LUT University

LAND OF THE CURIOUS

1.12.2022

Yhteiskunta sähköistyy – mitä se tarkoittaa

Jero Ahola, D.Sc., Professor, Energy Efficiency
Department of Electrical Engineering
LUT University
email: jero.ahola@lut.fi
twitter: @JeroAhola

Tavoitteena nettonollapäästöt 2050 mennessä

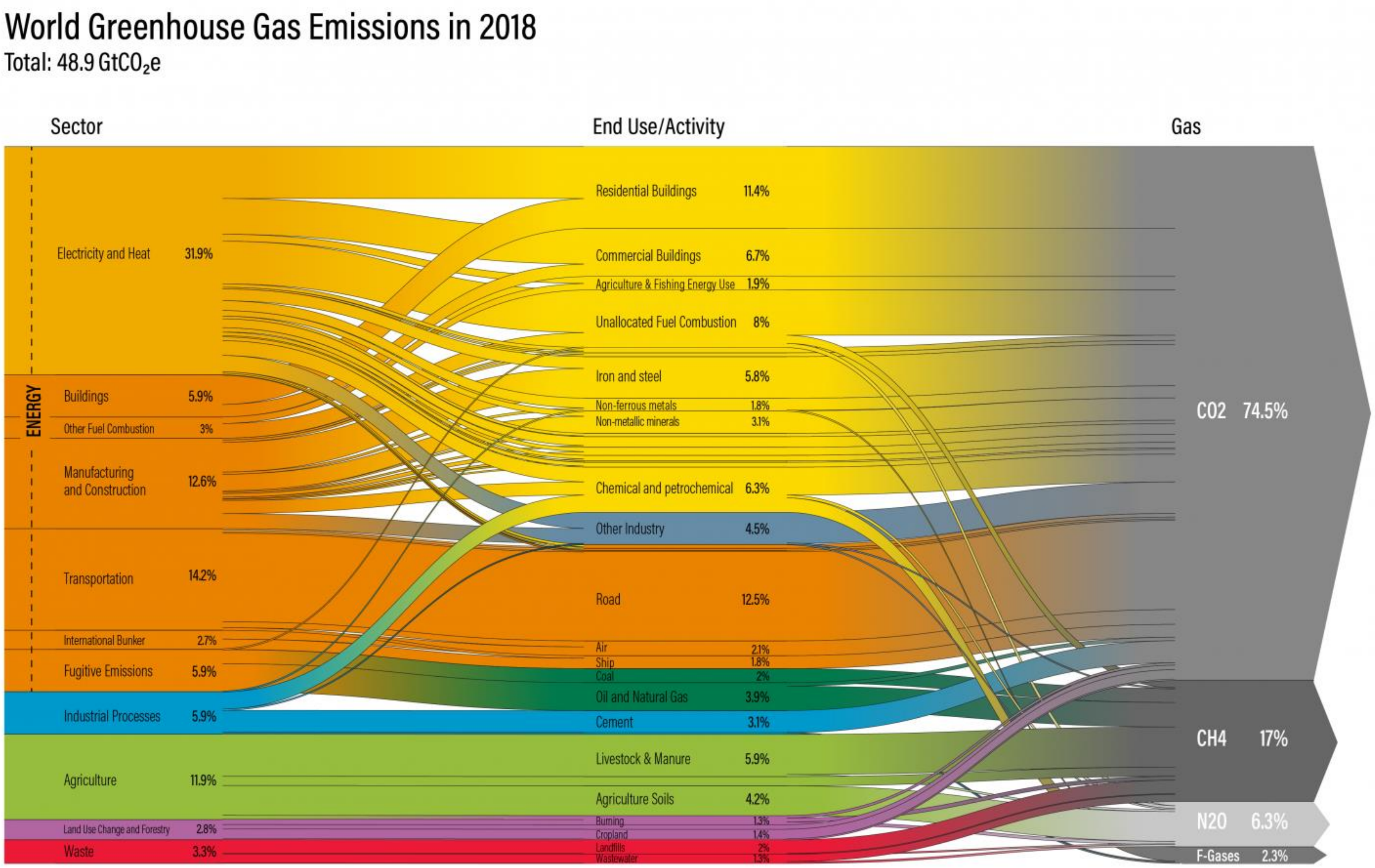
Electricity and heat (32%)

Industry (13%)

Transportation (14%)

Agriculture and land use change (15%)

ENERGY (73 %)

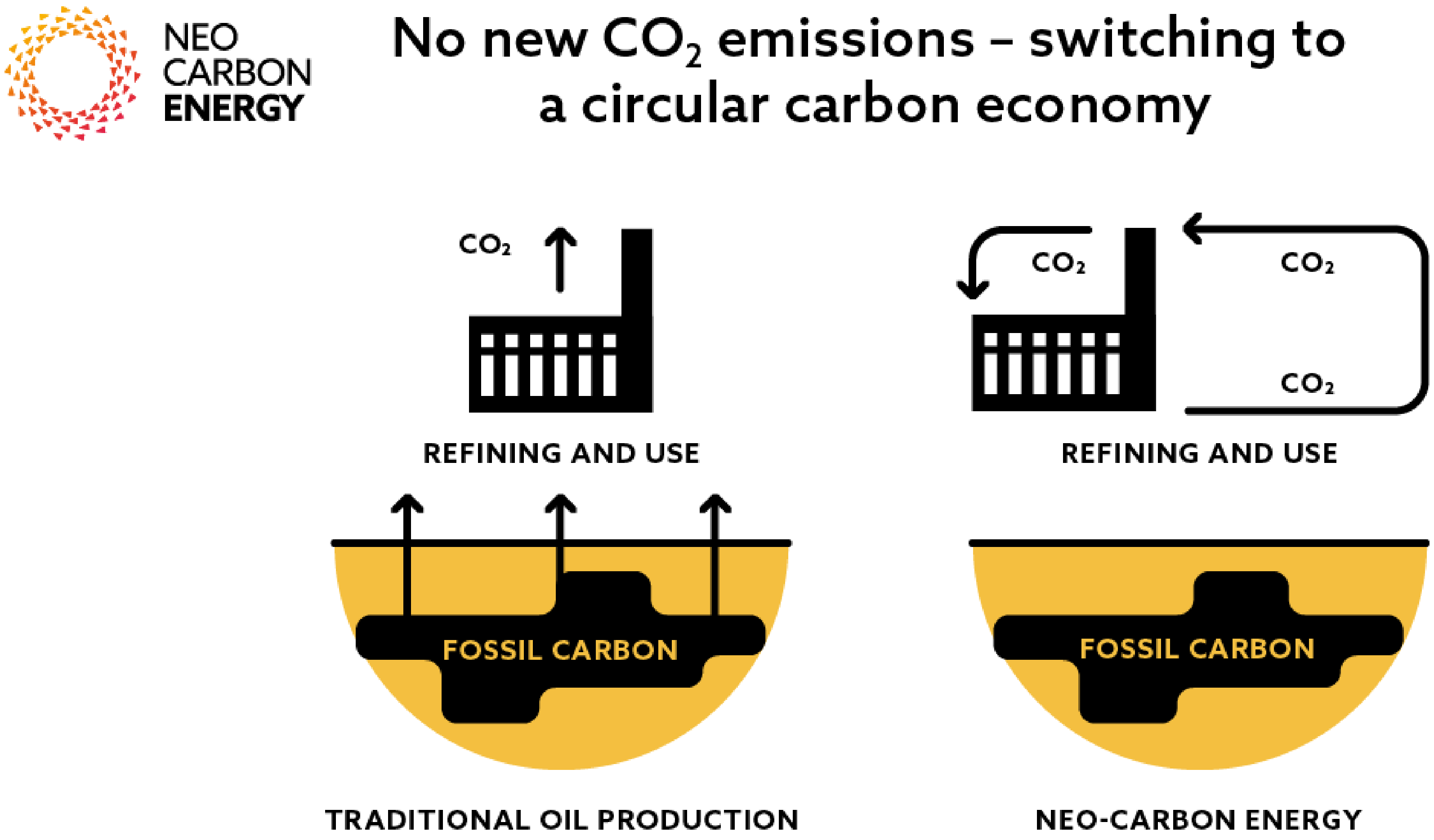


For < +2 ºC climate goal we have to have net-zero GHG emissions by 2050

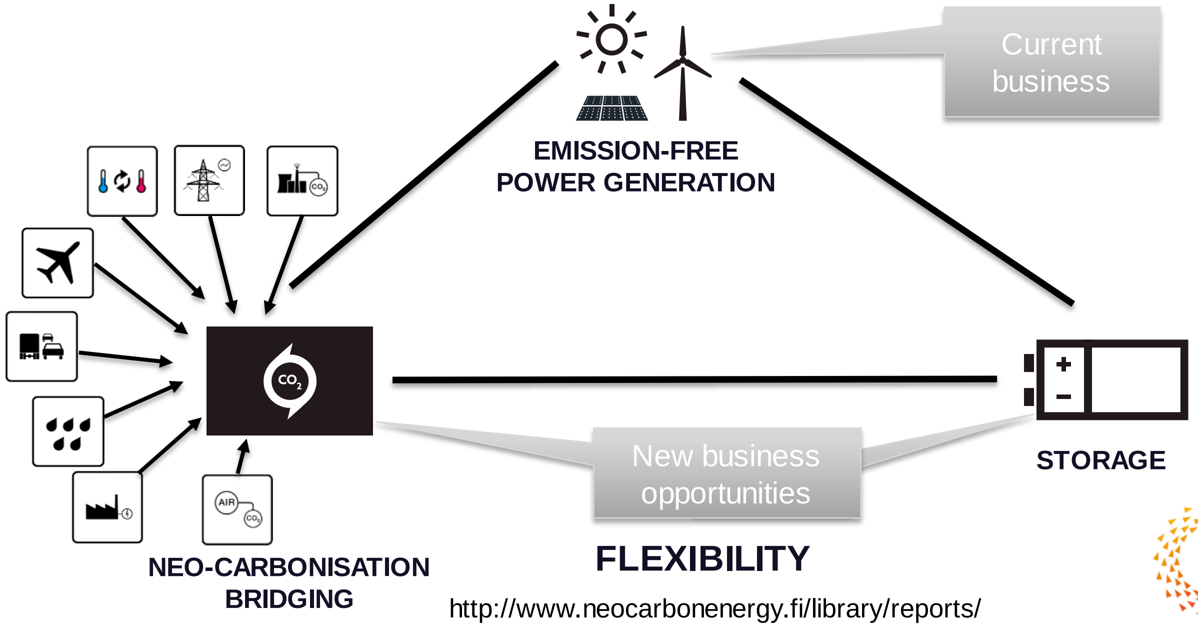
Source: Greenhouse gas emissions on Climate Watch. Available at: https://www.climatewatchdata.org

WORLD RESOURCES INSTITUTE

Fossiilisen hiilen energiataloudesta hiilidioksidin kiertotalouteen



Ratkaisu: Sähköistetään kaikki energian käyttö joko suoraan tai epäsuorasti



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.

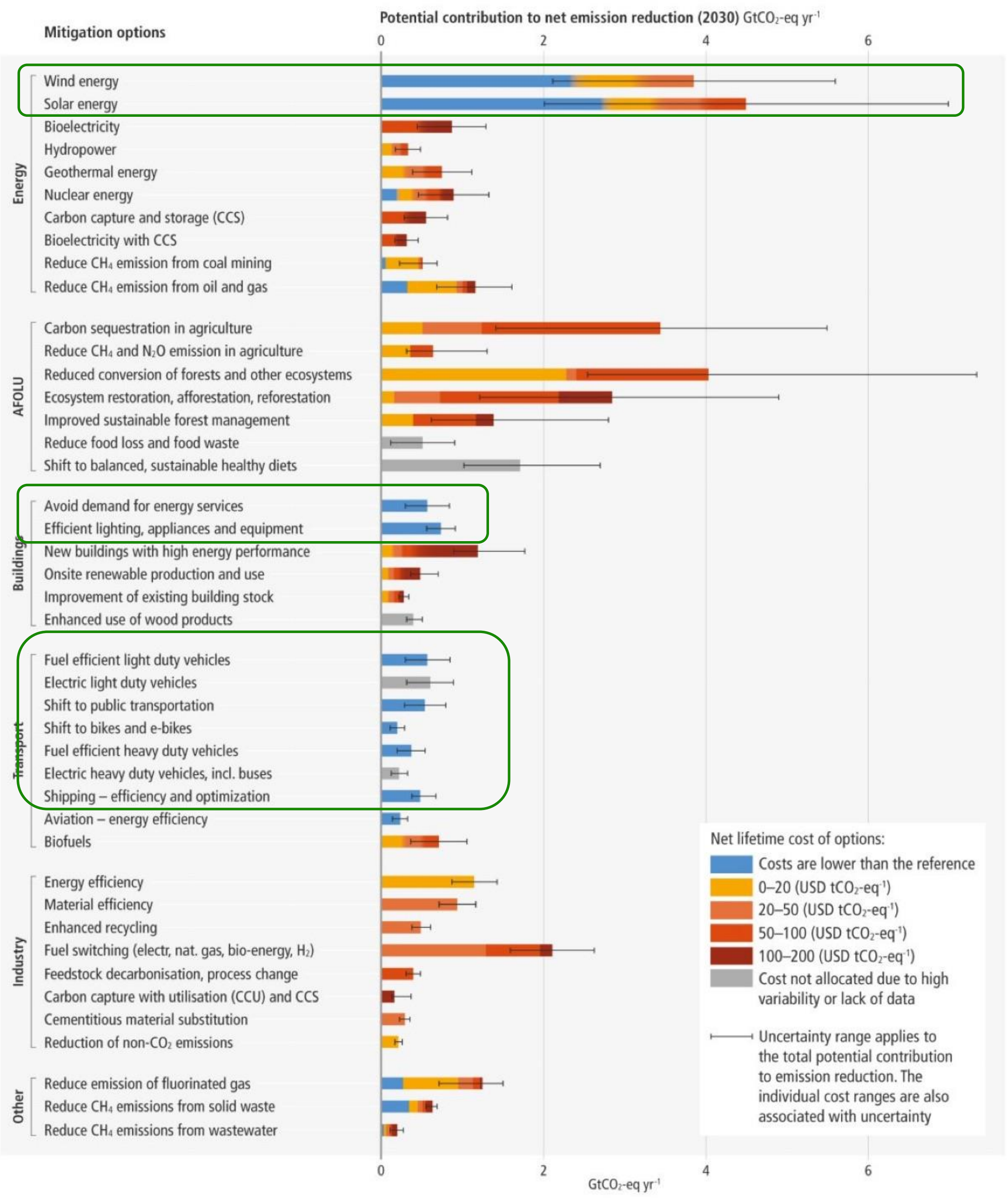


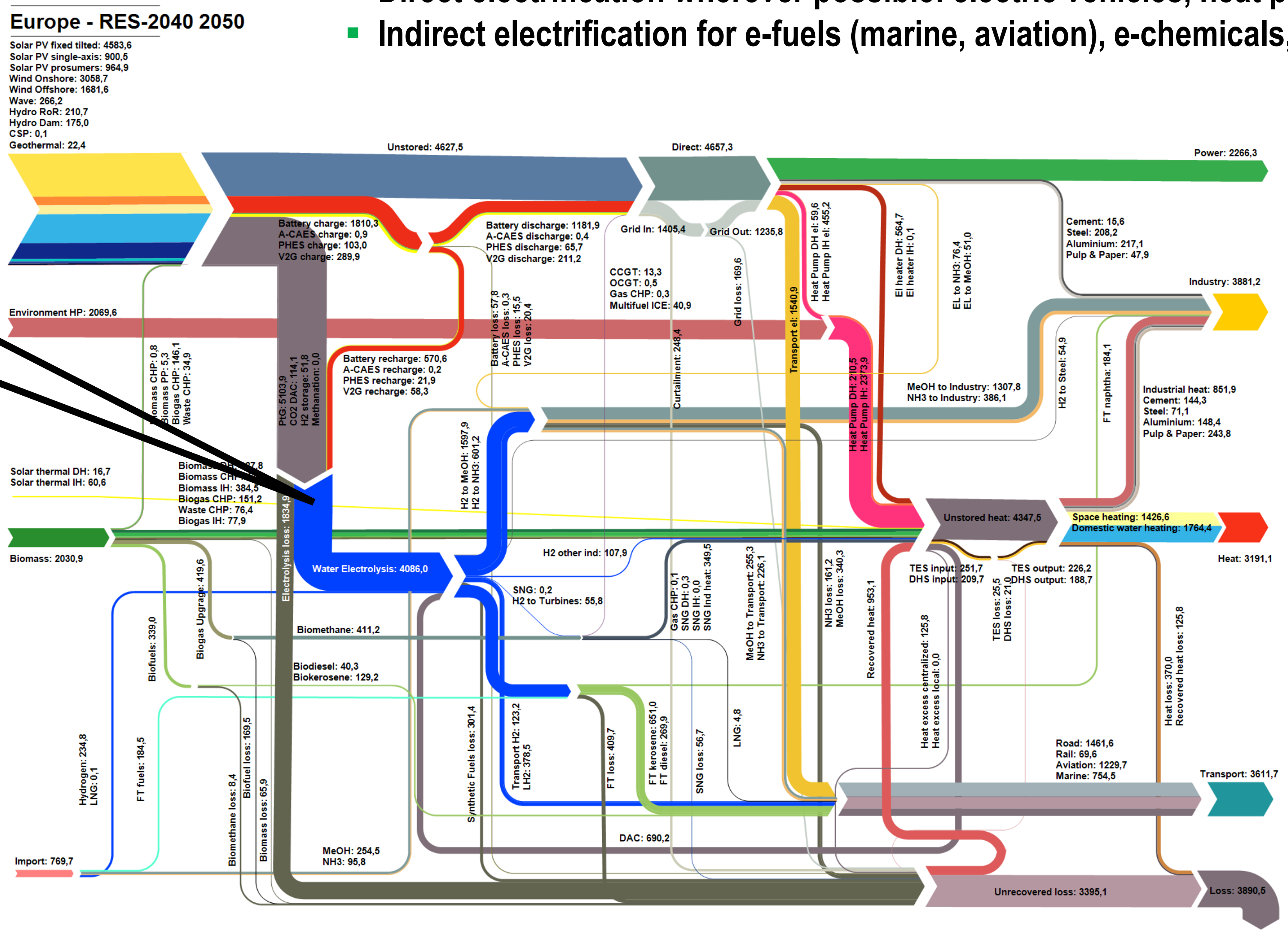
Figure SPM.7: Overview of mitigation options and their estimated ranges of costs and potentials in 2030.

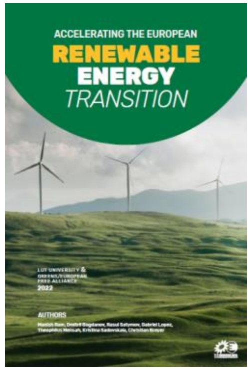
Sähköön pohjautuva Euroopan energiajärjestelmä

LUT University

- 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

Hydrogen economy is a subset of power-to-x - economy





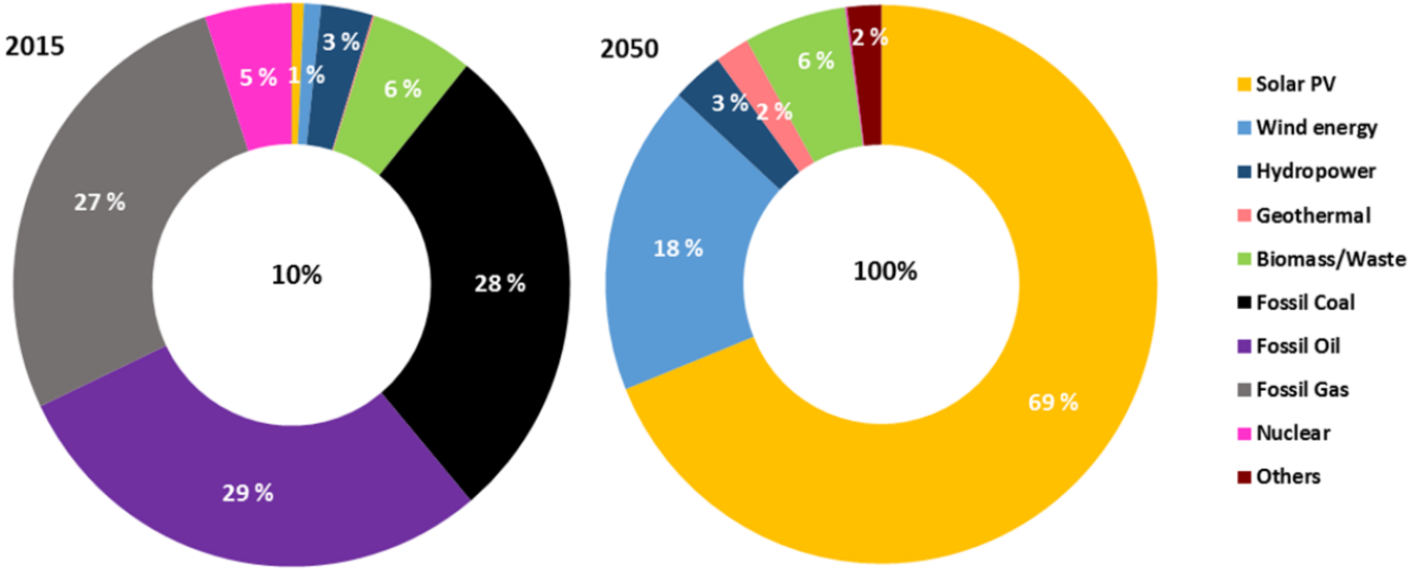
Europe

Source:
Greens/EFA, 2022

Päästötön energiajärjestelmä on mahdollinen ja se ei ole nykyistä fossiiliseen energiaan perustuvaa järjestelmää kalliimpi.

Total Primary Energy Demand Shares

Open your mind. LUT.
Lappeenranta University of Technology



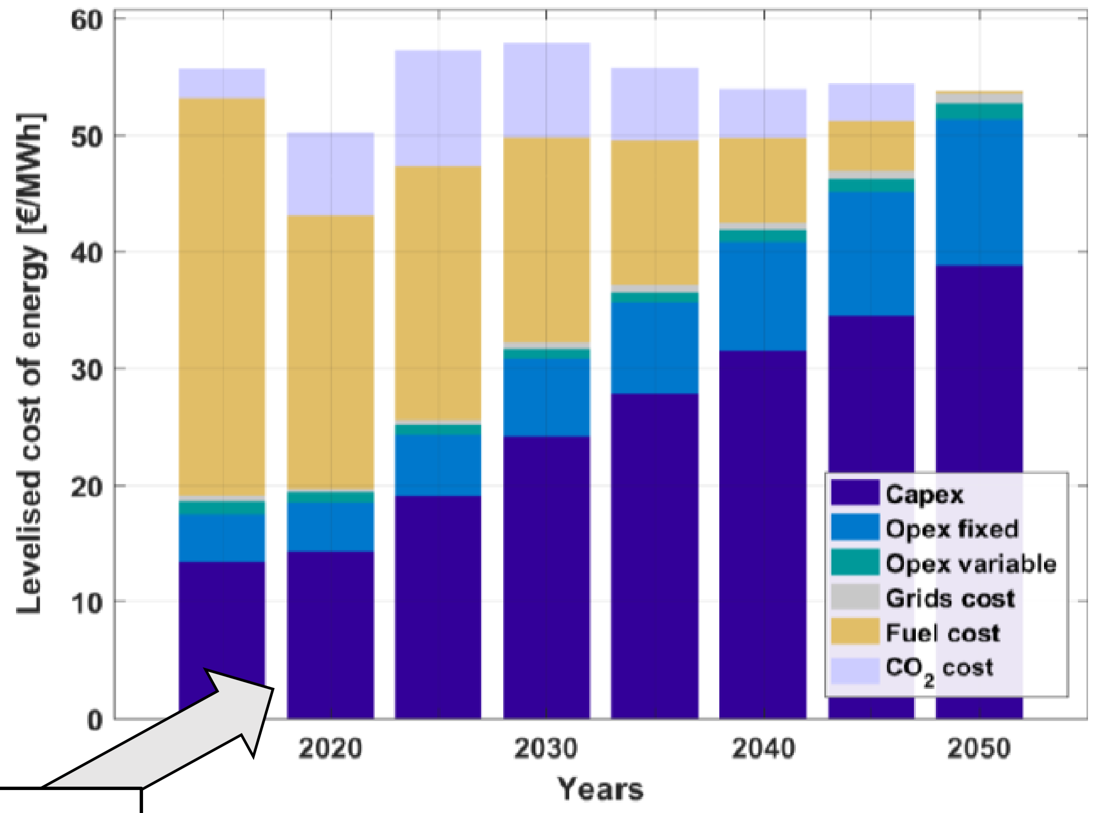
Key insights:

- TPED shifts from being dominated by coal, oil and gas in 2015 towards solar PV and wind energy by 2050
- Renewable sources of energy contribute just 22% of TPED in 2015, while in 2050 they supply 100% of TPED
- Solar PV drastically shifts from less than 1% in 2015 to around 69% of primary energy supply by 2050, as it becomes the least cost energy supply source

12 APR 2019 RENEWABLES, STUDY, UNCATEGORIZED

New Study: Global Energy System based on 100% Renewable Energy

The new study by the Energy Watch Group and LUT University is the first of its kind to outline a 1.5°C scenario with a cost-effective, cross-sectoral, technology-rich global 100% renewable energy system that does not build on negative CO2 emission technologies. The scientific modelling study simulates a total global energy transition in the electricity, heat, transport and desalination sectors by 2050. It is based on four and a half years of research and analysis of data collection, as well as technical and financial modelling by 14 scientists. This proves that the transition to 100% renewable energy is economically competitive with the current fossil and nuclear-based system, and could reduce greenhouse gas emissions in the energy system to zero even before 2050.



Huge technology business opportunity

LUT University

ENERGYWATCHGROUP

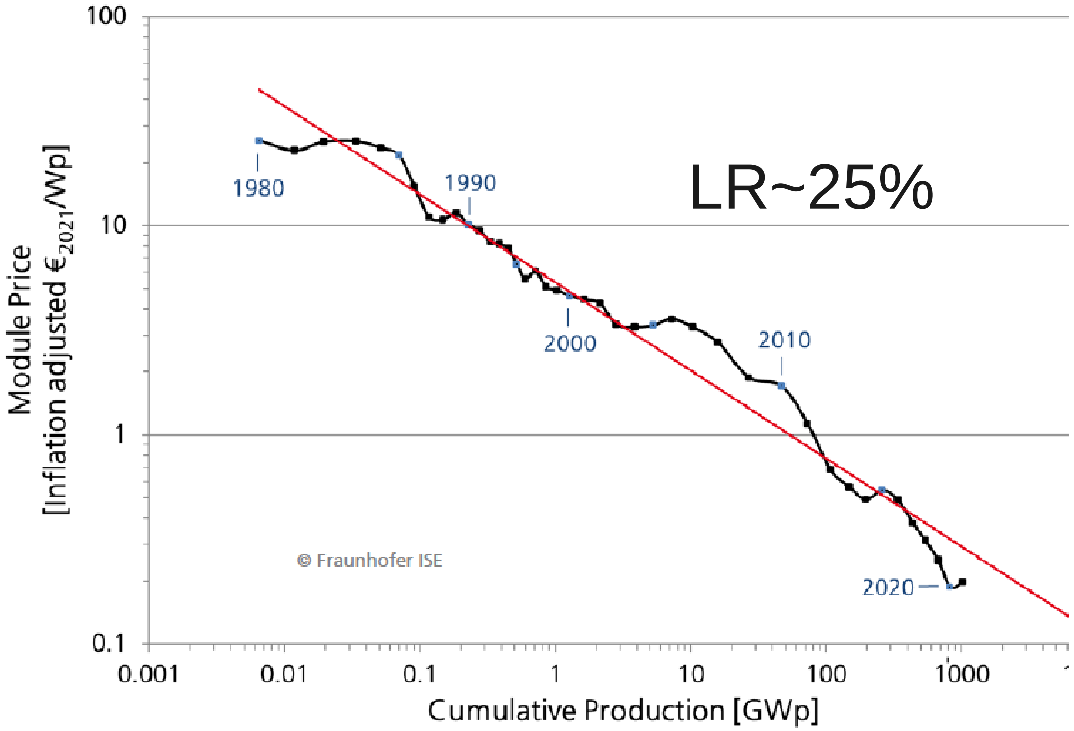
Source: http://energywatchgroup.org/new-study-global-energy-system-based-100-renewable-energy

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.

Siirtymä fossiilisten polttoaineiden hyödyntämisestä sarjatuotettuihin sähköenergiateknologioihin

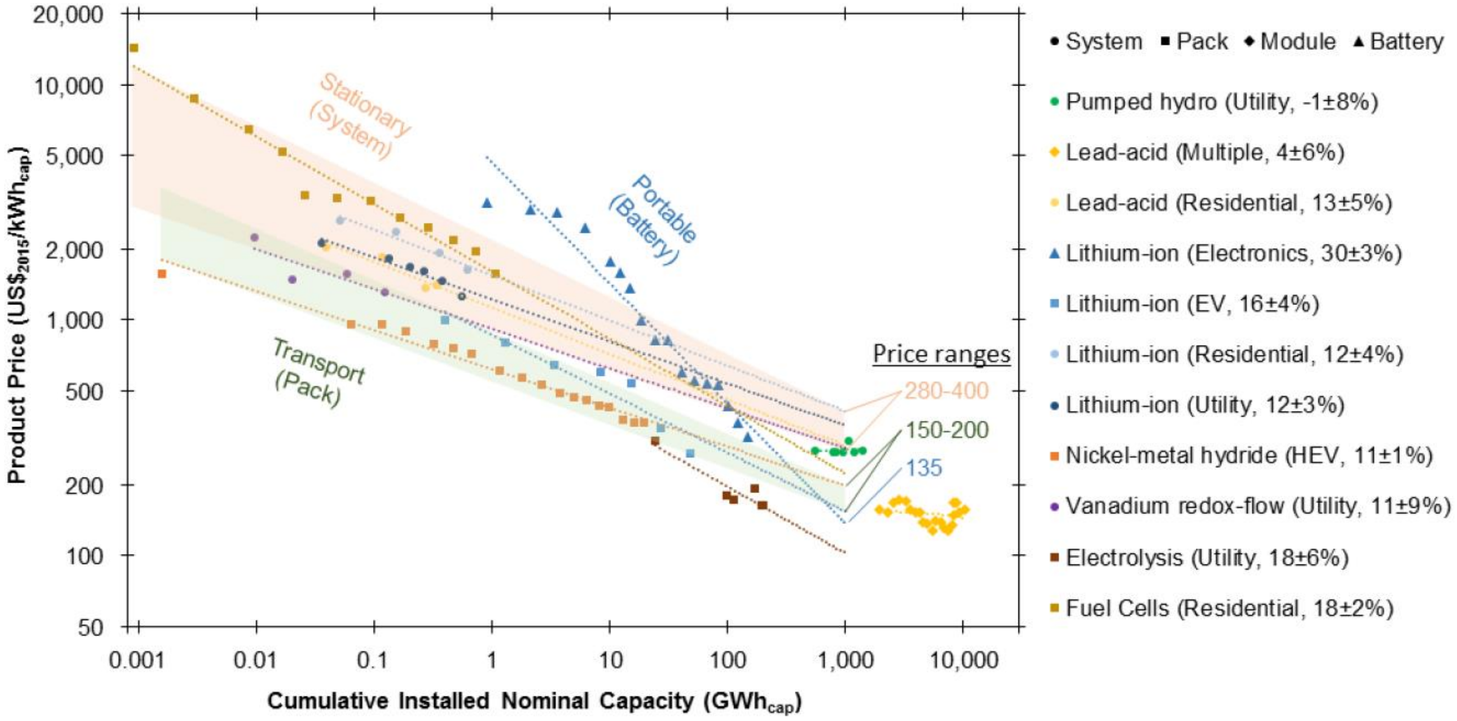
Sarjatuotetut energiateknologioiden oppimiskäyrät

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

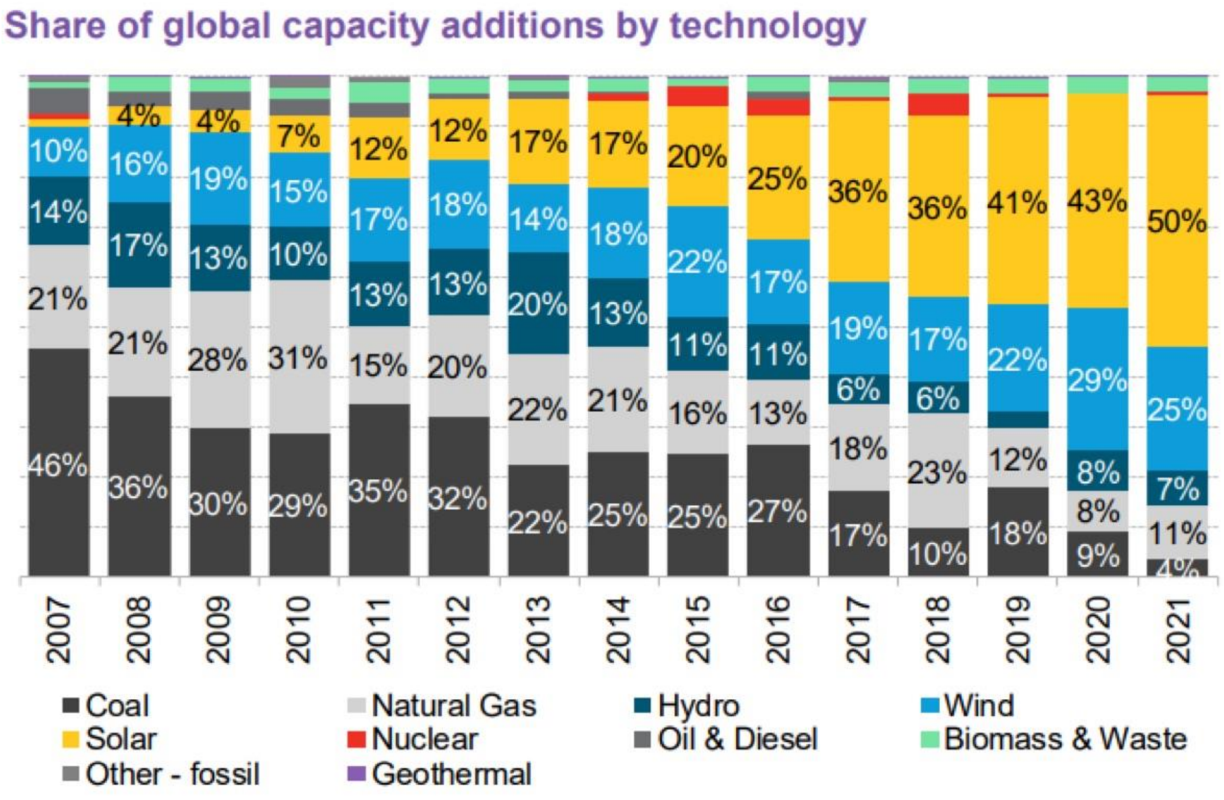


Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell, The future cost of electrical energy storage based on experience rates, Nature Energy volume 2, Article number: 17110 (2017)

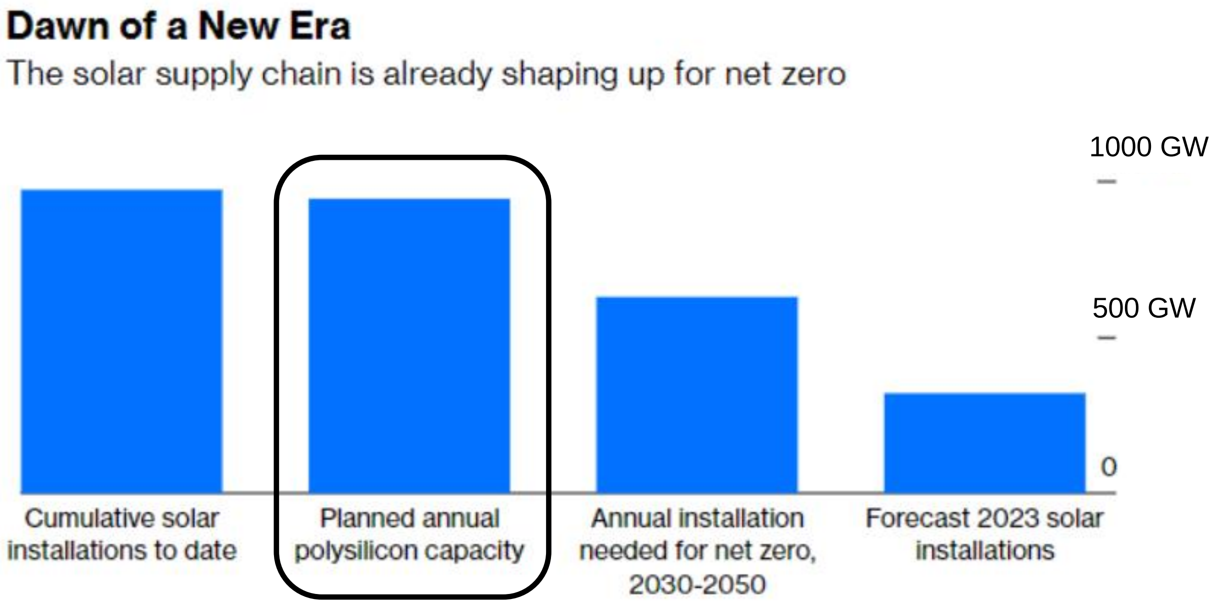
Energiamurros on epäilemättä käynnissä

LUT University

- Cumulative solar PV installations reached 1 TW in March 2022
- 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

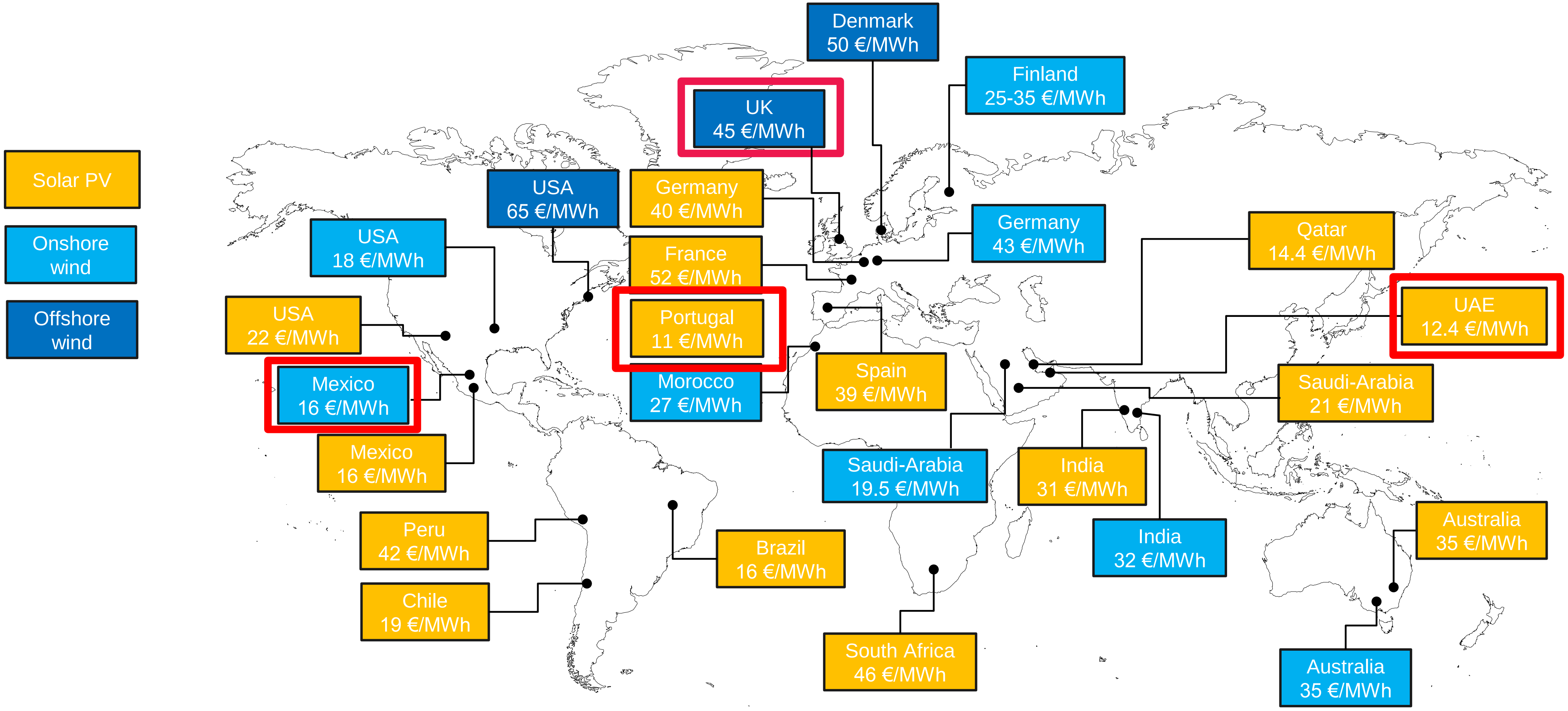


Source: BloombergNEF. Note: Share of global capacity additions excluding retirements.



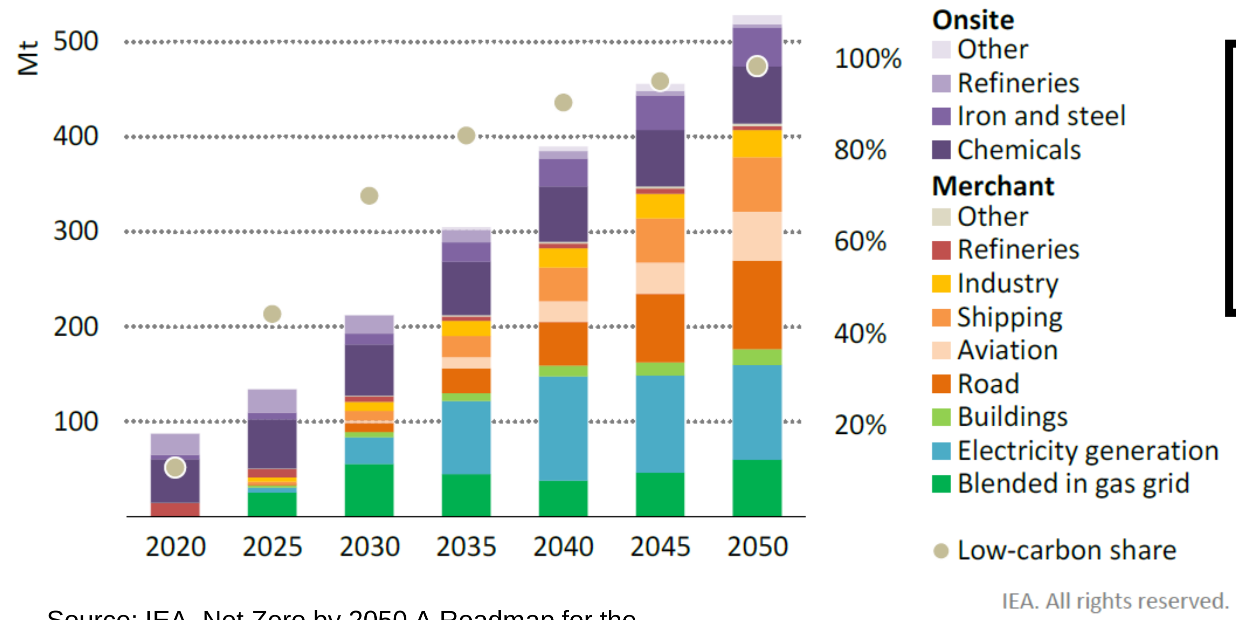
Source: BloombergNEF, International Energy Agency, JinkoSolar

Tuuli- ja aurinkovoiman PPA-sopimusten hintoja 2020->

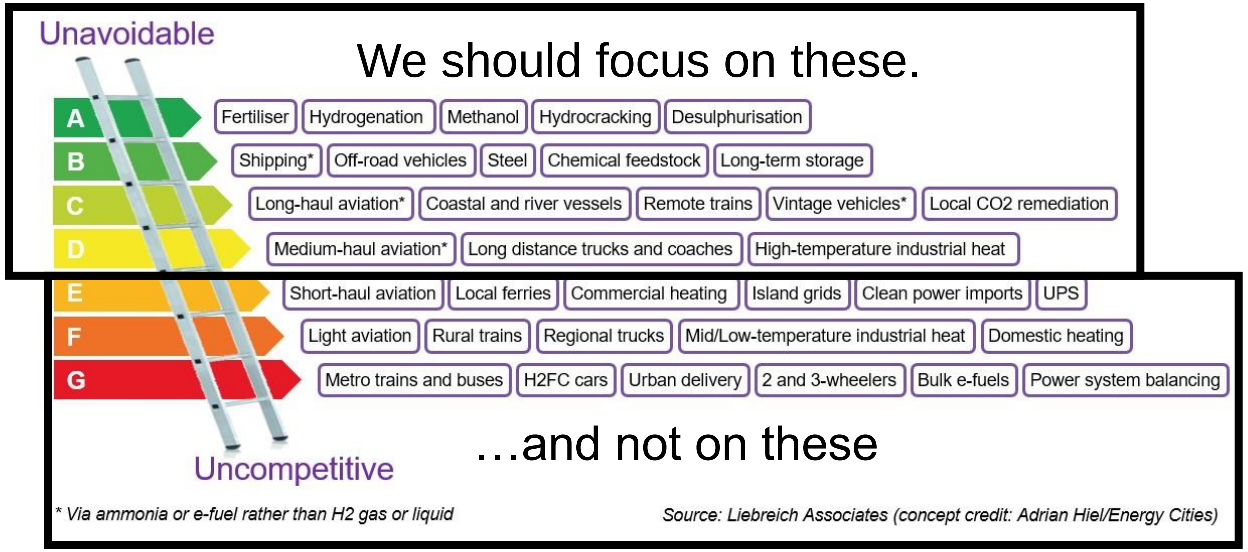


IEA Net Zero by 2050: Vedyn tarve

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



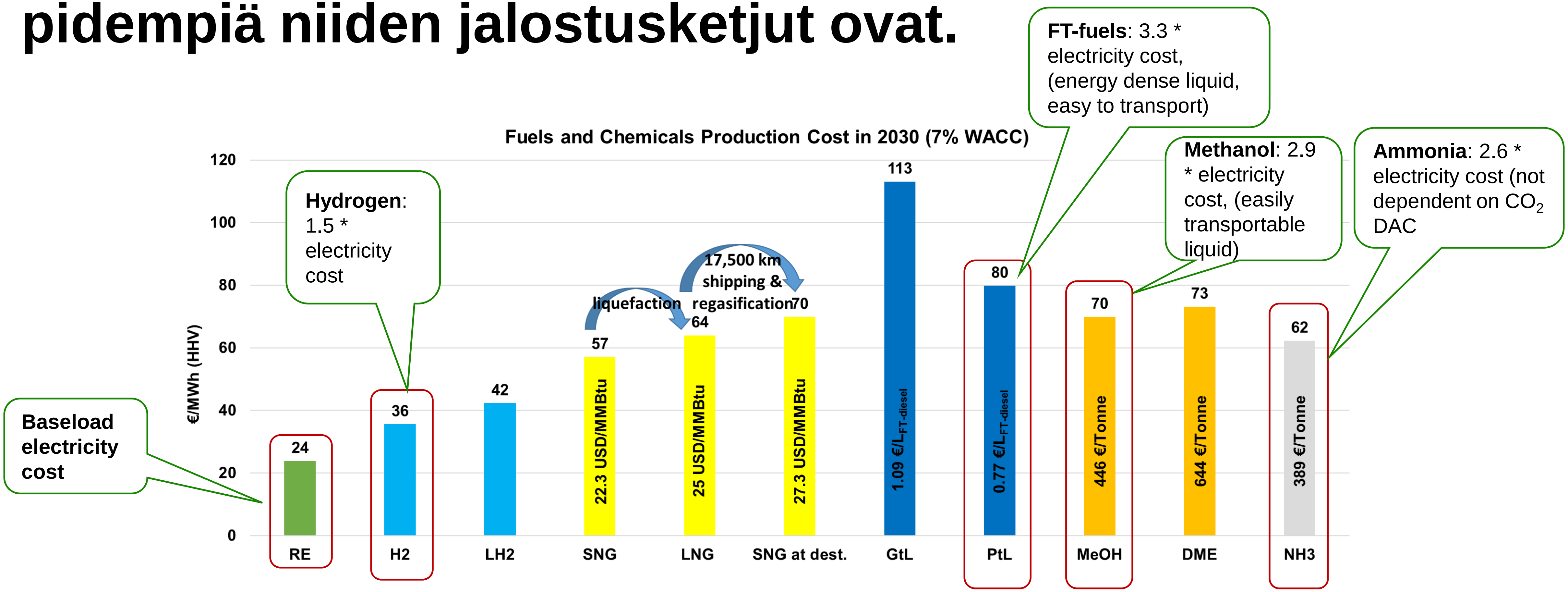
Source: IEA, Net Zero by 2050 A Roadmap for the Global Energy Sector, 2021 : https://www.iea.org/reports/net-zero-by-2050



- 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

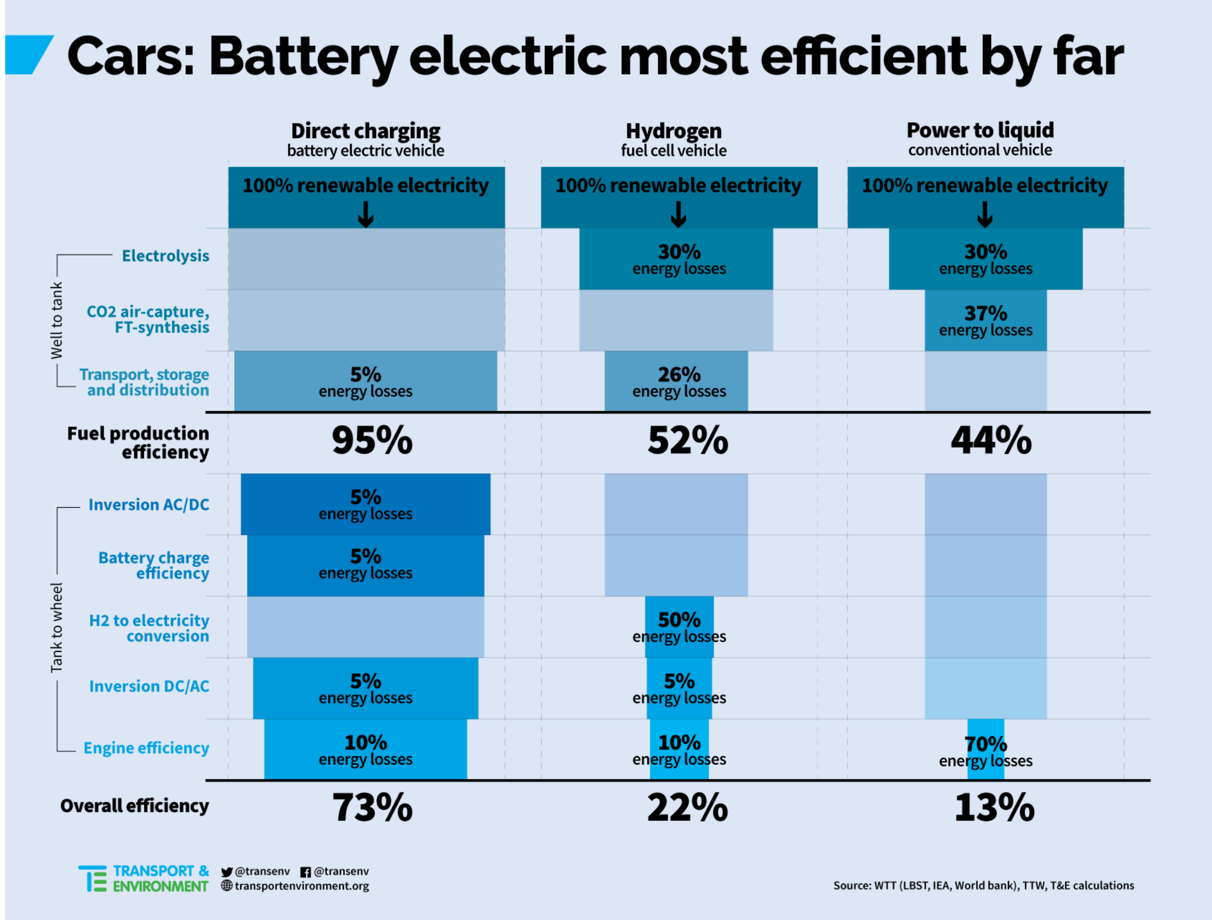
Source: Dmitrii Bogdanov, et. Al., Low-cost renewable electricity as the key driver of the global energy transition towards sustainability, Energy, Volume 227, 2021, 120467, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2021.120467.

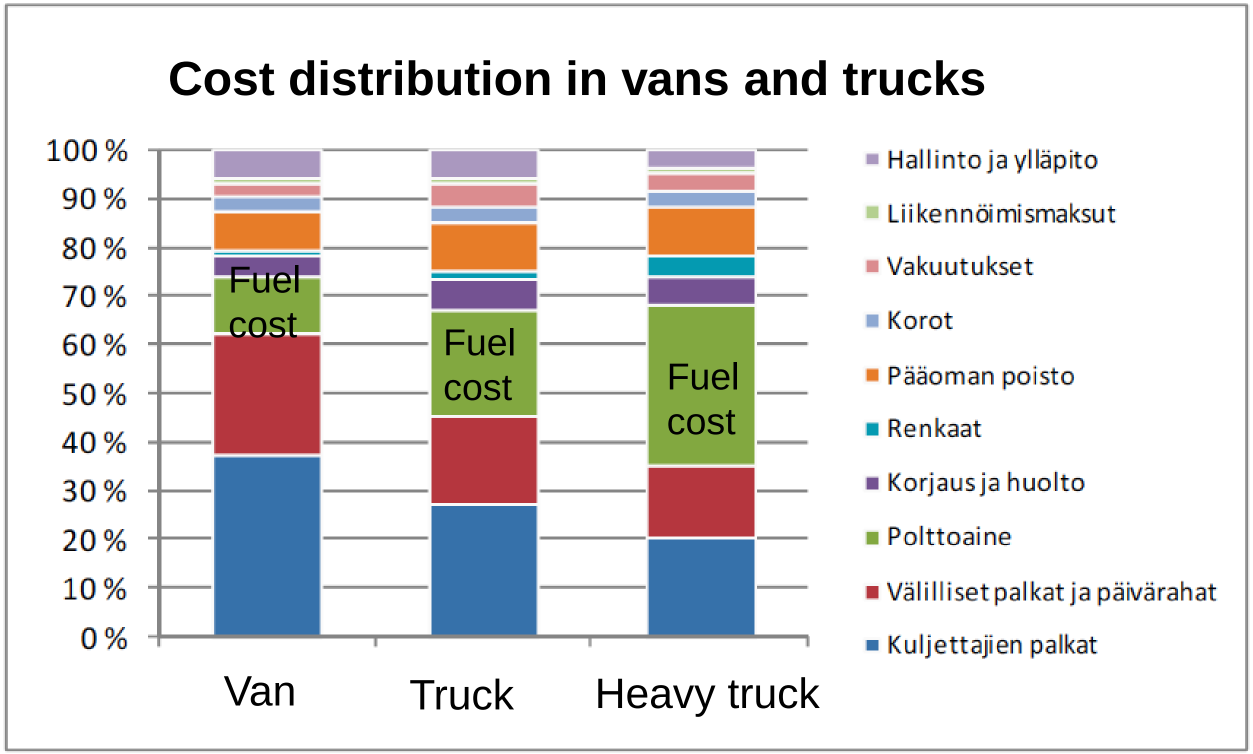
Puhdas sähkö on tulevaisuudessa edullisinta energiaa. Sähköpolttoaineet maksavat sitä enemmän mitä pidempiä niiden jalostusketjut ovat.



Source: http://www.neocarbonenergy.fi/wp-content/uploads/2016/02/13_Fasihi.pdf

Esimerkki: Vedyn tai sähköpolttoaineiden käytössä tieliikenteessä ei ole välttämättä taloudellista järkeä





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

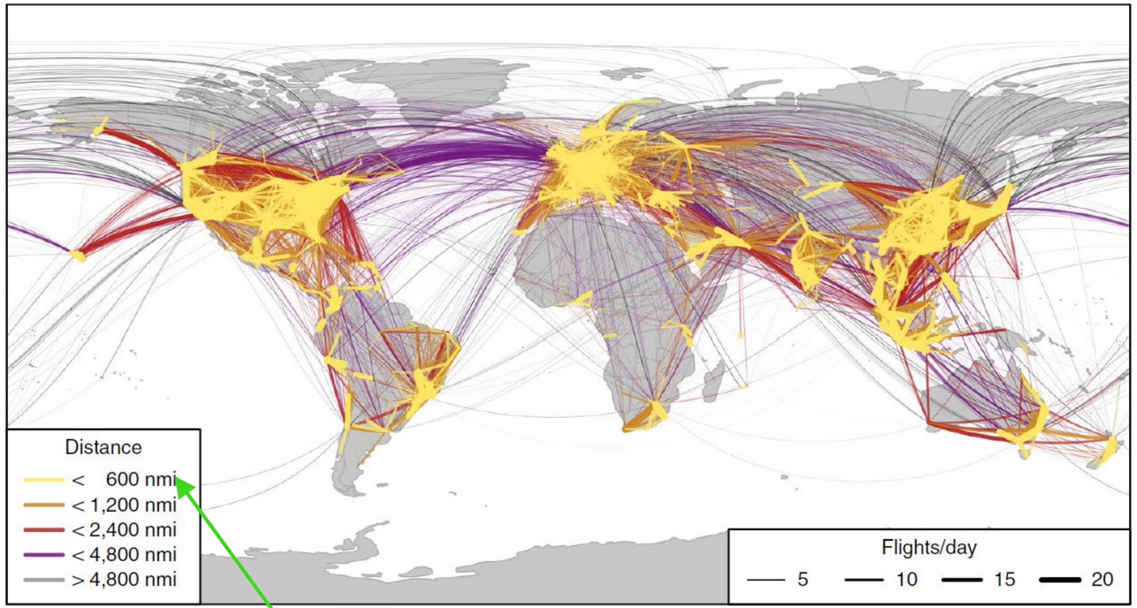
Kiinalainen sähkökuorma-auto ja akunvaihtoasema

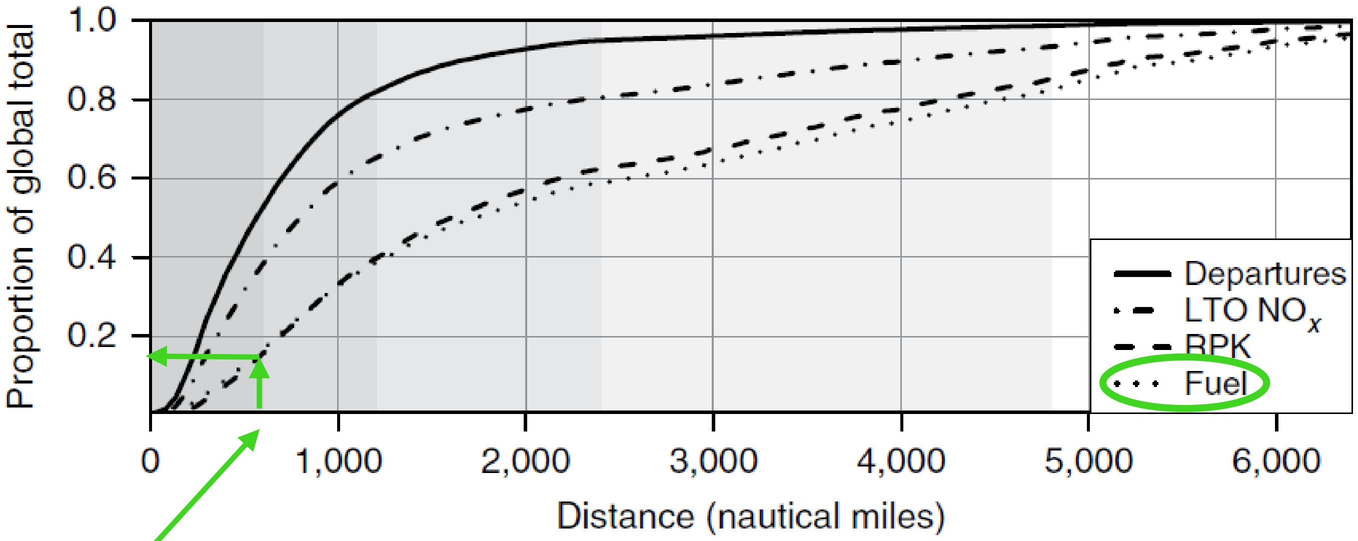
Description

- Battery pack is located behind the cabin of the truck. The capacity is 3-4 times of the capacity of EV car
- Battery weights 3.2 tons and it has a capacity of 280 kWh
- Battery gives around 150-200 km of electric range. It also powers other functions, such as the mixing of cement
- Used battery is transferred automatically to the battery warehouse and replaced with a charged one
- The whole operation takes about five minutes

Akunvaihto sähkökuorma-autoon

Sähköistämisestä huolimatta valtavasti sähköpolttoaineita tarvitaan lentoliikenteeseen ja merenkulkuun





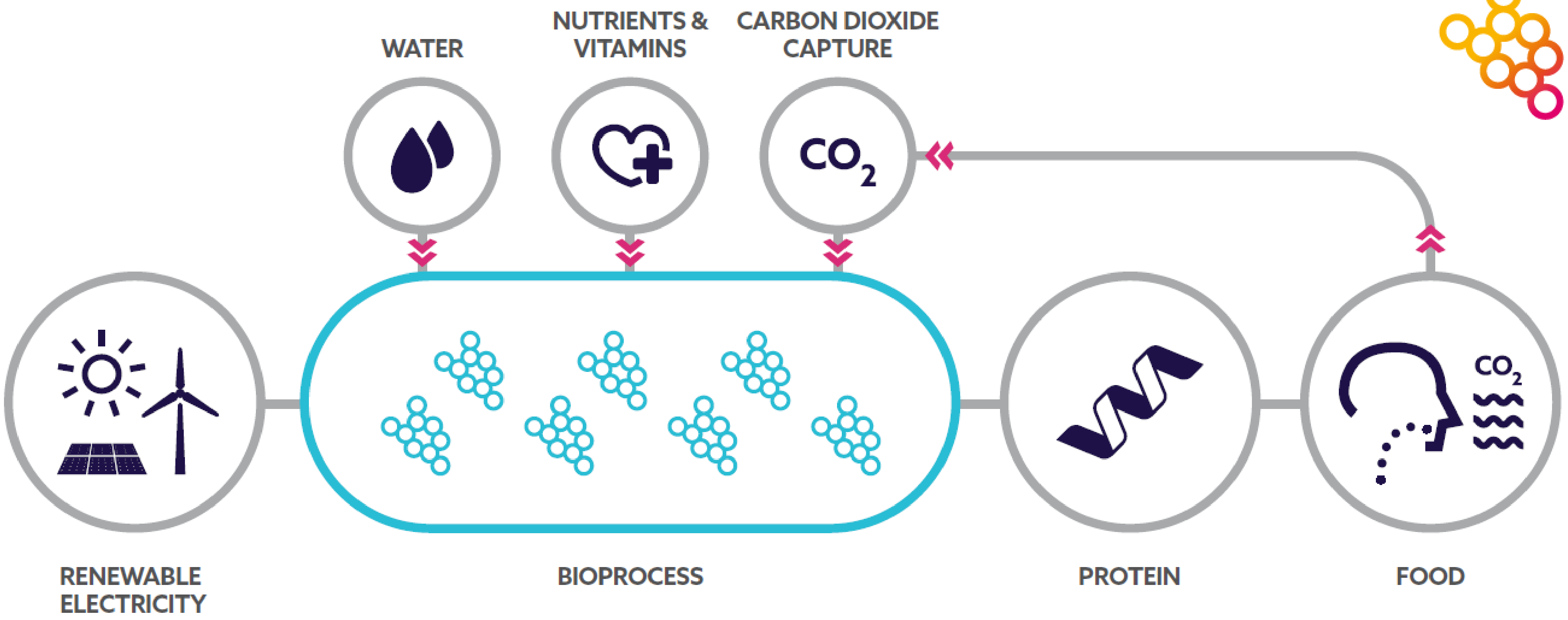
Electric flights at distances < 600 nmil (1100 km) ~15 % of total fuel consumption of battery energy density 800 Wh/kg will be reached

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

Sähköstä ruokaa - Neo-Carbon Food

THE PRINCIPLE

Neo-Carbon Food is a microbial process. Protein production takes place in a reactor suitable for microorganisms to grow and divide. The energy of the process is electricity, and carbon dioxide is the carbon source.



Teknologiateollisuuden
100-vuotissäätiö

J&AE JANE AND AATOS
ERKKO FOUNDATION

ACADEMY
OF FINLAND

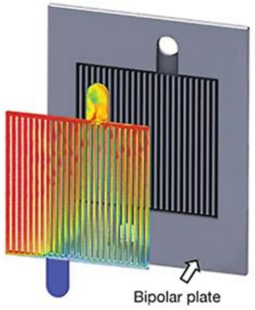
Neo-Carbon Food – Food from electricity pilot
at LUT Lappeenranta campus in 2019
https://www.youtube.com/watch?v=KTEEmRcShBw

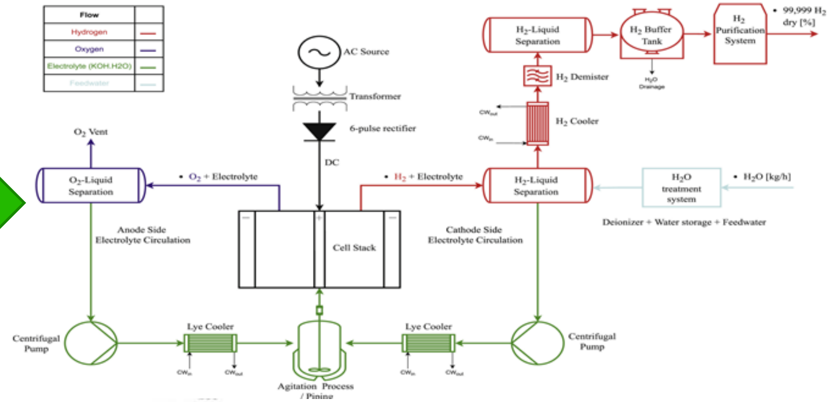
1.12.2022

LUTn viimeisiä PtX-tutkimustuloksia

Multiscale-multiphysics modelling by LUT – Research objectives: system cost, dynamic performance and efficiency

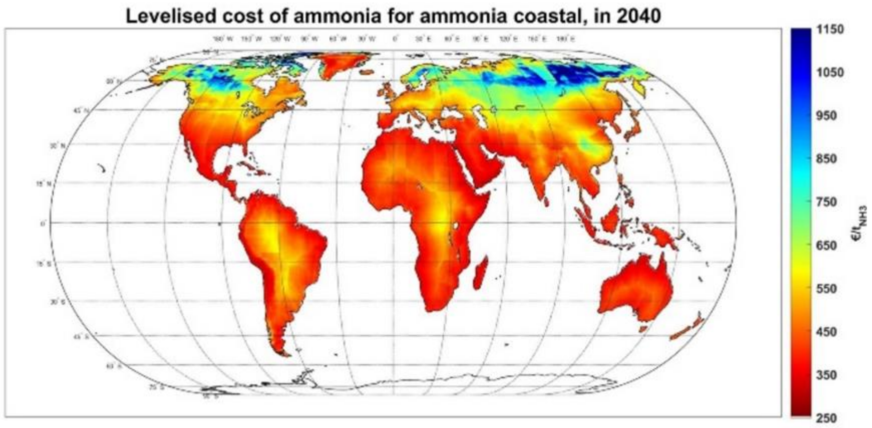
Cell and stack design

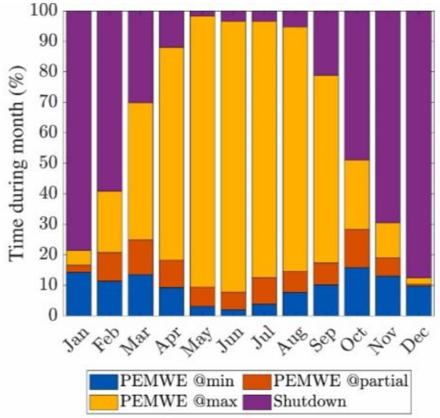




Electrolyser system operation

Global energy transition





Optimisation of battery buffered solar PV and wind power-based production of green hydrogen

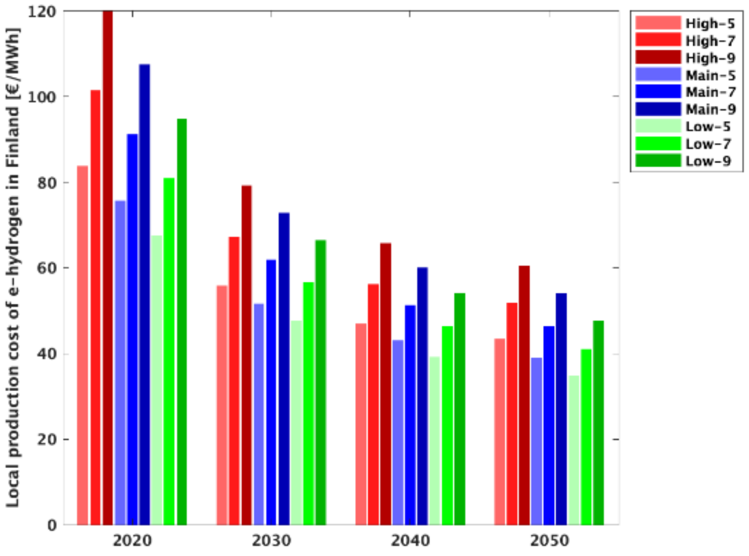
Vetyä ei kannata taloudellisesti kuljettaa pitkiä matkoja

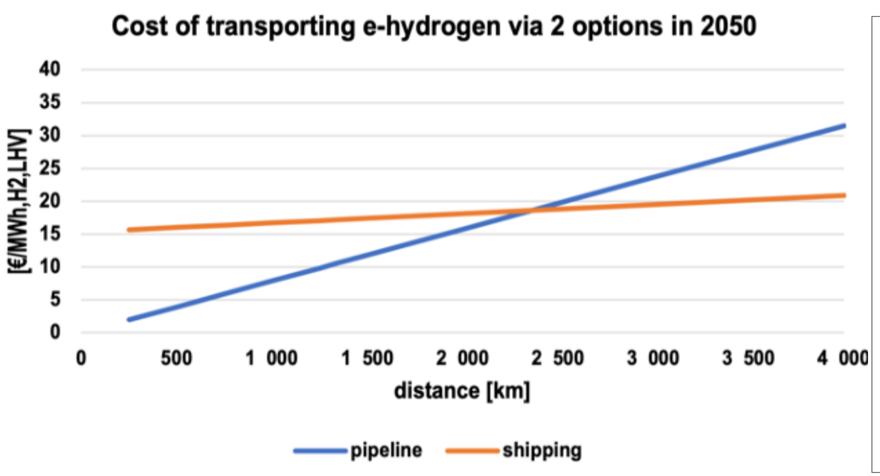
LUT University

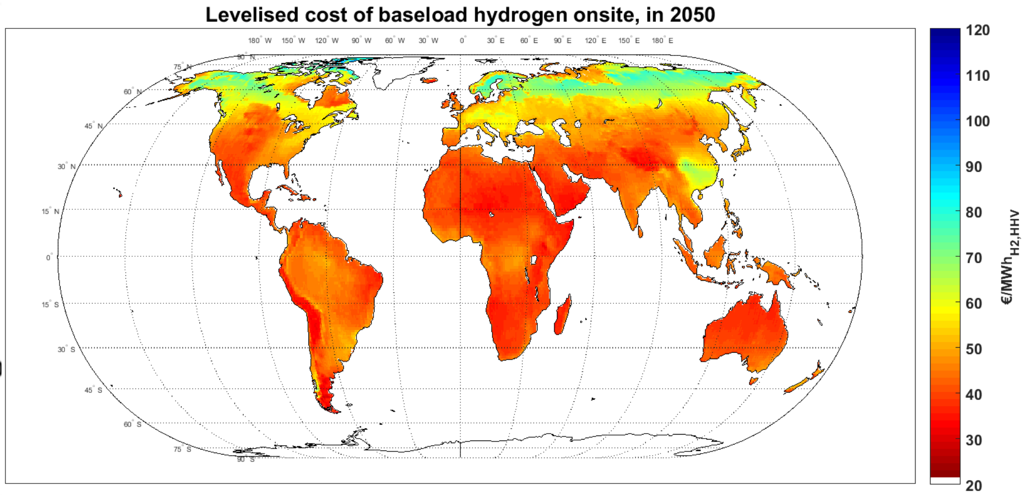
source: Galimova et al., 2022. 8th International Conference on Smart Energy Systems, Aalborg, Denmark, September 13-14, under review at a journal

Key insights:

- Renewable-electricity based hydrogen can be produced at acceptable cost anywhere in the world
- To better assess attractiveness of imports transportation infrastructure needs to be considered
- Imported hydrogen costs were found to be significantly higher than H_2 produced domestically (case FI, DE)
- Local supply of H_2 is more economical across both cases and all years, since transportation costs are high
- Pipeline transport is lower in cost for short distances, whereas shipping is more economical for distances over 1500 km

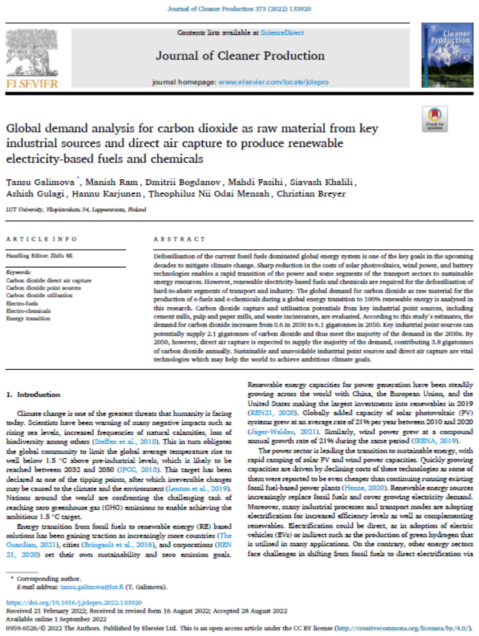






Hiiltä pitää ottaa PtX-polttoaineisiin ilmasta

LUT University


Journal of Cleaner Production 373 (2022) 133920

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Global demand analysis for carbon dioxide as raw material from key industrial sources and direct air capture to produce renewable electricity-based fuels and chemicals

Tansu Galimova *, Manish Ram, Dmitrii Bogdanov, Mahdi Fasihi, Siavash Khalili, Ashish Gulagi, Hannu Karjunen, Theophilus Nii Odai Mensah, Christian Breyer

LUT University, Yliopistonkatu 34, Lappeenranta, Finland

ARTICLE INFO

Handling Editor: Zhifu Mi

Keywords:
Carbon dioxide direct air capture
Carbon dioxide point sources
Carbon dioxide utilisation
Electro-fuels
Electro-chemicals
Energy transition

ABSTRACT

Defossilisation of the current fossil fuels dominated global energy system is one of the key goals in the upcoming decades to mitigate climate change. Sharp reduction in the costs of solar photovoltaics, wind power, and battery technologies enables a rapid transition of the power and some segments of the transport sectors to sustainable energy resources. However, renewable electricity-based fuels and chemicals are required for the defossilisation of hard-to-abate segments of transport and industry. The global demand for carbon dioxide as raw material for the production of e-fuels and e-chemicals during a global energy transition to 100% renewable energy is analysed in this research. Carbon dioxide capture and utilisation potentials from key industrial point sources, including cement mills, pulp and paper mills, and waste incinerators, are evaluated. According to this study's estimates, the demand for carbon dioxide increases from 0.6 in 2030 to 6.1 gigatonnes in 2050. Key industrial point sources can potentially supply 2.1 gigatonnes of carbon dioxide and thus meet the majority of the demand in the 2030s. By 2050, however, direct air capture is expected to supply the majority of the demand, contributing 3.8 gigatonnes of carbon dioxide annually. Sustainable and unavoidable industrial point sources and direct air capture are vital technologies which may help the world to achieve ambitious climate goals.

1. Introduction

Climate change is one of the greatest threats that humanity is facing today. Scientists have been warning of many negative impacts such as rising sea levels, increased frequencies of natural calamities, loss of biodiversity among others (Steffen et al., 2018). This in turn obligates the global community to limit the global average temperature rise to well below 1.5 °C above pre-industrial levels, which is likely to be reached between 2032 and 2050 (IPCC, 2018). This target has been declared as one of the tipping points, after which irreversible changes may be caused to the climate and the environment (Lenton et al., 2019). Nations around the world are confronting the challenging task of reaching zero greenhouse gas (GHG) emissions to enable achieving the ambitious 1.5 °C target.

Energy transition from fossil fuels to renewable energy (RE) based solutions has been gaining traction as increasingly more countries (The Guardian, 2021), cities (Bringault et al., 2016), and corporations (REN 21, 2020) set their own sustainability and zero emission goals. Renewable energy capacities for power generation have been steadily growing across the world with China, the European Union, and the United States making the largest investments into renewables in 2019 (REN21, 2020). Globally added capacity of solar photovoltaic (PV) systems grew at an average rate of 21% per year between 2010 and 2020 (Jäger-Waldau, 2021). Similarly, wind power grew at a compound annual growth rate of 21% during the same period (IRENA, 2019).

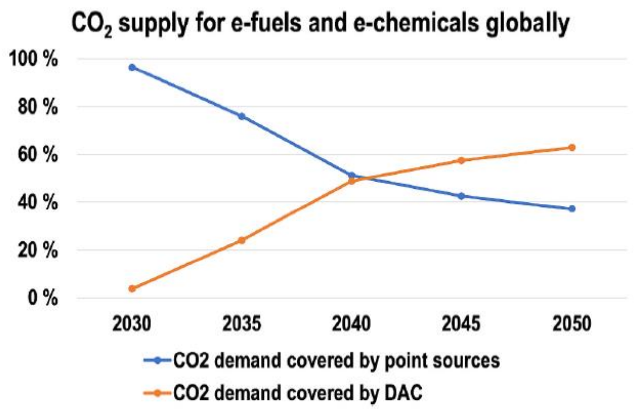
The power sector is leading the transition to sustainable energy, with rapid ramping of solar PV and wind power capacities. Quickly growing capacities are driven by declining costs of these technologies as some of them were reported to be even cheaper than continuing running existing fossil fuel-based power plants (Hense, 2020). Renewable energy sources increasingly replace fossil fuels and cover growing electricity demand. Moreover, many industrial processes and transport modes are adopting electrification for increased efficiency levels as well as complementing renewables. Electrification could be direct, as in adoption of electric vehicles (EVs) or indirect such as the production of green hydrogen that is utilised in many applications. On the contrary, other energy sectors face challenges in shifting from fossil fuels to direct electrification via

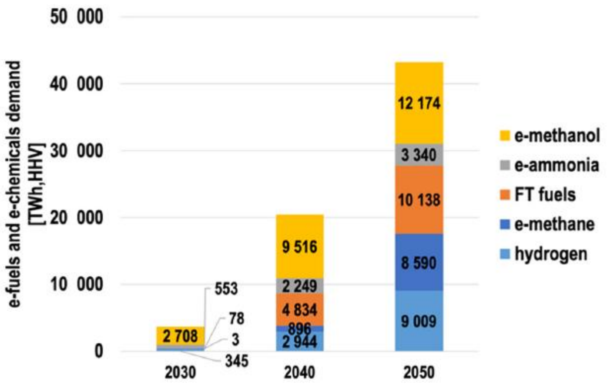
* Corresponding author.
E-mail address: tansu.galimova@lut.fi (T. Galimova).

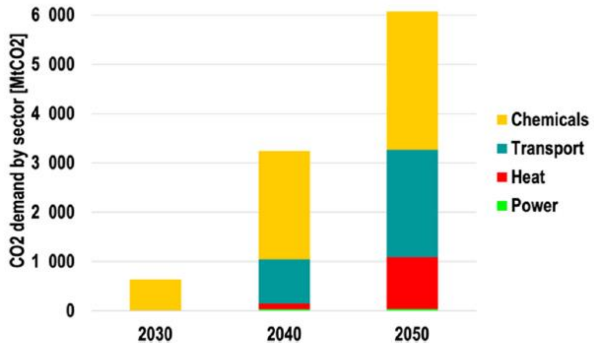
https://doi.org/10.1016/j.jclepro.2022.133920
Received 21 February 2022; Received in revised form 16 August 2022; Accepted 28 August 2022
Available online 1 September 2022

Key insights:

- e-fuels demand in order of 40,000 TWh
- 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

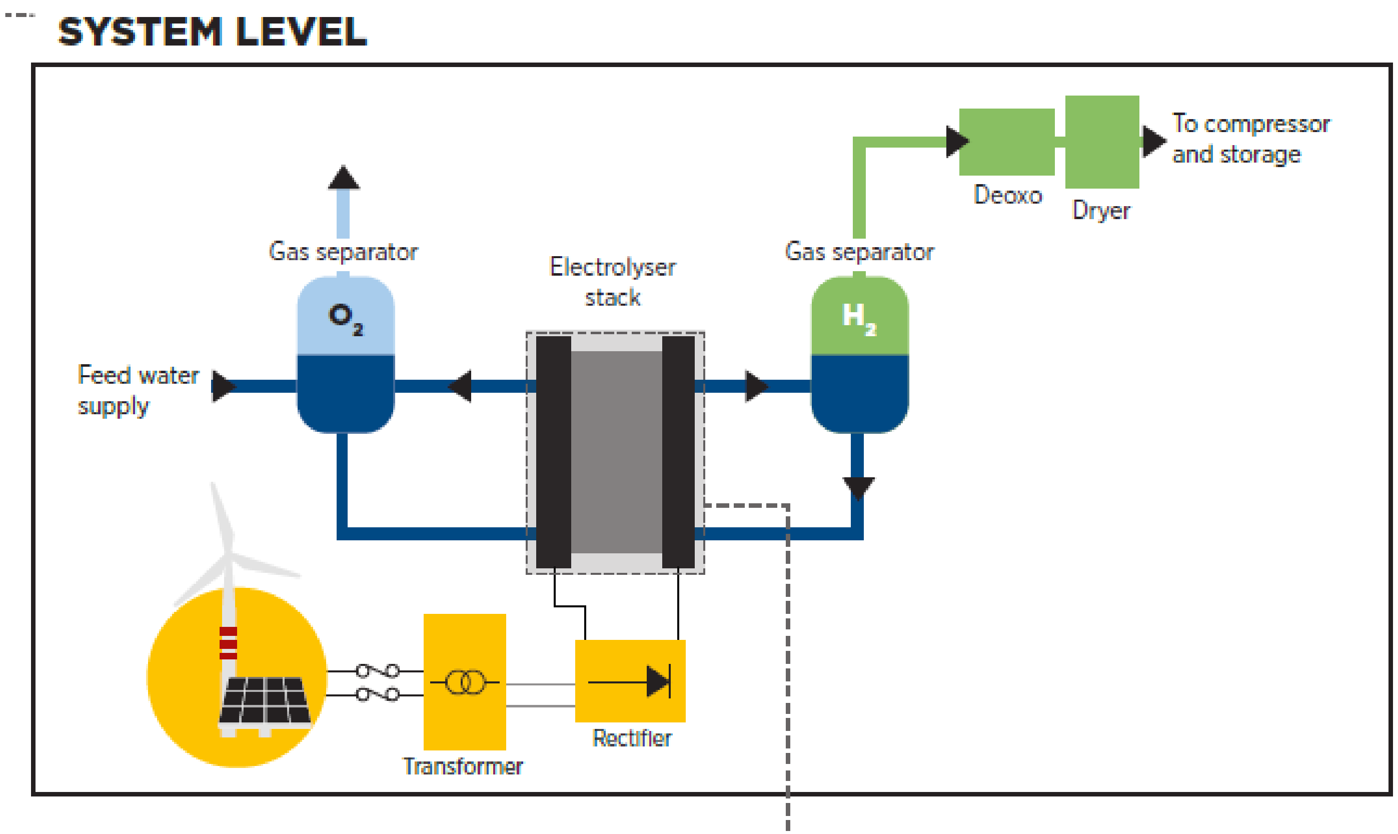






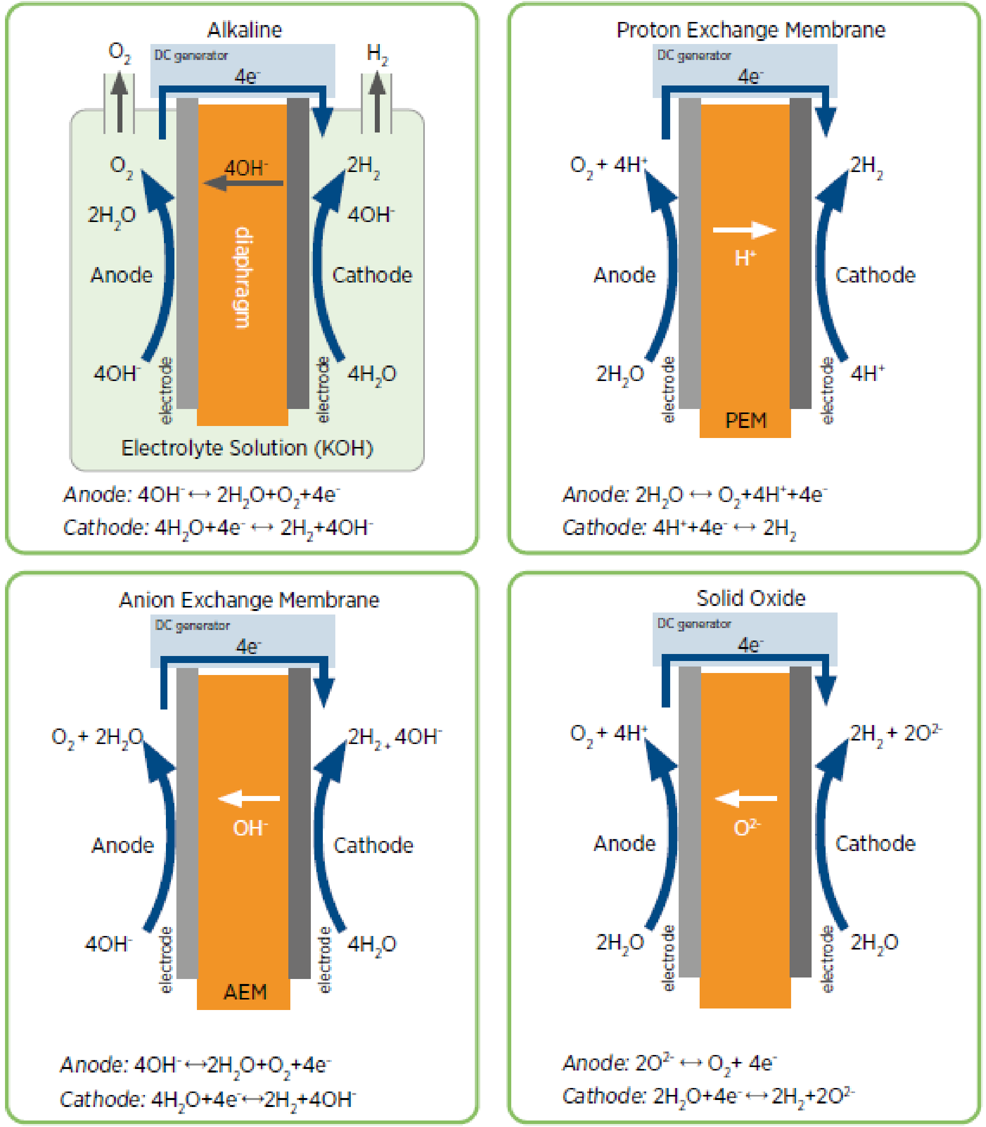
source: Galimova et al., 2022. J of Cleaner Production, 373, 133920

Vihreän vedyn tuotanto – tyypillisimmät kennoteknologiat



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.

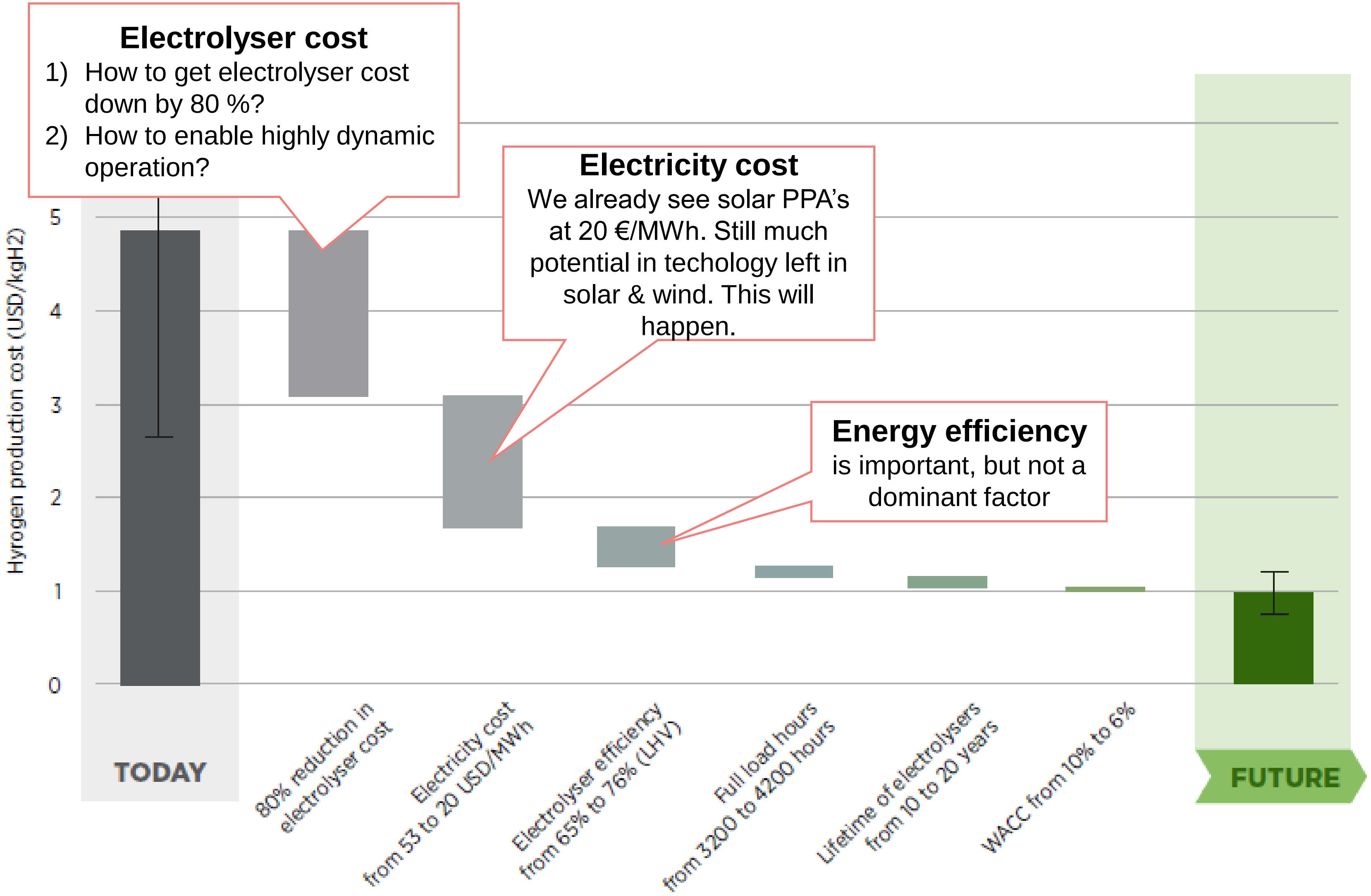


Teollisuuskokoluokan alkalivesielektrolyysilaitos (Woikoski Oy)

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

Miten saadaan edullista vihreää vetyä?



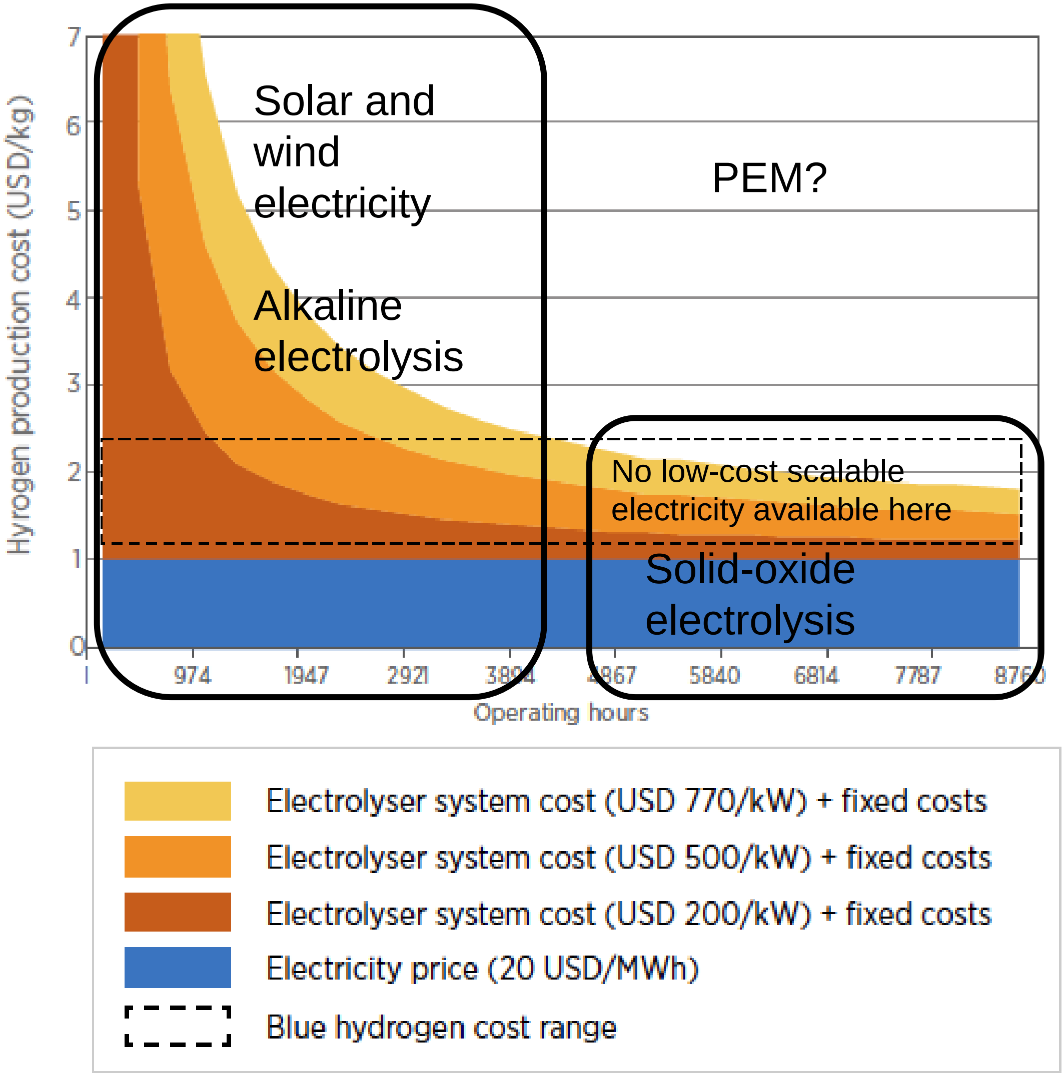
Source: IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency, Abu Dhabi

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).

Tuuleen ja aurinkoon perustuve vihreän vedyn tuotanto

LUT University

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

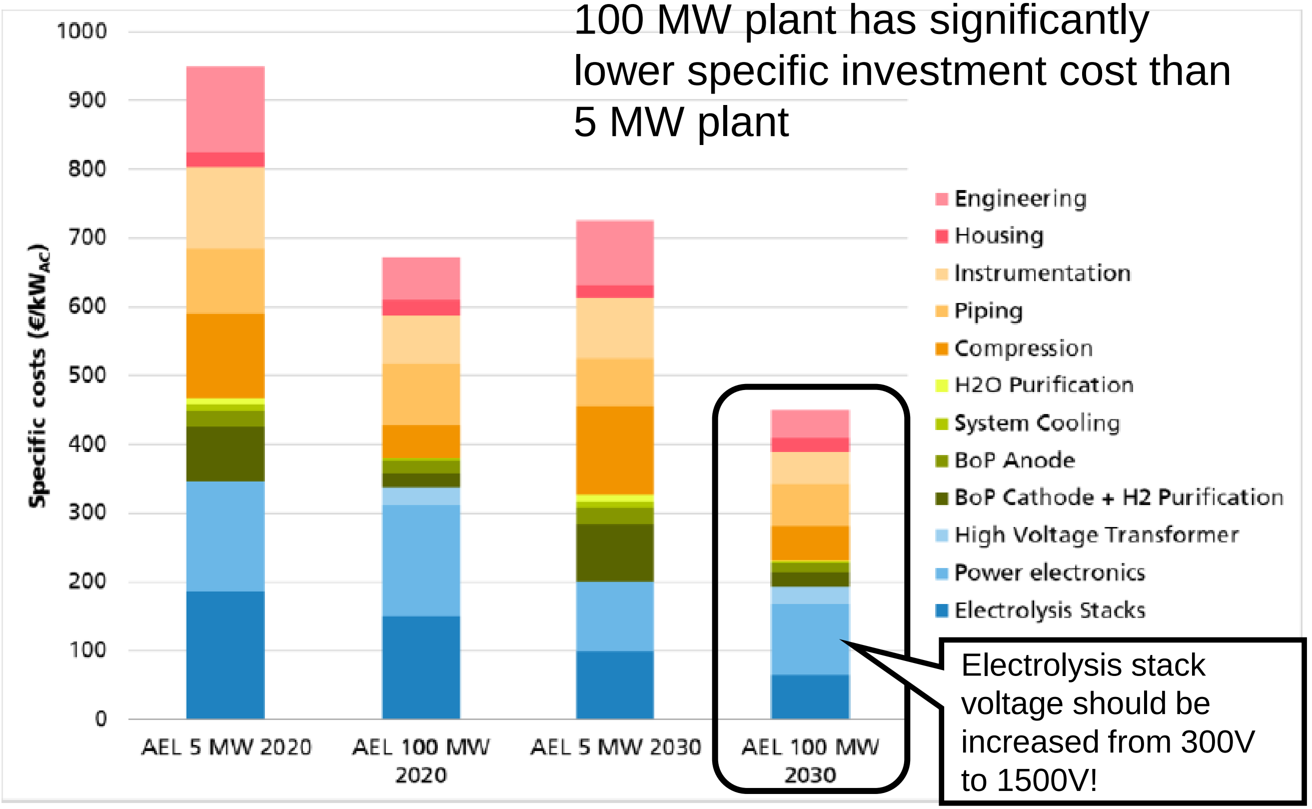


Figure 3-6: Specific costs of 5 MW and 100 MW next generation AEL systems (including mechanical compressors) for the design scenarios 2020 and 2030

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

Teollisen kokoluokan alkaalivesielektrolyysin mallinnus

In this case, more than 10 % of current is leakage current -> It does not produce hydrogen. The problem gets even worse at partial loads or when more electrolyzer cells are connected in series.

Ovenpotentials can be reduced by better catalysts, membranes and increasing temperature. Overpotentials are reduced at partial loads.

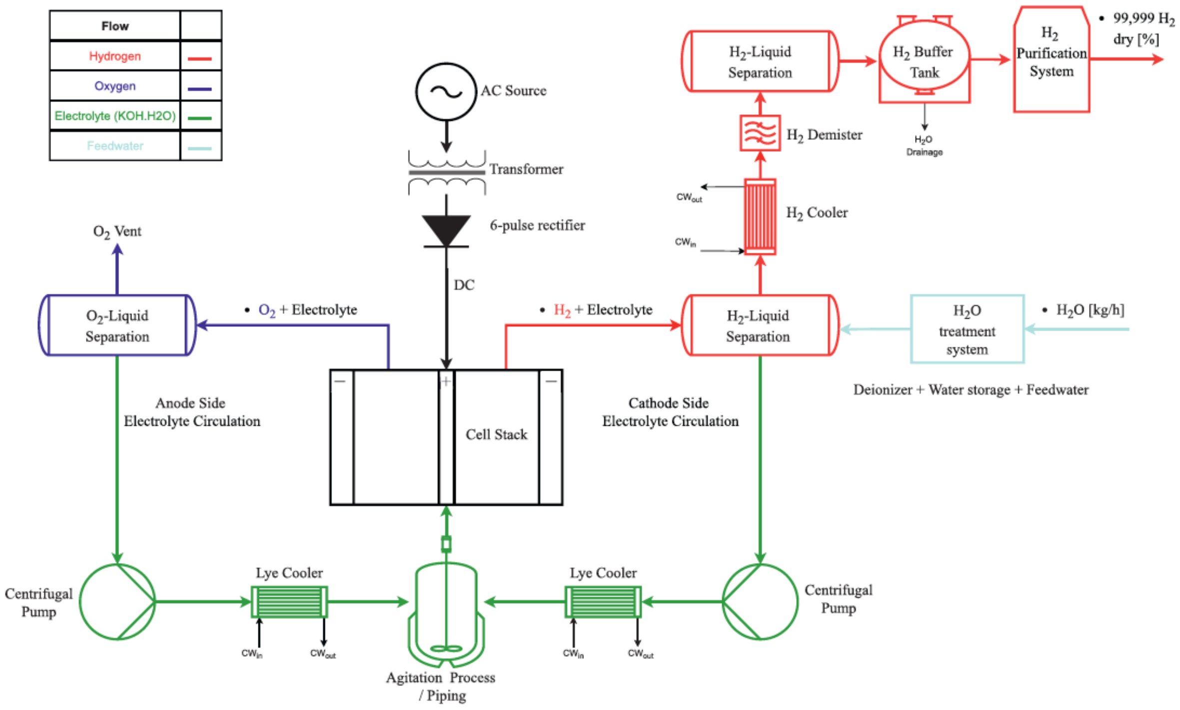


Fig. 1 — Formulated alkaline water electrolyzer plant process diagram.

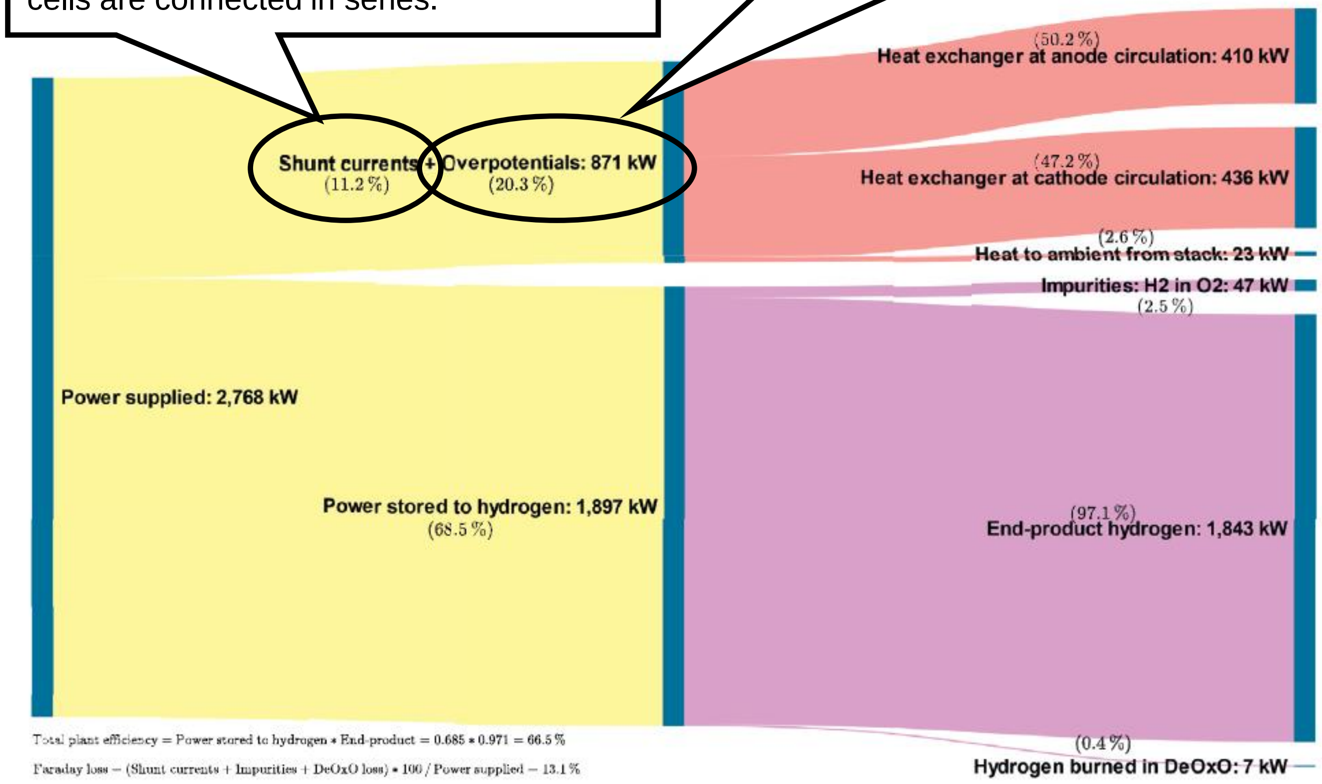


Fig. 9 — Supplied power consumption/distribution in the stack and system level.

Source: Georgios Sakas, Alejandro Ibáñez-Rioja, Vesa Ruuskanen, Antti Kosonen, Jero Ahola, Olli Bergmann, Dynamic energy and mass balance model for an industrial alkaline water electrolyzer plant process, International Journal of Hydrogen Energy, Volume 47, Issue 7, 2022, Pages 4328-4345, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2021.11.126.

Alkaalivesielektrolyysin omimaisenergian kulutus

In order to run alkaline water electrolysis energy efficiently at partial load currents, we have to have a <u>low leakage current electrolyzer stack design</u>.

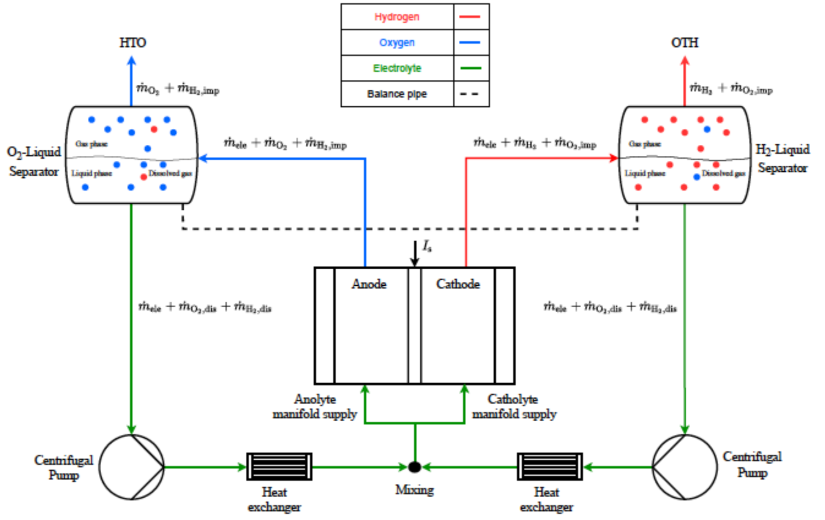
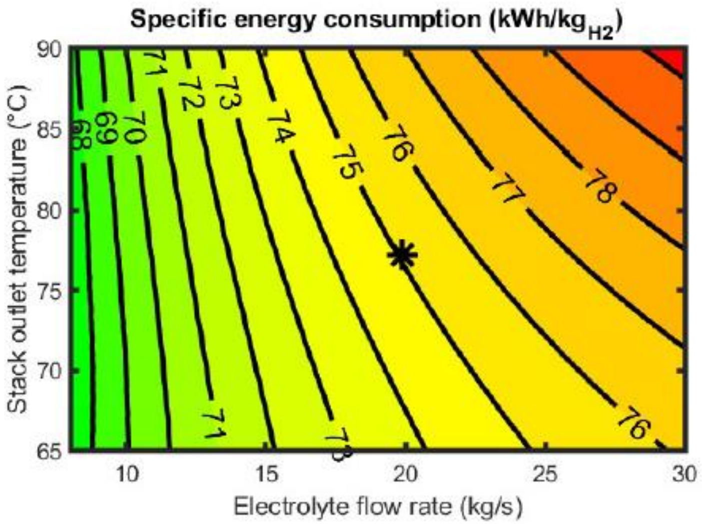
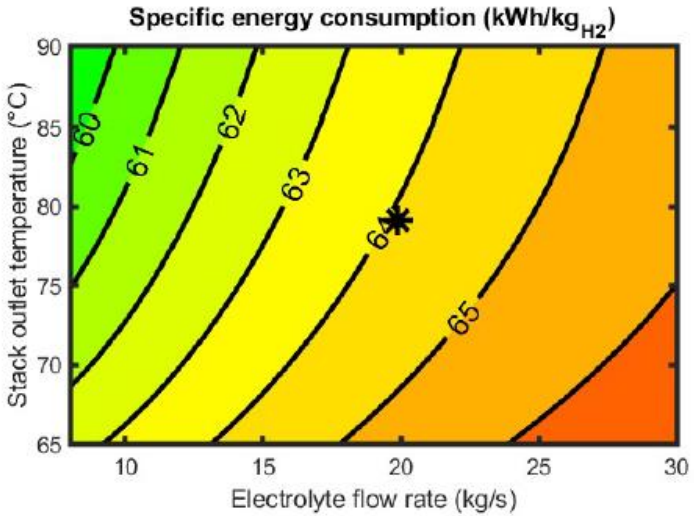


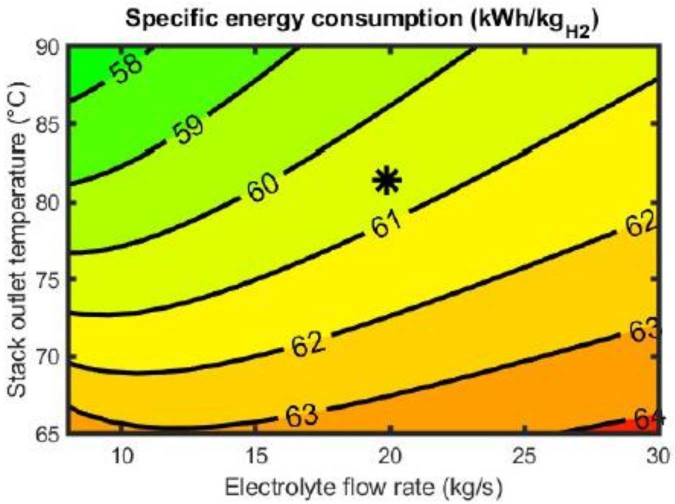
Fig. 2: Modelled process layout of the circulation loop of an industrial AWE and illustration of the gas crossover phenomenon resulting from the gas dissolution in the separation vessels.



50 % load current



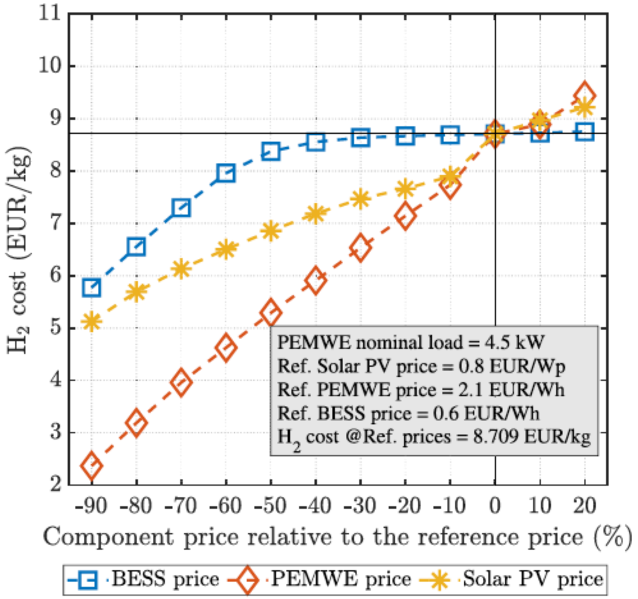
75 % load current



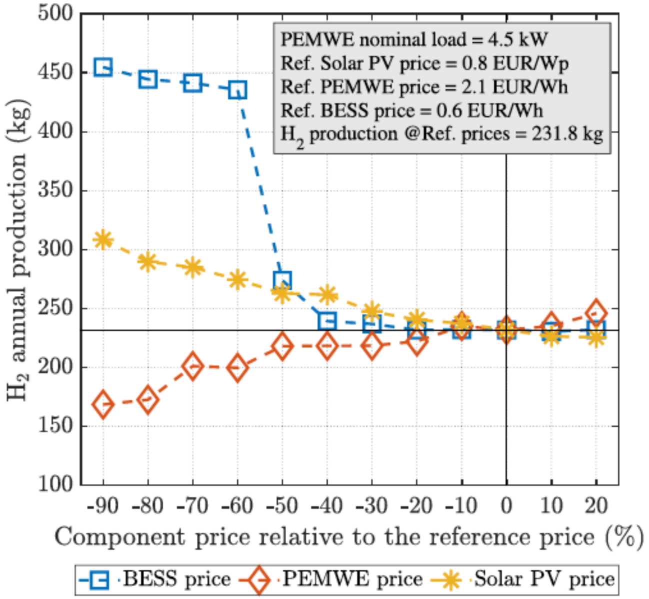
100 % load current

Source: Georgios Sakas, Alejandro Ibanez Rioja, Santeri Pöyhönen, Lauri Järvinen, Antti Kosonen, Vesa Ruuskanena, Jero Ahola, Sensitivity analysis of the process conditions that affect the shunt currents and the SEC in a bipolar configuration stack of an industrial-scale alkaline water electrolyzer process, manuscript under review.

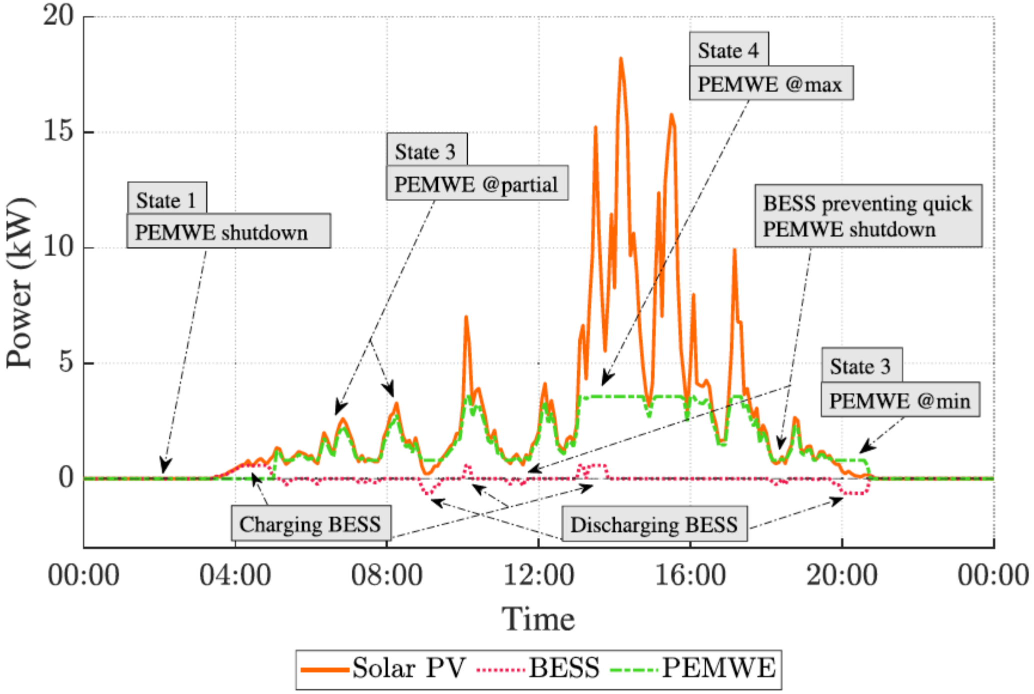
Miten tuottaa edullista vihreää vetyä – Pääkomponenttien mitoituksen ja järjestelmän ohjauksen yhteisoptimointi



(a) Cost of the hydrogen produced.



(b) Total production of hydrogen



Source: Alejandro Ibáñez-Rioja, Pietari Puranen, Lauri Järvinen, Antti Kosonen, Vesa Ruuskanen, Jero Ahola, Joonas Koponen, Simulation methodology for an off-grid solar–battery–water electrolyzer plant: Simultaneous optimization of component capacities and system control, Applied Energy, Volume 307, 2022, 118157, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2021.118157.

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.