B.A

BatteryMBA

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Can Grid connected Battery systems support transmission and distribution infrastructure?

Introduction

The integration of renewable energy and low-carbon solutions will pose significant challenges to our infrastructure and power networks. Replacing traditional thermal assets with renewable sources will force consideration of the change from hydro thermal system to one with a higher percentage of assets which will provide variable generation, the need for balancing options will rely on technology that can react quickly to cover flexibility in power generation, for example in the event of solar generation clouding over or wind slowing this can cause curtailing Megawatts of energy which can be lost or gained quickly, add this to a quickly shifting load usage profile as we transition on an individual consumer level to industry power usage change. Battery Energy Storage Systems (BESS) producing balancing or ancillary services (frequency and voltage to stabilize the grid when needed) and spare energy capacity will be essential to have a reliable transmission system and secure supply of power when needed.

One problem seen by industrial energy consumers and network operators is the need to upgrade network capacity or connection capacity. This very much depends on the local context. In many countries, generation occurs in a

Patricia Darez, Lee Handyside and John Deptford, prepared the original version of this note 'Can Grid connected Battery systems support transmission and distribution infrastructure?' BA review Mariano Rubio No. BA-CS-010, as the basis for open case study class discussion.

centralised manner, and it does not always happen right next to where the energy is needed. For example, coal or diesel power plants are rarely near cities as doing this would mean people are exposed to pollution and there would be community opposition to the projects. Wind energy assets need to be in places with good wind resources, and this is often not near settlements or industry. As more of these assets are built, transmission networks need to upgrade to connect them and hence increase their renewable energy generation in the electricity mix. Other reasons: production or usage has exceeded the current capacity, expansion of activities on the site, or the introduction of an Electric Vehicle fleet has driven the peak usage of electricity above the threshold of the connection. We also need to consider ageing, less reliable infrastructure in many industrial economies that are being pushed to operational limits with an increase in loading and worsening environmental conditions. Another consideration in this analysis is the ability to upgrade connections, some consumers may not have an available network or distribution; therefore, the entire network to their substation may need additional cabling either overhead or underground pushing upgrade costs well into Millions.

Could Battery Connected systems allow industrial consumers to find a quick fix, could a BESS system allow the deferral of an expensive electricity connection upgrade for several years, or could it be the answer on a more permanent basis? Could it be a solution to avoid costly transmission delays, which are often prone to community conflicts?

First, how would batteries allow an upgrade to be deferred or delayed? Batteries can offer a limited volume of power above and beyond the connected capacity, so if you have an available connection of 1.2 MW and for periods of time your energy requirements exceed this to 1.4 MW, then you're faced with an energy gap and would need to consider a power upgrade. Exhibit A shows how a battery could support these peak periods allowing, the load forecast diagram shows overtaking the infrastructure capacity; this is the point where traditionally an upgrade would be implemented, ensuring the capacity was above the usage. By adding a battery solution, the deferral could be delayed for a number of years as load forecasting is understood, observed, and realised.

How the energy consumed could be supported from a Battery system Exhibit B. Stored energy is released from the battery whenever the load is above the connected threshold, as demonstrated by the blue line.

Deferring upgrades on power networks with Energy storage

In 2017 Arizona Public Service (APS) built a 2 MW, 4-hour duration battery energy storage system for less cost than its next best alternative – a 20-mile transmission upgrade[1] – making them one of the first electricity companies in the nation to use battery-based energy storage in place of traditional infrastructure for basic grid operation. Fluence wrote a Whitepaper[2] on this, and they concluded that over three-quarters of the value of Transmission deferral came from the optionality of energy storage rather than the time value of money. Therefore, it is critical that utilities accurately value non-wires alternatives like battery energy storage when making investment decisions to protect ratepayers especially when facing uncertain future load growth.

According to the comparative table in Exhibit C, if we focus on the special case of Chile, the CNE (National Commission of Energy), which is the institution that proposes transmission upgrades, has already proposed a storage system (BESS) to alleviate transmission restrictions in the Diego Almagro area (Parinas SE) which is in a region which has a lot of PV generation. During the daylight hours, a lot of energy is curtailed as it cannot be taken to the central region for consumption.

“The project comprises control and BESS storage system located in the substation of Parinas and Lo Aguirre, which will be able to control a power flux via the 500kV line that connects these two substations and coordinate in the event of failure of any of the lines which exist between the substations. It should allow an increase of between 400 and 500MVA transmission capacity.

The storage will have a minimum capacity of 500 MVA/125 MWh in each substation and needs to be able to control voltage at the connection point via reactive power (either injecting or absorbing). The equipment needs to be used at least 10 times per year.

However, it is interesting to note that there have been objections by the CEN (the Chilean TSO) and ACENOR (which is the association of large industrial consumers) and a resolution on whether the project can be accepted will be determined by the panel of experts.

[1] For Chile, consider an investment of 400.000USD/km of a 220kV 170MVA line or around 1 million USD/km if the line has a 1000MVA capacity. For storage, consider an investment of 1millionUSD/MW (2h of storage). So to normalise the alternatives in the given example, the options would be 2MW, 4h storage, 4 million USD aprox. vs a 20 mile (32km) line, which would mean an investment of almost 13 million USD in the best of cases

[2] Transmission & Distribution: Using Real Option Pricing Models to Value Energy Storage Optionality in T&D Investment Deferral, by Taylor Sloane, Market Applications Associate, Fluence

Implementation of variable renewable energy sources and low carbon generation into the power networks

Conventional generators (for example, fossil fuels and nuclear) have played a crucial role in safeguarding the stability of the electricity system through their provision of inertia: in a system disturbance, the rotating machines connected to the grid help all generators remain synchronized by resisting a change in the frequency of the grid. If unrectified, stability faults can result in blackouts with high economic and societal costs.

Technologies like solar PV and wind lack rotating masses directly connected to the grid and therefore cannot provide inherent system inertia. For wind lack inertia on a large level problems are solved, using the inertia from wind power blades it does not require any new hardware, only software updates. As a result, generation disturbances, frequency, and voltage deviations necessitate the installation of new stability sources. Grid-forming inverters, which use power electronics to set the correct frequency ("artificial inertia"), and synchronous condensers are current technological solutions.

Variable Renewable Energy, in particular onshore wind and solar PV, have become in the last decade the cheapest way of producing electricity (Lazard LCOE 2021), see Exhibit D.

In addition to this there is a worldwide drive to achieve net zero electricity generation by 2050 which will involve taking out of action coal, diesel and gas generation plants.

As such, any Cost-effective transition toward low-Carbon electricity supply will necessitate improved system flexibility to address the challenges of increased balancing requirements due to variable renewable energy sources and degradation in asset use.

Energy storage systems such as BESS can provide flexibility and reduce investment requirements in the generation, transmission, and distribution infrastructure. The additional flexibility could reduce the requirement for investment in low-carbon generation capacity and an improved ability to deal with uncertainty in future system development.

Barriers to implementing BESS

Aside from the science, engineering, supply chain, and cost challenges facing the implementation of BESS projects, as a new concept, there are several non-technical barriers that much be overcome.

Grid suppliers manage load using traditional on-demand technology pumped hydropower or 'always read' generators such as fossil fuel plants, using existing infrastructure and cheap fuel sources. The shift in mentality towards BESS requires a change in the way regulation, taxes, and business models operate.

The rapid adoption of BESS is forcing barriers to be broken down rapidly.

Regulation

Traditionally, governments have classed energy storage as a 'Consumer Asset' when charging and a 'Power Generation asset' when discharging, without consideration of the complexity of the systems.

Technology changes fast, and by design, regulations are stable and not intended to follow trends. One of the challenges with rapidly emerging solutions is breaking through regulatory limitations to capitalise on the full potential or value.

'Many public policies and regulations must be updated to encourage the deployment of energy storage... they do not recognize the flexibility of storage systems or allow them a level playing field'. Source: Edison Electic Institute via [Deloitte: Supercharged: Challenges and opportunities in global battery storage markets](#) (1)

The UK Electricity Act 1989 defined energy storage activities under energy generation as 'generating at a relevant place'. EU Directive 2009/72/EC defined Energy Storage as 'An asset that produces electricity. The lack of definition in legislation caused challenges for businesses to adopt energy storage, due to the lack of relevant legislation that addressed the implementation of an energy storage system.

In 2013 Energy Storage was identified as one of the '[Eight Great Technologies'](#) (2) for the UK. The Department for Business, Innovation, and Skills referred to the national grid's peak consumption of 60GW, the generation capacity of 80GW, and only 3GW storage capacity, primarily in water storage systems offering significant potential to offer energy cost savings, reduce carbon emissions and offer economic growth.

In 2020, the UK government began to make building non-hydro energy storage systems easier by removing the requirement for Significant Infrastructure Planning Consent and deferring the approvals to the local planning authority level. However, Energy Storage did not have its own asset class definition until July 2022's 'Energy Security Bill' (3), which was a response to the Ukraine War, where the government committed to supporting investment in and development of BESS technology.

Germany added energy storage as an asset under the Energy Industry Act (EnWG) (4) in June 2022, defining energy storage as 'the final use of electrical energy is postponed to a later point in time than when it was generated.

Germany currently rewards wind farm owners through a 95-100% feed-in tariff that does not promote investment in energy storage to generate revenue. A change in regulation could offer further benefits for the provision of 'always ready' by a renewable source, creating additional value for the wind farm owner.

In countries where carbon credit trading is present, the value of 1 Tonne of CO2 equivalent is around EUR8-13 (5). The price to offset is expected to rise to USD$50 by 2030 (6). Carbon Taxes in countries like canada was worth approx USD50 (7) per Tonne of CO2 equivalent. Meanwhile, with the latest technology, it costs around USD 600 to remove 1 tonne of CO2 (8) from the atmosphere. A change to regulations to place a higher value on carbon-cutting projects, subsidized by higher penalties for net emitters, would be justified to subsidize or generate income for BESS projects while removing fossil fuel load following generating capacity and power wastage from the grid.

An example of an initiative to overcome initial regulatory hurdles is the UK's Ofgem 'Energy Sandbox' (9), a scheme designed to support entrepreneurial businesses' trial/pilot and enter the market with regulatory relief, giving temporary permission to break rules based on an application and assessment. An initial assessment is commenced within 5 working days of application, and a full assessment is complete in 3-4 months, which is significantly faster than a regulatory change responding to new technology.

Market Design

The benefits of BESS are well-defined, and the technology is proven; however, there are changing regulatory environments and government incentives around the world. The changing regulations affect how the implementation of a

BESS is treated as a business. Designing simplified business use cases can help design the market conditions that would support feasibility.

The use cases are:

- Grid integration, owned by power companies as a load levelling device
- Energy storage as a service, owned by entrepreneurial ventures and generating cashflow

Under traditional legislation around the world, it was only possible to treat a system as a consumer and generator of power and push the value of BESS as a way to gain value from arbitrage of peak and offpeak power prices.

The value of a BESS system in the grid is greater than the difference between the input and output KWh rates. BESS can store excess power generated from renewable and low-carbon sources and displace the requirement for 'always ready' fossil fuel generation.

Treating BESS as a storage service would value can be derived from

- Reduction in energy waste / increased network efficiency
- Reduction in requirement to operate load following generation assets
- Use as a carbon offset device and gaining value from emissions trading
- Grid security/grid modernisation
- Debottlenecking power transmission systems, reducing the need for new transmission lines by localising renewable power generation and storage

The total value as a storage device is greater than an arbitrage device, but as yet the market hasn't evolved to assign a commoditised value to energy storage as a service.

Financing

Whilst utility companies have access to corporate finance, banks have not been readily offering finance to many BESS venture projects. It is a new, expensive, and CAPEX-intensive technology; the regulatory and market framework is not evolving fast enough to capture the full value of the systems, as energy arbitrage alone does not give enough value to make a project feasible. Financing projects is relying on niche funds.

BESS is expensive and capital-intensive. A large portion of the cost is the cells. The perception that BESS is a high-cost alternative to massive infrastructure projects is rapidly becoming outdated as costs change.

The rate of change in the cost of battery systems is rapid, and traditional forecasts indicate a constituted decline. See Appendix E

Forecasts have regularly been predicted to continue to drop significantly until 2050, see Exhibit F.

Strong projections for cost savings were forecast, however from 2021-2022, Wärtsilä have reported a 25% (10) increase due to price inflation. The unpredicted price increase is due to the raw material costs and market conditions (11).

Mineral commodity prices are market-driven. The lithium boom, as an example, has seen the pricing of a 5.8% Li_2O spodumene concentrate vary from approx $1000/wet tonne, down to $400/wet tonne, and up to $4000/wet tonne in 2022.

Whilst low prices gave short-term benefits to cell manufacturers, it led key mines to rapidly close and go into a ‘care and maintenance’ operation pending market recovery. Taking a mine into care and maintenance immediately stops supply, changing the supply/demand balance. From the price recovery, it can take a high cost and at least 12 months to resume mining, processing, and shipping activities, leading to a lag in rebalancing the supply/demand.

In 2022 Lithium Carbonate Equivalent supply capacity is expected to rise from 497,000 to 636,000 tonnes per year. However, the demand has jumped from 504,000 to 641,000 tonnes per year, maintaining a deficit in the market. The supply chain requires years to build mining and processing capacity and may only do so with long-term contracts to guarantee feasibility.

The unstable pricing of components is a risk that large-scale BESS implementation would have to budget for, and can lead to significant risk in the economic modeling of a project, with a wide gap in the high and low-case models. There is a limited structured mechanism to hedge price risk to cell costs, which could be a deterrent to investors in systems highly exposed to cell prices.

The high-cost risk is a barrier to financing an early-stage project.

Conclusion

There is an option to see this solution make an entry into the market, but the answer is dependent on several factors, including location, regulation, grid stability, the infrastructure of the energy within a location, government policy, renewable strategy, cell pricing and availability, financial security and investment strains. See Exhibit G.

The following questions are asked to help assess the feasibility of the solution:

- Can battery energy storage be used to defer upgrades on power networks?
- What strain is witnessed on energy networks with the implementation of renewable sources and low-carbon generation?
- What are the barriers to implementing BESS (or other types of storage) in grids when not treated as a basic transmission asset?
- Will we see this solution make an entry into the market?

Comments by industry experts

- Battery Energy Storage Systems are essential within the commercial power landscape. With the number of energy sources increasing, the use of these systems is key to balancing the energy load. - White Paper by Al Caceras Executive Director Gallagher Energy Practise, Texas Risk Considerations for Battery Energy Storage Systems | Gallagher USA (ajg.com) (12)
- We're delivering proof that high power storage for the stabilization of the power grid is already an attractive business case. CTO Wemag AG Building a battery power plant WEMAG | Aggreko (13)
- In the UK, Centrica has estimated between 40 and 50GW of flexible capacity will be needed to support the transition to renewables. That need not be entirely battery storage, of course, everything from hot water tanks to industrial demand response, pumped storage, and gas peaking plants will need to be called upon, but it's a fair assumption that storage will make up the lion's share of this standby capacity - the National Grid ESO believes up to 25 GW of standalone battery storage will be needed in 2035 for instance. Managing Director Centrica Business Solutions Battery storage – the ying to renewables' yang | Centrica plc (14)

The quantitative benefits of deploying flexibility technologies in this analysis are broadly consistent with the results of other recent studies. To illustrate, this study found that the net benefits of deploying flexibility technologies, inclusive of their costs, are in the range of £1.4-2.4 bn/year in 2030, assuming an electricity carbon emissions intensity target of 100 g/kWh in 2030.

For comparison, a recent Committee on Climate Change study found a gross benefit from deploying flexibility technologies of £3-3.8 bn/year in 2030, the additional benefit is largely explained by this being a gross saving, i.e. not including the cost of the additional flexibility technologies deployed.

Similarly, a report by the National Infrastructure Commission4 states that gross benefits could range from £2.9- 8.1 bn/year in 2030. In this case, the difference is largely explained by these again being gross, not net benefits and by this analysis assuming an emissions intensity target of 50 g/kWh in 2030 for the high end of the range. These methodological differences explain most of the differences in the results, and given the large uncertainties inherent in this sort of analysis, the studies are all largely in agreement that new sources of flexibility could reduce the cost of the UK energy system by billions of pounds cumulatively by 2030.

An Analysis of electricity system flexibility for Great Britain - The Carbon Trust An_analysis_of_electricity_flexibility_for_Great_Britain.pdf (publishing.service.gov.uk) (15)

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(2) https://www.gov.uk/government/speeches/eight-great-technologies
(3) https://www.current-news.co.uk/news/biggest-reform-of-our-energy-system-in-a-decade-landmark-energy-bill-unveiled-to-parliament
(4) https://www.energy-storage.news/germany-finally-gives-energy-storage-its-own-legal-definition/
(5) https://www.goldstandard.org/blog-item/carbon-pricing-what-carbon-credit-worth
(6) https://www.greenbiz.com/article/carbon-offset-prices-set-increase-tenfold-2030
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(8) https://www.science.org/content/article/cost-plunges-capturing-carbon-dioxide-air?cookieSet=1
(9) https://www.ofgem.gov.uk/sites/default/files/docs/2020/08/ofg2033_energy_regulation_sandbox_web.pdf
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(15) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

Exhibits

Exhibit A

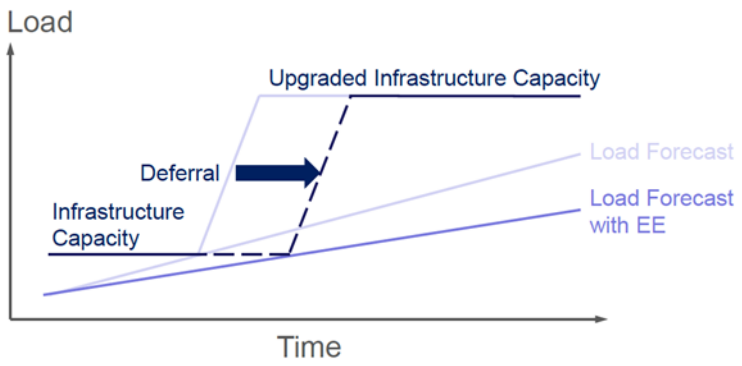


Exhibit B

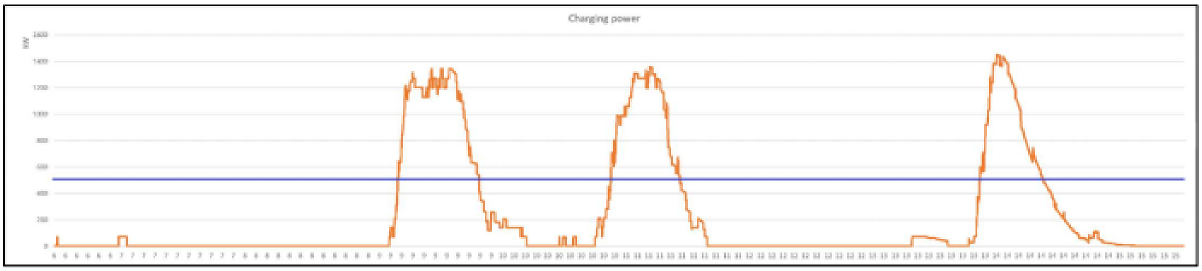
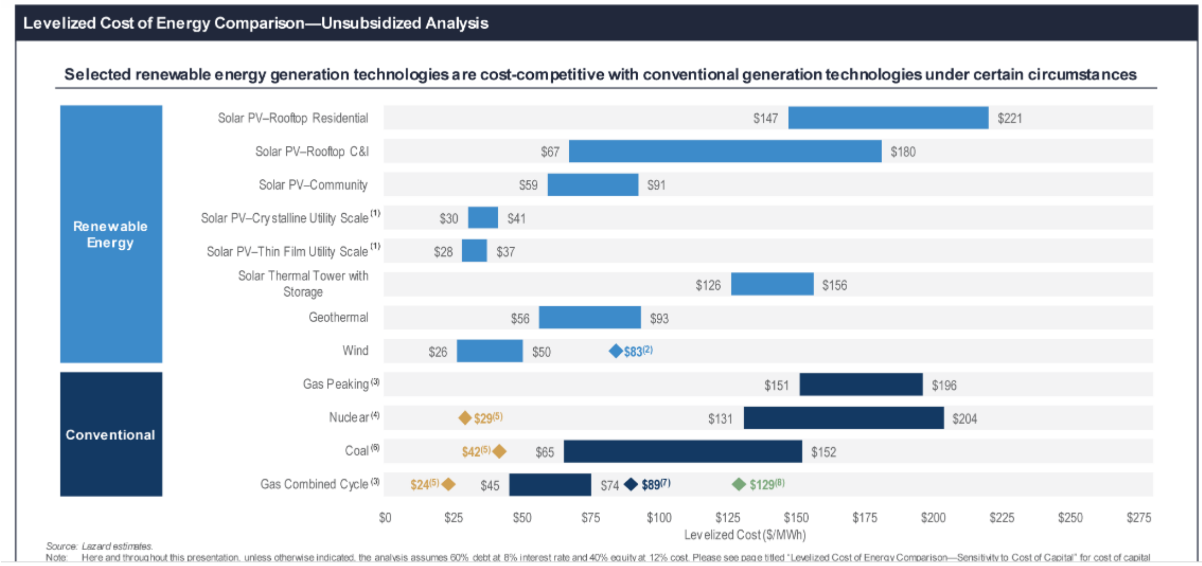


Exhibit C

	Transmission line	BESS
Cost	400kUSD Per km (170MVA, 220kV). In the example above, for Chile, 13 million USD would be required.	1 million USD for 1MW (2h storage). In the example above, for Chile 4million USD would be required.
Time to approve	Unknown (community opposition plays a big part in environmental approval)... In Chile, several transmission lines have more than 2 years of delays from their original budgeted timeline.	1 year to approve, 1 year to implement
Community	As a general rule, they are against it unless it is underground which is a lot more costly	Supportive/Neutral
Others	They allow to move energy over large distances (but there are losses) Less use due to N-1 criteria[3]	Additional resilience due to the decentralized infrastructure (system which can be used to provide local energy when not being used as a transmission asset). Modular and re-deployable.

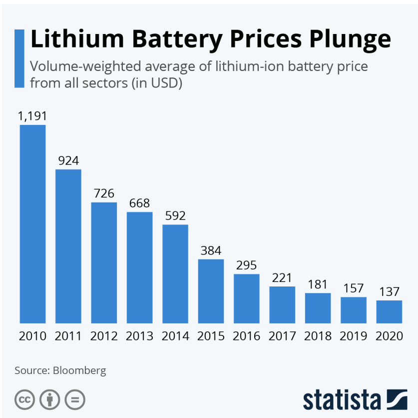
[3] N-1 is a criterion for transmission grid operation. It means that the grid shall be capable of experiencing outage of a single transmission line, cable, transformer or generator without causing losses in electricity supply. For example, if there are 2 transmission lines of 100MW between two nodes, they are not used at 100% capacity. One of them can be used at 100% and the other one is there just in case back up is needed or both of them are used at 50% capacity.

Exhibit D



https://www.lazard.com/perspective/levelized-cost-of-energy-levelized-cost-of-storage-and-levelized-cost-of-hydrogen/

Exhibit E



Source: Statisa/Bloomberg

This is because if there was a failure in any of the two lines during normal operation then the back up line could take the additional load at that very moment and avoid disconnection of the system (providing transmission resilience and reliability).
If both lines were used at 100% capacity and for any reason one of them was disconnected, it would start a cascade effect which is likely to disconnect the second line due to overload. This creates a domino effect which could cause a complete grid Black out. A recent example of this during the heatwave July 2022 in London:
https://www.bloomberg.com/opinion/articles/2022-07-25/london-s-record-9-724-54-per-megawatt-hour-to-avoid-a-blackout?srnd=premium-uk

There are ways of operating both lines at 100% via power electronics but many grids do not implement these systems as they are relatively new technology. ERAG (Automatic Energy Generation Reduction) and EDAG (Automatic Energy Generation Disconnection) signals can be sent to automatically curtail the generation and protect the system. These solutions allow maximisation of generation and transmission infrastructure without compromising system security.

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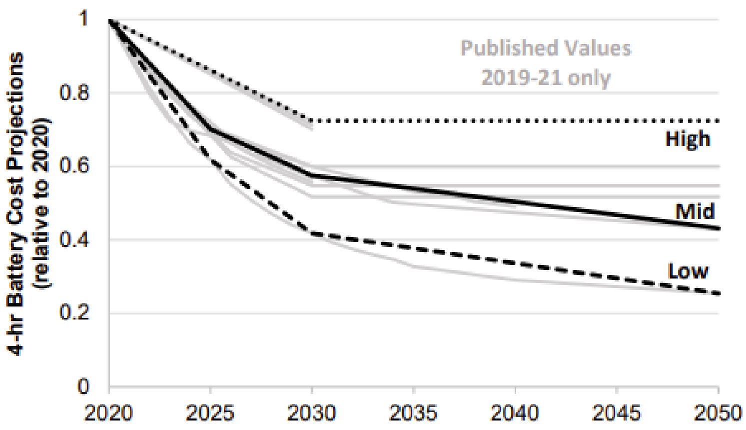
Exhibit F



Source: https://www.nrel.gov/docs/fy21osti/79236.pdf

Exhibit G

Strengths

- Increased speed in response and flexibility to support the grid
- Ability to "fill the Gaps" in power load profiles
- Benefits of power security and resilience
- Change in direction with ownership of asset, private companies investing and financing solutions
- Can be a lower capex solution – (in some cases)
- Technology development of storage solutions pushing lower cost on MWh solutions
- Alternative services developing that can add further revenue and applications to further build the business case

Weakness

- Technical solutions still not defined or regulated in some markets
- Nervousness to implement
- New technology with little long-term historic data
- Grid code outdated and needing amendment
- Grid operator's reluctance to change

Opportunity

- Decrease Generating asset capacity
- Increase renewable penetration
- Create system stability
- Lower the energy costs for consumers
- Create partnerships and joint venture financing
- Market creation
- Decarbonization

Threats

- Credibility of solutions
- Speed of projects, Engineer, Procure, construct
- Stability of revenues within these markets
- Stability of energy pricing
- Changes/advancement of grid regulations
- Red tape