Storage - what could possibly go wrong?

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Abstract

Electricity storage has been argued to be highly valuable to future low carbon energy systems. Challenges that remain are for technologies to reduce in cost and for appropriate market structures to be developed to ensure storage is built and operated in the best system interest.

This paper focuses on the alignment between storage technologies, system needs and the priorities of system actors.

Firstly, the cost developments in Li-Ion battery technology are reviewed. These are contrasted with alternative storage options and in the light of long term system needs.

Secondly, this paper discusses the misalignment in operating priorities between different system actors.

Based on this review, this paper argues that historic applications for storage have fostered a technology lock-in in favour of storage technologies with short storage duration, high performance and high costs.

A strategic approach towards future system flexibility may therefore need to address a portfolio of technology development, market re-design and changes in to the current institutional structures.

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1 Introduction

Decarbonisation pathways commonly suggest a sequential process:

1) Renewable and low carbon technologies are deployed to displace thermal plants and decarbonise electricity
2) Services are shifted from oil (transport) and gas (heating) towards electricity
3) New forms of flexibility are delivered to solve emerging system challenges

Radcliffe (2012) argues that this sequence is likely to leave a flexibility gap, which needs to be addressed strategically as part of the transition process.

Grid scale storage is expected to play a major role in this process. Significant system savings of over £8bn have been identified for appropriate flexibility solutions (Strbac et al. 2016,National Infrastructure Commission (2016)).

However, such 'system optimal' solutions are generated under assumptions of ideal asset allocation and operation. In practice, market failures and misalignment of interests between institutions can lead to sub-optimal outcomes.

In the next section the possible misalignments between long term system needs and incremental deployment of storage are discussed.

1.1 Methodology

The finding presented here are based on a mixture of qualitative and quantitative assessments of the system needs for storage, building on system modelling and technology needs assessments (DECC (2012), Strbac et al. (2016), Grünewald et al. (2011–9AD)) as well as a wide range of sources on the performance of storage technologies cited by Grünewald (2012b) and ARUP (2012).

The argument is not based on a dedicated model, but a synthesis of findings in literature.

2 On the right path?

2.1 Cost reductions in storage

Figure 1 shows the dramatic manufacturing cost reduction observed in the literature on Li-Ion battery technology. Current reported costs are approximately \$200 per kWh and continue to fall. Some forecast ranges already begin to look modest, yet even the most optimistic predictions do not fall below an asymptotic target of approximately \$100 per kWh.

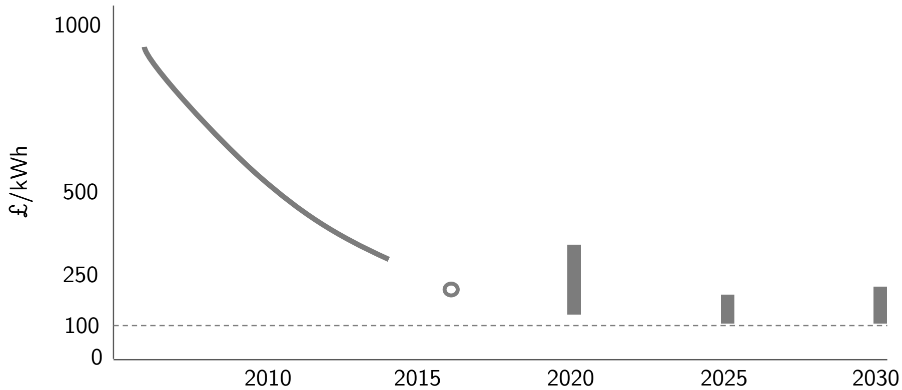

Figure 1: Cost reduction and predictions for Li-Ion (Based on Nykvist and Nilsson (2015))

This cost reduction is significant and opens up new markets and opportunities for Li-Ion storage. However, the grid storage market is quite different from mobile devices and transport applications, which have driven development and deployment until now.

2.2 What is needed in grid storage?

In Figure 2 the difference priorities in the three markets is highlighted. For mobile devices cost, lifetime and storage capacity requirements are moderate, whereas the need for technical performance on energy density, specific energy and efficiency are extremely high, due to the fact that these devices are hand held. Efficiency in this context is not driven by economic efficiency, i.e. avoiding loss of a precious charge. For hand held devices efficiency is first are foremost a safety feature. Inefficient storage is prone to overheating with potentially dangerous implications. Cooling systems are not viable for such devices.

Despite the dominant role, which Li-Ion is establishing in mobile and transport applications, its long term use for grid applications may be less appropriate and could lock out alternatives with the prospect to match future needs more closely.

2.3 Technology options - Not just batteries

The key performance indicators in Figure 3 compare a range of storage properties for selected technologies. All of these technologies are currently deployed, though in some cases in very small numbers or capacity.

The cost row highlights the extent of the differences. It is worth noting that the deployment levels span from mass manufacturing in the case of Li-Ion batteries to

	Mobile devices		EV		Grid	
Cost	Lack of alternatives	low	Early adopter willing to pay	low	Competitors: gas, diesel...	**high**
Lifetime	High device turnover	medium	High device turnover	medium	Reliability required	**high**
Energy	Daily charging accepted	medium	Range anxiety	**high**	Hours, days (longer?)	**high**
Power	Steady load modest peaks	medium	Fast charging, acceleration	**high**	Relative to energy	medium
Size	Miniatu-risation	**high**	Space is at a premium	**high**	Remote low cost locations	low
Weight	Handheld devices	**high**	Moving mass	**high**	Irrelevant	low
Efficiency	For heat management	**high**	Economics and range	**high**	Less important with high RES	low

Figure 2: Priorities differ between mobile, transport and grid applications

		Li-Ion	Flow battery	Pumped hydro	Compres-sed air	Thermal	Power to gas
Cost	\$/kWh	500 – 150	500	150	80 – 250	**5 – 300**	**4 – 50**
Lifetime	yrs	3 – 10	10	**60**	**40**	**10 – 30**	**>10**
Energy	kWh/kW	2	**5+**	**4 – 30**	**2 – 26**	**10**	**>10**
Power	MW	**0.001 – 10**	**0.1 – 100**	**200 – 2000**	**100 – 300**	**0.001 – 100**	**0.01 – 100**
Size	m^3	**1 – 1000**	10 – 10k	>10m	100k – 500k	0.1 – 10k	100 – 500k
Weight	t	**0.03 – 300**	20 – 20k	>10m		0.1 – 10k	
Efficiency	%	**>90**	80	73	45 – 70	40 – 80	35

Figure 3: Key performance indicators of storage technologies (bold for high performance). Based on Grünewald (2012b), Bruce (2016) and ARUP (2012)

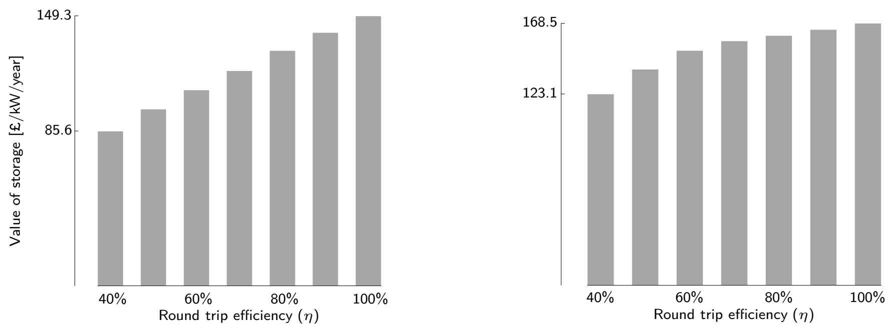

Figure 4: Modest increases in the value of storage from added efficiency (Source Grünewald (2012a))

advanced lab scale technologies like flow batteries. Further cost reduction could therefore be envisaged, but the data is not sufficient to draw firm conclusions about their cost reduction potential.

Values in Figure 3 stem from a range of sources and span from actual costs to future projections where these are available. Even if claims for Li-Ion to reach $100/kWh were realised, existing technologies may be able to deliver significantly lower costs. Compressed air (which has only been deployed twice, such that the ranges in Figure 3 are in fact the full extent of data) has not experience learning or scaling effects, which could make it a very serious competitor for grid applications.

Thermal and power to gas technologies are listed at costs that are currently achievable, assuming such facilities were build at GW scale. The extremely low costs are a result of the scalability in energy capacity of these technologies independent of the power.

This is the fundamental difference between Li-Ion and the other technologies in Figure 3, which makes them more suitable for grid applications: their energy capacity can be scales independently from the power of the system. This feature is the principal reason why their key performance matrix aligns better with the grid storage priorities in Figure 2.

Properties in which technologies perform especially well are highlighted in bold. While Li-Ion matches the requirements for mobile and transport applications in Figure 2 very closely, it is these more 'scalable' technologies, which better match long term grid storage needs.

Efficiency, which is one of the strengths of Li-Ion technologies highlighted in Figure 3, becomes less commercially relevant in grid applications. As Grünewald (2012a) and Strbac et al. (2012) have suggested, the additional value of storage with higher efficiencies is modest, especially in scenarios with high shares of low short run marginal cost generators (see Figure 4).

3 Operation - who wants what?

Operator	Strategy	Condition		Conflict
		Charge	Discharge	
End user (autonomy)	Minimise import Avoid export	High RES, low demand at home	Low RES, high demand at home	No alignment with system needs, poor grid use, higher grid cost for other users
DNO (local)	Constrain demand to feeder capacity	Always, esp. briefly at voltage rise	When feeder constraint is reached	Low risk demands high charge level (strategic reserve)
TNO	Better utilisation of asset Avoid constraints	High RES, low demand in region A with storage	Low RES in A, high demand in region B without storage	Higher use of existing transmission capacity, less able to serve remote peaks
Utility (Generator)	Improve load factor of existing plant	When SO calls for plant turn down	Low RES, high national demand	Can create artificial peak by scheduling maintenance
System operator	Reduce cost of flexibility Displace part loaded plant	Fall in demand, rise in RES	Rise in demand, fall in RES	Operation based on rate (not quantity)
Independent commercial operator	Trade on market volatility and distortions	Low market price	High market price	If price ≠ value storage operation can reduce common value

Figure 5: Operating strategies for a range of system actors

This section merely seeks to introduce the issue of operation strategy using a high level, illustrative overview of the differences between actors and institutions. A more rigorous and evidence based approach should be taken to quantify the tensions hypothesised here.

Figure 5 provides a summary of some of the tensions that could arise between different operators. Some of these will be briefly elaborated here.

The emergence of residential storage solutions, such as MOIXA or the Tesla Powerwall, have encouraged some to advocate greater 'self sufficiency' or even 'grid defection'. The motivation is rarely an economic one. In most places, especially with national grid infrastructure, grids provide lower cost backup than storage or even diesel generators could provide. Consumers investing in such storage solution therefore put a high value on their independence (often as a result of perceived poor experience with suppliers). So long as these costs remained 'private', there is no case against such moves.

However, the grid is a common asset and defecting it can increase costs not only for the defector, but also for those remaining on the system. At the time when a 'self-sufficient' user charges a battery from his 'surplus renewable generation' a neighbour may now have to buy grid electricity from a less efficient generator at a higher cost. Trade has been reduced at the commercial detriment of all.

Furthermore, current system operation and infrastructure costs are socialised in many countries and charge on a per kWh basis. A user who remains on the grid, but rarely uses it due to local RES and storage, still benefits from the most valuable grid services during critical periods, but contributes a disproportionately small share to the costs. Thus, the 'use of system' costs for all other participants will increase.

At the other end of Table 5 are commercial operators, who would be less prone to paying a premium for independence, but still could cause the overall system costs to increase in similar ways. Assuming a simple business model of buying low to charge and selling high, assumes that these costs accurately reflect the value to the system. A market where this link is open to debate is the balancing market - arguably a key market for fast acting storage operators. The premium put on imbalance charges is not a reflection on system costs, but rather an insurance mechanism to guard against imbalance and ultimately blackouts. Historically the volatile nature of these markets was necessary to ensure slow acting plant can be kept responsive. Recent moves towards capacity markets have already highlighted potential inadequacy of this mechanism. In addition, markets for very specific response purposes have been created, typically with particular plant types delivering the service. This portfolio of markets means that a unit of electricity at the same place and the same time can be traded in different markets and at different prices.

For a generator, which can only produce a positive quantity or electricity, the allocation of its output is unambiguous and would tend to go to to highest available offering. Storage affords its operator new opportunities to trade between markets and their idiosyncrasies in particular. This is to say that regulators not only have to consider the effectiveness of a market mechanism to deliver the desired response, but also for compatibility of this mechanism with others currently active in the market.

4 Conclusions

This paper argues that despite the dominant role of Li-Ion batteries, the long term needs for grid storage are not best served by this technology. The requirements of mobile and transport applications, which have supported their development, are fundamentally different from future grid storage needs.

New market arrangements, which are informed by what is technically possible at present, seek to support storage deployment and to do so in the context of short term system needs. The immediate balancing requirements still call for relatively short storage durations.

It is therefore conceivable that sub-optimal technologies could become locked into the energy system and inhibit the uptake of vital future storage requirements for which batteries would be prohibitively expensive and perform unnecessarily well in areas which are not required by the grid.

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