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LUT ELECTRICAL ENGINEERING 2023

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RESEARCH LABORATORIES

Applied Electronics
- Prof. Pertti Silventoinen

Control Engineering and Digital Systems
- Assoc. Prof. Tuomo Lindh
- Prof. Olli Pyrhönen
- Assoc. Prof. Pedro Nardelli
- Assistant prof. Niko Nevaranta

Electricity Markets and Power Systems
- Prof. Samuli Honkapuro
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- Prof. Behnam Mohammadi-Ivatloo
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- Assoc. Prof. Pasi Peltoniemi
- Prof. Juha Pyrhönen
- Assoc. Prof. Lassi Aarniovuori

Renewable Electricity Generation and Storage
- Prof. Jero Ahola
- Prof. Pertti Kauranen

Solar Economy
- Prof. Christian Breyer

FOCUS ON THE ELECTRIFICATION OF THE WHOLE ENERGY SYSTEM

- Energy system modelling
- Smart grids and electricity markets
- Wind and solar power generation
- Electrochemical energy conversion and storage methods (PtX)
- Electrified drivelines for different industrial and mobile applications
- Electric transportation systems
- Sector integration and electricity grids
- Measurement, control, estimation, identification, optimization and communication methods
- Power electronics, control electronics and sensors for different energy applications

Research staff (~130): 14 profs., 38 doctors, 52 post-graduate students + research assistants, turnover ~10 M€

Head of Department
- Prof. Jero Ahola

Vice Head of Department
- Prof. Pertti Silventoinen

Head of Education
- Dr. Katja Hynynen

Vice Head of Education
- Adjunct Prof. Janne Nerg

7.2.2023

Energian varastoinnista

Jero Ahola, D.Sc., Professor, Energy Efficiency
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LUT University
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Tavoitteena nettonollapäästöt 2050 mennessä

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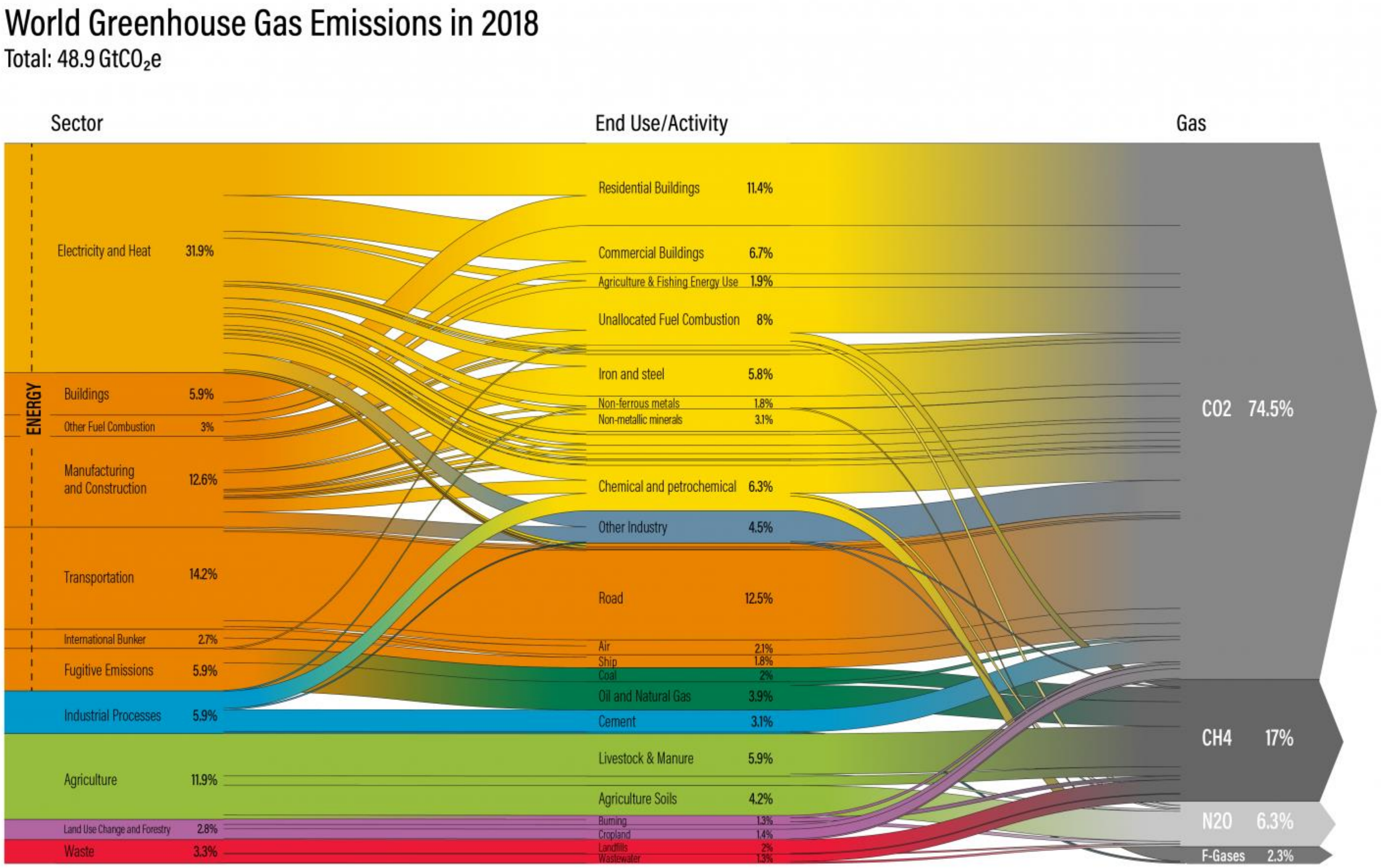
Electricity and heat (32%)

Industry (13%)

Transportation (14%)

Agriculture and land use change (15%)

ENERGY (73 %)

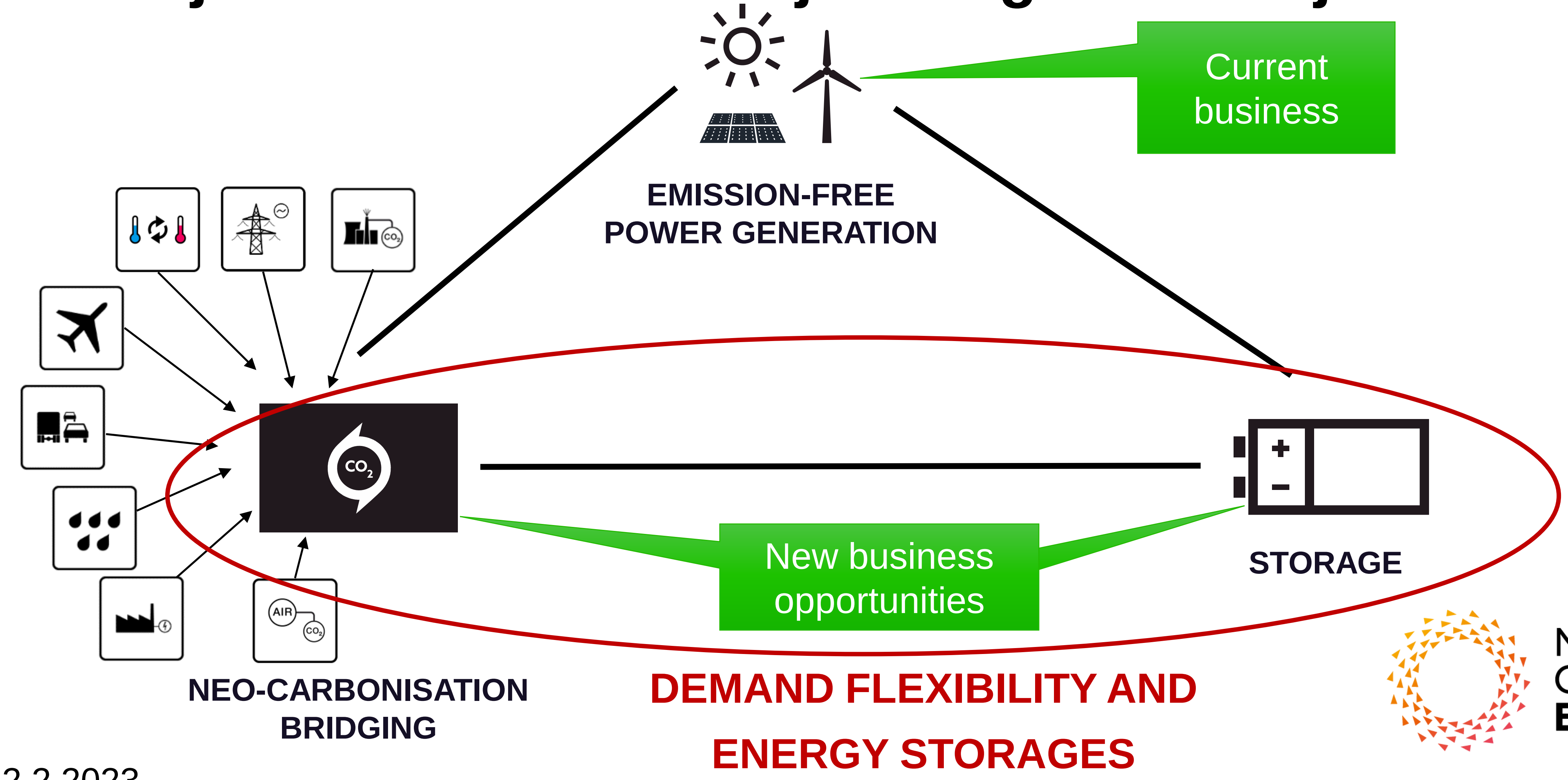


For < +2 ºC climate goal we have to have net-zero GHG emissions by 2050

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

WORLD RESOURCES INSTITUTE

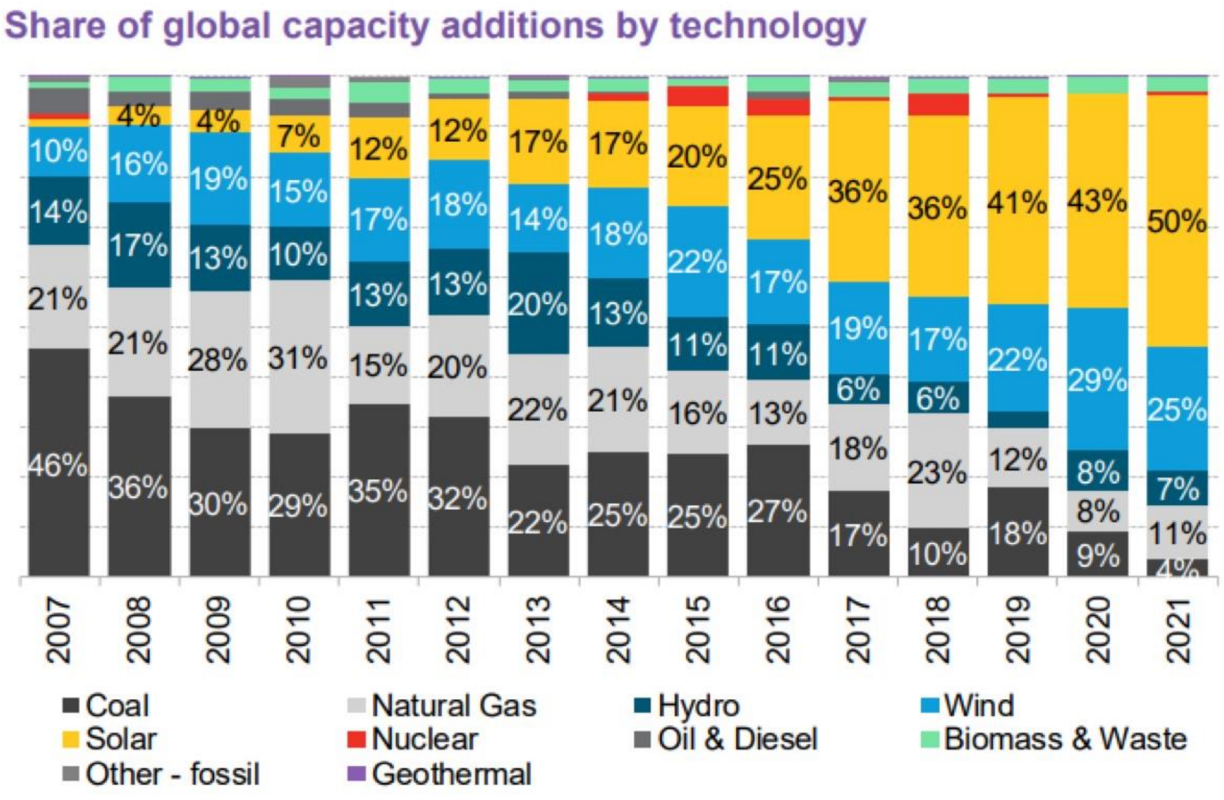
Vaihtelevaan sähköön perustuva energiajärjestelmä tarvitsee joustavaa kulutusta ja energiavarastoja



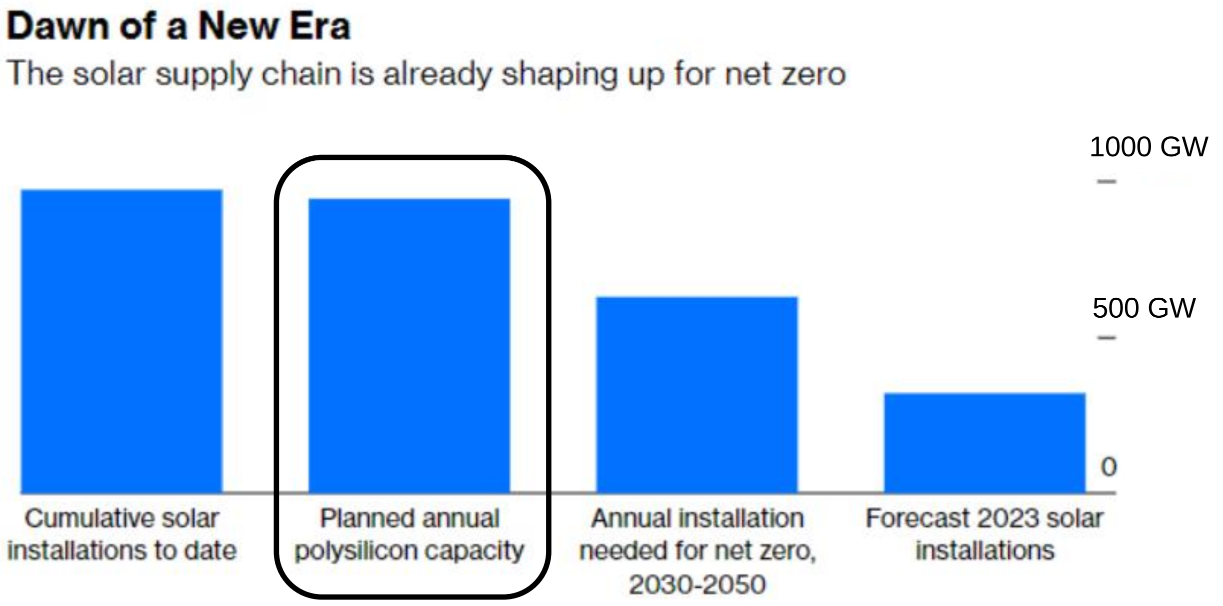
Siirtymä fossiilisten polttoaineiden hyödyntämisestä sarjatuotettuihin sähköenergiateknologioihin

Aurinkosähkön kasvu todennäköisesti yllättää lähivuosina

- 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

Sähköön pohjautuva Euroopan energiajärjestelmä

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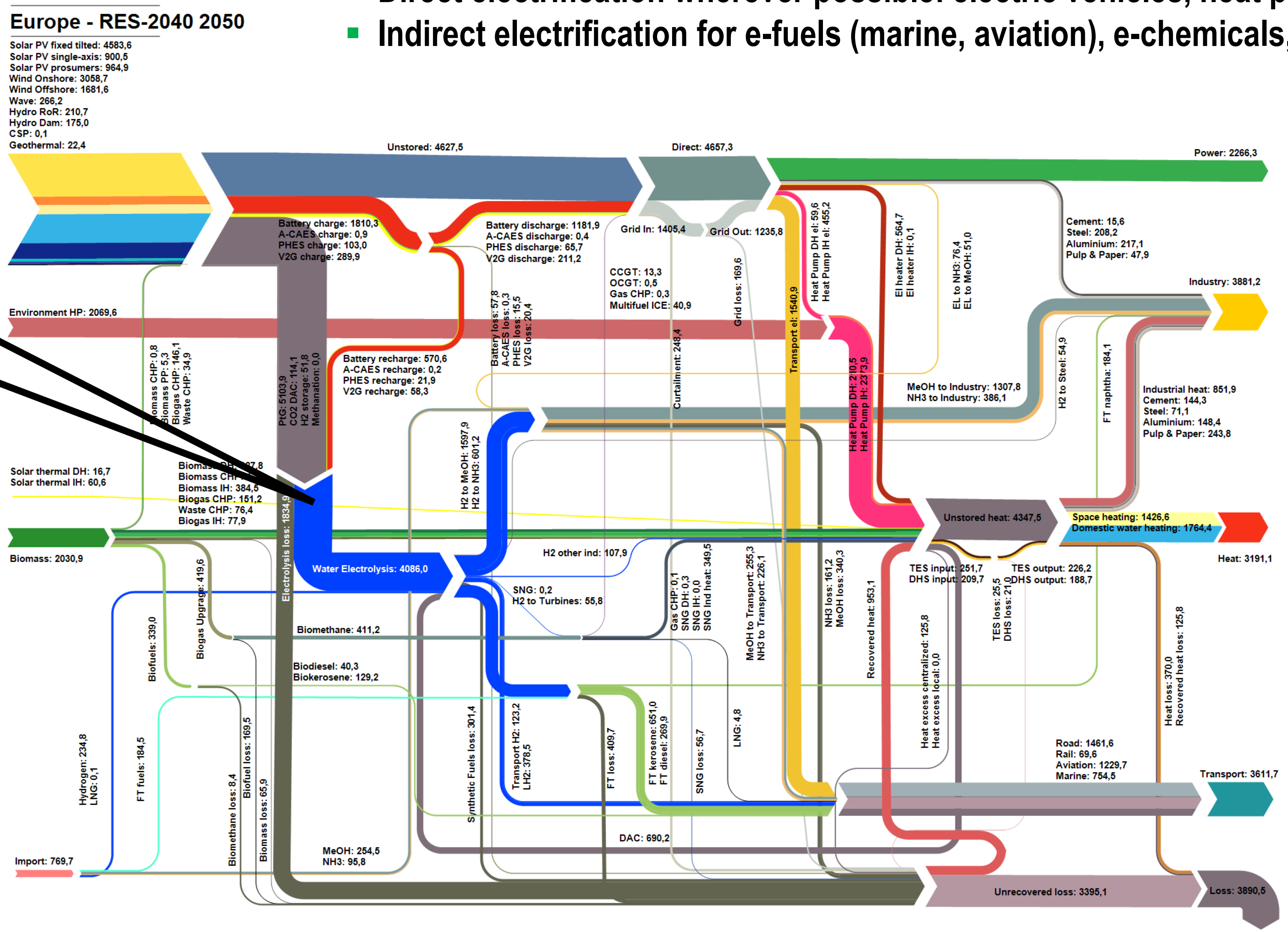
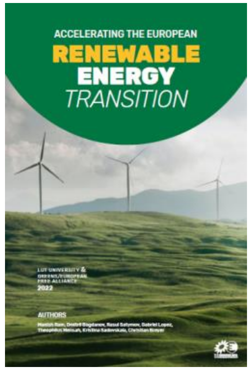
- Zero CO_2 emission low-cost energy system is based on electricity
- Core characteristic of energy in future: Power-to-X Economy
  - Primary energy supply from renewable electricity: mainly solar PV and wind power
  - Direct electrification wherever possible: electric vehicles, heat pumps, desalination,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

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





Europe

Source:
Greens/EFA, 2022

Sähköenergian varastointitapojen luokittelu

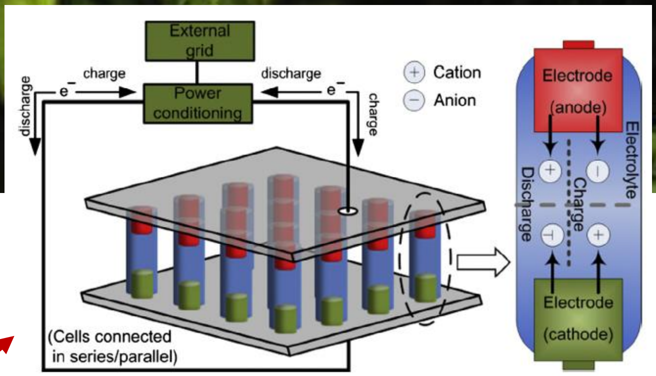
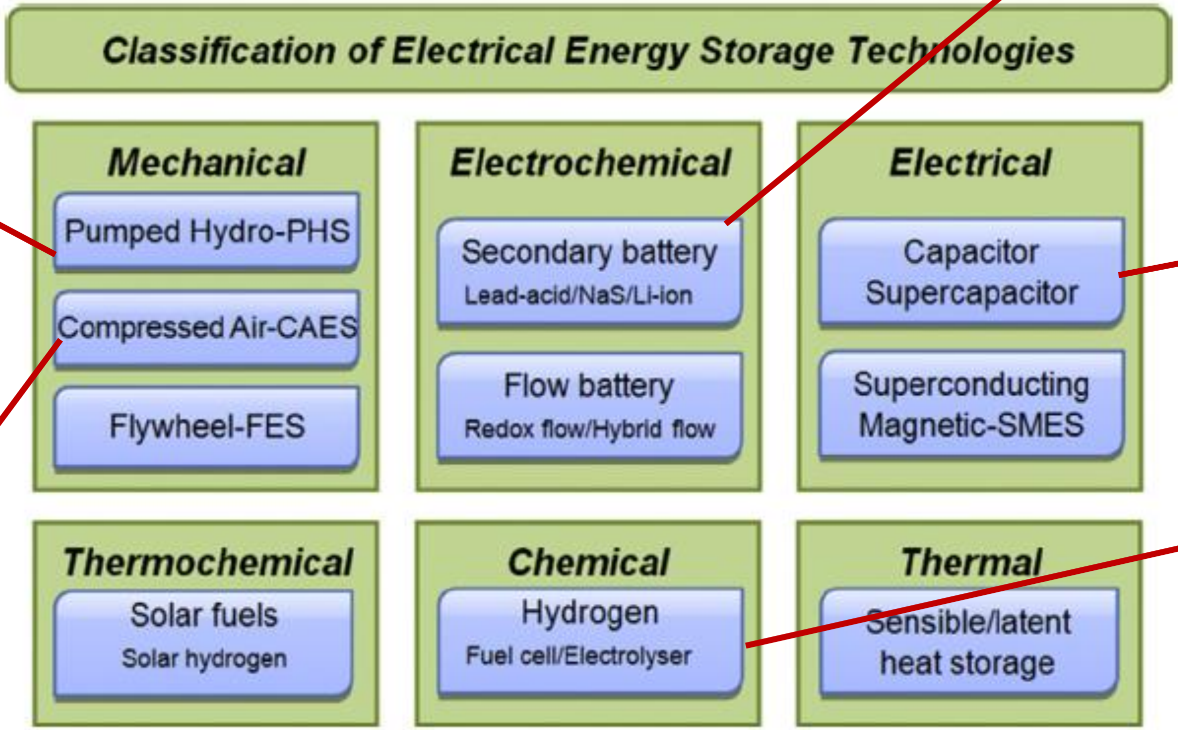


Fig. 7. Schematic diagram of a battery energy storage system operation.



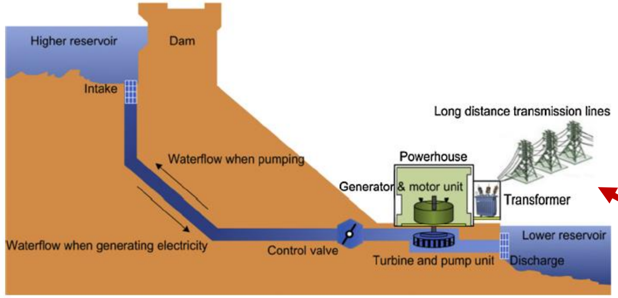


Fig. 4. A pumped hydroelectric storage plant layout.

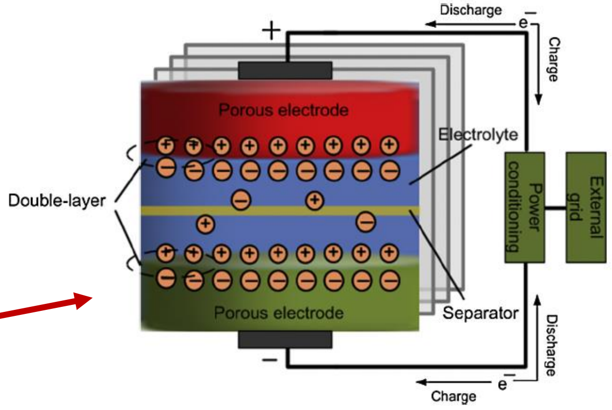


Fig. 9. Schematic diagram of a supercapacitor system.

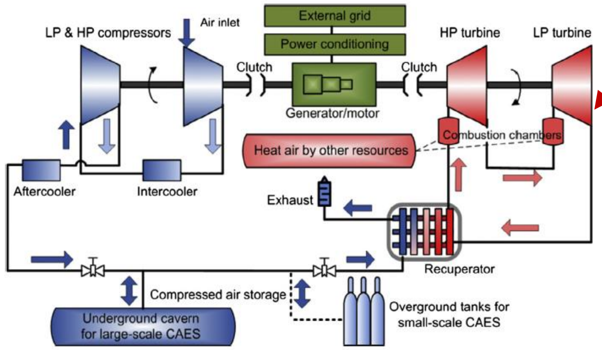


Fig. 5. Schematic diagram of a CAES plant/facility.

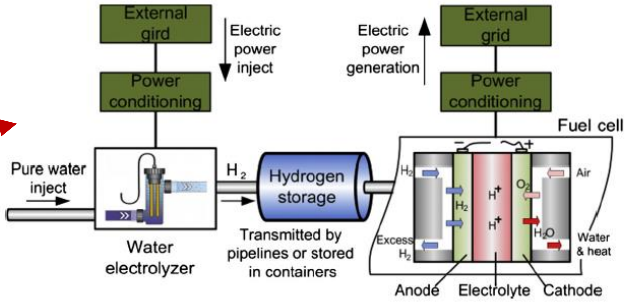
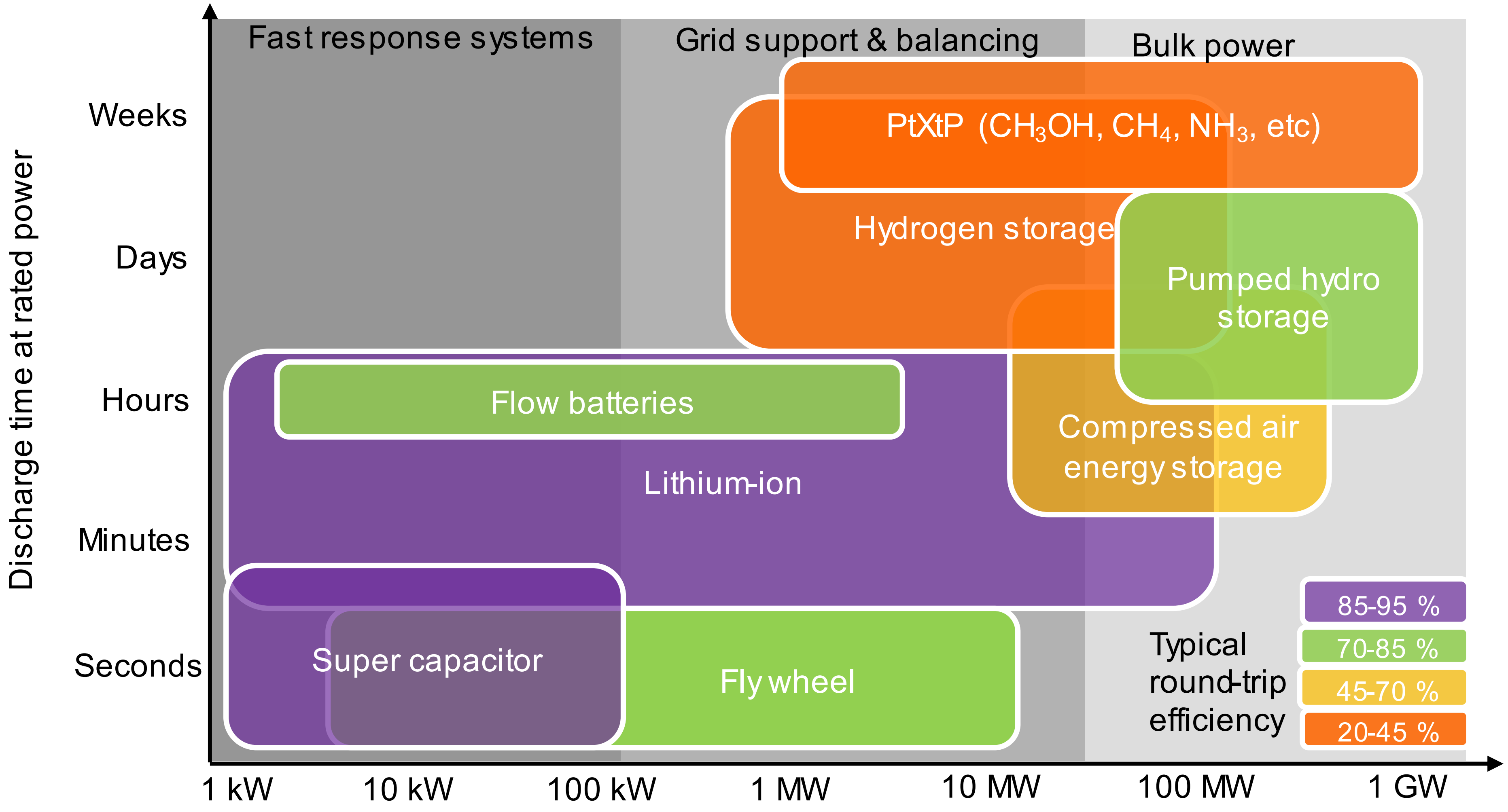


Fig. 12. Topology of hydrogen storage and fuel cell.

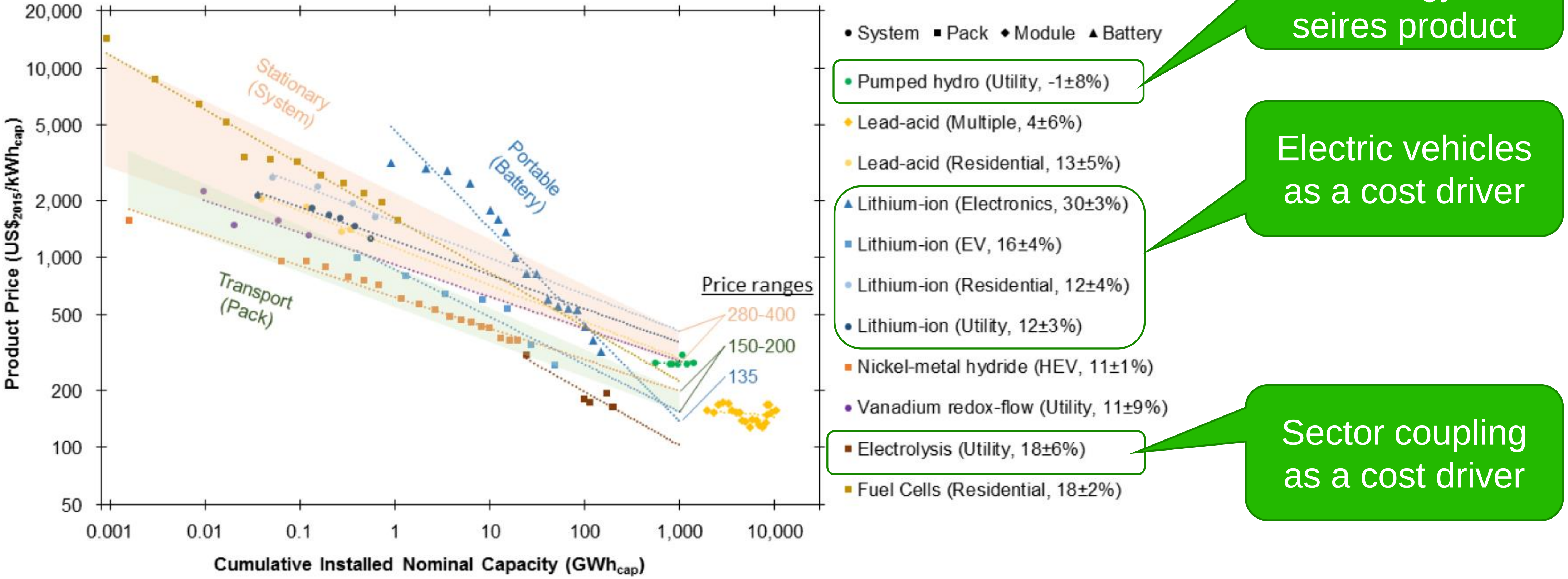
Source: Xing Luo, et.al. ,Overview of current development in electrical energy storage technologies and the application potential in power system, Applied energy, 137, (2015) 511-536.

Sähköenergian varastointiteknologioiden vertailua



Oppimiskäyriä sähköenergian varastoteknologioissa

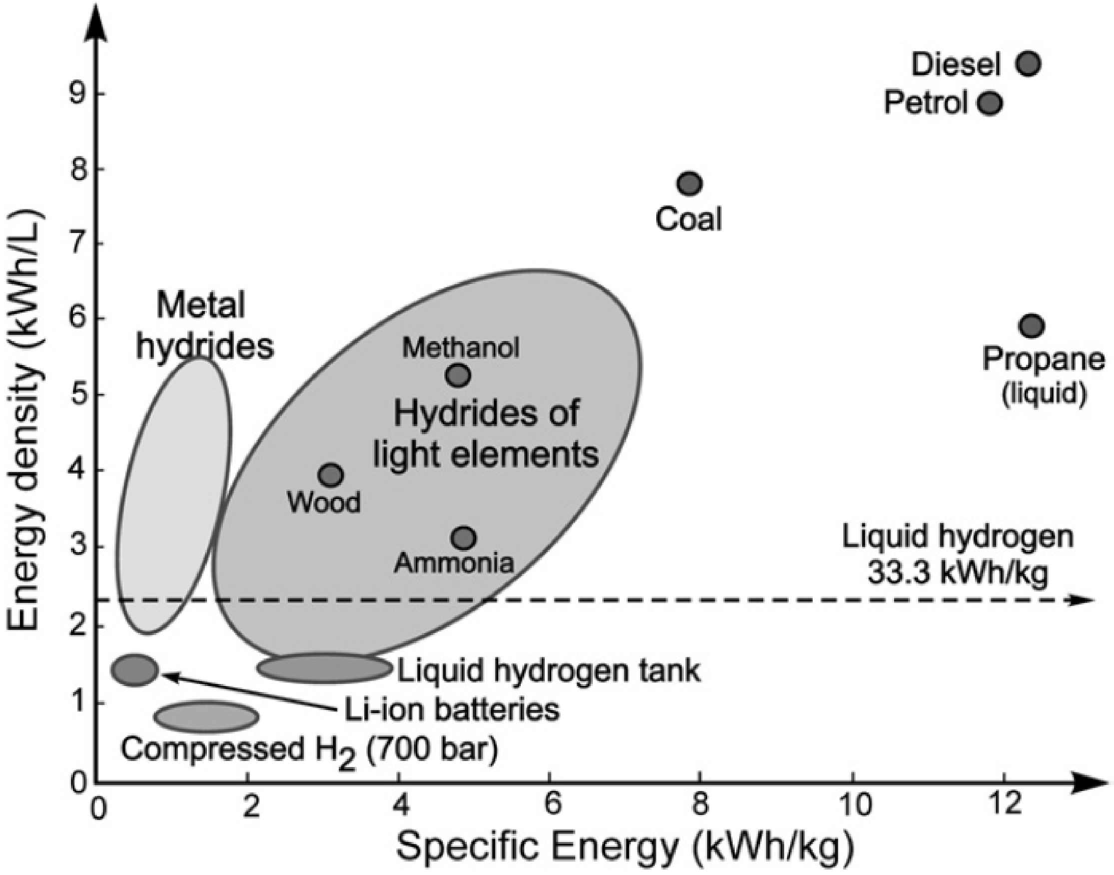
Electricity storage learning curves



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)

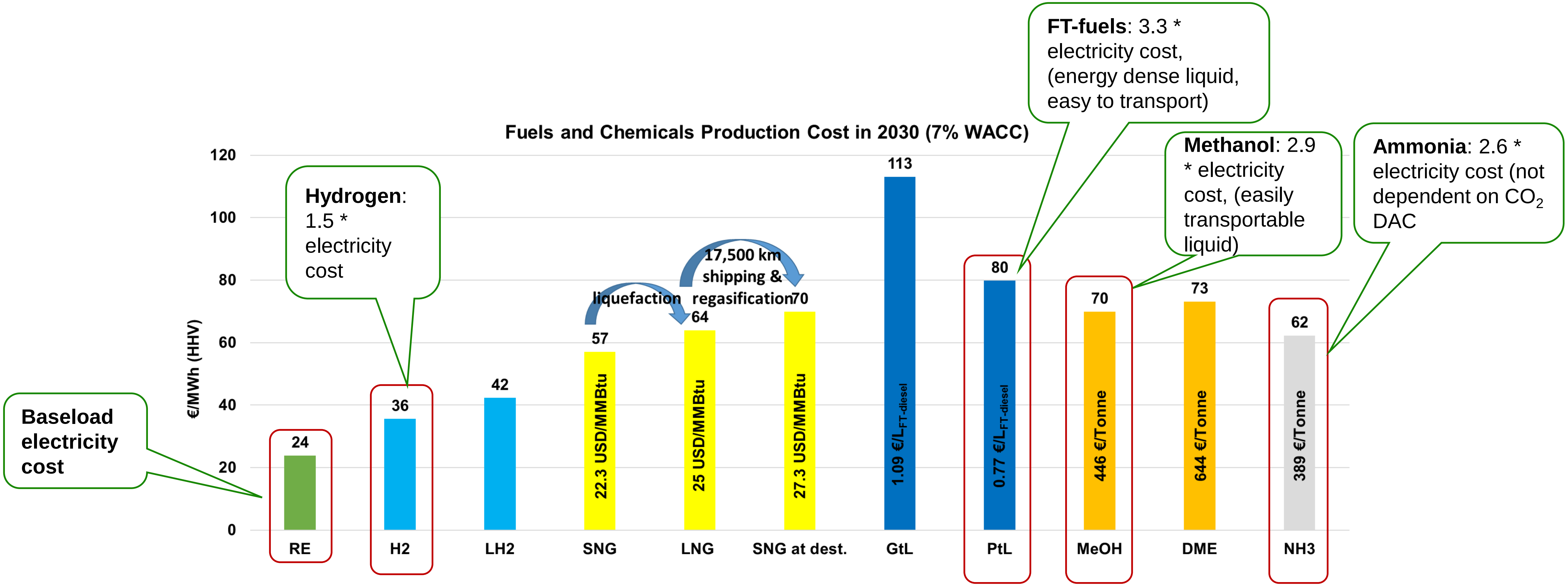
Akkuihin verrattuna polttoaineiden varastointikapasiteetti on edullista ja niiden energiatiheys on kertaluokkaa akkuja suurempi

- Energy storage creates turnover only when it is charged and discharged -> Dimensioning and cycles
- In short-term energy storages energy efficiency and dynamics dominate
- In seasonal energy storages the investment cost (€/kWh). The efficiency is less important factor.
- In seasonal energy storages there is necessarily no relationship between storage size and nominal power.



Lähde: A. Sabartbaeva, et. al., Hydrogen nexus in sustainable energy future, Energy and Environmental Science, Vol. 1, No 1, July 2008, pp. 79-85

Power-to-x –polttoaineiden tuotantokustannus on riippuvainen jalostusasteesta: energiatiheyden nosto ja varastointi-kustannuksen alentaminen nostavat tuotantokustannusta



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

US DOE GLOBAL ENERGY STORAGE DATABASE

- Globally there is roughly 650 GWh of grid-connected electricity storage capacity available. The nominal power of storage capacity is 190 GW.
- More than 90 % of current storage capacity consists of pumped hydro storages. The fraction of lithium-battery-based energy storages potentially surpasses pumped hydro after 2030.
- The dimensioning of energy storages (C/P) is dependent on technology. Based on US DOE data:
  - Pressurized air: 25 h
  - Pumped hydro: 3.3 h
  - Flow batteries: 3.8 h
  - Lithium batteries 1.4 h
  - Flywheel: 0.1 h

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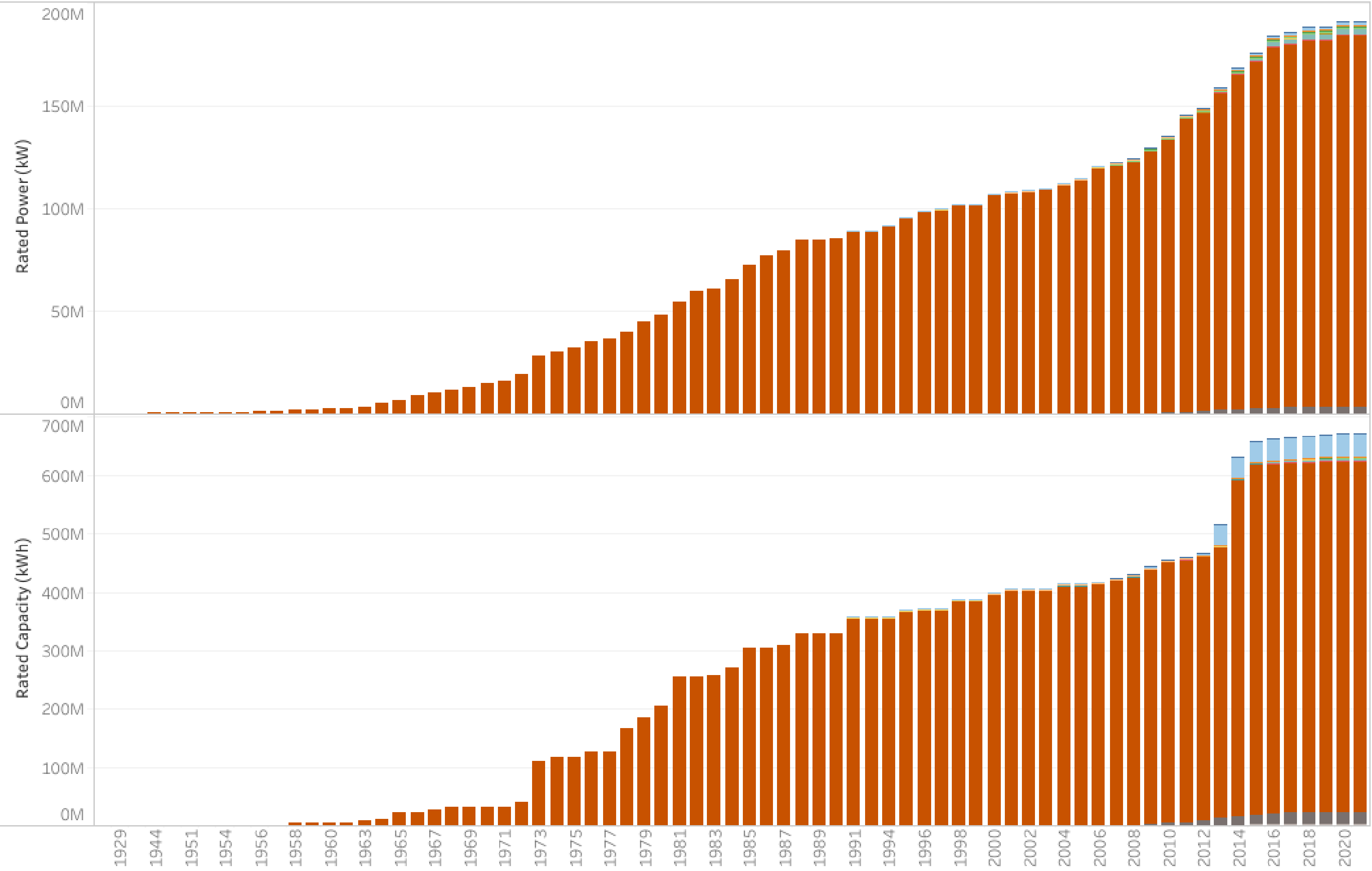
Cummulative Sum of Energy Storage Installations by Year



Notes:
1. If the project commisioning date is not available in the database, the year represents either the constructed date or announced date. The projects for which the constructed/comissioned/announced date were not available have been omitted from the visualization.
2. The discharge duration of a few projects are missing in the database and thus are not included in these visualizations. Please download the full database from the Projects page for more accurate information.
3. Details on energy storage technology categorization can be found at U.S. Department of Energy's Energy Storage Handbook (https://www.sandia.gov/ess/publications/doe-oe-resources/eshb)

- Technology Mid-Type Unknown
- Compressed air energy storage
- Electro-chemical capacitor
- Flow battery
- Flywheel
- Heat thermal storage
- Hydrogen storage
- Latent heat
- Lead-acid battery
- Lithium-ion battery
- Nickel-based battery
- Pumped hydro storage
- Sensible heat
- Sodium-based battery
- Zinc-based battery

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Akkuvarastoista

Sähköautojen akut voivat mahdollistaa uusiutuviin perustuvan sähköjärjestelmän tarvitseman tuntien tason energianvarastoinnin

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- Majority of global battery capacity will be located in electric cars. Estimate is 68-144 TWh, (1-2 billion cars)
- Estimate for required grid battery capacity is for 4 hours, 3.4-19.2 TWh in 2050.
- The short-term grid energy storage need can be potentially covered by a combination of EV batteries (vehicle-to-grid) and second-use EV batteries as a stationary energy storage.

Article https://doi.org/10.1038/s41467-022-35393-0

Electric vehicle batteries alone could satisfy short-term grid storage demand by as early as 2030

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Check for updates

Chengjian Xu[1], Paul Behrens[1], Paul Gasper[2], Kandler Smith[2], Mingming Hu[1], Arnold Tukker[1,3] & Bernhard Steubing[1]

The energy transition will require a rapid deployment of renewable energy (RE) and electric vehicles (EVs) where other transit modes are unavailable. EV batteries could complement RE generation by providing short-term grid services. However, estimating the market opportunity requires an understanding of many socio-technical parameters and constraints. We quantify the global EV battery capacity available for grid storage using an integrated model incorporating future EV battery deployment, battery degradation, and market participation. We include both in-use and end-of-vehicle-life use phases and find a technical capacity of 32–62 terawatt-hours by 2050. Low participation rates of 12%–43% are needed to provide short-term grid storage demand globally. Participation rates fall below 10% if half of EV batteries at end-of-vehicle-life are used as stationary storage. Short-term grid storage demand could be met as early as 2030 across most regions. Our estimates are generally conservative and offer a lower bound of future opportunities.

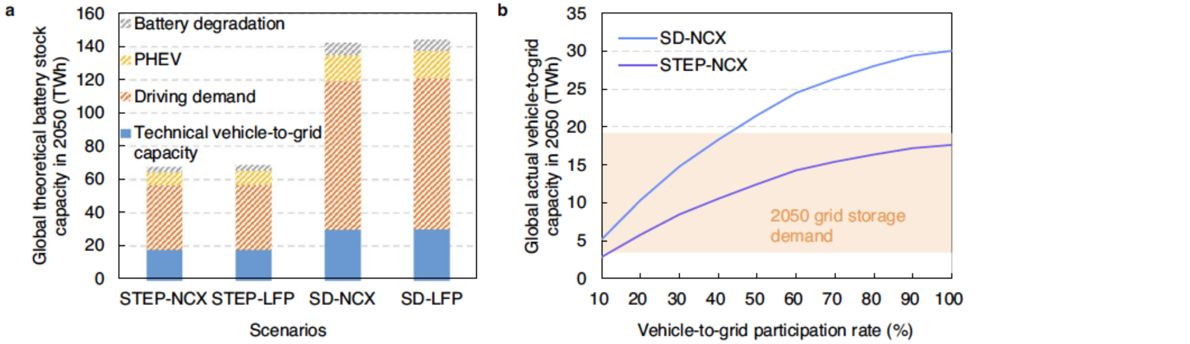

Fig. 3 | Global available vehicle-to-grid capacity in 2050. a Technical vehicle-to-grid capacity. Hatched bars indicate the capacity limits due to key factors and blue bars the technical vehicle-to-grid capacity. **b** Real-world vehicle-to-grid capacity as a function of participation rates. Results are shown for the STEP-NCX and the SD-NCX scenarios with a comparison to the range of storage demand computed by IRENA and Storage Lab models in 2050 (orange shading). Please see Supplementary Fig. 16 for global real-world vehicle-to-grid capacity under STEP-LFP and the SD-LFP scenarios and Supplementary Figs. 17–20 for regional real-world vehicle-to-grid capacity.

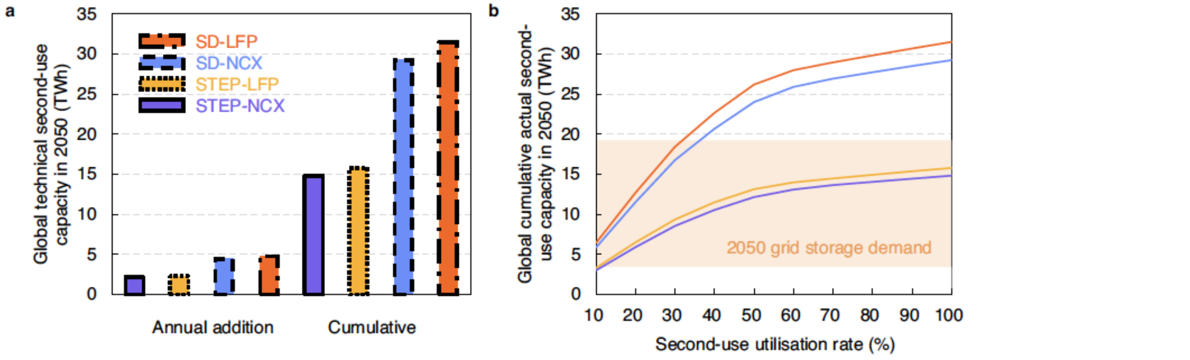

Fig. 4 | Availability of second-use capacity globally in 2050. a Average annual additions and cumulative technical capacity of second-use batteries in 2050. Here capacity refers to the technically available capacity considering battery degradation but without considering battery second-use utilisation rate. **b** Impacts of second-use utilisation rate on cumulative actual second-use capacity and a comparison to storage demand in 2050 (orange shading). See Supplementary Figs. 22–25 for regional actual second-use capacity.

Source: Xu, C., Behrens, P., Gasper, P. et al. Electric vehicle batteries alone could satisfy short-term grid storage demand by as early as 2030. Nat Commun 14, 119 (2023). https://doi.org/10.1038/s41467-022-35393-0

Raskas liikenne voi perustua vaihtoakkuihin

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

Suomessa akun yhdistäminen omakotitalon aurinkosähköjärjestelmään on vielä taloudellisesti haasteellista

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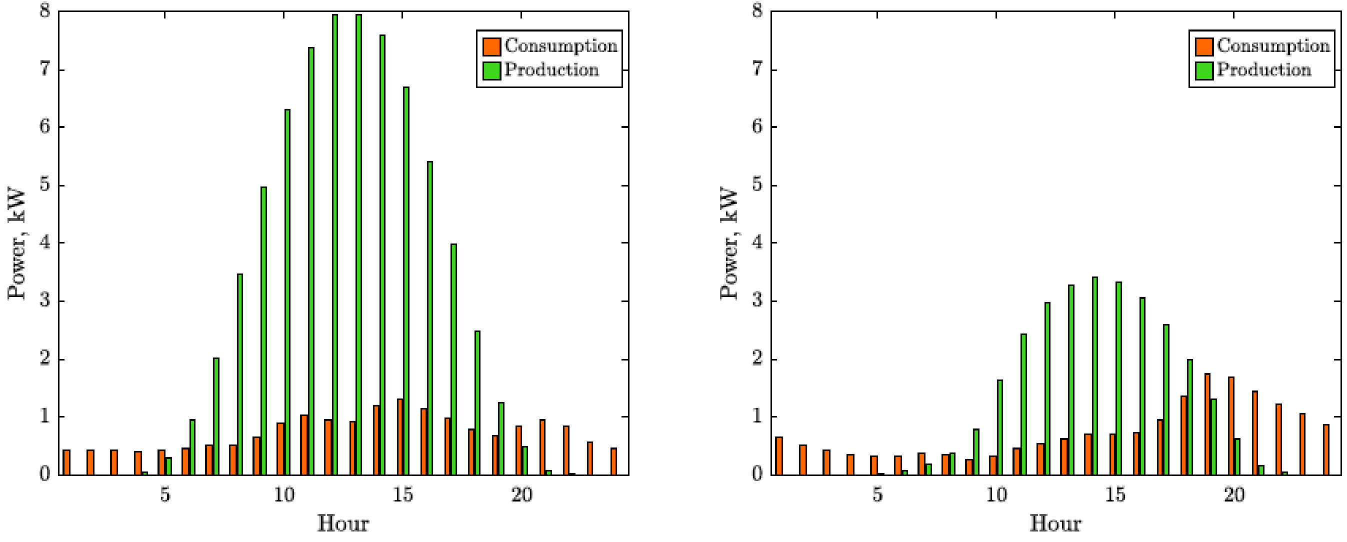
- Two Finnish houses with solar PV system were used as a pilot cases
- The PV system sizes were 21.1 kWp for a house A and 8 kWp for a house B. The studied years were 2017-19.
- Hourly PV production, electricity consumption, and electricity SPOT prices were used as a source data. Also the cost of electricity sales, purchase, distribution, and taxes were taken into account.
- The value of battery is less than 25 €/kWh,a and decreases as the battery size is increased.
- The battery value could potentially increase if it would be used to store low cost grid electricity.



(a) House A. (b) House B.

Fig. 1. Average distribution of power consumption and generation throughout the day from March to October for (a) House A and (b) House B.

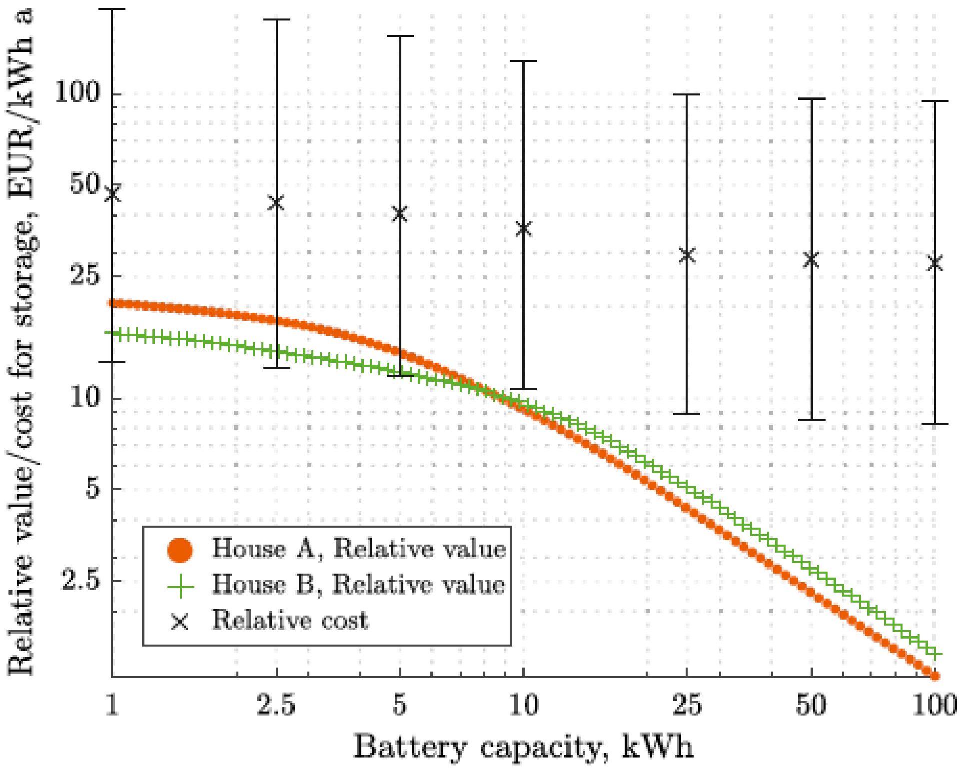


Fig. 12. Relative cost of the investment in a battery storage system divided by 15 years of expected operation compared with the annual relative monetary value of the system. Hourly net metering is employed for both the houses under study.

Source: Pietari Puranen, Antti Kosonen, Jero Ahola, Techno-economic viability of energy storage concepts combined with a residential solar photovoltaic system: A case study from Finland, Applied Energy, Volume 298, 2021, 117199, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2021.117199.

7.2.2023

Vedyn tuotannosta ja varastoinnista

Kiinalaisten alkaalivesielektrolyyserien hintataso on jo 300 €/kW -> Edullisen vedyn tuotanto ei vaadi korkeaa huipunkäyttöaikaa

According to BNEF's new report, *1H 2022 Hydrogen Market Outlook*, Chinese alkaline electrolyser systems cost $300 per kW in 2021, compared to $1,200/kW for Western equivalents, with proton exchange membrane (PEM) electrolysers even more expensive, at $1,400/kW (*see panel below*).

'China wants to dominate': Kerry and Gates urge US to step up for hydrogen

Read more

Record breaker | World's largest green hydrogen project, with 150MW electrolyser, brought on line in China

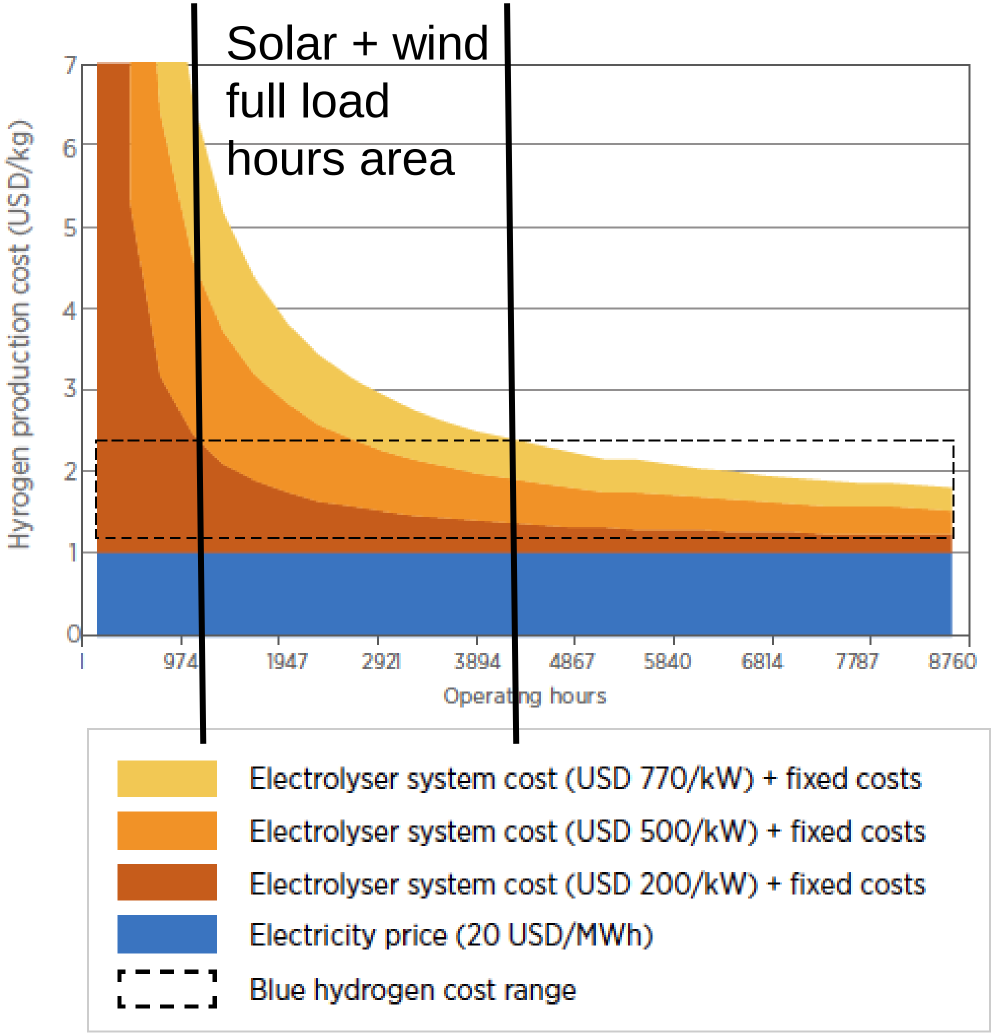
Read more

However, that price gap will slightly shrink slightly this year, with improved automation and economies of scale at Western factories driving down alkaline electrolyser costs by 17% to $1,000/kW, with PEM systems falling 14% to $1,200/kW. By comparison, Chinese alkaline electrolysis set-ups will fall by just 10% to $270/kW.

BNEF puts the cost of a Chinese alkaline electrolyser system at $220/kW in 2021, with onsite installation at an additional $50-60/kW and another $20-30/kW for civil engineering by developers — giving a total cost of $300/kW.

The analyst adds that "new products with more compact designs" have sold for even less, pointing to a 13MW project won by Chinese manufacturer Jingli for 19.55m yuan ($3.08m) — including all equipment and installation — which works out at $237/kW. Two of Jingli's 6.5MW electrolyser stacks take up less space than the 5MW machines that are popular in China, it explains.

BNEF also suggests that the prices of Western electrolysers are likely to fall faster than Chinese ones due to factory automation.



Vedyn tuotanto ja varastointi: Tuotanto tulee joustamaan tuulen perässä

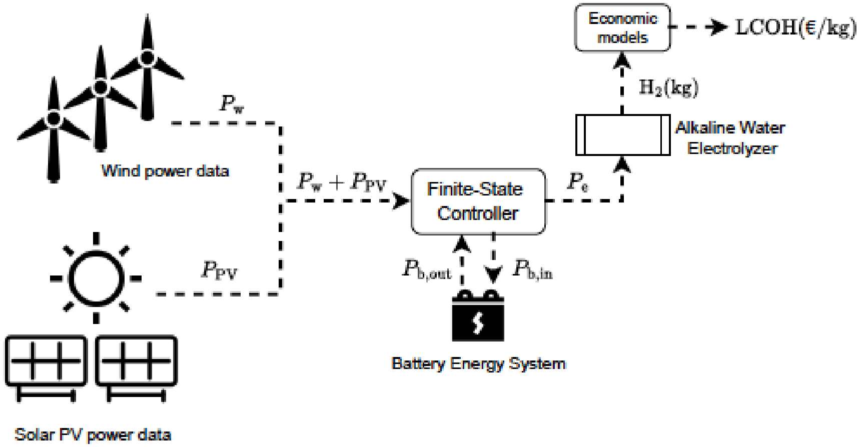
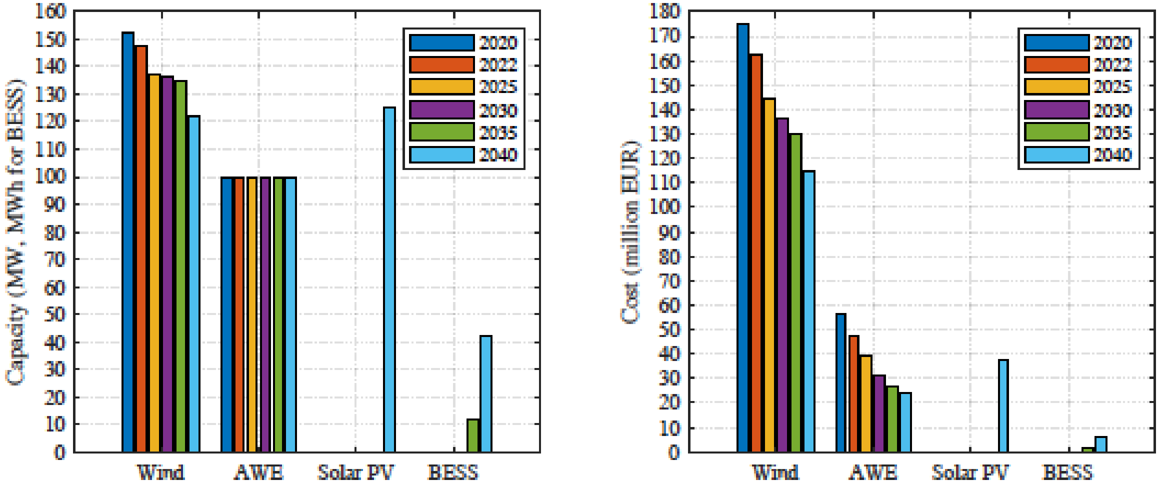


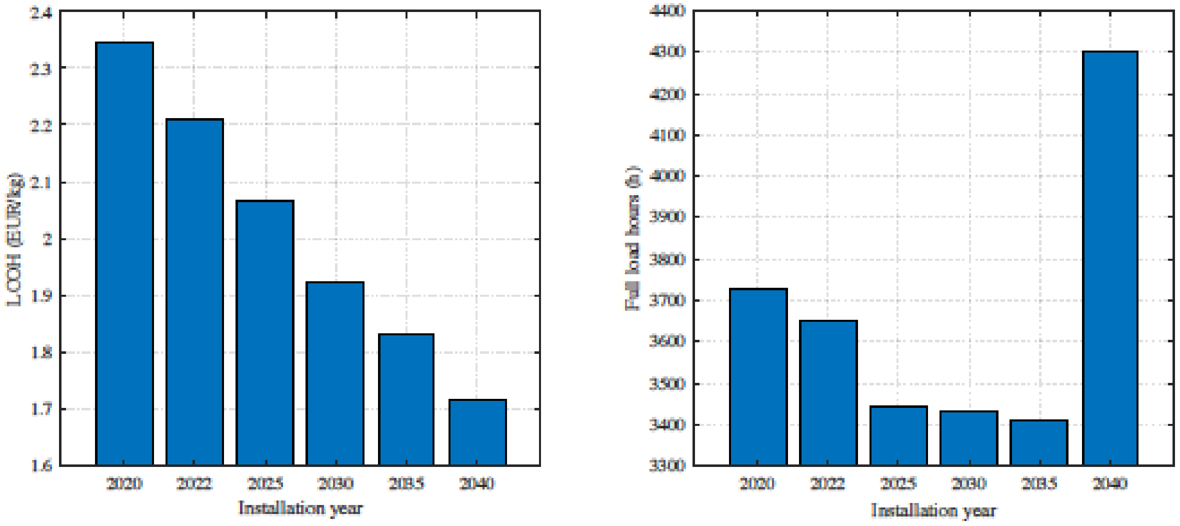
Fig. 1: Simplified flowchart of the off-grid green hydrogen production system.



(a) Optimal component capacities.

(b) Investment costs.

Fig. 5: Optimal capacity of each component in the different installation years (a). Investment cost allocated to each component (b).



(a) Levelized cost of hydrogen.

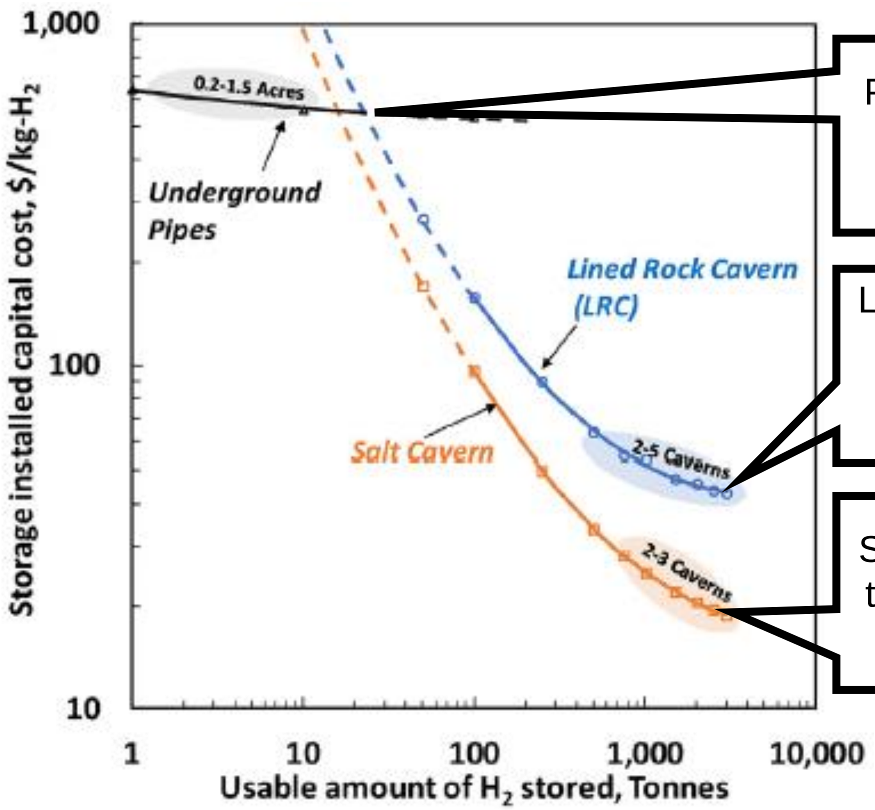
(b) Annual average full-load hours of he electrolyzer.

Fig. 9: Levelized cost of hydrogen (LCOH) in (a), and annual average full-load hours of the alkaline electrolyzer in (b), for each installation year simulated.

Source: Alejandro Ibanez-Riojaa, Lauri Järvinen, Pietari Puranena , Antti Kosonen, Vesa Ruuskanen, Katja Hynynen, Jero Ahola, Pertti Kauranen, Off-Grid Solar PV-Wind Power-Battery-Water Electrolyzer Plant: Simultaneous Optimization of Component Capacities and System Control, under review in Applied Energy.

Vedyn varastointi teollisessa kokoluokassa on suhteellisen edullista

- The investment cost of industrial-scale hydrogen storage (€/kWh) is roughly a percent of the investment cost of a battery energy storage
- It enables the production of baseload hydrogen based on variable wind and solar power.



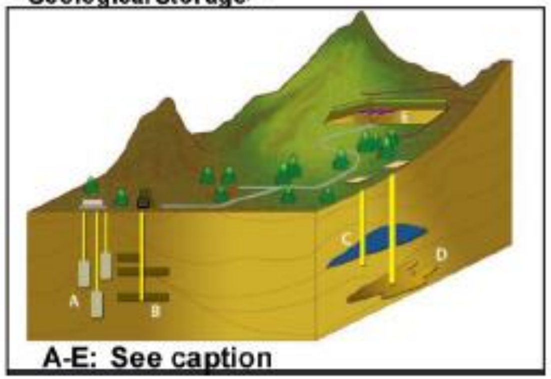
(a) Installed capital cost

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]



A-E: See caption

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

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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.