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NERC SCIENCE OF THE ENVIRONMENT

Cost-effective electricity storage: Who will win the race?

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Context - Cost estimates in energy systems modelling

Low cost energy storage could play a key role in decarbonising our energy system by facilitating the uptake of more intermittent and inflexible low-carbon generation.

This role is analysed in energy systems modelling, which has significant impact on policy-making.[1] Modelling assumptions for future costs of storage influence the model outcomes with an impact on the policy support technologies may receive, and as result the actual future role of energy storage.

This work combines three complementary tools to derive robust future cost estimates of storage, and then analyses the value of storage in future energy systems via energy systems modelling.

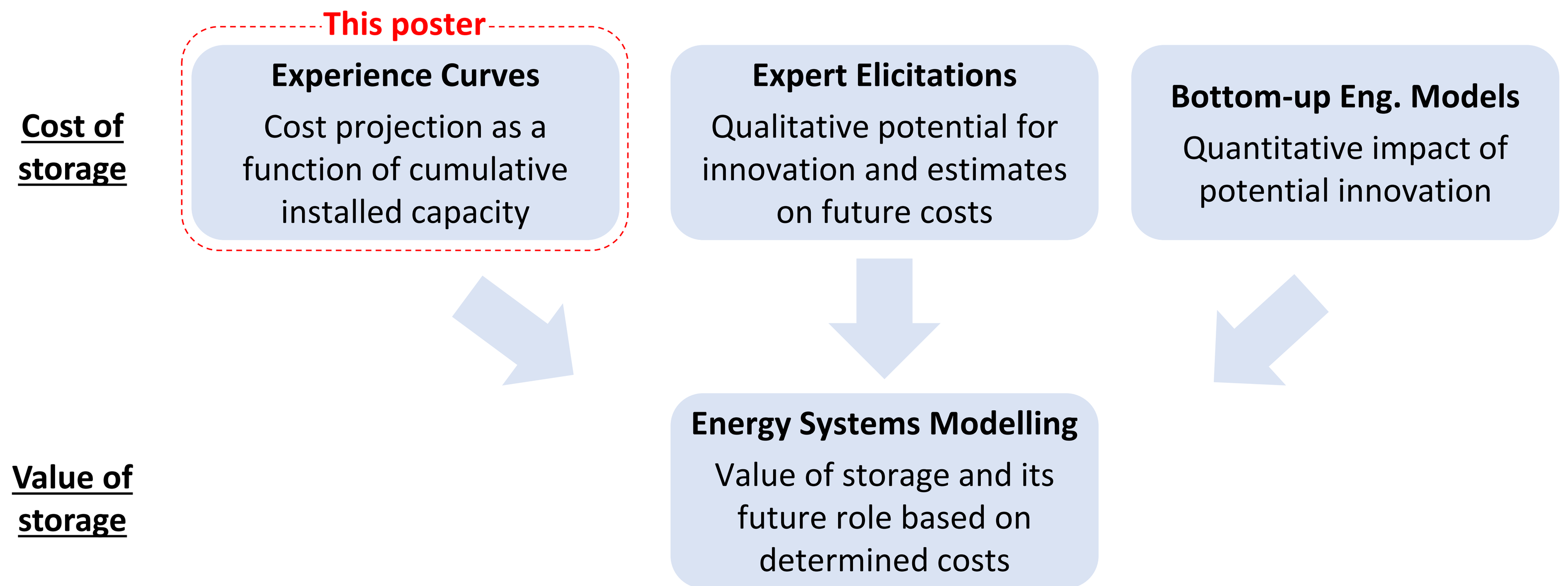

Fig. 1 - Research project approach (3-year PhD)

Experience curve theory

Experience curves show the *improvement* of a technology parameter (e.g. cost, size) as a function of *experience* (e.g. cumulative capacity, time). Arguably, this method is most objective with a measurable statistical accuracy.[2] The relation between product cost and cumulative production appears most precise to forecast technological progress.[3]

- *Cost (P) as a function of cumulative capacity (X)* $P_n = P_{base}\left(\frac{X_n}{X_{base}}\right)^{-\alpha}$
- *Learning Rate (L)* $L = 1 - 2^{-\alpha}$

1936: Theodore Wright describes effect of learning on production costs in aircraft industry and proposes a mathematical model (cost vs. cumulative production)[4]

1962: Kenneth Arrow finds, the model holds true for the whole capital goods industry[5]

1968: BCG extends model to include all inputs required to deliver product to end user[6]

2000: IEA publishes experience curves for energy generation technologies[7]

Method - Experience curve compilation

100+ sources reviewed for

- Published experience curves
- Data on historic prices and installed capacities

Sources include

- Academic journal papers,
- Company and industry reports
- Manufacturers (websites, conversations)

Based on available data, different methods were applied to produce curves or cost estimates.

Table 1 – Methods to derive learning curves and cost estimates for energy storage technologies

	Data availability	Method
A	Published experience curve	Use curve
B	Published experience curve; more recent data	Update curve
C	Price and capacity data available	Derive curve
D	Insufficient data – component experience curve	Price estimate and proxy curve
E	Insufficient data	Price estimate

- **System scope:** Complete storage system, excluding power conversion (inverter, transformer) and installation, commissioning costs ("ex-works")
- **Data scope:** Global average sales price and globally installed capacity data

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Results - Experience curves converge

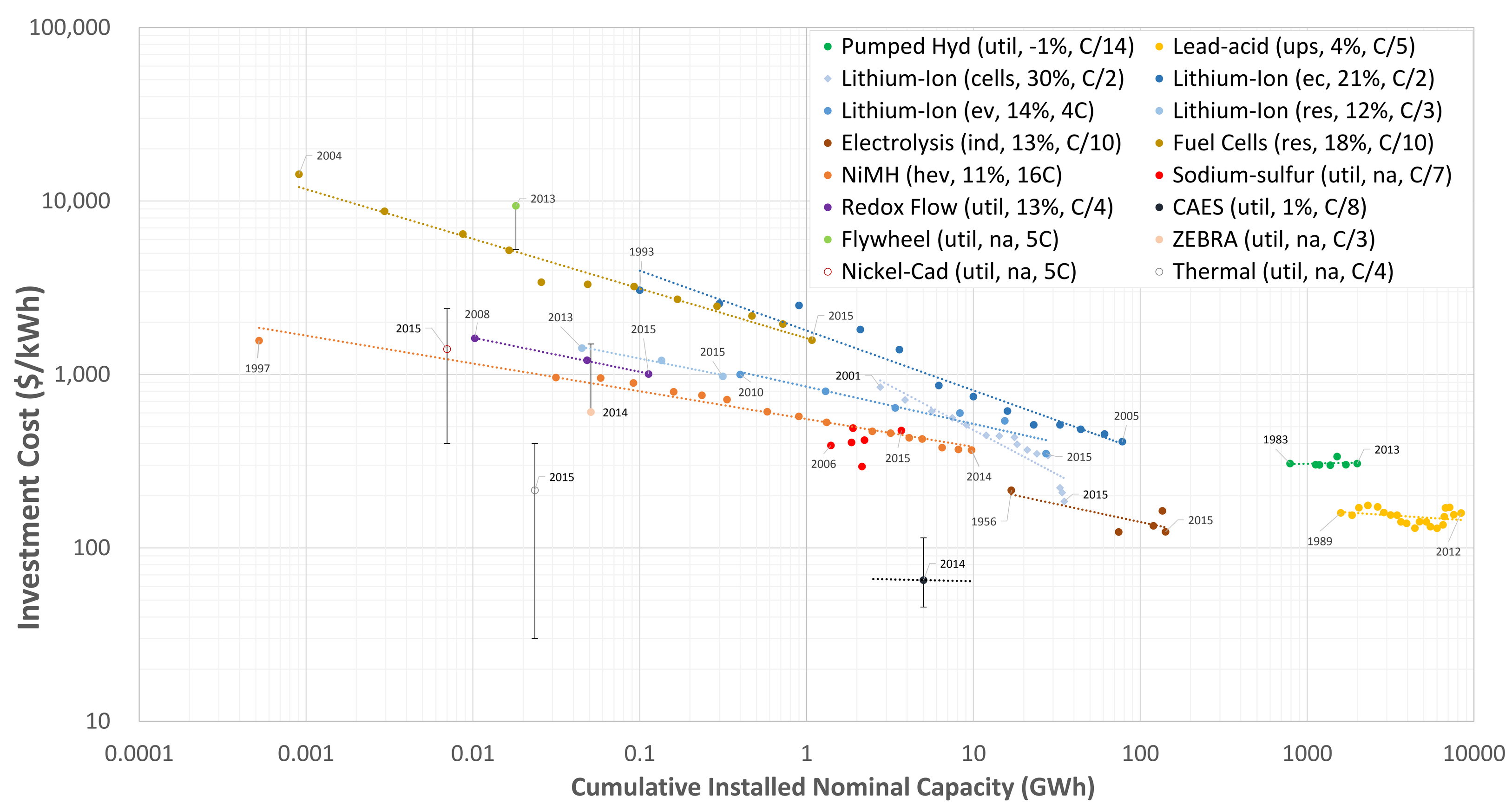

Fig. 2 – Technology-specific experience curves; Legend: Application, Experience Rate, C-rate

Cost trajectories converge towards a narrow range of 150 – 300 $/kWh at 1 TWh.

	< 1 GWh	1 – 100 GWh	> 1,000 GWh
Costs ($/kWh)	600 – 10,000	300 – 1,000	150 – 300
Learning Rate	12 – 18%	11 – 21%	0 – 4%

Exceptions to this trend are:

- Lithium-Ion Cells (<200$/kWh): Different scope, only battery cells in focus
- CAES (50 - 100$/kWh): Potentially cost-effective technology, but few operational examples
- Thermal (30 - 400$/kWh): Potentially cost-effective technology, but no operational examples

Discussion - Coincidence or logic?

What if, all technologies had a common cost floor...

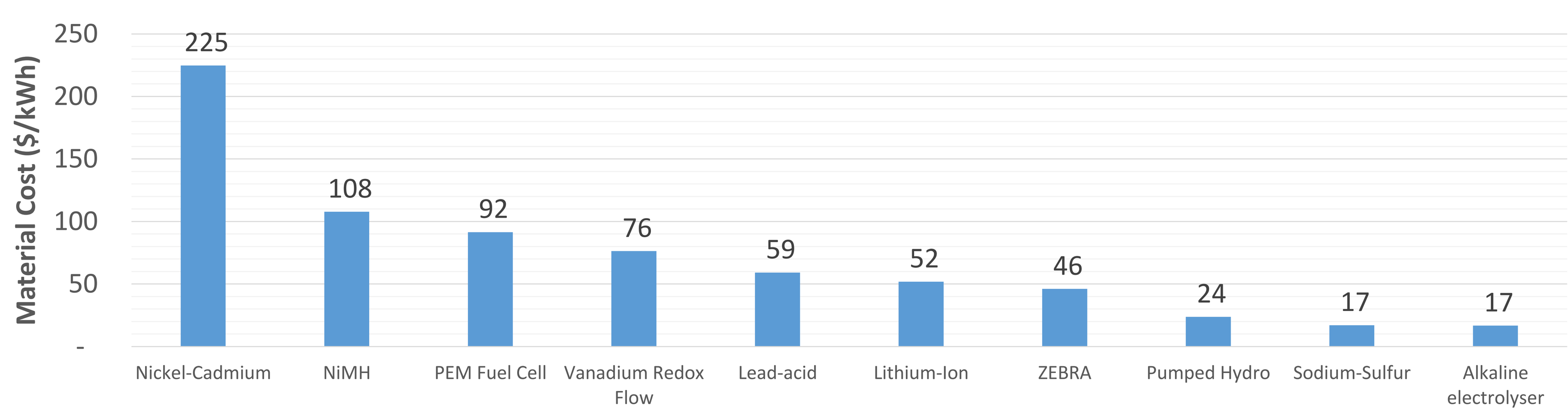

Fig. 3 – Commodity cost floor (reference year: 2014)

Majority of technologies with commodity cost floor between 50 – 100 $/kWh

Engineering rules of thumb suggest material : manufacturing cost ratio of 1:3 for mature products, which would result in overall cost floor for majority of technologies between 150 – 300 $/kWh.

... that is reached for all technologies after 1 TWh was produced?

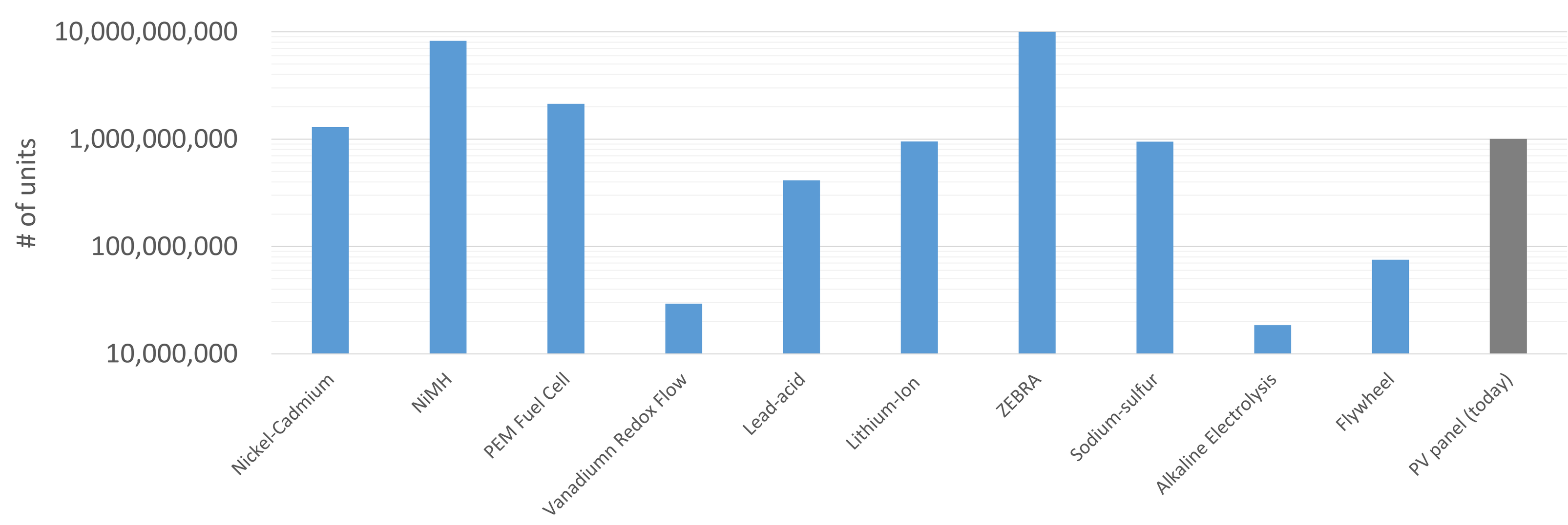

Fig. 4 – Number of units to be produced to reach 1 TWh cumulative capacity

At least 10 million units must be produced to reach 1 TWh for each technology.

Arguably, after producing 10mn samples, experience is exhausted and cost floor is reached. This hypothesis is confirmed by lead-acid (ER=4%, 10mn+ units), but not by PV (ER=24%[9], 1bn+ units).

Next steps - Which energy systems model to choose?

Electricity Market

- Electricity sector only
- VBA-based
- Low spatial resolution
- High temporal resolution

Multi-scale energy systems

- Flexible system scope
- Python-based
- High spatial resolution
- High temporal resolution

Integrated Assessment

- Energy sector, emissions
- TIMES, TIAM
- Low spatial resolution
- Low temporal resolution

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