The competitive landscape for energy storage technologies

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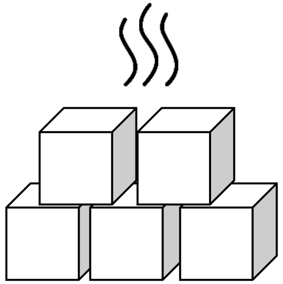
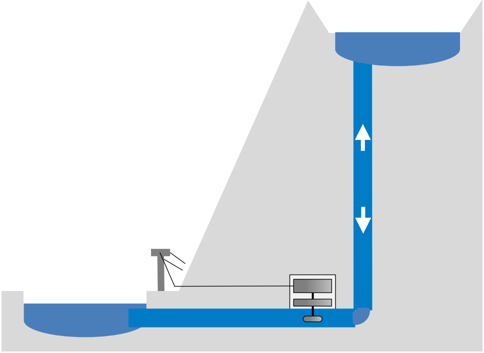
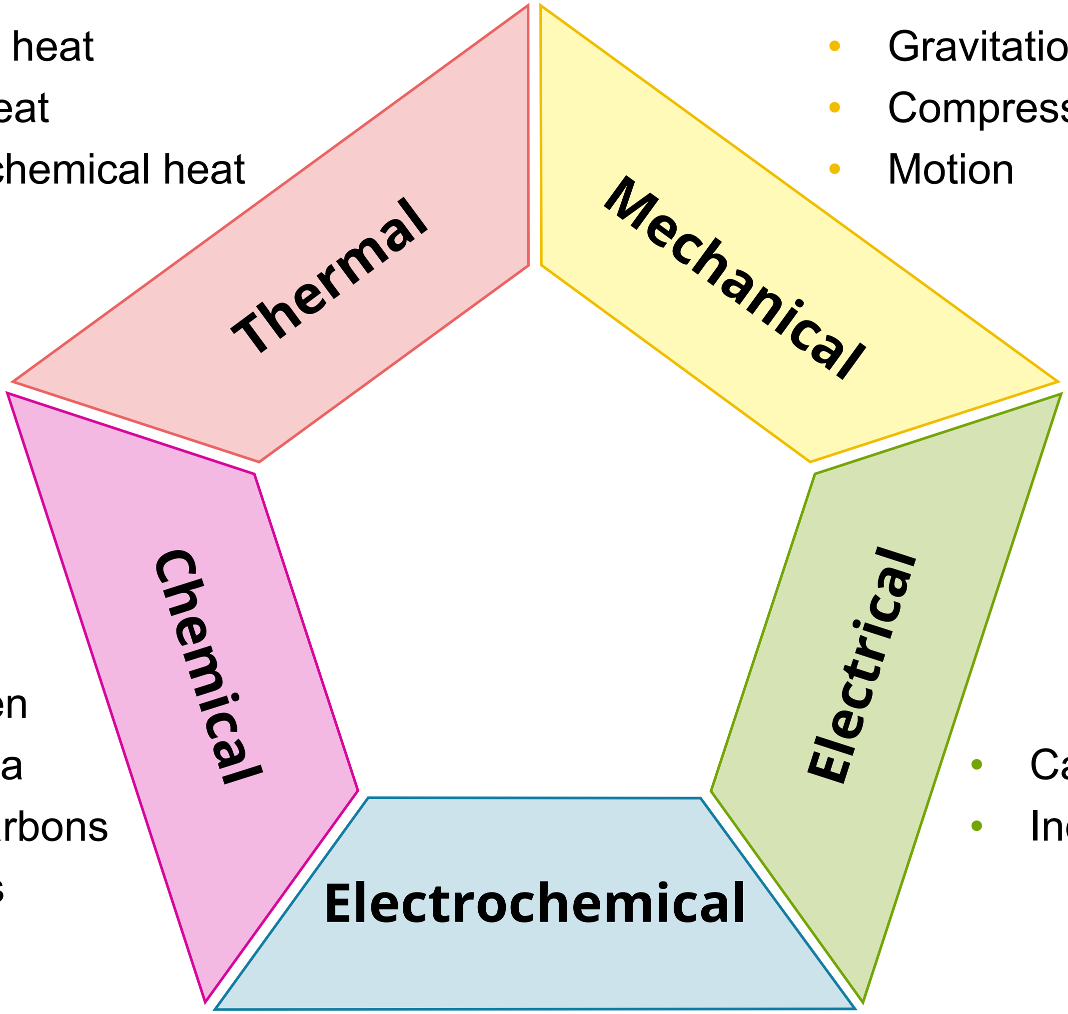
There are many diverse energy storage technologies…

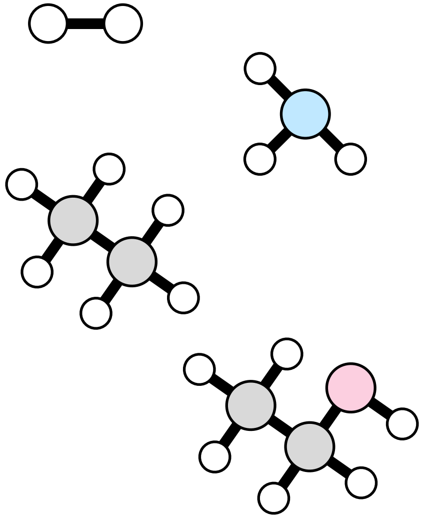


- Sensible heat
- Latent heat
- Thermochemical heat

- Gravitation
- Compression
- Motion

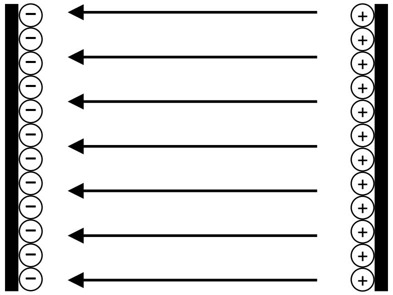


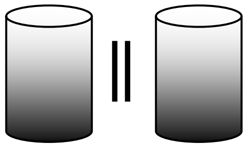




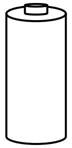
- Hydrogen
- Ammonia
- Hydrocarbons
- Alcohols

- Capacitance
- Inductance

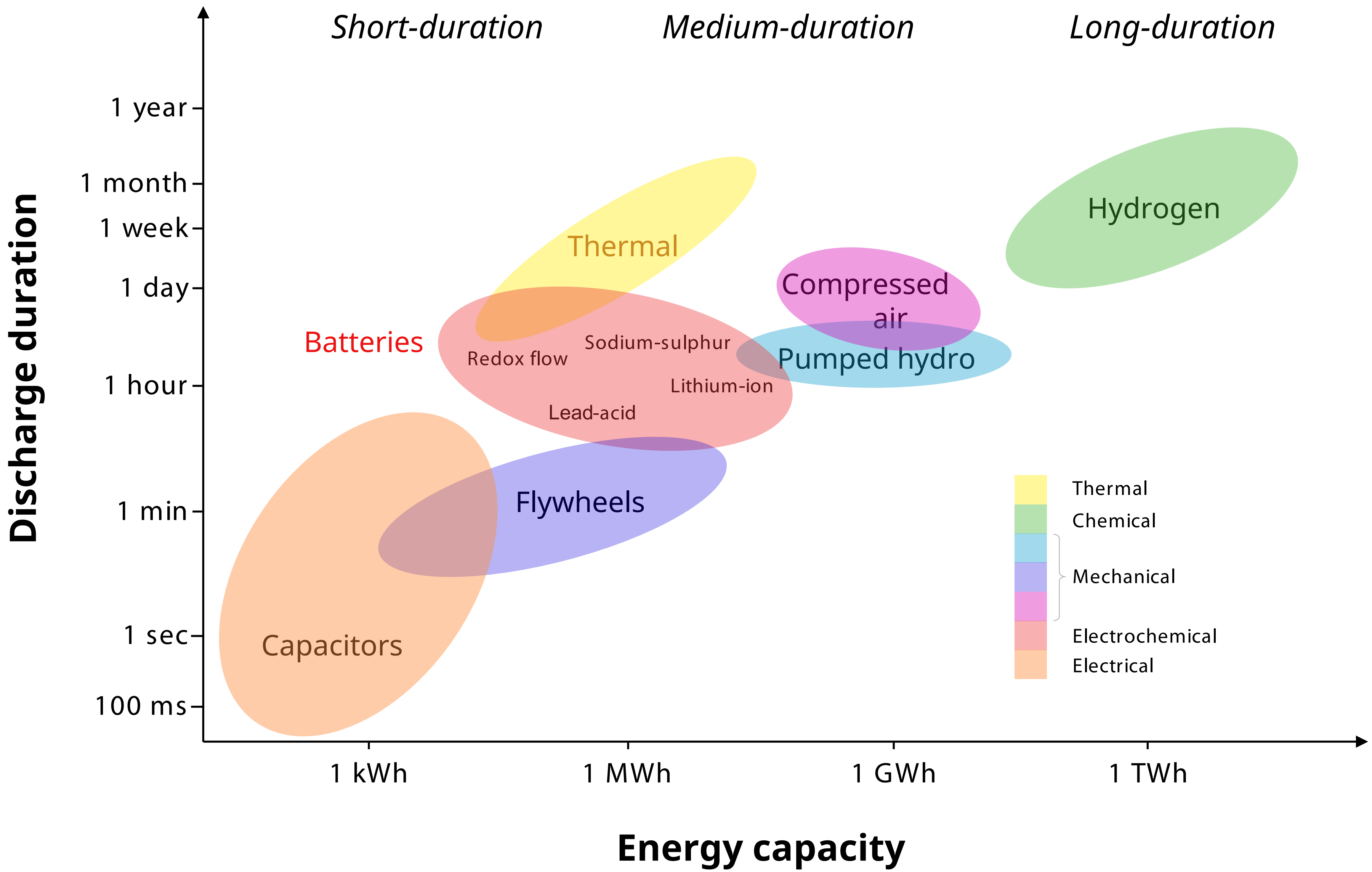




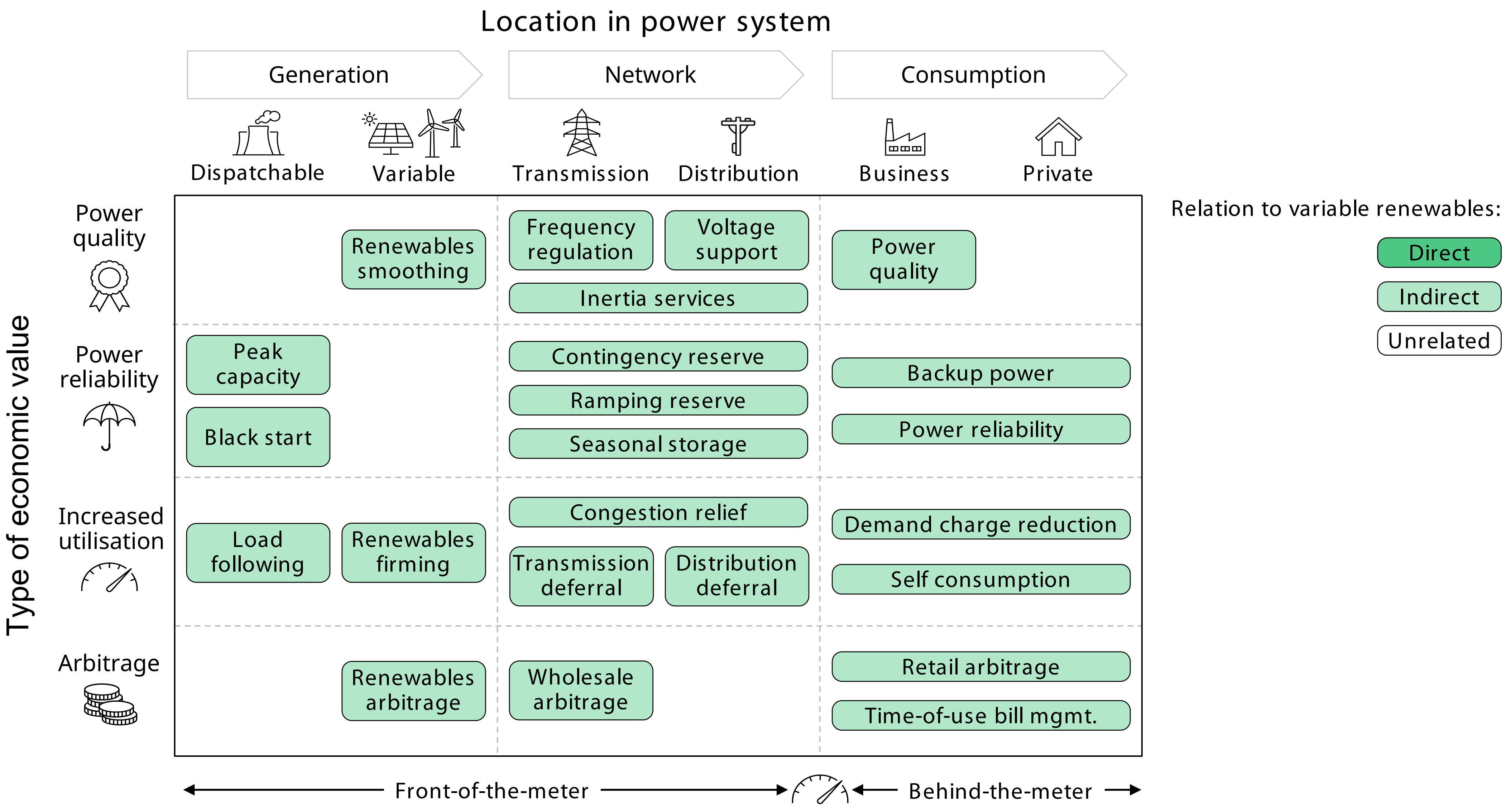
- Sealed batteries
- Flow batteries



… that all have very different characteristics



At the same time, there is a wide range of applications…



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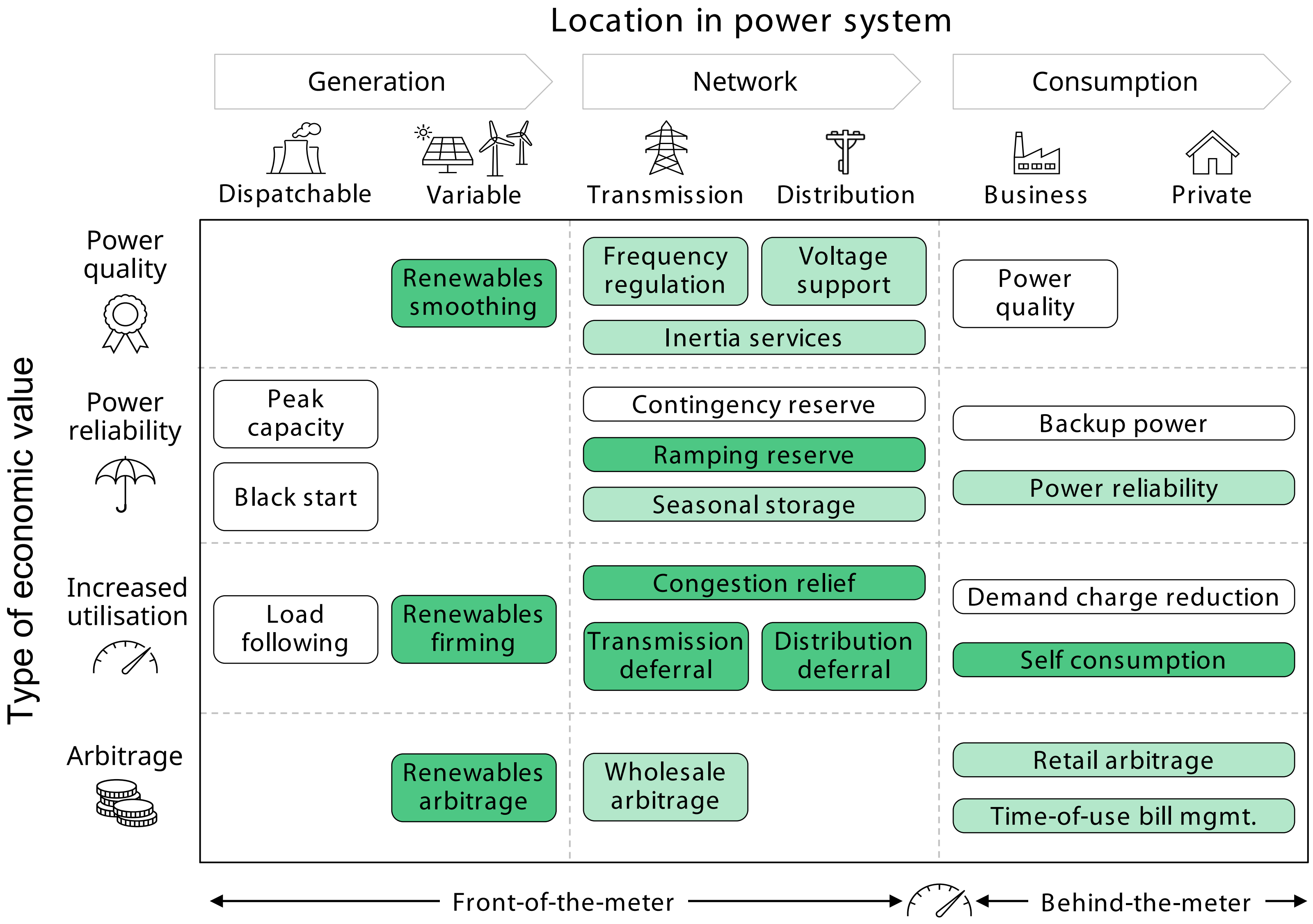


Relation to variable renewables:

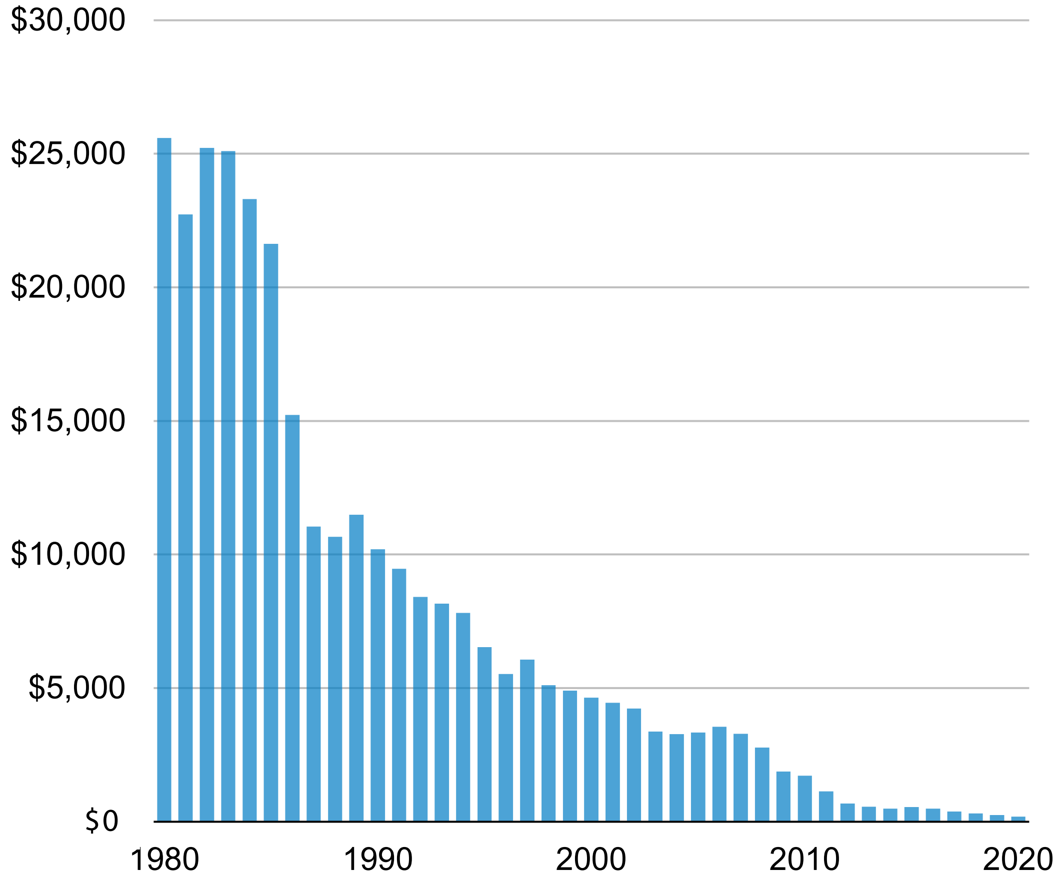
- Direct
- Indirect
- Unrelated

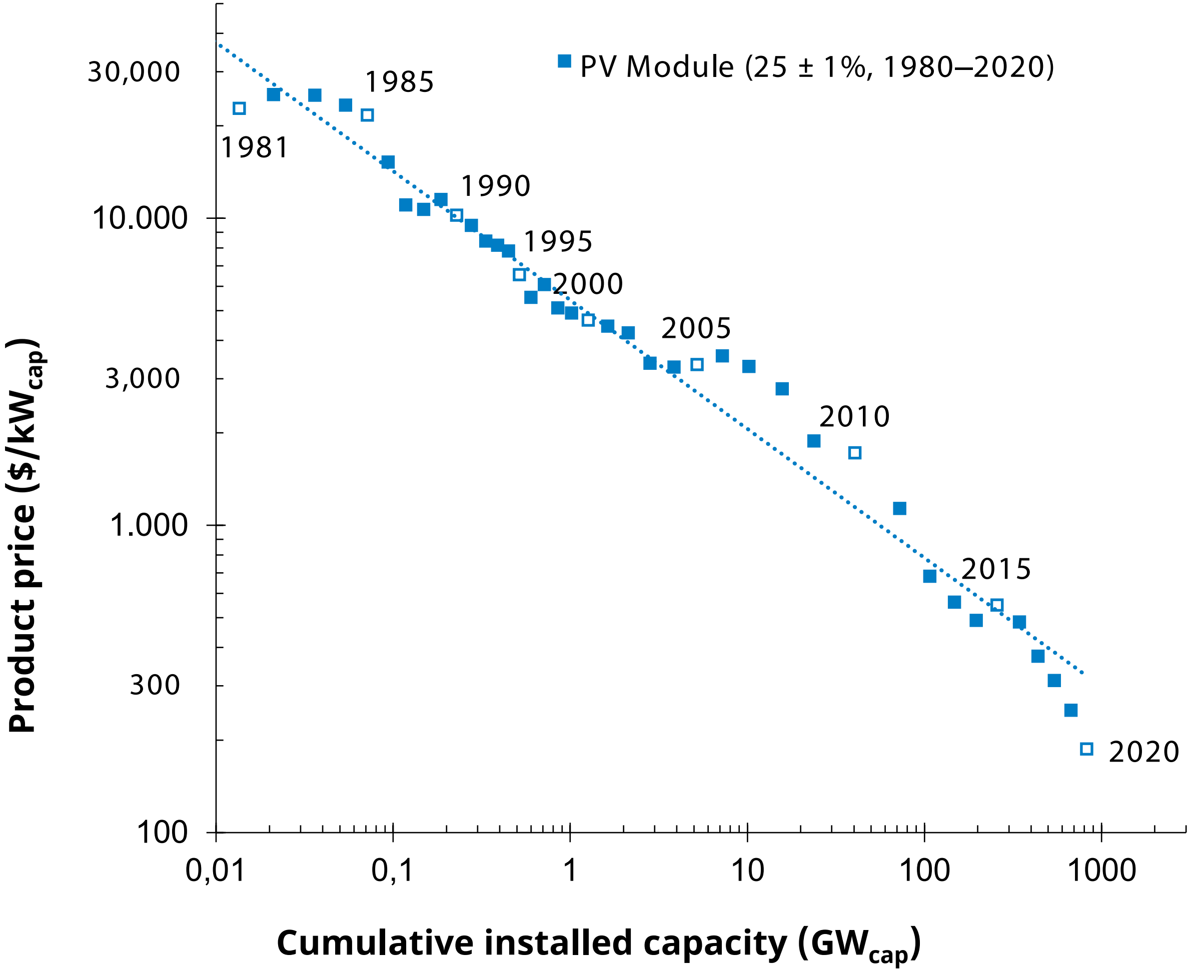
Storage is complex.

There are many technologies and services they can provide for the clean energy transition.

Falling prices can be expressed by their *'experience curve'*

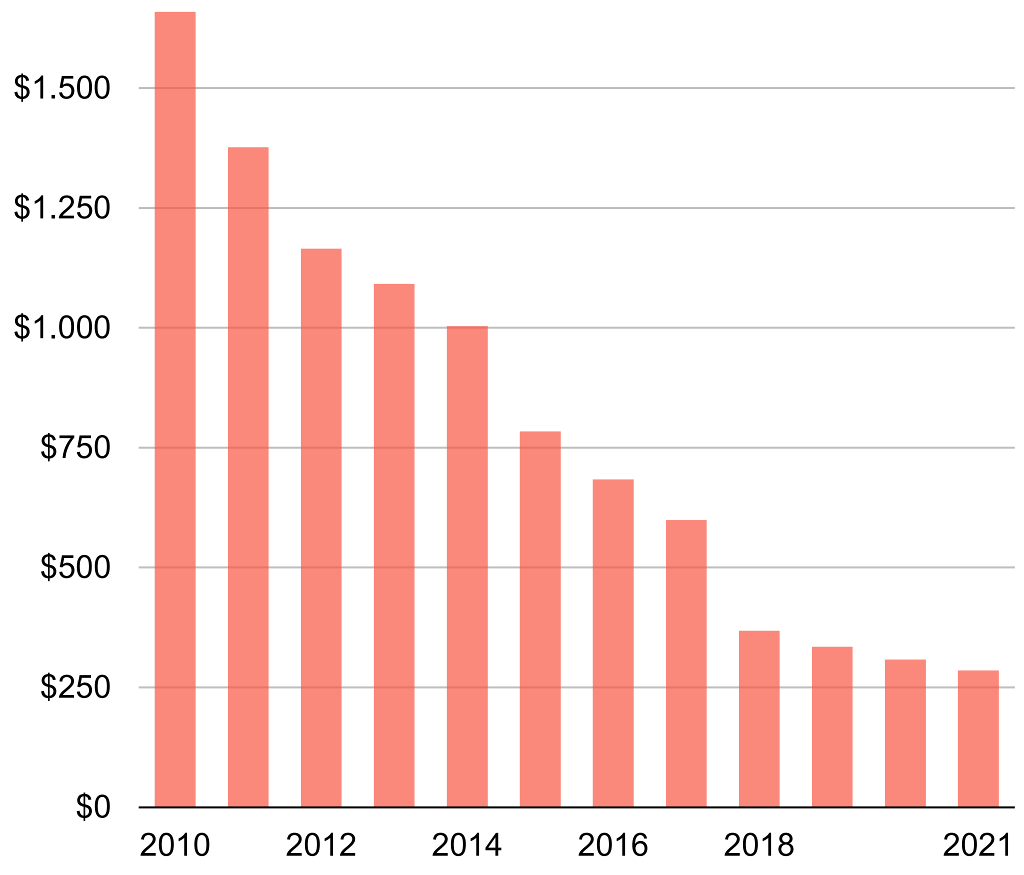
Solar PV modules ($/kW)

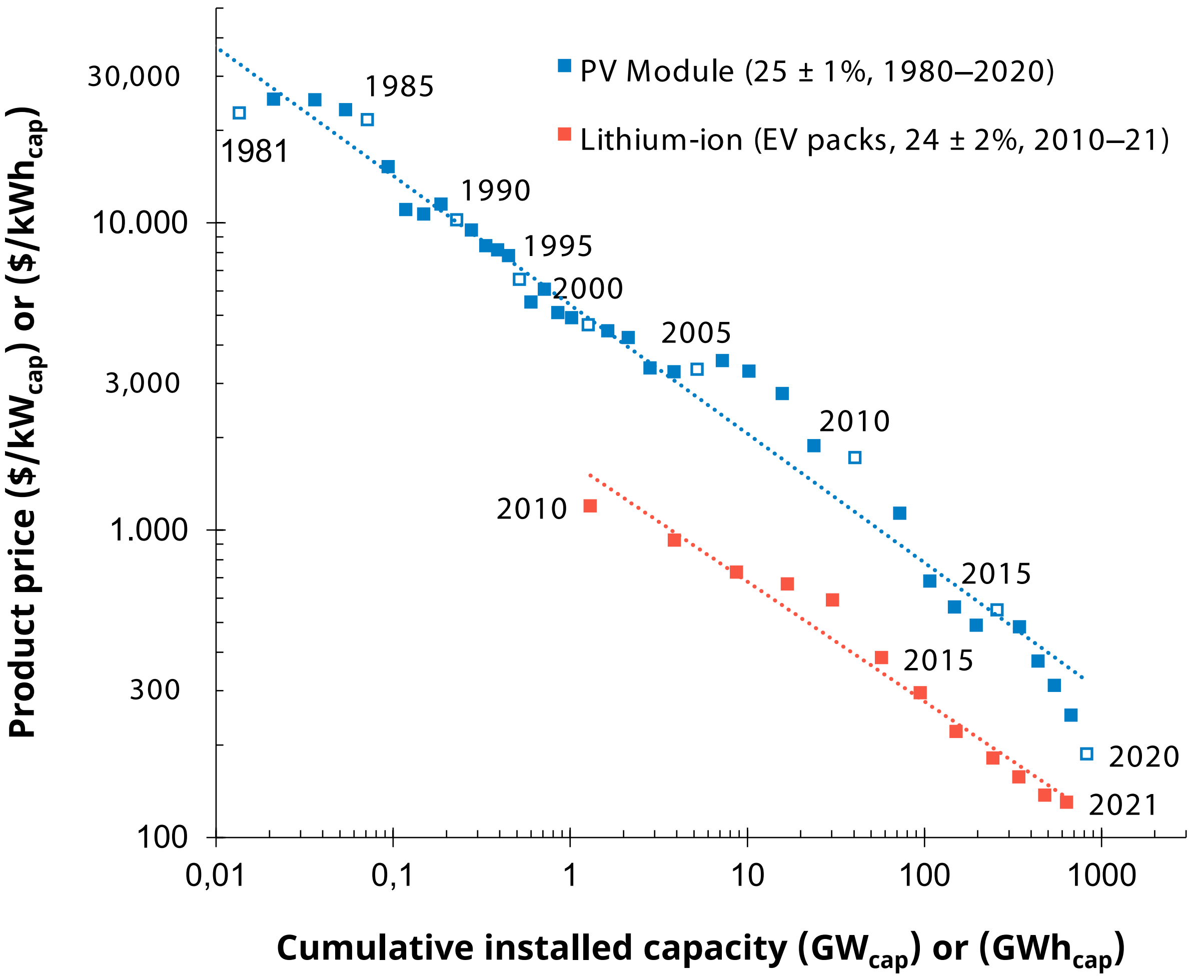




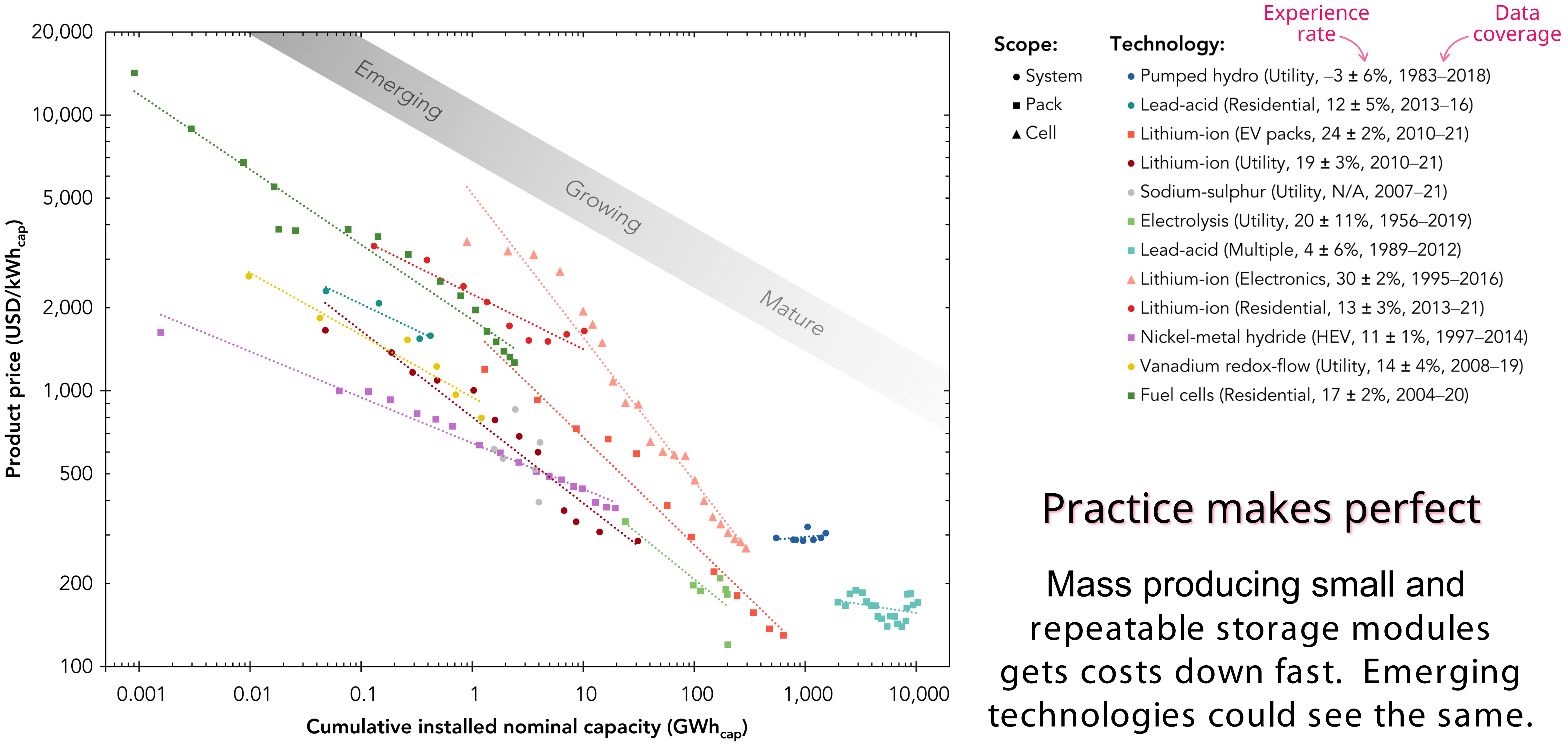
Lithium-ion prices fall at a similar rate as solar PV

Lithium-ion battery packs ($/kWh)





Similar trends are seen across other storage technologies



Practice makes perfect

Mass producing small and repeatable storage modules gets costs down fast. Emerging technologies could see the same.

Lifetime cost is *the* metric for economic decision-making

- 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)
- Also accounts for auxiliary energy (e.g. air conditioning)

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

Costs

NEQU [WU& / OYj] ? (Kpxguvo gpv - Q(O - Ej cti kpi - Gpf qh nkhg) / (Gpgti { ecr cekv{ · E{ engu r gt {gct · Nkhgvko g)

Output

(all costs and energy output are discounted over the 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

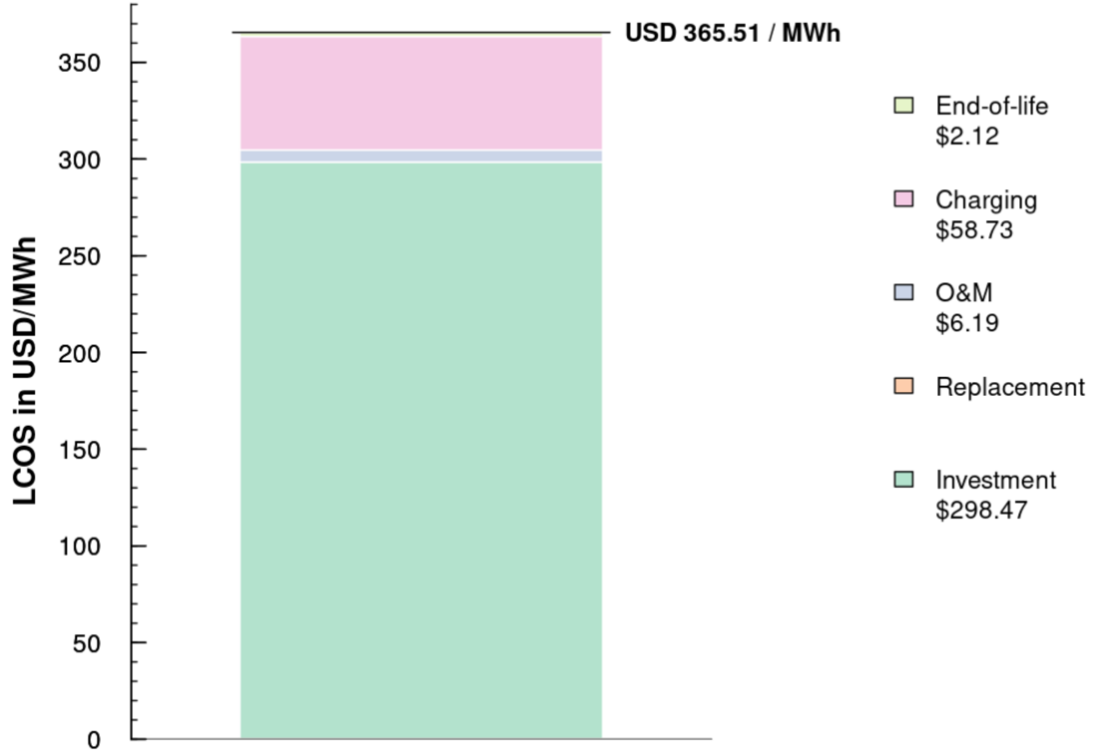
- Option 1 - Technical: Number of years after which energy capacity degraded to e.g. 80%
- Option 2 - Economic: Pre-defined number of years, e.g. secured revenue

Comparisons must use application-specific lifetime cost

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

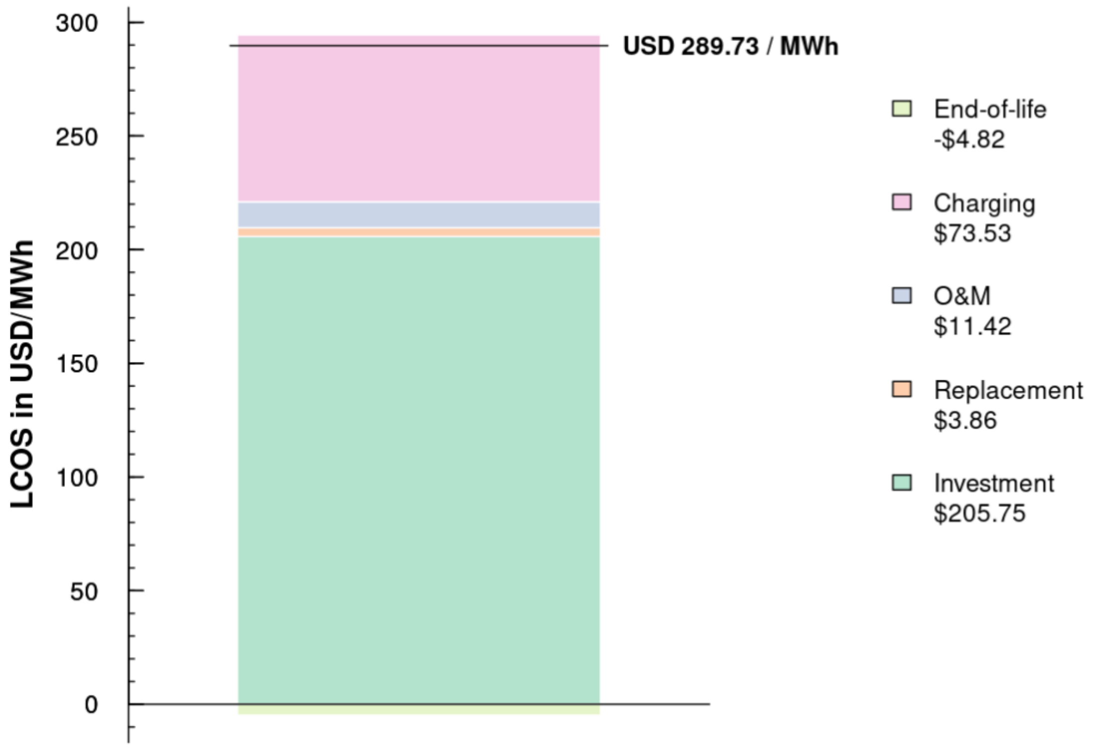
Lithium-ion:

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



Vanadium redox -flow:

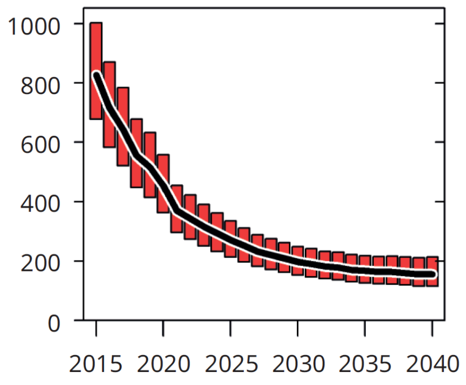
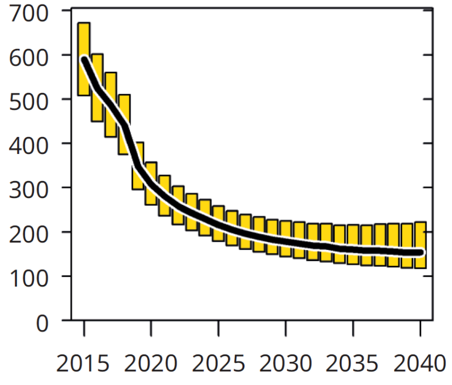
(625 $/kWh capex, 68% efficiency, 20000 cycle lifetime)



The competitiveness of technologies will change over time

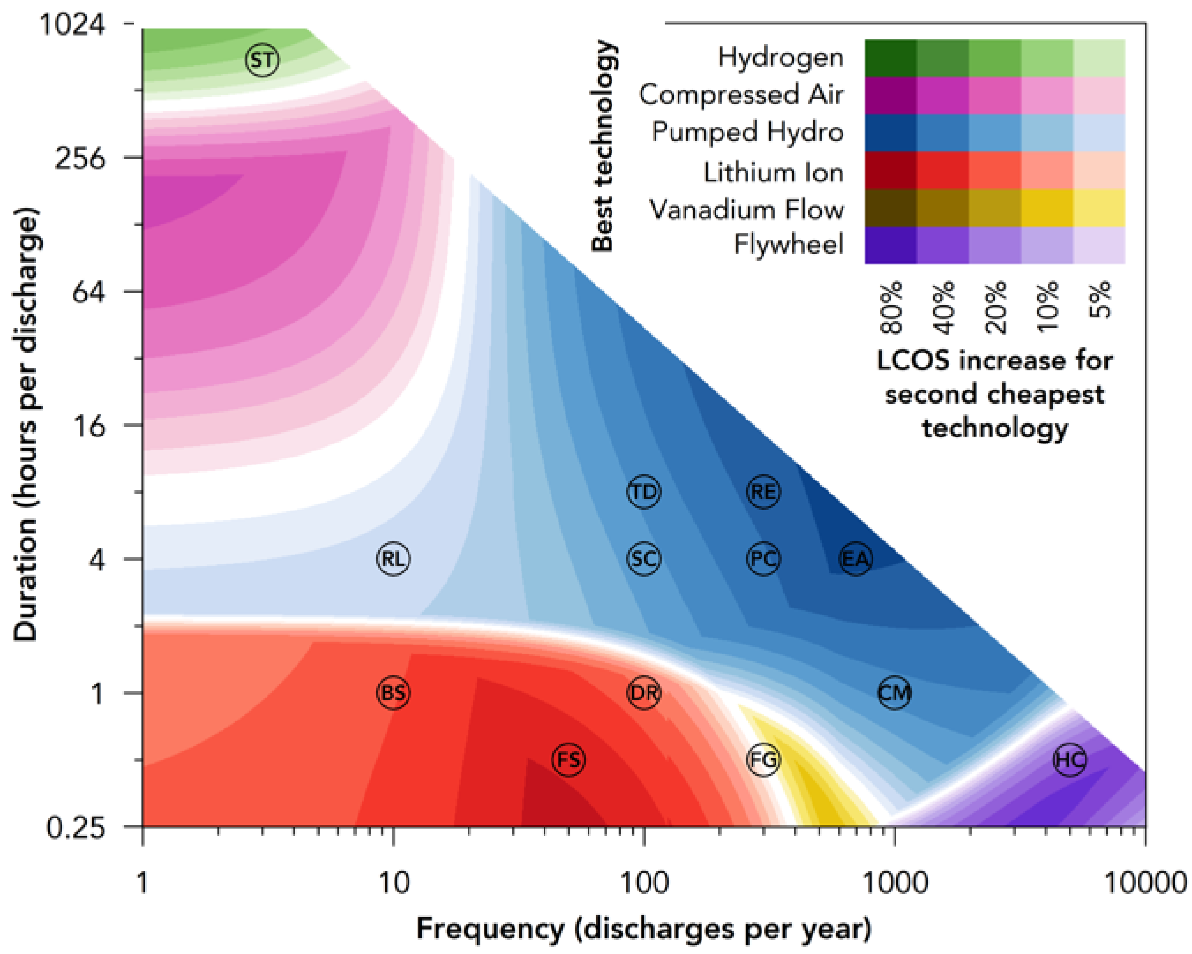
PC Peak capacity

Power capacity	10 MW
Discharge duration	4 hours
Annual cycles	300
Response time	>10 seconds
Electricity price	50 USD/MWh

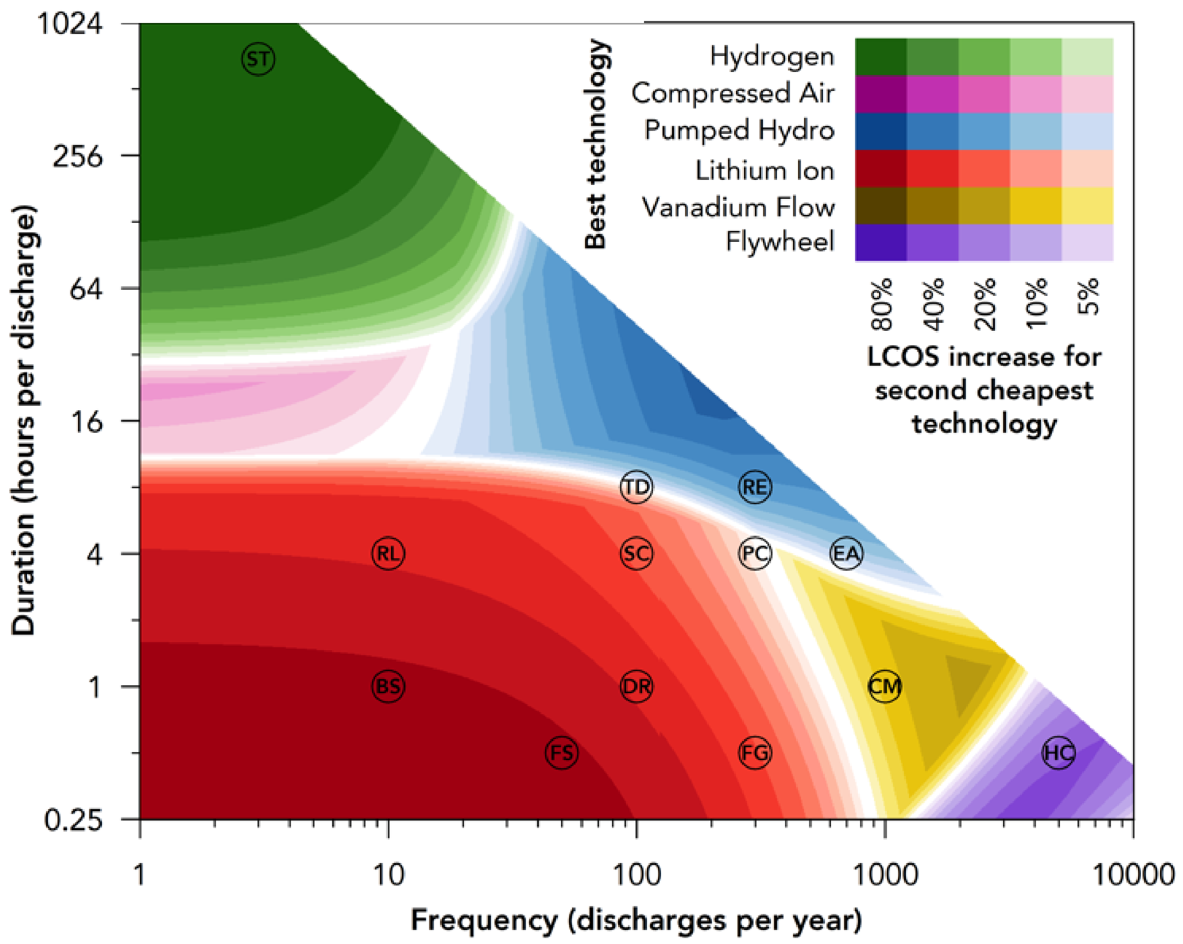
			Lithium ion	Vanadium redox flow
Median and range of LCOS in USD/MWh				

Current costs and how fast they fall with scale-up determines which technologies win each application

2020:

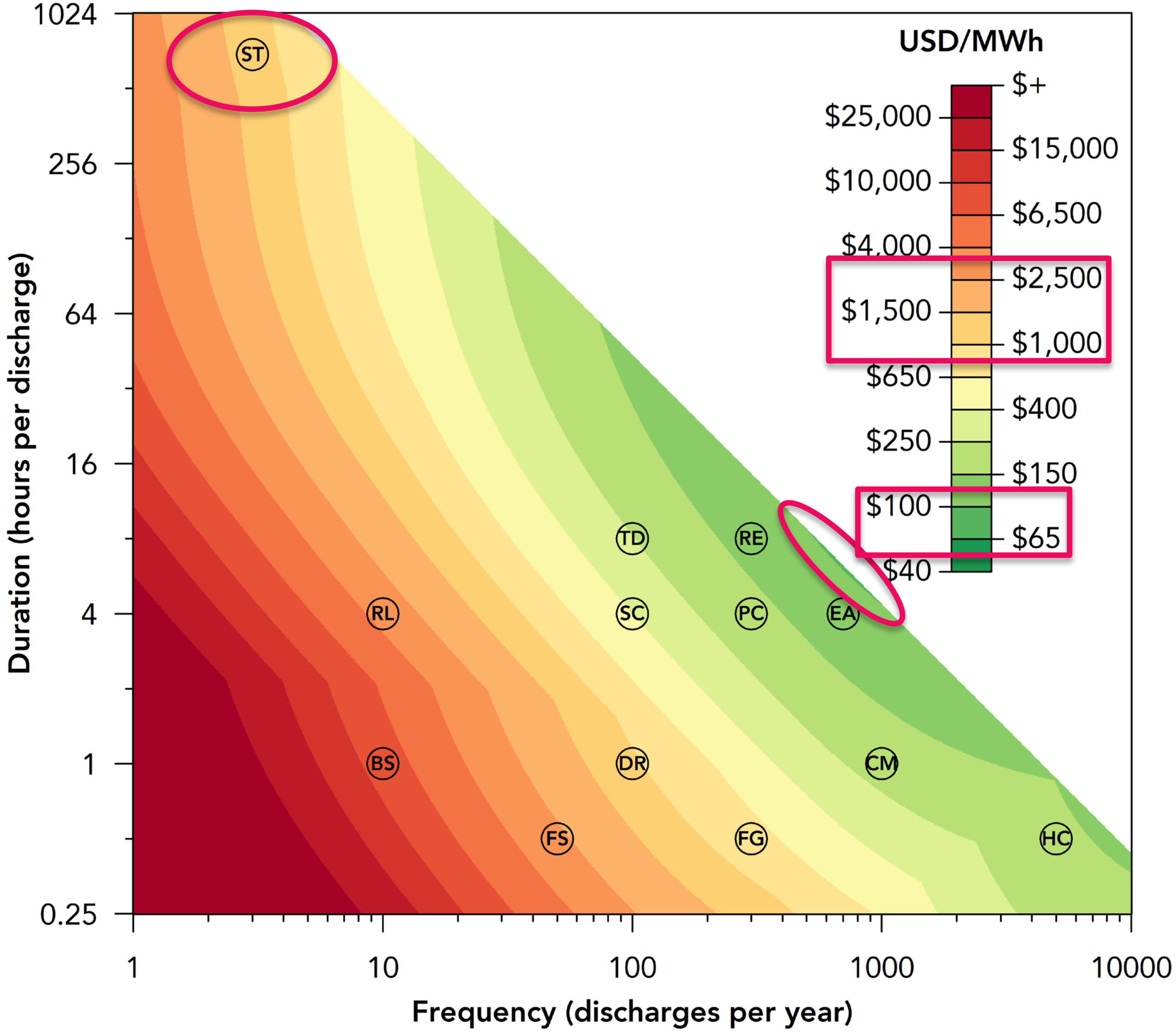


2030:



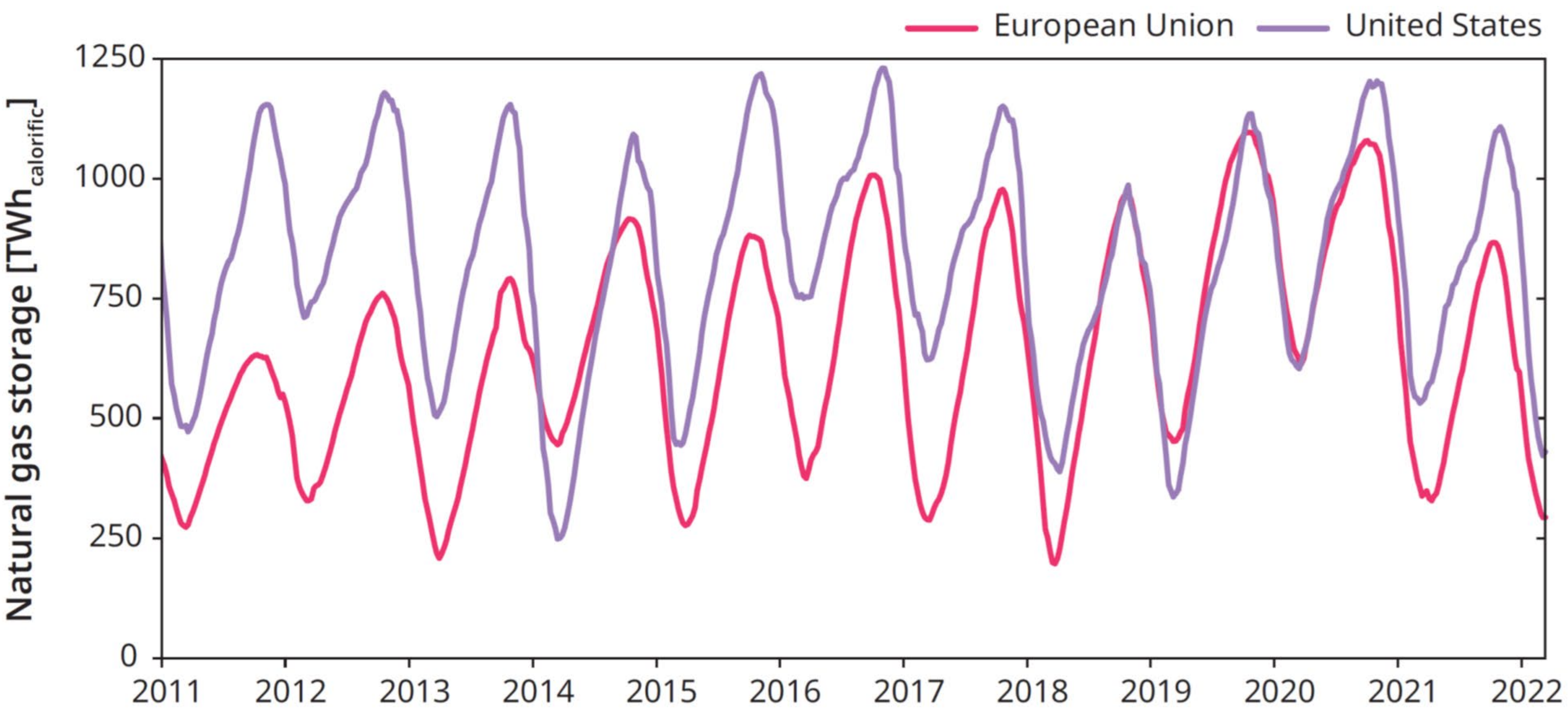
Circles denote typical power system applications. (ST) Inter-seasonal storage *(not currently monetized)* — (RL) Power reliability — (TD) Transmission & distribution investment deferral — (RE) Renewables integration — (SC) Increasing self-consumption — (PC) Peaking capacity — (EA) Energy arbitrage — (BS) Black start — (DR) Demand charge reduction — (CM) Congestion management — (FS) Frequency response (ramping / inertia) — (FG) Frequency regulation (power quality) — (HC) High cycle *(not currently monetized)*

Currently, offering 4-10 hours of storage is the cheapest Moving energy between seasons will cost ~10x more…



… but that is what we need (at PWh-scale!) if we are to end our reliance on fossil fuels

US & EU seasonal natural gas storage:



Some routes forwards:

- Push long-duration technologies with low power costs
- Develop new products to monetize longer duration storage

References

All slides from:

Schmidt & Staffell, 2023. *Monetizing Energy Storage.* Oxford University Press.

See also:

Schmidt et al., 2017. *The future cost of electrical energy storage based on experience rates.* Nature Energy 2:17110

Schmidt et al., 2019. *Projecting the future levelized cost of electricity storage technologies.* Joule 3(1):81

You can reproduce and customise all the analyses presented here:

www.EnergyStorage.ninja