Langzeitstromspeicher. Die technische Perspektive.

Inga Beyers

Leibniz Universität Hannover, Institut für Elektrische Energiesysteme, Fachgebiet Elektrische Energiespeichersysteme

Agenda

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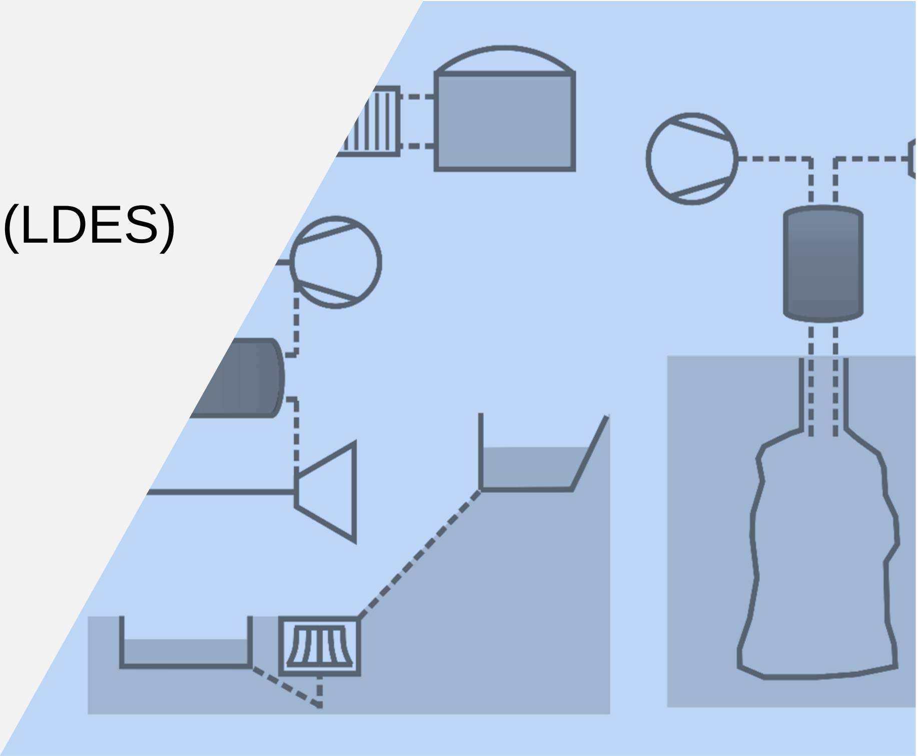
01 – Definition and demands of long-duration energy storage (LDES)

02 – Suitable technologies for grid-scale LDES applications

03 – Four hypotheses on power-to-power (P2P) LDES



Definition and demands of long-duration energy storage (LDES)

– Definition

- Emerging consensus in academia is that long duration energy storage is defined by a nominal discharge duration ≥ 10 h [1]

$$t_{\text{dis}}^{\text{nom}} = \frac{E_{\text{dis}}^{\text{nom}}}{P_{\text{dis}}^{\text{nom}}}$$

- Nominal discharge durations specified in upcoming LDES auctions
  - United Kingdom: ≥ 8 h [2]
  - California: ≥ 12 h, multi-day [3]
  - Germany, Kraftwerksstrategie: ≥ 72 h [4]
- Other potential criteria
  - Separate scalability of energy and power
  - Low marginal costs for energy capacity

– Demands

- World-wide [5]
  - 2040
  - 1.5 - 2.5 TW power capacity
  - 85 - 140 TWh energy capacity

- Europe [6]
  - 2050
  - 401 - 602 GWh energy capacity

- Germany [7]
  - 2050
  - 27 GW power capacity
  - 414 GWh energy capacity

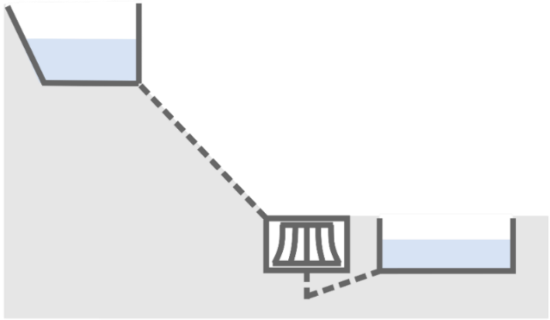
- USA [8]
  - 2050
  - 230 - 630 GW power capacity
  - 2.7 - 225.5 TWh power capacity

Suitable technologies for grid-scale LDES applications

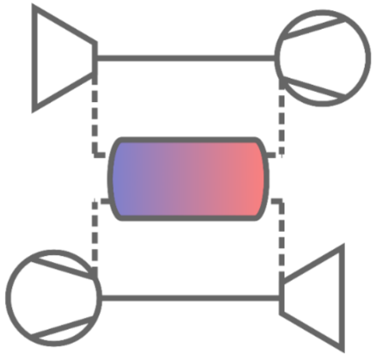
– **Suitable:**

Redox-Flow Batteries

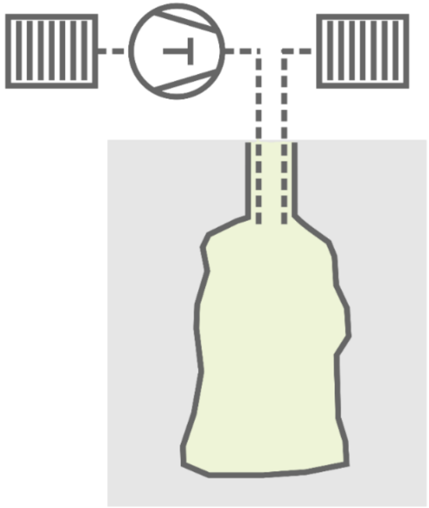
Pumped Hydro Storage



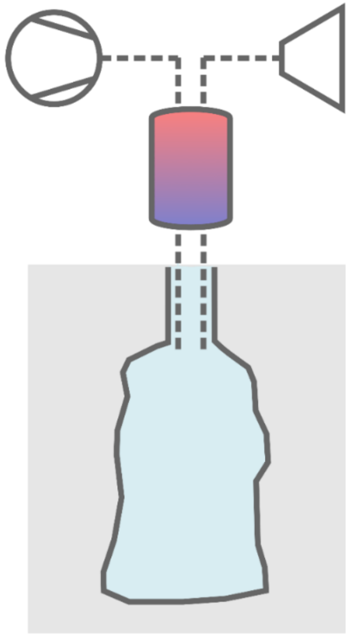
Pumped Thermal Energy Storage (PTES), a subcategory of Carnot Batteries



Power-to-Power (P2P) Hydrogen Storage



Adiabatic Compressed Air Energy Storage (A-CAES)



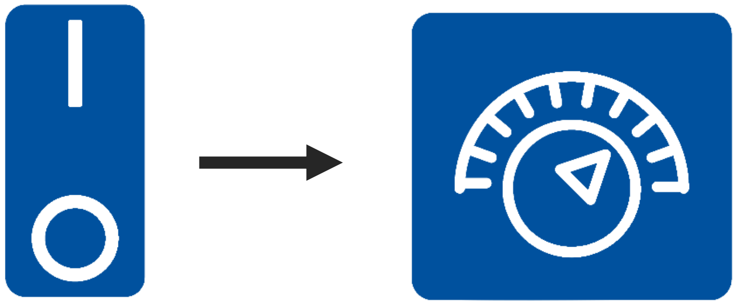
– **Excluded:**

- Liquid Air Energy Storage (LAES) which has a system roundtrip efficiency < 50 % [9]
- Gravity Energy Storage, which has system roundtrip efficiencies of ~ 80 % [10], but with a very low volumetric energy density. Footprint is too big for large-scale application in Europe.

Hypothesis 1:
"It is time for a pumped-hydro storage renaissance"

– **Next-generation pumped hydro is flexible, fast and grid-beneficial**

- "Old" pumped hydro has no flexibility in the charging direction
  - A pump connected to the electricity grid via a synchronous machine has a constant speed and can't regulate its power intake
- Current focus:



- Enabling technologies: variable speed drives and hydraulic short-circuit

– **Pumped hydro is not a "dead" technology**

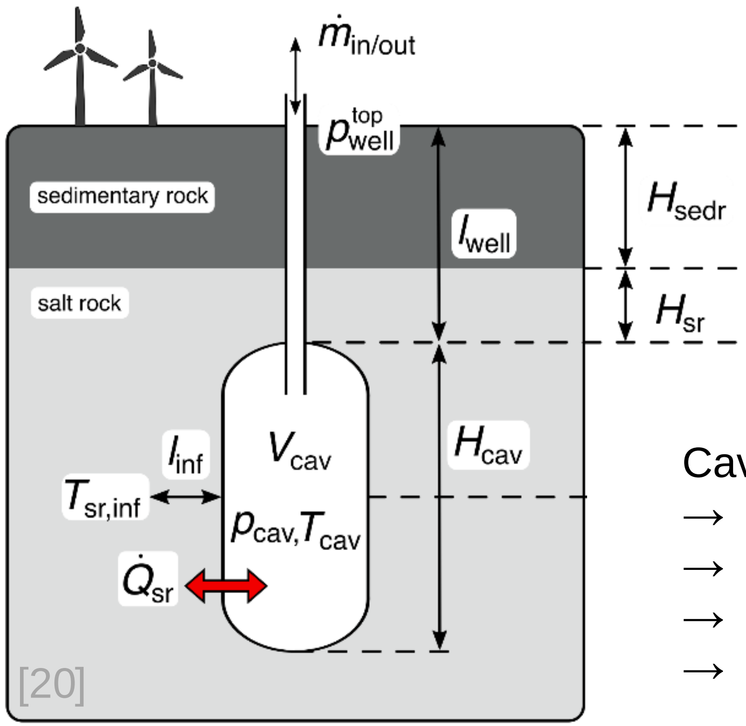
- Commissioning of Nant-de-Drance in Switzerland in 2022 [11]
- Limberg III in Austria set for commissioning in 2025 [12]
- Don't buy into the narrative of "no more pumped hydro potential" in Germany
  - Pumped hydro potential in select German federal states

	Power	Energy	Study
NW	9.4 GW	55.7 GWh	LANUV, 2016 [13]
BW	19 GW		EnBW, 2012 [14]
BY	11 GW	66 GWh	BLU, 2014 [15]
TH	4.83 GW	38.7 GWh	TMWAT, 2011 [16]
Total	44.23 GW	> 160.4 GWh	

Hypothesis 2:
“Germany can become Europe‘s long-duration energy storehouse”

– **Large-scale storage in form of salt caverns**

- Two technologies can profit: Adiabatic Compressed Air Energy Storage (A-CAES) and Hydrogen Power-to-Power systems



Cavern attributes:
→ Tight
→ Cheap
→ Self-healing
→ Low footprint

– **Relevant developments**

- Grid-scale adiabatic compressed air energy storage has been demonstrated in Zhangjiakou, China [17]
  - Commissioning in September 2022
  - 100 MW / 400 MWh system using pressure vessels instead of caverns
  - Round-trip efficiency of 70.4 % [18] → charging / discharging efficiency of ~ 84 %
- Emerging consensus: hydrogen storage in salt caverns is possible and unproblematic
  - HyCAVmobil project filled a demonstrator cavern, hydrogen quality remains high [19]
- Expect roundtrip efficiencies of ~ 30 % (via fuel cells) or ~ 35 % (via gas turbines) for hydrogen power-to-power systems

Hypothesis 2:
“Germany can become Europe‘s long-duration energy storehouse”

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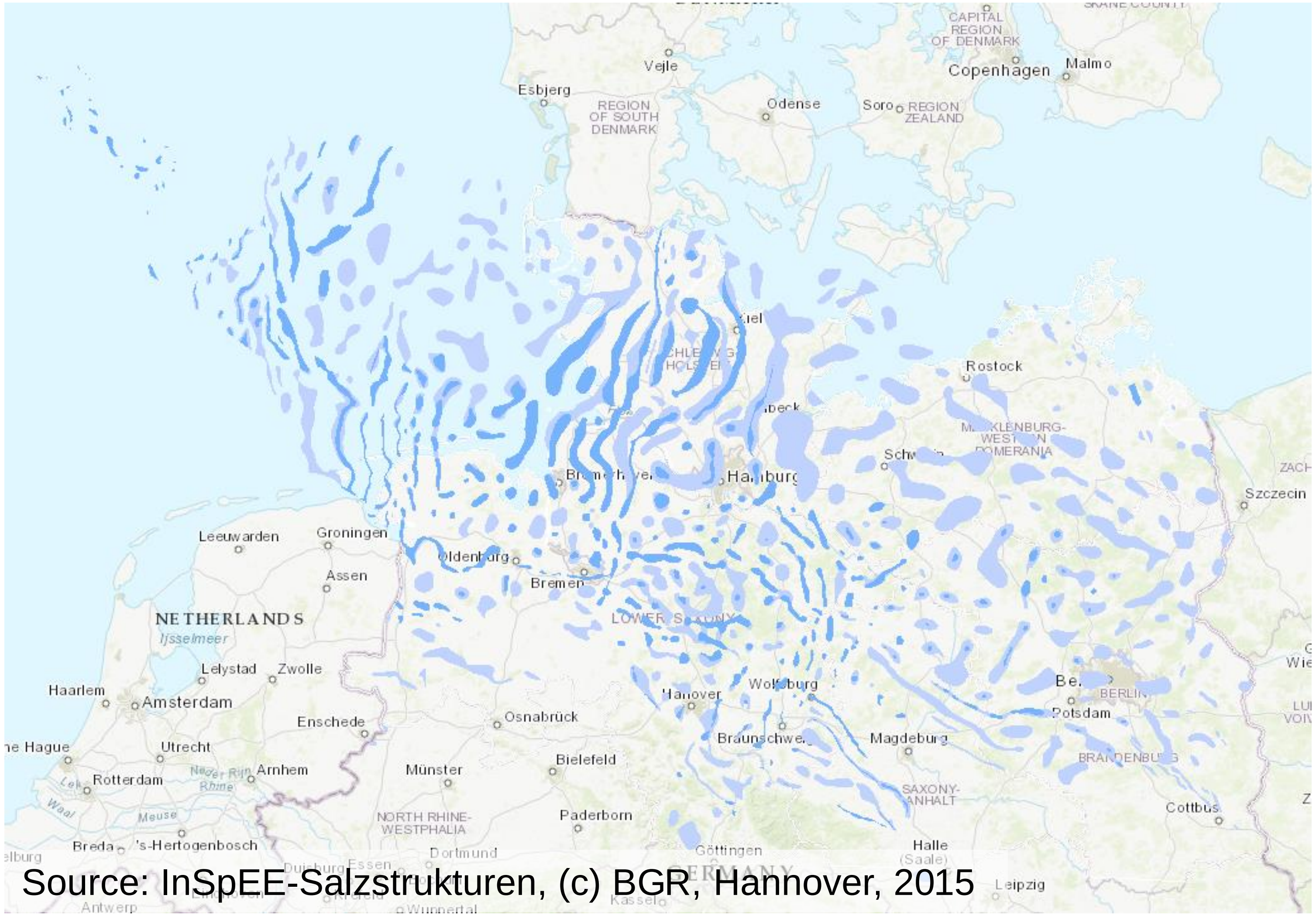


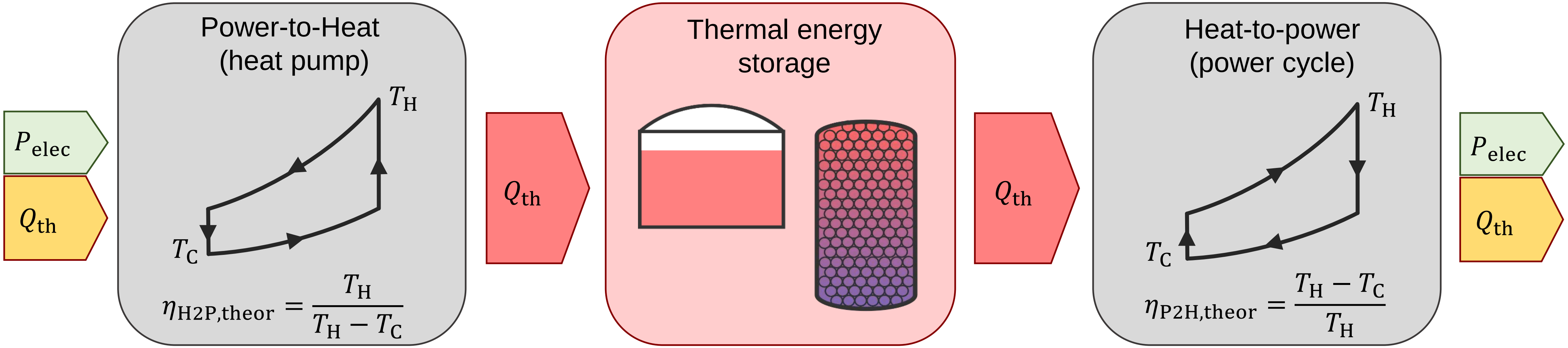
Source: InSpEE-Salzstrukturen, (c) BGR, Hannover, 2015

– **Germany’s cavern storage potential**

- Germany has 270 salt caverns that currently store natural gas [21]
  - Operators are looking for a transformation perspective
- Conversion of existing salt caverns from natural gas to hydrogen storage has 32.4 TWh storage potential [22]
  - Ensuring hydrogen purity will be a challenge
- Northern Germany has vast further salt cavern potential of
  - 7.6 TWh compressed air or
  - 3478 TWh hydrogen [23]

Hypothesis 3:
“Carnot batteries are not going to prevail as pure P2P storage systems”

- Carnot batteries is a collective term for all technologies that convert electric power to heat (charging), store it in thermal energy storage, and reconvert heat to electric power.
- Pumped thermal energy storage (PTES) is deemed most suitable for grid-scale applications.

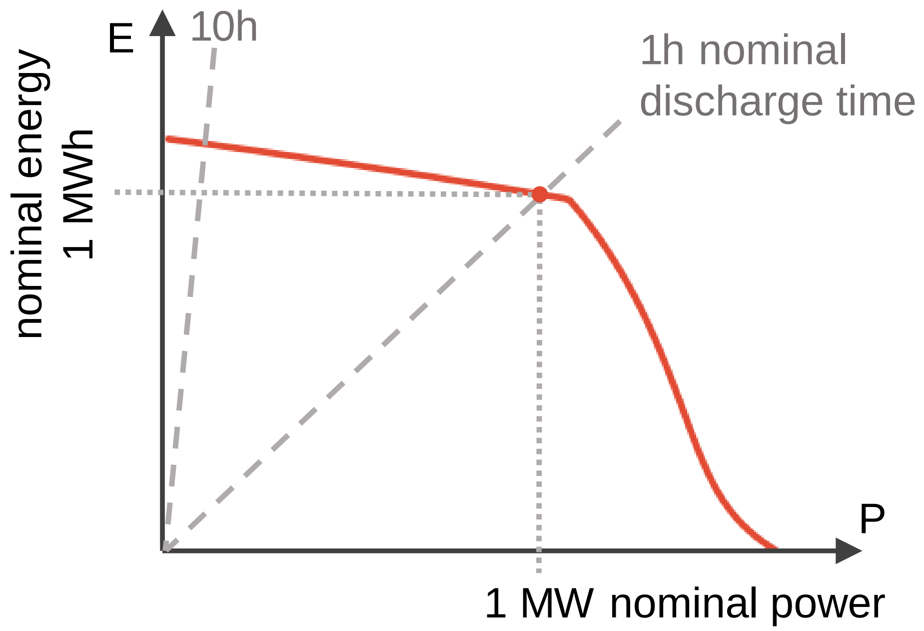


- Technology Readiness Level 5 - 7 [24, 25], expected P2P round-trip efficiencies of 50 - 65 % [9]
- Latest research sees a limited role for power-to-power PTES in Europe [26], but there is unique sector-coupling potential of thermally integrated Carnot batteries

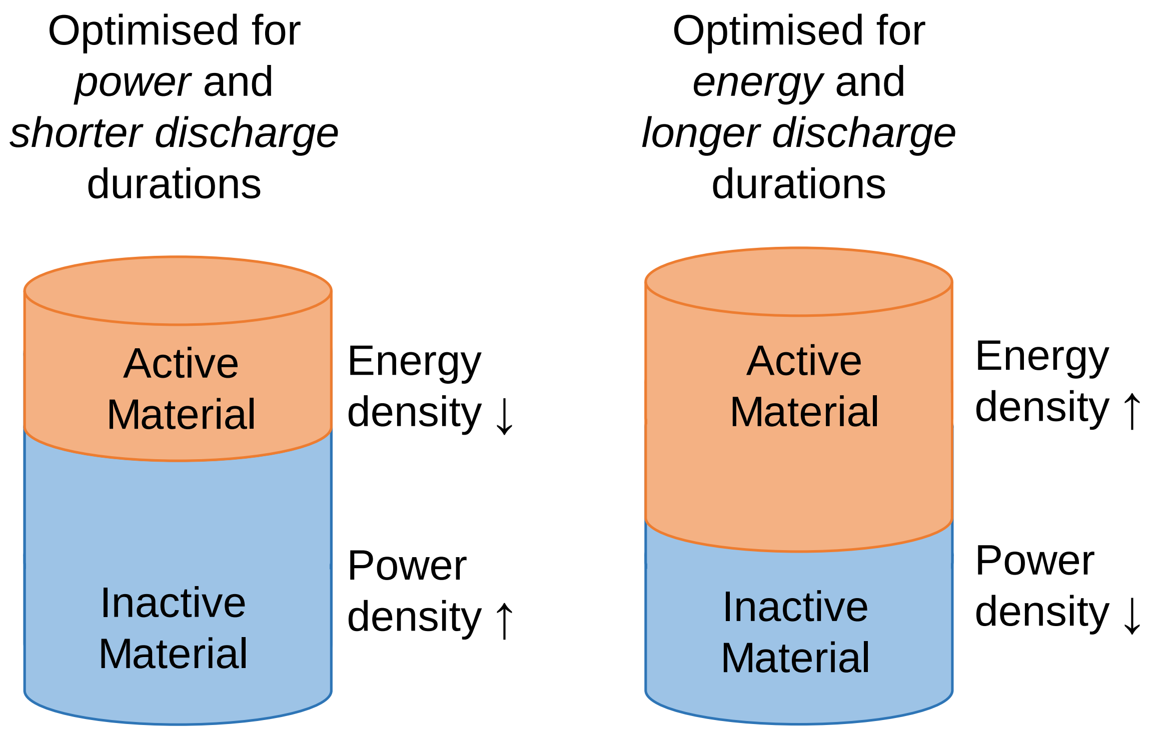
Hypothesis 4:
“The competition is not between different long-duration storage technologies, but between LDES technologies and cheap Li-Ion batteries”

– **Regular lithium-ion batteries absolutely *can* discharge for long durations!**

  • In fact, you will even get more energy out of Li-Ion batteries, when discharging in part-load [27]

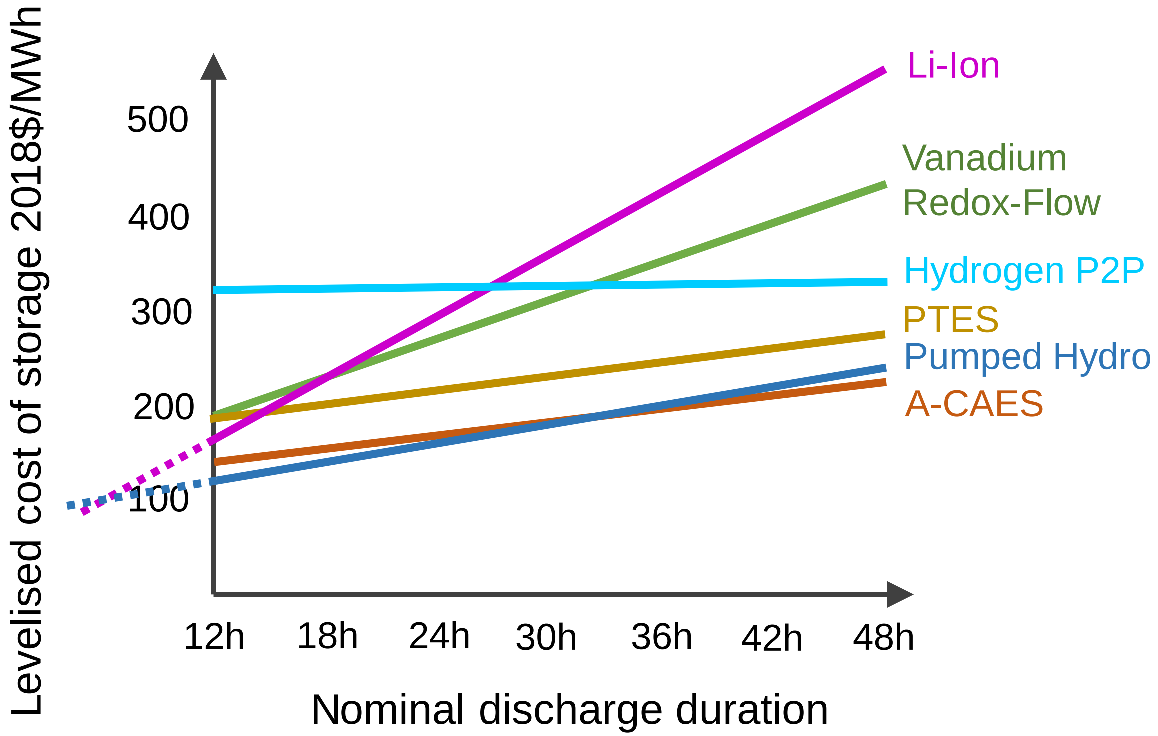


– **Lithium-ion cells can be optimised for longer discharge durations**



Hypothesis 4:
“The competition is not between different long-duration storage technologies, but between LDES technologies and cheap Li-Ion batteries”

– **The fall of Li-Ion marginal energy capacity costs continually shifts the LDES parity point**



Source: Hunter et al. 2021 [28]

– **Lithium-ion batteries are coming for long-duration energy storage:**

- CATL, the world‘s largest cell manufacturer, has joined the LDES council in May 2024 [29]
- The UK regulator Ofgem previously excluded Li-Ion batteries for its upcoming LDES auction, but reversed that decision in March 2025 [2]
- The Australian market has seen announcement of several Li-Ion battery projects with $t_{\mathrm{dis}}^{\mathrm{nom}}$ = 8h
  - 50 MW / 400 MWh, RWE + Tesla [30]
  - 3 GW / 24 GWh, Quinbrook + CATL [31]
  - 275 MW / 2.2 GWh, Ark Energy + Hanwha [32]
- LDES start-up Energy Vault now offers Li-Ion battery project development as well” [33]

Thank you for your attention!

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– Summary of hypotheses

1) “It is time for a pumped-hydro storage renaissance”

2) “Germany can become Europe‘s long-duration energy storehouse”

3) “Carnot batteries are not going to prevail as pure P2P storage systems”

4) “The competition is not between different long-duration storage technologies, but between LDES technologies and cheap Li-Ion batteries”

– Contact details

- E-Mail: beyers@ifes.uni-hannover.de
- LinkedIn:
- Electric Energy Storage Systems Group

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