Imperial College London

Cost Trajectories for Electrical Energy Storage Technologies

Oliver Schmidt, Adam Hawkes, Ajay Gambhir, Iain Staffell

26 April 2018 | Enerstock 2018
Çukurova University, Adana, Turkey

Grantham Institute

Investment costs for lithium-ion batteries have fallen dramatically in recent years

Recent cost developments

Average: 3,000 $/kWh

Powerwall 1: 1,100 $/kWh

Powerwall 2: 500 $/kWh

October 2013

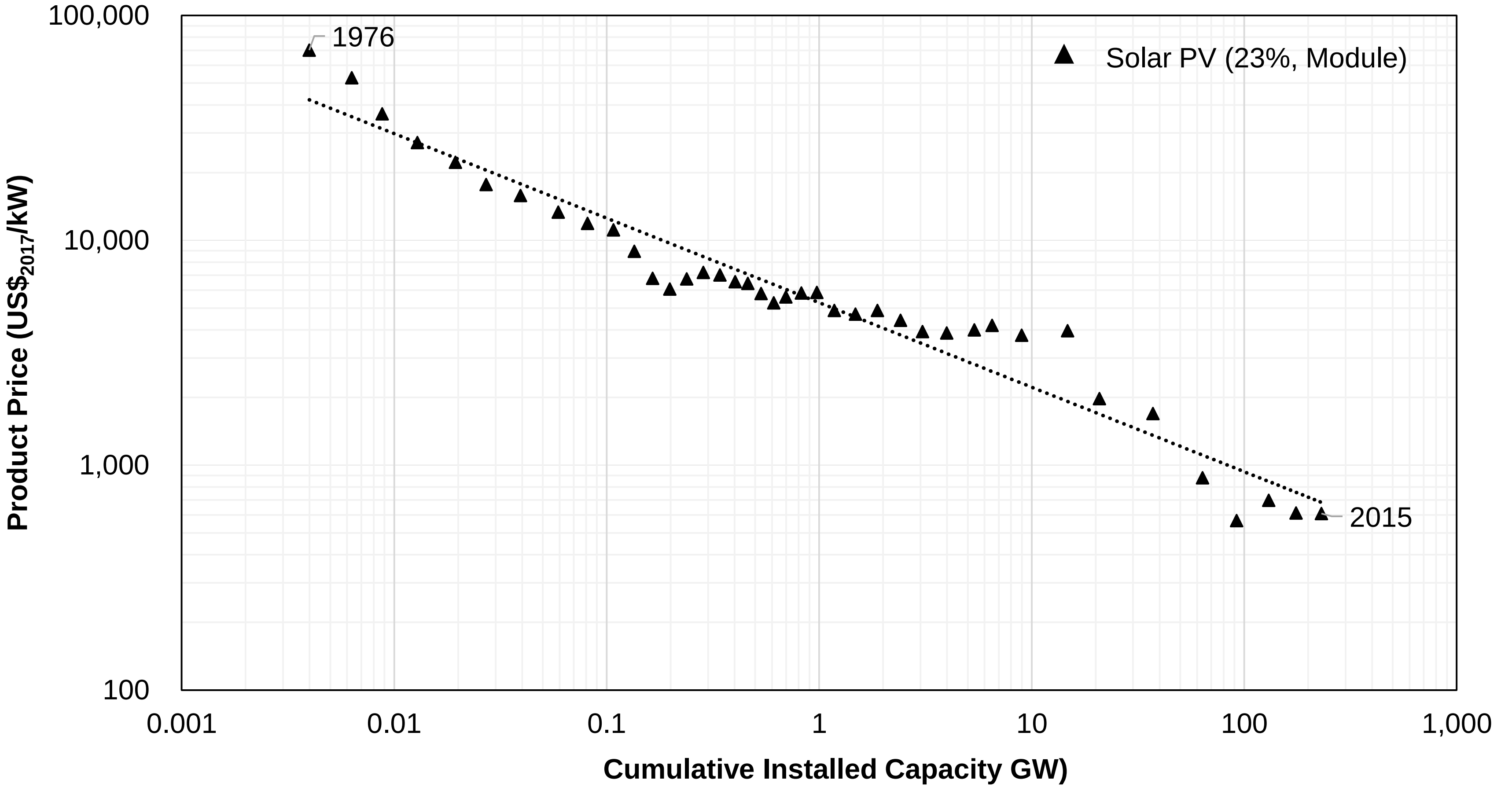
April 2015

October 2016

Sources: Tepper, M. Solarstromspeicher-Preismonitor Deutschland 2016. (Bundesverband Solarwirtschaft e.V. und Intersolar Europe, 2016); www.solarfixni.co.uk/solarpanelsystems/tesla/; www.tesla.com/powerwall

Experience curves are an objective tool to model cost reductions for technologies

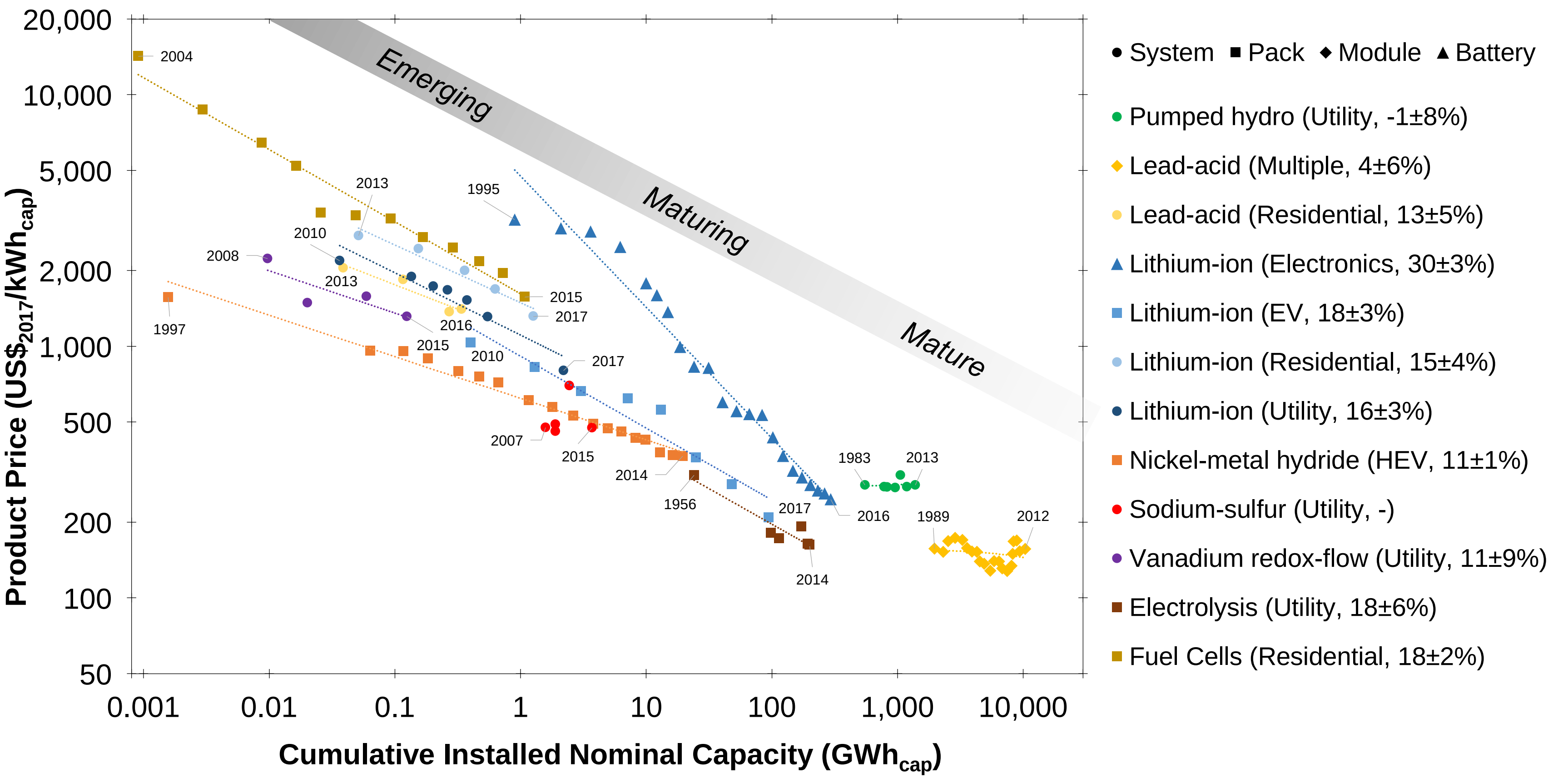
Method



Source: Liebreich, M. Keynote - Bloomberg New Energy Finance Summit 2016. (Bloomberg New Energy Finance, 2016).

We derive a 1st-of-its-kind experience curve dataset for storage technologies…

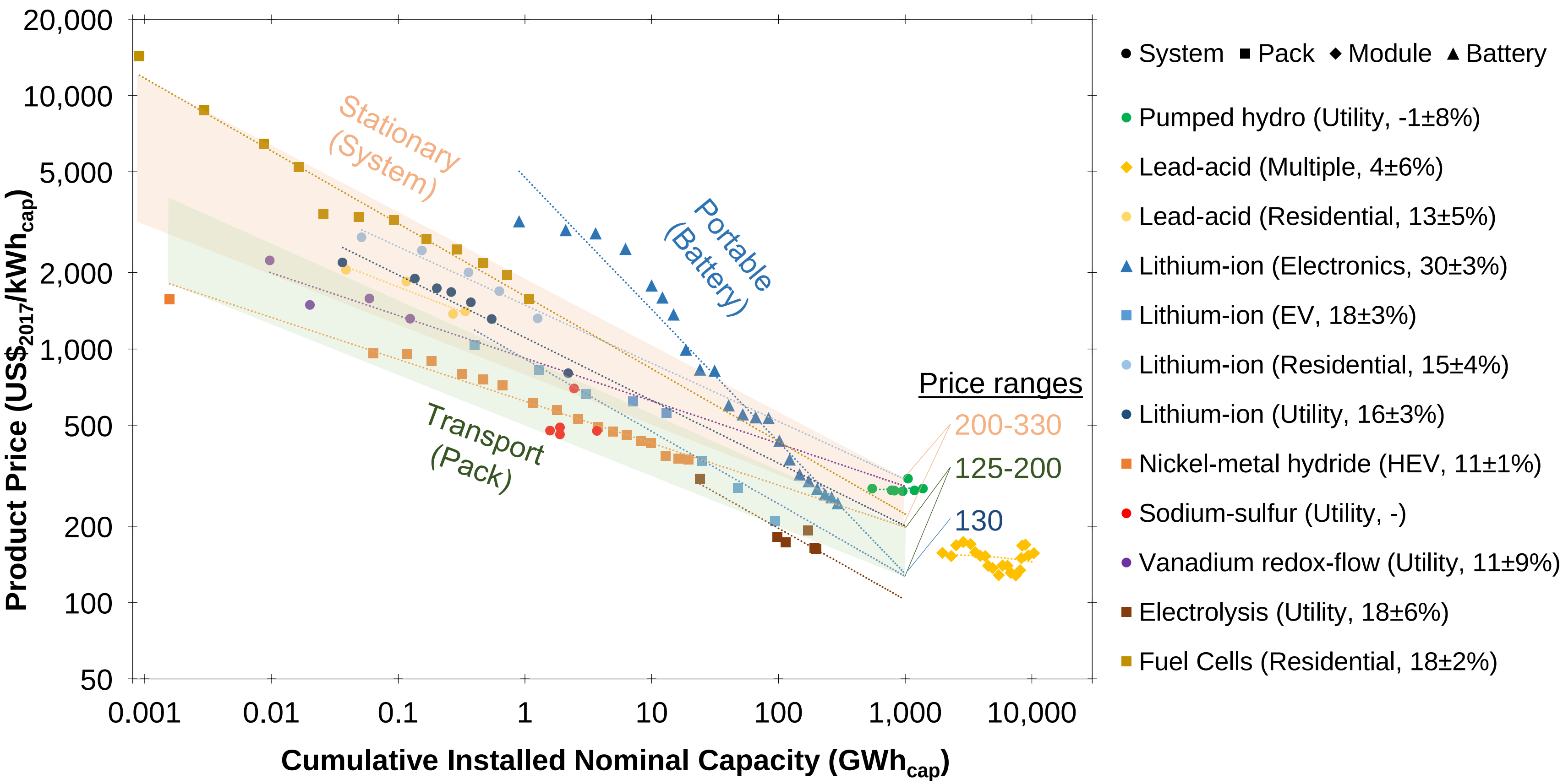
Dataset



Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

… that enables evidence-based cost projections

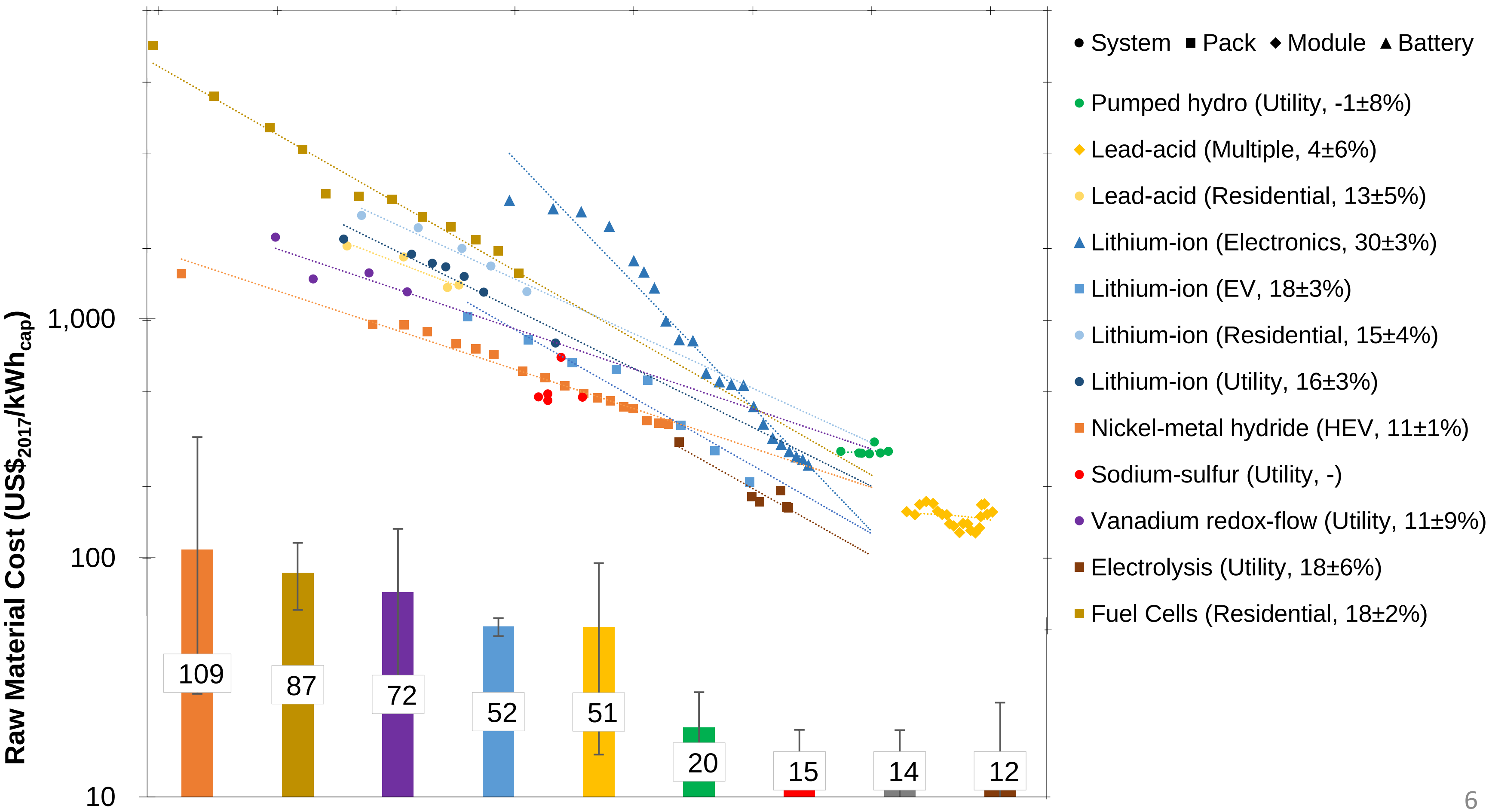
Result



Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

Raw material costs suggest that these cost projections are not infeasible

Sanity Check – Raw material cost



Investment cost reductions affect storage profitability in various applications

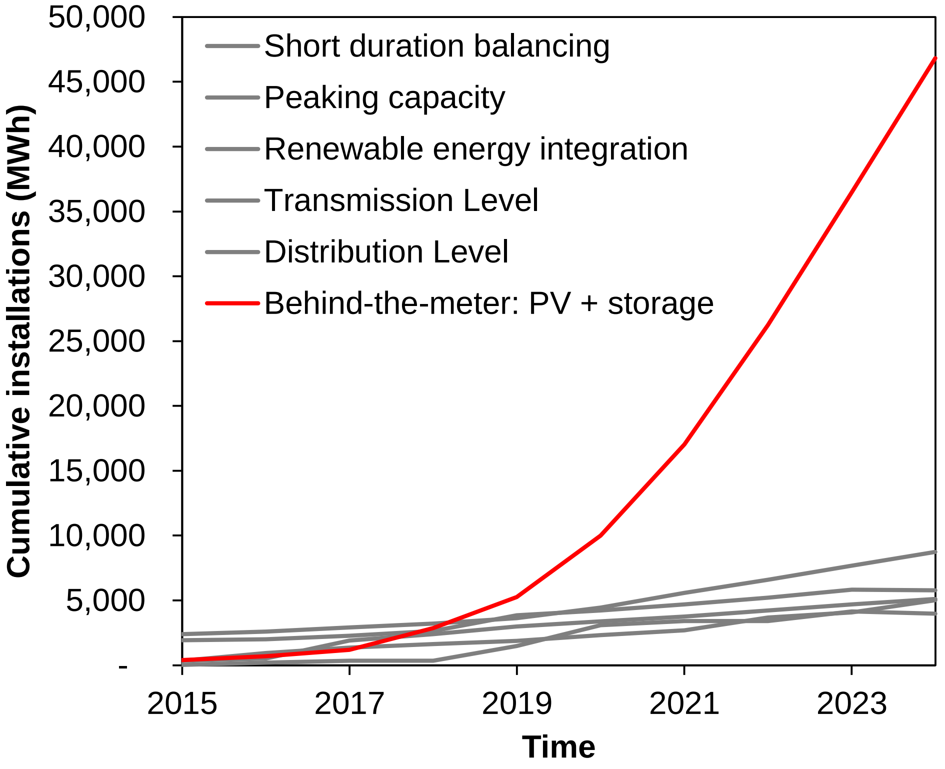
Analysis – Competitiveness

Home storage

Electric vehicles

The market for home storage appears poised for growth…

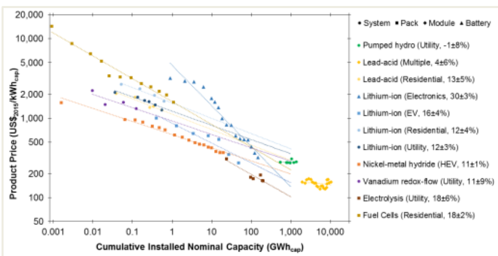
Analysis – Competitiveness (Home storage)

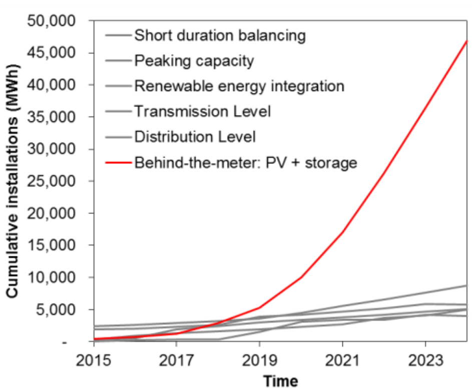


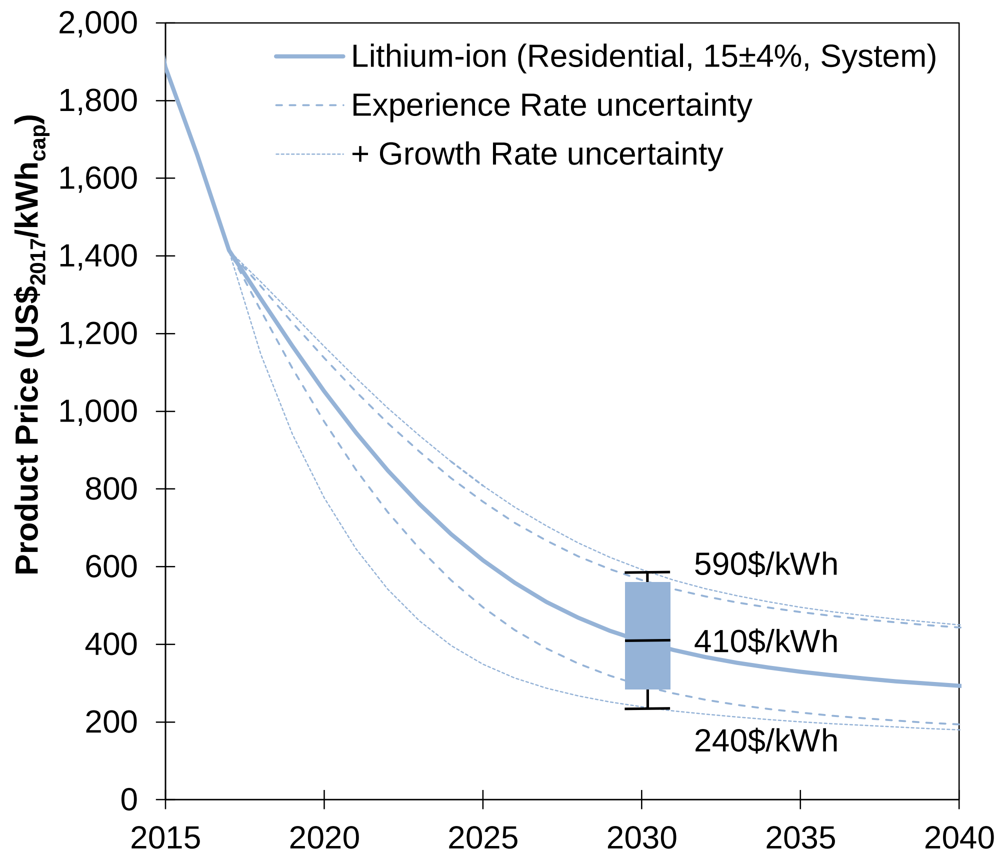
Source: www.tesla.com/powerwall; L. Goldie-Scot, Global Energy Storage Forecast 2016-24, Bloomberg New Energy Finance, 2016.

with cost of installed residential li-ion systems falling to 300-780 $/kWh by 2030

Analysis – Competitiveness (Home storage)



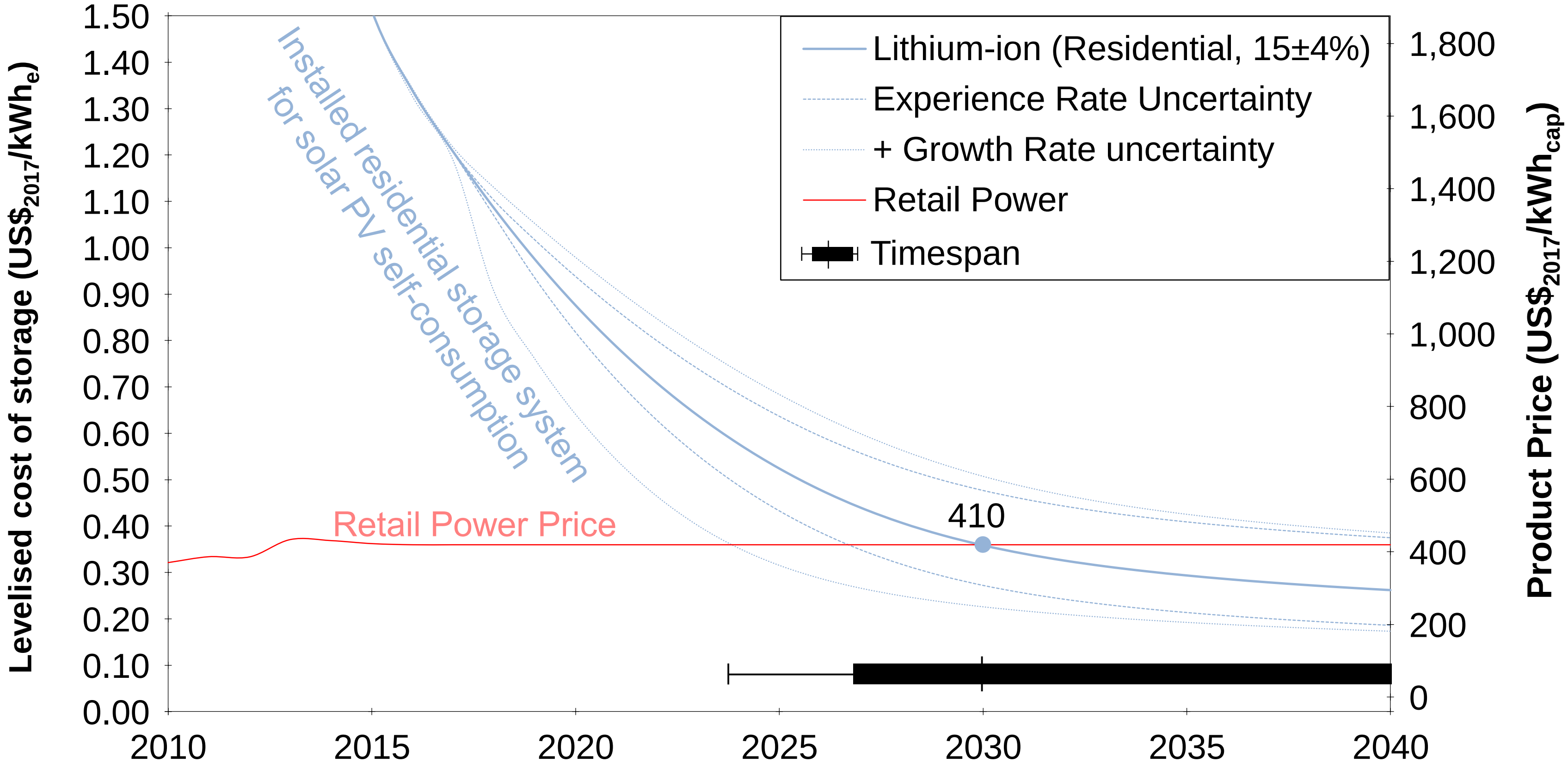




Source: Own Analysis

Still, residential batteries are unlikely to make economic sense in GER before 2030

Analysis – Competitiveness (Home storage)



Source: O. Schmidt, A. Hawkes, A. Gambhir & I. Staffell. The future cost of electrical energy storage based on experience rates. Nat. Energy 2, 17110 (2017)

The electrification of transport attracts most attention, because …

Analysis – Competitiveness (Electric Vehicles)

Tesla's Model 3 could be the car that makes electrics mainstream

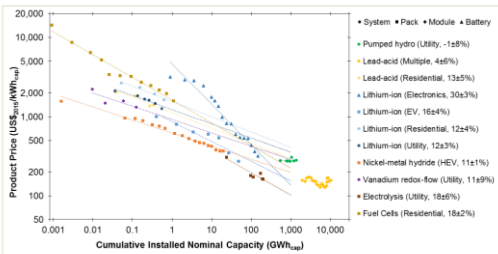
60,000 GWh

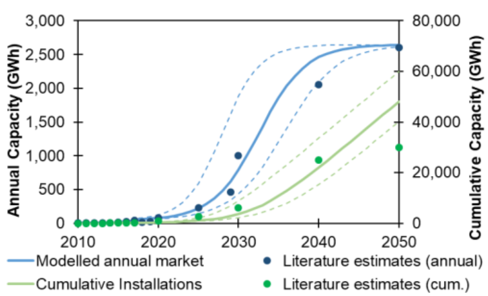
(capacity of EV batteries if all passenger cars are electric)

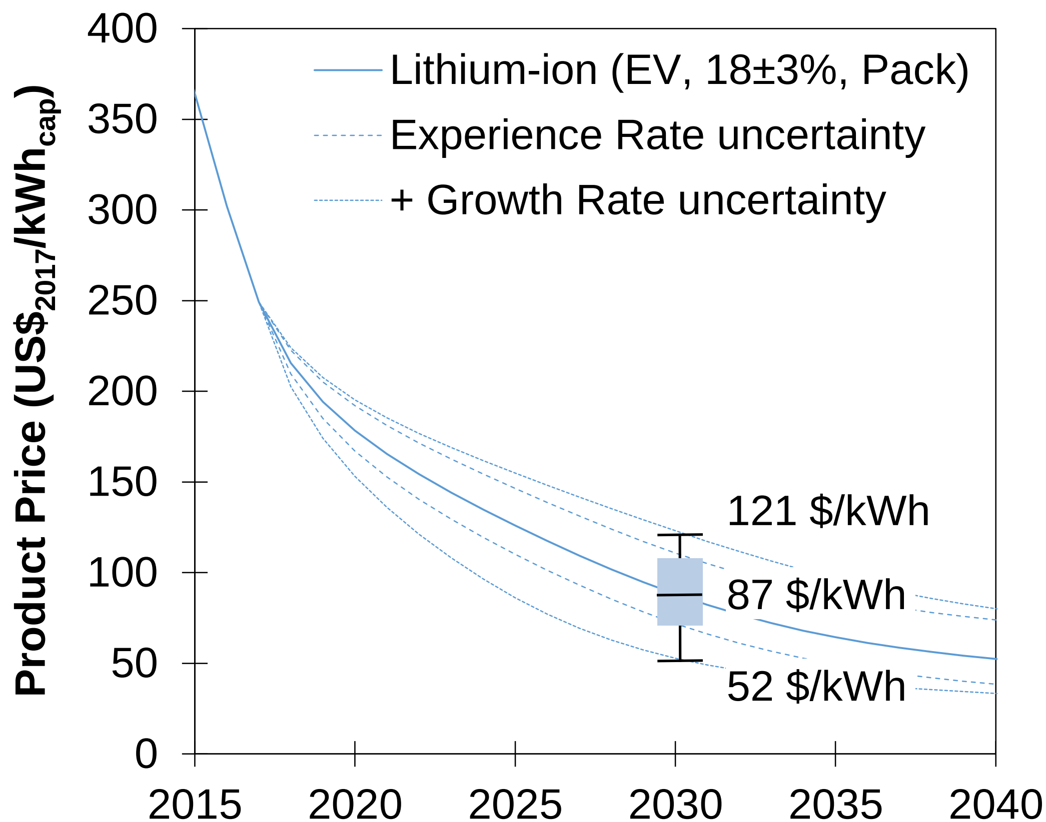
Source: Global EV Outlook 2017, International Energy Agency (2017) https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

EV battery pack costs may reach current raw material cost levels by 2030

Analysis – Competitiveness (Electric Vehicles)



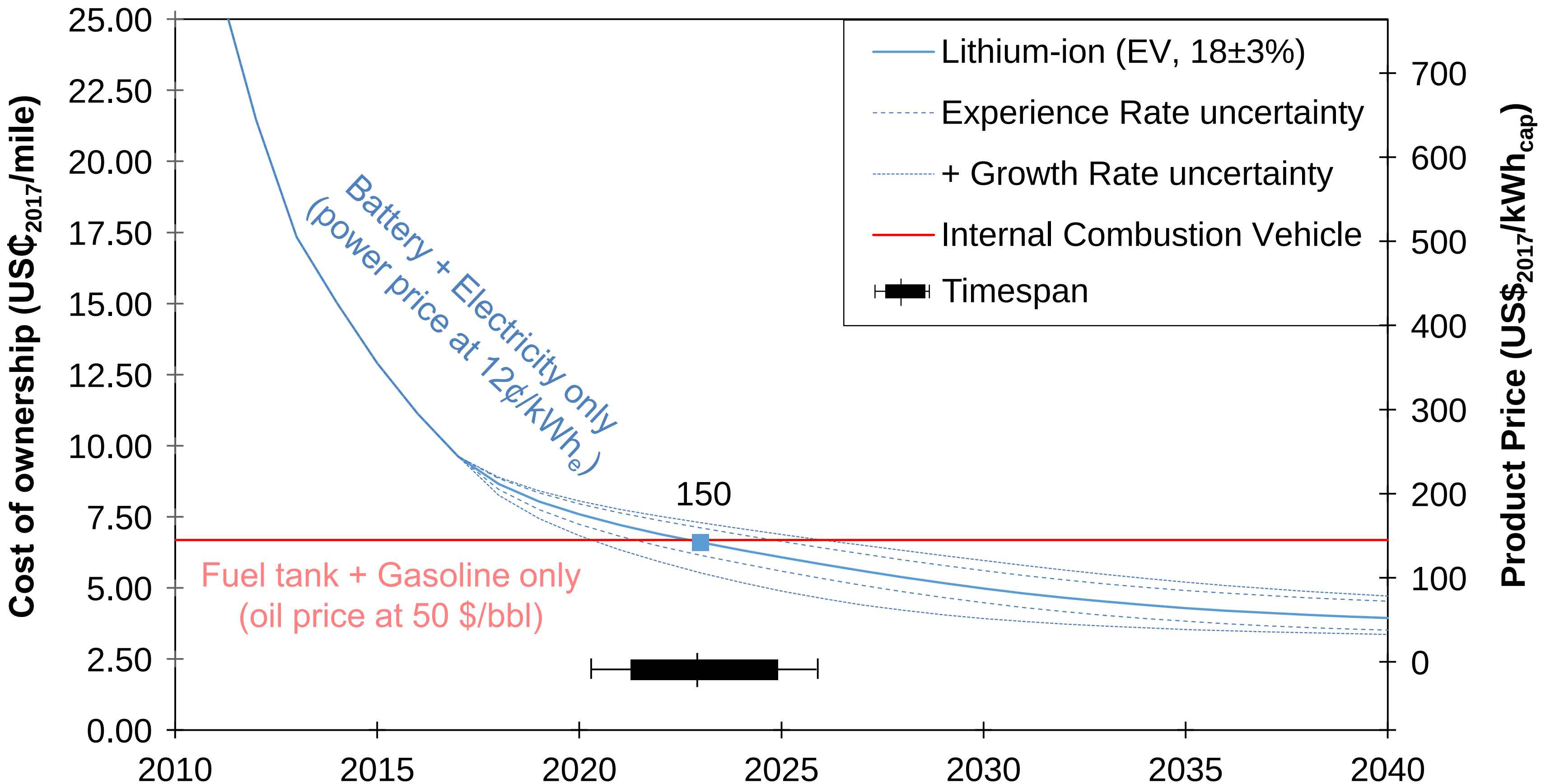




Source: Own analysis

Electric cars will beat conventional ones between 2021 and 2026

Analysis – Competitiveness (Electric Vehicles)



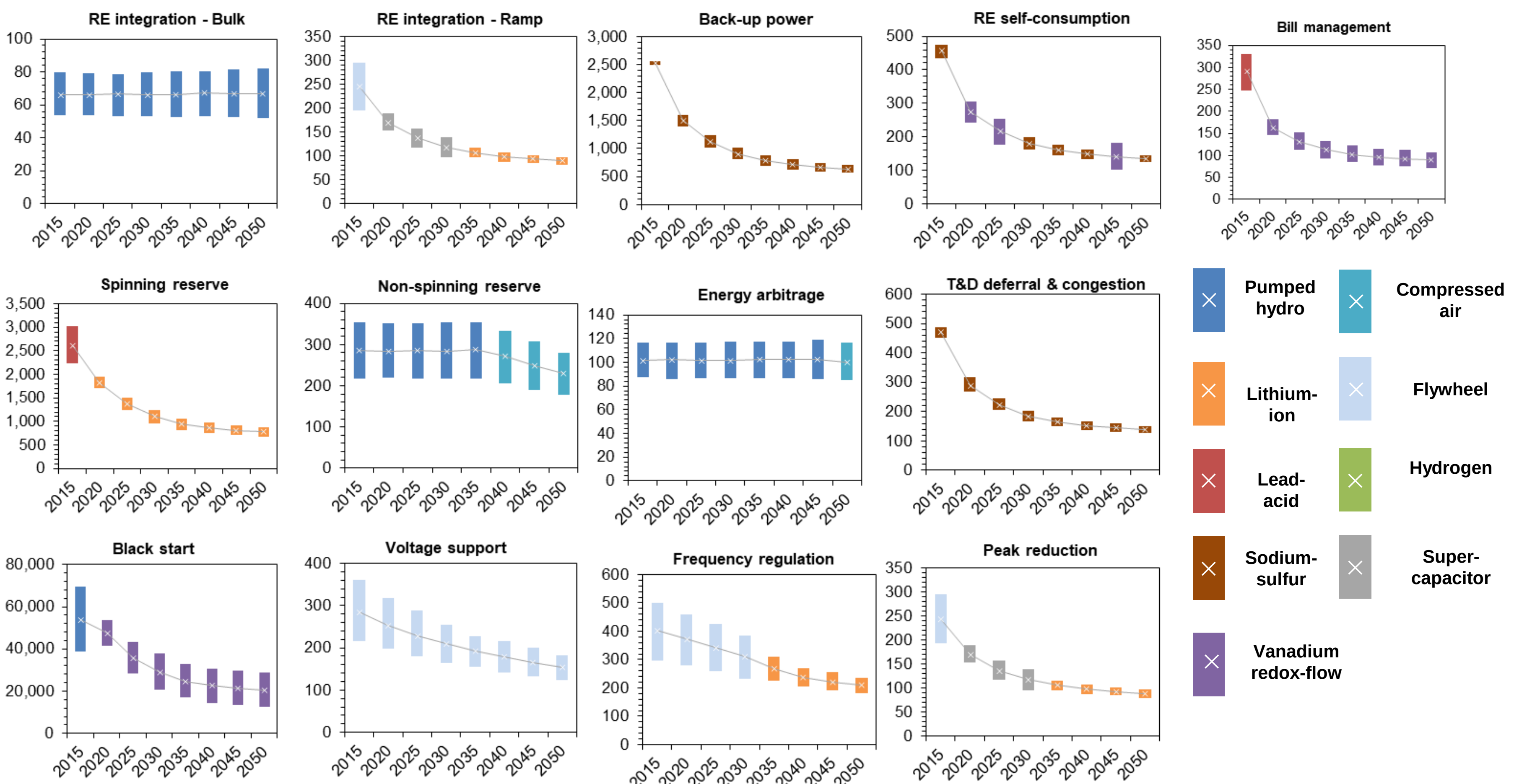
Source: Own analysis

Questions?

Oliver Schmidt | PhD Researcher in Energy Storage
Grantham Institute - Climate Change and the Environment
Imperial College London, Exhibition Road, London SW7 2AZ
Tel: +44 (0) 7934548736
Email: o.schmidt15@imperial.ac.uk
Website: www.storage-lab.com

Similarly, future LCOS for multiple storage technologies in various applications

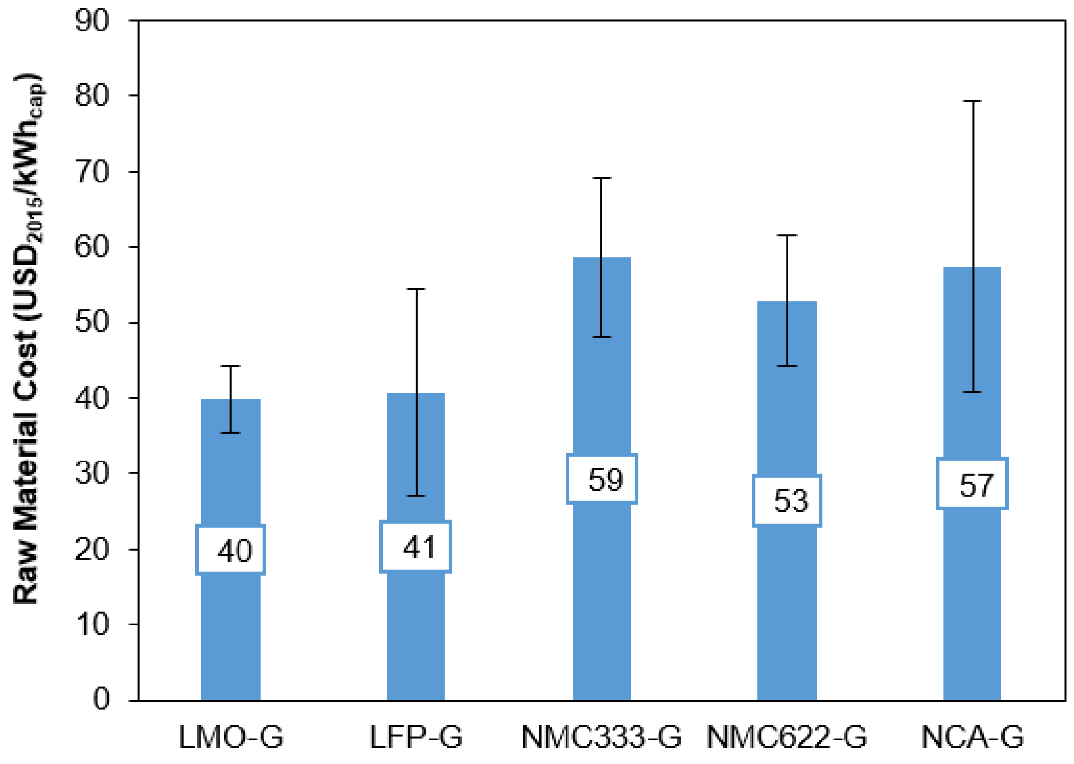
Future LCOS for storage technologies



Source: Sylvain Melchior, MSc thesis, Sustainable Energy Futures 2016/2017

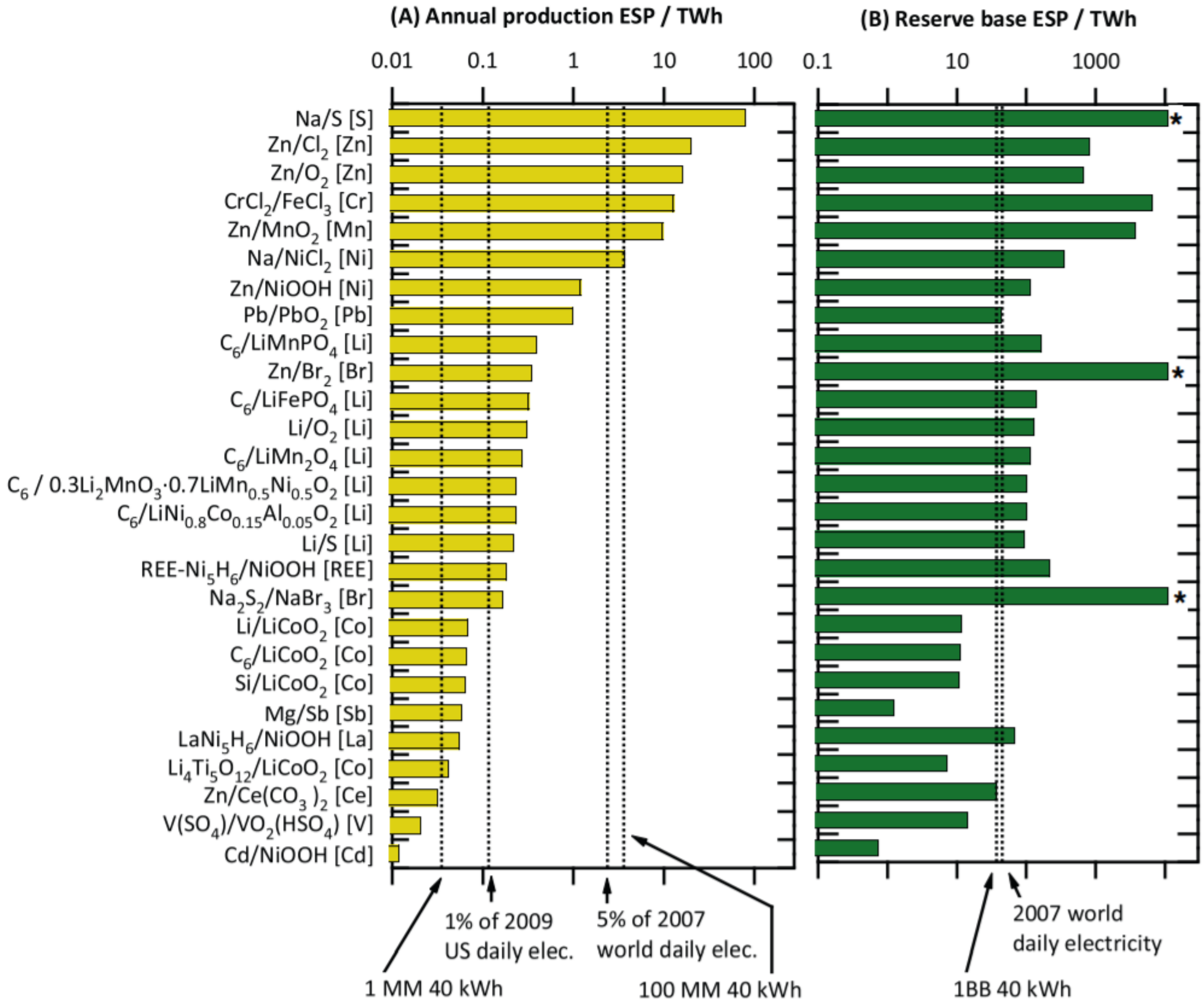
Lithium-ion raw material cost

Lithium-ion



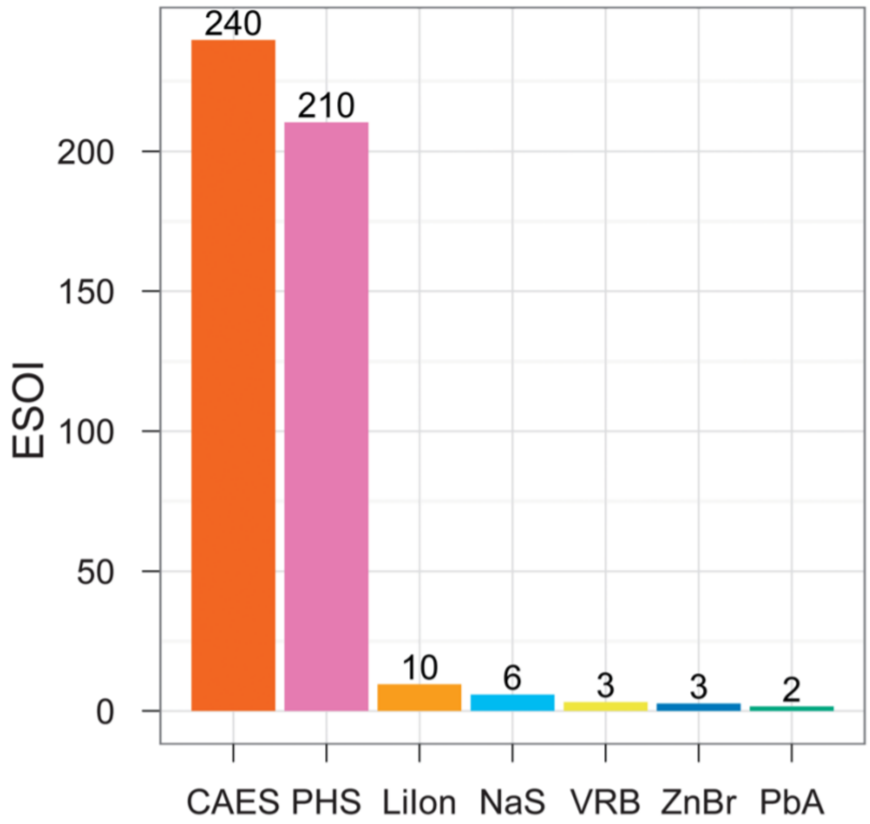
Source: Own analysis

Storage materials – reserve base



Source: Own analysis

ESOI of different storage technologies



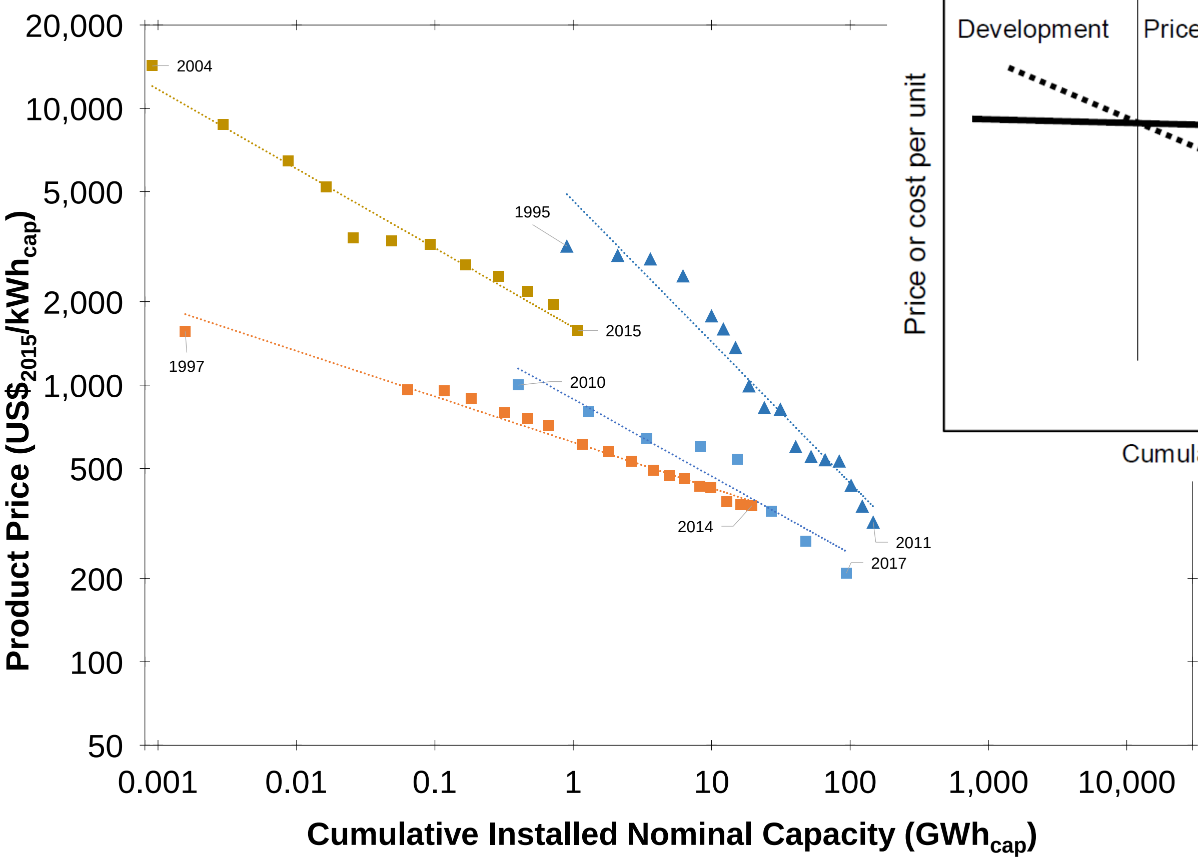
Cost figures can refer to different scopes containing not all cost components

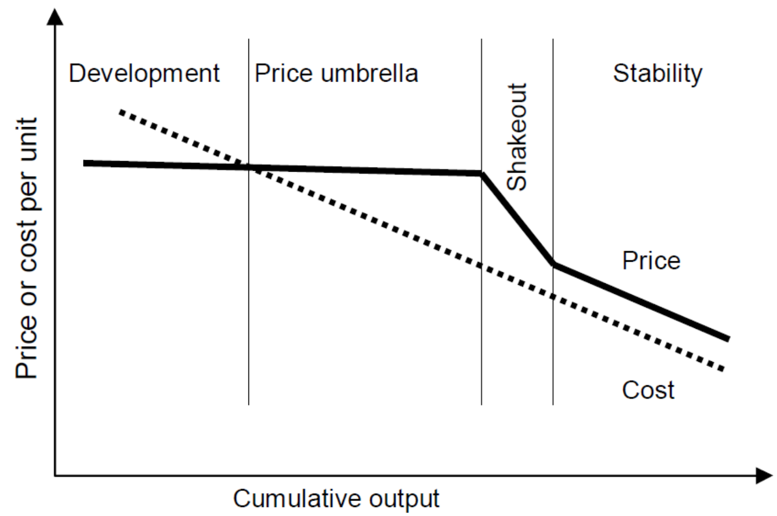
Technology scope, application and relative cost

	Cell	Consumer electronics	20% of installed system
	Module	-	-
	Pack	Electric vehicles	30% of installed system
	System (ex-works)	-	65% of installed system
	Installed system	Stationary applications	100%

However, experience rates of immature technologies can be highly uncertain

Uncertainty Check





Application-specific LCOS account for all relevant cost and performance parameters

Formula

$$LCOS\left[\frac{\$}{MWh}\right] =$$

$$\frac{Capex + \sum \frac{Capex_R}{(1+r)^{R*T_r}}}{\#cycles \; * \; DoD \; * C_{nom\_e} * \eta_{RT} \; * \; \sum_{n=1}^{N} \frac{(1+Deg)^n}{(1+r)^n}}$$

$$+ \frac{\sum_{n=1}^{N} \frac{Opex}{(1+r)^{n+T}}}{\#cycles \; * \; DoD \; * C_{nom\_e} * \eta_{RT} \; * \; \sum_{n=1}^{N} \frac{(1+Deg)^n}{(1+r)^n}}$$

$$+ \frac{\frac{Disposal}{(1+r)^{N+1}}}{\#cycles \; * \; DoD \; * C_{nom\_e} * \eta_{RT} \; * \; \sum_{n=1}^{N} \frac{(1+Deg)^n}{(1+r)^n}}$$

$$+ \frac{P_{el}}{\eta_{RT}}$$

Capex:	Investment cost ($)
$Capex_r$:	Replacement cost ($)
Opex:	Operating cost ($)
Disposal:	Disposal cost ($)
P_{el}:	Power cost ($/kWhel)
r:	Discount rate (%)
C_{nom_e}:	Nominal capacity (MWh)
DoD:	Depth-of-discharge (%)
N:	Lifetime (years)
#cycles:	Full cycles per year (#)
Deg:	Annual degradation (%)
n:	Period (year)
T_r:	Replacement interval (years)
R:	Replacement number (#)
T_c	Construction time (years)

Note: Construction time and self-discharge not explicitly considered for simplification; these parameters affect capex and period, and discharged energy respectively.