Storing Energy at Utility-Scale

An Overview

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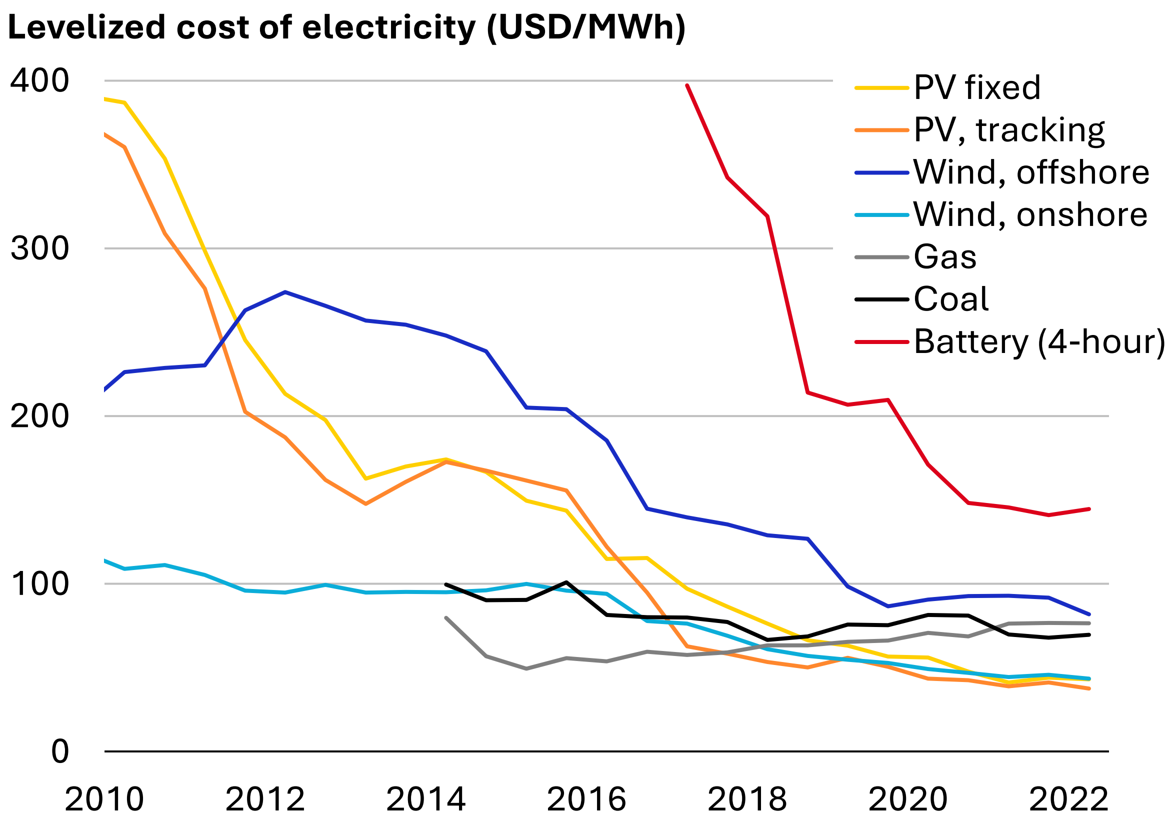
Renewables are the future of electricity generation

Cost:



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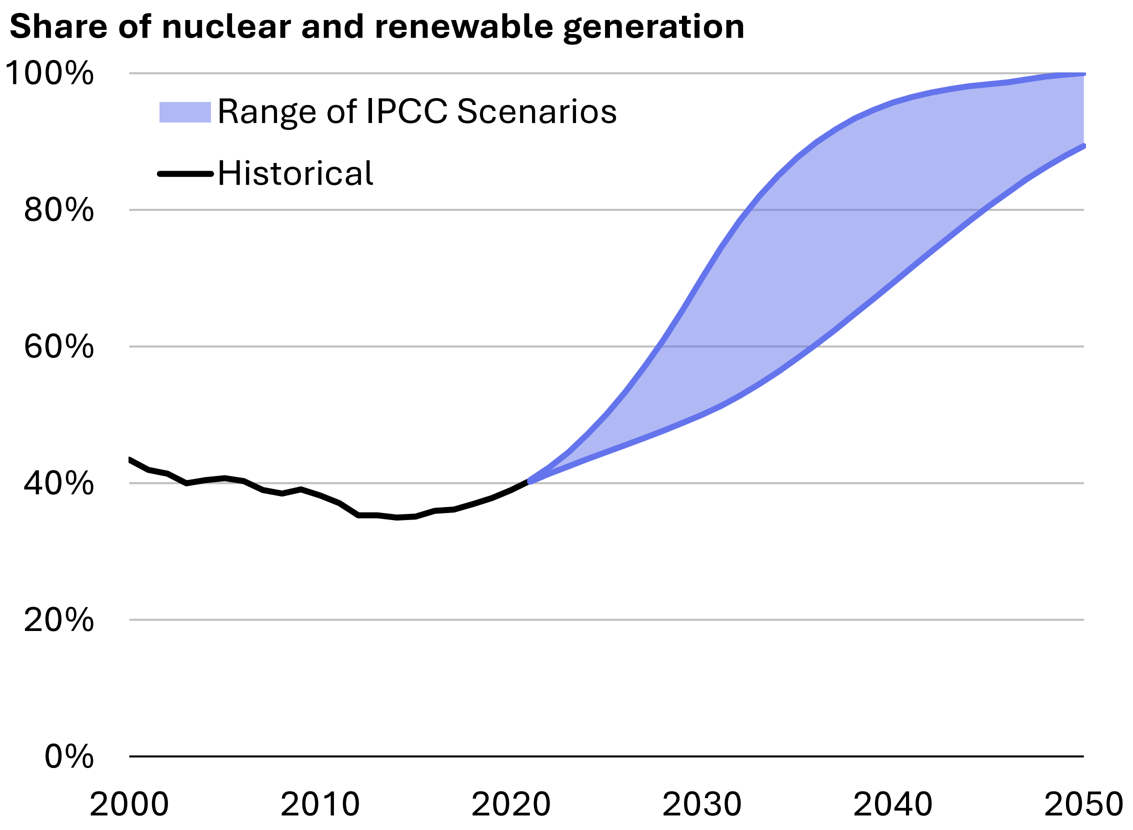
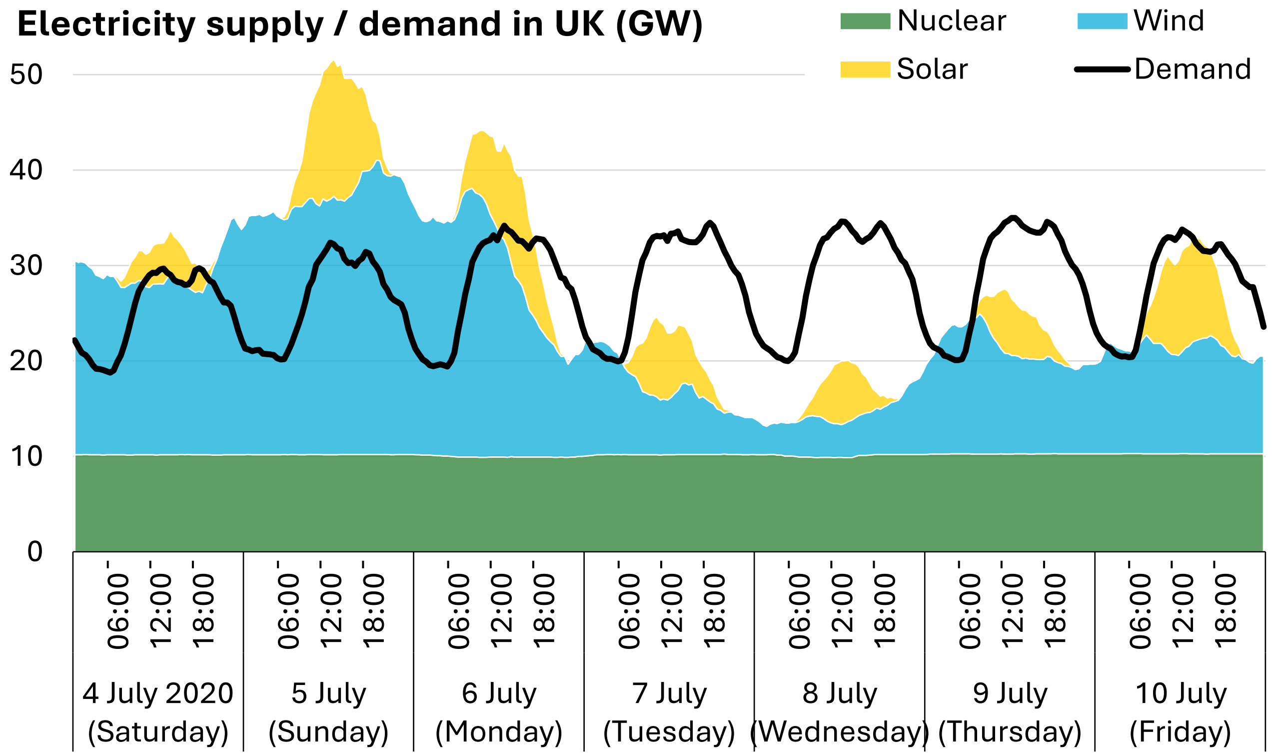


Flexibility is needed to match Renewables and demand

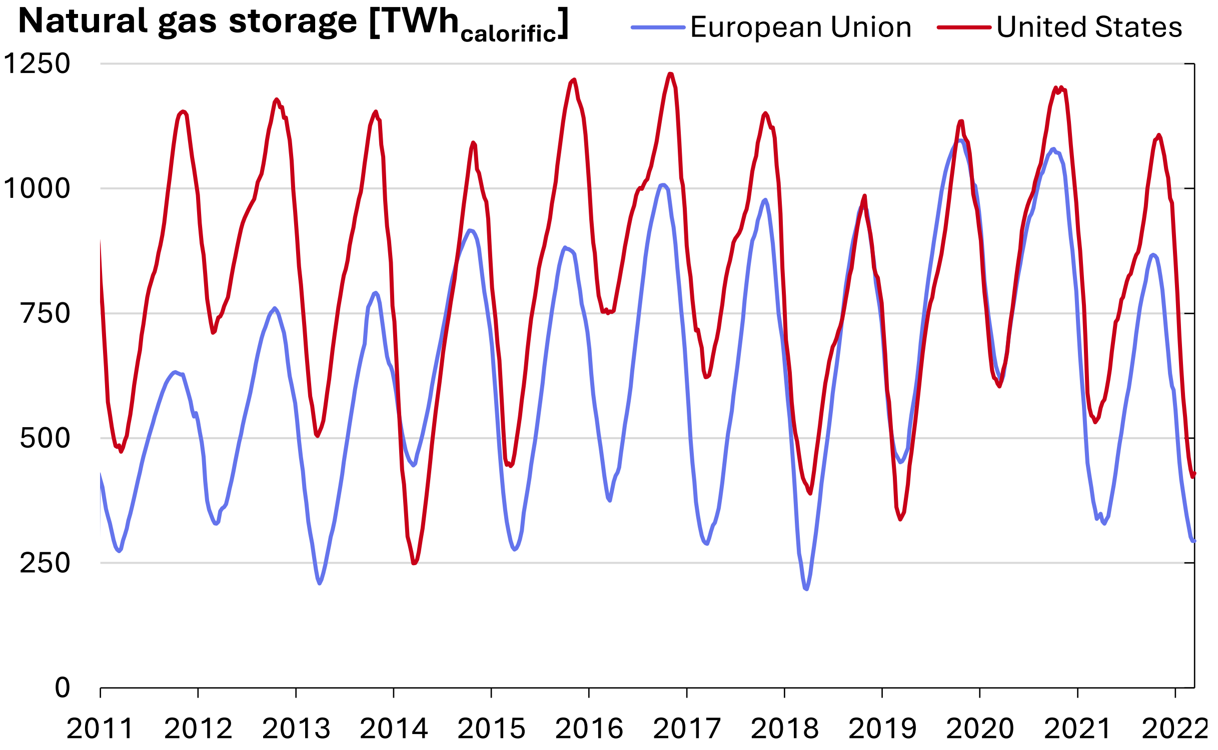
Hourly / Daily



UK storage capacity 2022

- Pumped storage: 30 GWh
- Battery storage: 3 GWh

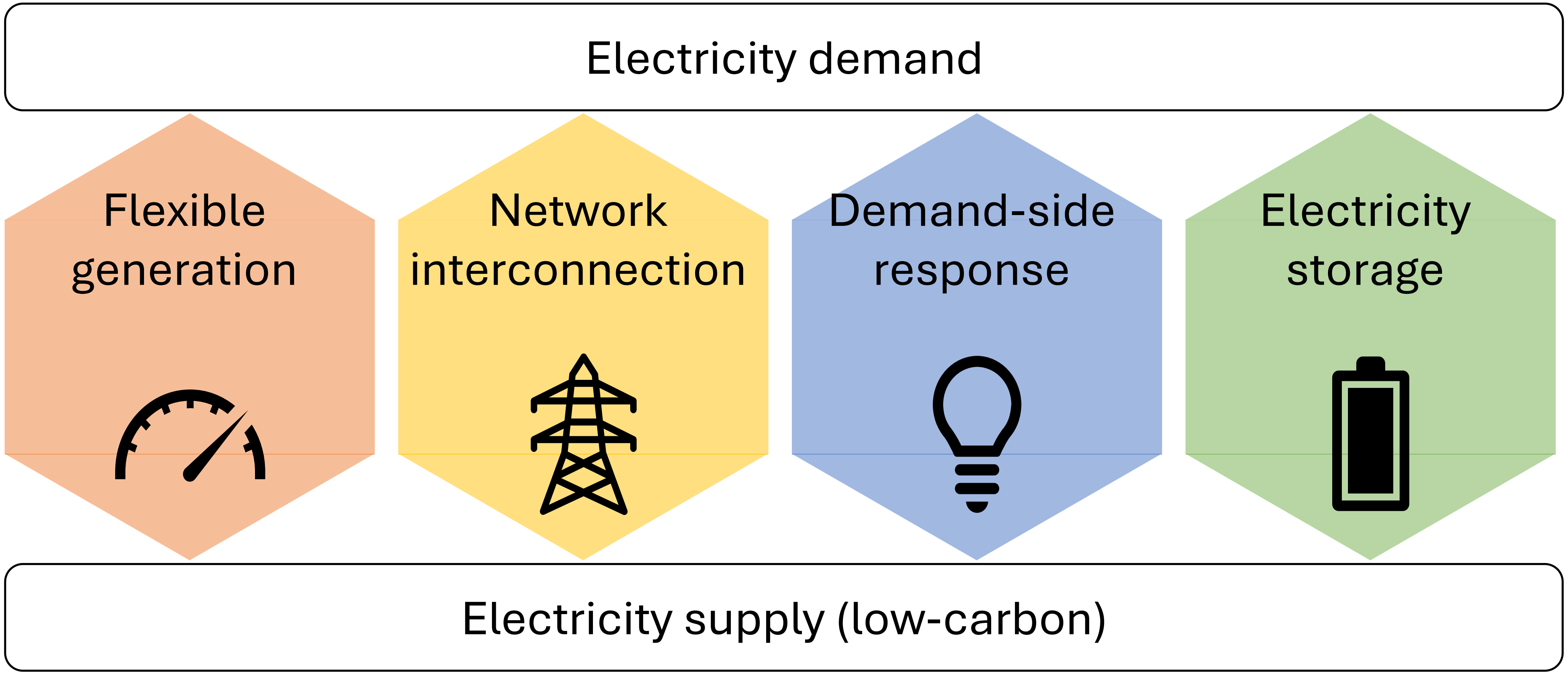
Monthly / Yearly



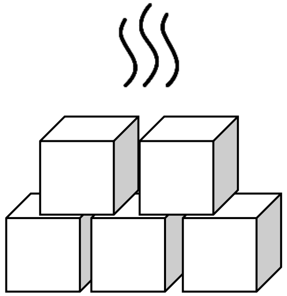
UK storage capacity 2022

- Fossil fuels: 100 TWh
- Pumped storage: 0.03 TWh

Electricity storage is <u>one form</u> of flexibility

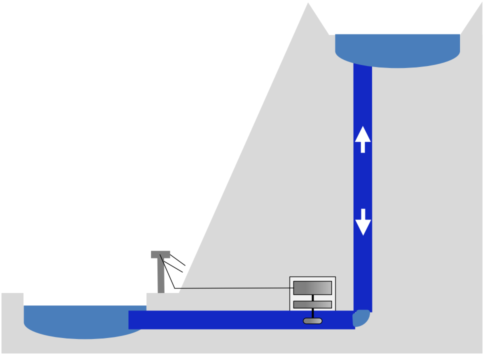


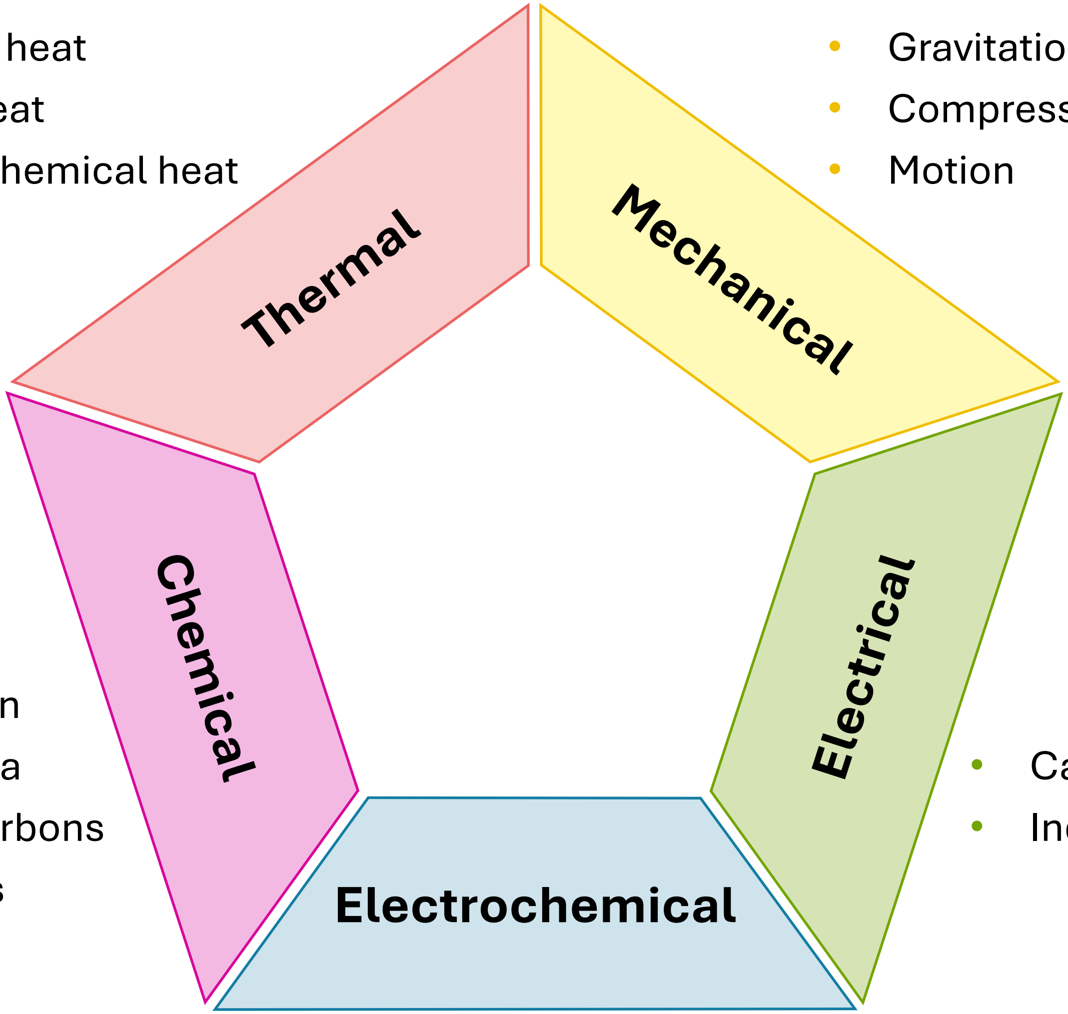
All storage technologies belong to five categories

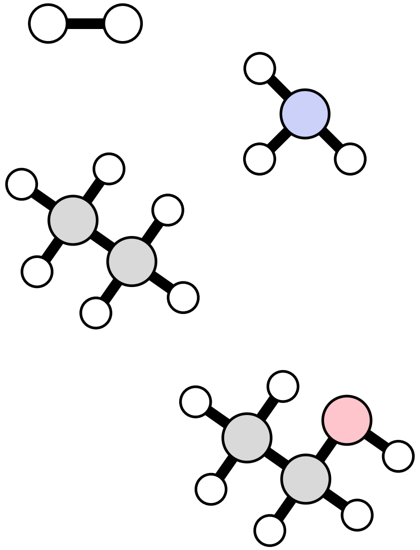


- Sensible heat
- Latent heat
- Thermochemical heat

- Gravitation
- Compression
- Motion

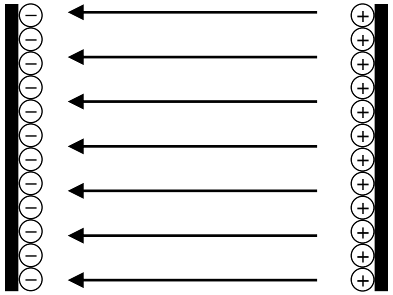


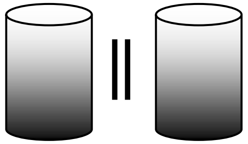




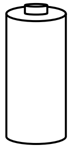
- Hydrogen
- Ammonia
- Hydrocarbons
- Alcohols

- Capacitance
- Inductance

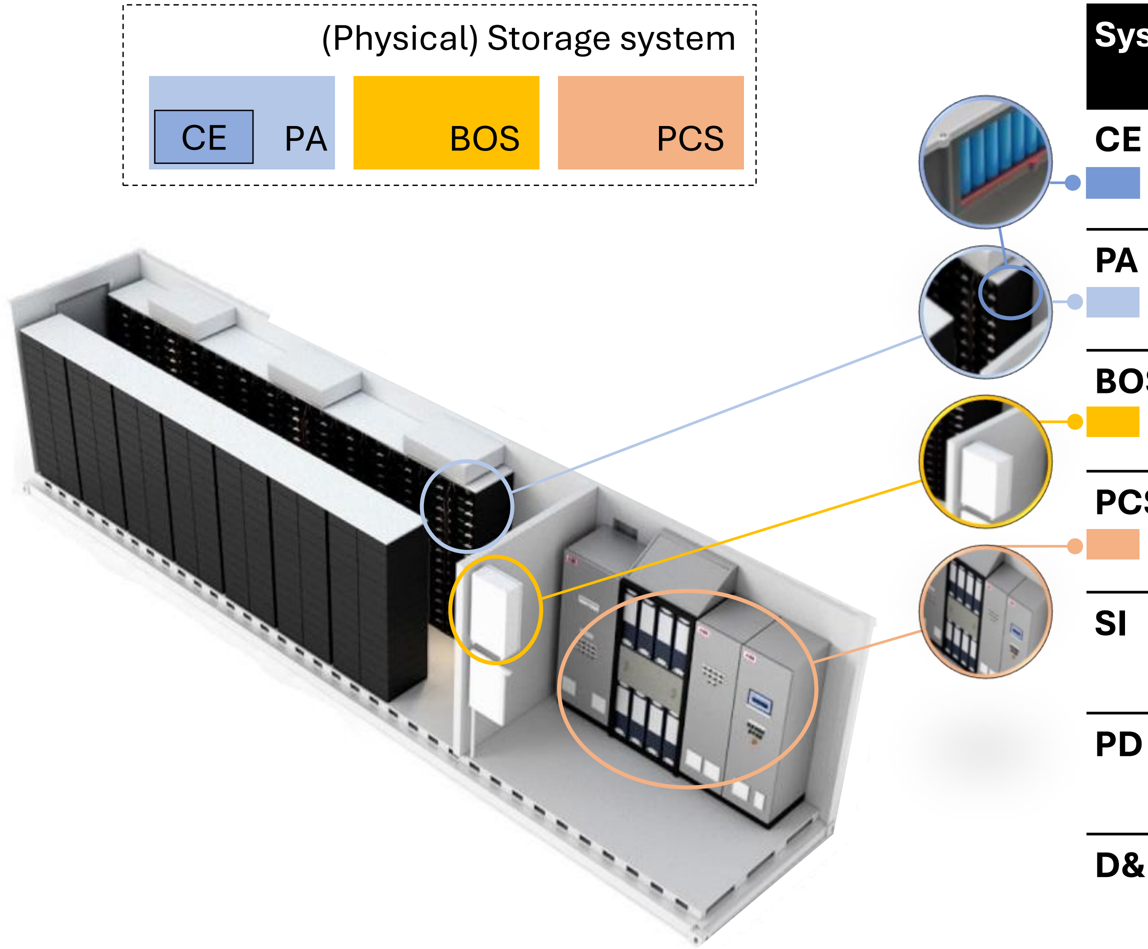




- Sealed batteries
- Flow batteries



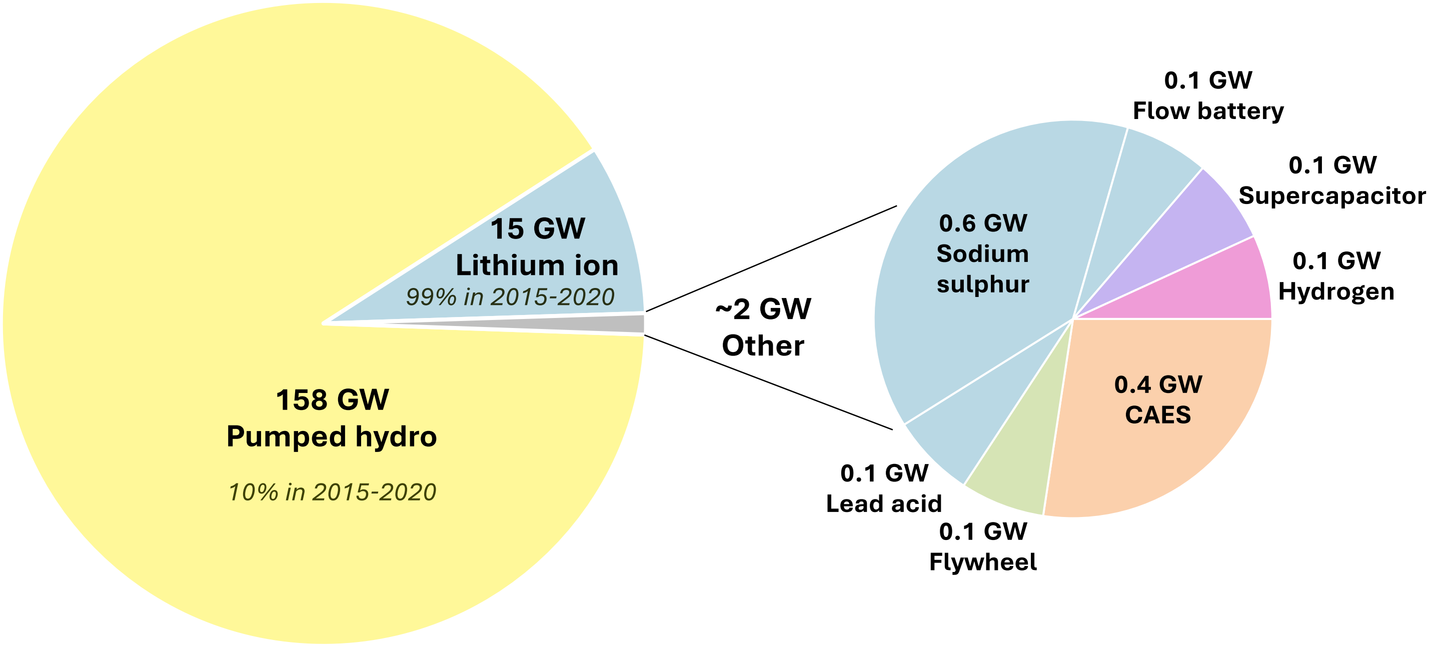
Battery systems have various cost components



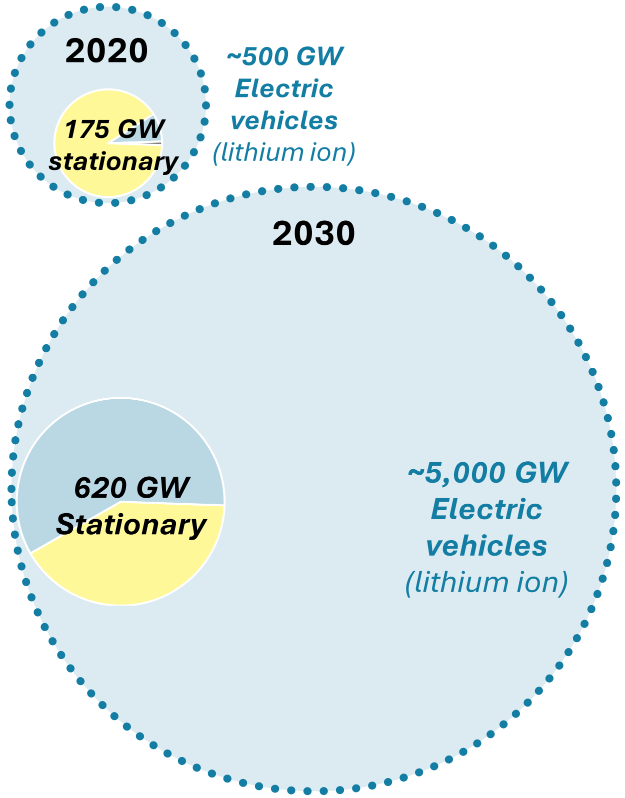
System scope		Components		Cost share
CE	Cell	• Electrodes • Electrolyte	• Electrical contacts	~35%
PA	Pack	• Cell connectors • Housing	• Battery mgmt. system (“BMS”)	~15%
BOS	Balance-of-system	• Container • Monitors, controls	• Thermal control • Fire suppression	~10%
PCS	Power conversion	• Inverter/converter • Data management	• Energy mgmt. system (“EMS”)	~10%
SI	System integration	• Assembly of components	• Tailoring to application	~5%
PD	Project development	• Land acquisition • Permits	• Financial and technical studies	~10%
D&I	Distribution & Installation	• Engineering • Procurement	• Construction • Commissioning	~15%

Pumped hydro most widely deployed – batteries catch up

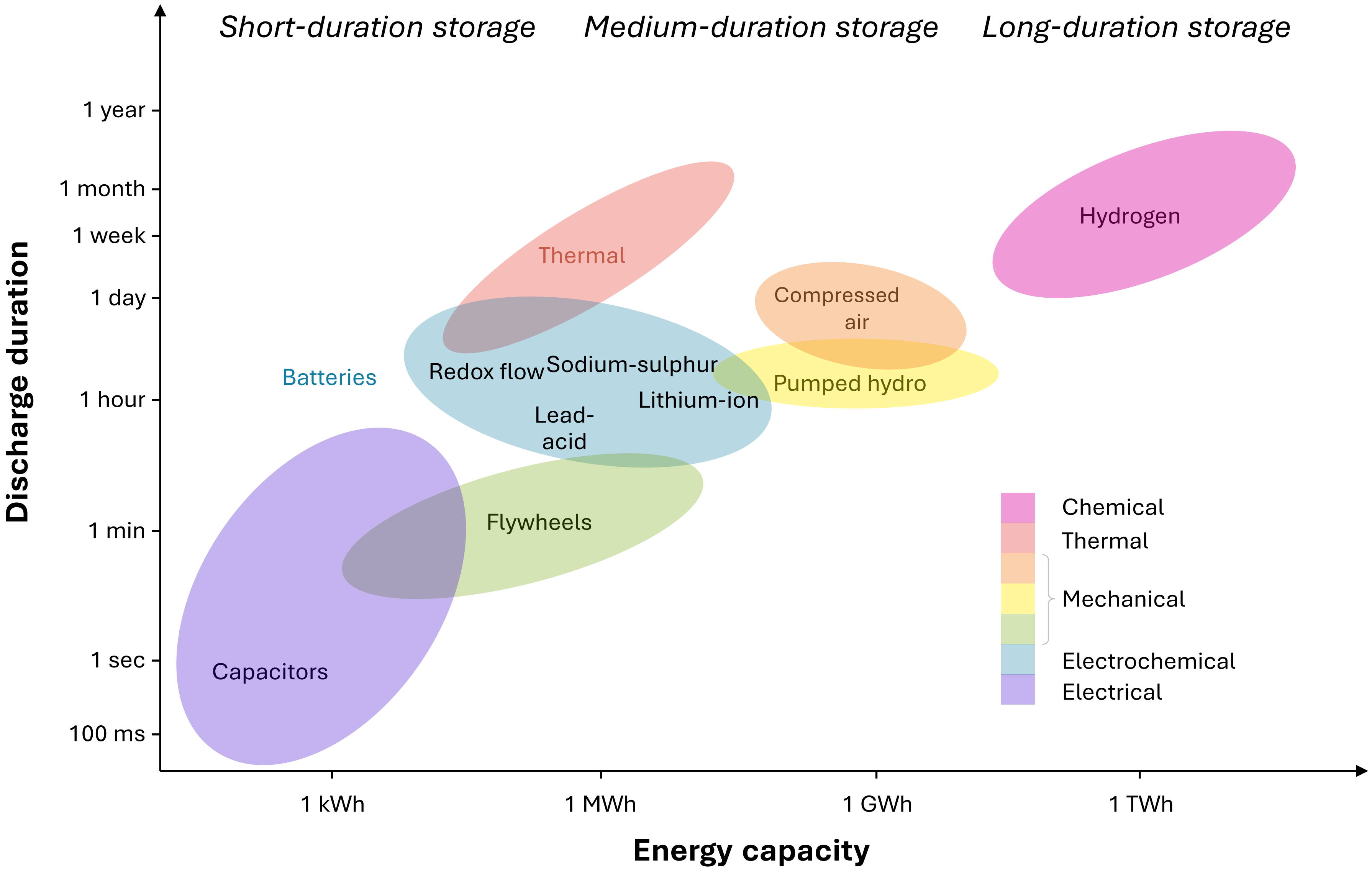
2020 stationary storage deployment



Stationary vs. Transport



The different technologies are used for different applications



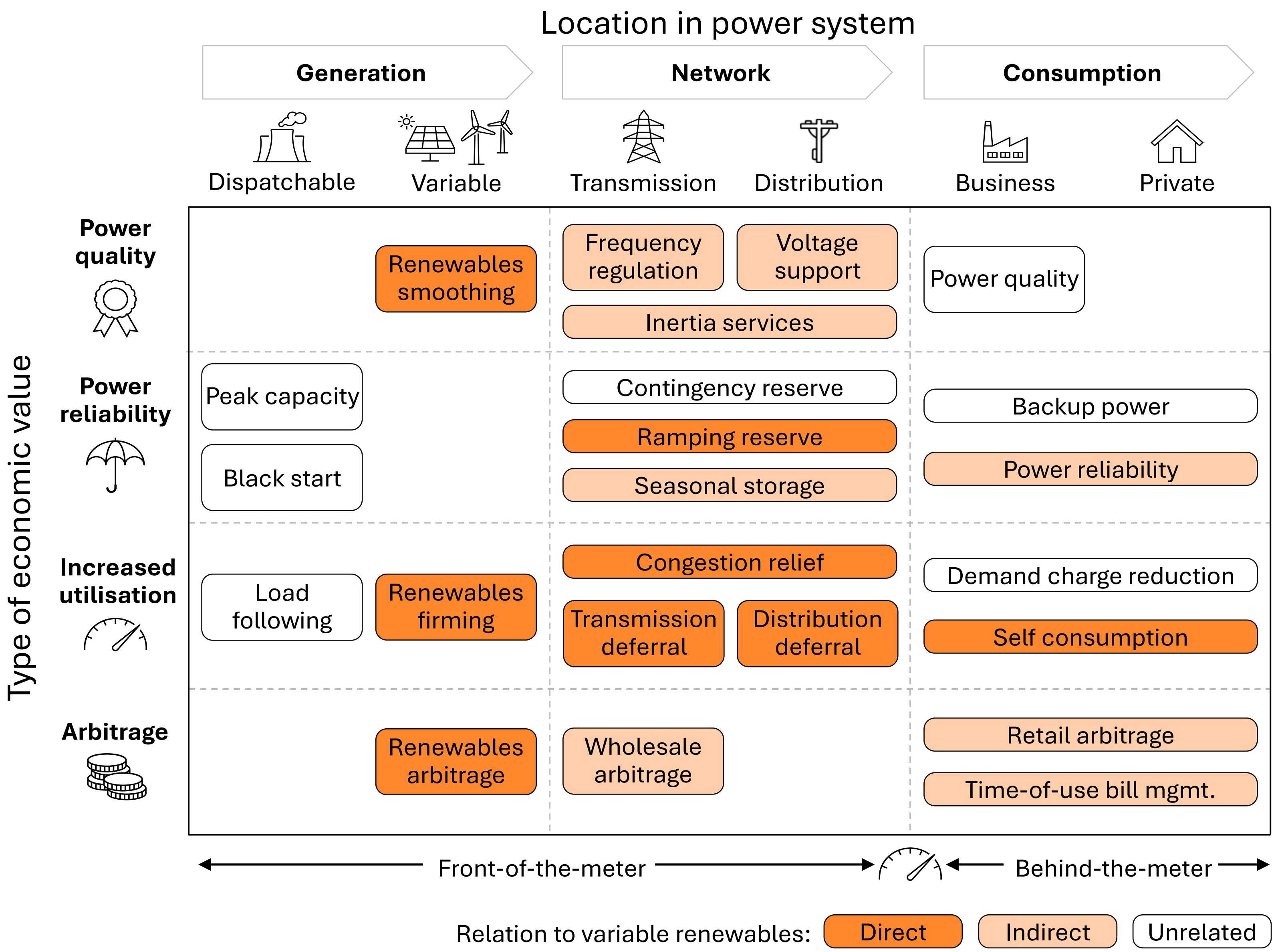
Longer duration storage needed as power system evolves

RE / nuclear energy share: <20% → >80%

Phase	Description	Archetype application	Deployment potential	Discharge duration	Response time
Pre-2010	Integrated energy market & low-cost nuclear power	Various	low	Mostly 8-12 hours	Minutes
1	Restructured energy market & reducing system inertia	Frequency regulation	low	< 1 hour	Milliseconds to seconds
2	Narrowing of peak periods & reducing RE+storage cost	Peak capacity	mid	2-6 hours	Seconds to minutes
3	RE+storage cost lower than other generators	Renewables integration	high	4-12 hours	Minutes
4	No fossil fuel generators & very low storage cost	Seasonal storage	uncertain (?)	>12 hours	Minutes to hours

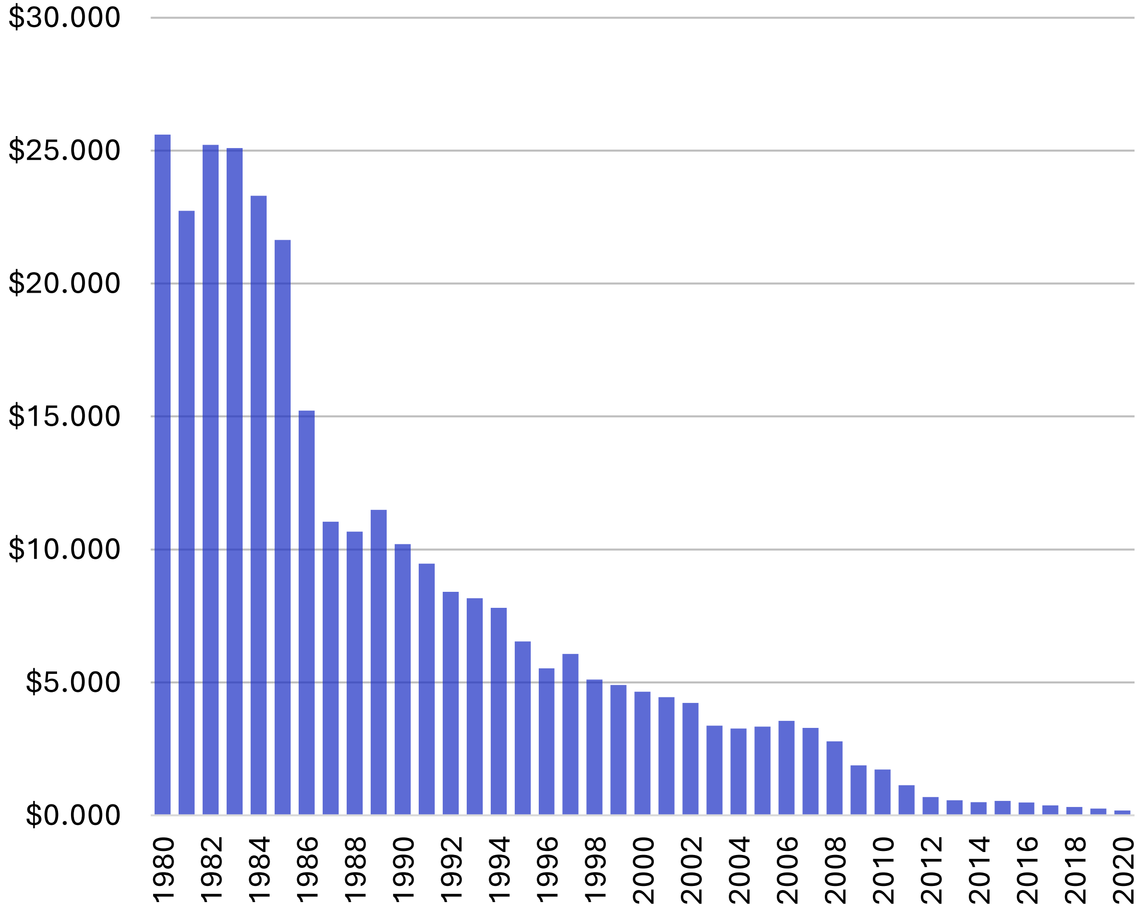
Legend: low · mid · high · ? uncertain

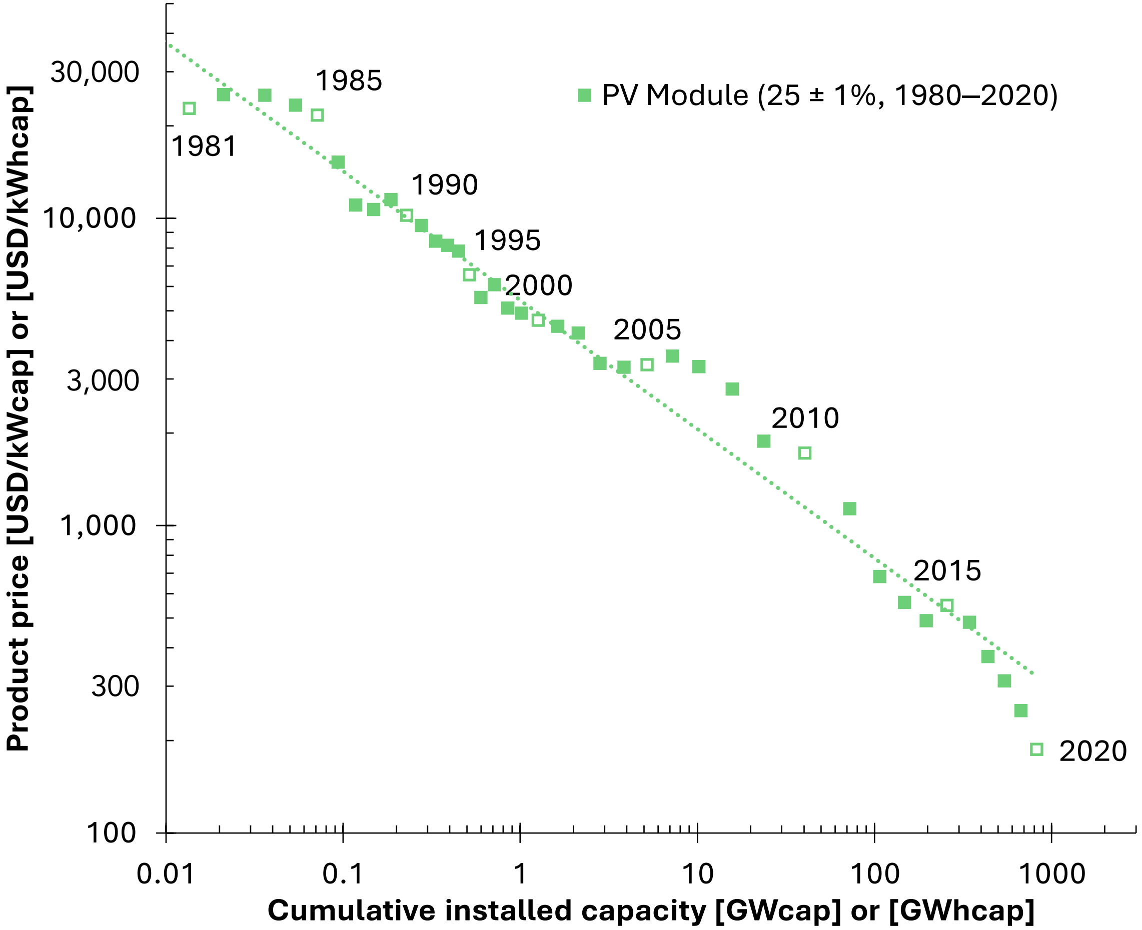
Range of specific energy storage applications is much wider



Falling prices can be expressed by their 'experience curve'

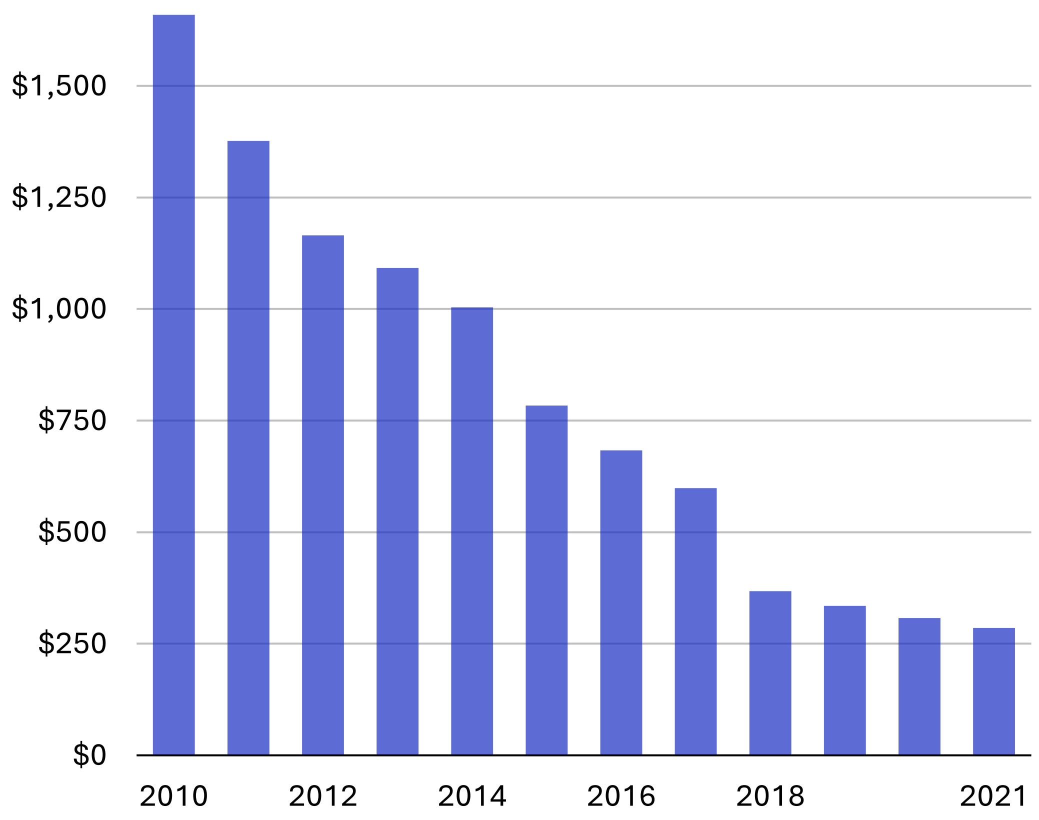
Solar PV modules [USD/kW]

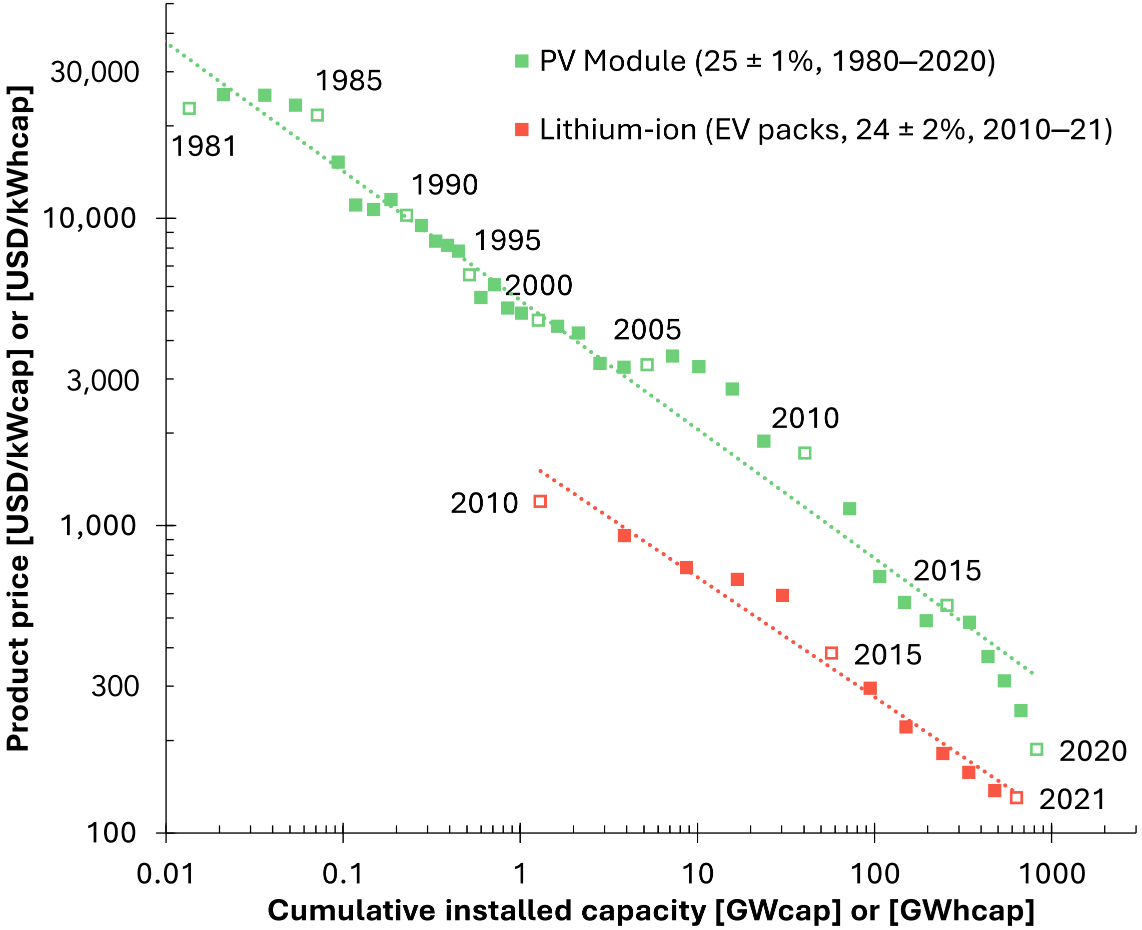




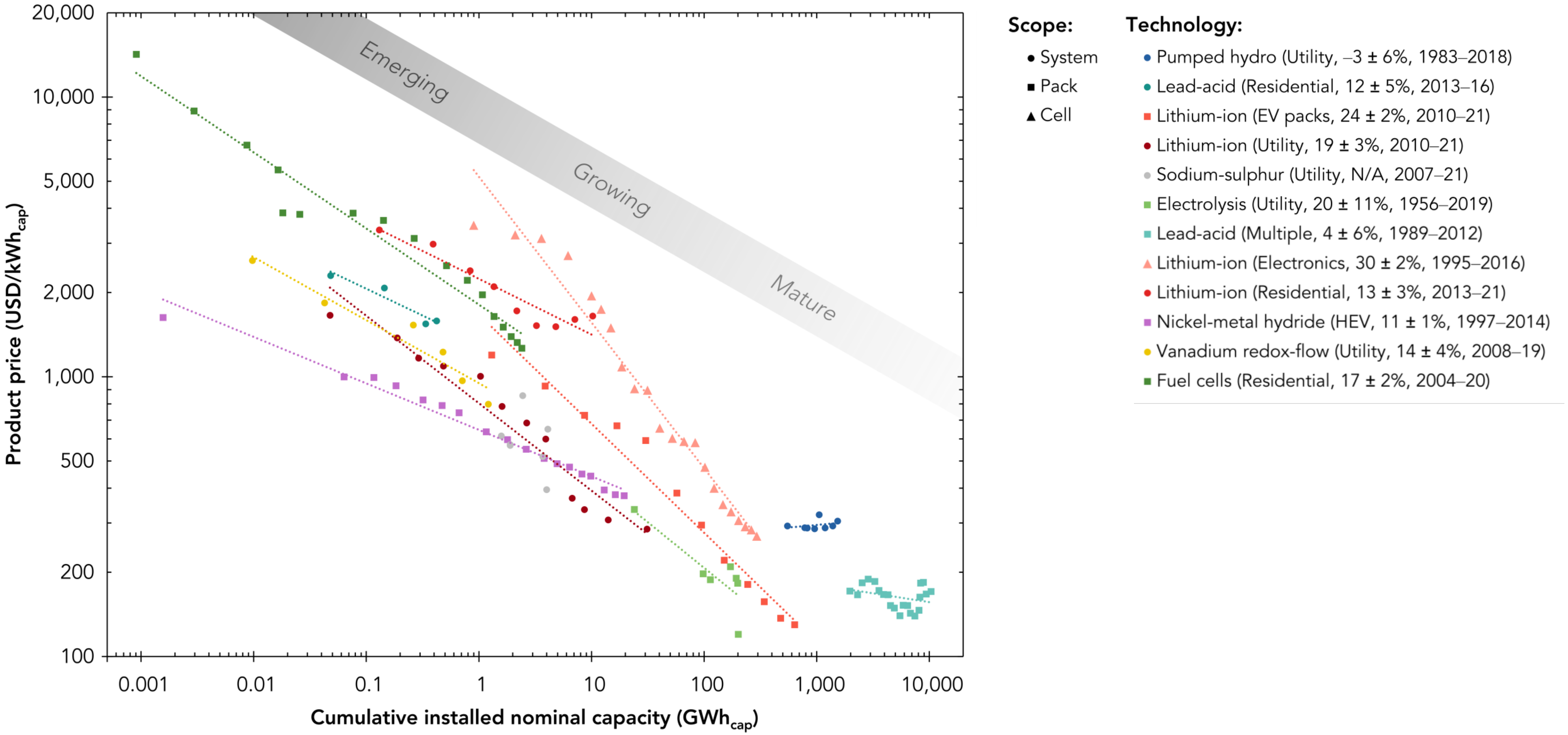
Lithium-ion prices fall at a similar rate as solar PV

Lithium-ion battery pack [USD/kWh]

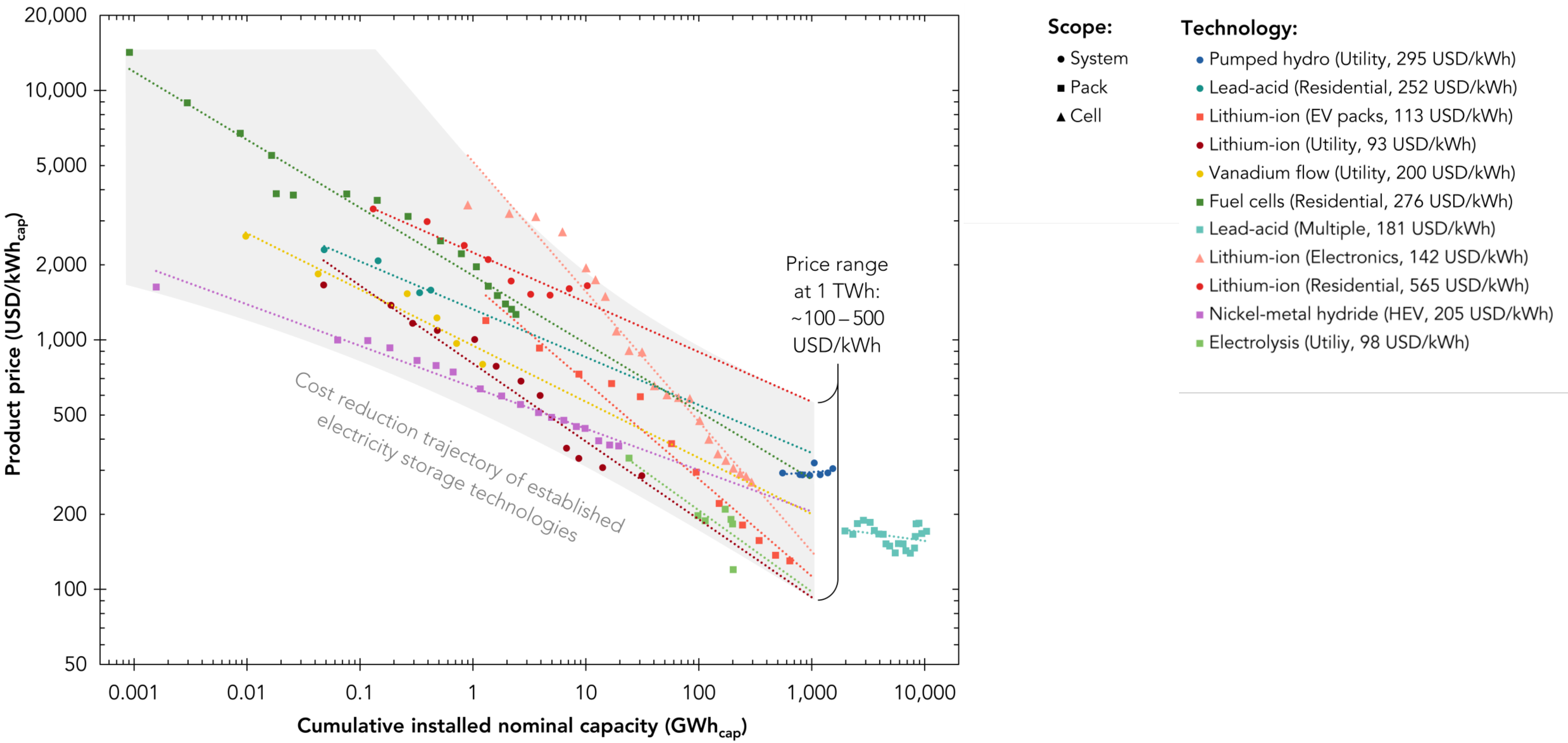




Similar trends are seen across other storage technologies



The tech that brings most capacity to market is cheapest



Schmidt & Staffell (2023): Monetizing Energy Storage

Lifetime cost of energy delivered is a more important metric

- Accounts for all cost components required to serve specific application (e.g. power conversion to enable fast response)
- Includes replacement cost to account for degradation

Cost to operate, insure and periodically service technology components

- Reflects round-trip efficiency, because more energy is purchased than discharged (respective power price depends on application)
- Thereby also accounts for auxiliary energy (e.g. AC)

Can be a cost or a value depending on the reusability or recyclability of the technology, its components and raw materials

Levelised Cost Of Storage

$$\text{LCOS}\left[\frac{\text{US\$}}{\text{MWh}}\right] = \frac{\text{Investment} + \text{O\&M} + \text{Charging} + \text{End of life}}{\text{Energy capacity} \cdot \text{Cycles per year} \cdot \text{Lifetime}}$$

- Electricity that is discharged each cycle; should include annual degradation
- If it refers to electricity charged (against common practice), round-trip efficiency and DoD must be accounted for here

- Determined by application served by the storage system
- Can have significant impact on degradation and overall lifetime as cycle life is limiting factor for most technologies

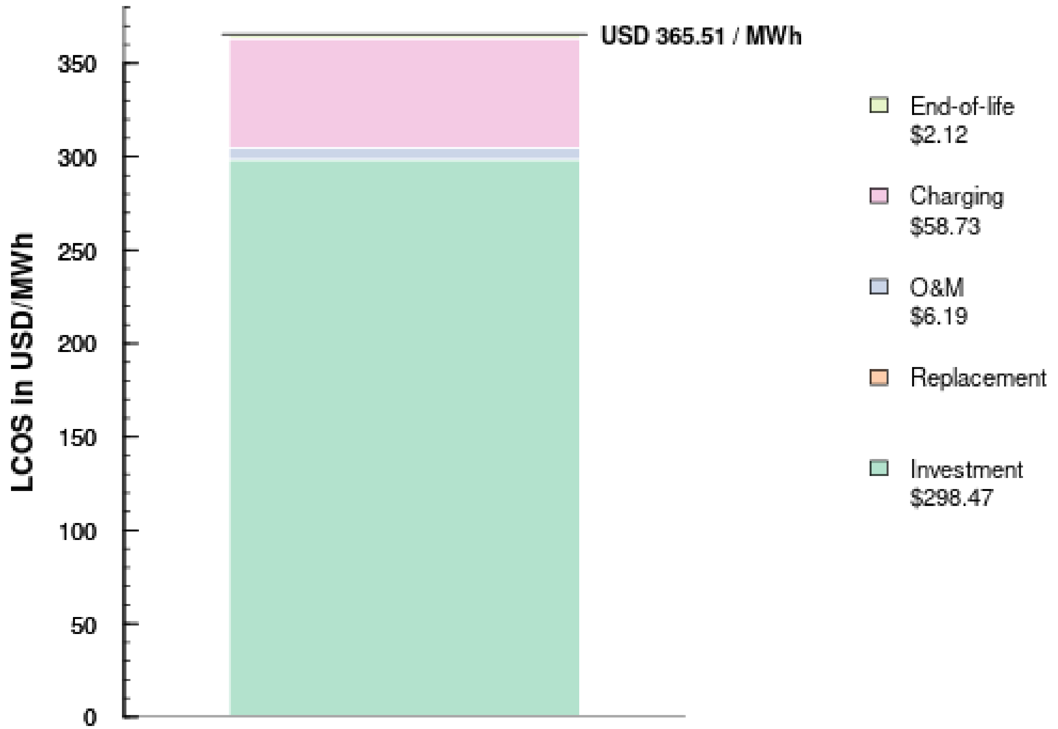
- Option 1 - Technical: Number of years after which energy capacity degraded to e.g. 80%
- Option 2 - Economic: Pre-defined number of years, e.g. secured revenue

Comparisons should use application-specific lifetime cost

Providing peak capacity (300 cycles per year x 4 hours per cycle):

Lithium-ion:

(362 USD/kWh capex, 86% efficiency, 3500 cycle lifetime)



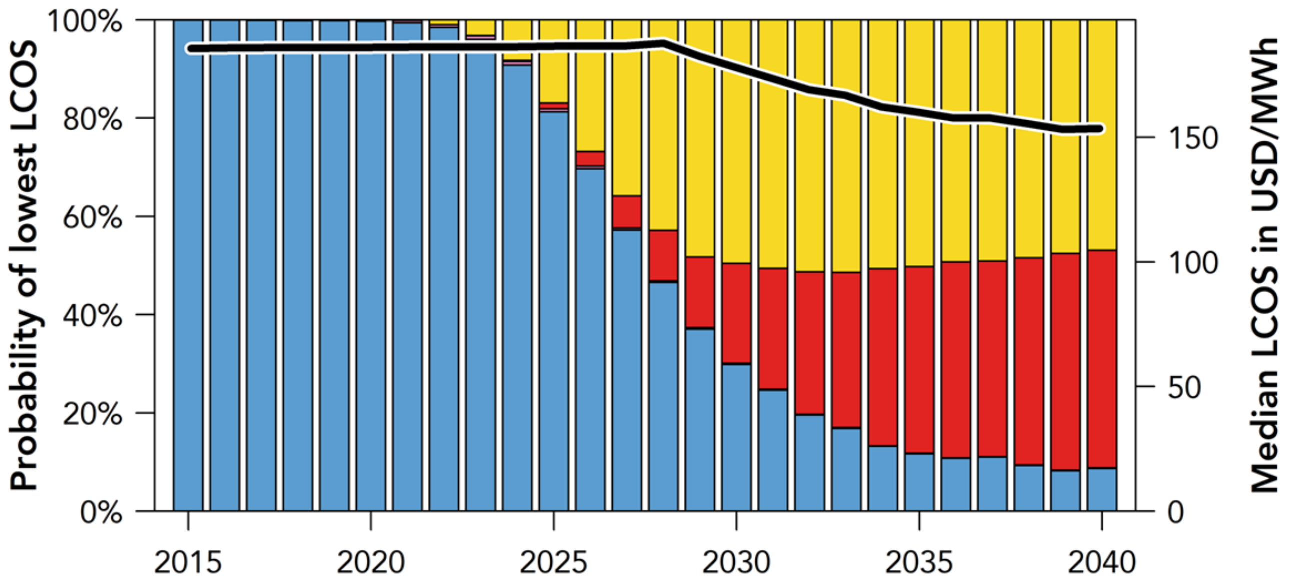
Vanadium redox-flow:

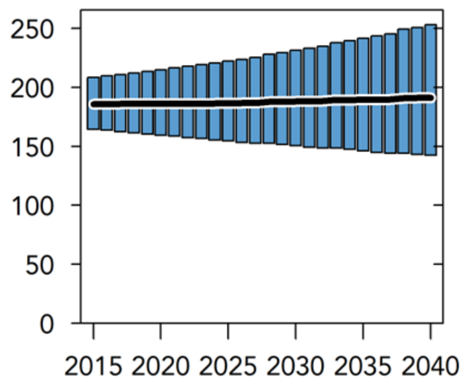
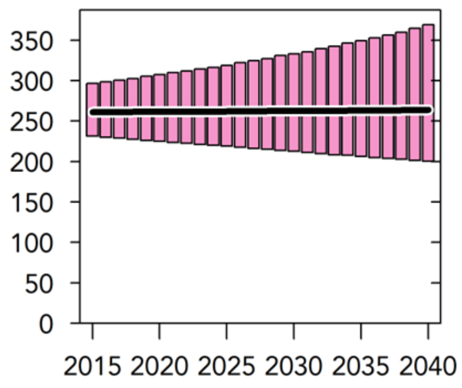
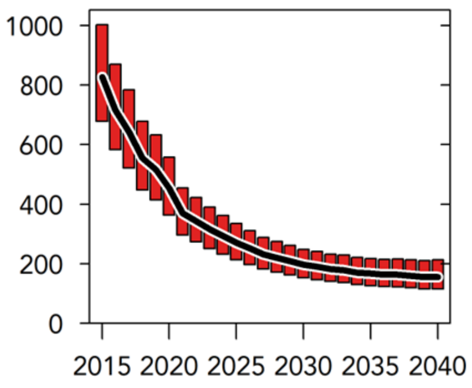
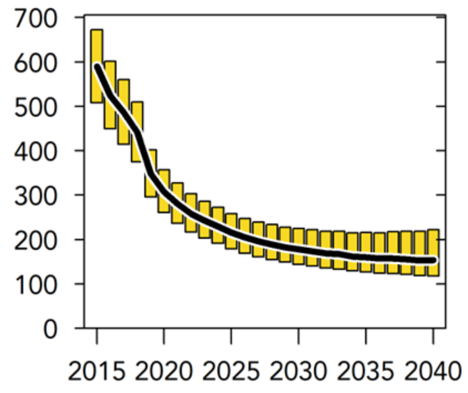
(625 USD/kWh capex, 68% efficiency, 20000 cycle lifetime)

The competitiveness of technologies will change over time

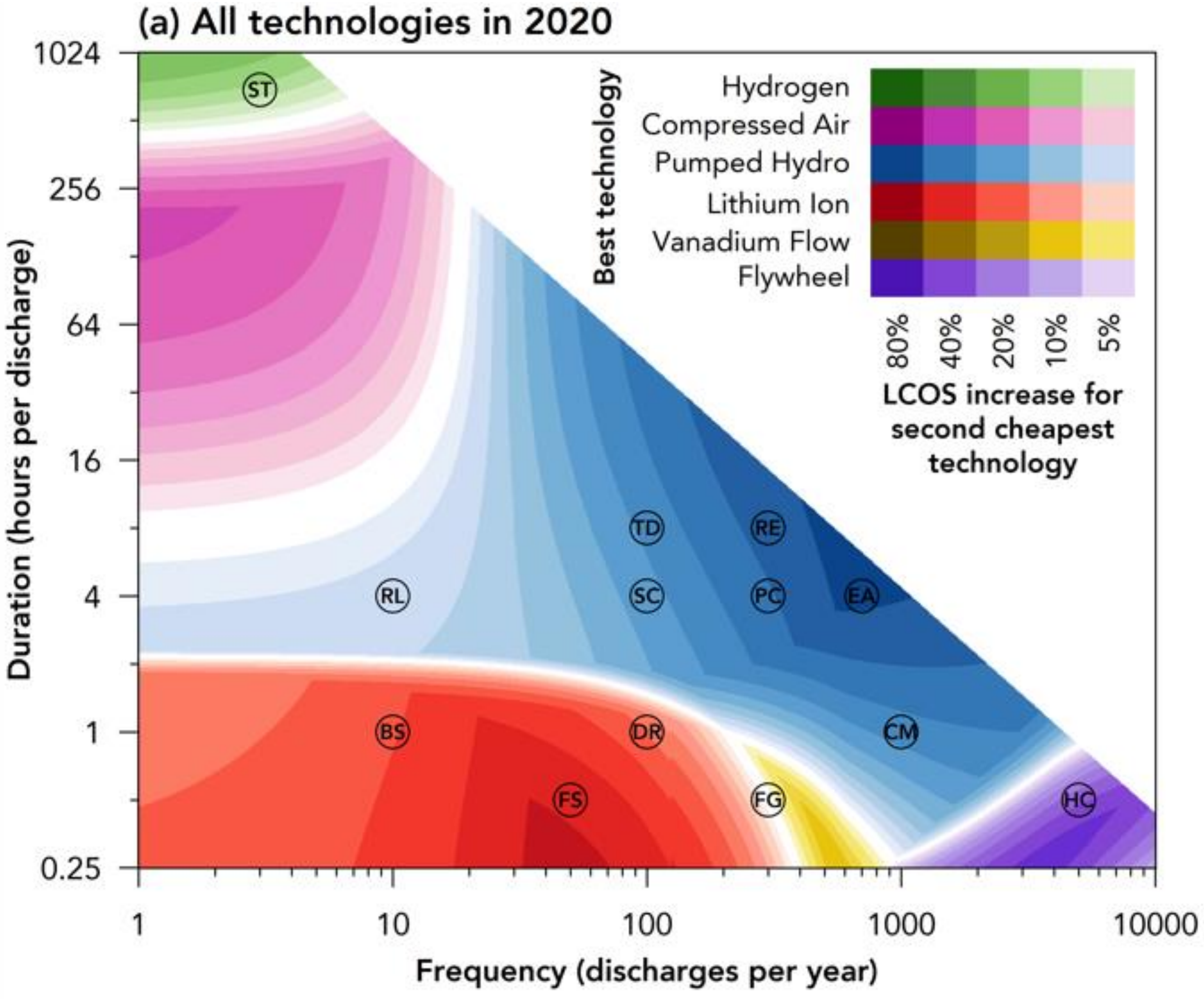
(PC) Peak capacity

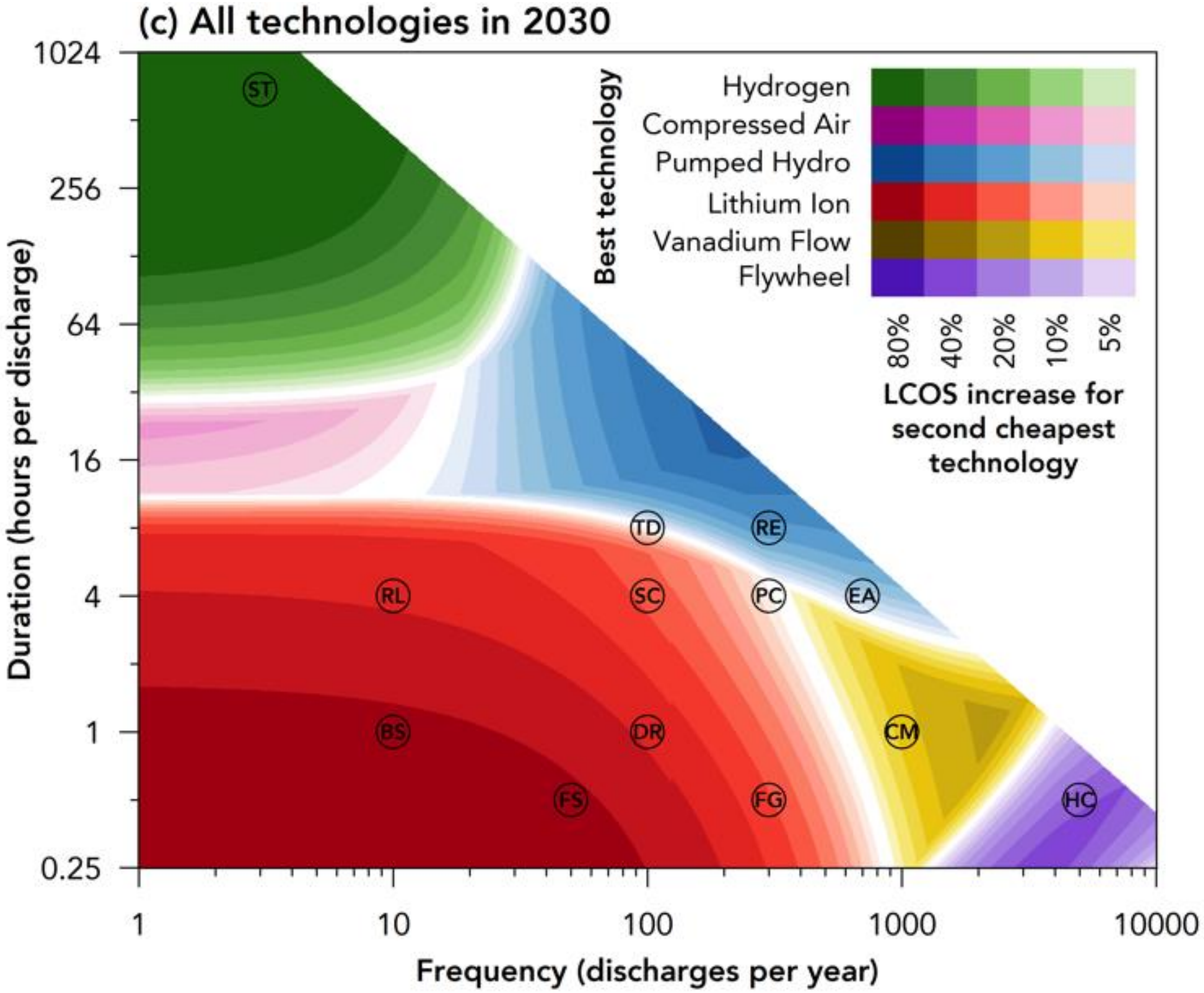
Power capacity	10 MW
Discharge duration	4 hours
Annual cycles	100
Response time	>10 seconds
Electricity price	50 USD/MWh



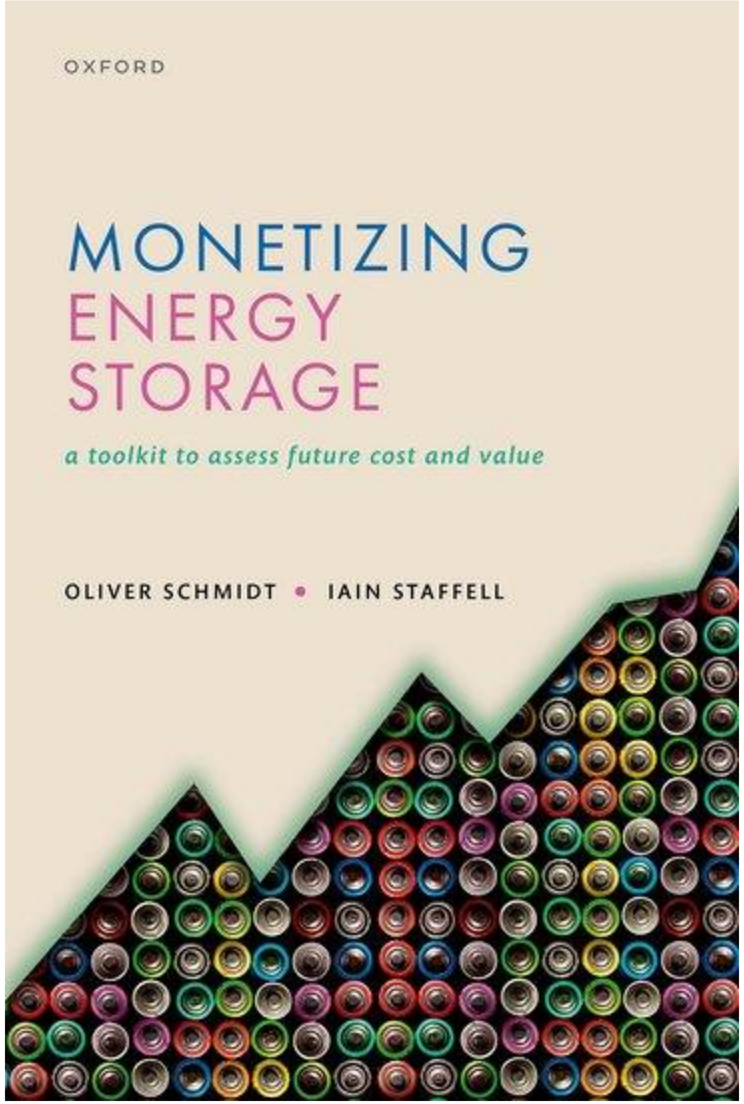
	Pumped hydro	Compressed air	Lithium ion	Vanadium redox flow
Median and range of LCOS in USD/MWh				

Depending on the applications, different technologies win





All content of this presentation comes from one book



"Essential for me as an investor to navigate this complex, fast-paced energy storage industry."

Gerard Reid, Alexa Capital

"A must-read for industry and policy professionals."

Julia Souder, Long Duration Storage Council

- Published next month
- **Digital version is for free**
- Download link: https://global.oup.com/academic/product/monetizing-energy-storage-9780192888174

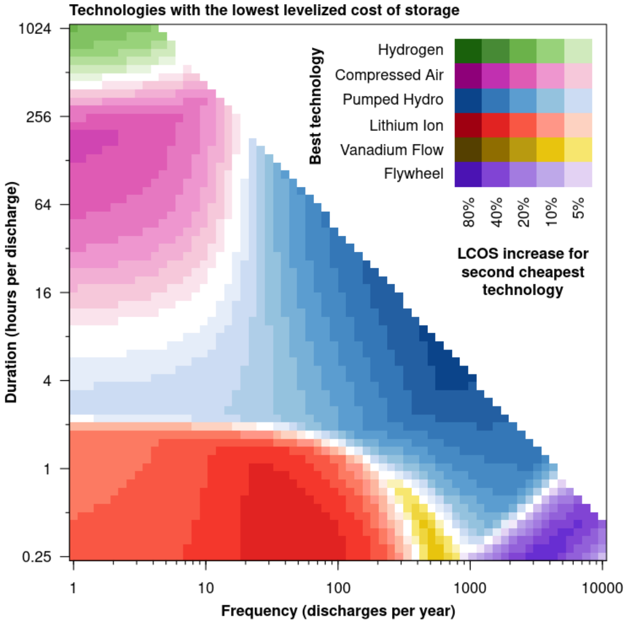
All analyses can be re-produced by you!

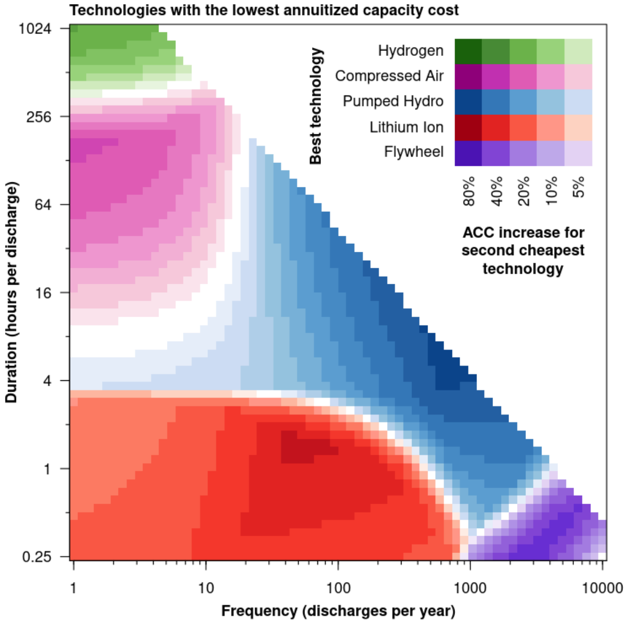
Energy storage analysis toolkit

Project economics | Cost components | Cost variation | Cost projection | Investment cost projection | Competitive landscape | Storage dispatch | System need | System value

Competitive landscape

1. Choose technology
2. Click 'Load values' to obtain respective input parameters
3. Manually refine parameters based on your own insights if needed and click 'Save values'
4. Click 'Go!' to identify the most cost-competitive technology across the application landscape





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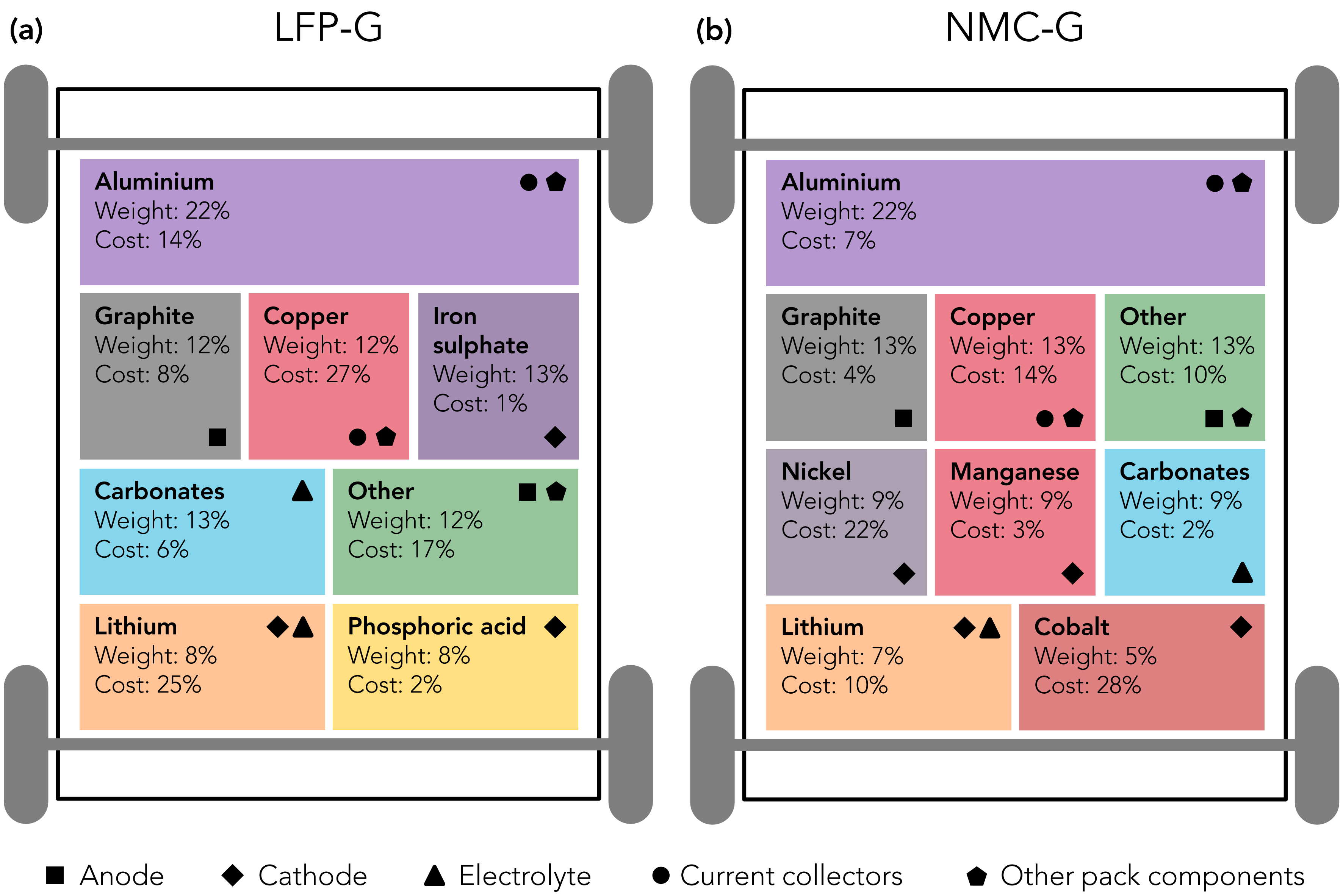
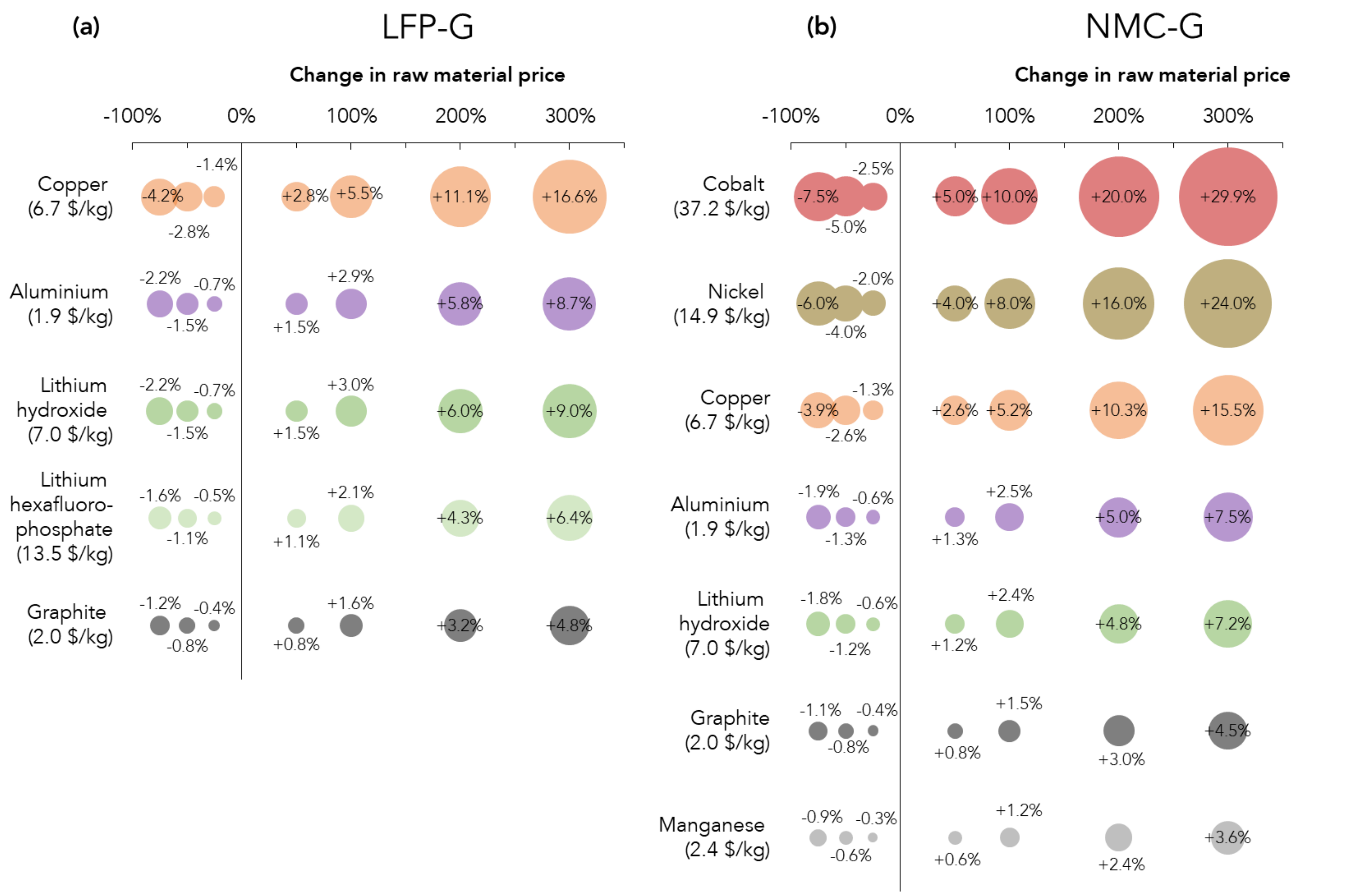
More insights on electricity storage: Storage Lab

Lithium-ion batteries use surprisingly little lithium



Raw material prices must quadruple for real impact



China dominates the lithium-ion value chain