Imperial College London

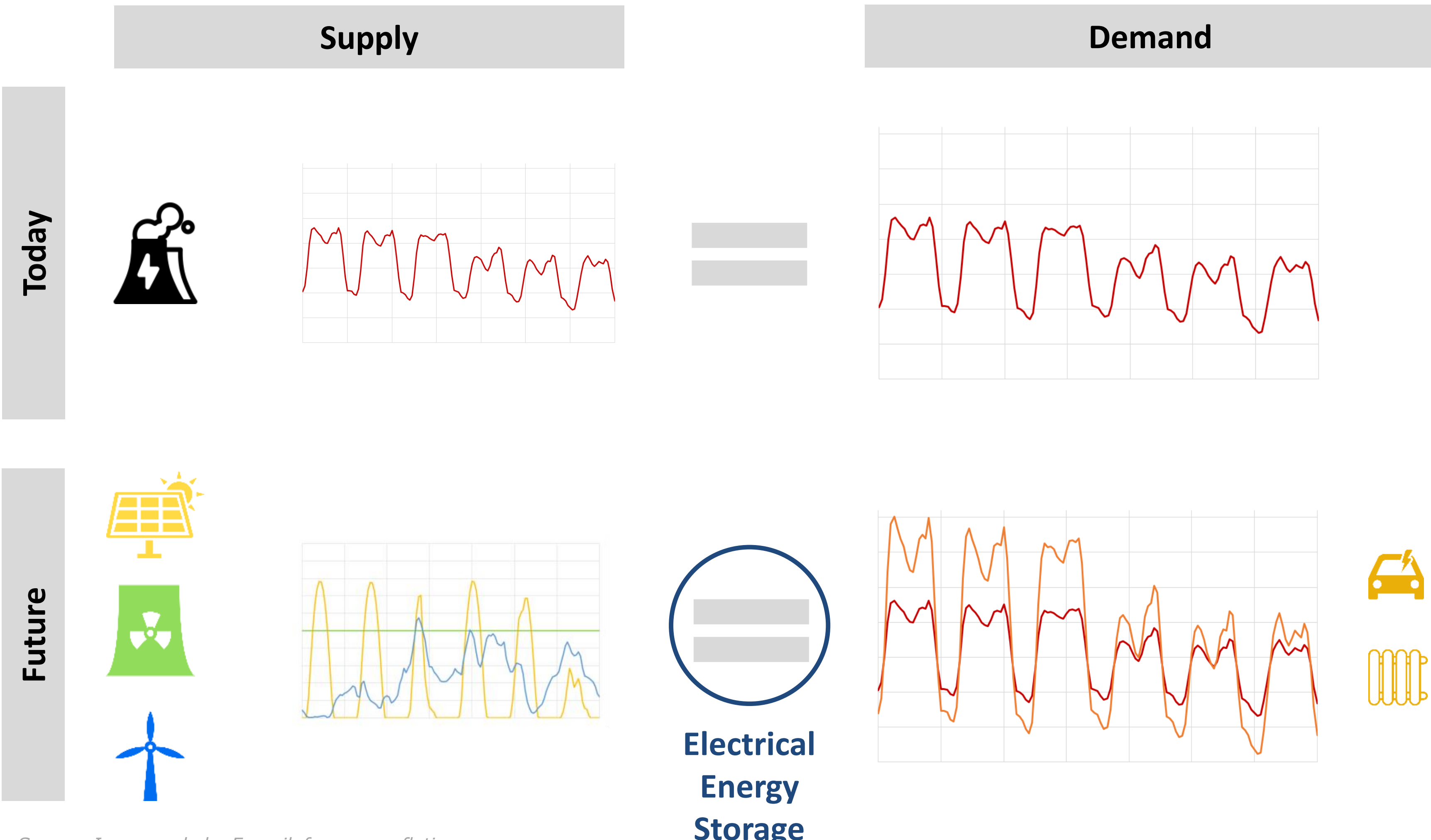
Cost projections for electrical energy storage

Oliver Schmidt,
Adam Hawkes, Ajay Gambhir, Iain Staffell

Bergen Economics of Energy and Environment Research Conference
22-23 May | NHH, Bergen

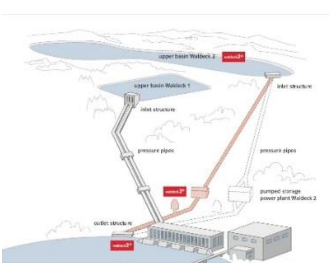
Grantham Institute

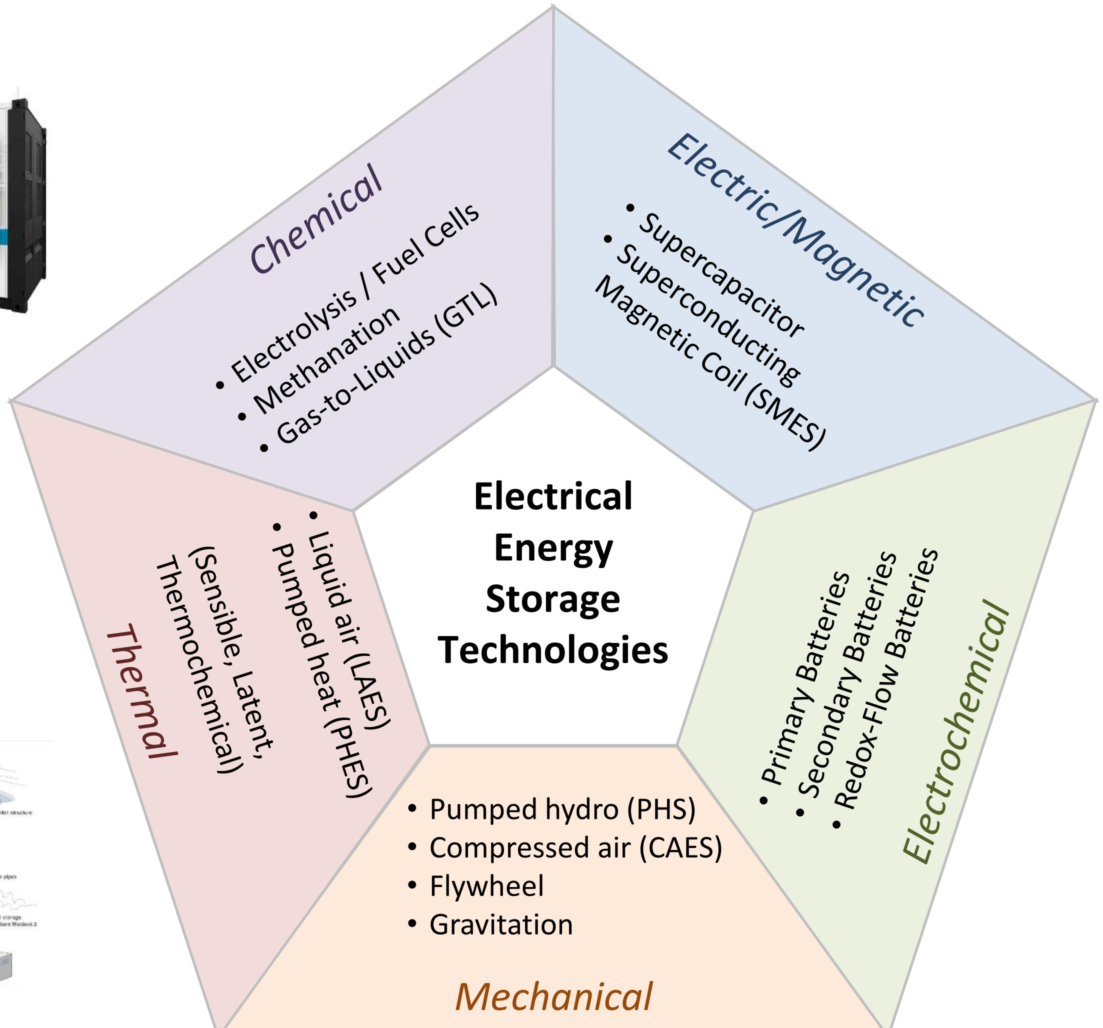
The need for electrical energy storage



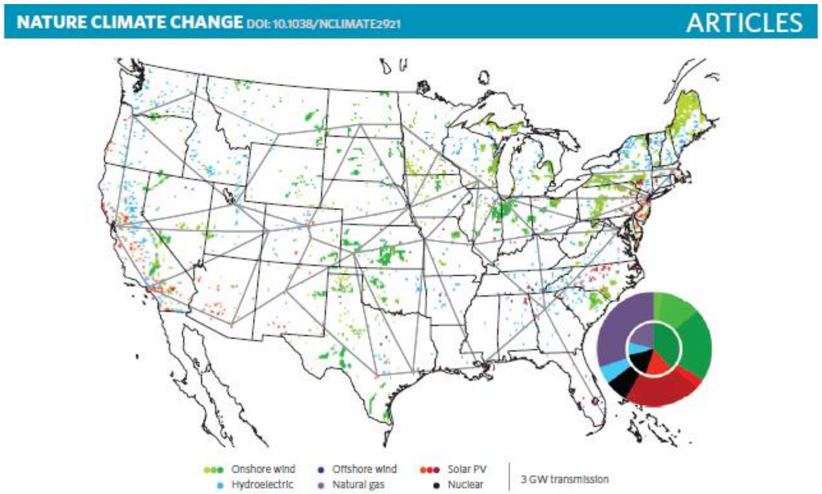
Source: Icons made by Freepik from www.flaticon.com

Electrical energy storage technologies





Question: How much will storage cost?



“Our results show that [...] CO_2 emissions [...] can be reduced by up to 80% [...], **without electrical storage.”**

vs.

“Production of cylindrical 2170 Li-ion cells used in Powerwall 2 started on **January 4th 2017**.”

“**15 GWh p.a.** will be devoted to stationary battery packs.”

Source: MacDonald AE, Clack CTM, Alexander A, Dunbar A, Wilczak J, Xie Y. Future cost-competitive electricity systems and their impact on US CO2 emissions. Nat Clim Chang. 2016:4–7.

Quote 1: www.tesla.com/blog/battery-cell-production-begins-gigafactory
Quote 2: www.greentechmedia.com/articles/read/Tesla-CTO-on-Energy-Storage-We-Should-All-Be-Thinking-Bigger
Video: www.youtube.com/watch?v=4F9ON-8rSnM

Example: Residential Li-ion systems (inst.)

Average: 3,000 $/kWh

Powerwall 1: 1,100 $/kWh

Powerwall 2: 500 $/kWh

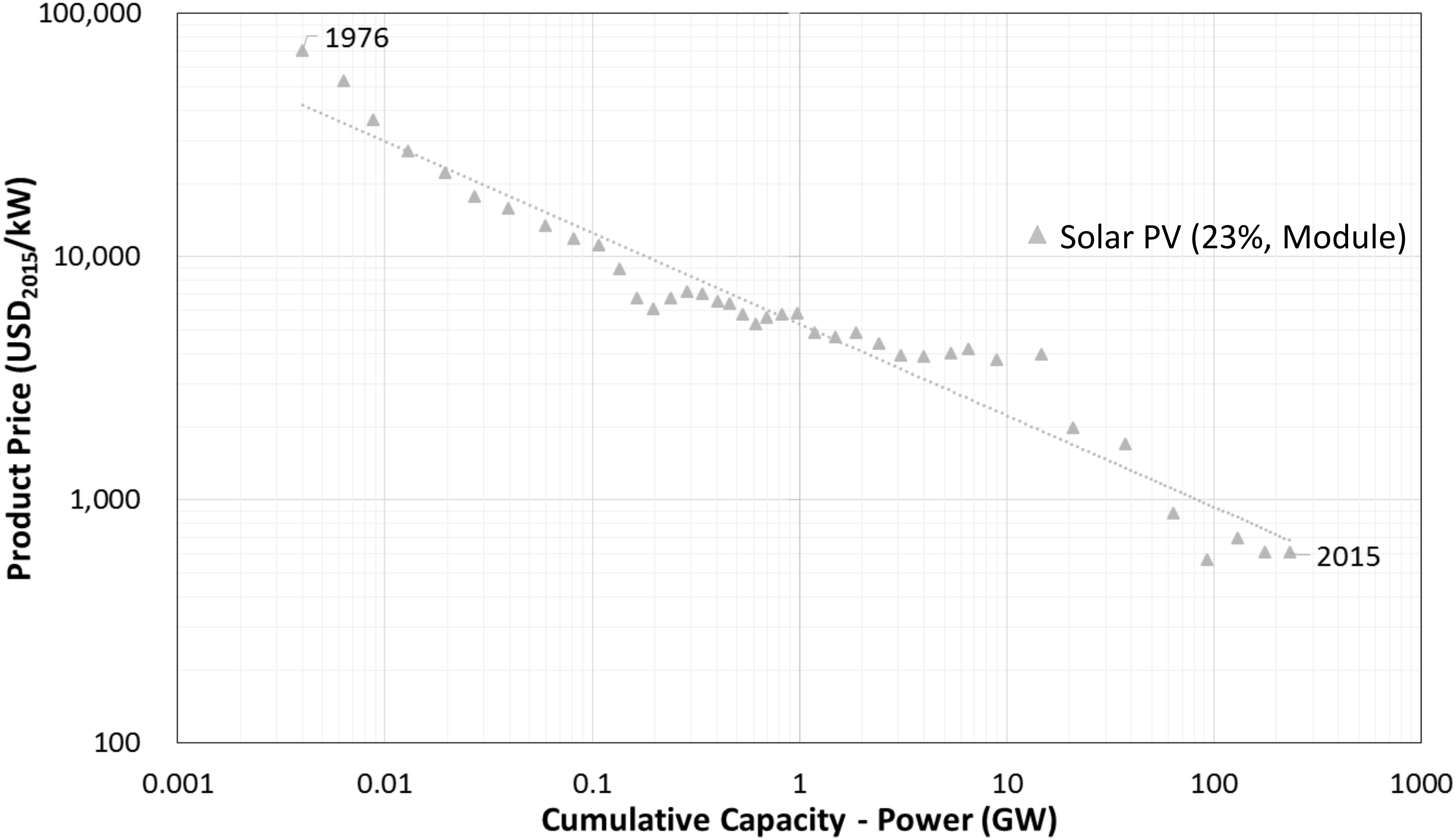
October 2013

April 2015

October 2016

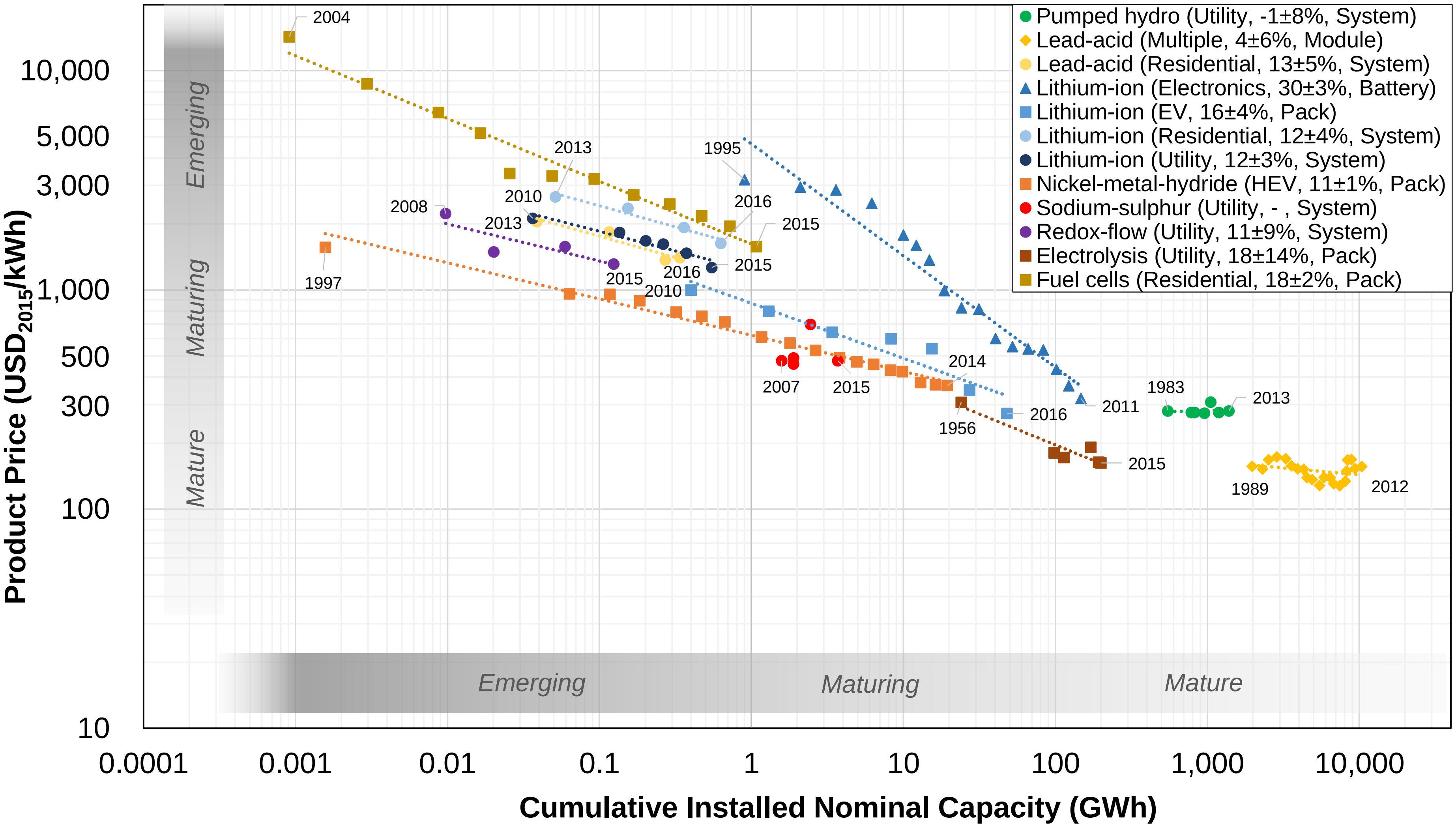
Sources: Tepper, M. Solarstromspeicher-Preismonitor Deutschland 2016. (Bundesverband Solarwirtschaft e.V. und Intersolar Europe, 2016)
www.solarfixni.co.uk/solarpanelsystems/tesla/
www.tesla.com/powerwall

Method: Experience curve analysis

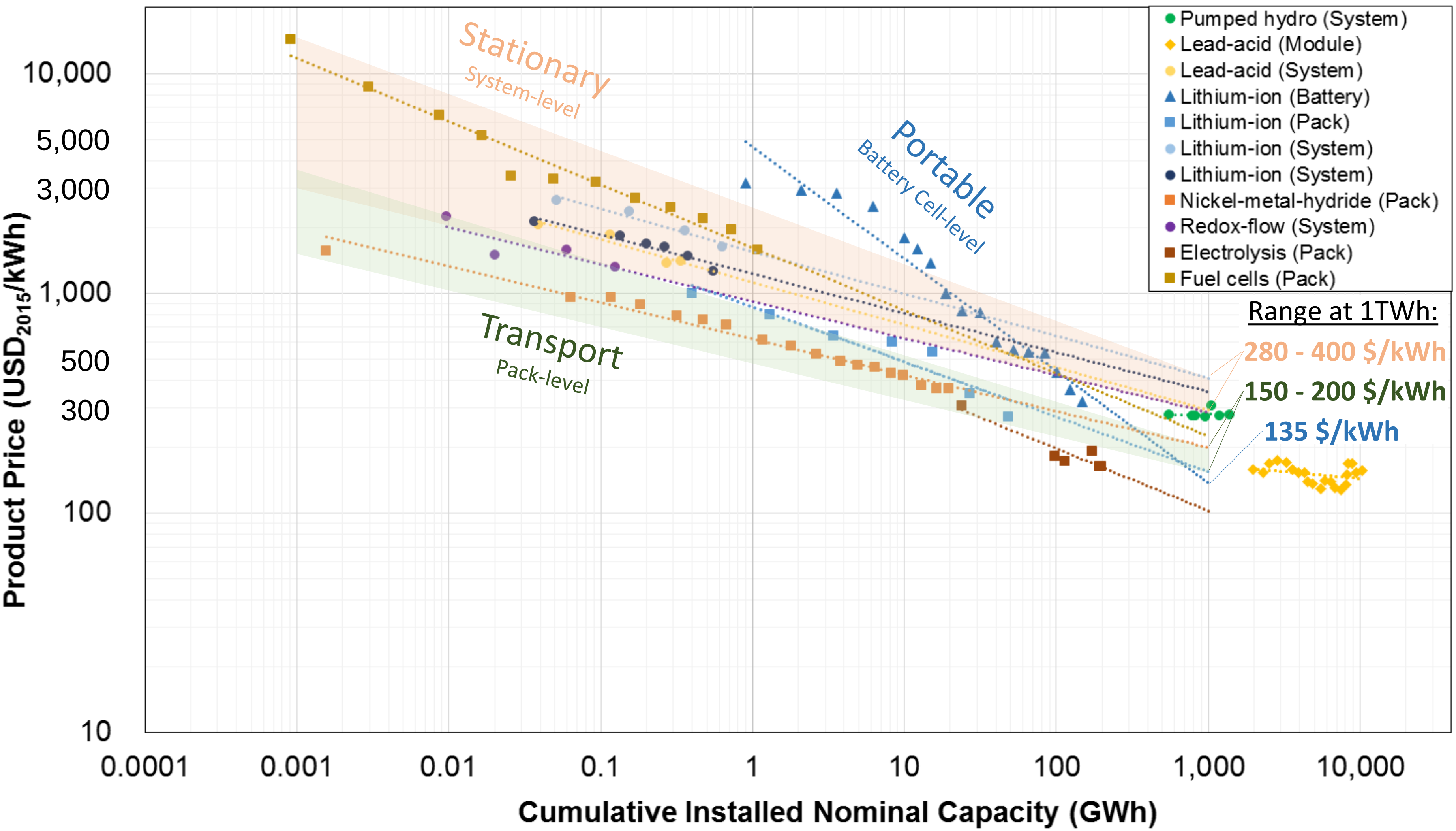


Source: Liebreich, M. Keynote - Bloomberg New Energy Finance Summit 2016. (Bloomberg New Energy Finance, 2016).

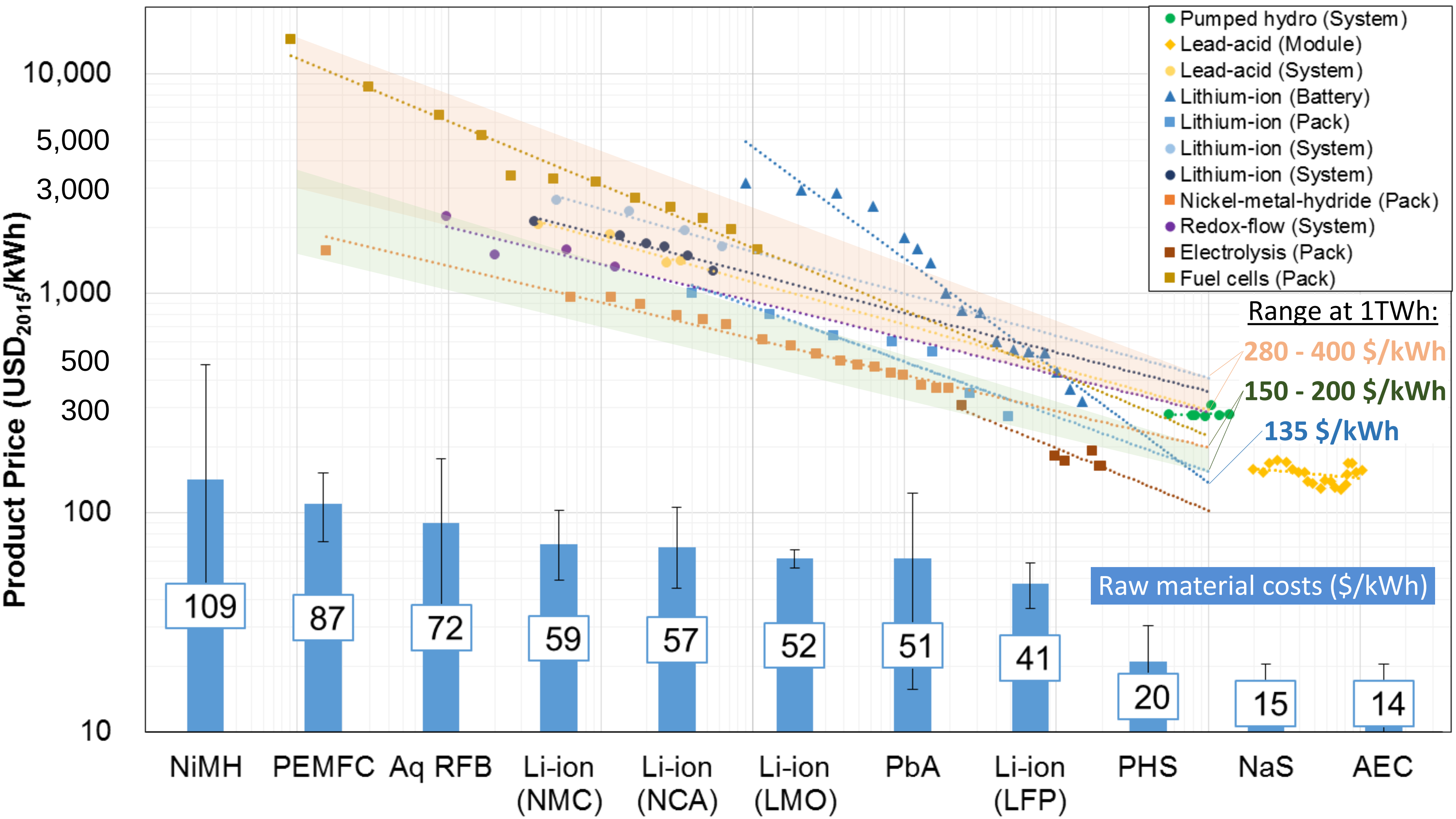
Result: Energy storage experience curves



Costs for installed stationary systems fall to 280-400 $/kWh once 1 TWh is built

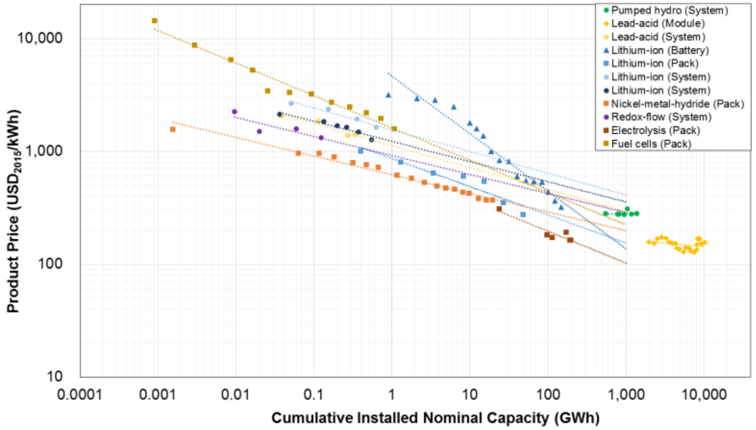


Based on raw material costs as lower boundary, identified price range is feasible



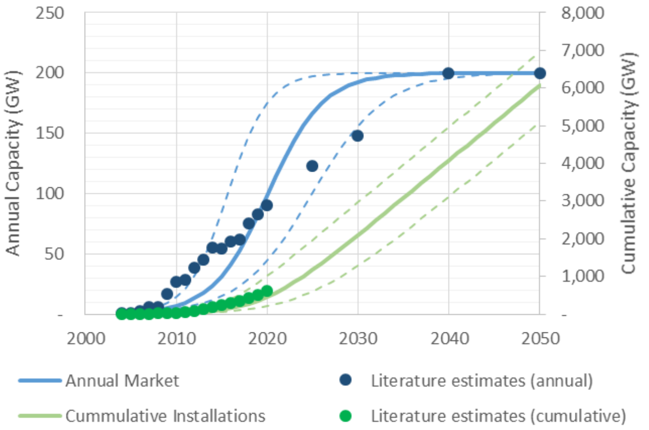
Analysis: Timeframe of cost reduction

Experience curves
(f: cumulative capacity)

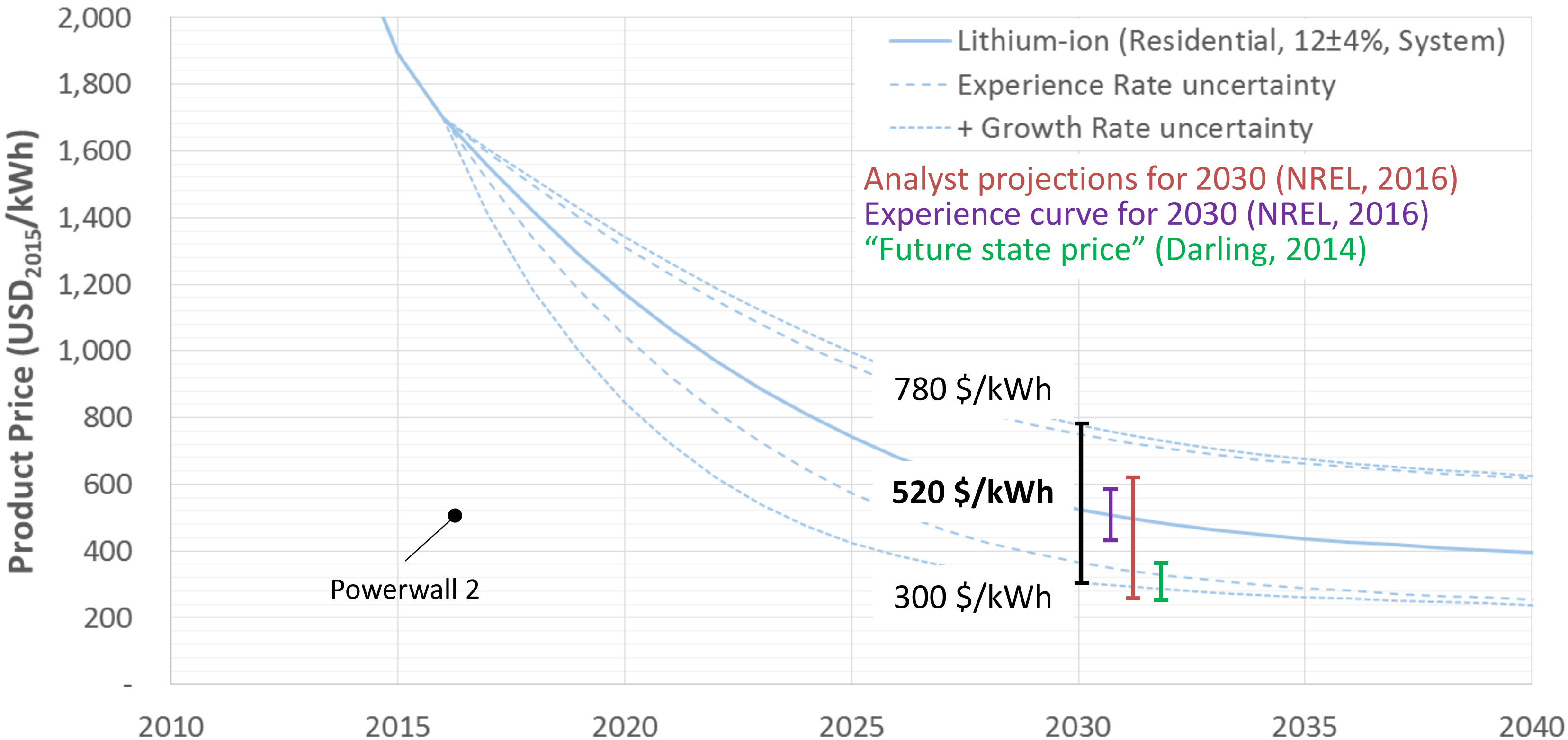


+

Growth rate
(in cumulative capacity)



Projections for residential Li-ion systems are on higher end of similar estimates



Powerwall 2 could represent step-change not captured by experience curve analysis

Sources: www.tesla.com/powerwall. (Accessed: 7th November 2016)
www.lazard.com/media/438042/lazard-levelized-cost-of-storage-v20.pdf
Feldman, D. et al. Exploring the Potential Competitiveness of Utility-Scale Photovoltaics plus Batteries with Concentrating Solar Power, 2015 – 2030. (NREL, 2016).
Darling, R. M., et al. Pathways to low-cost electrochemical energy storage: a comparison of aqueous and nonaqueous flow batteries. Energy Environ. Sci. 7, 3459–3477 (2014).

Analysis: Levelised cost of storage (LCOS) for residential PV-coupled systems

Definition

Constant price per $kWh_{discharge}$ at which net present value of storage project is zero

Formula

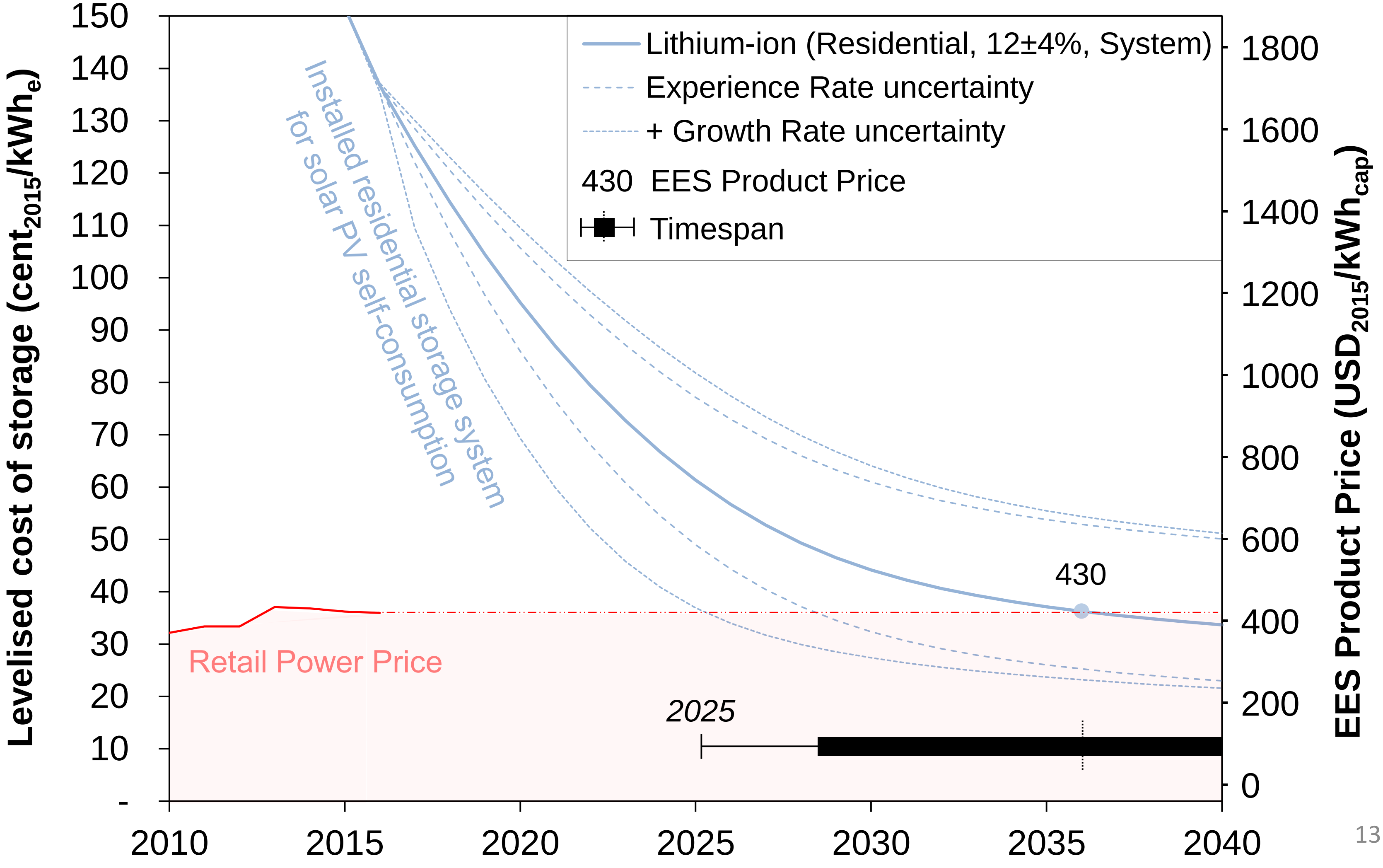
$$LCOS = \frac{CAPEX + O\&M\ (disc.) + Charging\ cost\ (disc.) + Residual\ value\ (disc.)}{Total\ energy\ discharged\ (disc.)}$$

Input Parameters

Capital cost	*see exp curve*	Lifetime	10 years
O&M cost	0%	Cycles	250 p.a.
Charging cost (PV)	0.14-0.05 $/kWh	Depth-of-discharge	80%
Residual value	0%	Round-trip efficiency	92%
WACC	5%	Annual degradation	1%

Sources: https://www.apricum-group.com/how-to-determine-meaningful-comparable-costs-of-energy-storage/

Residential storage for PV self-consumption unlikely to be economic before 2035



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

Formula – Levelised Cost of Storage

$$LCOS = \frac{CAPEX}{\#cycles * DOD * C_{\text{rated}} * \sum_{n=1}^{N} \frac{(1-DEG*n)}{(1+r)^n}}$$

$$+ \frac{O\&M * \sum_{n=1}^{N} \frac{1}{(1+r)^n}}{\#cycles * DOD * C_{\text{rated}} * \sum_{n=1}^{N} \frac{(1-DEG*n)}{(1+r)^n}}$$

$$- \frac{\frac{V_{\text{residual}}}{(1+r)^{N+1}}}{\#cycles * DOD * C_{\text{rated}} * \sum_{n=1}^{N} \frac{(1-DEG*n)}{(1+r)^n}}$$

$$+ \frac{P_{\text{elec-in}}}{\eta(DOD)}$$

With:

$\#cycles$	= full charging/discharging cycles per year
DOD	= depth of discharge
C_{rated}	= rated capacity
DEG	= annual degradation rate of capacity[4]
N	= project lifetime in years
r	= discount rate (e.g., weighted average cost of capital)
$O\&M$	= O&M cost (assumed to be constant)
V_{residual}	= residual value (after project lifetime)
$P_{\text{elec-in}}$	= charging electricity tariff (assumed to be constant)
$\eta(DOD)$	= round-trip efficiency at *DOD* (assumed to be constant)

1) Assuming linear degradation

Sources: https://www.apricum-group.com/how-to-determine-meaningful-comparable-costs-of-energy-storage/

Electric vehicles could be competitive with conventional cars between 2022 and 2034