KEY VALUE DRIVERS FOR GRID-SCALE MERCHANT STORAGE

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CohnReznick Capital

BLACK & VEATCH

CONTENTS

1.0 INTRODUCTION

Energy storage is critical to transitioning the grid to a low-carbon future while maintaining reliability and controlling energy costs. In 2021, grid-scale battery storage arrived in full force when cumulative Battery Energy Storage System/Project ("BES Project" or "BESS") installed capacity doubled from the year prior. Similar market growth is expected to continue:

- The US market is expected to grow at an over 50% CAGR from 2021-2026[1].
- An estimated 250 GW of BESS is currently in interconnection queues across deregulated markets[2] (~56% of renewables queue on a MW basis).
- Black & Veatch forecasts that 175-200 GW of BESS will come online in these markets over the next 30 years.

Sponsors are increasingly planning to operate BES projects in wholesale power markets on a mostly or fully merchant basis. Debt financings of such projects have confirmed bankability for key technologies and validated lender appetite for the merchant business model. Capital providers are ready for merchant storage, but underwriting best practices are still in flux. Certain market participants (e.g., thermal peaker owners) may have a head start in merchant markets, but they must still master the technical fundamentals of batteries that drive value.

To support the growth of this industry, participants must understand key factors that impact the economics and valuation of energy storage projects, particularly those deriving revenues from merchant strategies. This paper provides insights from CohnReznick Capital's ("CRC") and Black & Veatch's ("BV") experience in battery storage project financing and M&A transactions, addressing the following **commercial and technical considerations that impact project cash flows and valuation for grid-scale merchant battery storage projects:**

- **Merchant revenue strategies & forecasting methodologies**
- **Drivers of degradation**
- **Strategies to offset degradation (oversizing and augmentation)**
- **Estimating and underwriting overall project useful life**

Although the paper discusses technical matters in the context of front-of-meter grid-scale standalone storage, renewables-paired and behind-the-meter systems are similarly relevant for discussion. Equally important to project value are siting, development, and contracting best practices. Since these matters have been addressed by other industry participants[3] this paper will not discuss them.

- 1 Wood Mackenzie 2021 Base Case Forecast Updated, Feb 2022
- 2 CAISO, ERCOT, NYISO, ISO-NE and PJM
- 3 K&L Gates Energy Storage Handbook, Orrick Energy Storage Update

1.1 BUSINESS MODEL PRIMER – WHY MERCHANT?

The first wave of grid-scale BES projects benefitted from state-sponsored or mandated utility procurement with revenue contracts priced to cover developers' capital investment and operating costs. Although this business model will continue to play an important role in storage development, **we expect a significant share of projects, over time, to be independent developments operating as merchant facilities**. This paradigm shift is being driven by several factors:

1. **BESS costs have declined due to improvements in technology:** Over the past ten years, BESS turnkey Engineering, Procurement and Construction ("EPC") costs have decreased by over 80% on average[4]. History indicates that costs will decline and performance will improve further as technology matures. As a result, upfront costs will allow BES projects to enter wholesale power markets economically rather than remaining confined to niche or ultra-high-value applications.
2. **Expanded wholesale market access:** FERC Order No. 841 has paved the way for ISOs to integrate a variety of storage resources into wholesale power markets. Storage can now earn **energy arbitrage, ancillary services, and capacity revenues** in wholesale markets across the United States. These markets in turn provide the necessary price signals for developers to optimally site BES projects.
3. **Increasing price volatility:** Continued deployment of renewables will increase generation intermittency and therefore price volatility, providing sustained merchant revenue opportunities for BES projects. For example, CAISO and ERCOT already present high volatility due in large part to material renewables penetration. The Northeast markets (NYISO, ISO-NE and PJM) and others will exhibit similar characteristics unless deployment of storage can fully keep pace with both new and existing renewables (a challenging scenario).
4. **Economics of revenue contracts:** BES projects can enter into contracts for capacity attributes (e.g., RA, capacity, NWA, tolling), but these may not provide meaningful return on capital invested. Revenue insurance products are available but are shorter-term and carry material premiums. These products may allow sponsors to take on more debt and increase IRR, but both the contract and debt can delay the sponsor's payback relative to operating unlevered and fully merchant.

- 4 Black & Veatch proprietary data, March 2022

2.0 CONCEPTS IN WHOLESALE MERCHANT REVENUE FORECASTING

Understanding market mechanics and revenue forecasting methodologies is critical to making sound investments in BES projects whose economics hinge on wholesale revenues. Sponsors and financiers must consider several factors in revenue estimation for merchant storage that may differ from their experience with other assets:

1. **Volatility is good:** Market volatility of supply/demand and prices creates opportunities for BES projects to profit on daily (or multi-day) price swings. Even as renewables penetration pushes down *average* power prices, it increases intraday *standard deviation* of prices.

2. **Revenue stacking:** It is important to understand the interplay of various revenue sources available to a project. These sources vary based on market, use case, and period. For example, in markets where current renewables penetration is relatively lower (e.g., Northeast), near-term revenue will primarily be driven by capacity and ancillary services, with energy arbitrage becoming a stronger driver over time. Moreover, not all revenue streams are available simultaneously - the optimal or sub-optimal choice to engage in energy arbitrage vs. ancillary services in a given time frame can materially impact project revenues. Finally, state-specific revenue streams such as Massachusetts' Clean Peak Standard can be evaluated as additive to energy arbitrage, ancillary services, and capacity revenues.

3. **Granular price forecasts:** Revenue estimation for merchant storage cannot rely solely on the monthly power price forecasts widely used in the renewables market. Instead, the task calls for detailed hourly or sub-hourly price forecasting followed by optimization algorithms to capture the reality of BES project operations. Attempting to calculate such granular strategies within a traditional excel model is impractical. The top line must be estimated using specialized software and summarized for further financial modeling.

2.1 FORECASTING STEPS

The following process is typically used to estimate merchant revenues for BES projects:

- **Step 1 – Forecast the market**: Forecast hourly or sub-hourly prices (energy & ancillary services) under a given set of fundamental market assumptions (e.g., load, gas prices, supply mix, etc). Scenarios can be compared by varying these market assumptions and repeating the next steps.

- **Step 2 – Optimize dispatch**: Forecast how the project would behave to maximize revenue if it had a 'crystal ball' to know all prices from Step 1 in advance **("Perfect Foresight")**. Perfect Foresight can therefore be understood as an intermediate step to arrive at an expected result.

- **Step 3 – Derive the base case**: Adjust the results of Step 2 to account for the lack of Perfect Foresight in practice **("Imperfect Foresight")** due primarily to the following factors:

  1. Since operators don't have a crystal ball, they will make informed but sometimes sub-optimal dispatch decisions (e.g., committing to sell an ancillary service, foregoing a larger than expected energy price spike).
  2. Errors in forecasting renewable generation
  3. Unexpected market participant behavior and outages

The first factor would typically result in lower revenues and can be modeled either with **direct discounts** to Perfect Foresight or **rules-based dispatch**. Discounts can be derived by comparing actual operating results with back casted Perfect Foresight. In the absence of actual operating data, the forecaster can limit foresight in the dispatch model and/or assume that the project takes a rules-based approach to dispatch in a given month/hour based on strategies that would have been optimal in the same month/hour of prior years.

The impact of the other two factors can usually go in either direction as they can result in an upside or downside to the base case. The impact of these factors can be captured using scenario-based modeling and sensitizing renewable forecast error and resource outages based on historical data.

While Imperfect Foresight represents a reasonable approach to derive a "base case", the more actively an asset is managed, the more likely it is that revenues closer to Perfect Foresight may be achieved. Additionally, improvement in forecasting techniques over time would also contribute to convergence between Imperfect and Perfect Foresights.

2.2 ENERGY ARBITRAGE DEEP DIVE

BES projects can profit from charging (buying energy) when market prices are low and discharging (selling energy) when prices are high. Markets with significant expected renewables penetration and retiring thermal generation will exhibit low-to-negative pricing when renewable generation exceeds demand. For example, in CAISO today, BES projects can reliably charge (buy) during the day when solar supply exceeds electricity demand, and discharge (sell) in evening hours when solar goes offline and demand is high.

To forecast energy arbitrage revenue for a BES project, close attention must be paid to market trends shaping supply and demand. Additionally, it is important to assess price volatility at various levels (hourly, sub-hourly, day-ahead and real-time) since a BES project operator can optimize charging and discharging decisions instantaneously to take advantage of the various market price movements.

Market price volatility can be broadly classified into two categories, both of which must be assessed to ensure all components of energy arbitrage revenue are fully captured:

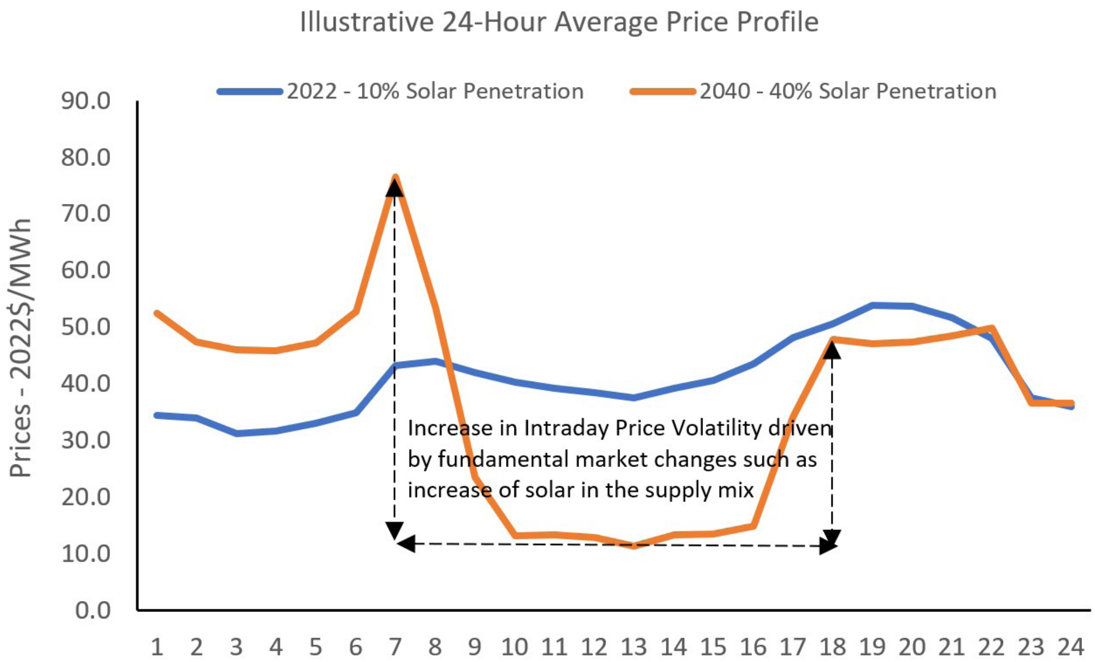


Figure 2-1: Example of Fundamentals-Driven Market Price Volatility

- **Fundamentals-Driven Market Price Volatility:** Long-term price volatility patterns are driven by fundamental changes in a market such as load growth, load usage patterns, generation retirements, renewables and storage deployment, and fuel prices. For example, increased solar penetration in various markets will increase intraday price volatility as shown in Figure 2-1. This type of market price volatility can be derived using production cost models and assumptions on various fundamental drivers under normal operating conditions.

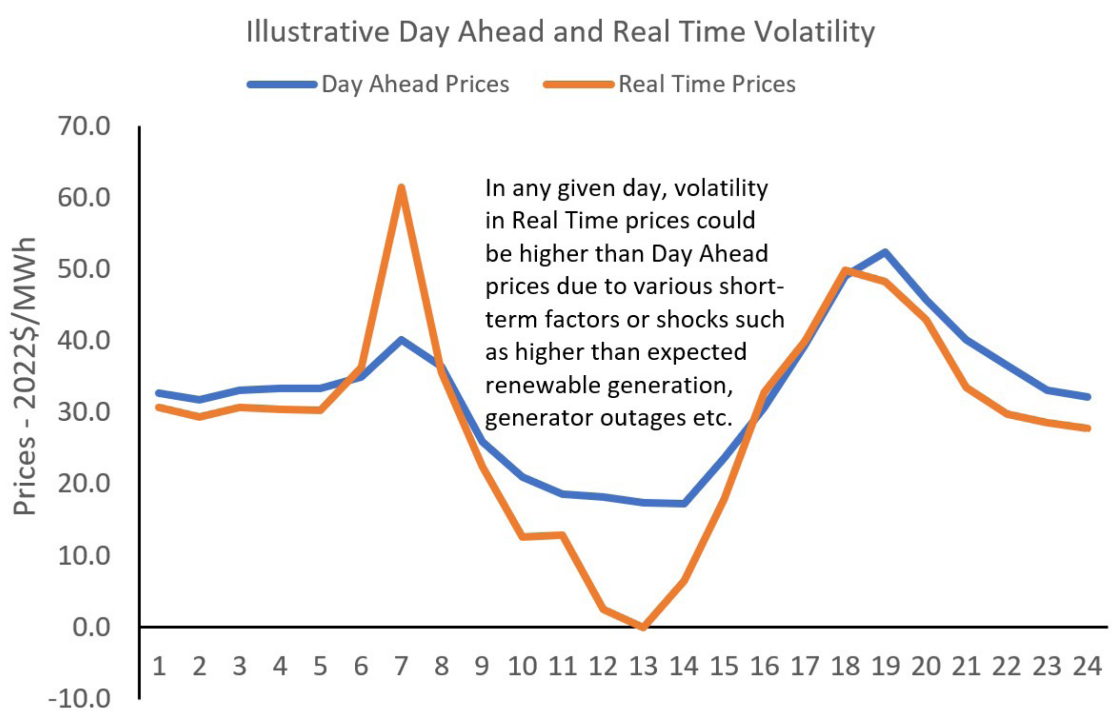


Figure 2-2: Example of Shocks-Driven Market Price Volatility

- **Shock-Driven Market Price Volatility:** Unforeseeable events impact energy prices on a shorter-term basis (sub-hourly, hourly, intraday) and drive additional volatility. Examples of these shorter-term "shocks" to the market include weather conditions, renewable forecast errors, and unanticipated generation outages. These shocks are also the primary drivers of volatility and divergence between day-ahead and real-time prices. Since this type of market volatility is driven by random occurrence, it can be evaluated through a combination of historical and stochastic analysis. As an illustration, Figure 2-2 reflects differences between day-ahead and real-time prices, which are typically driven by market shocks.

2.3 ANCILLARY SERVICES DEEP DIVE

Ancillary services generally encompass operating reserves and regulation services that are required to continuously balance generation and demand to stabilize grid frequency:

- **Operating reserves** are capacity standing by to be dispatched on short notice (typically within minutes). This includes for example spinning and non-spinning reserves.
- **Regulation services** require generators to increase or decrease energy output or consumption every few seconds.

The following are typical characteristics of these markets:

- **Competitive:** Price is determined by the system's demand for the service and the availability of resources that could readily provide it.
- **Commitment-based:** Generators bid competitively and receive payment at market clearing prices for committing to provide a service, but may or may not be called upon to do so.
- **Co-optimized with energy markets**: At any time, a resource can typically only commit to either energy or ancillary (i.e., participation is mutually exclusive)[5].

- 5 In certain markets, generators can simultaneously bid energy and a limited scope of operating reserves.

How lucrative will ancillary services markets be for BES projects, and for how long? In the near term, early mover BES projects can earn strong revenues from ancillary services markets, however BESS penetration has the potential to saturate these markets and drive down prices. This is due to several factors:

1. **Market size:** Ancillary market sizes are much smaller than energy or capacity markets[6].
2. **Change in marginal resources:** Historically higher-cost thermal resources have set clearing prices. BES projects can provide ancillary services with lower costs thanks to their spontaneous ramping capabilities and lack of fuel costs, positioning them to eventually set clearing prices.

Over time, the mutual exclusivity of ancillary/energy market participation should set ancillary prices at the opportunity cost of energy arbitrage. This would make participation of energy storage resources indifferent towards energy or ancillary markets. Although ancillary service revenues are expected to decline over time, they are unlikely to completely disappear for BES projects.

2.4 CAPACITY REVENUE DEEP DIVE

BES projects can receive capacity revenue in all deregulated markets except ERCOT, where a capacity market does not exist. Capacity revenue can be a significant portion of total project revenue, especially in the Northeast markets like PJM, NYISO and ISO-NE, where there is a centralized capacity market.

The price of capacity reflects the economic cost of a market to procure sufficient firm generation capacity to meet future peak demand with a reliable reserve margin. Price varies by region and over time to reflect the general balance between peak load and available capacity. For example, the capacity price has ranged from ~$2-10/kW-month in ISO-NE and ~$1-5/kW-month in PJM RTO over the last decade.

Capacity revenue depends not only on market capacity prices but also on the effective load carrying capability ("ELCC") or reliability contribution of a resource. For example, a 100 MW unit with an ELCC of 50% will receive capacity payments for only 50 MW of its capacity. BESS ELCC is typically high (70-100%), implying that BESS can receive significant revenue for its reliability. However, it is important to assess how the ELCC of a BES project could change over time.

- 6 For example, in 2021 PJM had a peak load of 148 GW, with operating reserve requirements of only 2.6 MW and regulation requirements of 0.5-0.8 GW. Currently most ISOs are not planning explicitly to increase these requirements, however, this could change if dispatchable resources & storage fail to keep pace with further deployment of renewables and grid reliability is materially threatened.

3.0 TECHNICAL PERFORMANCE AND OPERATION ISSUES

Understanding the drivers of degradation is crucial to underwriting a BES project. Different use cases result in different degradation profiles and different strategies to offset degradation can materially impact cash flows and useful life.

These considerations apply to most battery types, but this paper focuses on Lithium-ion ("Li-Ion"). While other promising technologies exist and will be needed for longer-duration storage (e.g., flow batteries), CRC and BV currently observe commercial deployments of primarily Li-Ion[7] in merchant applications given this chemistry is well adapted to this role and provides attractive performance and useful life relative to its costs and peers.

3.1 WHAT IS DEGRADATION AND WHY DOES IT MATTER?

Greater degradation means higher maintenance costs to maintain the same energy capacity and performance levels (see section 3.3 on augmentation). Degradation is also a major variable in determining the overall useful life of a project (see section 3.6 on useful life).

When discussing BESS performance and degradation, two of the most important factors are:

1. **Capacity:** Energy capacity denotes the total amount of energy that a battery is capable of storing (e.g., 1 MWh). Power denotes the instantaneous rate at which a battery can discharge energy (e.g., 1 MW). With use/cycles and the passage of time, a battery will be capable of storing and discharging less energy and discharging at a lower power. A battery's state of health ("SoH") is the ratio of its current capacity to its beginning-of-life capacity, indicating how much capacity has faded.
2. **Round-trip efficiency ("RTE"):** RTE denotes how much energy is converted between charging and discharging due to chemical and electrical losses. Higher RTE means more MWh can be discharged for every MWh charged. RTE also degrades with use/cycles and the passage of time.

- 7 According to U.S. Energy Information Administration (EIA), over 90 percent of the installed power and energy capacity of large-scale battery storage operating in the US is Li-Ion based. This is consistent with CRC and BV's observation in the industry.

3.2 CAUSES OF DEGRADATION

Degradation is mainly a function of battery chemistry, use case, and environmental factors:

- **Chemistry (sub-chemistry within Li-Ion)**
  - The majority of grid-scale Li-Ion BESS uses lithium ferro phosphate (LFP) instead of nickel manganese cobalt (NMC), which is more common in electric vehicles given its marginally higher energy density.
  - LFP batteries have a lower degradation rate over their lifetime than NMC but typically experience higher initial degradation.
- **Use Case**
  - All BESS will experience some baseline degradation over time regardless of use. However, the more frequently BESS is charged and discharged ("cycle"), and the deeper the average depth of discharge ("DoD"), the more it degrades. BESS may be operated until degraded to a minimum SoH ("cliff"), which can differ depending on the use case of the BESS but generally ranges from 60-80% SoH. Beyond this minimum SoH, BESS may still function with significantly decreased performance or may be decommissioned.
  - Energy arbitrage typically involves close to one full cycle per day to take advantage of a project's energy capacity (e.g., charge fully during daytime renewables production, discharge throughout full evening peak load). In this case, DoD is a more material driver of degradation.
  - Ancillary services typically involve multiple shorter windows of charging and discharging. This higher cycling rate but lower DoD for each cycle may result in fewer cycles overall relative to an energy arbitrage strategy.
- **Environmental Factors**
  - Warmer battery cell temperatures are correlated with faster cell degradation. At warmer/humid sites, this can typically be mitigated with a properly sized HVAC system (with commensurately higher capex and opex).

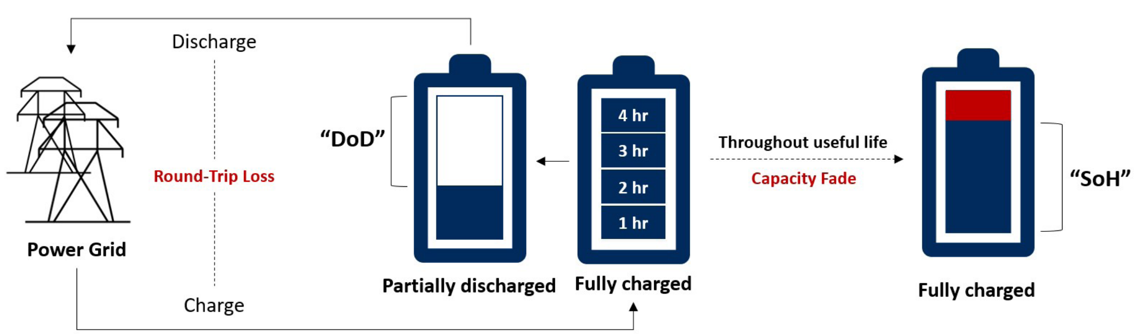


Figure 3: Illustrative Energy Storage Function and Performance

3.3 OVERSIZING AND AUGMENTATION STRATEGIES

Sponsors may choose to offset degradation by installing **excess capacity upfront ("oversize")** and/or **additional capacity over time ("augmentation").** To discuss these strategies in detail, we must first briefly introduce modern grid-scale BESS architecture:

- Cabinet-like enclosures contain battery modules aggregated into racks that are stacked and connected in series. Some balance of plant ("BOP") equipment is integrated into these enclosures.
- BOP equipment includes a power conversion system (bi-directional inverter, "PCS"), battery management system ("BMS"), energy management system ("EMS"), fire suppression system ("FSS"), a heating, ventilation, and air conditioning or liquid cooling system ("HVAC"), and transformer. PCS and transformers are typically adjacent to rather than integrated within the enclosure cabinets.
- Multiple enclosures are connected in series to shared or dedicated PCS, then to transformers, and ultimately to the grid.

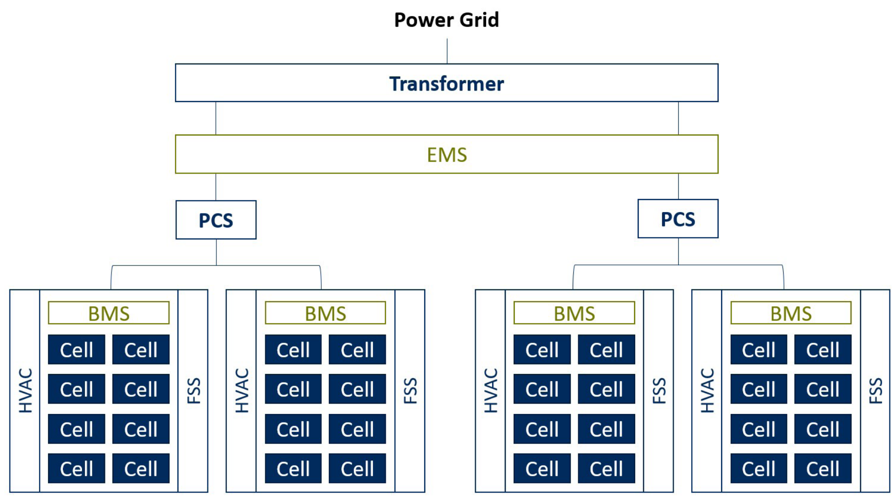


Figure 4: Illustrative Energy Storage Facility Breakdown

To meet operating objectives while balancing economic returns, sponsors and their operation and maintenance ("O&M") contractors may use a combination of the following approaches:

1. **Oversize:** At COD, install excess capacity relative to the required or maximum interconnection capacity, and connect this excess capacity as degradation occurs / once required.
2. **Augmentation:** Install additional capacity over time to offset degraded capacity. Sponsors must decide whether to install at COD empty enclosures, excess PCS, and possibly transformers to accommodate more battery modules in the future or install these systems in full only as they become necessary[8].

8 Sponsors must also consider risk of default by original OEMs and system compatibility with future equipment from different OEMs. For example, certain OEM enclosures may not easily accommodate battery cells/modules from other manufacturers. Mixing technologies also presents challenges.

Figure 5 provides an illustrative view of these strategies in combination. In this example, an oversized system of additional enclosures and battery modules is installed at COD but not connected until needed. Excess enclosures without battery modules are also installed at COD. As the BESS degrades, the initial oversized capacity is connected to maintain the overall capacity. As the BESS further degrades, additional modules are added to the existing enclosures, and/or additional full enclosures are installed.

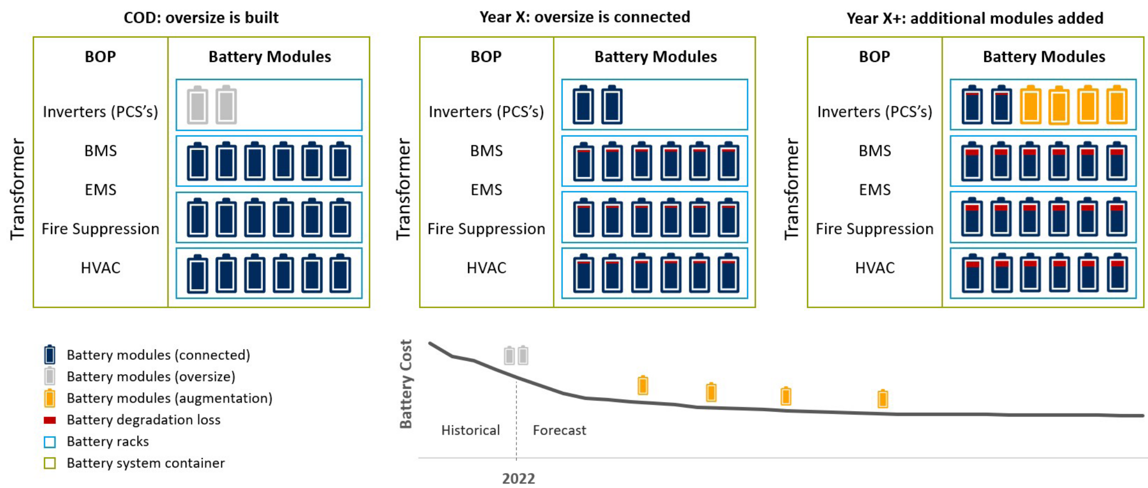


Figure 5: Illustrative BESS Oversize and Augmentation

3.4 CHOICE OF AUGMENTATION STRATEGY & TIMING

There may be multiple "right answers" on the timing and mix of oversizing and/or augmenting. The most feasible and economically beneficial solution differs by project and sponsor. Factors to consider include contractual requirements, revenue prospects, and the future costs of augmentation (equipment and EPC):

- **Degradation Tolerance:** Depending on use case and revenue strategy, a BES project may not always require a steady capacity. On the one hand, a project with contracted capacity revenues may be required to maintain a minimum SoH/capacity. On the other hand, a fully merchant project may have no contractual augmentation requirements. Such a project could operate with continually degrading capacity or augment only if/when future revenue opportunities justify doing so (sponsor retains greater optionality).

- **Battery Cost:** Further cost declines can be expected in the coming decades thanks to manufacturing economies of scale, continuing technology advancement, and a more mature industry ecosystem. However, this trend may be weakened/delayed by near-term supply chain pressure and inflation. The more a sponsor believes that battery costs will decrease in the future, the more it makes sense to augment in the future rather than oversize initially.

- **EPC Cost:** Augmentation costs on a $/MWh basis depend on how the augmentation is implemented. **Installing new enclosures** (potentially requiring new PCS/transformers as well) involves civil and structural work. The $/MWh EPC cost of such augmentation would be high, as it is similar to the EPC of a full project but without the economies of scale. **Adding new modules to existing enclosures** is more straightforward with commensurately lower cost.

3.5 AUGMENTATION RISK ALLOCATION

When evaluating a BES project, sponsors and financiers must develop a robust understanding of both the augmentation strategy itself, as well as which parties are responsible and at risk for carrying it out. Augmentation is typically implemented by the O&M contractor, who sources equipment from a manufacturer (sometimes related parties). O&M contractors commonly provide a performance guaranty on availability, RTE, and capacity. The provisions and tenor of the O&M agreement impact how and when augmentation cost and volume risk are shifted between the O&M contractor and sponsor. CRC and BV have observed variations in the following general approaches:

1. **Annualized Fixed Cost:** Cost is included in a flat annualized and scheduled fixed O&M fee (contractor fully wraps and is responsible for achieving minimum performance however necessary, subject to sponsor following pre-agreed operating parameters).
2. **Periodical Fixed Cost:** Cost is included and fixed in the O&M fee schedule but paid as additional lump sums in the periods when augmentation is required (contractor fully wraps and is responsible for achieving minimum performance, but the timing of augmentation is agreed to upfront).
3. **As-Needed Cost:** Cost is paid by the sponsor as required, but O&M contractor may perform the work on a cost+ basis (sponsor takes downside risk and upside on future required augmentation volumes and cost thereof).
4. **Upfront Capital Cost:** A sizable additional cost is charged by the supplier/contractor to cover augmentation through a specified period (more common for utility-owned projects, less common for projects owned by IPPs and financed in the PF market).

3.6 BALANCE OF PLANT EQUIPMENT

Augmentation cost/benefit analysis often centers primarily on battery cell/module costs (energy capacity), but BOP systems also require refurbishment/replacement to achieve an extended useful life. Major BESS BOP equipment such as PCS, SCADA, HVAC, and transformers are all mature equipment with a long history of operations in other applications, such as solar PV and wind. The O&M, major maintenance needs, and overall expected useful life for these systems in a BESS are materially similar to those assumed and underwritten in those other applications. As with solar and wind, components can be replaced or repaired at the end of their useful life in order to extend the useful life of the overall system.

3.7 WHAT IT ALL COMES DOWN TO: USEFUL LIFE

The finite useful life of battery cells/modules is typically the limiting factor on the overall useful life of a battery storage project. Once a critical mass or majority of battery modules reaches their residual SoH (cliff), they rapidly degrade and must be decommissioned in short order. The sponsor would then face an important decision point:

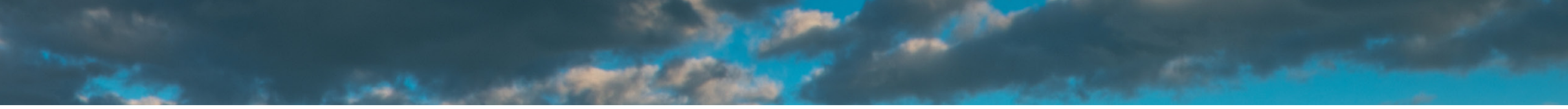
a. **Decommission the project** *or*

b. **Repower the project** by replacing most of the energy capacity and BOP equipment (as required), then continue to operate the project for X+ years.

CRC/BV have observed sponsors' and financiers' ability to value and underwrite repowering to achieve 30 years or more of overall project useful life with proper budgeting for degradation, O&M service, energy augmentation, and BOP equipment replacements/repairs. This approach is highly subject to:

1. Sponsor/financier views on future revenue prospects.
2. Signoff by an Independent Engineer on key operating assumptions and major maintenance budgets.
3. The project having site control, permits, and interconnection through the repowered useful life (or reasonableness of renewal).

Determining the useful life of BES projects requires balancing commercial risk tolerance and subjective market views with technical feasibility. Prior to engaging with external parties, CRC and BV recommend that sponsors seeking an extended useful life engage with commercial and technical consultants to construct a detailed operations and major maintenance forecast.



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