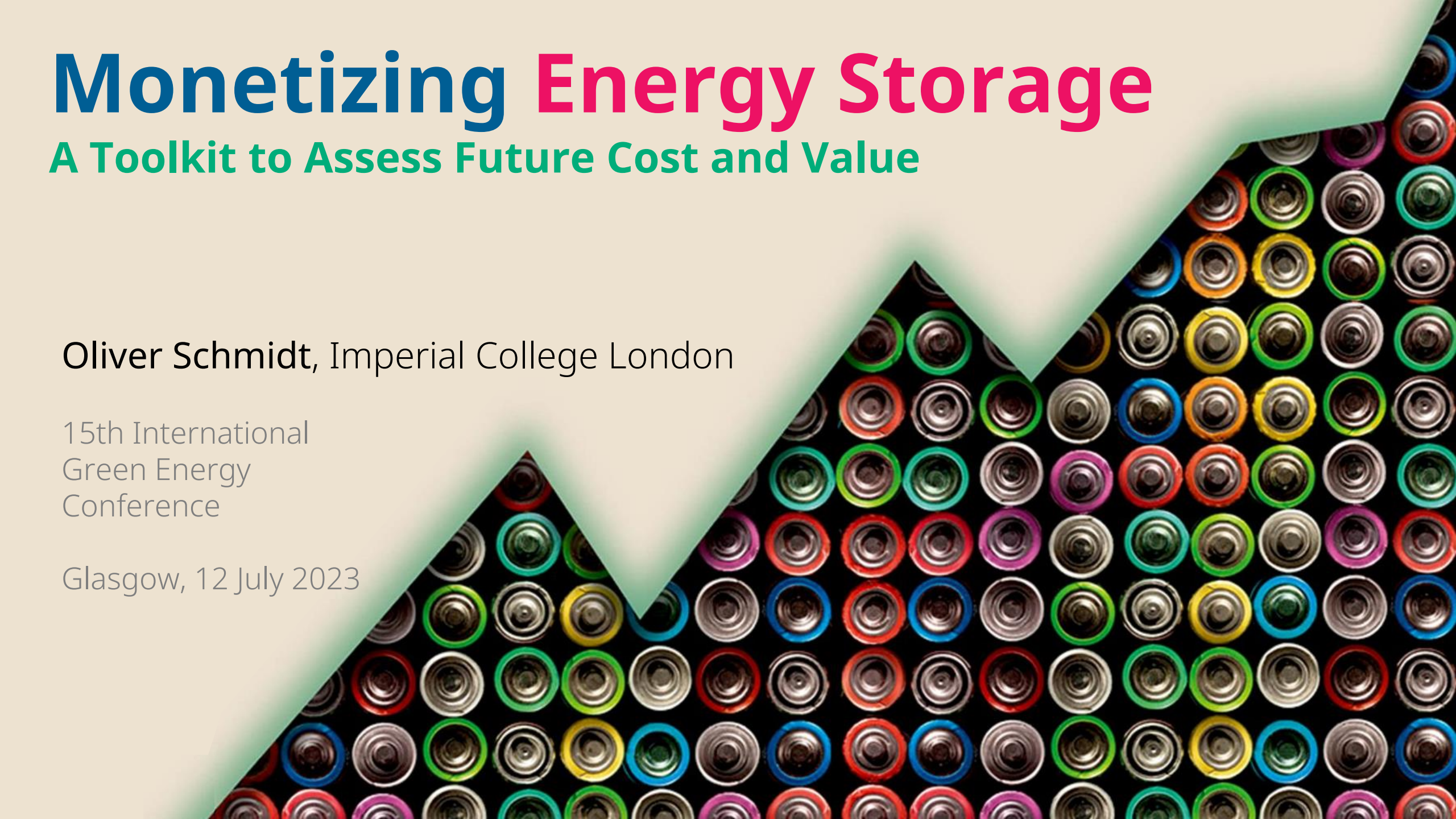
# Monetizing Energy Storage

## A Toolkit to Assess Future Cost and Value

**Oliver Schmidt**, Imperial College London

15th International
Green Energy
Conference

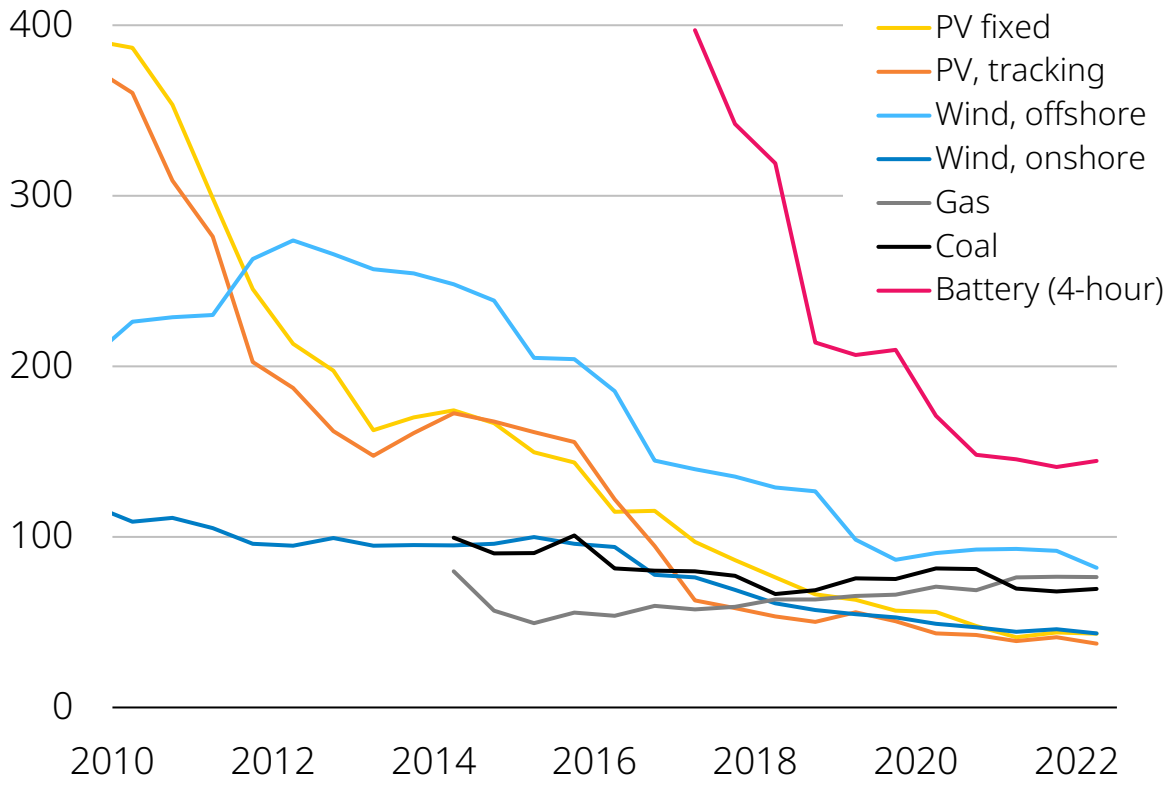
Glasgow, 12 July 2023



# Renewables (RE) are the future of electricity generation

## Cost:

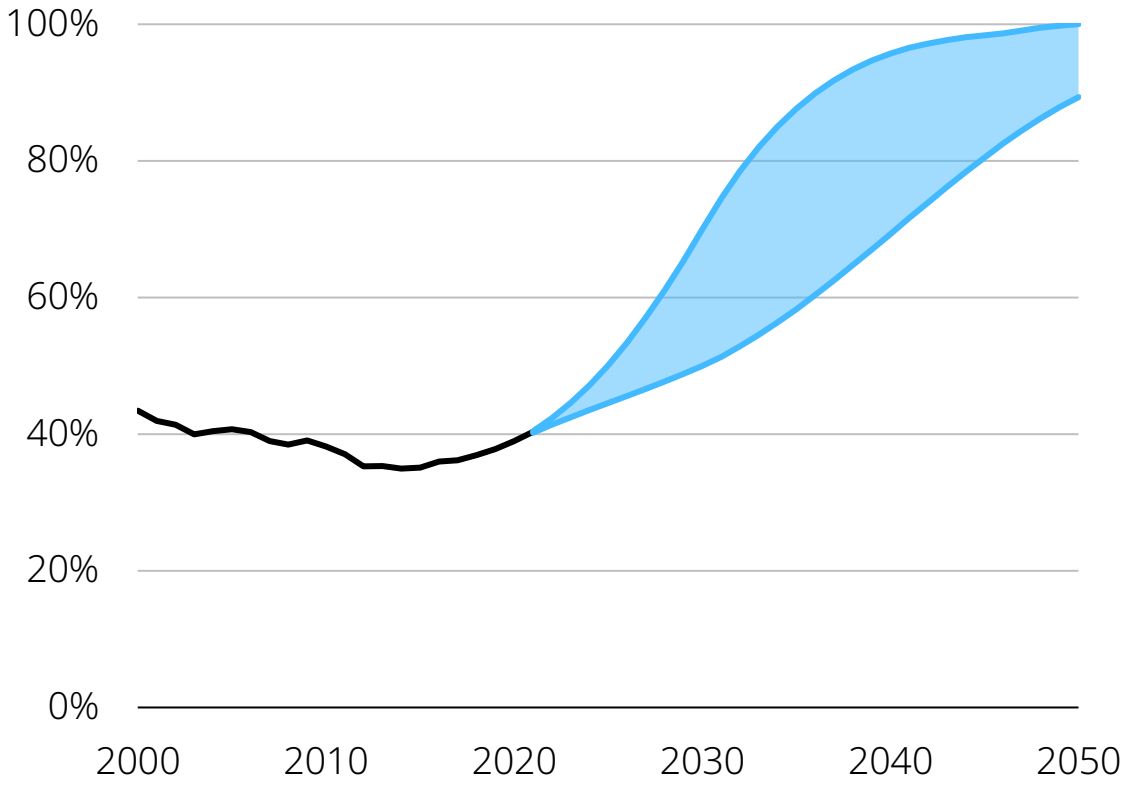
Levelized cost of electricity (USD/MWh)




*Data from BloombergNEF*

## Share:

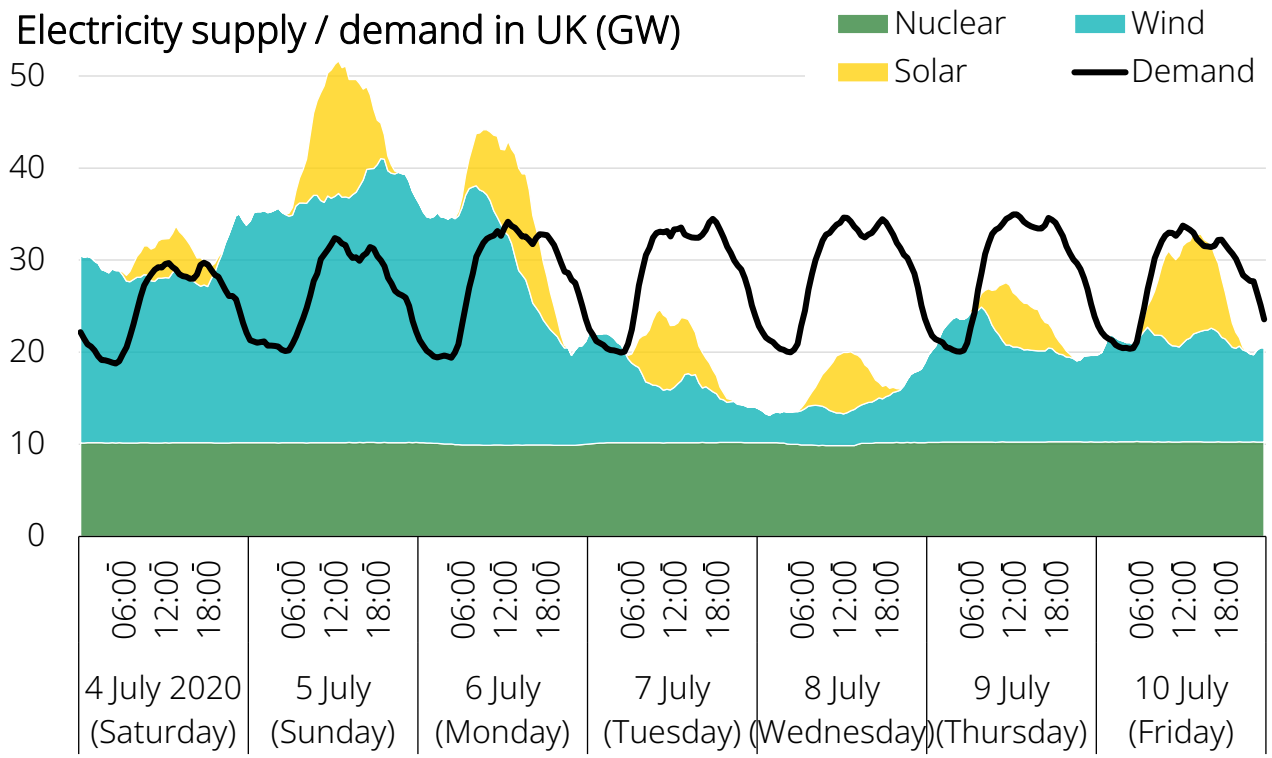
Share of low-carbon electricity generation




*Data from the IPCC 6th Assessment Report*

# Flexibility is needed to match RE supply and demand

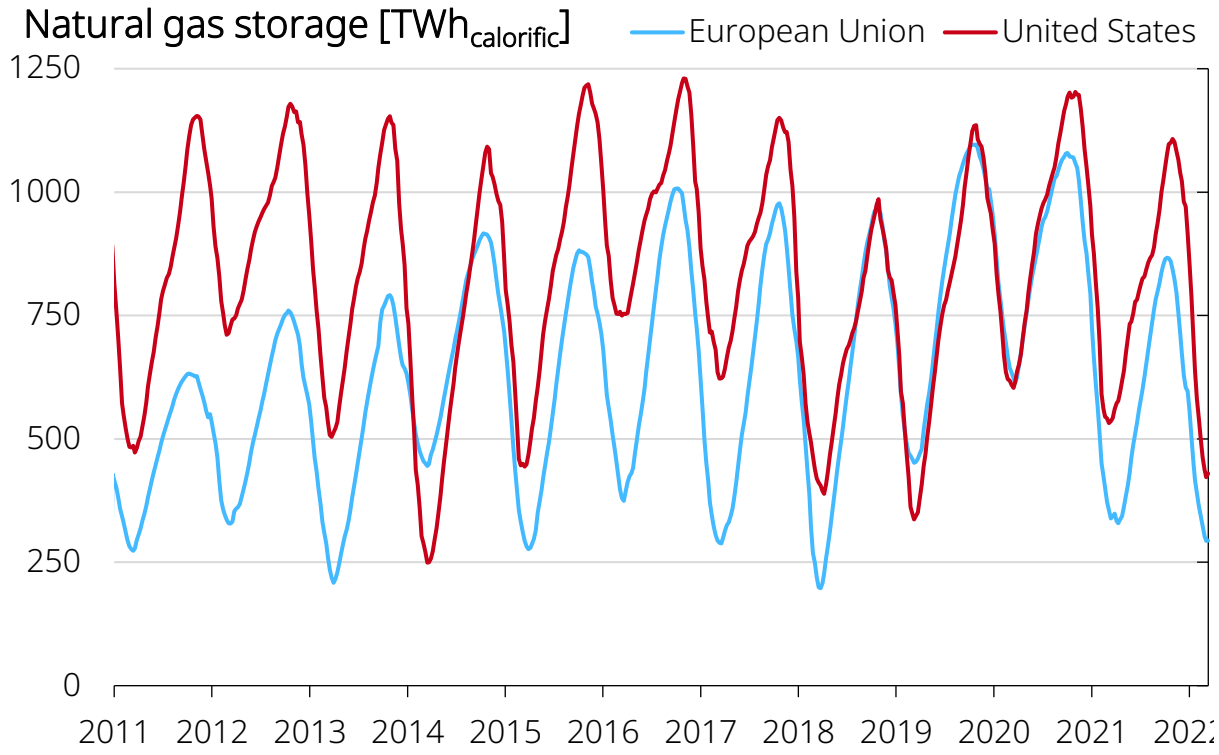
## Hourly / Daily




UK storage capacity 2022

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

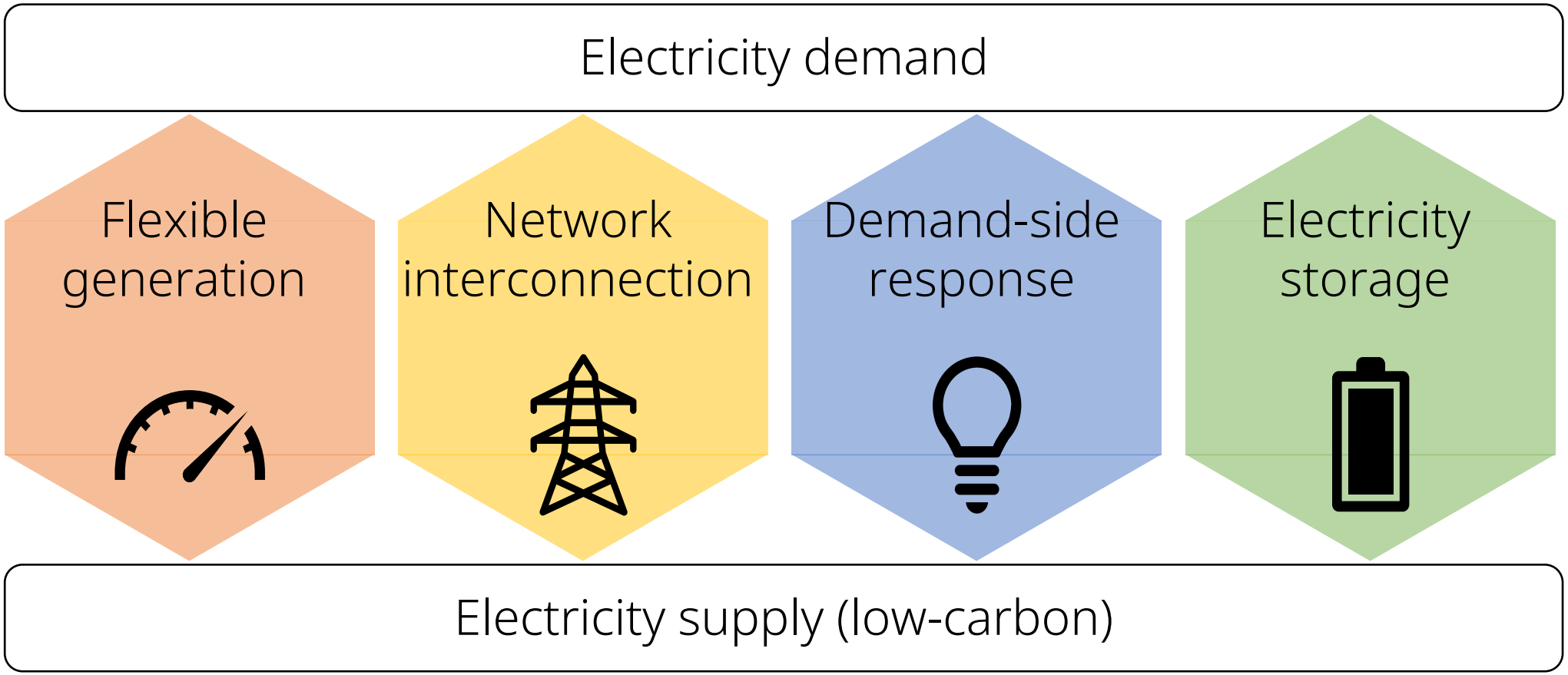
## Monthly / Yearly



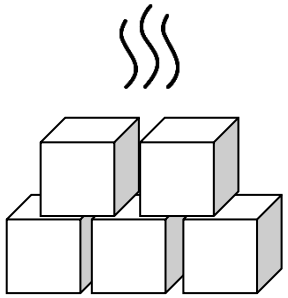

UK storage capacity 2022

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

# Electricity storage is one form of flexibility

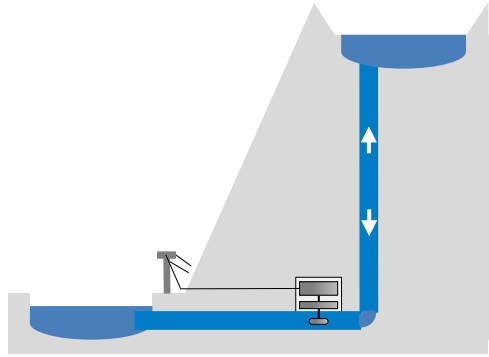


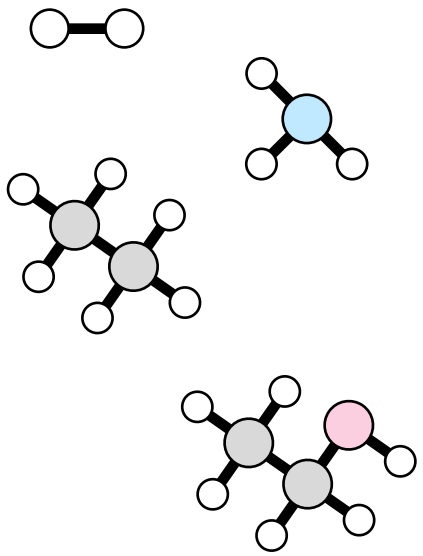
# There is a wide range of energy storage technologies…



- Sensible heat
- Latent heat
- Thermochemical heat

- Gravitation
- Compression
- Motion





- Hydrogen
- Ammonia
- Hydrocarbons
- Alcohols

Thermal

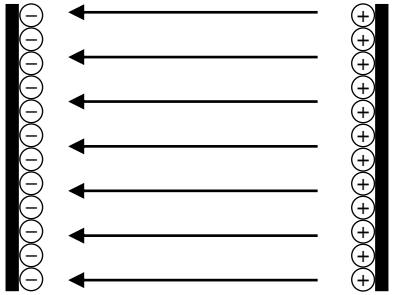
Mechanical

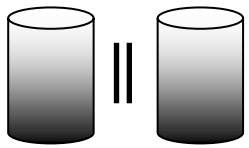
Chemical

Electrical

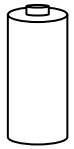
Electrochemical

- Capacitance
- Inductance

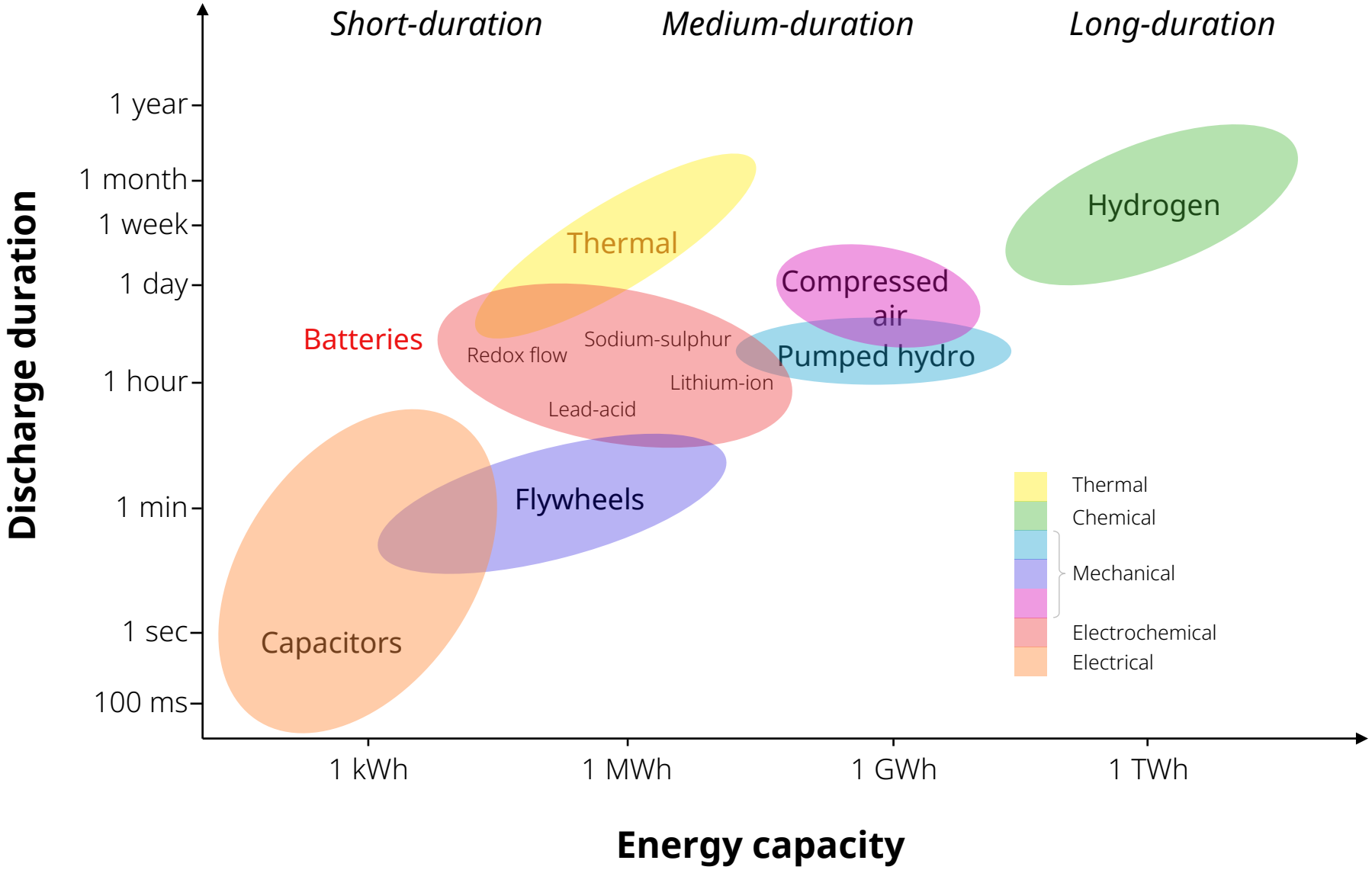




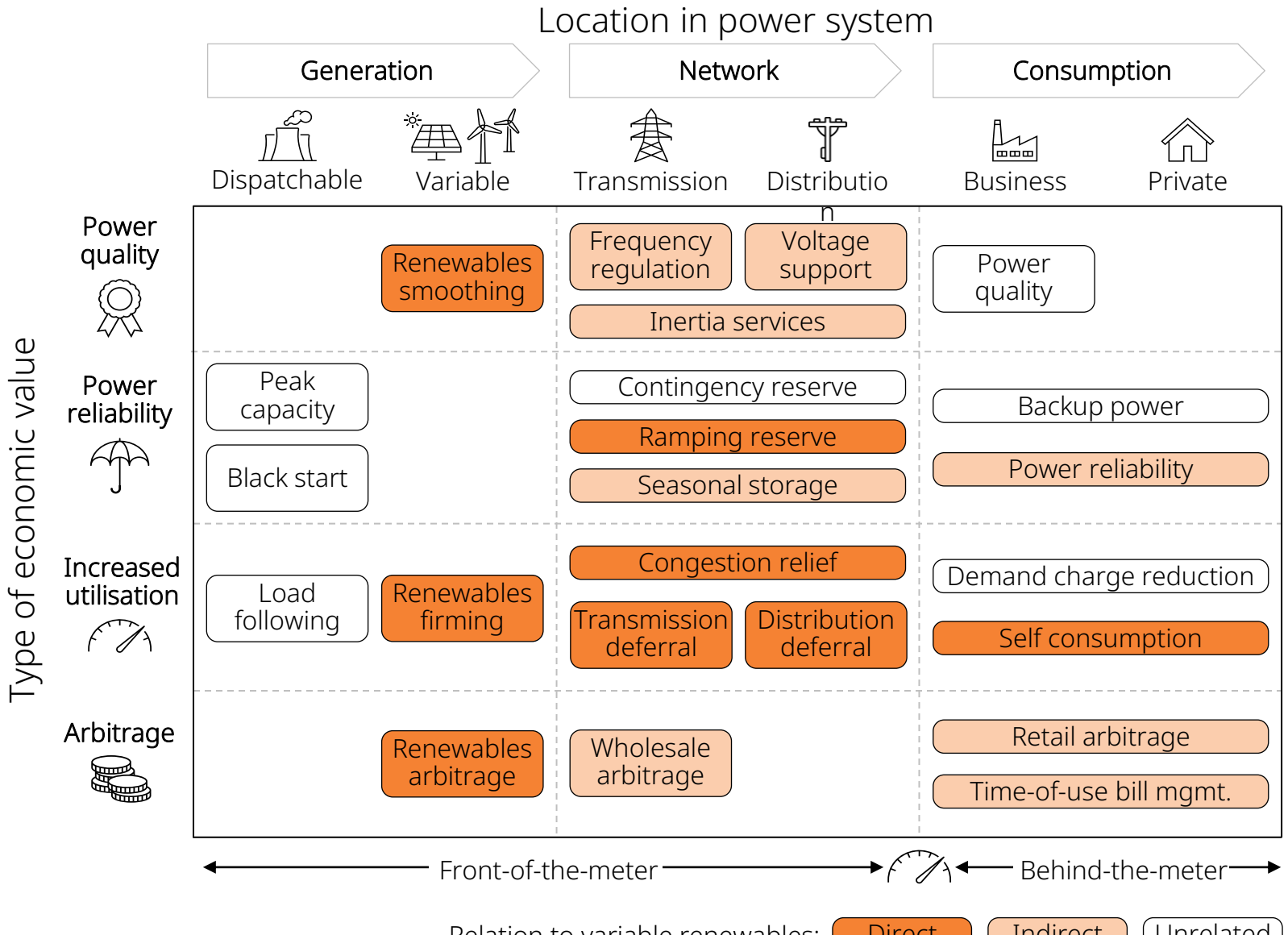
- Sealed batteries
- Flow batteries



# … that all have very different characteristics

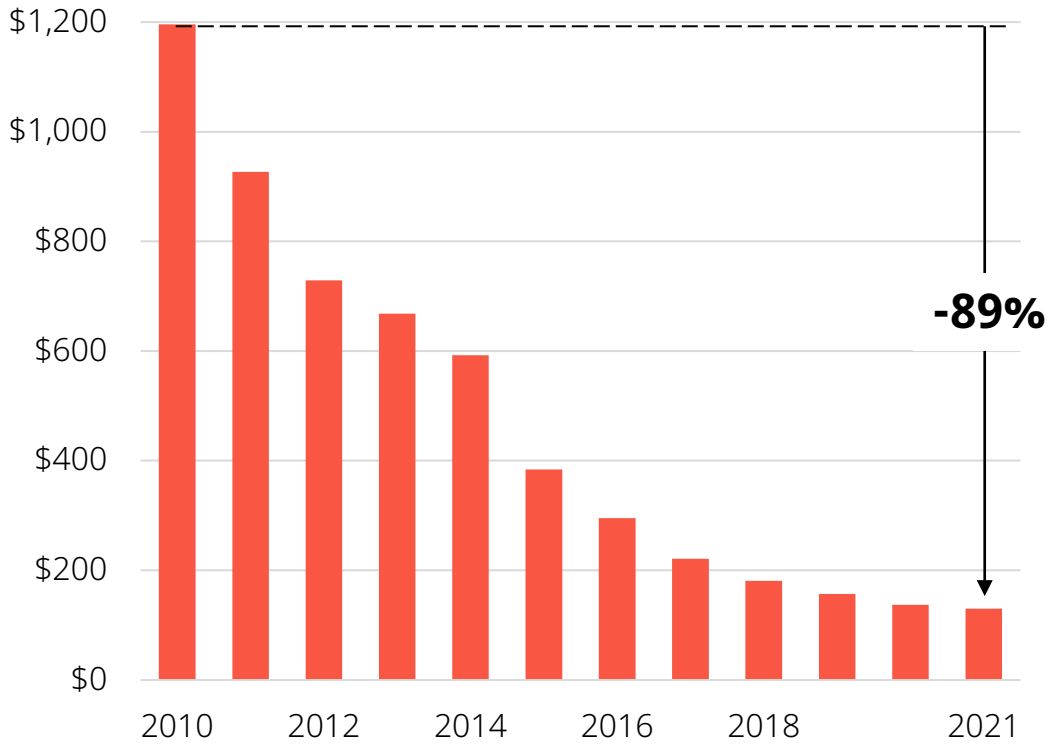


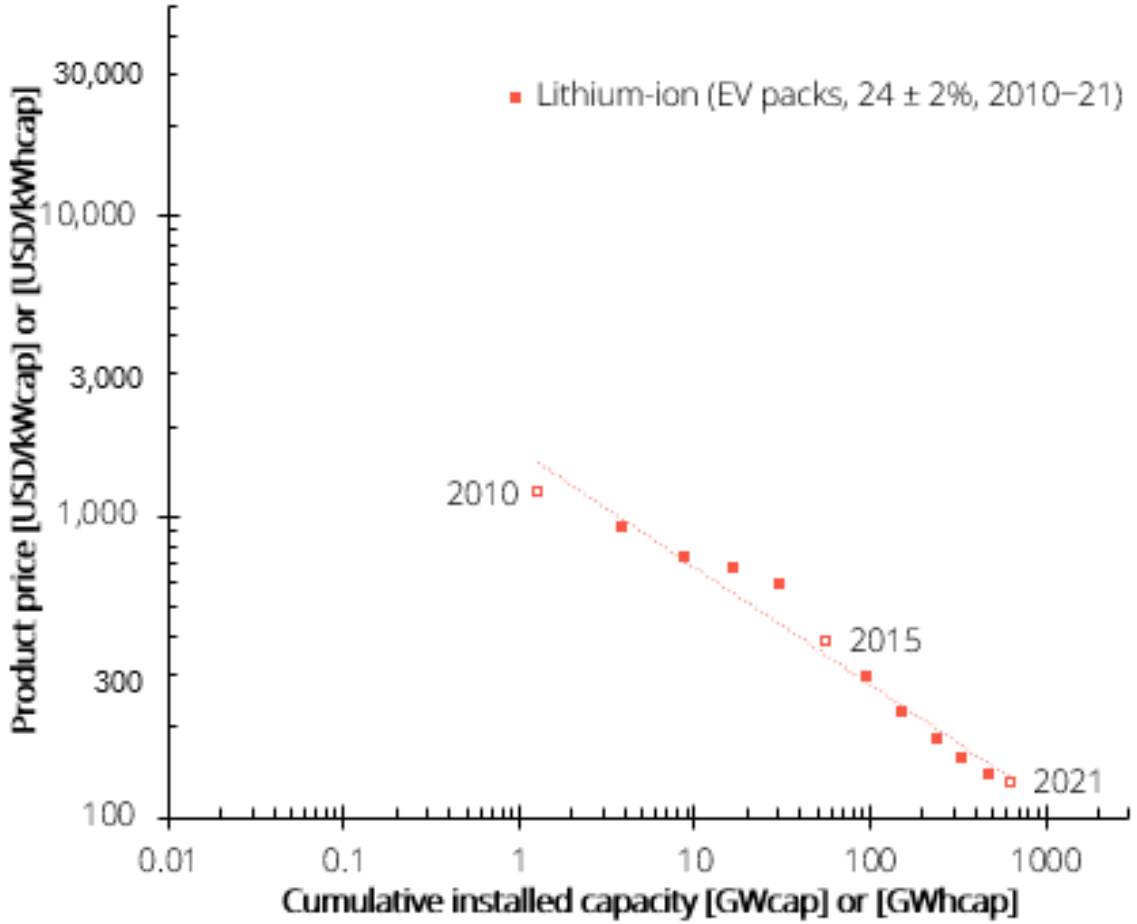
# At the same time, there is a wide range of applications…



# In addition, prices of selected technologies are falling fast

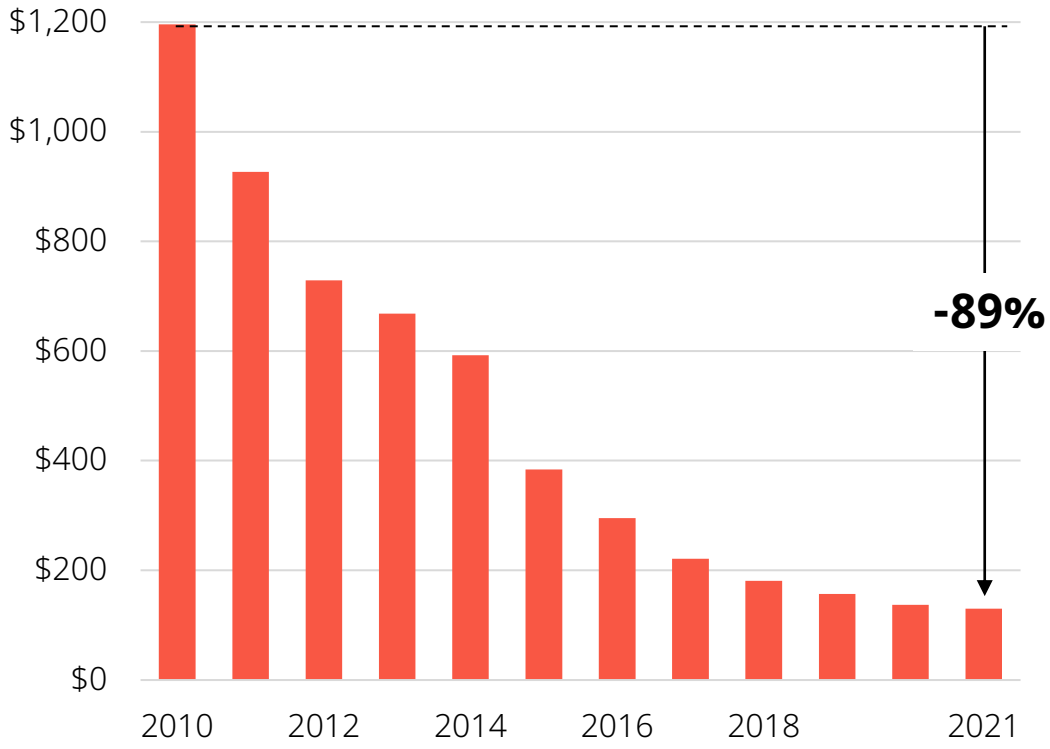
Lithium-ion battery pack [USD/kWh]

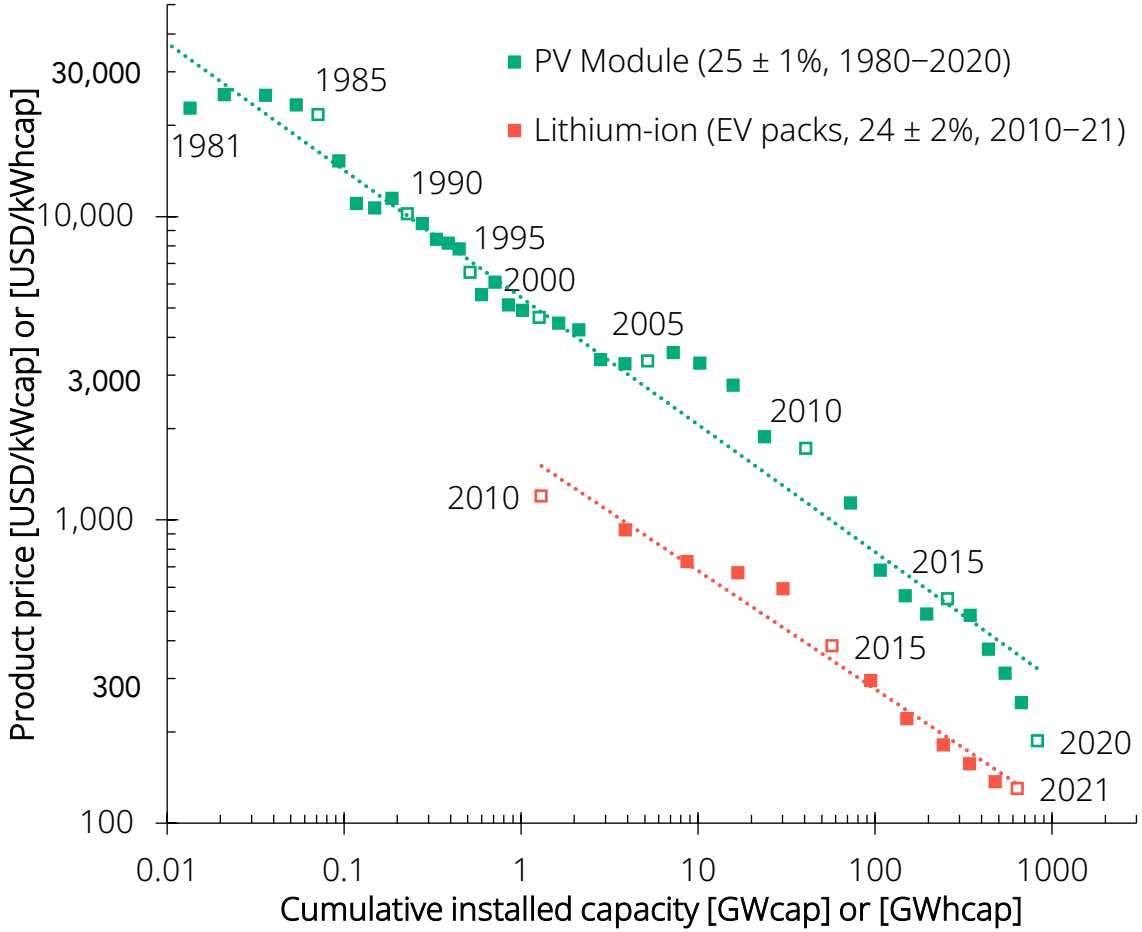


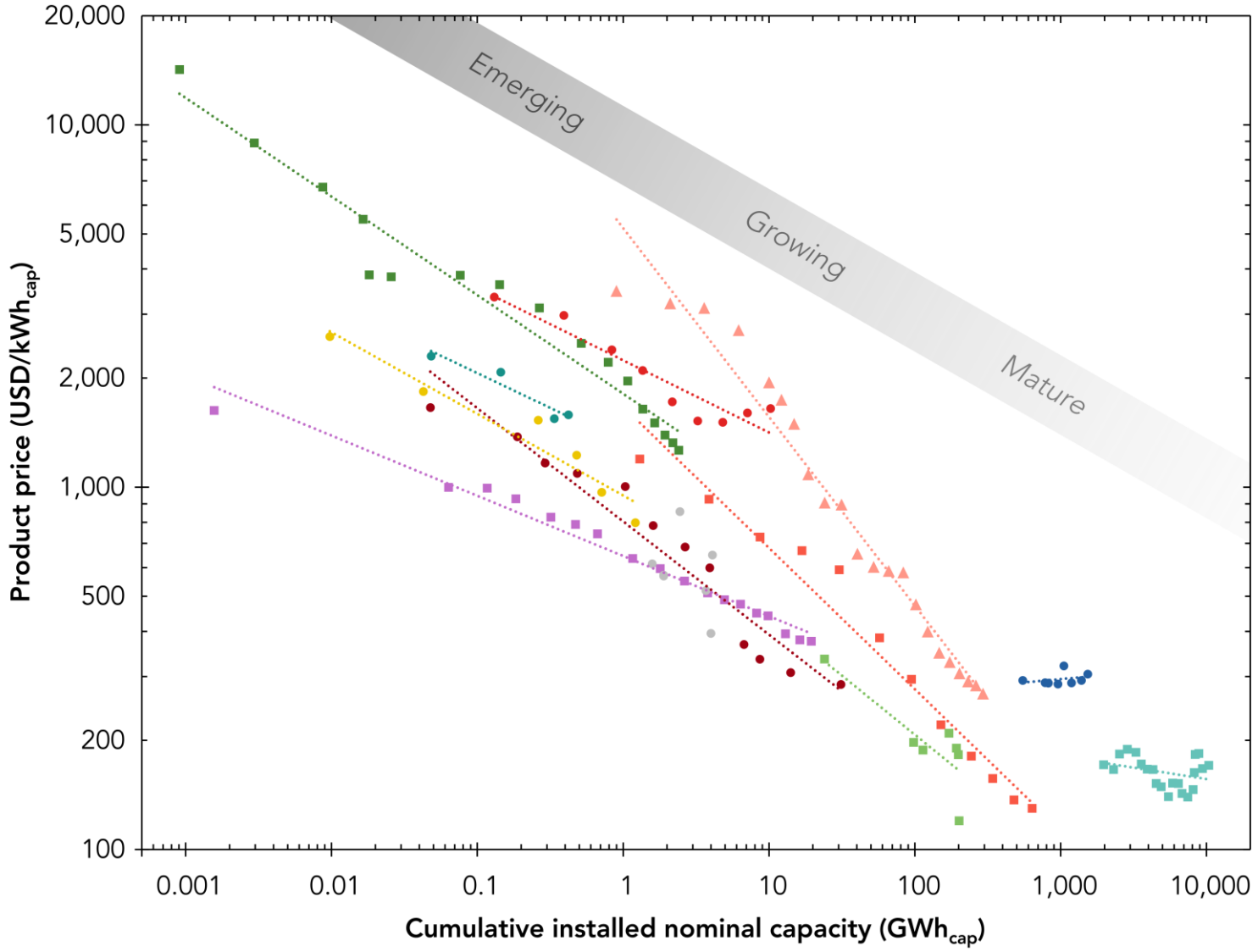
# In addition, prices of selected technologies are falling fast

## Lithium-ion battery pack [USD/kWh]



# Similar trends are seen across many storage technologies




**Scope:**

- System
- Pack
- Cell

**Technology:**

- Pumped hydro (Utility, –3 ± 6%, 1983–2018)
- Lead-acid (Residential, 12 ± 5%, 2013–16)
- Lithium-ion (EV packs, 24 ± 2%, 2010–21)
- Lithium-ion (Utility, 19 ± 3%, 2010–21)
- Sodium-sulphur (Utility, N/A, 2007–21)
- Electrolysis (Utility, 20 ± 11%, 1956–2019)
- Lead-acid (Multiple, 4 ± 6%, 1989–2012)
- Lithium-ion (Electronics, 30 ± 2%, 1995–2016)
- Lithium-ion (Residential, 13 ± 3%, 2013–21)
- Nickel-metal hydride (HEV, 11 ± 1%, 1997–2014)
- Vanadium redox-flow (Utility, 14 ± 4%, 2008–19)
- Fuel cells (Residential, 17 ± 2%, 2004–20)

# 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)
- 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

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

- 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

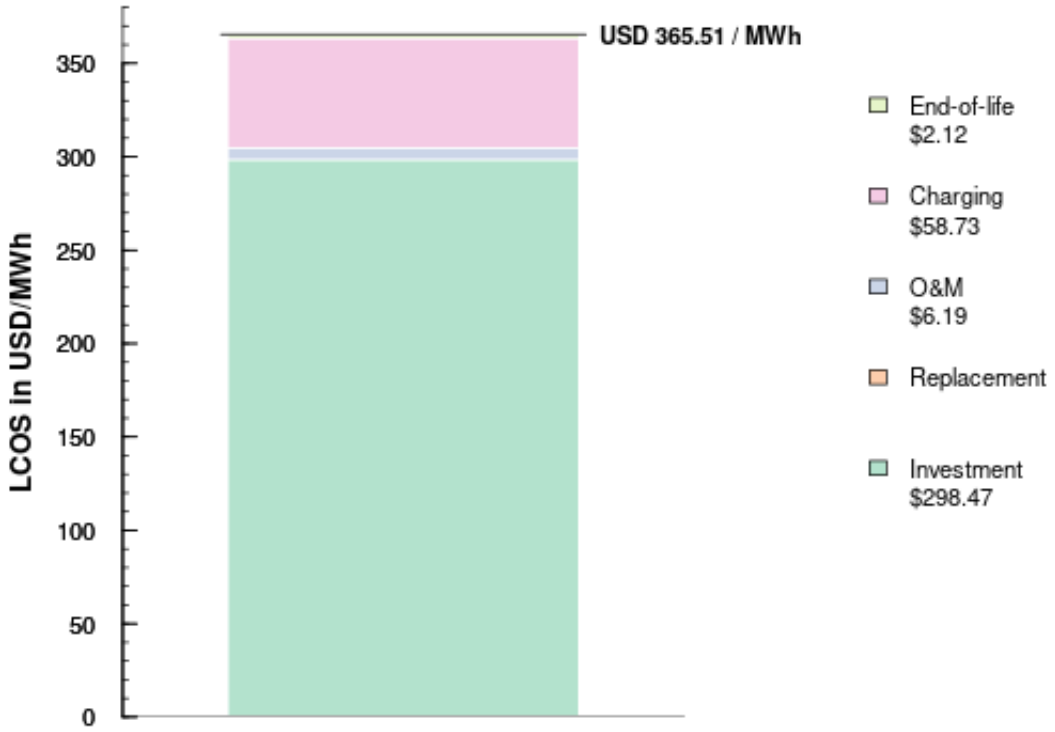
Schmidt & Staffell (2023): Monetizing Energy Storage

# 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)



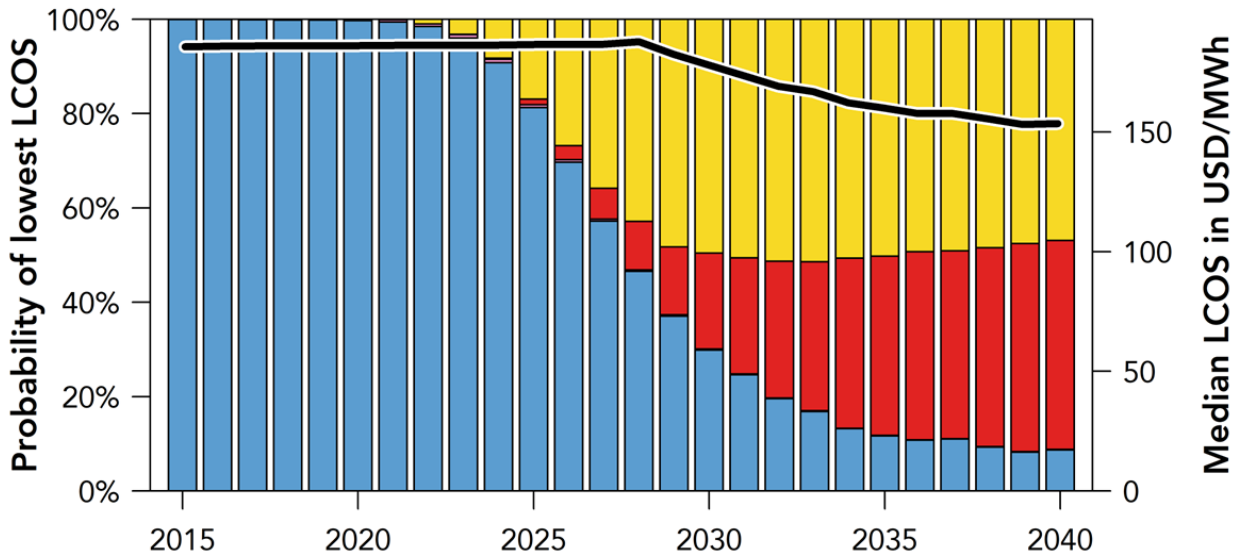

## Vanadium redox-flow:

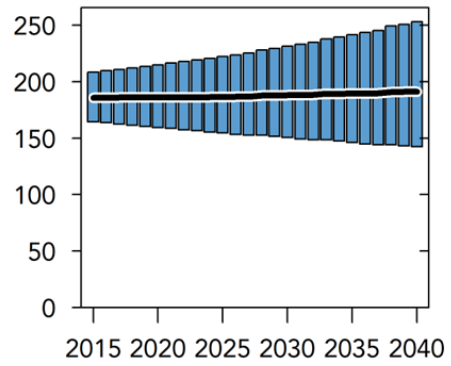
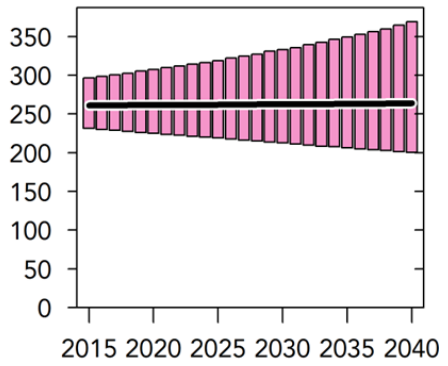
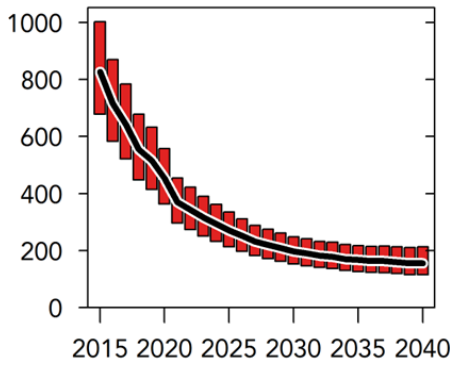
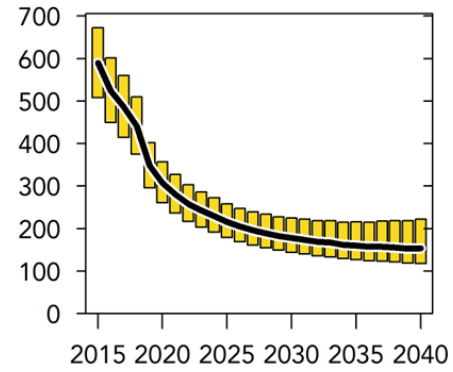
(625 USD/kWh capex, 68% efficiency, 20000 cycle lifetime)

# The competitiveness of technologies will change over time

## PC Peak capacity

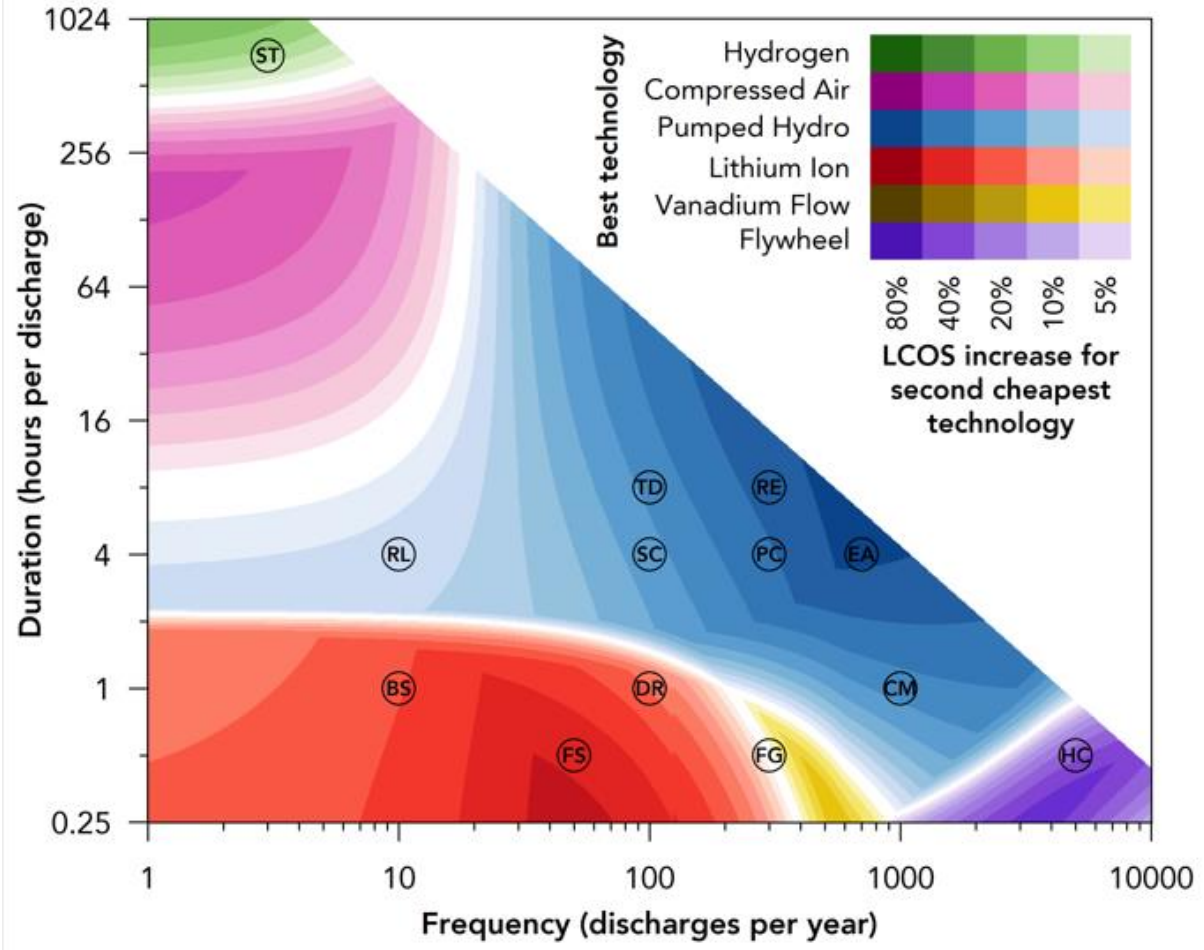
| | |
|---|---|
| Power capacity | 10 MW |
| Discharge duration | 4 hours |
| Annual cycles | 300 |
| Response time | >10 seconds |
| Electricity price | 50 USD/MWh |



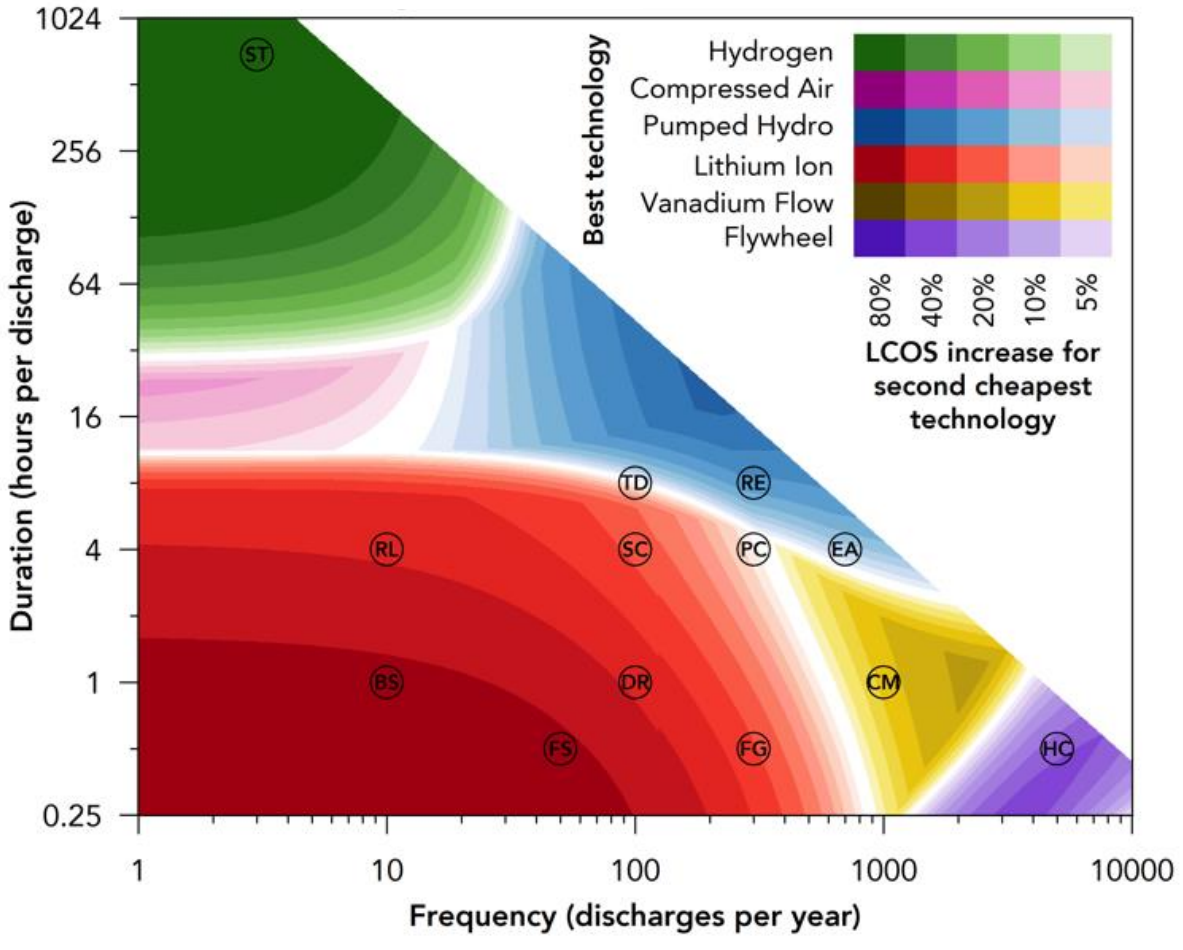

| | Pumped hydro | Compressed air | Lithium ion | Vanadium redox flow |
|---|---|---|---|---|
| Median and range of LCOS in USD/MWh |  |  |  |  |

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

2020:

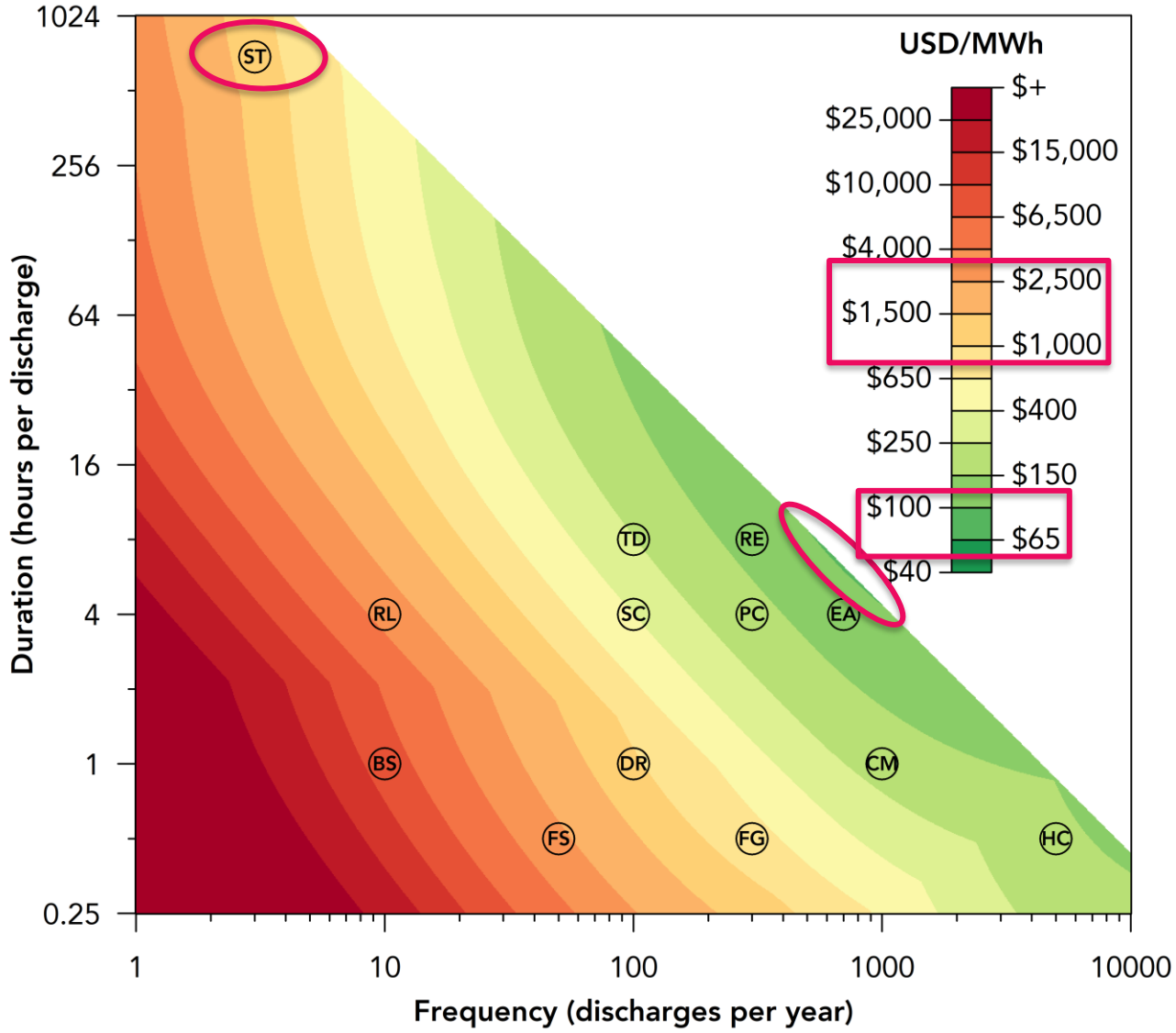



2030:

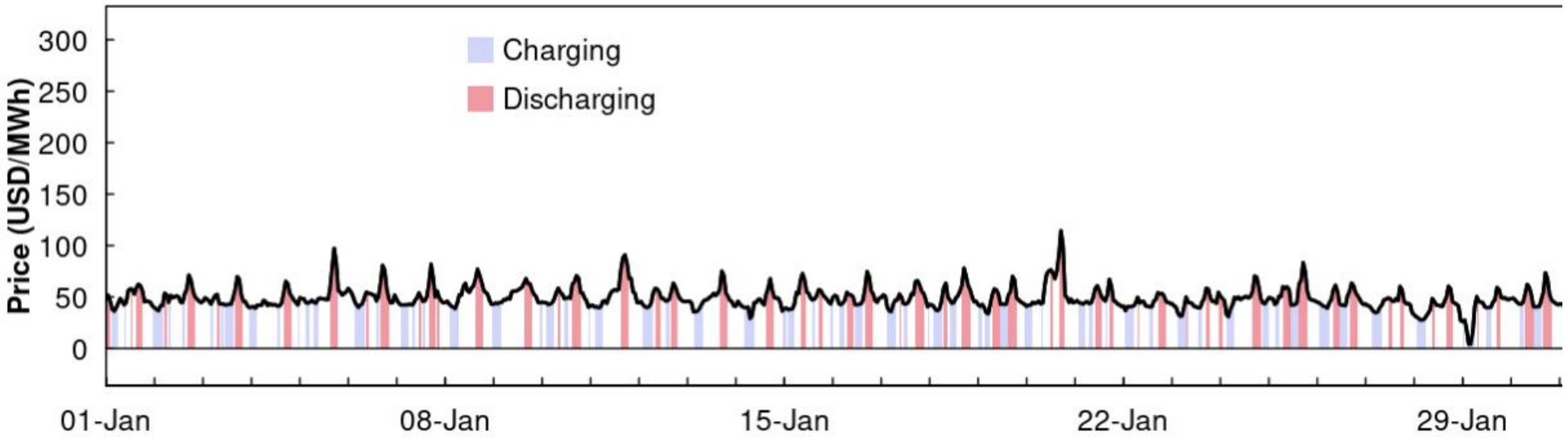


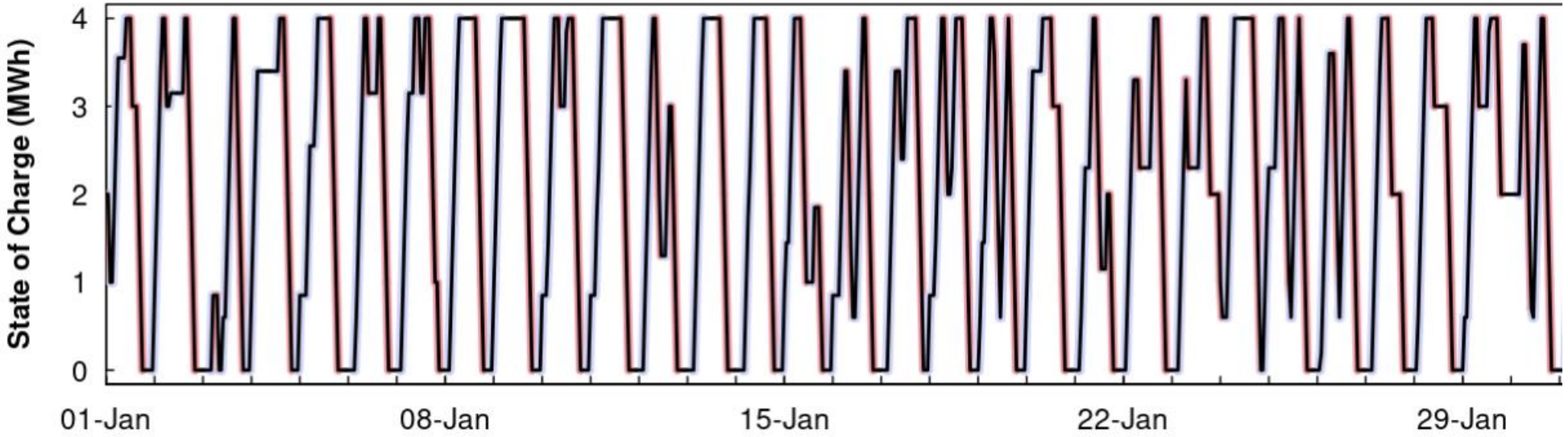

Circles denote typical power system applications: (ST) Inter-seasonal storage *(not currently monetized)* — (RL) Power reliability — (TD) Transmission & distribution investment deferral — (RE) Renewables integration — (SC) Increasing self-consumption — (PC) Peaking capacity — (EA) Energy arbitrage — (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



# In terms of revenue, there is limited value to moving energy over longer time horizons

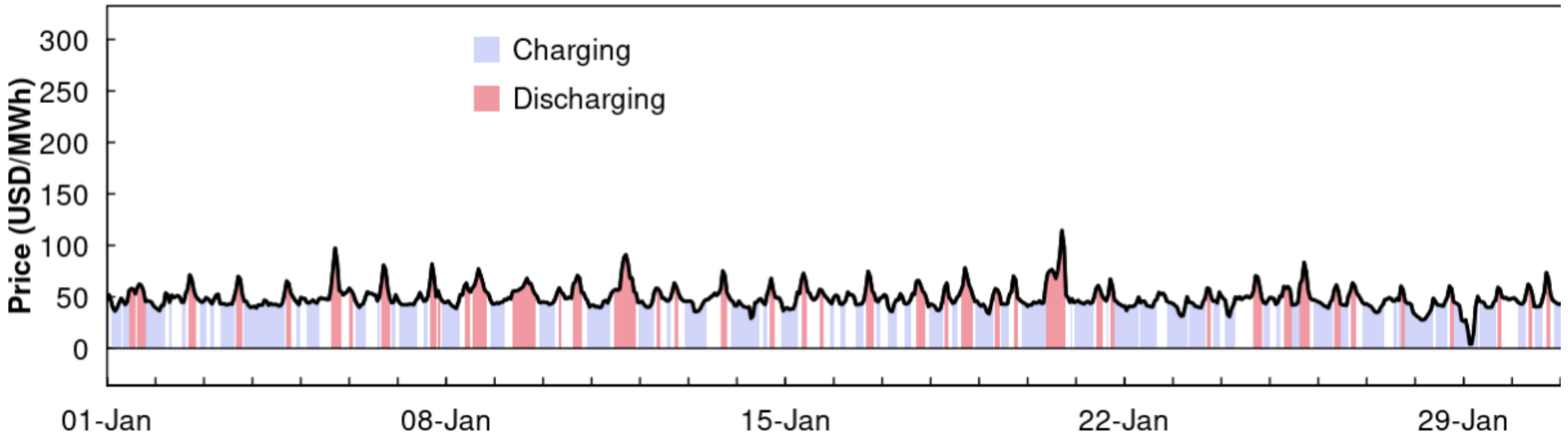


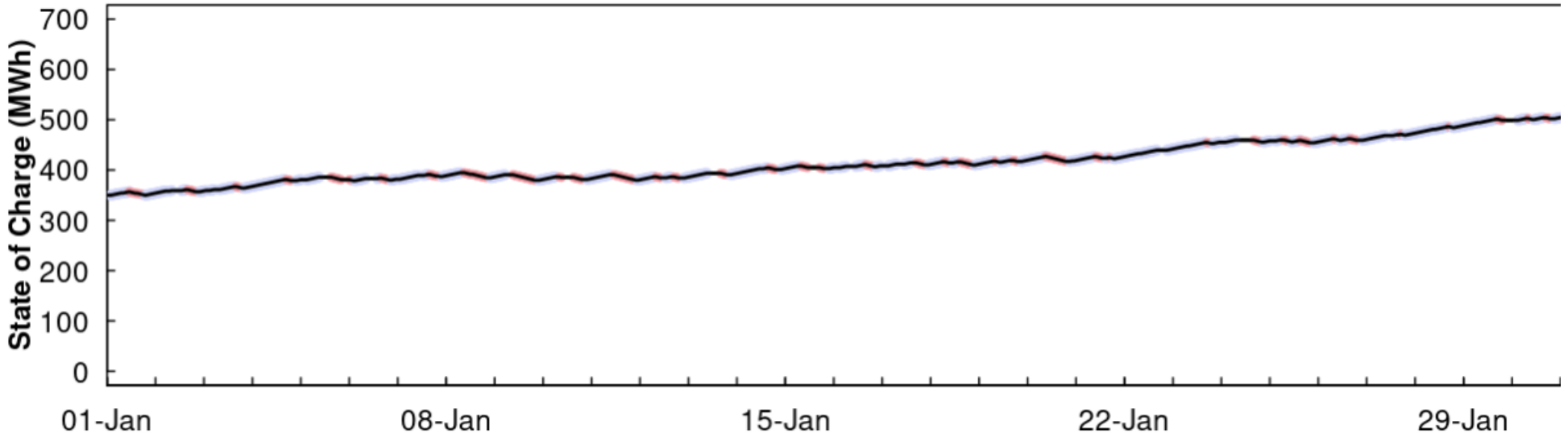




Size: 1 MW
Duration: 4 h
Efficiency: 85%

**Revenue:**
**$ 30,070**

# In terms of revenue, there is limited value to moving energy over longer time horizons



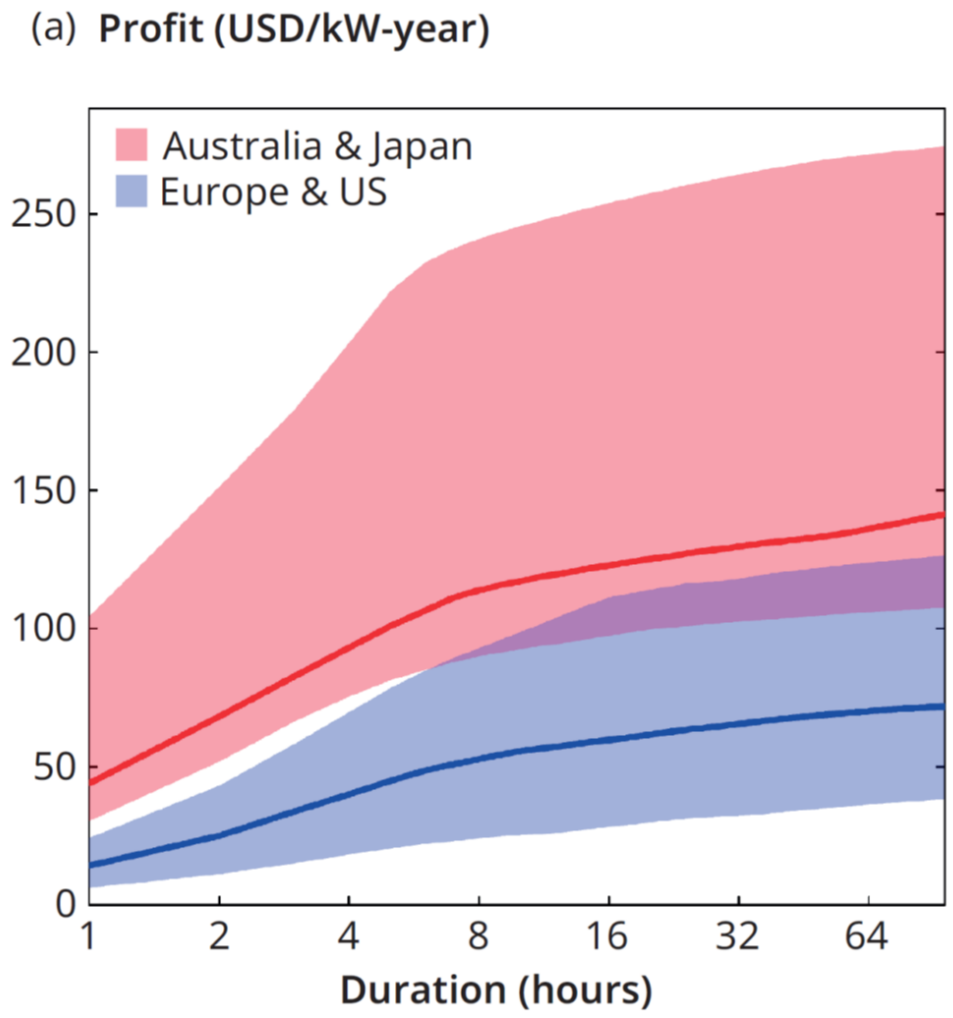



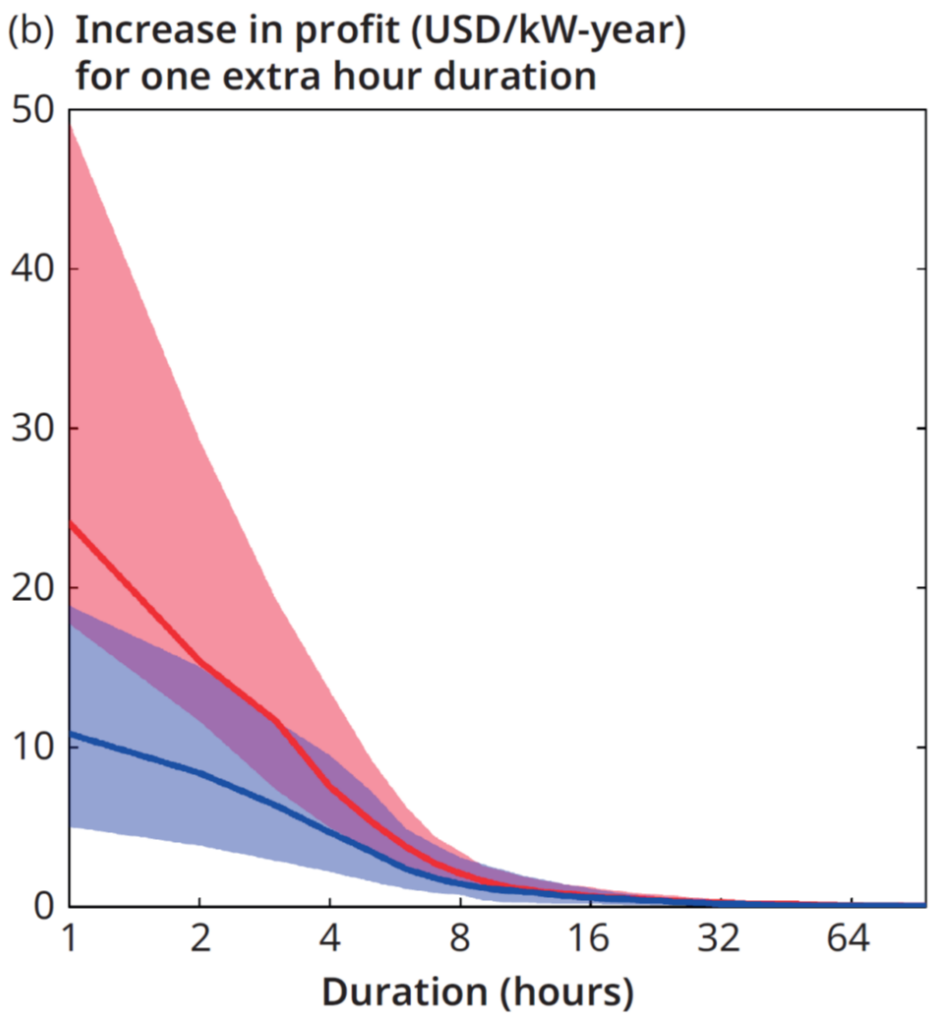

Size: 1 MW
Duration: 4 h
Efficiency: 85%

**Revenue:**
**$ 50,733**

x1.7

# Increase in profitability beyond 8-hour arbitrage is marginal

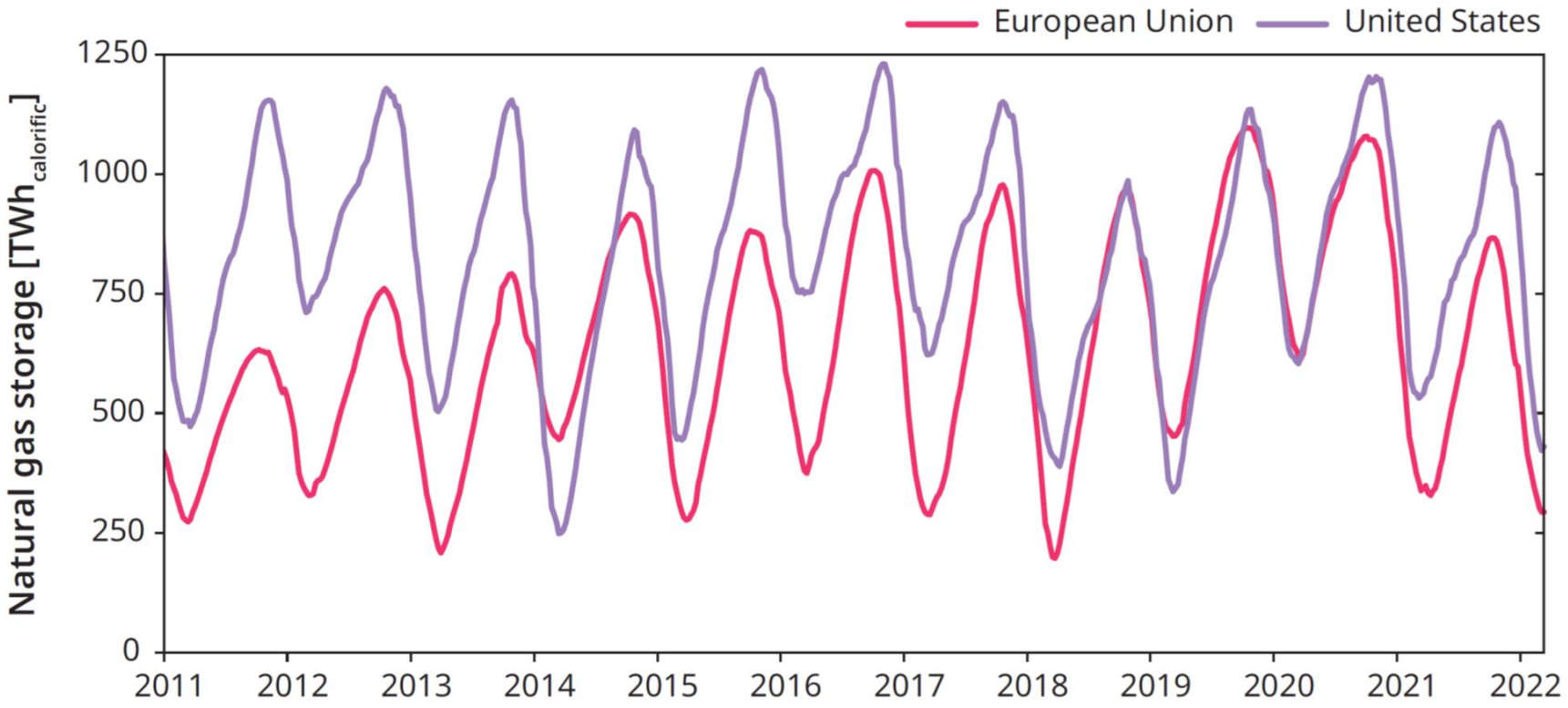



Based on day-ahead wholesale prices from 2012-19 in various markets

# But, we do need to deploy TWh-scale seasonal storage!

US & EU seasonal natural gas storage:




Routes forwards:

- Develop low-cost long-duration storage technologies
- Provide markets beyond arbitrage to remunerate long-duration storage

# All insights available in one book…

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

Gerard Reid, Alexa Capital

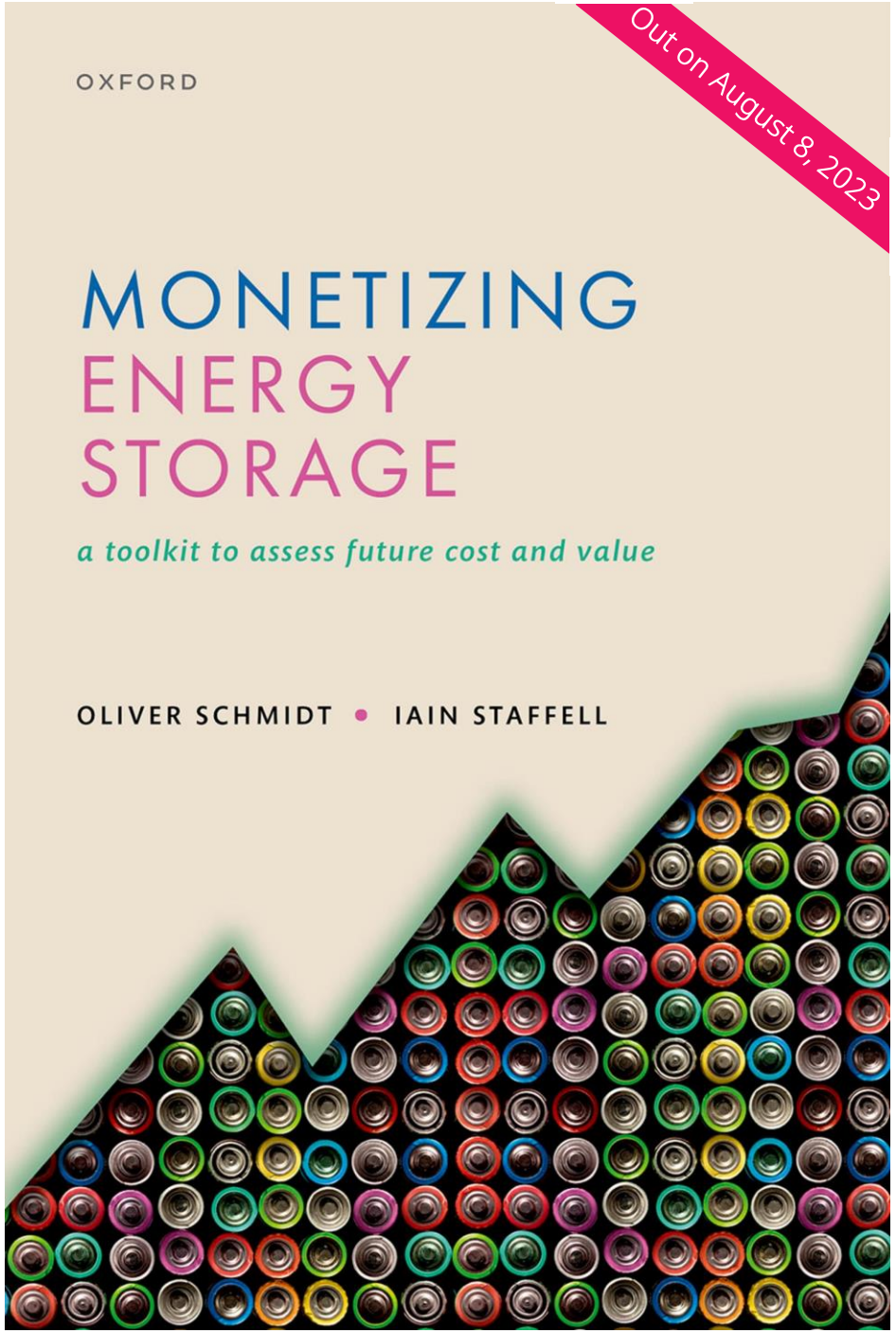
"Ground-breaking – an essential read"

Professor Dan Kammen, UC Berkeley

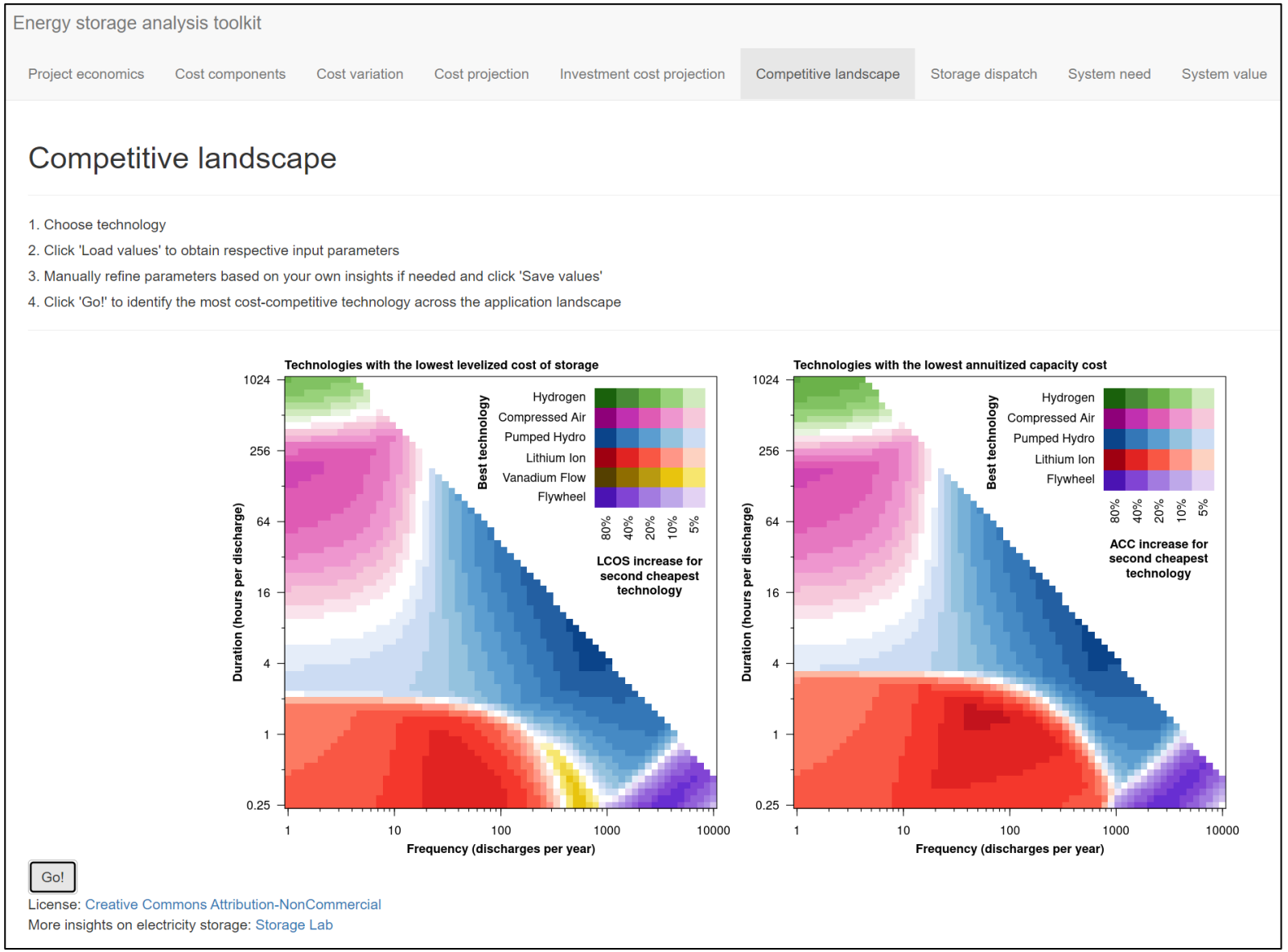
"The go-to resource … exemplary in terms of academic rigour set in a real-world context"

Professor Jim Skea, IPCC

Search: Monetizing Energy Storage



# … and all analyses can be re-produced by you!

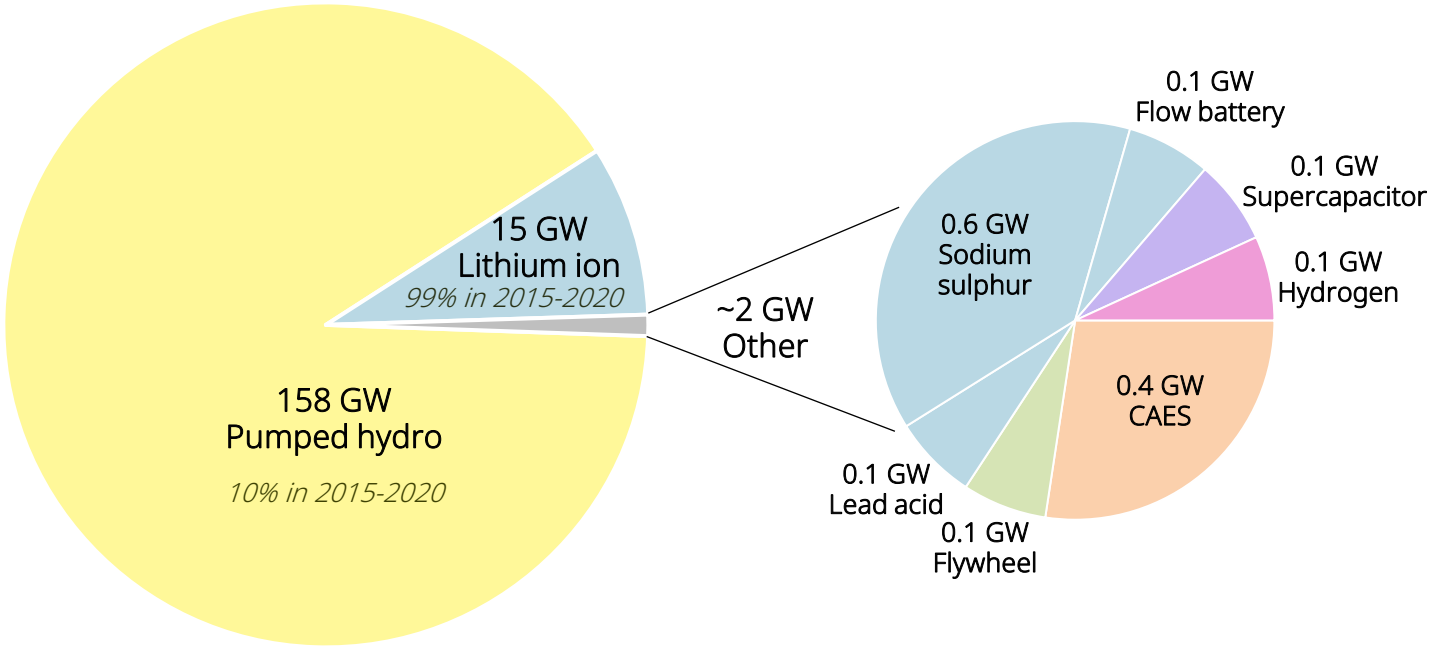



You can reproduce and customise all the analyses presented here:

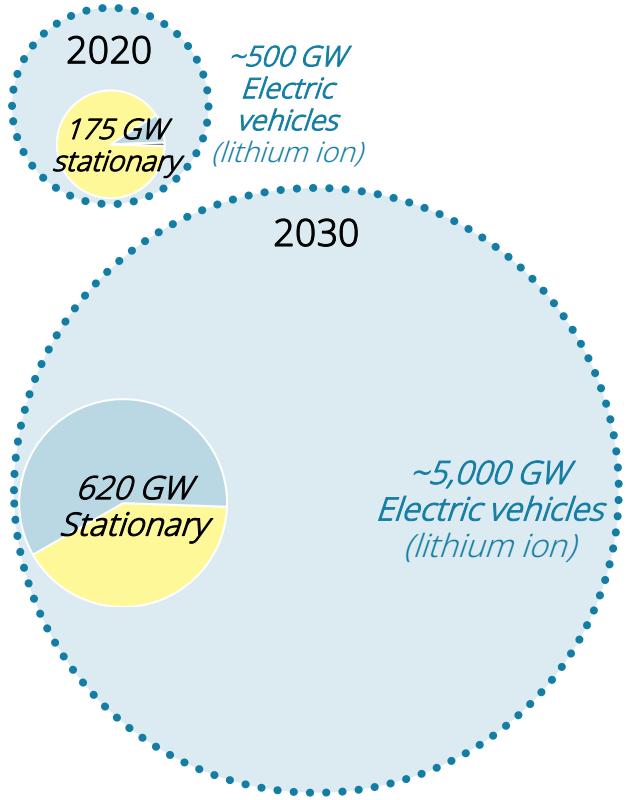
www.EnergyStorage.ninja

# Pumped hydro most widely deployed – batteries catch up

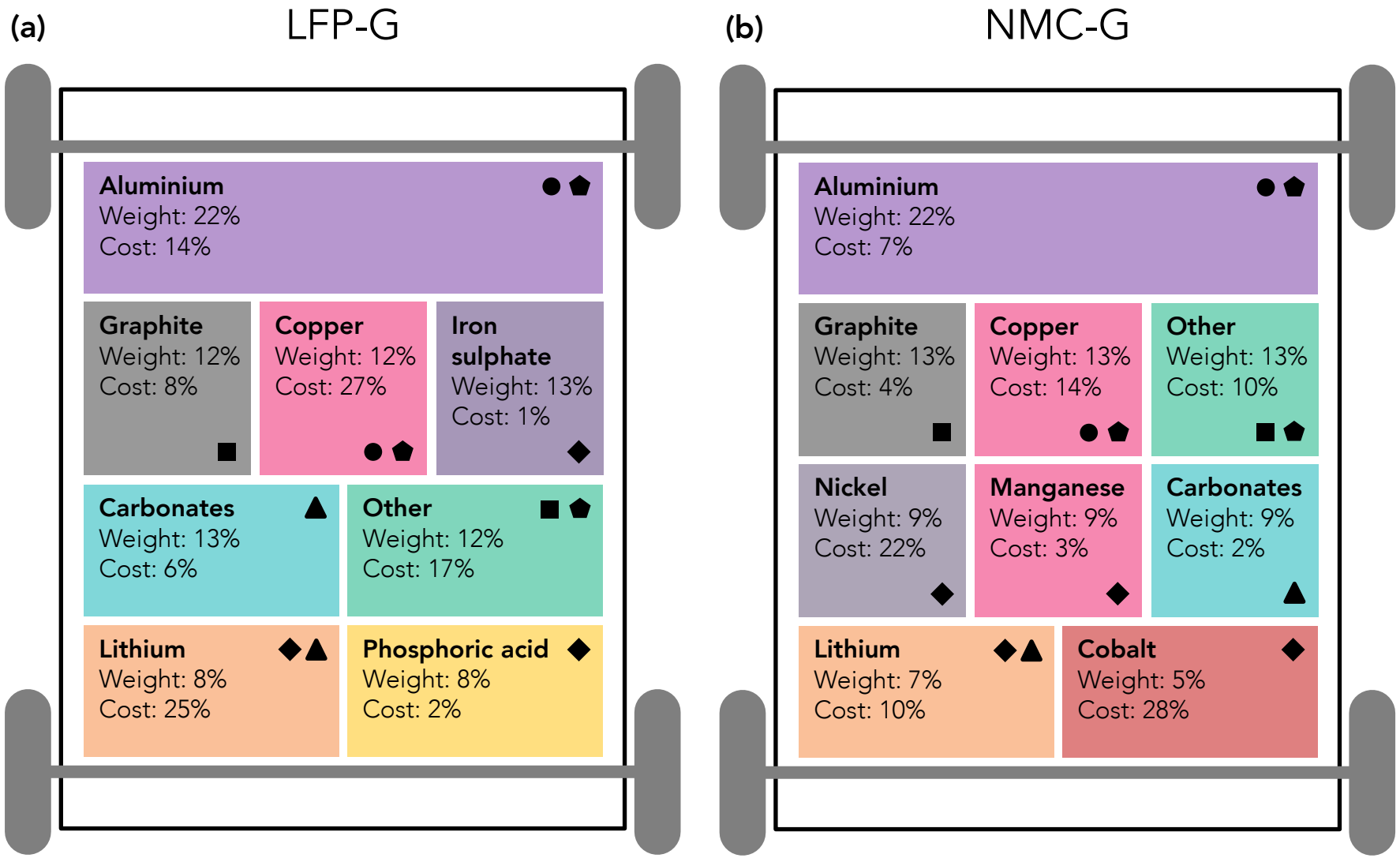
## 2020 stationary storage deployment



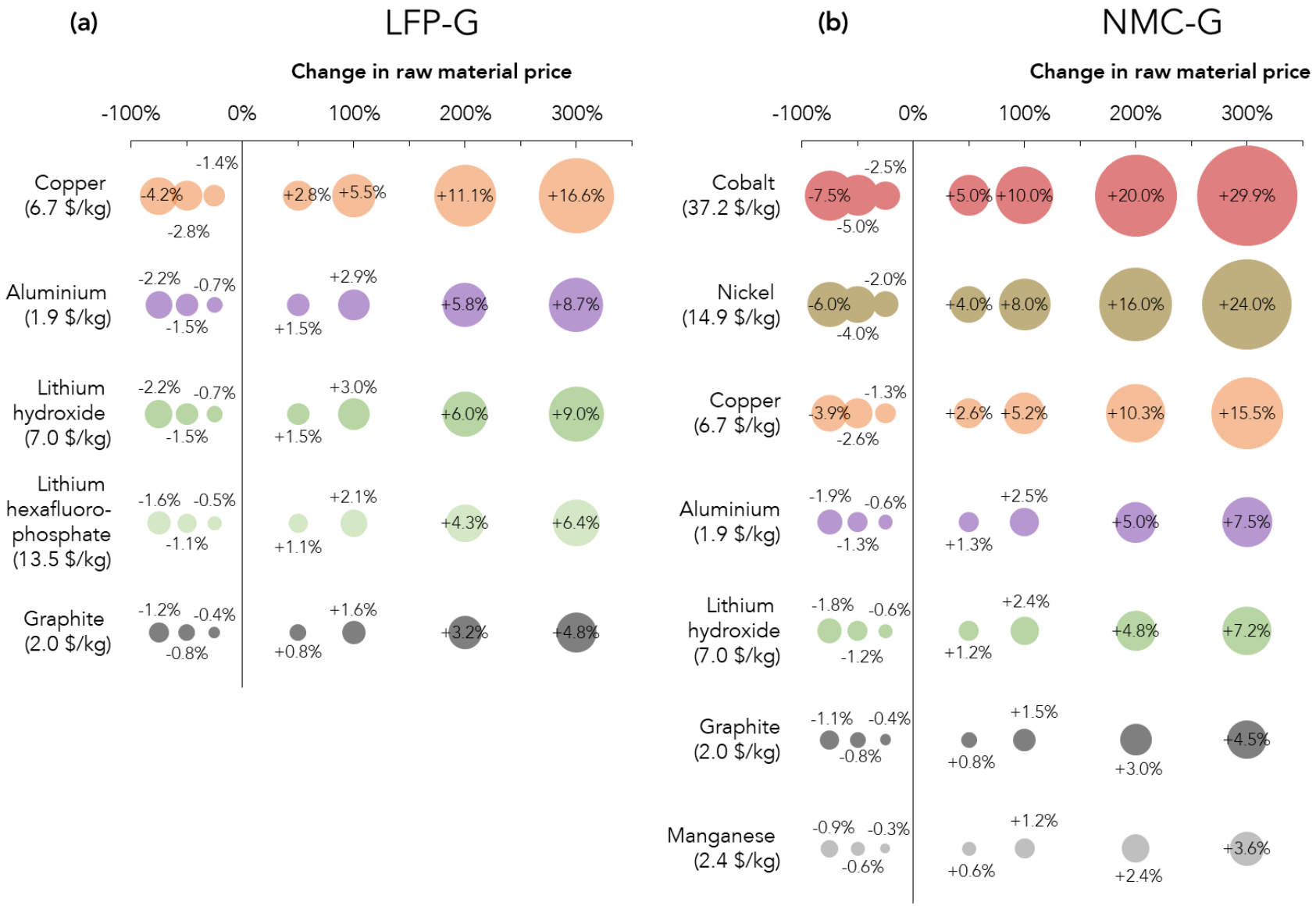

## Stationary vs. Transport



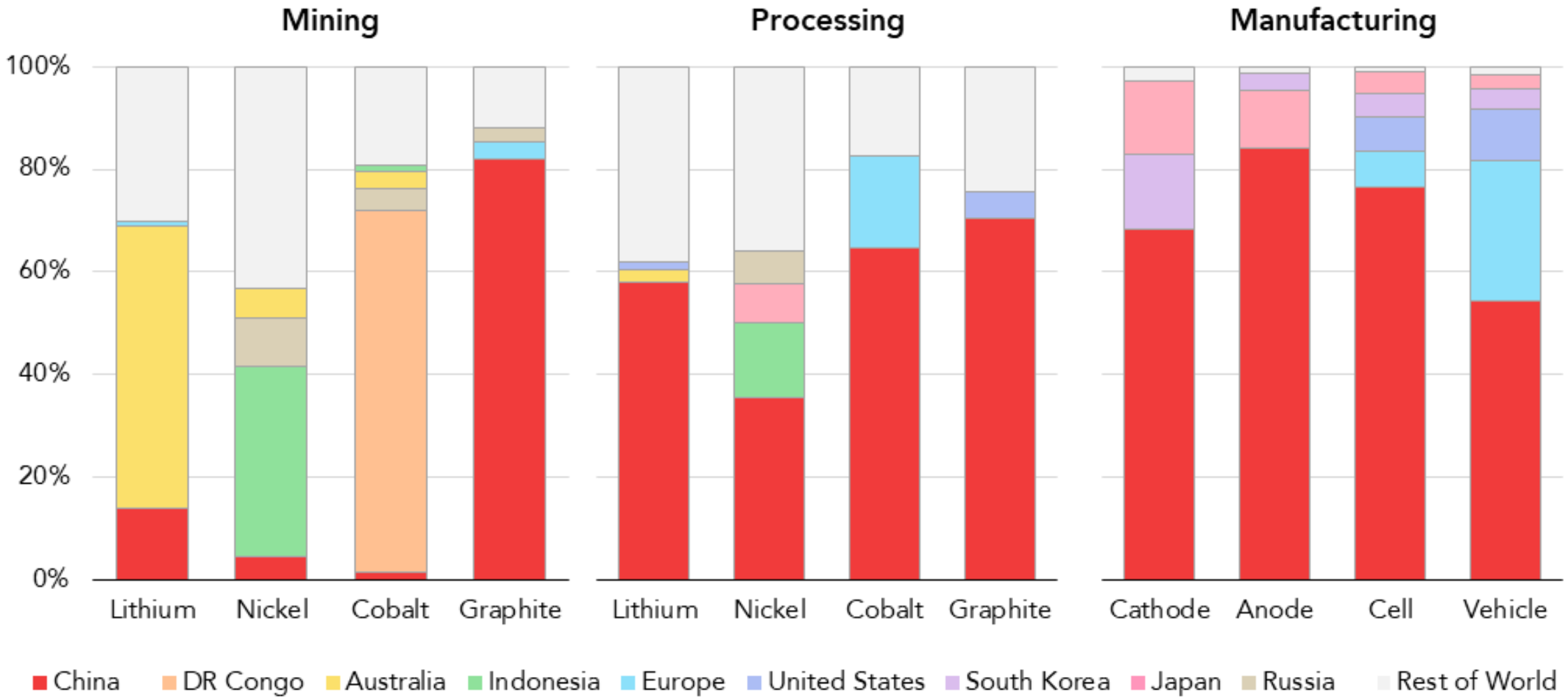
# Lithium-ion batteries use surprisingly little lithium



# Raw material prices must quadruple for real impact



# China dominates the lithium-ion value chain



# Falling prices can be expressed by their ‘experience curve’

## Solar PV modules [USD/kW]