EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Battery Energy Storage Lifecyle Cost Assessment Summary

2020

Project Manager
Erin Minear

3002020048

December 2020

Disclaimer of Warranties and Limitation of Liabilities

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

REFERENCE HEREIN TO ANY SPECIFIC COMMERCIAL PRODUCT, PROCESS, OR SERVICE BY ITS TRADE NAME, TRADEMARK, MANUFACTURER, OR OTHERWISE, DOES NOT NECESSARILY CONSTITUTE OR IMPLY ITS ENDORSEMENT, RECOMMENDATION, OR FAVORING BY EPRI.

THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) PREPARED THIS REPORT.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or

e-mail askepri@epri.com.

Acknowledgements

This report was prepared by

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, California 94304

Principal Investigators
E. Minear
M. Simpson
D. Long

This report describes research sponsored by the Electric Power Research Institute (EPRI).

EPRI would like to acknowledge the following individuals and organizations who contributed to this research: Vignesh Ramasamy, National Renewable Energy Laboratory; Shane Bediz, IHI Terrasun; Brian Knowles, Hyde Engineering Services; Marcus Alexander, EPRI; Brittany Westlake, EPRI; Neil Kern, EPRI; and others who preferred not to be listed.

This publication is a corporate document that should be cited in the literature in the following manner:
Battery Energy Storage Lifecycle Cost Assessment Summary: 2020. EPRI, Palo Alto, CA: 2020. 3002020048

Abstract

Lithium ion battery energy storage system costs are rapidly decreasing as technology costs decline, the industry gains experience, and projects grow in scale. Cost estimates therefore need to be updated regularly for incorporation into utility planning studies and for comparisons to conventional alternatives. This report summarizes key findings from EPRI reports *Battery Energy Storage Installed Cost Estimation Tool* (3002019154) and *Battery Energy Storage Ongoing Cost Study & Estimating Tool* (3002018500).

Keywords

Energy storage
Lithium ion
Cost

Contents

Scope and Background

Cost Assessment Scope

Technology Focus

This cost assessment focuses on lithium ion battery technologies. Lithium ion currently dominates battery storage deployments and is approximately 90% of the global capacity of stationary electrochemical energy storage installations.[1] Given current and projected costs, lithium ion is likely to remain in a leading position for most stationary applications for at least the next five to ten years.

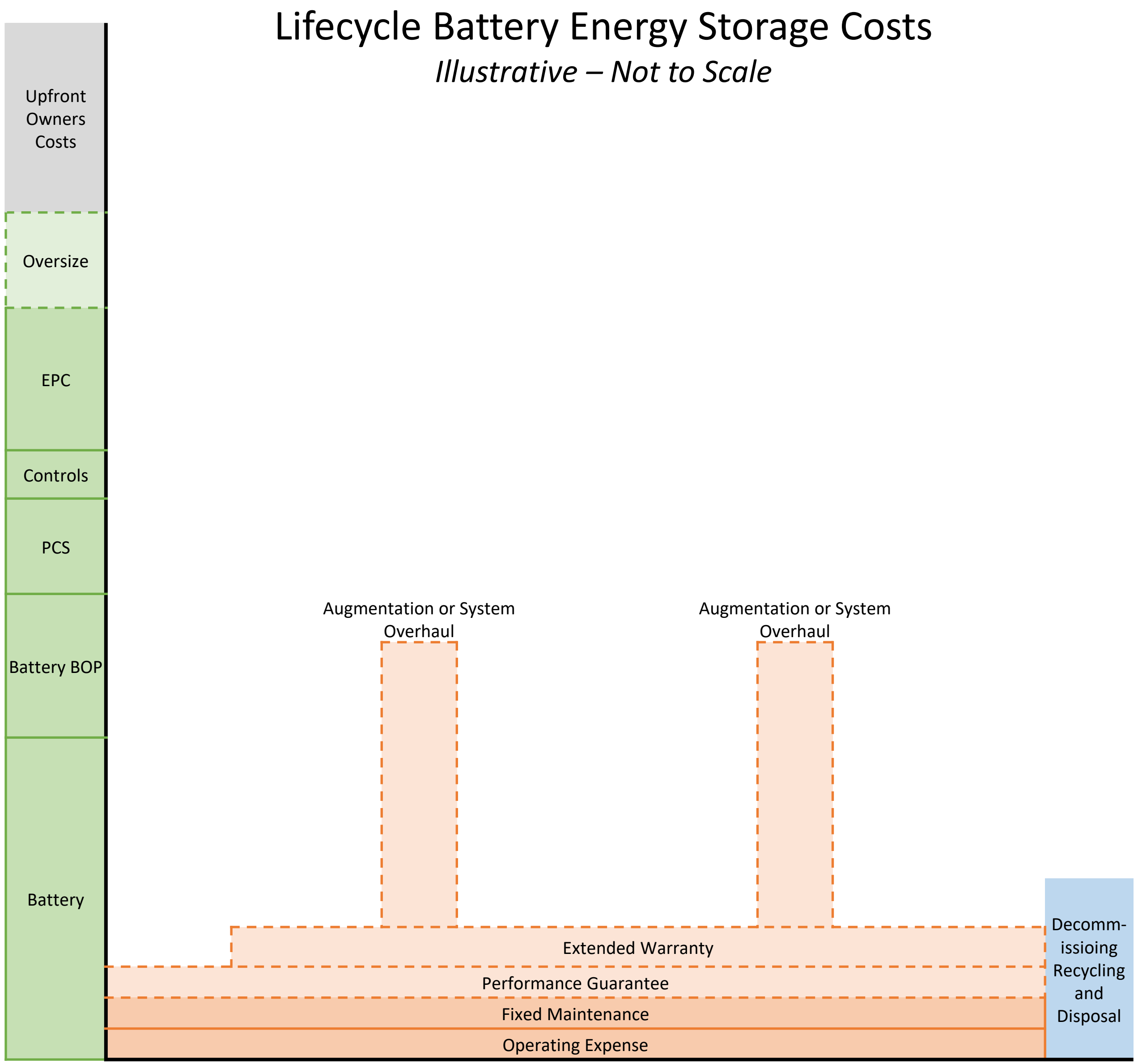
Scope

The main categories in lifecycle cost of a BESS are shown in the figure to the right. The dashed lines indicate costs that may not be present in some projects. This assessment focuses on turnkey engineering procurement, construction (EPC) installed costs, fixed maintenance (or maintenance service agreement) costs.

Data Collection Methodology

Data and input was collected from EPRI projects, publicly-available and fee-based analyses[2], and surveys of vendors, integrators, analysts, consultants, and service providers. Reviews of other cost studies attempted to account for differences in the scope and underlying assumptions.

[1] Source: China Energy Storage Alliance Global Energy Storage Market Analysis 2020.2Q Summary
[2] See Appendix A for list of studies reviewed



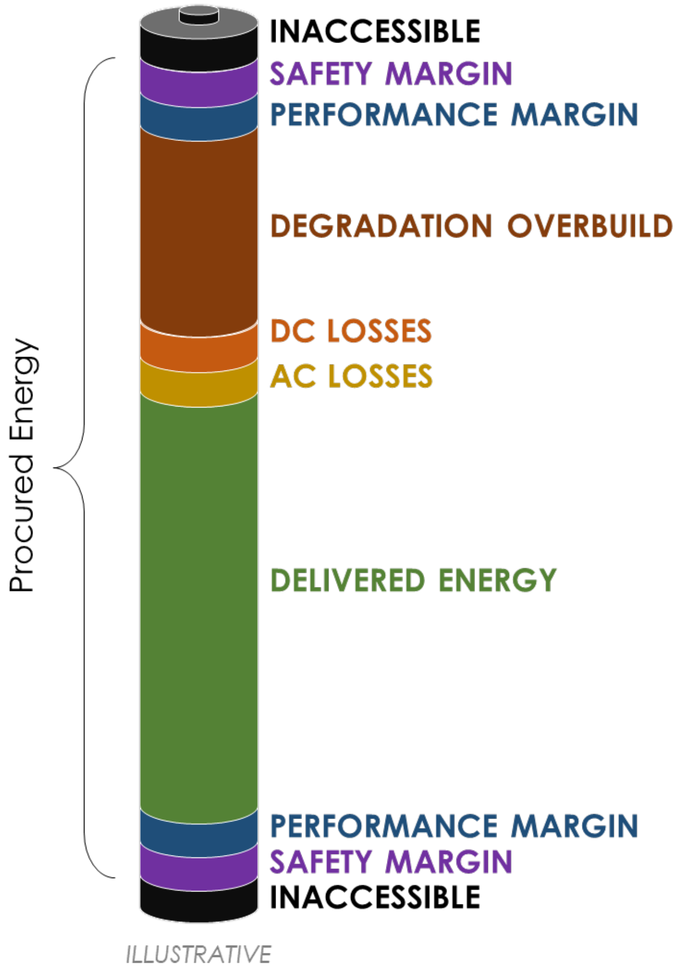
Challenges with Evaluating Energy Storage Costs

Costs are a critical component of evaluating energy storage as a solution in resource planning. General cost studies, such as this report, can guide planners in the absence of project-specific information, but the following caveats should be considered.

- **Scope of costs:** Cost studies vary on what is included and excluded from the scope of supply. The installed costs referenced in this report assumes turnkey EPC costs excluding land, interconnection, financing, taxes, and other owner's costs. See Appendix B for additional details on the scope boundaries. Similarly, with maintenance there are varying levels of service provided.
- **System energy capacity:** The total energy a system can deliver is lower than the manufacturer nameplate rating when accounting for safety and performance margins and losses. The next slide shows the different segments of energy capacity that may impact the usable amount of energy.
- **Technology:** Costs vary by technology and even within the category of lithium ion, there are cost differences between chemistries and manufacturing tiers.
- **Project-specific details:** Application, location, existing infrastructure, code and standards requirements, and other project details will impact cost.
- **Limited operational experience:** There is relatively limited operational data and end of life decommissioning experience which brings uncertainty and adds contingency in ongoing costs.

Impact of Sizing Assumption on System Costs

Because the battery is such a significant portion of the installed cost, it is critical to clearly communicate energy assumptions that are factored in to cost estimates. There may be a notable difference between the total energy procured and the usable energy delivered. This study assumes battery cost based on the nominal DC energy capacity after supplier-withheld safety and performance margins.



Segment of energy capacity that the supplier withholds – usually the top or bottom of the chemical energy capacity window – protected by the BMS

Segment of energy capacity that the supplier or operator withholds to provide additional buffer between the operational energy and the safe operating limits

Optional 'headroom' energy to reduce balancing needs and maintain power capacity across the operational state-of-charge (SOC) window

Optional segment of energy capacity planned to increase available energy so that delivered energy can be dispatched for a number of years or cycles while the total energy degrades

Segment of energy capacity planned to increase available energy so that delivered energy can be dispatched despite DC energy lost during charge and discharge of the battery (due to losses in battery cells, cables, busses, auxiliary loads, and other DC systems)

Segment of energy capacity planned to increase available energy so that delivered energy can be dispatched despite AC energy lost during charge and discharge of the battery (due to losses in the inverter, transformers, auxiliary loads, medium voltage collection circuits, and other AC systems)

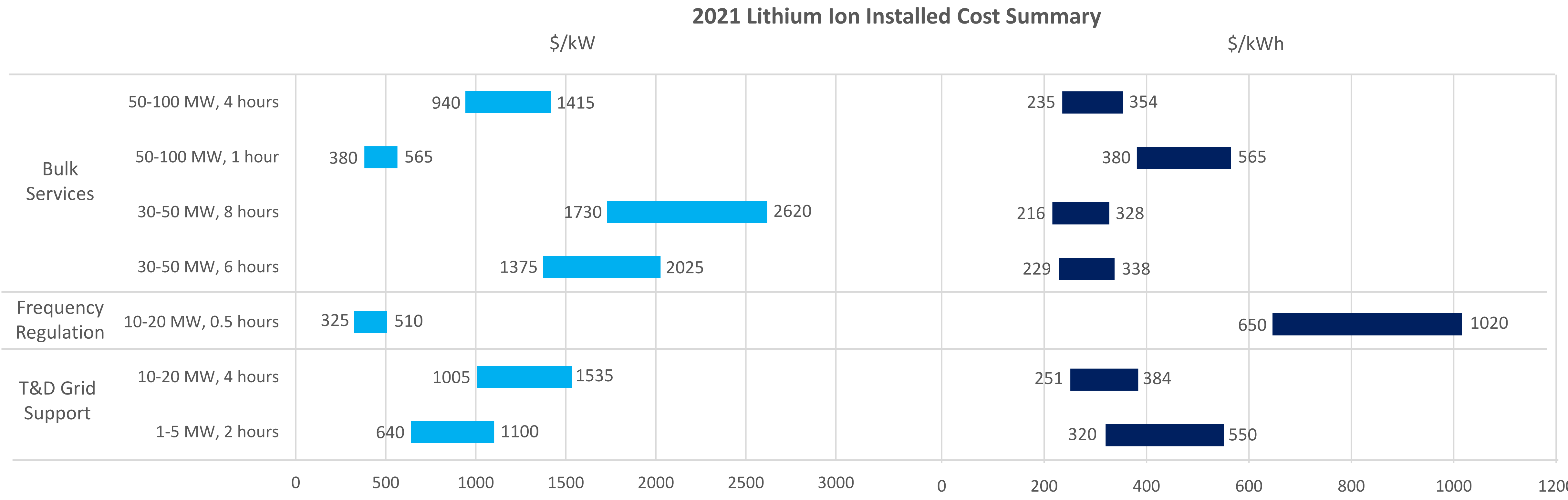
Segment of energy capacity planned for the dispatchable end use energy required at the point of interconnection (POI)

Source: Usable Capacity in Battery Energy Storage Systems (3002019753)

Cost Results and Discussion

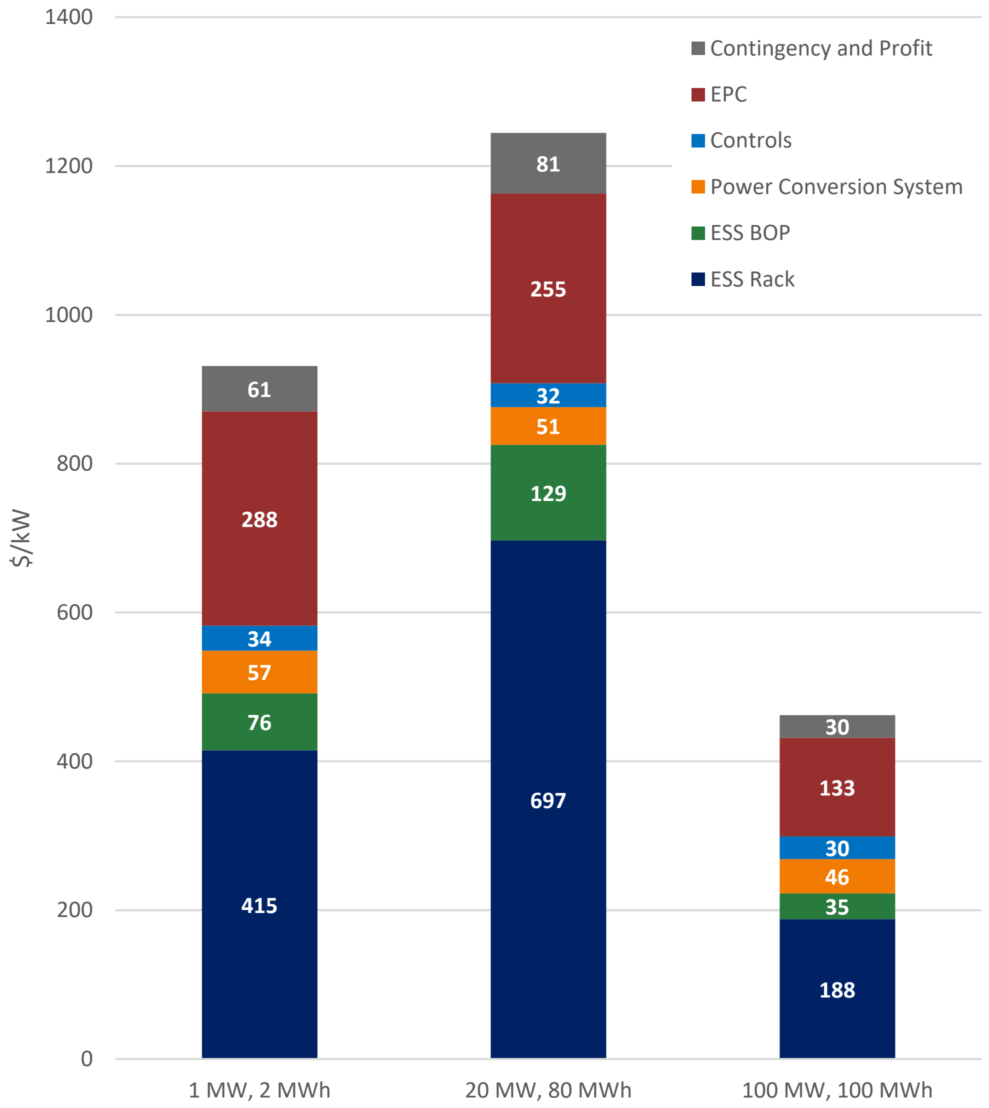
Lithium Ion BESS Installed Cost Summary: 2021

Turnkey EPC energy storage installed cost ranges for select sizing configurations in 2021 are summarized in the chart below. The various configurations represent example applications (or use cases) and provide a sense of how costs scale with capacity and duration. A range of cost is provided as project-specific costs can vary by locational factors (e.g. labor rates, accessibility, site conditions), economies of scale, supplier or integrator experience, and design or code requirements. Additional sources of variation and cost ranges within different categories are discussed on the next slide. Note: The costs exclude interconnection upgrades, switchyard, land, taxes, and other costs assumed to be owner's costs.

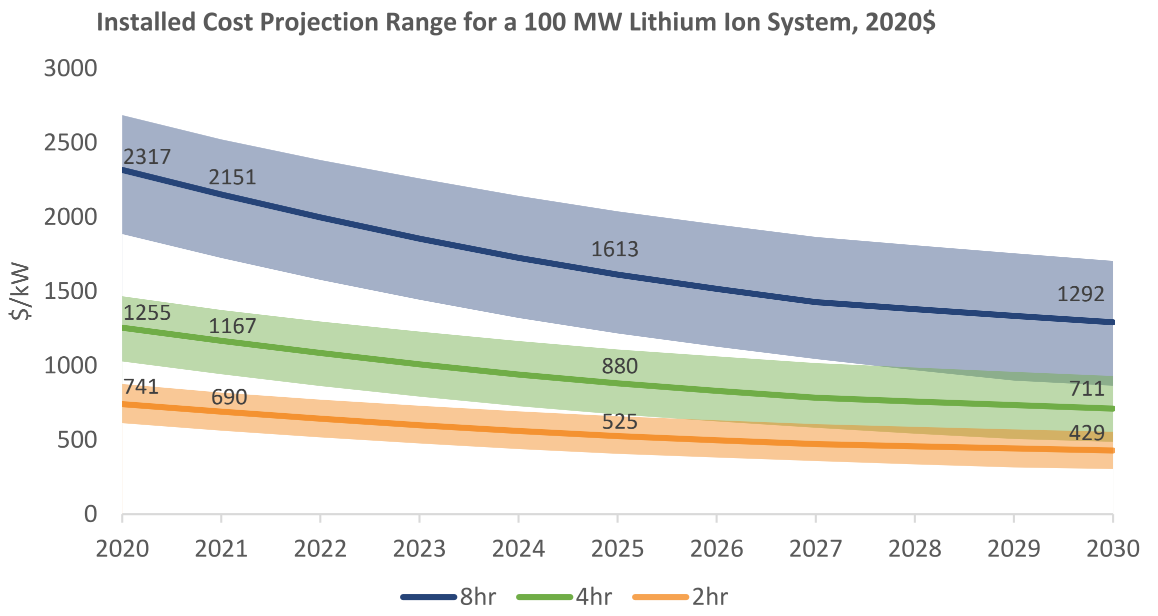


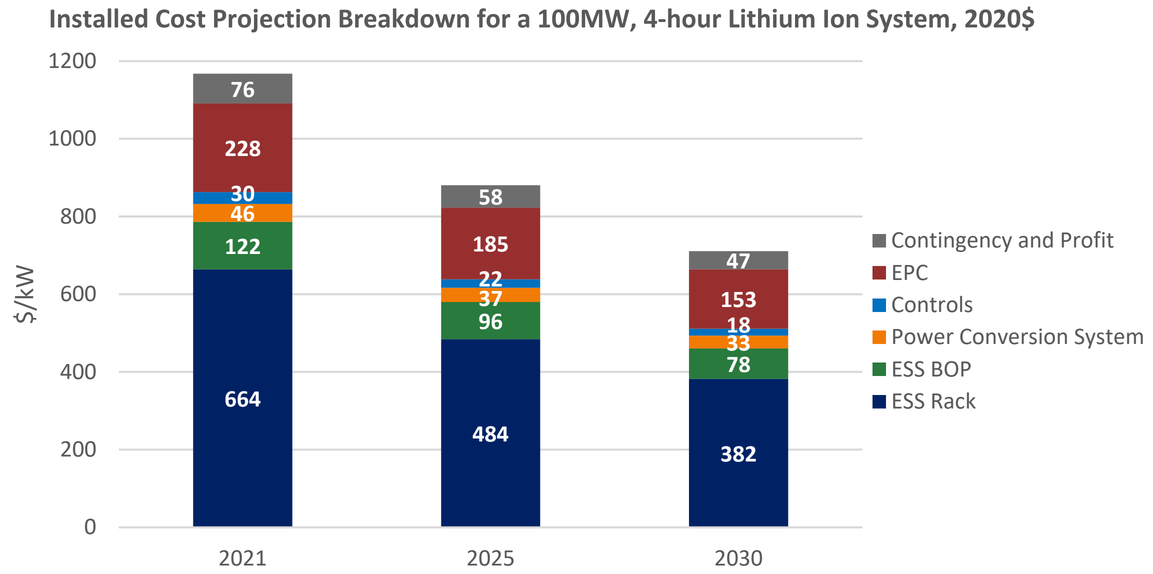
Lithium Ion BESS Installed Cost Breakdown: 2021

Category	Additional Sources of Variation
ESS Rack	**Battery chemistry:** NMC and LFP are the most common lithium ion chemistries, but others used for stationary applications include NCA, LMO, and LTO. 2021 volume prices were largely reported in the range of $150-$160/kWh for LFP and $170-185 for NMC. **C-rate:** Even within a given chemistry and manufacturer, there are different cell options depending on the power and energy needs. "Power" cells are higher cost on a per unit energy basis than "energy" cells.
ESS BOP	**Design requirements:** Thermal management, safety features (e.g. fire and gas detection and suppression, explosion protection), and enclosure type (e.g. container, cabinet) impact costs and, in some cases, may be dictated by local codes or owner specification. Cells with lower energy density and/or higher power requirements will also require more BOP infrastructure.
PCS	**PCS design:** Design variations include input/output voltage, capacity rating (e.g. centralized or rack-level), and inverter functions.
Controls	**Operational requirements:** Integration requirements (e.g. market participation, cloud, DERMS) and use case requirements (e.g. multiple use applications) will impact level of control sophistication and cost.
EPC	**Factory integration versus field installation:** Certain BESS designs allow for reduced field labor (e.g. when batteries shipped in the rack). **Fixed Costs:** Engineering, general expenses, and mobilization have fixed costs with some scaling with size. Therefore, EPC costs for smaller system are a higher percentage of the total cost than larger systems.



Lithium Ion BESS Installed Cost Projections





Lithium ion installed costs are projected to decrease by over 40% by 2030. The top figure illustrates projected installed cost for a 100 MW system with upper and lower bounds based on the potential differences in costs captured in the previous page. The longer duration systems have a larger range due to the cost sensitivities of the battery portion which makes up a larger percentage of the installed cost.

The bottom figure illustrates an example breakdown of installed cost for a 100MW, 4hr system through 2030. Cost reductions will likely be accomplished across all major cost categories.

Battery cost declines are based on electric vehicle battery pack cost projections with adjustments for stationary racks. The gap between electric vehicle packs and stationary racks is assumed to decrease over time as stationary energy storage grows in manufacturing scale. Battery cost projections are lower than previous EPRI estimates which included some uncertainty around material prices. However, in the last two to three years battery manufacturers have adjusted their formulas and managed their supply chains to minimize impact of changes in the metals markets.

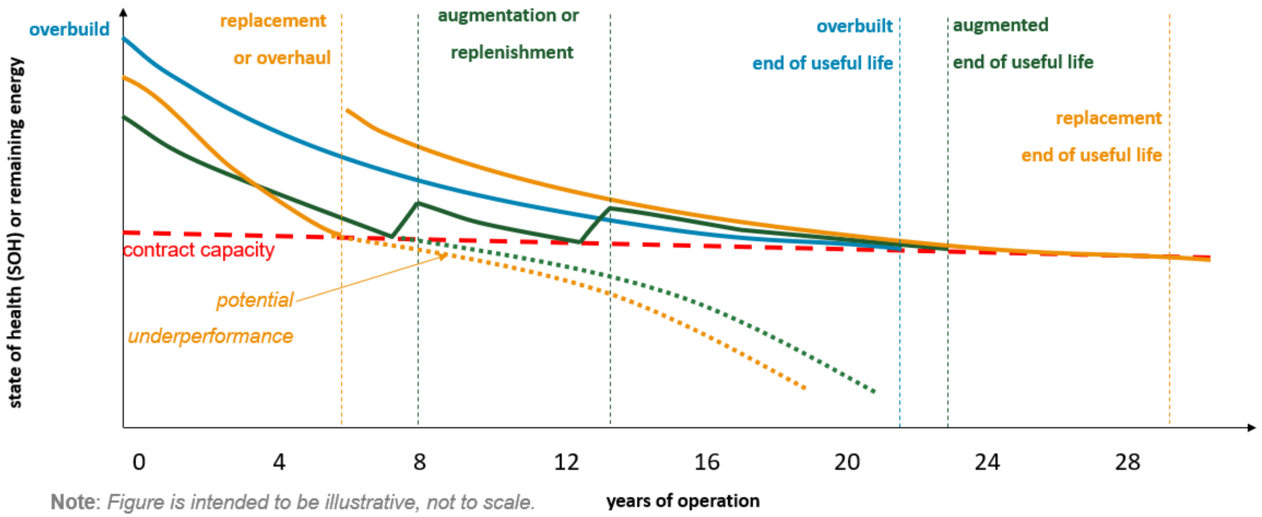
O&M | Maintenance Services Agreement

The service agreement costs collected in this study ranged from $2/kW-yr – $14/kW-yr. While this cost metric may be appropriate for other forms of generation, including renewable energy, it has the potential to be misused for storage because the power-to-energy ratio will impact the normalized cost. For a 4-hour system, most costs were in the $2/kw-yr – $6/kW-yr range for large scale systems.

Category	Sources of Variation
Preventative maintenance	A list of tasks can be found in the Energy Storage Operation and Maintenance Tracker [3]. There may be some owner's tasks or responsibilities that should be accounted for separate from a service agreement. The frequency of maintenance tasks may be dictated by the design, use-case, environmental conditions, and manufacturer recommendations. Additionally, there may be tasks that are out of the warranty scope that are contracted separately on a time and materials basis.
Monitoring	The level of monitoring can range from completely under the owner's responsibility to 24/7 monitoring by a service provider. Monitoring may include alarm management, alerts, and performance analytics that can inform predictive and corrective maintenance plans.
Response time	If the system is serving a critical function, then response time may need to be integrated into the contract. Response time should consider geographic location (e.g. proximity to service personnel and equipment supplies/warehousing). Additionally, an inventory of spare parts may be needed to avoid delays in bringing the system back online after an outage.
Service provider	Service providers can include system integrator, EPC, third party provider, original equipment manufacturers (OEM), and specialists (e.g. HVAC and fire suppression). There may be a need for multiple service providers as some equipment providers have restrictions on who can maintain their components. Several solar O&M providers are now offering energy storage maintenance and their ability to leverage the tracking and coordination infrastructure has brought down the lower end of the cost range from EPRI's previous studies.
Guarantees	Energy capacity maintenance and performance guarantees may be bundled with a service agreement or addressed separately. Because the scope of the guarantee is often owner-driven and can vary significantly, this assessment did not gather costs and are assumed to be excluded from the service agreement cost estimates.

O&M | Energy Capacity Maintenance

For some energy storage use cases, there may be a need to maintain a minimum energy capacity over the life of the project in order to meet reliability or performance objectives. This can be accomplished by one or a combination of several energy maintenance strategies described below. However, addressing lithium ion degradation and maintaining a minimum energy capacity is *not* required for every project.



Note: *Figure is intended to be illustrative, not to scale.*

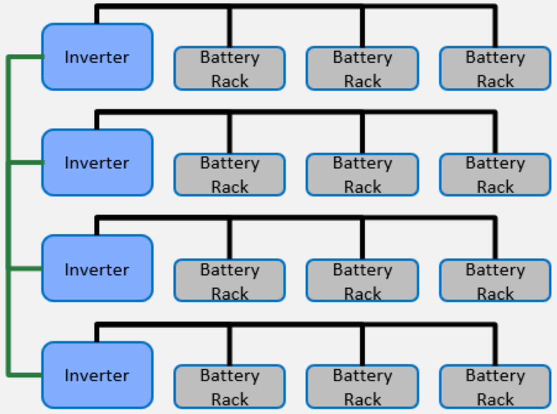
Category	Description	Advantages/Disadvantages
Initial Overbuild	Installing additional energy capacity at the start of the project to account for future degradation. The overbuild could produce the guaranteed energy capacity throughout the project's life or delay the need for augmentation or replacement.	- / + Higher upfront capital costs which may have added benefit from the U.S. Federal Investment Tax Credit (ITC) if paired with solar + Likely the simplest approach as all the integration is done up front.
Augmentation	Additional energy installed during the project's operational life to account for the loss of energy due to degradation. Augmentation can extend the life of the existing batteries by reducing the usage on those modules. Examples of augmentation strategies are on the next slide.	+ Defers capital expenditures while taking advantage of potential module cost reductions or system enhancements. - Requires expandable system design, including structural, power electronic, and control components. + Provides flexibility if use case or needs change over time.
Replacement	New modules replace the original modules when they have reached their end of life, which can be defined by a warranty, recommendation from the manufacturer, or business decision.	

O&M | Augmentation Implementation Strategies

Considerations:

- Upfront cost
- Flexibility
- Downtime
- Complexity
- Controls

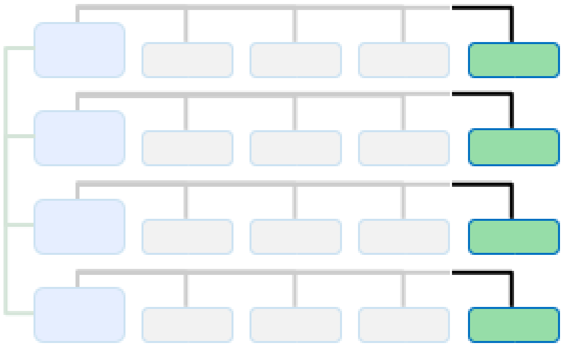
Original System



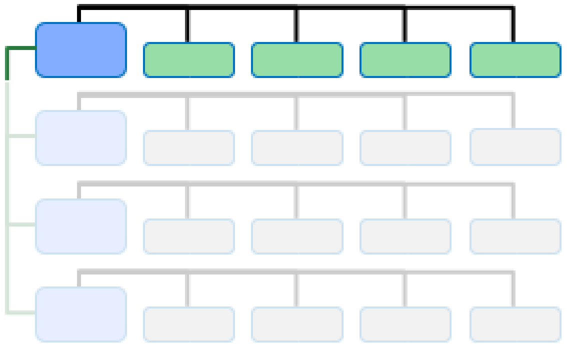
New Inverter / Converter

New Battery Rack

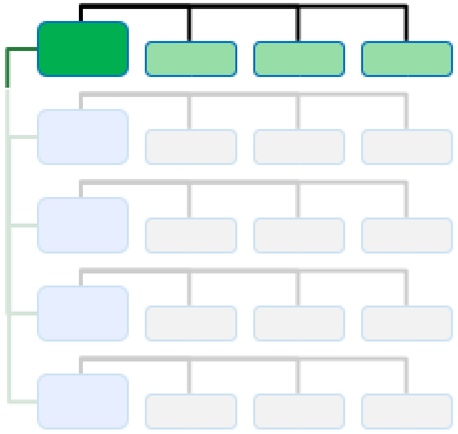
Rack based: New with Old



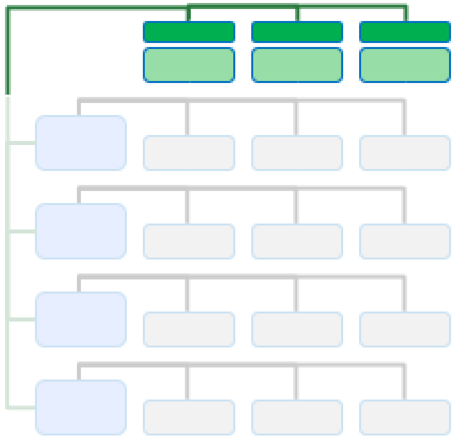
Rack based: Shuffle and Repower



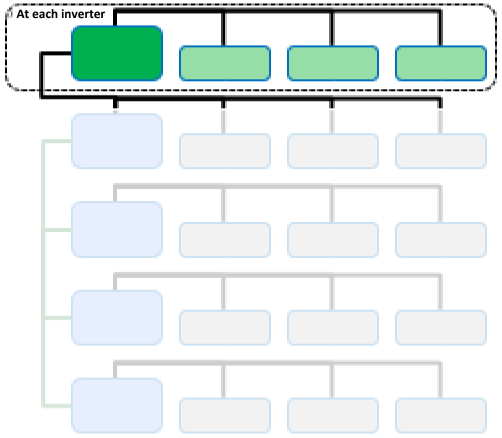
AC Based: Large Inverter



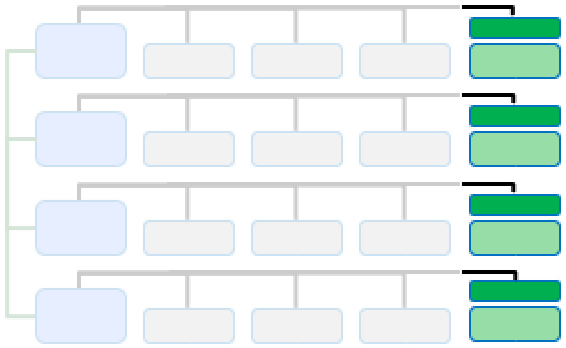
AC Based: Small Inverter



DC Based: Large Converter



DC Based: Small Converter



There are several approaches to battery augmentation and currently there is no preferred method in terms of cost and system performance. The implication of these approaches is not fully understood as there is limited field experience.

Decommissioning and End of Life

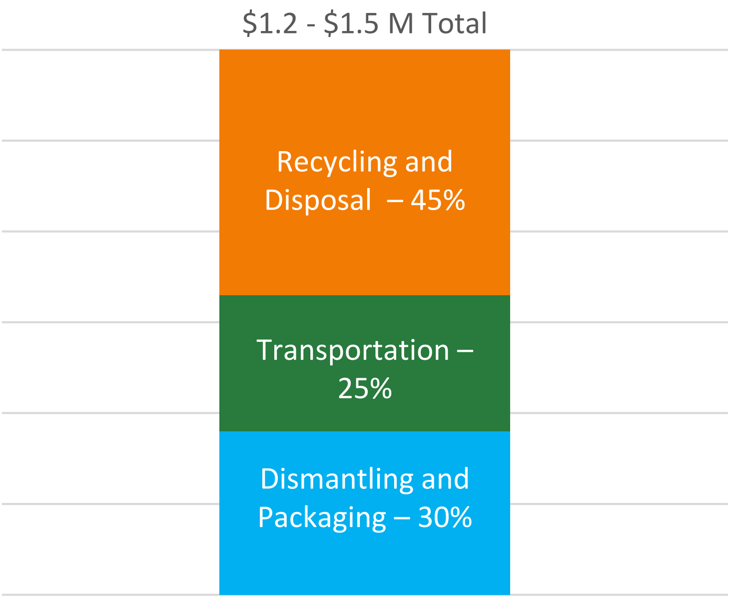
Although there has been a rapid increase in deployed energy storage, most systems have not reached their end of life and therefore the industry is still gaining experience decommissioning battery systems. In 2017, EPRI estimated end of life costs using the methodology and assumptions laid out in a battery storage disposal and recycling report [4]. The scope of costs included decommissioning and disposal of the battery system but excluded other balance of plant equipment and site restoration. With industry feedback, EPRI has updated methodology that will be published later this year. One example system cost breakdown is shown in the figure to the right. However, a detailed analysis is needed to capture chemistry, system design, location, and project timeline considerations.

Category	Sources of Variation

Recycling and disposal	• Recoverable materials – Costs vary by chemistry
	  • NCA, NMC, LTO - $1.00 per pound
	  • LMO, LFP - $2.50 per pound
	• Ease of disassembly of modules

Transportation	• Distance to recycling or disposal centers • Battery weight – lower energy density systems will cost more to ship
Dismantling and packaging	• Labor rates • Field dismantling or removal to third party location • Ease of disconnection/removal modules and balance of plant • Low energy density batteries and high-power applications have more balance of plant materials increasing dismantling cost.

10 MW, 20 MWh Removal and Disposal Cost, 2030$



Assumptions:

- For a remote location with union rates and per diem
- NMC chemistry, modules removed on site, balance of system dismantled off-site
- Long distance for battery transportation (>2,000 miles)
- Inflation rate: 2.5%

References and Appendix

References

[1] *Battery Energy Storage Installed Cost Estimation Tool*. EPRI, Palo Alto, CA: 2020. 3002019154

[2] *Battery Energy Storage Ongoing Cost Study & Estimating Tool*. EPRI, Palo Alto, CA: 2020. 3002018500

[3] *Energy Storage Operation and Maintenance Tracker.* EPRI, Palo Alto, CA: 2020. 3002019222

[4] *Recycling and Disposal of Battery-Based Grid Energy Storage Systems: A Preliminary Investigation.* EPRI, Palo Alto, CA: 2017. 3002006911.

Appendix A: List of Studies Reviewed

Bloomberg New Energy Finance. *2019 Lithium-ion Battery Price Survey.* Bloomberg New Energy Finance, New York: NY: December 3, 2019.

Bloomberg New Energy Finance. *2019 Long-term Energy Storage Outlook.* Bloomberg New Energy Finance, New York: NY: July 31, 2019.

E3. *Minnesota Energy Storage Cost-Benefit Analysis.* December 2019

Lazard. *Lazard's Levelized Cost of Storage – Version 5.0*. November 2019.

National Renewable Energy Laboratory. *Cost Projections for Utility-Scale Battery Storage.* Golden, CO: June 2019. NREL/TP-6A20-73222.

National Renewable Energy Laboratory. *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020 (Draft)*

National Renewable Energy Laboratory, Sandia National Laboratory, SunSpec Alliance, and the SunShot National Laboratory Multiyear Partnership (SuNLaMP) PV O&M Best Practices Working Group. 2018. *Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-73822.

Pacific Northwest National Laboratory, Argonne National Laboratory, and Oak Ridge National Laboratory. *Energy Storage Technology and Cost Characterization Report.* Richland, WA, July 2019. PNNL-28866.

Wood Mackenzie Power & Renewables. *U.S. front-of-the-meter storage system price trends H1 2020.* June 2020.

Wood Mackenzie Power & Renewables and Energy Storage Association. *U.S. Energy Storage Monitor Q2 2020 Full Report.* June 2020.

Appendix B: Assumptions for Installed Cost Categories

ESS Rack

- Battery modules
- Rack hardware
- BMS (module and rack)
- String isolation/protection

ESS Balance of Plant (BOP)

- Enclosure
- Thermal management
- Fire protection

Power Conversion System

- Bi-directional inverter

Controls/SCADA

- Site controller (EMS)
- Networking hardware
- Communications cable
- Sensors
- SCADA software
- Data historian package

EPC

ESS Installation

- Electrical contracting labor
- Materials (cable, raceway, commodities)

AC BOP and Installation

- Transformers
- Medium voltage cables
- AC switchgear
- Meters and enclosures
- Protective relays
- Associated installation

Site Work

- Grading
- Trenching
- Mobilization
- Foundations
- Fencing
- Finishing (e.g. gravel)

Engineering and Management

- Electrical, civil, and structural design
- SCADA and communication design
- Protection
- Stamped drawings
- Field engineering support
- Project management
- Field supervision
- General expenses
- Commissioning
- Shipping

Contingency and Profit

- EPC contingency and profit
- Integrator/developer contingency and profit

Owner's Cost (excluded from Turnkey EPC Installed cost)

- Switchyard
- Interconnection (upgrades and telemetry)
- Land
- Permitting
- Process and Project Contingency
- Financing
- Taxes
- Others

Together…Shaping the Future of Electricity

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electricity generated and delivered in the United States with international participation extending to nearly 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; Dallas, Texas; Lenox, Mass.; and Washington, D.C.

Together…Shaping the Future of Electricity

3002020048

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com