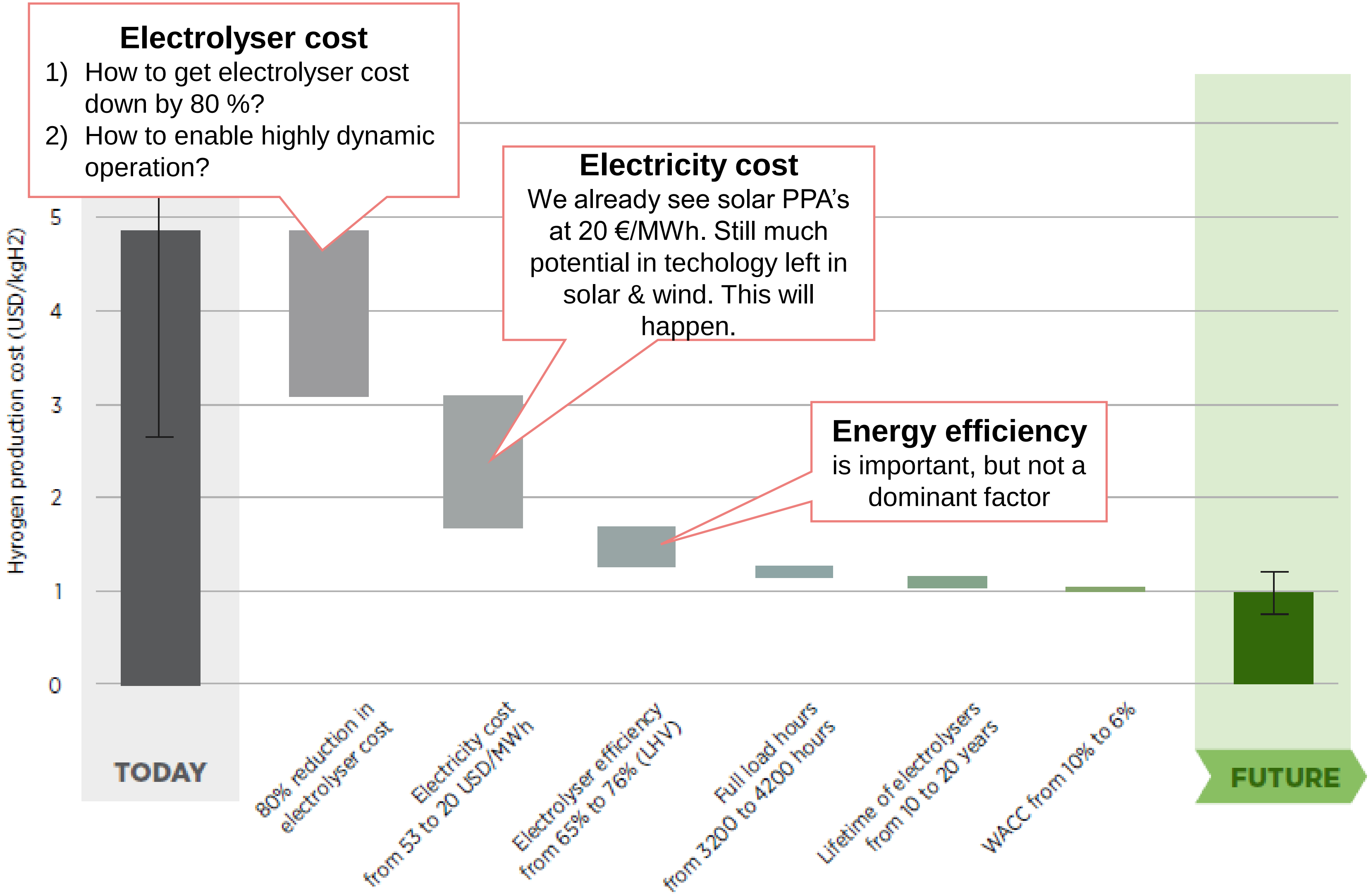
Source: IEA, Net Zero by 2050 A Roadmap for the Global Energy Sector, 2021 : https://www.iea.org/reports/net-zero-by-2050



- 7 TW of electrolyzers is needed 500 Mt_{H2}/a capacity factor 4000 h/a (wind power)
- 14 TW of electrolyzers is needed if solar power is used (capacity factor 2000 h/a)
- 11 TW in 2050 based on source (below) without chemical industry

Source: Dmitrii Bogdanov, et. Al., Low-cost renewable electricity as the key driver of the global energy transition towards sustainability, Energy, Volume 227, 2021, 120467, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2021.120467.

Most important factors affecting green hydrogen costs



Note: 'Today' captures best and average conditions. 'Average' signifies an investment of USD 770/kilowatt (kW), efficiency of 65% (lower heating value – LHV), an electricity price of USD 53/MWh, full load hours of 3200 (onshore wind), and a weighted average cost of capital (WACC) of 10% (relatively high risk). 'Best' signifies investment of USD 130/kW, efficiency of 76% (LHV), electricity price of USD 20/MWh, full load hours of 4200 (onshore wind), and a WACC of 6% (similar to renewable electricity today).

Source: IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency, Abu Dhabi

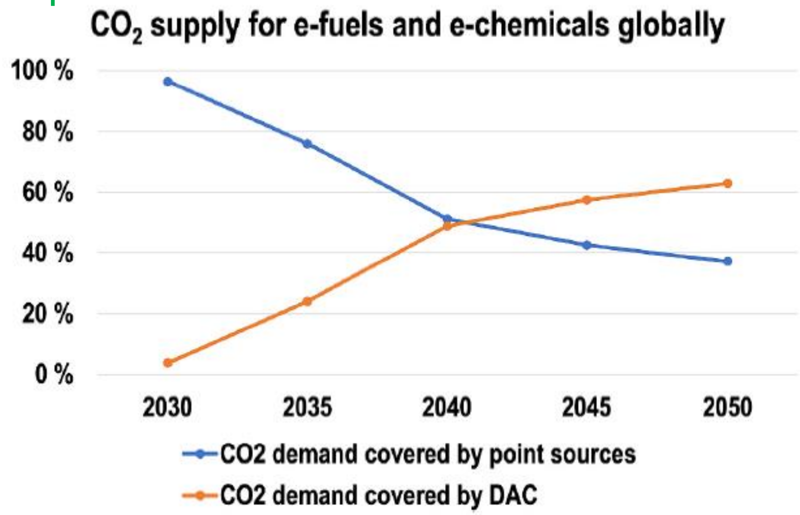
Bio-based CO_2 will be a starting point for PtX fuel production

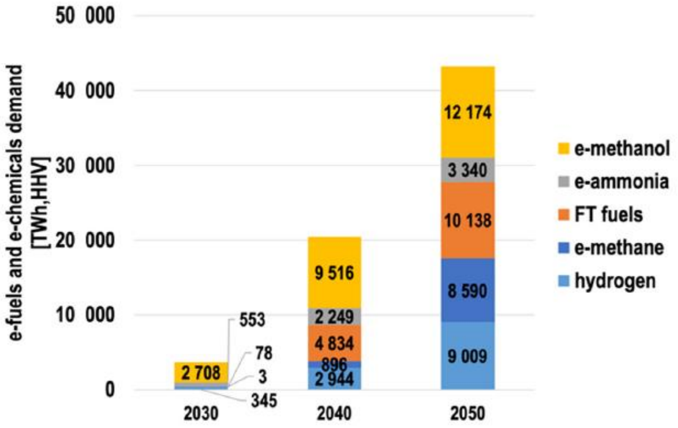
Key insights:

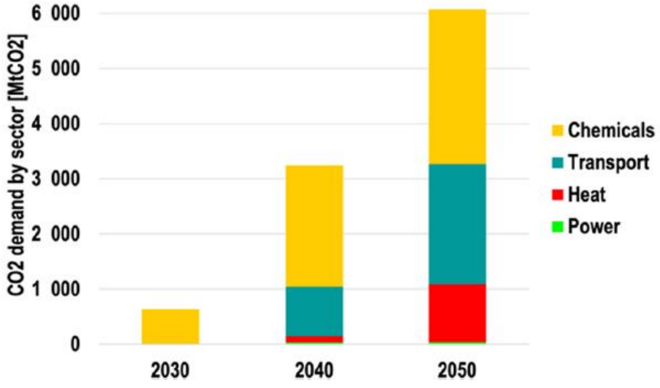
- e-fuels demand in order of 40,000 TWh in 2050
- key e-fuels are e-methanol and e-kerosene jet fuel, maybe some e-methane
- largest demand sectors: chemicals, transport, and maybe high-temperature industrial process heat
- hydrocarbon-based e-fuels require CO_2 as raw material
- sustainable or unavoidable point sources are usable, such as waste incinerators, pulp and paper mills, maybe cement mills
- largest source for CO_2 as raw material will be direct air capture

European objectives approved by the Parliament and the Council	AVIATION Incorporation rate of low-carbon fuels	MARITIME Carbone intensity reduction
2025	2%	2%
2030	6%	6%
2035	20%	14,5%
2040	34%	31%
2045	42%	62%
2050	70%	80%

Table 1: Decarbonisation trajectories for the aviation and maritime sectors, as adopted by the European Parliament and Council in 2023.

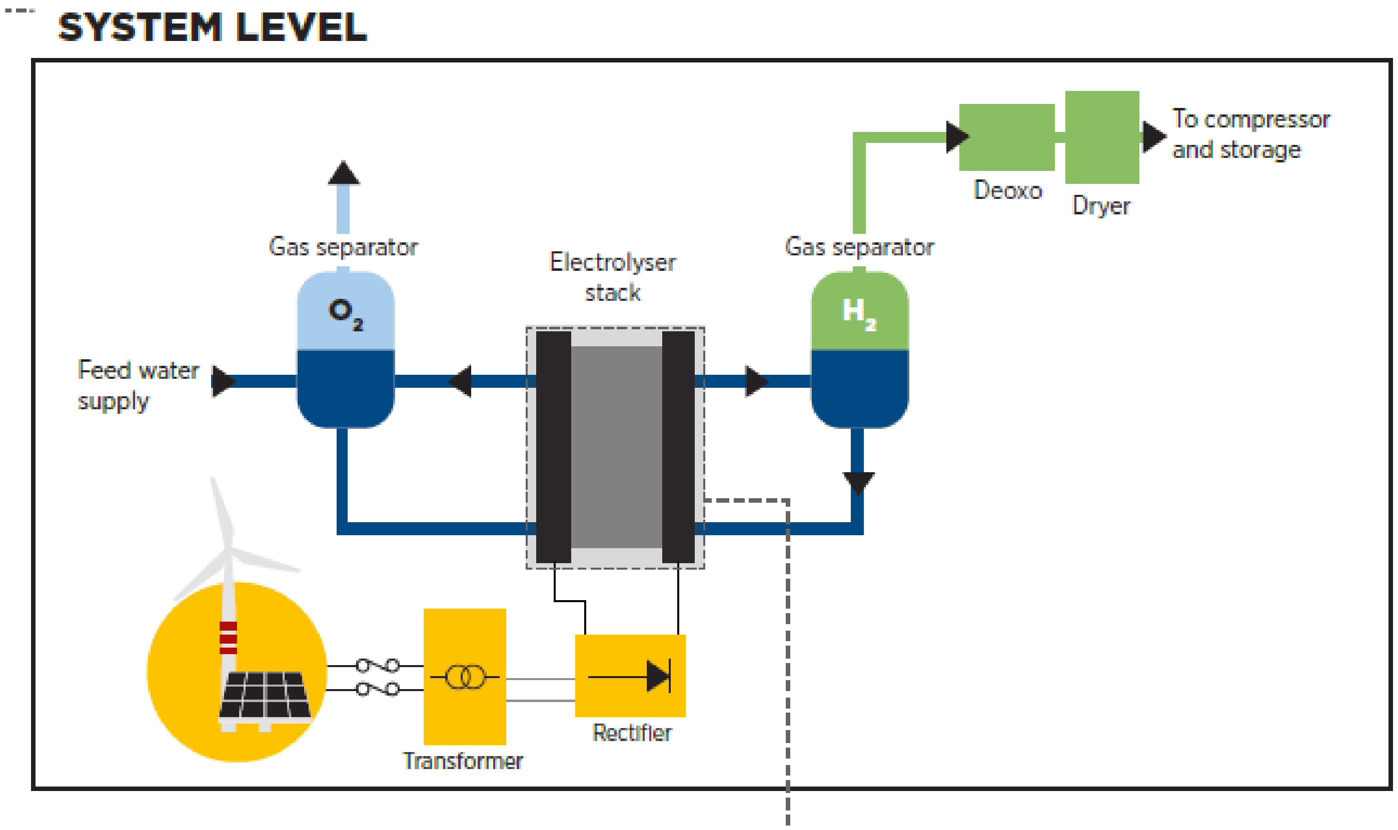






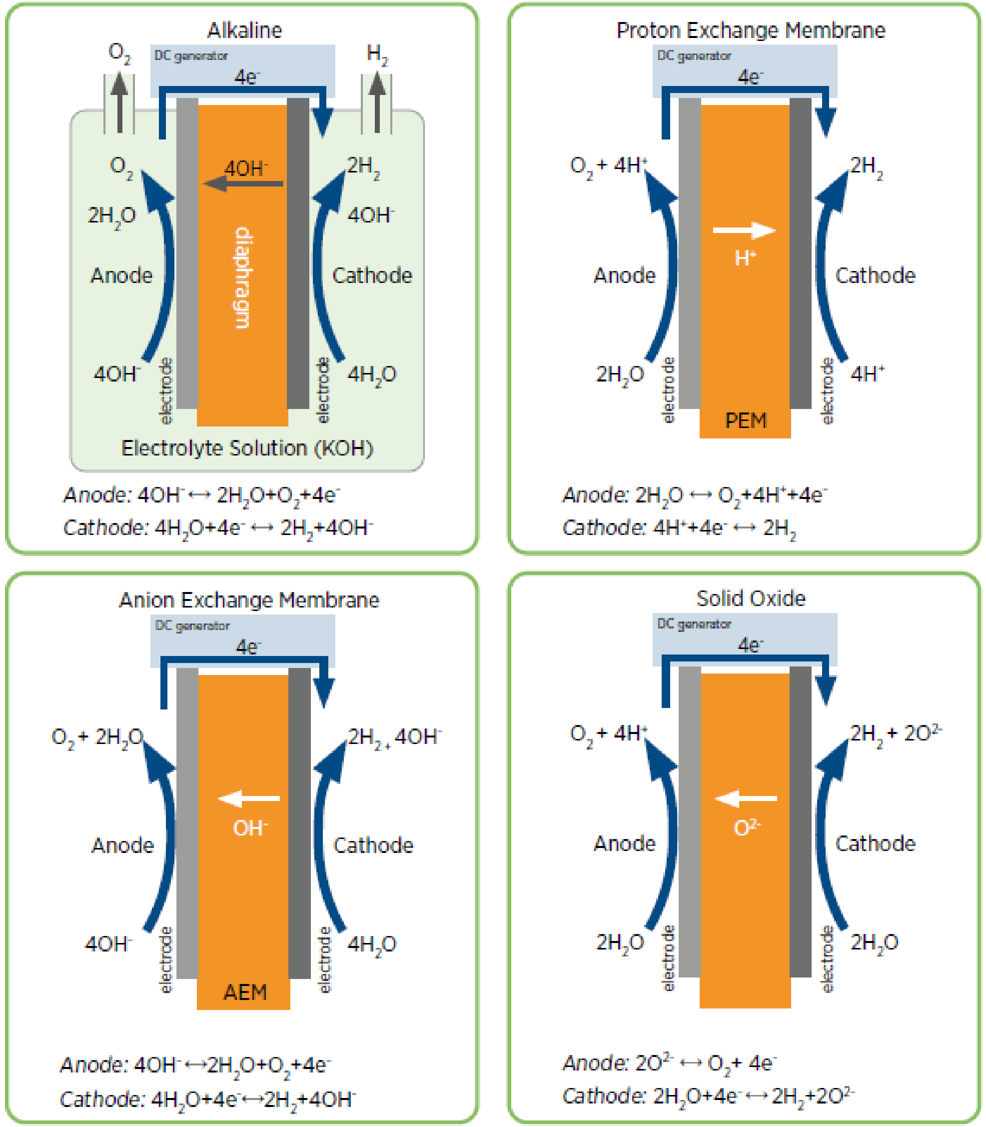
source: Galimova et al., 2022. J of Cleaner Production, 373, 133920

Green hydrogen production – common electrolysis cell technologies



Source: IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency, Abu Dhabi

Different types of commercially available electrolysis technologies.



Industrial-size alkaline water electrolysis plant (Woikoski Oy)

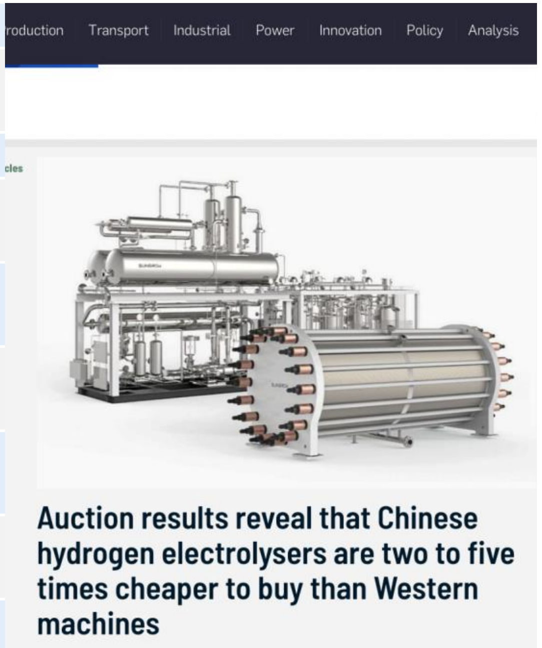
Summary:

- Located in Kokkola, Finland
- Power-to-Hydrogen: 1800 Nm^3/h (H_2)
- 3x3 MW pressurized alkaline water electrolyzers, 3x600 Nm^3/h, 16 bar (H_2)
- The main use of H_2 plant is at nearby Cobalt plant, hydrogen delivery by a pipeline
- The rest of H_2 compressed to 200-300 bar and stored in bottles for delivery with trucks

Chinese electrolyzers cost 20-50% compared to European products

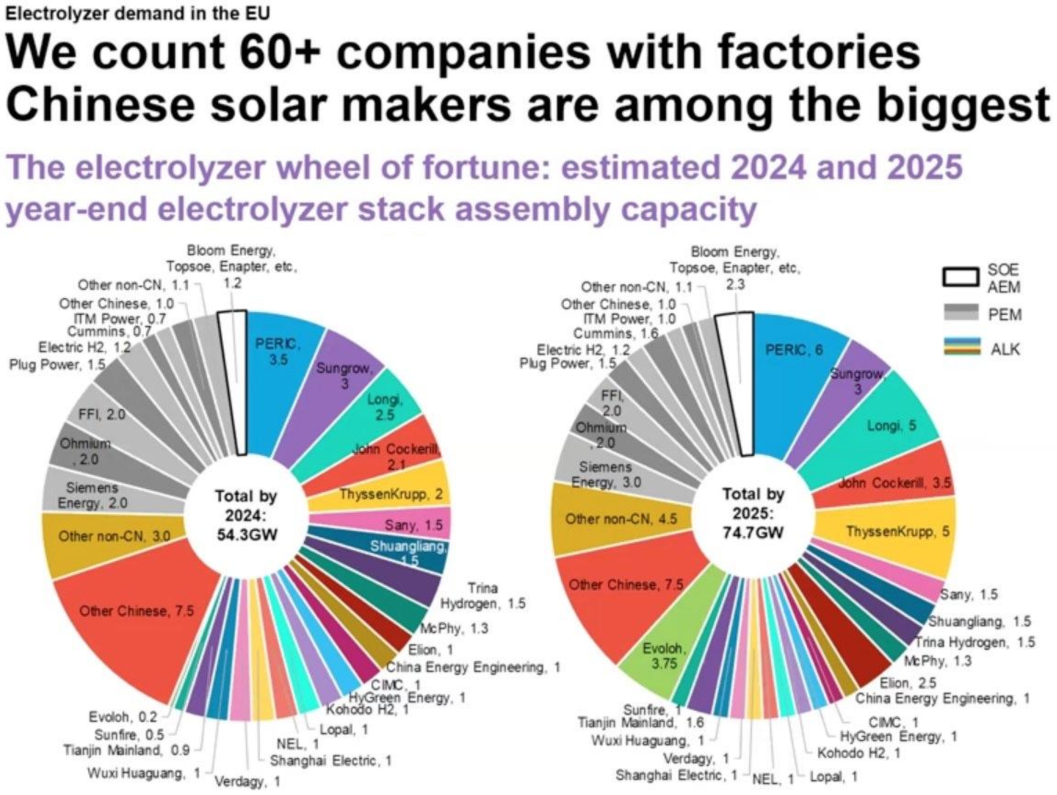
Table. Winning bid prices in Chinese auction in 2023

Manufacturer	Type	Price ($)
Sungrow Hydrogen	ALK (5MW)	961,504
Wuxi Huaguang	ALK (5MW)	992,758
Guangdong Shengqing	ALK (5MW)	994,830
Trina Solar Hydrogen	ALK (5MW)	1,004,681
Beijing Power Equipment Group	ALK (5MW)	1,041,786
Tianjin Mainland Hydrogen	ALK (5MW)	1,053,900
Shanghai Electric	ALK (5MW)	1,072,423
Cockerill Jingli Hydrogen	ALK (5MW)	1,081,812
Shuangliang Group	ALK (5MW)	1,090,042
Peric	ALK (5MW)	1,100,000
Longi Hydrogen	ALK (5MW)	1,112,256
Shanghai Electric	PEM (1MW)	484,680
Sungrow Hydrogen	PEM (1MW)	567,209
BriHyNergy	PEM (1MW)	626,741
SPIC Hydrogen	PEM (1MW)	728,858
Cummins Enze	PEM (1MW)	750,418



Source: https://www.hydrogeninsight.com/electrolysers/auction-results-reveal-that-chinese-hydrogen-electrolysers-are-two-to-five-times-cheaper-to-buy-than-western-machines/2-1-1570717

- Alkaline: ~200 USD/kW
- PEM: ~500-750 USD/kW



- Chinese companies focus on mostly on alkaline water electrolyzers for a good reason!

Green hydrogen production based on solar and wind power

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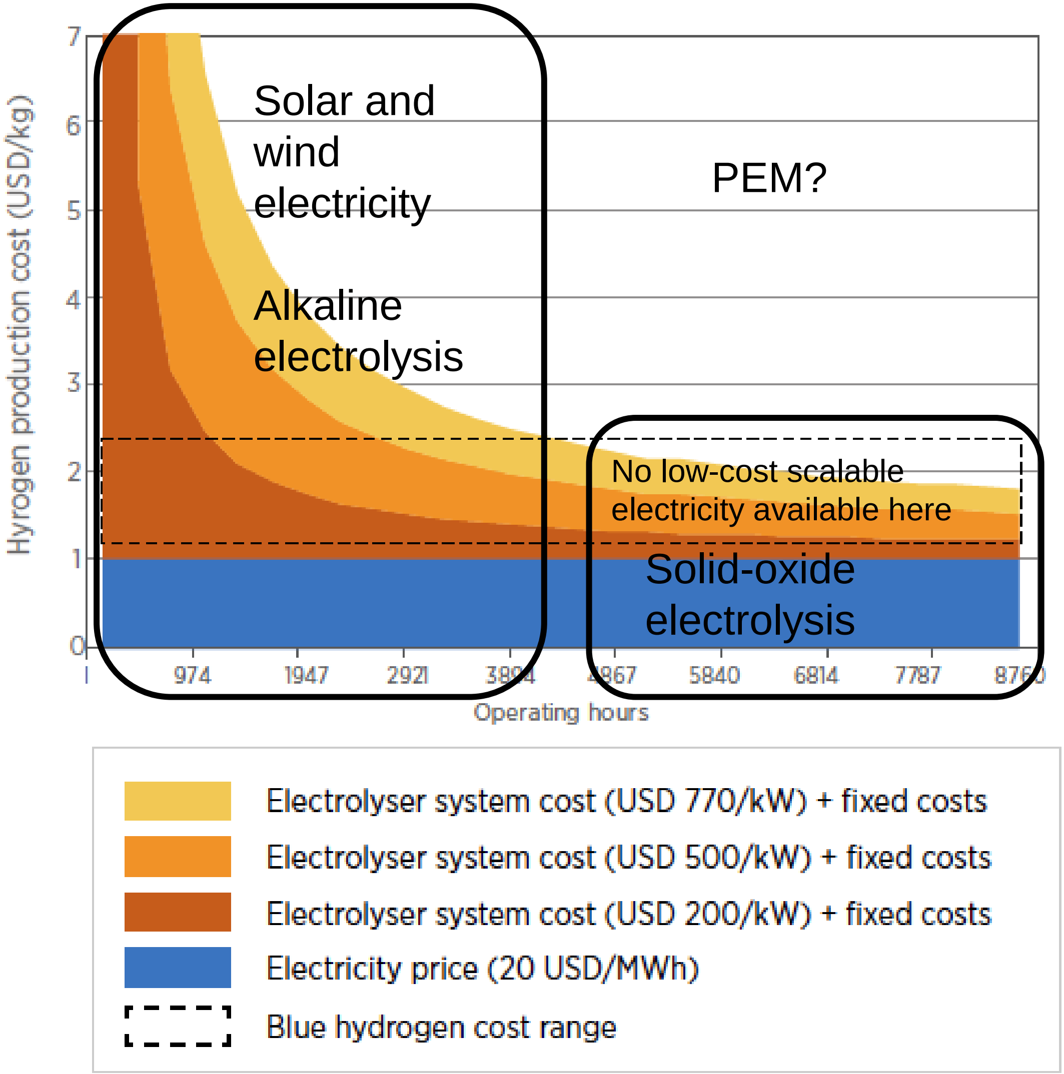
Effect of intermittency of electricity supply



Cost composition of alkaline water electrolysis

Electrolyzer plant size matters. 100 MW plant has significantly lower specific investment cost than 5 MW plant

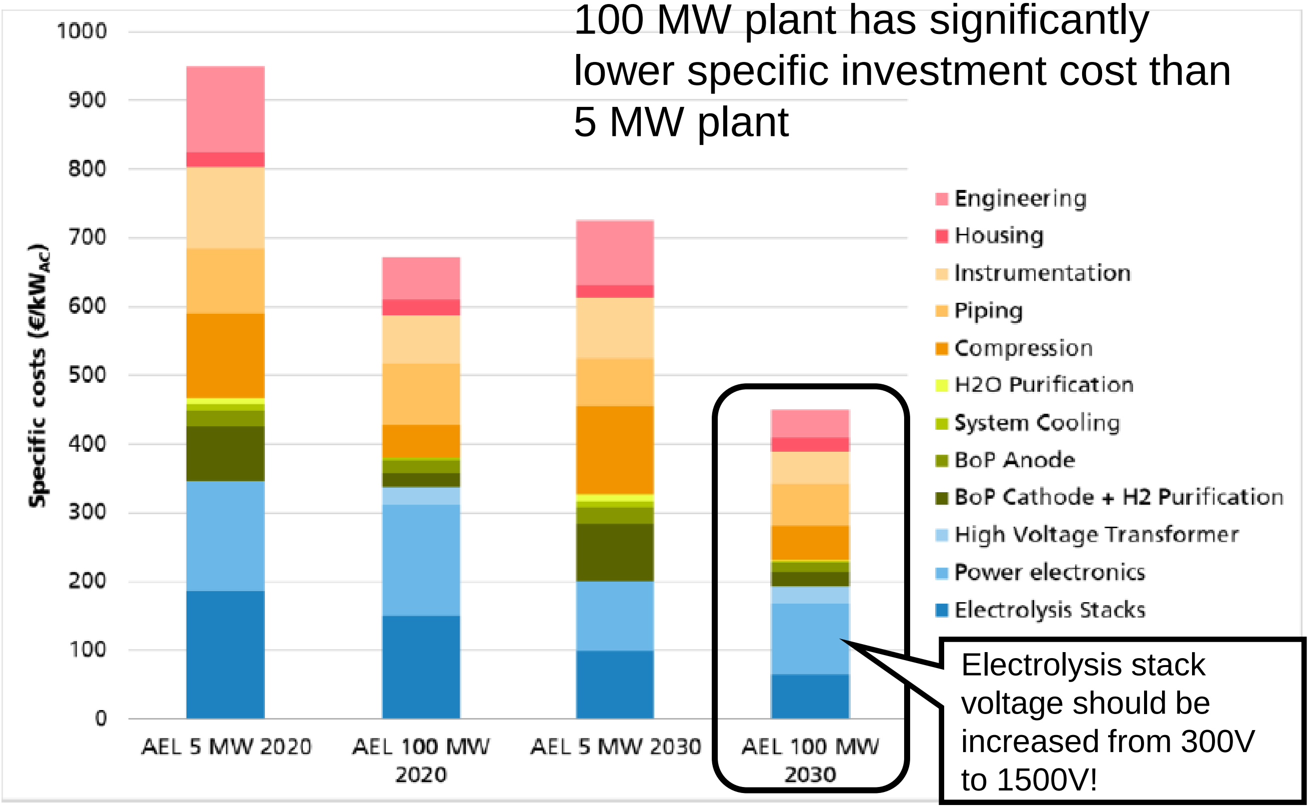
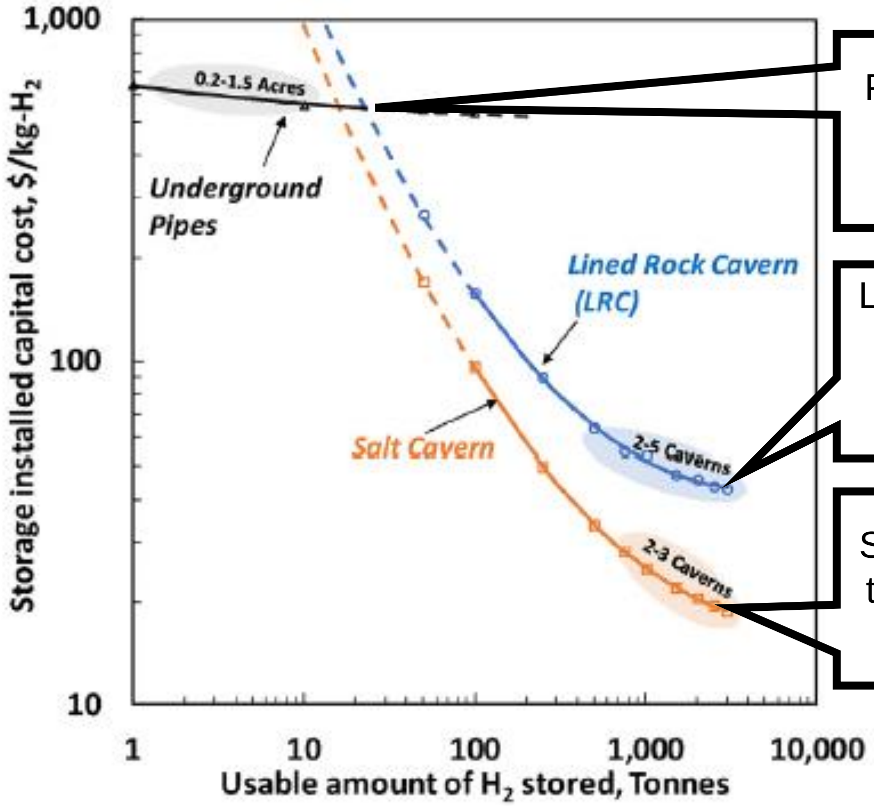


Figure 3-6: Specific costs of 5 MW and 100 MW next generation AEL systems (including mechanical compressors) for the design scenarios 2020 and 2030

Source: Marius Holst Stefan Aschbrenner Tom Smolinka Christopher Voglstätter Gunter Grimm, COST FORECAST FOR LOW-TEMPERATURE ELECTROLYSIS – TECHNOLOGY DRIVEN BOTTOM-UP PROGNOSIS FOR PEM AND ALKALINE WATER ELECTROLYSIS SYSTEMS, Frainhofer ISE, October 2021, https://www.ise.fraunhofer.de/en/press-media/press-releases/2022/towards-a-gw-industry-fraunhofer-ise-provides-a-deep-in-cost-analysis-for-water-electrolysis-systems.html

Hydrogen storages are needed to convert intermitted renewable hydrogen production into baseload hydrogen. The investment cost of industrial-size hydrogen storage is ~1% of battery storage



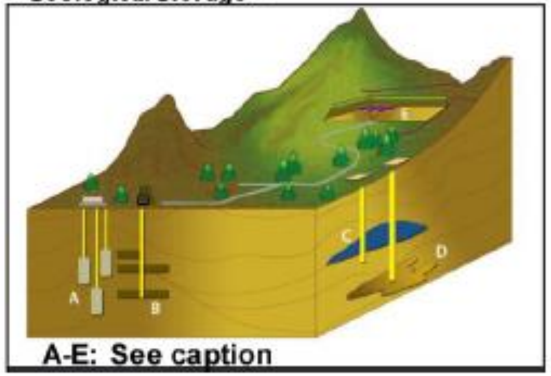
(a) Installed capital cost

Pipe storage 550 €/kgH_2 = 17 €/kWhH_2

Lined rock cavern (3000 tH_2), 44 €/kgH_2 = 1.3 €/kWhH_2

Salt cavern (3000 tH_2), 17 €/kgH_2 = 0.5 €/kWhH_2

Geological Storage[p4]

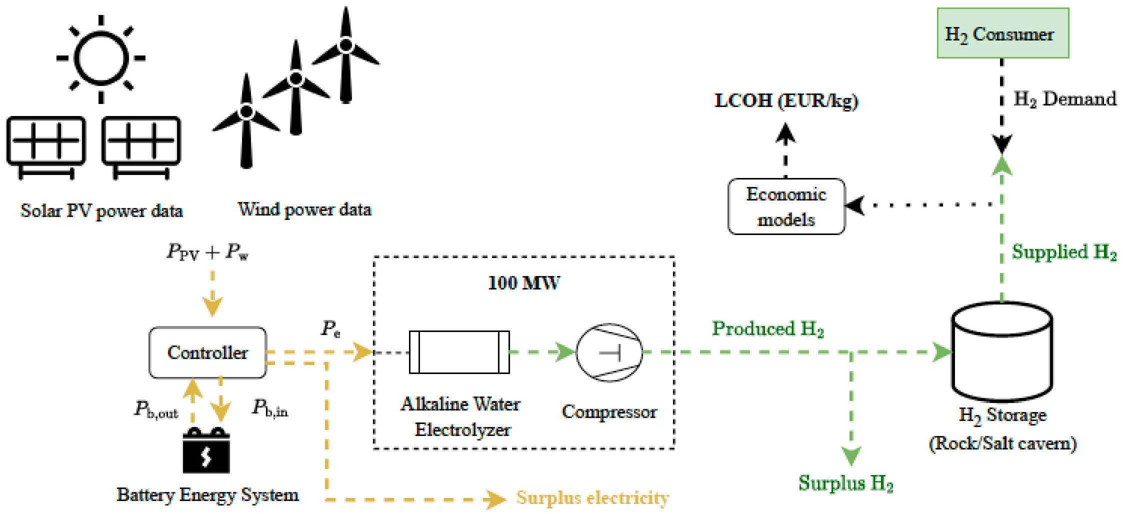


Lined Rock (Shown Tunnel Excavation)[p5]

NG Pipe Storage, Erdgas, Switzerland[p2]

Source: D.D Papadias, R.K. Ahluwalia, Bulk storage of hydrogen, International Journal of Hydrogen Energy 46, 2021, pp. 34527-34541

LUT result: Cost optimization of baseload green hydrogen production



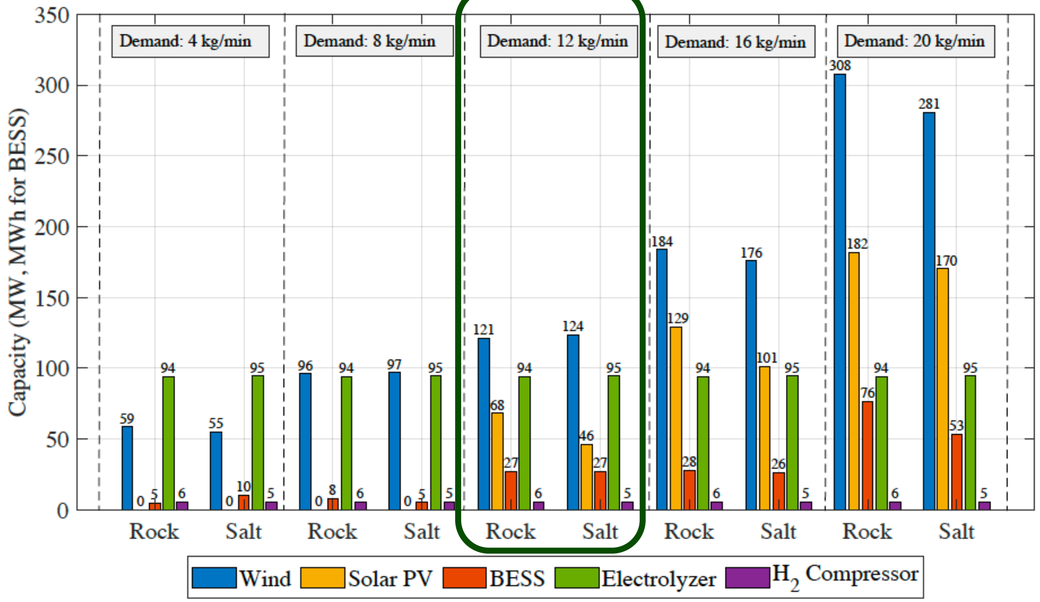


Fig. 5: Optimal components capacities for the rock and salt cavern systems at different demand rates (x-axis) for the installation year 2025 and the 5 % discount rate. Vertical dashed lines delimit the hydrogen demand rates.

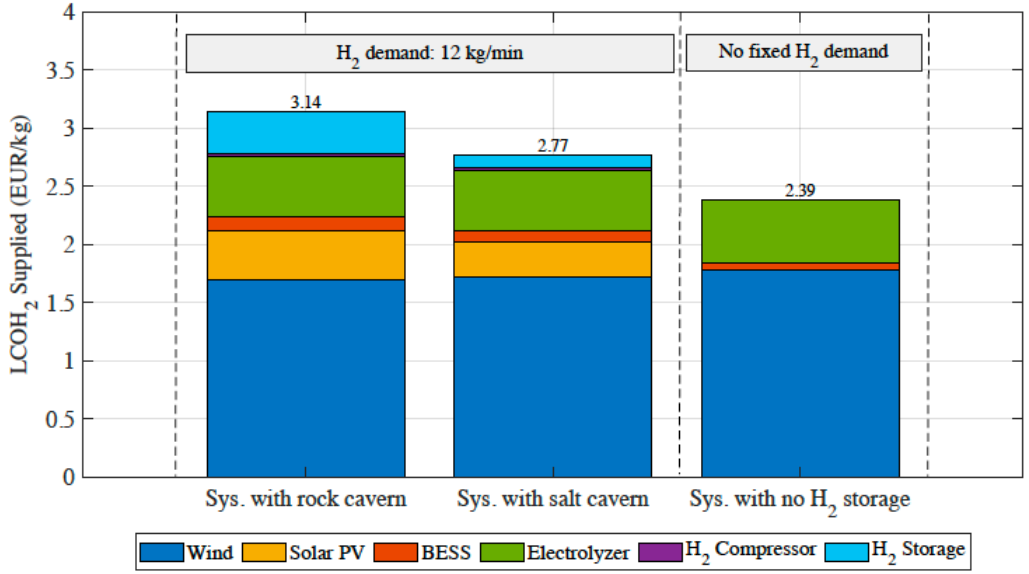


Fig. 11: Levelized cost of hydrogen (LCOH$_2$) of the hydrogen supplied for the rock and salt cavern systems at a fixed rate of 12 kg/min, as well as for a no demand with no hydrogen storage system. Optimization results for the installation year 2025 and the 5 % discount rate.

Source: Alejandro Ibáñez-Rioja, Lauri Järvinen, Pietari Puranen, Antti Kosonen, Vesa Ruuskanen, Katja Hynynen, Jero Ahola, Pertti Kauranen, Baseload hydrogen supply from an off-grid solar PV–wind power–battery–water electrolyzer plant, (under review) in Elesevier Energy journal.

LUT is one of the world's

TOP 10 UNIVERSITIES

in terms of climate actions – SDG 13

The Times Higher Education Impact Rankings 2021 assess the social and economic impact of universities against the UN's Sustainable Development Goals.