Cost-effective electricity storage: Will it enable us to fully decarbonise power generation?

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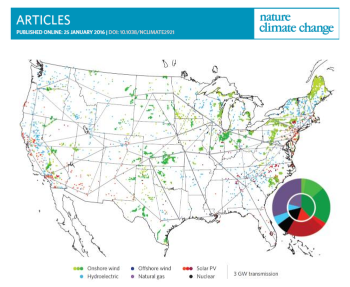
Cost projections for electrical energy storage are essential in determining its role in future low-carbon energy systems.

Electrical energy storage could play a pivotal role in future low-carbon electricity systems, balancing inflexible or intermittent supply with demand. This role can be quantified through energy system models with significant impact on policy-making.[1] But, cost data is scarce and uncertain necessitating wide cost range assumptions or the exclusion of storage from studies of future electricity systems.[2,3] A data-driven understanding of the potential future costs of storage could improve the validity of modelling results, increase investor confidence and enable policymakers to design suitable deployment policies.[4]



vs.

"Our results show that [...] CO_2 emissions [...] can be reduced by up to 80% [...], **without electrical storage."**[2]

"**15 GWh p.a.** in the Gigafactory will be devoted to stationary battery packs."[5]

Capital costs are on a trajectory to fall to 360±80 $/kWh for stationary systems, 200±10 $/kWh for battery packs and 135 $/kWh for batteries.

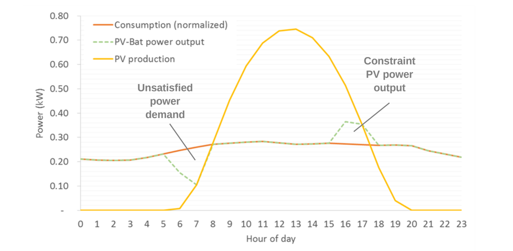
Experience curves of electrical energy storage technologies are derived based on historical price and capacity data (Figure 1). Based on these experience curves, future costs as a function of increased cumulative capacity are projected and their feasibility tested against indicative cost floors (Figure 2).

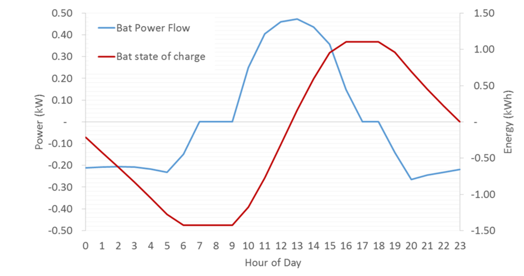
At 1TWh cumulative capacity, prices for installed stationary systems are at a narrow range between 280 and 440 $/kWh, and for battery packs between 190 and 210 $/kWh, regardless of technology. This implies that the one technology that manages to bring most capacity to market is likely to be the most cost-effective. Prices for portable consumer batteries reduce to 135 $/kWh.

Raw material costs for each technology are calculated by multiplying material inventories with commodity prices of the past 10 years. The analysis shows average raw material costs below 110 $/kWh for the technologies studied with experience curves. The identified cost reduction potentials of 135-440 $/kWh therefore appear feasible.

Dispatchable battery-coupled solar PV power could become competitive with conventional base-load power by 2030.

A utility-scale solar PV plant is coupled with a utility-scale Lithium-ion battery that converts daily PV generation into a continuous power supply that matches the local demand pattern on a daily basis 85% of the year (accounts for intra-day variation in irradiation).





By 2030, when the system could become competitive with coal- and gas-fired power, Li-ion battery capital costs have reduced from 1,000 $/kWh (2015) to 360 $/kWh, while solar PV system costs have come down from 1,300 $/kW (2015) to 500 $/kW (Figure 3).

The battery contribution to LCOE is 80% from 2015 through 2040. This is due to the lower experience rate (23%$_{PV}$ vs. 12%$_{Bat}$) that limits cost reduction despite high growth (18%$_{PV}$ vs. 38%$_{Bat}$).

Experience curves for electrical energy storage technologies.

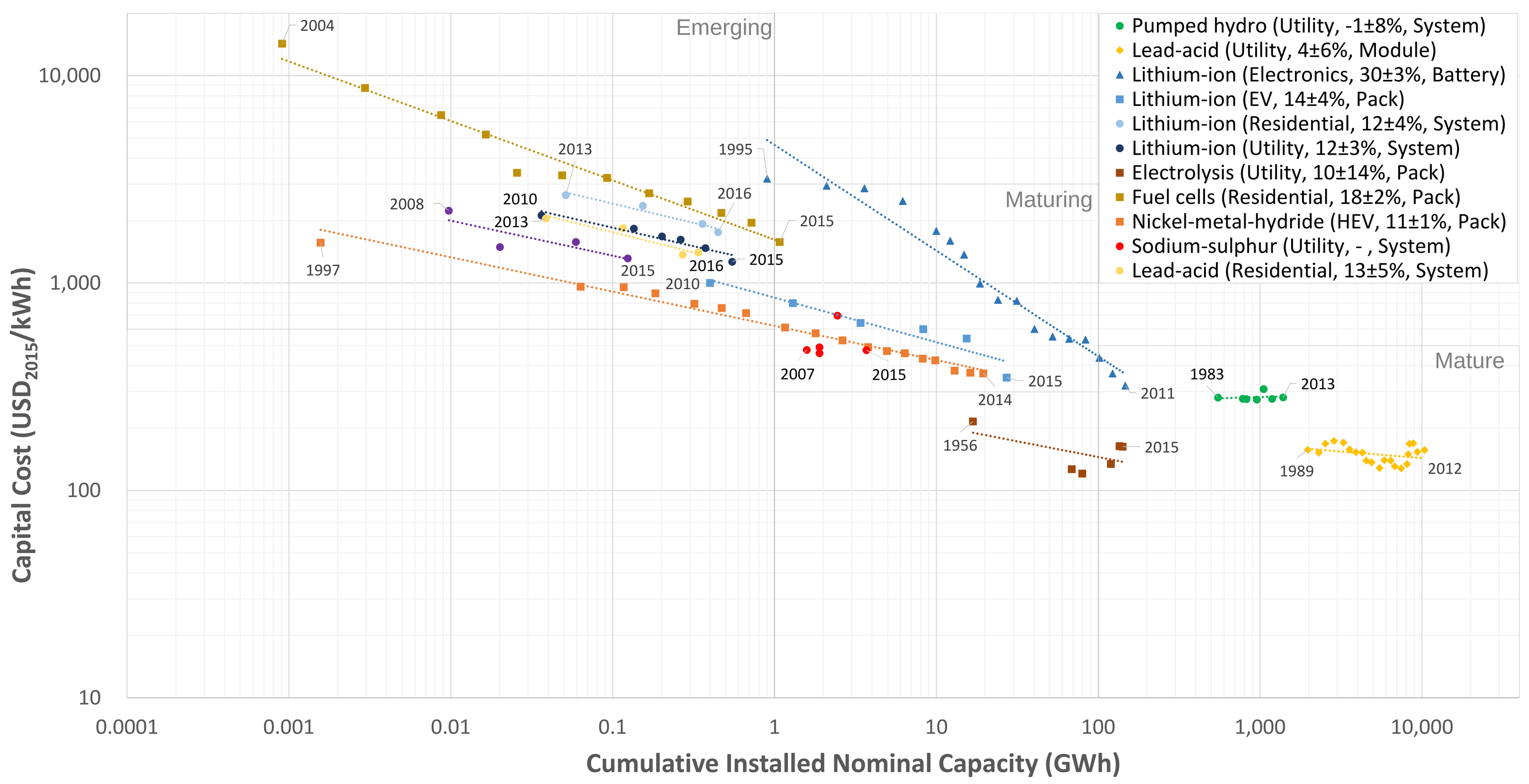


Figure 1 - Results shown for system costs per nominal capacity in energy terms. Legend indicates application, experience rate incl. uncertainty and system scope considered in this analysis. Applications: portable – electronics; transport – HEV, EV; stationary – residential, utility. System scope: ○ – Installed System, □ – Pack, ◊ – Module, Δ – Battery). Grey rectangles highlight overarching trend in cost reduction. Fuel cell and electrolysis prices must be considered in combination (Electrolysis converts electricity to hydrogen gas, Fuel cells reconvert to electricity).

Experience curve based cost projections and raw material costs.

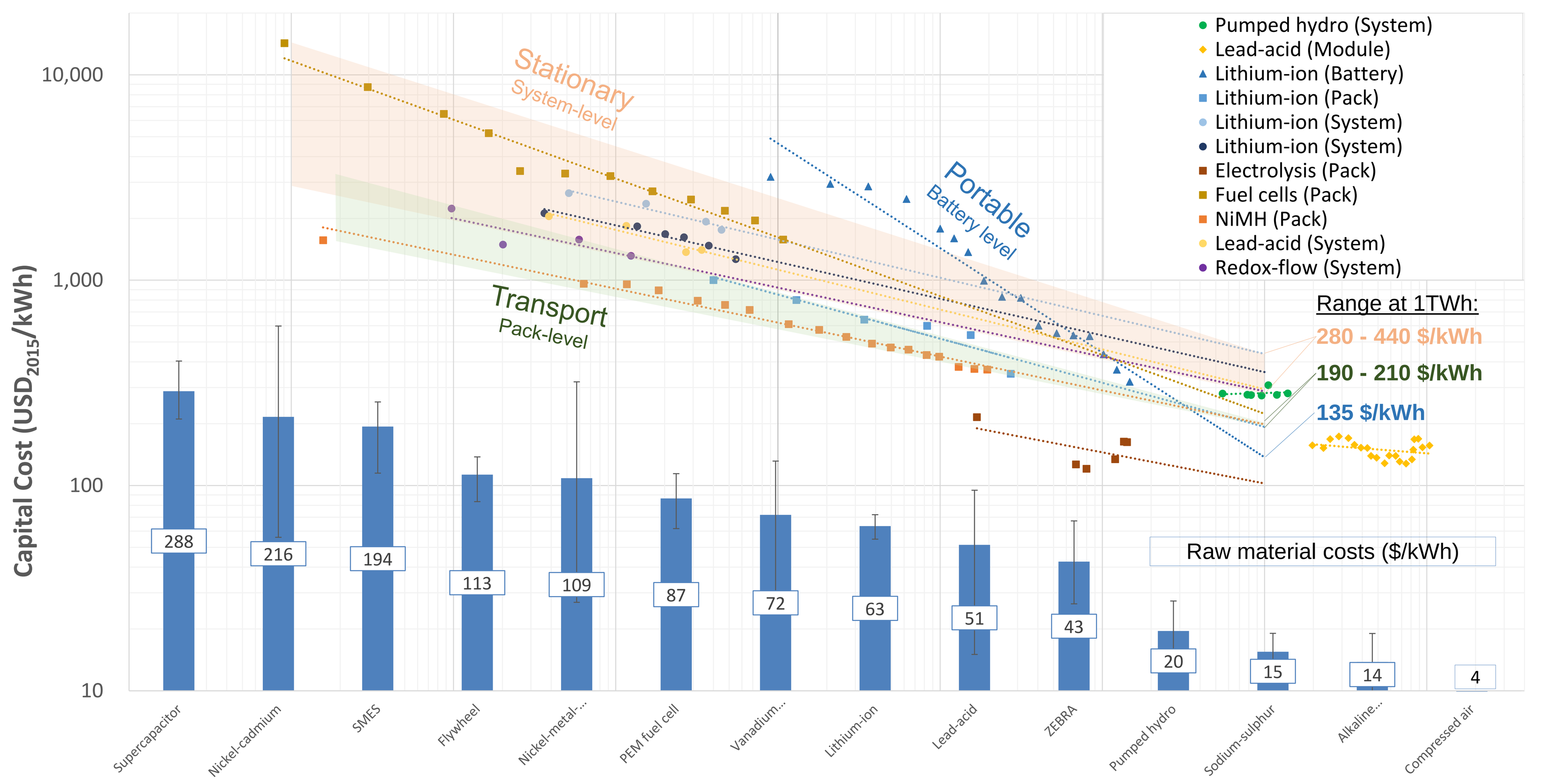


Figure 2 - Shaded trapezoids are visual guides covering the range for each application. These narrow to the price ranges given at the right of the figure. For stationary fuel cell/ electrolysis and utility-scale lead-acid storage, prices on pack- and module-level are shown. Blue bars show raw material costs on system-level for Pumped hydro and Compressed air and on pack-level for all other technologies. Error bars are based on variations in each technology's material inventory and minimum, average and maximum commodity prices over the past 10 years.

Levelised cost of electricity (LCOE) for conventional and solar PV power generation.

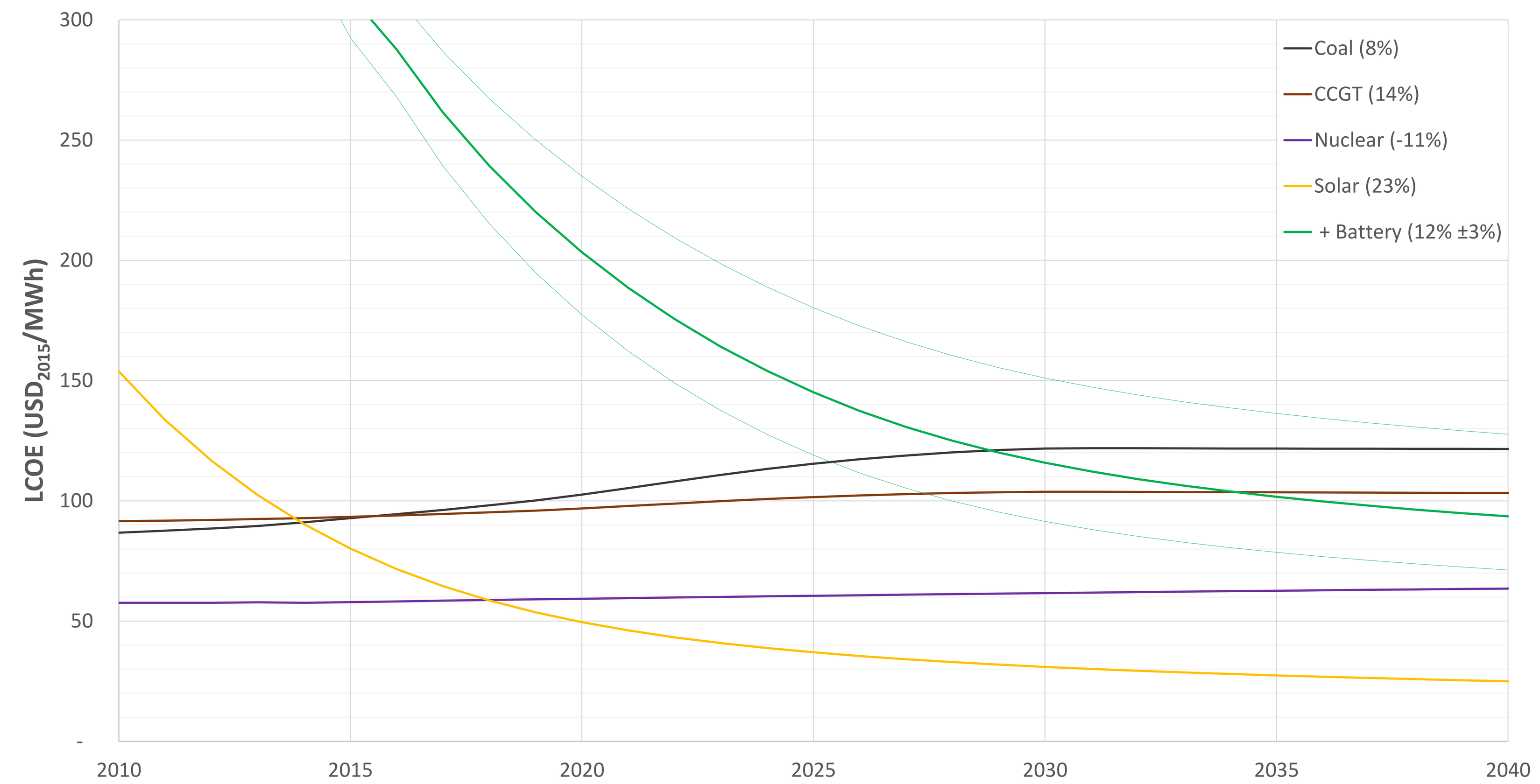


Figure 3 - LCOE projections based on experience rates (see legend), growth rates and projected CO_2-price development. PV generation modelled for Madrid (annual yield: 1669 kWh/kW). Battery sized to match PV generation with Spanish demand pattern on daily basis 85% of year (C-rate: 0.23). Cost data for generation technologies are based on OECD average and experience rates from the literature. Thin green lines represents LCOE accounting for uncertainty of battery experience rate.

Experience curve theory

Experience curves show the *improvement* of a technology parameter (e.g. cost, size) as a function of *experience* (e.g. produced capacity, time). It is the most objective method to forecast technological progress and the relation between product cost and cumulative production is the most precise.[6,7]

- *Price (P) as a function of cumulative capacity (X)* $P_n = P_{base}\left(\frac{X_n}{X_{base}}\right)^{-\alpha}$
- *Experience Rate (ER)* $ER = 1 - 2^{-\alpha}$

1936: Theodore Wright describes effect of learning on production costs in aircraft industry and proposes a mathematical model (cost vs. cumulative production)[8]

1962: Kenneth Arrow finds, the model holds true for the whole capital goods industry[9]

1968: BCG extends model to include all inputs required to deliver product to end user[10]

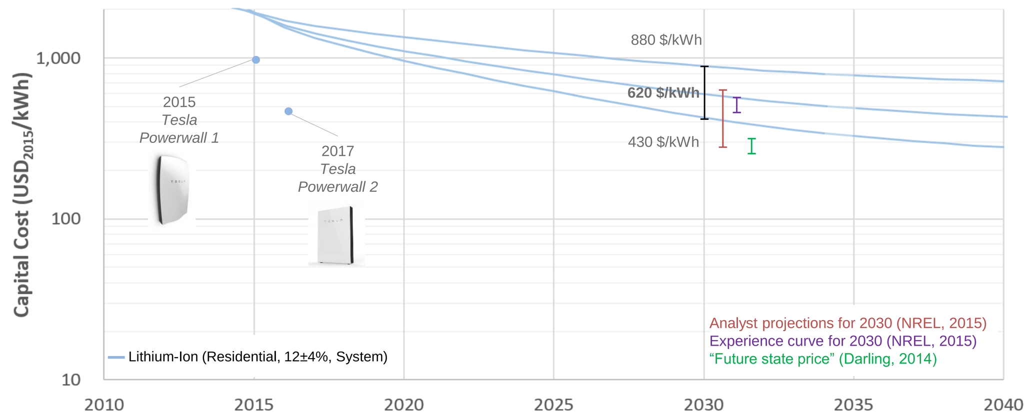
2000: IEA publishes experience curves for energy generation technologies[11]

Experience curve based analyses

- Cumulative deployment investments worth $175-520bn per technology achieve 135-440 $/kWh range
- These investment levels appear feasible given global annual investments in clean energy of $350bn[12]
- By 2030 electrical energy storage could cost 130-620 $/kWh (based on market growth assumptions)
- Tesla Powerwall 2 might represent a step change not captured in this experience curve analysis

Tesla Powerwall 2

- Official price estimate: 465 $/kWh[13] (installed system price for 2017)
- Battery Pack and Inverter produced in *Gigafactory* (vertical integration)
- Price could reflect unsustainable market penetration strategy



Why does it matter?

- Global power generation must be decarbonised by 2050[14]
- This could be achieved with dispatchable battery coupled solar PV power replacing conventional base-load power after 2030
- But, sufficient storage capacity must get deployed by 2030 to "pull" technologies along exp curves
- By removing policy barriers for electrical energy storage applications profitable already today[4]

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