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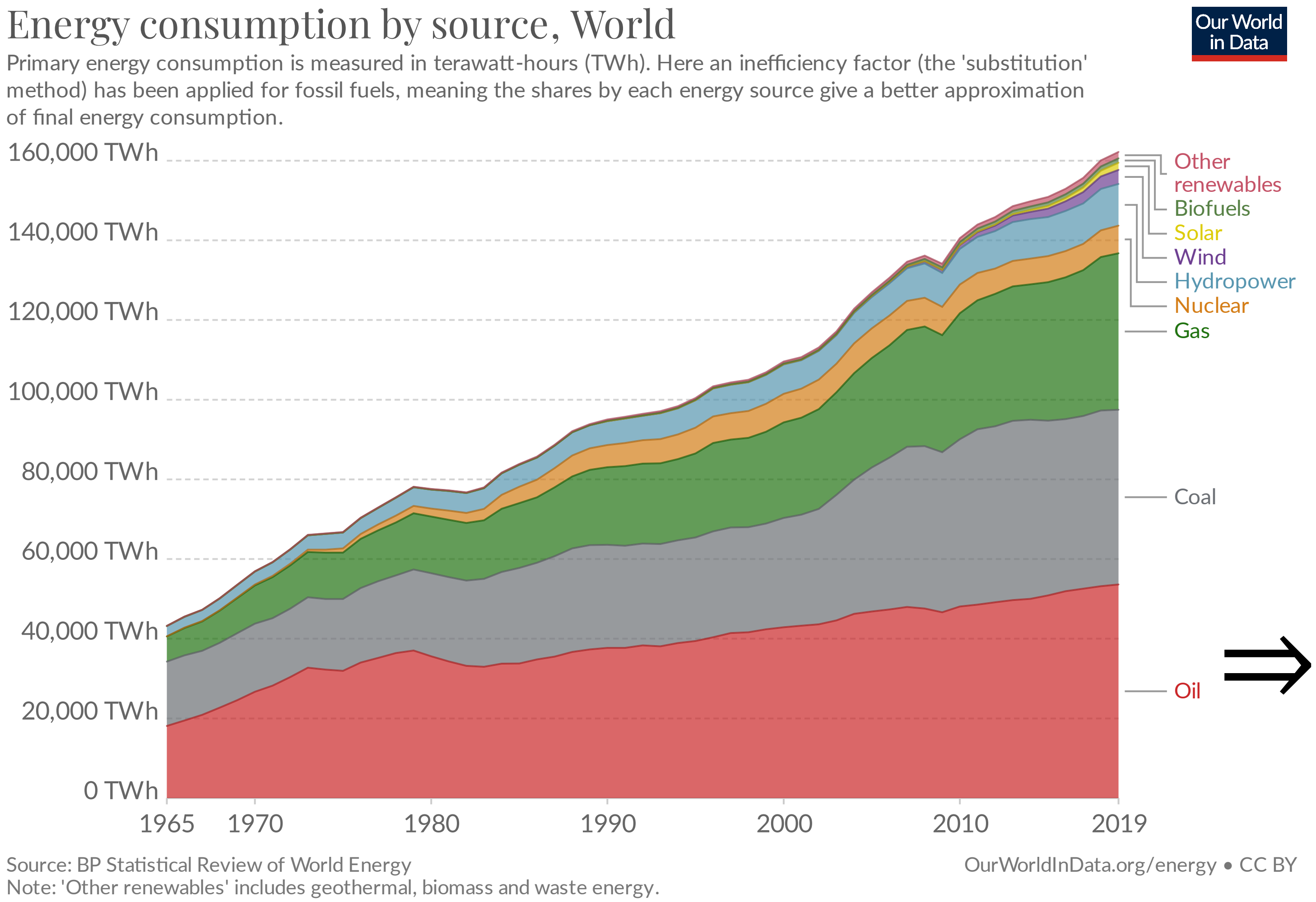
From elections towards an energy-resilient Europe – Pre-midsummer party on 11 June, Brussels

Green hydrogen production

Antti Kosonen, LUT
email: antti.kosonen@lut.fi
tel: +358 45 676 9878
twitter: @AnttiJKosonen

We already live in a hydrogen economy, what's the problem?



[What is a hydrogen economy?]

⇒

The problem is energy based on combustion, because in our energy sources, hydrogen is bound to carbon. Hydrogen is not available as such.

The goal is net zero emissions by 2050

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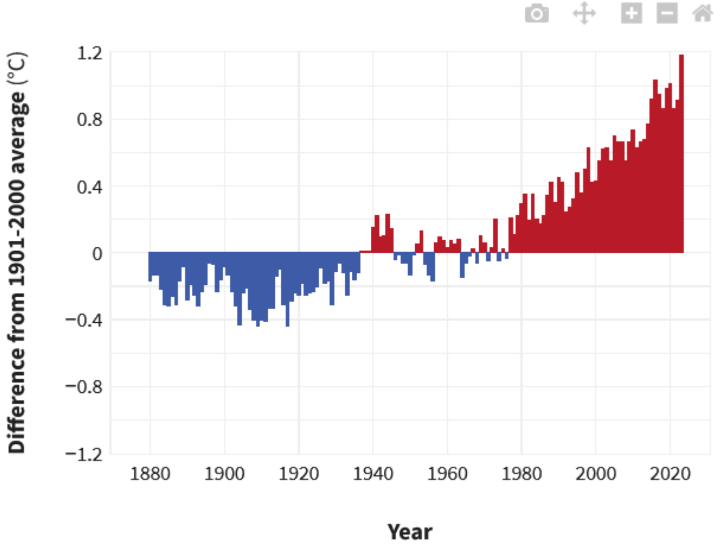
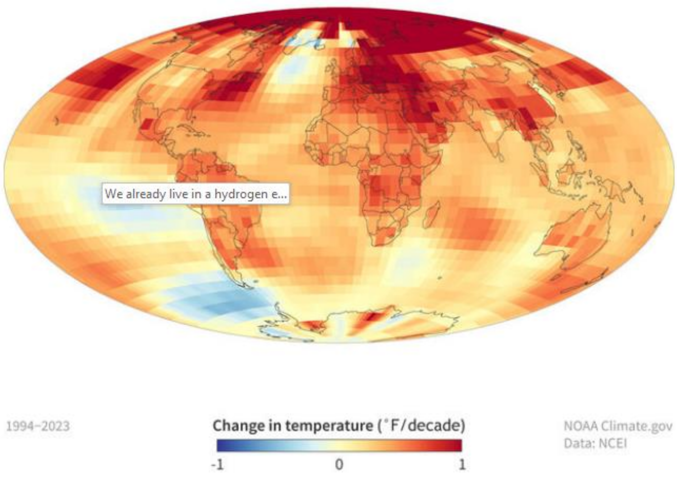
GLOBAL AVERAGE SURFACE TEMPERATURE



RECENT TEMPERATURE TRENDS (1994-2023)



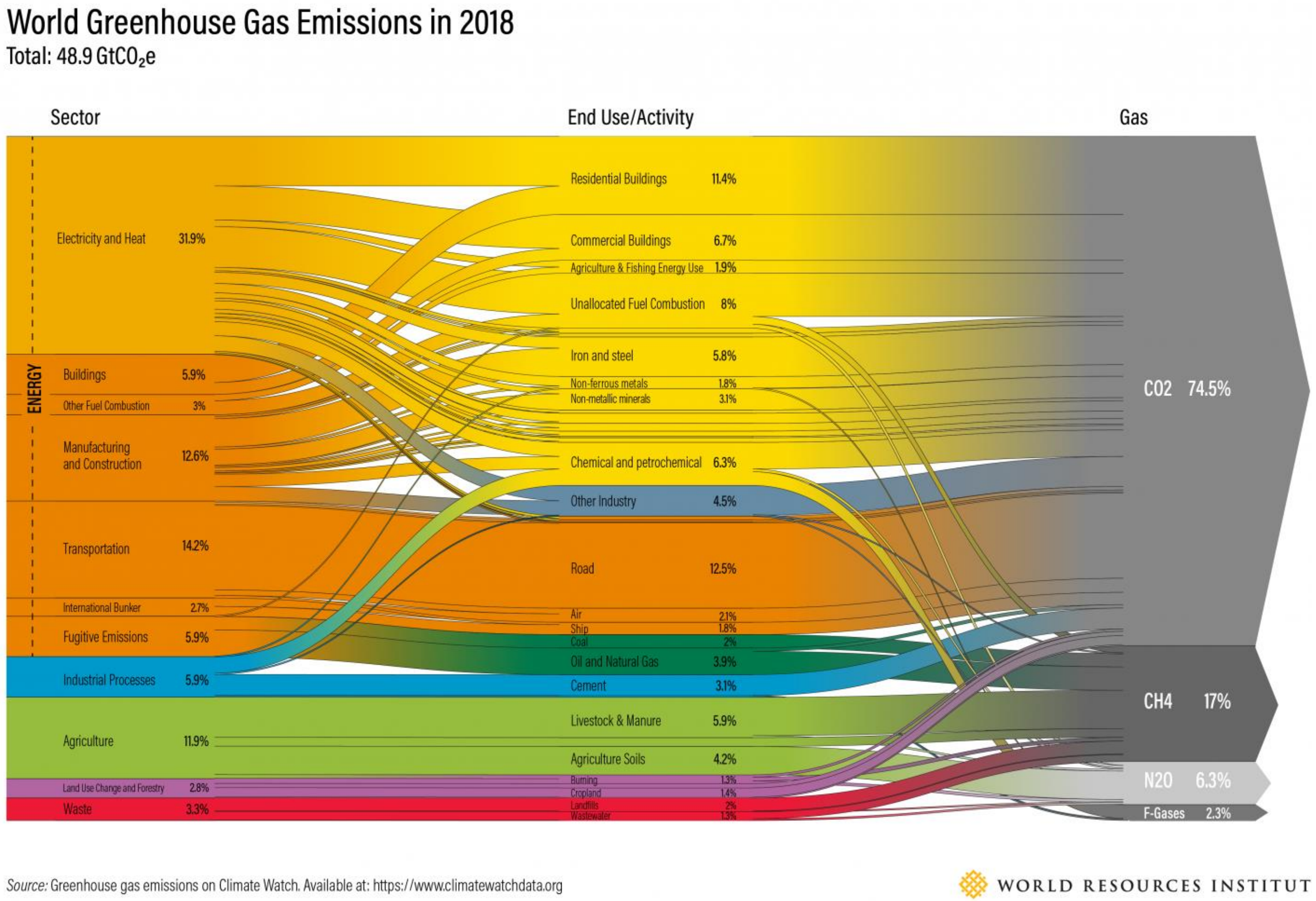
Electricity and heat (32%)

Industry (13%)

Transportation (14%)

Agriculture and land use change (15%)

ENERGY (73 %)



European energy system based on electricity

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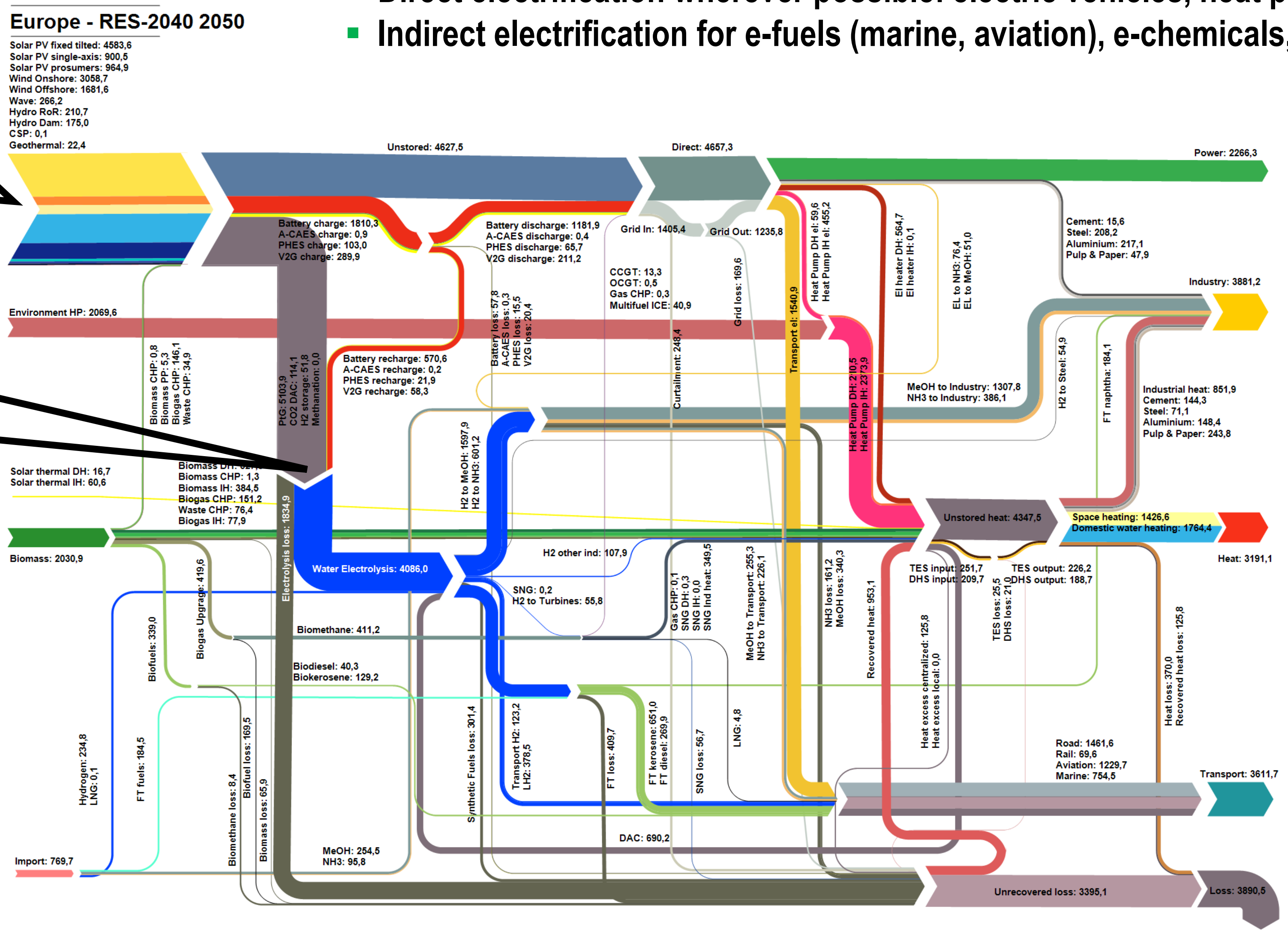
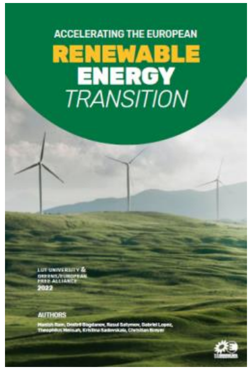
Electricity production 2,641 TWh (40 % RE) in 2022

- Zero CO_2 emission low-cost energy system is based on electricity (need about 12,000 TWh)
- Core characteristic of energy in future: Power-to-X Economy
  - Primary energy supply from renewable electricity: mainly solar 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

Electrical energy

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





Europe
Source:
Greens/EFA, 2022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POWER-TO-X

From electricity to chemical energy – Hydrogen production by alkaline water electrolyzer (AWE)

Fig. 3x3 MW alkaline water electrolyzer (AWE).

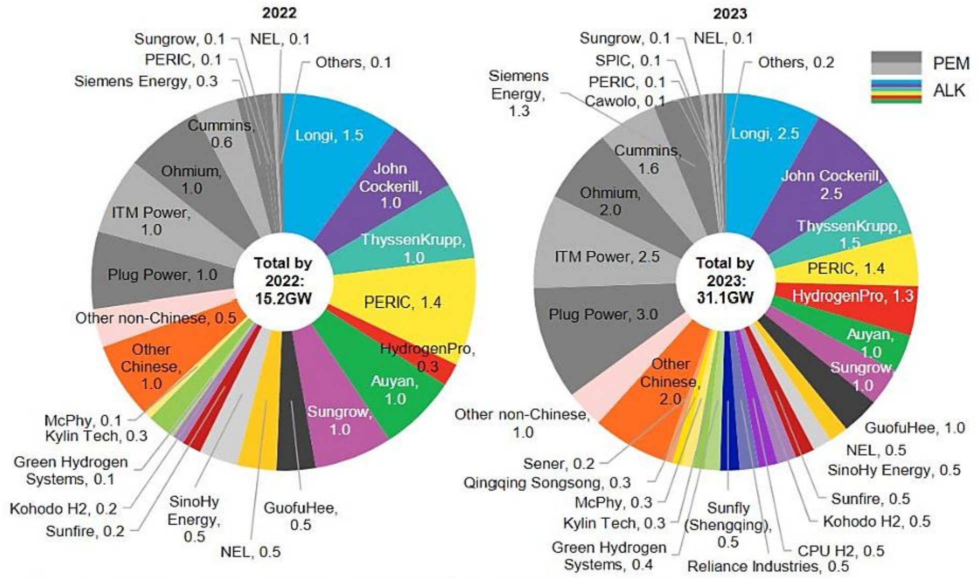
Summary:

- 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

G. Sakas, A. Ibáñez-Rioja, V. Ruuskanen, A. Kosonen, J. Ahola, O. Bergmann, Dynamic energy and mass balance model for an industrial alkaline water electrolyzer plant process, Int. J. Hydrogen Energy 47 (7) (2022) 4328–4345, https://doi.org/10.1016/j.ijhydene.2021.11.126

Main commercial water electrolyzer technologies

- Alkaline water electrolyzer (AWE)
  - Mature technology, but designed to operate at nominal point
  - Ready to scale up now → technology will be improved through the industry
- Proton exchange membrane water electrolyzer (PEMWE)
  - No liquid electrolyte, wide operation range
  - Industrial scale, but noble catalyst materials (iridium, platinum) restrict scaling up and decreasing the cost
- Solid oxide water electrolyzer (SOWE)
  - High operating temperature (700−1000°C) and efficiency at nominal point
  - Not industrial scale, problems to operate in partial loads and degradation of materials



Source: Company filings, industry sources, BloombergNEF. Note: The values refer to year-end capacities.

Fig. Annual electrolyzer manufacturing capacity. BloombergNEF

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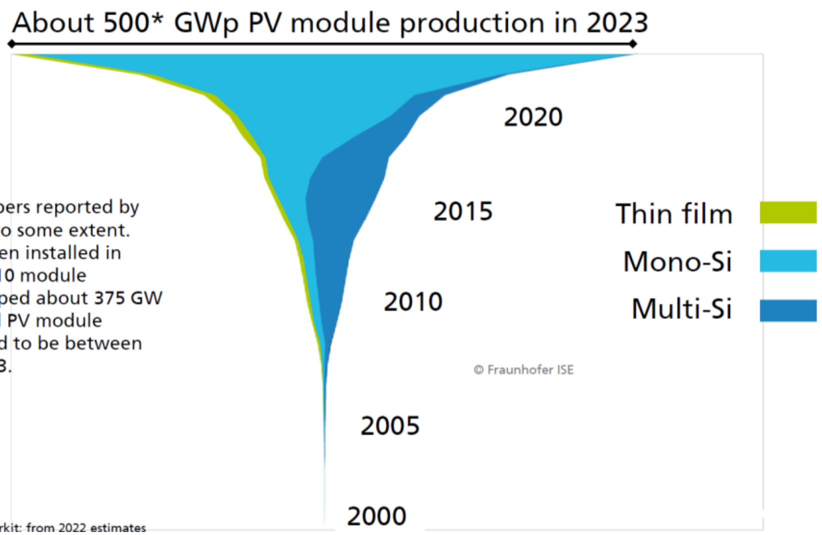
⇒ Most of the improvements are made elsewhere than in electrochemistry. Technology is scaling up now. Key technology in research!

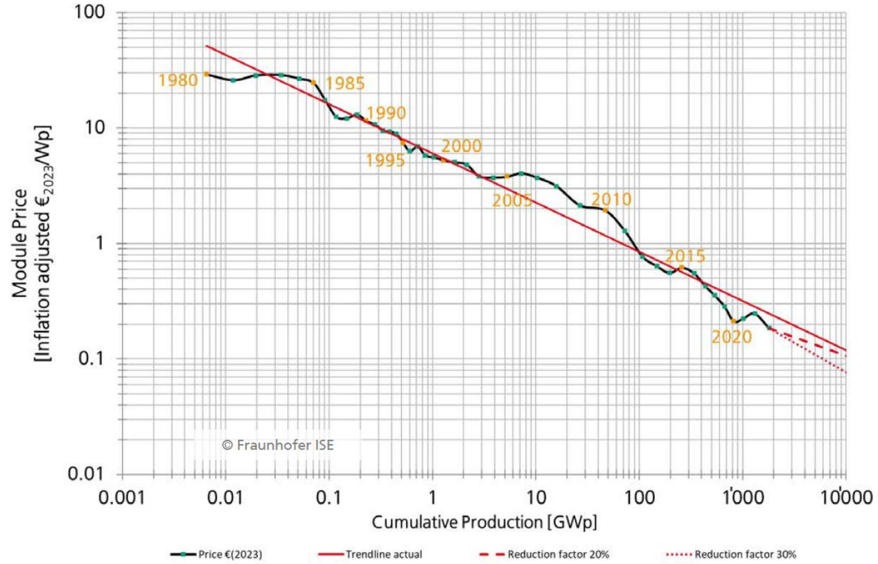
⇒ How much to invest in research? High risk that these are not winning technologies.

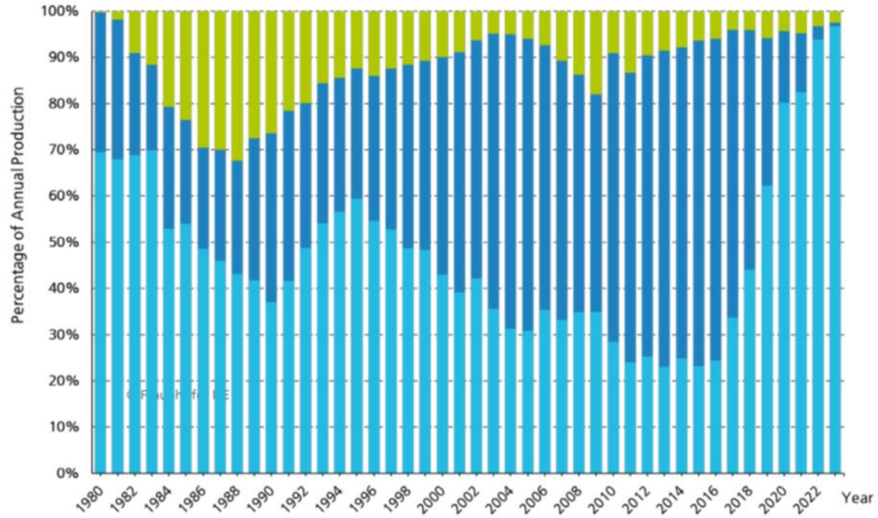
What have we learnt from solar power markets?



*2023 production numbers reported by different analysts vary to some extent. About 410 GW have been installed in 2023 globally. The TOP10 module producer together shipped about 375 GW PV panels in 2023. Total PV module shipments are estimated to be between 460 and 502 GW in 2023.

1. **Scaling up**
2. **Technology**
3. **Cost**
4. **Efficiency**

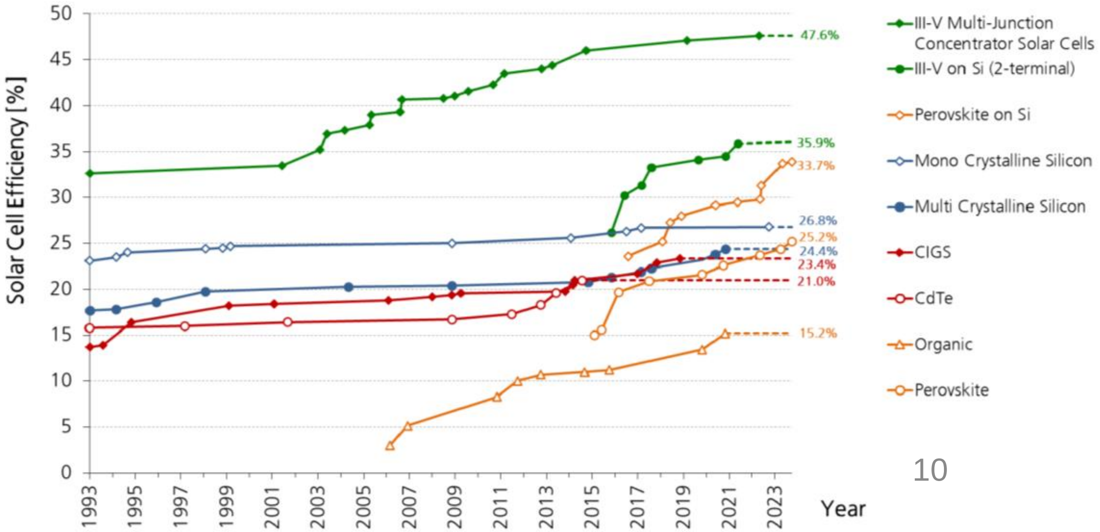




Production 2023* (GWp)

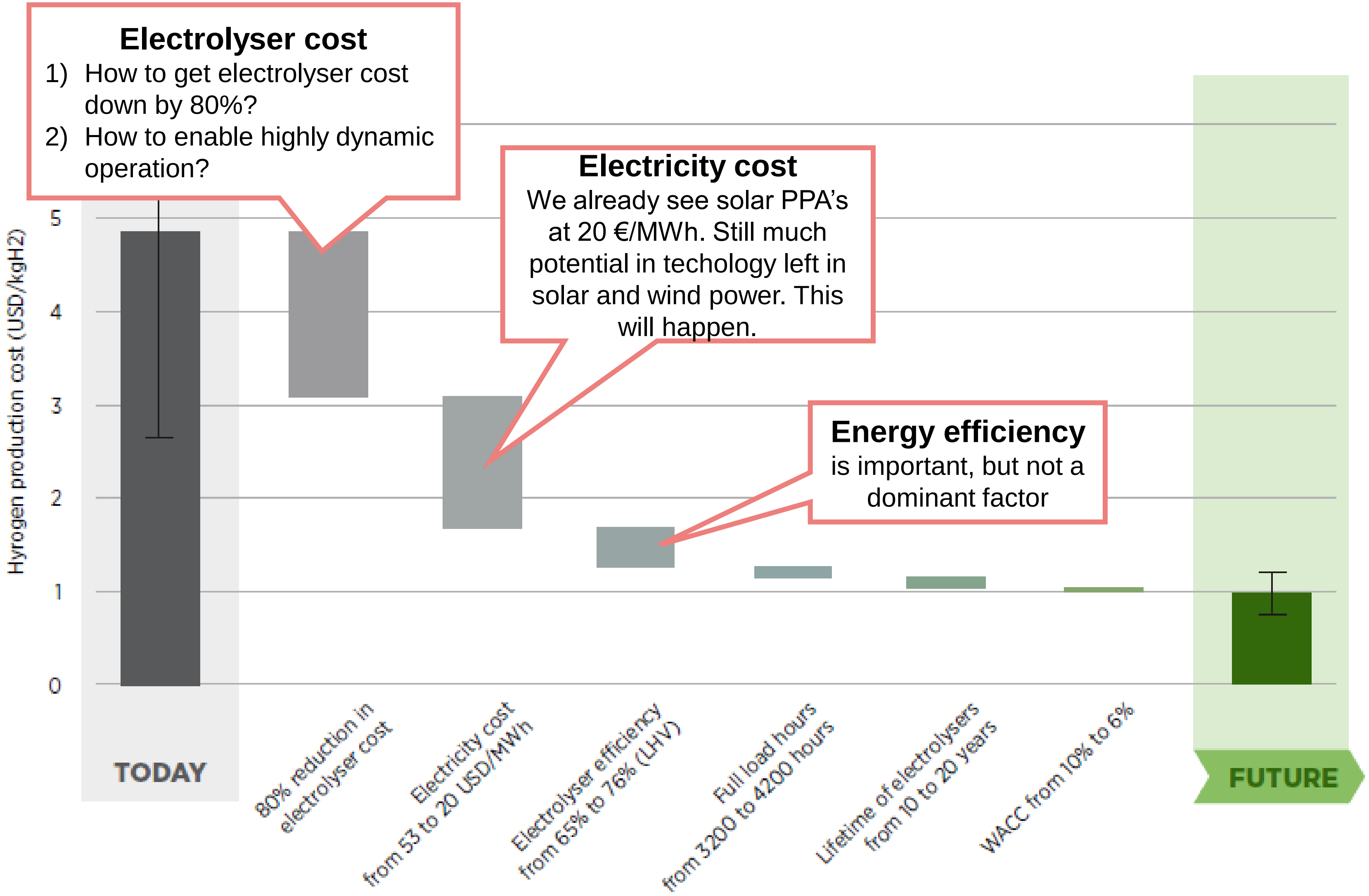
Thin film	13	
Multi-Si	4	
Mono-Si	485	
Total	502	(ITRPV)

*estimated numbers



Source: [Photovoltaics report](#).

How to produce cheap green hydrogen?

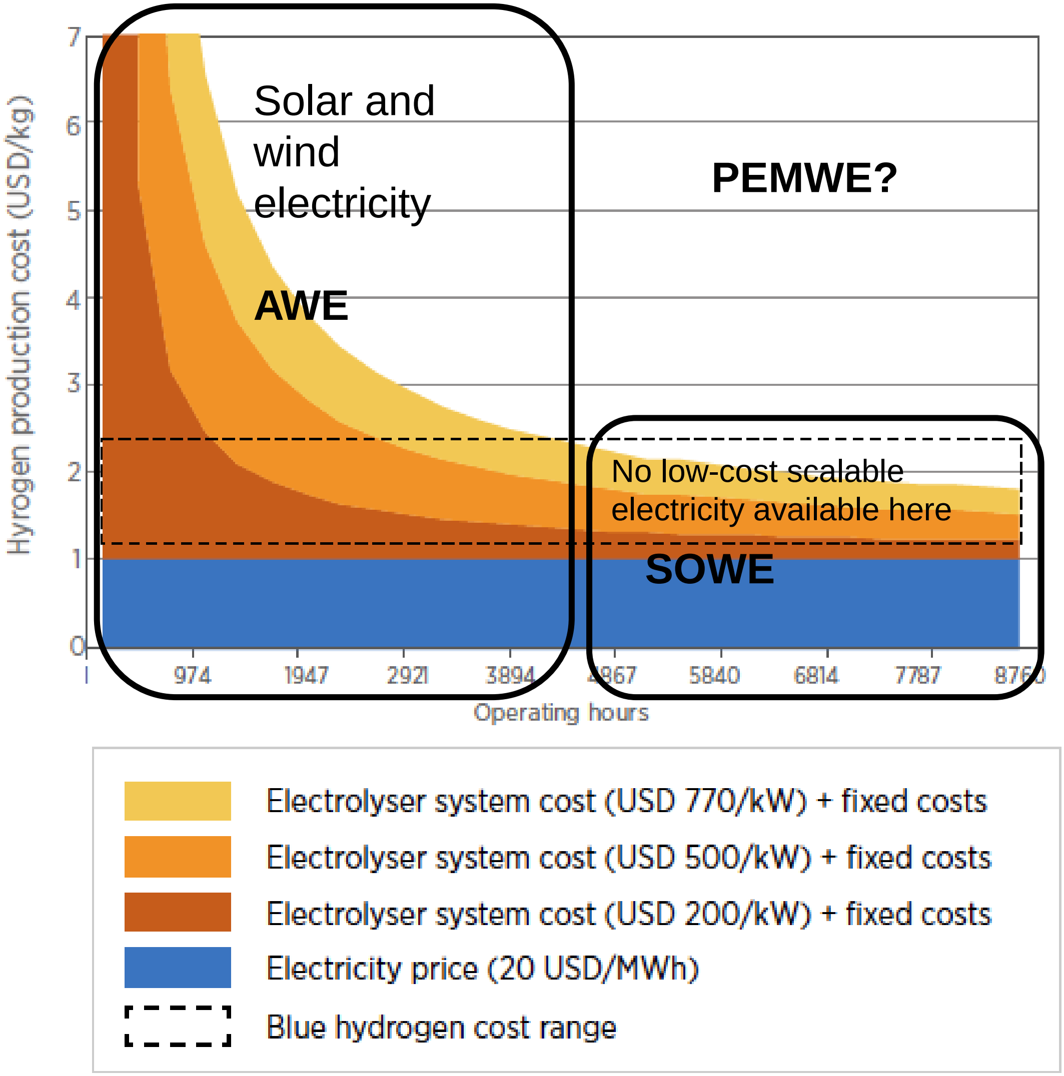


Note: 'Today' captures best and average conditions. 'Average' signifies an investment of USD 770/kilowatt (kW), efficiency of 65% (lower heating value – LHV), an electricity price of USD 53/MWh, full load hours of 3200 (onshore wind), and a weighted average cost of capital (WACC) of 10% (relatively high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

IRENA (2020), Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5 °C climate goal, International Renewable Energy Agency, Abu Dhabi.

GREEN HYDROGEN PRODUCTION BASED ON WIND AND SOLAR ELECTRICITY

Effect of intermittency of electricity supply



Cost composition of alkaline water electrolysis

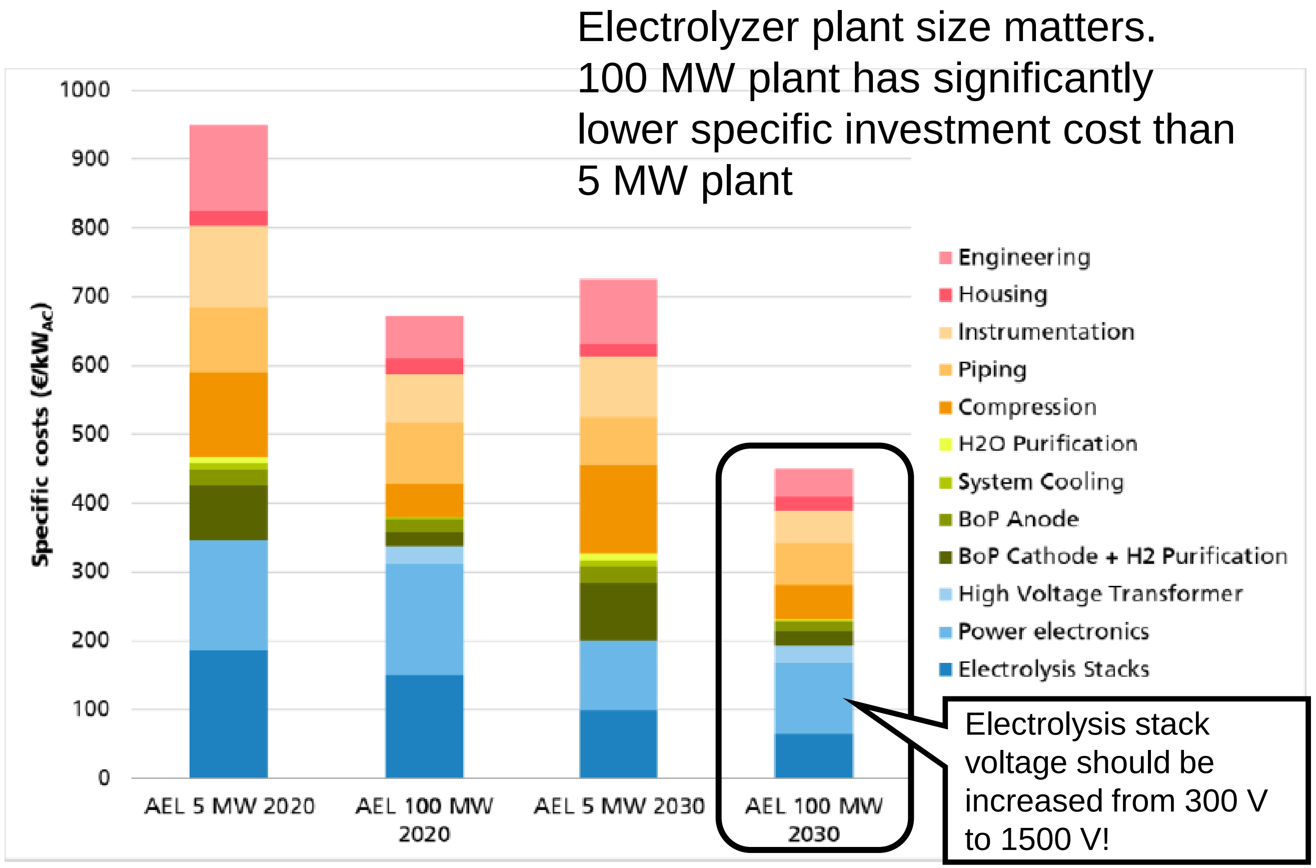
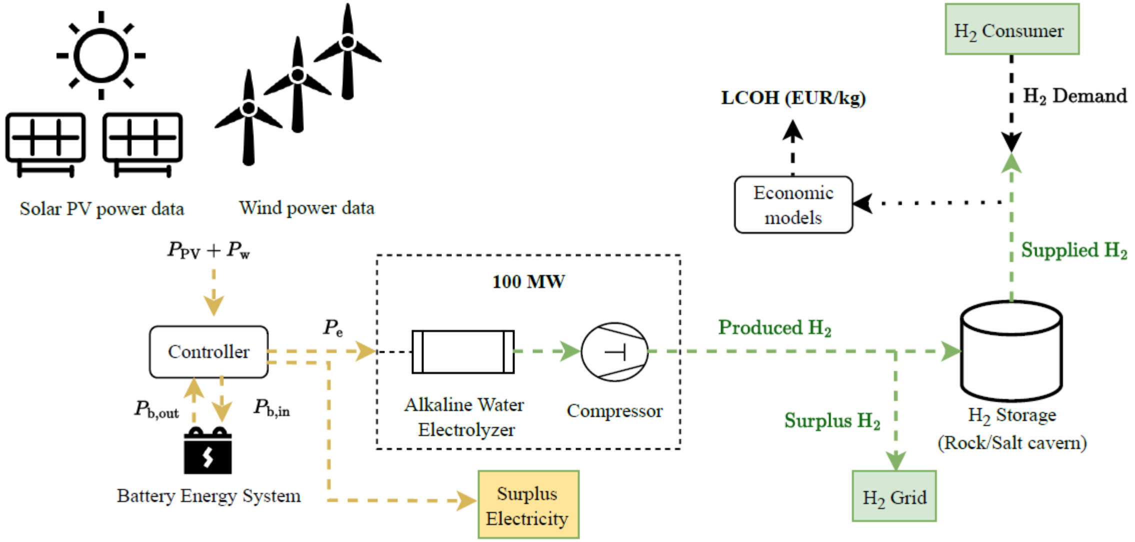


Figure 3-6: Specific costs of 5 MW and 100 MW next generation AEL systems (including mechanical compressors) for the design scenarios 2020 and 2030

Source: M. Holst, S. Aschbrenner, T. Smolinka, C. Voglstätter, G. Grimm, Cost forecast for low-temperature electrolysis – Technology driven bottom-up prognosis for PEM and alkaline water electrolysis systems, Fraunhofer ISE, Oct. 2021.

COST-EFFICIENTLY GREEN HYDROGEN WITH WIND AND SOLAR ELECTRICITY



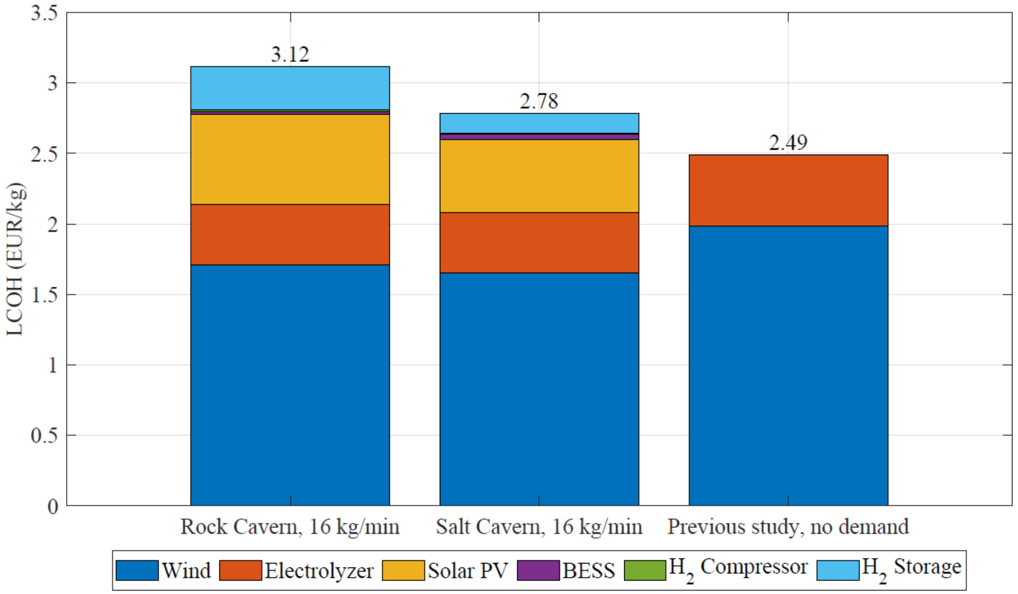


Fig. 10: Levelized cost of hydrogen (LCOH) supplied for rock and salt cavern systems at a fixed rate of 16 kg/min, as well as for a no-demand with no hydrogen storage system. Optimization

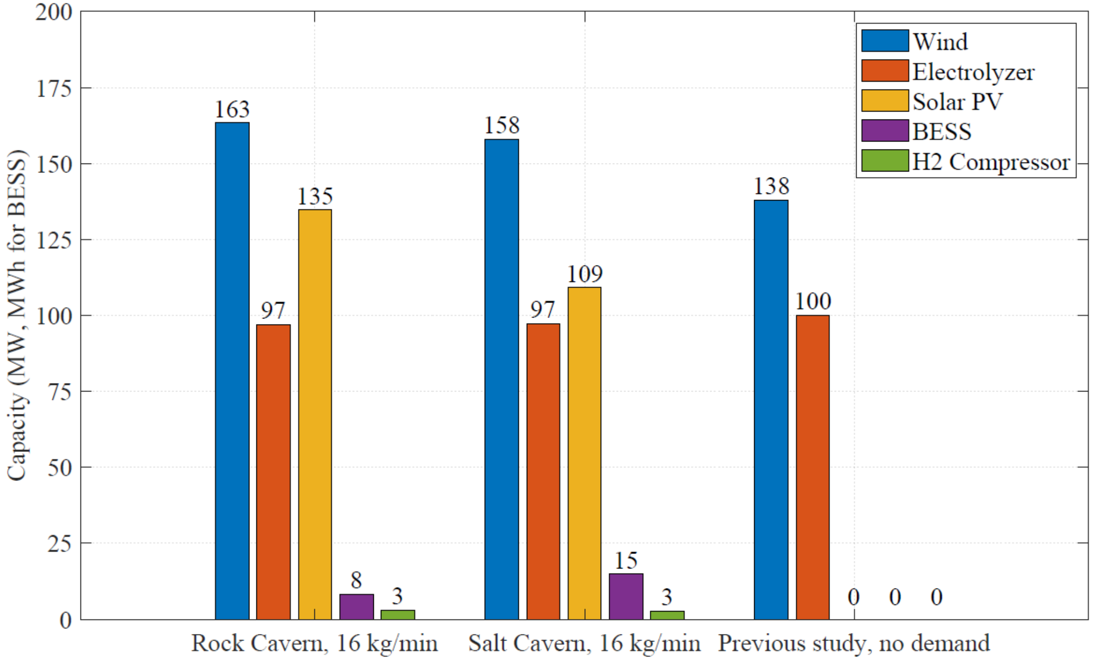


Fig. 11: Optimal component capacities for rock and salt cavern systems at a fixed rate of 16 kg/min, as well as for a no-demand with no hydrogen storage system. Optimization results for the installation year 2025 and 5 % discount rate.

Study carried out based on real wind and solar power data from South-East Finland.

Source: A. Ibáñez-Rioja, L. Järvinen, P. Puranen, A. Kosonen, V. Ruuskanen, K. Hynynen, J. Ahola, P. Kauranen, Baseload hydrogen supply based on off-grid solar PV–wind power–battery–water electrolyzer plant, to be published.

Key takeaways

- Focus on alkaline electrolysis technology
- Hydrogen production will be based mainly on wind and solar power
- Hydrogen production should be flexible, because cheap electricity is not available 24/7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