Energy Storage Cost Analysis: Executive Summary of 2017 Methods and Results

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Abstract

This is an executive summary of a report that was prepared as a utility resource for planners and other stakeholders who are tasked with evaluating energy storage. Grid-connected energy storage is growing rapidly and progressing from demonstration projects to commercial implementation. With this rapid growth comes an increased need to understand and analyze the costs of energy storage systems. This is particularly true when comparing conventional generation, or “wires-based” alternatives, with energy storage. To that end, this report provides projected installed costs for energy storage systems that are installed and begin commercial operation in 2018. Additionally, this report illustrates the importance of determining energy storage value, as well as cost. Because there are a multitude of energy storage sizes, locations, and uses, comparisons based on simplified duty cycle assumptions have potential to mislead planners and investors.

Keywords

Energy storage

Resource Planning

Energy storage systems

Costs

Contents

This report that was prepared as a utility resource for planners and other stakeholders who are tasked with evaluating energy storage and includes the following section and contents:

Methodology – Because normalized cost (on a $/kW or $/kWh) can be misleading for energy storage, this study looks at identifying costs associated with a particular power range and energy duration. Common use cases and technologies that are commercially available were selected as the focus of the study.

Cost Results – Results of the study were presented in ranges along with discussion to highlight that total installed costs can vary based on several factors. High level cost breakdowns were included for a transmission connected flow battery and several commercial behind-the-meter systems. Costs are based on a 2018 commercial operation date.

Next Steps for Cost Evaluation– Installation costs are only one portion of a full project cost-benefit analysis. Other costs and technology factors that impact project lifetime economics should be considered.

Cost Study Methodology

Description and discussion of approach to generate energy storage cost estimates

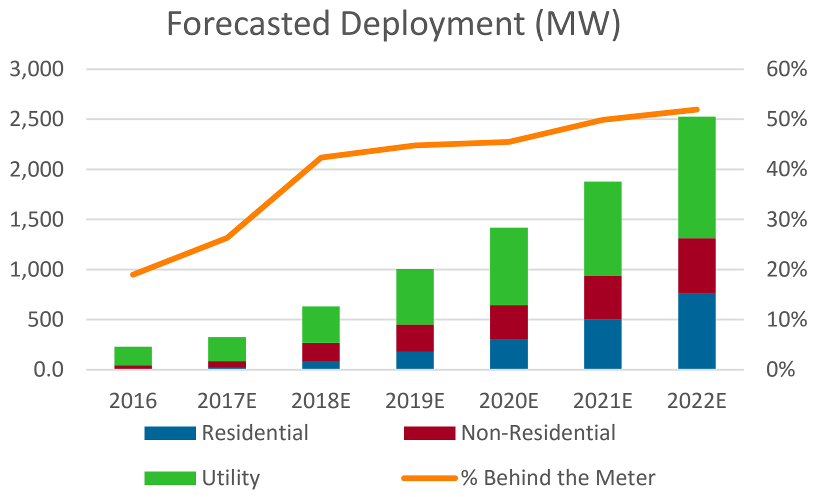
Focus of Study: Technology and Use Case

Because energy storage, unlike conventional generation, is an energy-limited resource, generalizing cost on a $/kW or $/kWh basis for a given technology can be misleading. The power and energy rating must be factored in. Therefore, this study evaluates the potential range of installation costs for energy storage systems of a particular size. The technologies selected were based on maturity and/or recent changes in cost due to technical advances or deployment experience. The scope of this study has shifted since the 2016 edition with added analysis for installed costs on flow battery and behind-the-meter lithium ion systems. The table below lists the technologies and primary use cases analyzed in this study.

Technology	Bulk Services	Frequency Regulation	T&D Grid Support	Customer Use (Behind-the-Meter)
Lithium Ion	X	X	X	X
Flow Battery	X		X	
Sodium Sulfur	X		X	
Lead Acid	X		X	
Flywheel		X		

Representative Use Cases for Detailed Cost Breakouts

The focus of the detailed breakouts are commercial customer applications or behind-the-meter systems (BTM) and a utility T&D flow battery system. BTM systems are now projected to become about 50% of the capacity (in MW and MWh terms) installed by 2022 [1]. Flow batteries were added to scope because there were several MW scale deployments in the 2017 and announced plans to deploy an 800 MWh vanadium flow battery on the Dalian peninsula in northern China. The increase in commercial deployments has yielded an increased interest from utilities wanting to understand the economics of this newer technology.



Based on data provided by GTM Research/US Energy Storage Monitor [1]

The four representative system sizes and use cases were included:

- 30 kW, 2 hour system: Represents a small commercial behind-the-meter system. The primary driver for this system would be reduction in a facility’s demand charge on their electric utility bill. System integrators have noted that smaller systems are becoming less common, because falling lithium ion prices have made it more economical to build larger systems.
- 250 kW, 2 hour system: Represents a medium commercial behind-the-meter system. The primary driver for these installations may be demand charge reduction similar to the 30kW, 2 hour system. There are several products available in this range, which yields more data points with respect to system cost.
- 500 kW, 4 hour system: Represents a large commercial behind-the-meter system which may be used to may serve both customer needs in addition to fulfilling resource adequacy or capacity obligations as part of an aggregation of BTM resources
- 20 MW, 4 hour system: Represents a transmission-connected asset. The 4 hour duration reflects a common qualification for resource adequacy or ISO/RTO capacity markets.

Data Collection Approach and Process

The overall objective of this effort was to gather recent cost information and develop complete system costs for energy storage systems for which procurement and installation would take place in 2018. Initial cost data and cost ranges were developed based on EPRI project experience and also assembled from other recent cost studies, taking into account scope (inclusions and exclusions). That initial dataset was refined by soliciting industry input from energy storage vendors, integrators, developers, general contractors, and engineering, procurement and construction (EPC) firms. Not all of the data collected were used in the analysis. In particular, outlier costs were removed in order to more conservatively anticipate costs in competitive bids responding to an energy storage request for proposal (RFP). The resulting installed costs in this report are intended to represent the reasonable range of competitive bids for a turnkey system, with owners' costs such as land excluded. The Energy Storage Integration Council (ESIC) Cost Template and Tool [4] was used as a framework to identify costs to be included and excluded and to specify the scope of installed costs.

Scope of Energy Storage Installation Costs

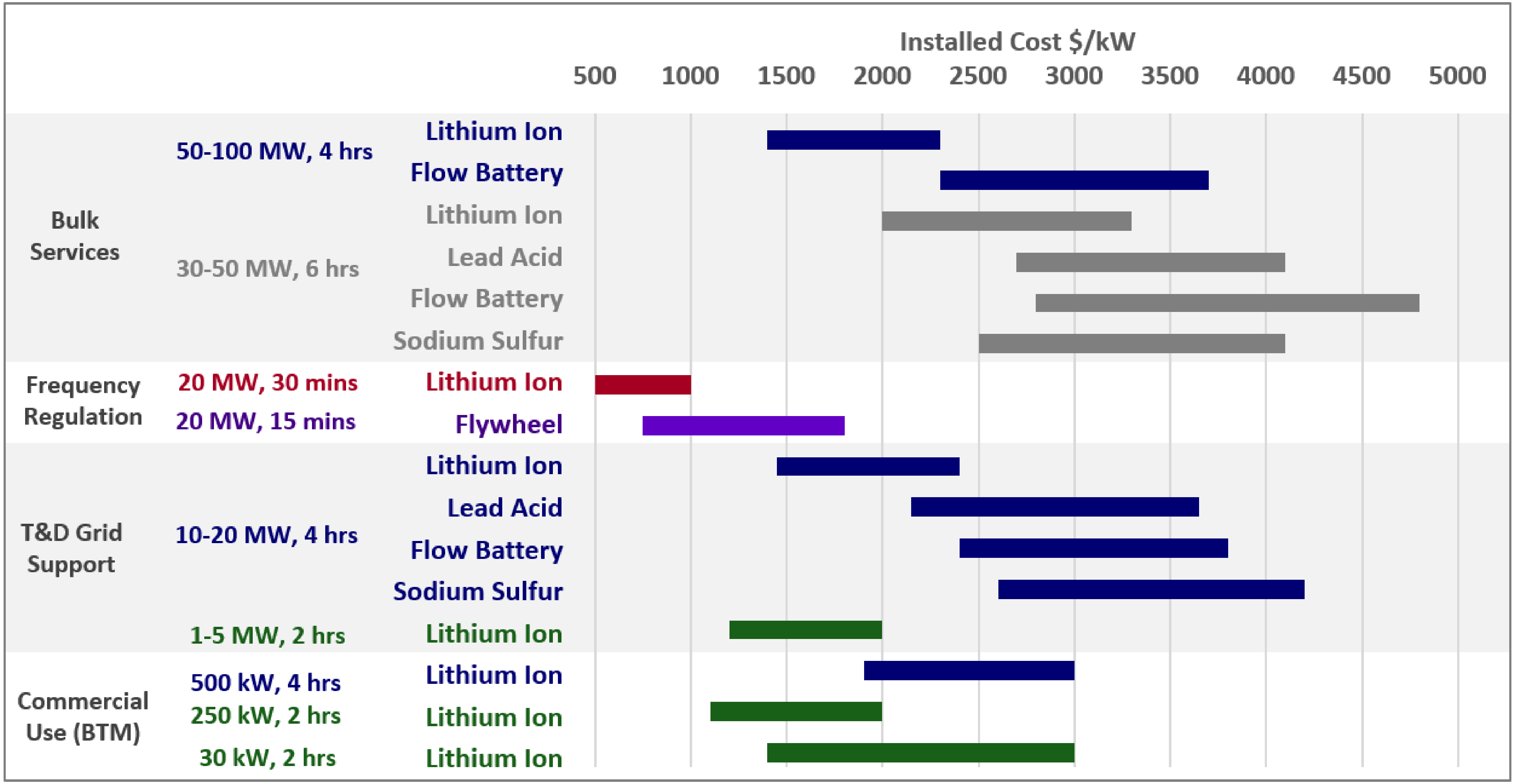
- Scope of turnkey installation is consistent with 2016 report [2], which was based on the assumptions included in EPRI Technology Assessment Guides, excluding project and process contingencies [3]
- Energy Storage Integration Council (ESIC) Cost Template and Tool contains an exhaustive list of energy storage project cost components. It was used to identify and communicate the scope of installation costs when collecting and analyzing information. [4]
- Table shown to right lists major cost categories in ESIC Cost Tool and Template and the assumptions for this studies project scope (i.e. inclusions/exclusions).
- Notable upfront costs which are excluded are land costs, utility program cost (use case analysis and procurement), and financing.
- Detailed line items in each of these cost categories are available by downloading the template at www.epri.com/esic.

Inclusions	Exclusions
▪ Storage Product ▪ ESS Shipping ▪ Project Management ▪ Engineering Study ▪ Grid Integration Equipment ▪ Metering & Telemetry ▪ Grid Integration Site Manager Software Purchase & Certification ▪ ESS Data Storage Computer & SCADA Software or Data Historian ▪ Site Installation ▪ ESS and BOP Installation ▪ Commissioning and Acceptance Testing ▪ Training ▪ Taxes and SG&A	▪ Project Development ▪ Upfront Financing Fees ▪ Upfront ESS Program Costs ▪ Recurring ESS Program Costs ▪ ESS Service & Performance Plans ▪ Grid Integration Site Manager Software Licensing ▪ ESS Software Licensing ▪ Extended Warranty Option ▪ Out of Warranty Grid Integration Component Replacements ▪ Planned Major Component Replacements ▪ Fixed O&M ▪ Variable O&M ▪ Insurance ▪ Periodic Inspections ▪ Scheduling Coordinator Fees ▪ Charging & Discharging Operations and Housekeeping Power ▪ ESS Decommissioning ▪ Grid Related Decommissioning

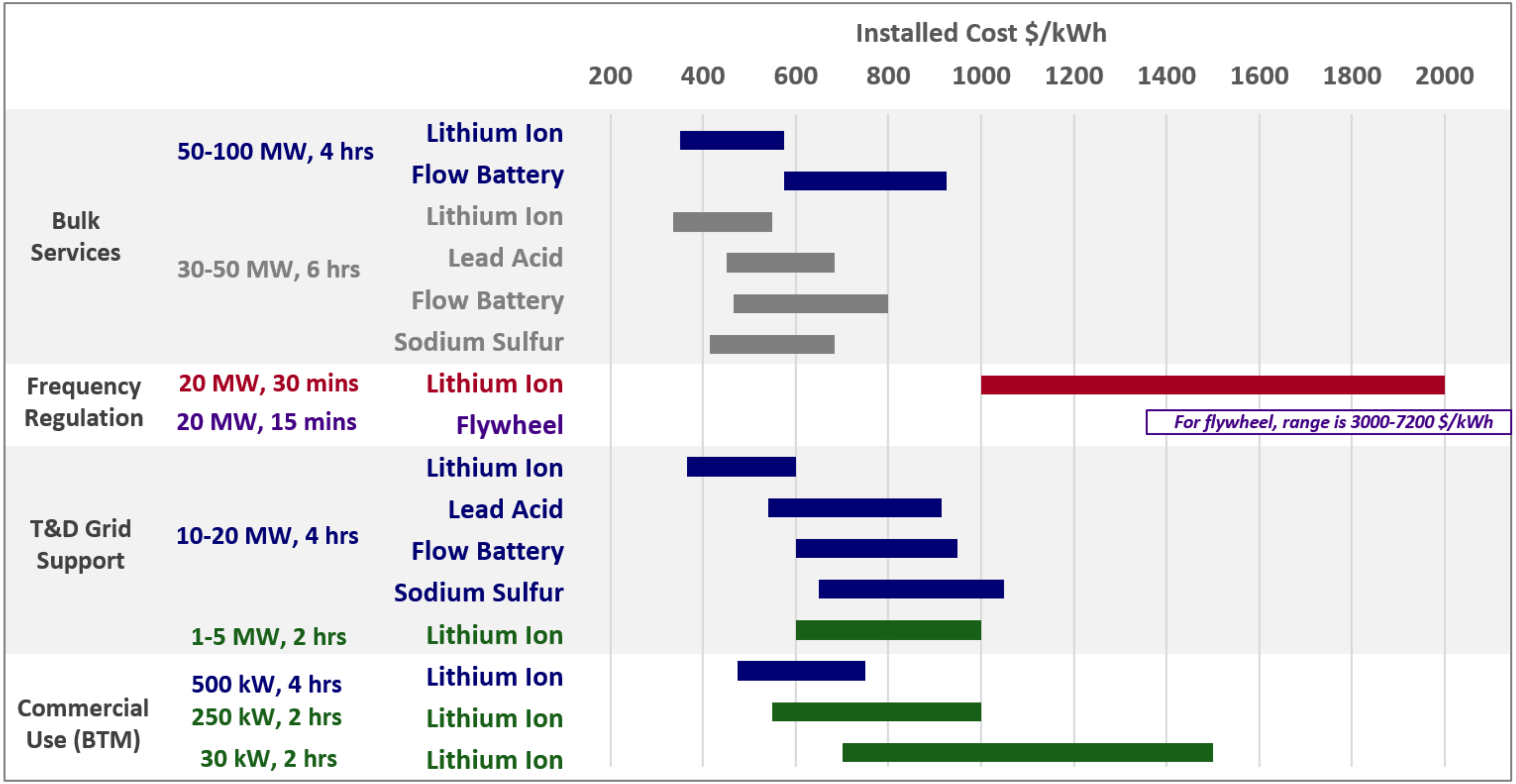
Summary of Cost Results

Cost ranges and illustrative examples for energy storage technologies

Energy Storage Installed Cost Summary per Unit Rated Power Capacity for 2018 Commercial Operation Date



Energy Storage Installed Cost Summary per Unit Rated Energy Capacity for 2018 Commercial Operation Date



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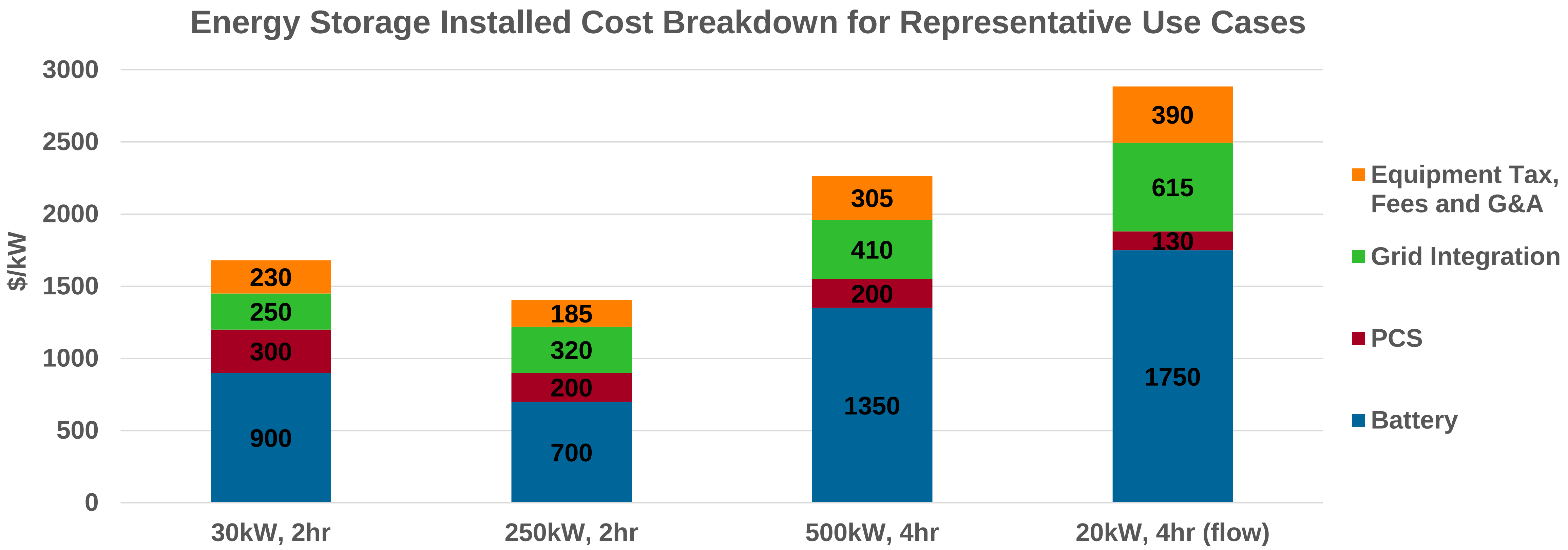
Energy Storage Installed Cost Summary for 2018 Commercial Operation Date

Application	Technology	Rating (MW)	Duration (hours)	Cost Range ($/kW)	Cost Range ($/kWh)
Bulk Services	Lithium ion	50-100	4	1400 - 2300	350 - 575
	Flow battery	50-100	4	2300 - 3700	575 - 925
	Lithium ion	30-50	6	2000 - 3300	335 - 550
	Lead acid	30-50	6	2700 - 4100	450 - 685
	Flow battery	30-50	6	2800 - 4800	465 - 800
	Sodium sulfur	30-50	6	2500 - 4100	415 - 685
Frequency Regulation	Lithium ion	20	0.5	500 - 1000	1000 - 2000
	Flywheel	20	0.25	750 - 1800	3000 - 7200
T&D Grid Support	Lithium ion	10-20	4	1450 - 2400	365 - 600
	Lead acid	10-20	4	2150 - 3650	540 - 915
	Flow battery	10-20	4	2400 - 3800	600 - 950
	Sodium sulfur	10-20	4	2600 - 4200	650 - 1050
	Lithium ion	1-5	2	1200 - 2000	600 - 1000
Customer Use	Lithium ion	0.5	4	1900 - 3000	475 - 750
	Lithium ion	0.25	2	1100 - 2000	550 - 1000
	Lithium ion	0.03	2	1400 - 3000	700 - 1500

Energy Storage Installed Cost Components for 2018 Commercial Operation Date



- Battery and PCS costs are intended to be representative of the total cost from the vendor/supplier, including hardware, BMS, system controller, warranty, shipping and field support
- Grid Integration includes balance of plant equipment, installation, commissioning, project management, and engineering
- Note: This is a simplified cost breakdown from what is included in the full report.

Factor Influencing Total Installation Costs

Cost Line Item	Potential Variations in Cost
ESS Product	• Packaging, thermal management, and fire suppression may be included in this cost if part of a pre-engineered system, but may be in site installation costs for a building design. • Warranty and shipping may be included, but terms should be verified to ensure responsibility of all parties is understood and all costs are accounted for. • Capacity overbuild, future augmentation or replacement will impact the distribution of project costs throughout the project life cycle
Grid Integration Equipment	• May be lower for behind-the-meter systems if existing electrical infrastructure can be used • For T&D utility connected systems, interconnection voltage and utility standards and requirements will impact equipment costs
Site Installation	• Indoor installations or sites using existing foundations may have reduced site cost • Permitting costs will vary by jurisdiction, their familiarity with storage technology characteristics and risks, and the processes in place to review and approve installation • Building design for larger systems will have a higher percentage of costs in this line item • Labor wage requirements (e.g. prevailing wage, union) can influence all installation costs
ESS and BOP Installation	• Similar to Grid Integration Equipment and Site Installation, this will vary by existing infrastructure, utility requirements and design of ESS Product (i.e. packaged system vs building design)
Commissioning and Acceptance Testing	• Heavily linked to the particular circumstances of a given storage application, including the extent to which on-site integration (as opposed to factory integration) is required • Performance and functional tests may take several weeks, and depending on monitoring and remote capabilities this may require on-site presence to conduct the tests.
Other Costs	• Fees and G&A costs may be linked to the type of purchase being made. There may be markup on equipment and subcontracts when procuring a turnkey system from an integrator or EPC.

Next Steps for Cost Evaluation

Discussion of cost-benefit analysis

Other Costs that Impact Project Lifetime Economics

The results from this study can be used as an input to a storage valuation tool, such as EPRI's StorageVET®. However, installation costs are just one component of the cost-benefit calculation. Below is a list of additional cost inputs in StorageVET.

- The cost of **replacement batteries**: There are many studies plotting the decline in the price of lithium ion batteries, but other factors are harder to predict, such as labor costs, commissioning costs, and other non-equipment costs.
- **Operations and Maintenance (O&M)** costs
  - **Fixed operations and maintenance (O&M)** costs: Generally, these costs are a small percentage of installed capital costs, but interviews with suppliers indicated that components of O&M costs vary with some including items such as warranties or performance guarantees while others do not, which can add to ongoing costs for monitoring or vendor risk mitigation.
  - **Variable operations and maintenance (O&M)** costs: Any electrical system requires regular care and maintenance service over its lifetime. The variable costs of an energy storage system are those tied to its operations, such that a system which operates only occasionally will have lower variable O&M costs than one that operates on a daily basis.
- **Project development** expenses: These costs are not captured in turnkey EPC installation costs and can include land costs, development of a solicitation, financing. (The ESIC cost tool has an extensive list of these costs.)
- **End of life** expenses: These costs are estimated at between 5% and 10% of an ESS cost, using information appropriate to decommissioning in 2017; however, this percentage is expected to decline as decommissioning practices improve with scale and experience and the expected build-out of facilities for disposing of electric vehicle batteries.
- Financing, projected future energy costs and value of services also impact cost and value. Visit www.storagevet.com for full list of economic inputs.

Technical Parameters that Impact Project Lifetime Economics

In addition to the ongoing costs, the following technical parameters can impact the overall lifetime costs of an ESS, including:

- **State of charge limits**: Limiting the SOC range could be contractually required or be done to preserve battery life.
- **Efficiency**: A central consideration in the analysis of lifetime ESS costs is the efficiency of a system. Roundtrip efficiency can have a direct bearing on equipment costs and the scale of a system needed to meet particular uses and requirements. Efficiency losses will depend on the duty cycle of the ESS as well as the technology employed. This characteristic describes only the roundtrip losses related to ac-to-ac conversion and does not include housekeeping power listed below.
- **Self-discharge rate**: Any battery will exhibit self-discharge, a process of loss of charge inherent in a given chemical process. To some extent, manufacturing faults or poor maintenance can exacerbate self-discharge, but in general this is a normal aspect of battery behavior. Subjecting batteries to excessive heat or deep discharges may increase self-discharge.
- **Housekeeping power** (or auxiliary power): Auxiliary power use encompasses consumption by components associated with the operation of an ESS, but not including efficiency losses. This may include, but is not limited to, controls, cooling systems, fans, pumps, and heaters necessary to operate and protect the system.
- **Cycles vs. Depth of Charge**: Many batteries undergo non-linear degradation as a result of cycling where shallower cycles result in more energy throughput. Modelling cycle life and duty cycle will inform potential replacement or augmentation costs.
- **Calendar life**: Lithium ion batteries can have a calendar life that is independent of cycle life, but like cycle life, calendar life can also affect replacement or augmentation costs.

Full Report

Energy Storage Cost Analysis: 2017 Methods and Results. EPRI, Palo Alto, CA: 2017. 3002010963.

For more information visit www.epri.com

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