2019 Energy Storage Market Evaluation

Final Survey Report

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1 Introduction

1.1 Program Description

This report presents results from primary and secondary data collection efforts completed by the evaluator for the following two NYSERDA energy storage initiatives:

1. Reducing Barriers to Deploying Distributed Energy Storage (DES) Investment Plan:[1] Energy storage is a multifaceted technology that cuts across many sectors, including clean energy production, energy efficiency, various types of customers and buildings, and both established technologies and those still in development. NYSERDA's energy storage strategy targets key barriers limiting energy storage adoption in three sectors: customer-sited (behind-the-meter [BTM] systems), transmission and distribution (T&D) system needs, and the transportation system. This initiative originally sought to reduce soft costs for customer-sited energy storage systems, specifically related to permitting, customer acquisition, and interconnection, by 25% per kWh in three years and 33% or more in five years, based on a 2015-16 baseline of $200/kWh at the time. This goal has now been recalibrated to the broader objectives described in the PSC Energy Storage Order which referenced estimates in the NYS Energy Storage Roadmap that New York can reduce total soft costs by up to $50 per kWh for a distribution/bulk storage system and up to $150 per kWh for a customer sited system by 2025 compared to 2017-18 costs. These soft cost reductions are now inclusive of all use cases and include permitting, interconnection, customer acquisition, as well as engineering and construction costs, and tools to support market replication. This initiative works in conjunction with NYSERDA's market acceleration storage incentives.[2]

2. Energy Storage Technology and Product Development Investment Plan:[3] There are many grid and consumer benefits from the increased use of renewable energy assets and energy storage. Optimizing the energy output and uptime of renewable resources will provide near-term

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[1] Clean Energy Fund Investment Plan: Energy Storage Chapter. Portfolio: Market Development. Matter Number 16-00681, In the Matter of the Clean Energy Fund Investment Plan. Revised April 19, 2019. https://www.nyserda.ny.gov/-/media/Files/About/Clean-Energy-Fund/CEF-Energy-Storage.pdf

[2] https://www.nyserda.ny.gov/All-Programs/Programs/Energy-Storage/Developers-Contractors-and-Vendors

[3] Clean Energy Fund Investment Plan: Renewables Optimization Chapter. Portfolio: Innovation & Research. Matter Number 16-00681, In the Matter of the Clean Energy Fund Investment Plan. September 7, 2018. https://www.nyserda.ny.gov/-/media/Files/About/Clean-Energy-Fund/CEF-Renewables-Optimization-chapter.pdf

economic benefits and decrease the total cost to deploying renewable technologies in the future. Energy storage can reduce the intermittency of solar and wind energy, helping these resources to be flexible assets deployed when needed. Energy storage can also avoid the need for new electric system infrastructure, increase system efficiency and resiliency, and reduce the need for fossil fuel plants to meet periods of peak electric demand. To meet these goals, NYSERDA is undertaking the following activities:

- Provide competitive funding opportunities in support of technology companies to leverage existing capabilities, validate technologies, create innovative products and applications, and otherwise facilitate energy storage development in New York. NYSERDA will issue broad competitive solicitations for project proposals to identify teams and approaches to address innovations focusing on:
    - Reduced hardware cost for energy storage components and devices, including reduced power electronics cost for energy storage systems.
    - Improved performance (efficiency, safety, energy density) of storage devices, especially for New York-specific applications and duty cycles—e.g., building demand response, EV charging, solar PV, and large-scale wind.
    - Load-side and generation-side applications of energy storage to reduce peak load, store and reuse solar PV and wind energy to help firm up these resources, and provide ancillary services.
- Facilitate strategic corporate partnerships among small- and medium-sized companies and large original equipment manufacturers to speed up the path to commercialization.
- Explore viability of establishing technical performance specifications that can serve as a market-relevant stretch goal to drive innovation. If appropriate, use the stretch goal as a technology challenge in one or more competitive solicitations.

1.2 Summary of Evaluation Objectives and Methods

The evaluation objectives and select results from the 2018 primary a data collection and literature review efforts completed by the evaluator are shown in Table 1 and Table 2. The evaluation design is longitudinal in nature and is structured to capture data over multiple years. This design allows program stakeholders to compare current market conditions to baseline market conditions established in 2017 and to observe market trends over time. The time-series data developed over the course of the evaluation will help NYSERDA and other program stakeholders better understand the actors and dynamics that drive the energy storage market in New York State as the market grows from its current nascent state.

Table 1: Evaluation questions mapped with 2018 primary data collection results

Objective: Develop a reliable, detailed, New York-based estimate of current soft costs ($/kWh) of DES systems as a component of the total installed cost ($/kWh, duration)

Evaluation Question(s)	2018 Findings
What is the current estimate of soft costs ($/kWh capacity) of DES systems?[4]	Average = $212/kWh Median = $200/kWh *n*=5
What is the installed cost per kilowatt-hour capacity for energy storage systems by duration?[5]	Average = $1,000/kWh Median = $1,000/kWh Duration not specified[6] *n*=5
How many alternative ownership models (e.g., third-party ownership, end-user ownership, performance contracting) are being used?	Limited data was reported in 2018 for both behind-the-meter (BTM) and front-of-the-meter (FTM) projects, though third-party performance contracting models and end-user ownership were mentioned by survey respondents. Given that this is an emerging market, this may not be indicative of larger trends over time.
What is the percent conversion rate (%) of prospective installations from proposal to installed projects?	Median = 5% Average = 18% *n*=5
What is the current cycle time (months) for the permitting process?[7]	Insufficient data collected.[8]
Are there challenges with siting and permitting requirements?	Two survey respondents mentioned known challenges with permitting requirements in New York City which have been the subject of significant NYSERDA engagement.
What is the cycle time (months) of projects from customer proposal to commissioning?	Reported total cycle time for BTM projects was 12 months. Insufficient data was collected for FTM projects; however, it appears this cycle time can be up to two times longer.

[4] Includes a combination of two- to four-hour systems.

[5] Duration is defined as the ratio of the storage system's energy capacity to power capacity which indicates the length of the system's full discharge.

[6] NYSERDA opted not to collect data in 2018 regarding system duration characteristics given the anticipated limited number of survey respondents.

[7] Definition of cycle time and permitting process details can be found in the survey document (Appendix A)

[8] Too few survey responses to accurately draw quantitative conclusions. Qualitative observations presented in Section 2.1.3.

Table 2: Evaluation questions mapped with literature review results

Objective: Develop a reliable, detailed estimate of current hardware and hardware balance of system (BOS) costs ($/kWh) of energy storage systems

Evaluation Question(s)	2018 Findings
What is the current hardware cost ($/kWh) for energy storage devices?	Typical utility-scale lithium ion (Li-ion) battery cost = $200/kWh. Battery costs are ~20% higher for commercial and industrial (C&I) and ~55% higher for residential. Unit cost may be significantly higher for high-performing batteries.
What is the current hardware BOS cost for energy storage systems including power electronics and hardware installation cost ($/kWh)?	Typical utility-scale power conversion system (PCS) hardware cost = $95/kW. PCS cost is ~90% higher for C&I and ~120% higher for residential. Typical utility-scale BOS hardware cost = $13/kW + $36/kWh. BOS costs are ~70% lower for C&I and ~300% higher for residential.
What is the current performance of energy storage systems in terms of efficiency, life, energy/power density, etc.	Nameplate efficiency varies from 85% to 100%, depending on technology. Real efficiency varies widely and is driven by use case. Density varies widely and depends on system design.

2 Market Characterization and Assessment

2.1 Primary Data Collection Results

This section summarizes DES system installation costs, project cycle times, characteristics of projects statewide, value propositions, ownership models, and barriers in the New York market. The data included in this analysis was compiled from 26 companies that responded to the evaluation survey. The analysis included all companies that contracted or completed DES projects in New York State in 2018. Not all companies answered all survey questions, however, so the evaluator presents the number of responses for each set of results. Section 5.1.3, "Respondent Characteristics," provides additional details regarding the companies that responded to the evaluation survey.

2.1.1 System Costs

The survey asked responding companies to provide information on average installed costs for their primary use case DES systems.[9] The evaluator collected information from five respondents serving commercial and industrial (C&I) BTM customers and three respondents serving utility front-of-the-meter (FTM) customers. While the survey sample includes a small number of respondents, the storage market in New York is relatively nascent with few players. NYSERDA tracks operational projects in New York State and has confirmed the survey responses collected by the primary research activities are representative of the market and capture the companies implementing most projects in the state.[10]

Survey respondents reported that 10 use cases were electrochemical systems, with nine lithium ion (Li-ion) installations (including one secondary use case) and another secondary use case lead-acid installation. Five of the Li-ion installations and the one lead-acid installation were BTM and the remaining four Li-ion installations were FTM. Three DES systems were installed in New York City, four in Westchester County, and the remaining two were installed in other parts of the

[9] The survey also asked companies to provide information on average installed costs for secondary use case DES systems. Two respondents provided both primary and secondary use case information as defined in the survey document (See Appendix A).

[10] A database of all distributed energy resource projects installed throughout New York is available here: https://der.nyserda.ny.gov/

state. Reported system size ranged from 60 kWh to 20,000 kWh, with the average and median system size both equaling 500 kWh. While the average system duration was not collected in the 2018 survey, the evaluator recognizes that system duration affects total system cost—shorter duration systems will be more expensive.[11] In future years, the evaluator will collect duration data on a project-specific basis and duration will be a consideration in reporting system costs.

The evaluator asked companies to estimate what percentage of total system cost was spent on hardware, engineering and construction, and soft costs. These categories are defined as follows:

- **Hardware costs:** Battery module, inverter, and BOS costs such as fire controls, power electronics, communication system, containerization, insulation, HVAC system, meter, control system, and outdoor containerization (when necessary).
- **Engineering and construction costs:** Cost of design, site preparation, transportation, siting, Professional Engineer approval, testing and commissioning, electrician and installation labor, wiring, fencing, and other overhead.
- **Soft costs:** Cost of customer acquisition, permitting and interconnection, and financing.

Seven of the eight respondents who provided complete use case information also provided soft cost information. The evaluator analyzed these use cases separately. The results presented in Table 3 are for respondents who provided complete soft cost data. The evaluator excluded from the analysis one respondent who provided incomplete soft cost data.

Table 3: Average costs of BTM C&I DES projects in 2017 and 2018, by component*

Name	Unit	2017		2018	
		Average	Median	Average	Median
Total average installed system cost	$/kWh	$883	$850	$1,000	$1,000
Hardware costs	%	62	60	55	50
Engineering and construction	%	22	20	24	20

[11] NYSERDA opted not to collect data in 2018 regarding system duration characteristics given the anticipated limited number of survey respondents.

Name	Unit	2017		2018	
		Average	Median	Average	Median
Soft costs	**%**	**17**	**15**	**21**	**20**
Customer acquisition costs	*%*	*3*	*3*	*2*	*2*
Permitting	*%*	*8*	*10*	*6*	*8*
Interconnection	*%*	*5*	*5*	*10*	*10*
Financing costs	*%*	*1*	*0*	*3*	*0*

*The percent sum of average hardware costs, engineering and construction costs, and soft costs should sum to 100, any variance is due to rounding. The median values do not necessarily sum to 100, due to the variance within data points. Soft costs are a sum of the average customer acquisition costs, permitting, interconnection, and financing costs. These also sum to 100 for average columns, but not the median columns.

Survey respondents indicated that average installed system costs in 2018 were $1,000/kWh. This value is slightly higher than the 2017 value. The percent of costs attributable to soft costs was 21% on average in 2018, which is also higher than the percent observed in 2017 (17%). While trends in installed system costs and soft costs appear to have increased over time, the limited number of respondents means that a few projects could skew these generalized results from one year to the next. The evaluator will continue to collect time-series data regarding these metrics in the coming years so that NYSERDA and other program stakeholders can monitor these trends as the market matures and an increasing number of DES projects are installed in New York State.

Few 2018 survey respondents reported installing FTM DES systems; however, of those that did, it appears that the larger scale of these installations located outside of the Con Edison service territory led to a lower average installed cost per kilowatt-hour than the BTM projects reported in Table 3.

2.1.2 Value Proposition and Alternative Ownership Models

Survey respondents cited several benefits of DES systems that were important in closing the deal for potential customers. As shown in Table 4, the most frequently cited benefits in 2018 shifted somewhat from 2017 with 75% of responding companies (n=4, 2 FTM, 2 BTM) citing distributed generation integration and non-wires alternative services most frequently. In 2017 (n=5), the investment tax credit, demand charge management, and demand response payments were the most frequently mentioned benefits (63%).

Table 4: DES system benefits important for deal closure

Benefit	Percent of Respondent Companies	
	2017	2018
Investment tax credit	63%	50%
Distributed generation integration	38%	75%
Non-wires alternative services	38%	75%
Demand charge management	63%	50%
Demand response payments	63%	50%
Resilience/backup power	38%	25%
Other	25%	0%

Multiple response question, 2017 n=9, 2018 n=4 (2 FTM, 2 BTM)

One of NYSERDA's objectives is to increase the number of alternative ownership models (e.g., third-party ownership, end-user ownership, performance contracting) for DES projects. Respondents provided limited data in 2018 for both BTM and FTM projects, though third-party performance contracting models and end-use ownership were mentioned for both categories. Given that this is an emerging market, this may not be indicative of larger trends over time.

2.1.3 Barriers in the New York State Market

NYSERDA aims to increase the percent conversion rate for DES projects receiving a proposal to projects receiving a contract. The development of a major storage proceeding in 2018 caused a pause in the market as DES developers waited for the State's plans.[12] The NYSERDA incentive program launched in early 2019 and is expected to positively influence the number of DES installations in New York State in 2019 and beyond. Developer reticence to engage in new projects in 2018 is supported by companies (n=5) that reported an average of 18% of 2018 projects that received a proposal went on to receive a contract, compared to an average of 45% in

[12] On June 21, 2018 Governor Cuomo announced the release of the State's Energy Storage Roadmap. The Roadmap identifies short-term recommendations for how energy storage can deliver value to New York electricity consumers and cost-effectively address the needs, and demands of the grid, supporting the Governor's energy storage target of 1,500 MW by 2025. In December 2018, the New York Public Service Commission (PSC) issued a landmark energy storage order, based upon the Roadmap recommendations. The order established a 3,000 MW by 2030 energy storage goal and deployment mechanisms to achieve both the 2025 and 2030 energy storage targets. On April 25, 2019, NYSERDA filed its approved implementation plan with the PSC that outlines the details of the incentive structure and design that will be used to support the incentive programs. The implementation plan adopts the foundational commitment of the energy storage order and aims to create a self-sustaining energy storage market over time.

2017 (n=6).[13] Conversely, companies reported an average of 25% of DES projects (n=5) waiting for permits to be approved in 2018, compared to an average of 42% of DES projects (n=9) waiting for permits to be approved in 2017.

Responses were not conclusive on how long the total project cycle time is for New York State-specific projects relative to other jurisdictions, with some companies reporting longer time required in New York State, while others said New York State was similar to or slightly faster than other jurisdictions. One company expanded upon its response and stated that New York State-specific projects tend to take longer than California and shorter than Canada.

2.2 Literature Review Results

The objective of the 2018 literature review was to primarily provide a reference for energy storage cost and performance metrics, with the data below providing an update to the more in-depth prior analysis for 2017. In addition to hardware costs for the battery, PCS, and BOS evaluated in 2017, the evaluators expanded the cost study to consider three additional cost components: energy management system (EMS); engineering, procurement, and construction (EPC); and total installed cost. The evaluators reviewed three performance metrics: efficiency, energy density, and lifetime (cycle and calendar). The evaluators also considered key parameters that impact cost and/or performance: duration, size, and use case. The 2018 analysis was based upon new data collected by the evaluator since the 2017 report, in addition to data collected for the prior analysis. The additional data sources are listed in Appendix A. The approach the evaluators used to analyze the data is described in Section 5.2.

[13] Some zero values were excluded because all companies included in the analysis reported at least one 2017 project installed, commissioned, or in the pipeline with an executed contract.

2.2.4 Cost

In addition to the battery, PCS, and BOS costs[14], the evaluators quantified typical costs of non-hardware components, including EMS, EPC, and total installed cost:

- **Battery**: Battery rack with battery management system (BMS)
- **PCS**: Inverter
- **BOS**: Enclosure, HVAC, transformer, switchgear, wiring, etc. (excludes interconnection and software costs)
- **EMS**: Software and controls
- **EPC**: Engineering, procurement and construction; may include development and other soft costs
- **Total installed cost**: Includes all components

Consistent with the 2017 report, evaluators analyzed these costs for their dependence on a variety of parameters:

- **Duration**: Dependence on energy to power ratio (hours)
- **Size**: Dependence on system size/grid location
- **Use case**: How the energy storage system is used (indirectly evaluated based on duration and grid location)
- **Time**: Historical and forecast cost reductions

The results of this analysis indicate that updated 2018 costs are lower than projected 2018 costs from the 2017 report.[15] Although a rapid decline in hardware costs is observed between 2017 and 2018, costs are expected to fall at a slower, though still significant, rate in future years (Section 2.2.4.6).

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[14] The battery, PCS, and BOS components make up hardware (HW)

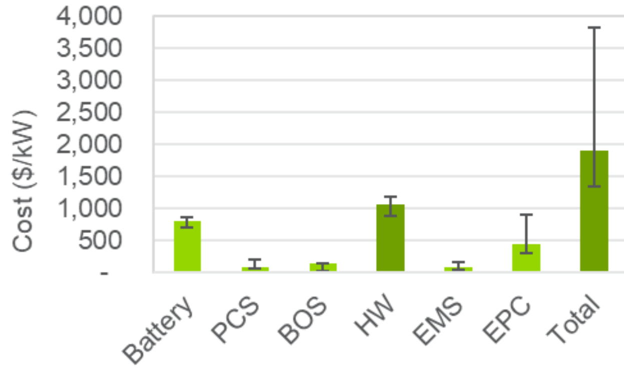
[15] NYSERDA. 2018. *2017 Energy Storage Market Evaluation*. Prepared by Navigant Consulting, Inc.

The 2018 data analysis shifted from primarily using a 2-hr baseline for the batteries to using a 4-hr baseline, which is consistent with the typical duration reported in the primary data collection in this evaluation. Hardware, EPC and soft costs derived from the primary data collection were higher than the costs derived from the literature review, which may be attributable to higher costs in New York State.

2.2.4.1 Variability in Costs

As shown in Figure 1, the variability in costs is driven primarily by labor and soft costs (EPC). Hardware (HW) and software (EMS) costs, on the other hand, show limited variability. Battery cost variability appears lower relative to last year due to the exclusion of high-cost batteries from the analysis.[17] Variability for other hardware components appears lower due to analysis of utility-scale costs only. Relative costs for behind-the-meter (BTM) systems are provided in Section 2.2.4.4. Note that total costs in Figure 1 are based on reported total system costs and are not equal to the sum of the component costs. Some uncertainties that drive variability in reported costs include:

Figure 1. Cost Variability (2018, Li-ion, Utility-scale, 4-hr)[16]



Source: Evaluator Analysis

- Data sources do not always indicate whether the data includes profit margins
- Data sources do not always specify whether theoretical maximum energy or actual usable energy is the basis for battery costs
- Some data sources may define components differently, particularly for non-hardware costs
- Assumptions of size and/or grid location are not always clearly specified

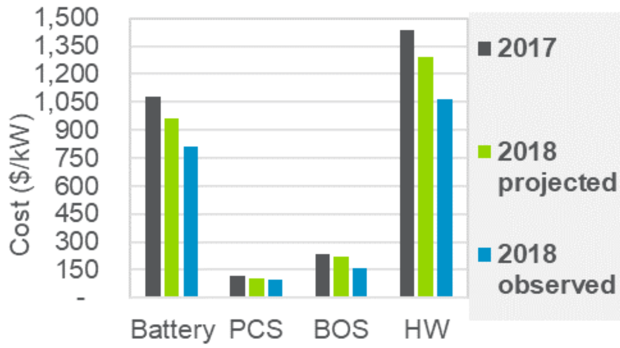
[16] Hardware (HW) is based upon the sum of battery, PCS, and BOS components, while Total Cost is based upon assessment of reported total system costs (not a sum of the values found for individual components).

[17] An example is lithium titanate (LTO), which is a high-performance technology primarily used for short-duration applications, whereas this analysis focuses on 4-hr batteries as a baseline.

- Data for a given year does not specify whether it is based upon prices for projects deployed in that year or bids provided that year for projects to be deployed in subsequent years

2.2.4.2 Comparison of Costs between 2018 and 2017 Analyses

Figure 2. Cost by Scale (2017 vs. 2018 Analyses, Li-ion, 4-hr)



Source: Evaluator Analysis

Similar to Section 2.2.4.6, the 2017 report projected costs over time.[18] Overall, observed 2018 costs are lower than projected 2018 costs. As shown in Figure 2, significant cost reductions were observed for all hardware components. Battery cost reductions are the biggest driver of overall hardware cost reductions, while PCS reductions were minimal in comparison. Although BOS costs fell by the largest relative percentage compared to other hardware components, this is likely due to refinements in cost estimates obtained through the additional data collected than actual cost reductions.

2.2.4.3 Dependence on Duration

The cost of an energy storage system varies depending on the duration (hr), which is equivalent to the ratio between the usable energy (kWh) and the maximum power (kW). Consistent with the 2017 report, the battery component has the most significant dependence on duration. As shown in Figure 3, the dependence of each component's cost ($/kW) on duration is approximately linear.[19] While battery costs scale primarily with energy, other hardware components scale primarily with power (PCS) or with a mix of power and energy (BOS).

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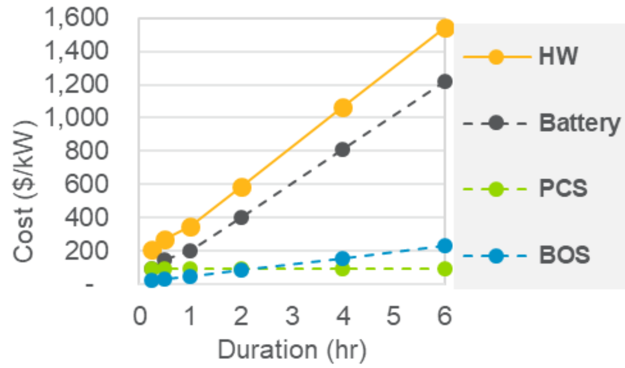
[18] NYSERDA. 2018. *2017 Energy Storage Market Evaluation*. Prepared by Navigant Consulting, Inc.

[19] The relationship for batteries is not entirely linear. At shorter durations, more expensive batteries and/or a narrower depth of discharge to limit degradation from rapid cycling is required.

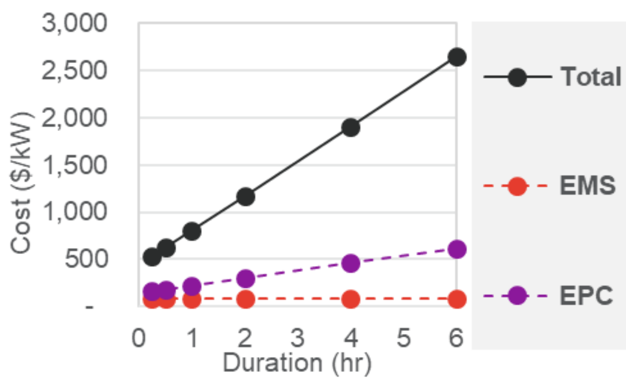
Figure 3. Cost by Duration (2018, Li-ion, Utility-scale, Hardware components)[20]



Source: Evaluator Analysis

Figure 4 shows cost by duration for non-hardware components. EMS cost, like PCS, scales almost exclusively with power. EPC and total installed costs, on the other hand, are driven by both energy, at longer durations, and power, at shorter durations.

Figure 4. Cost by Duration (2018, Li-ion, Utility-scale, Non-hardware components)[21]



Source: Evaluator Analysis

2.2.4.4 Dependence on Size

Observed 2018 costs indicate similar trends to those found in the 2017 analysis with respect to dependence upon size. As shown in Figure 5, both hardware and non-hardware costs tend to

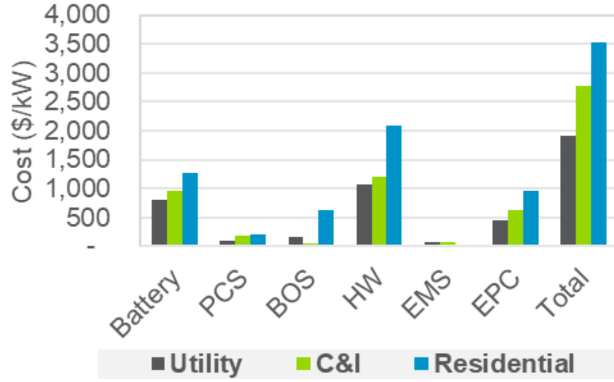
[20] Dashed lines represent costs at the component level while solid line represents cost for hardware components.

[21] Soft costs are not itemized in Figure 4. See discussion in Section 2.2.4.7.

increase as site location reduces in scale. Similar trends as last year are observed for hardware components:

- Battery: continuous reductions with scale
- PCS: affected by economies of scale and functionality enhancements

Figure 5. Cost by Scale (2018, Li-ion, 4-hr)



Source: Evaluator Analysis

- BOS: lower C&I BOS costs due to ability to leverage existing customer infrastructure

Costs for non-hardware components indicate similar trends. EPC and total installed costs are nearly double for residential projects as compared to utility scale projects. EMS costs, on the other hand, indicate no clear variability with size.

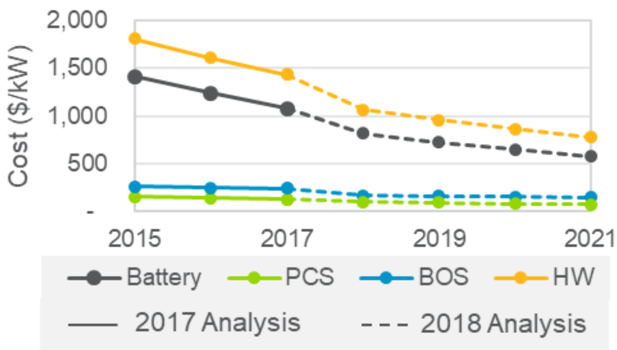
2.2.4.5 Dependence on Use Case

Consistent with the 2017 report, the variations in costs with use case are primarily driven by duration (Figure 3) and scale (Figure 5). While short-duration applications are primarily driven by component power costs and may use more expensive, high-performance batteries ($/kWh basis), long-duration applications are driven by component energy costs and may use less expensive batteries. While customer-sited systems may enable more applications (e.g., demand charge management, backup power), they also require greater benefits to offset higher costs. The introduction of additional applications may introduce new value streams (e.g., customer bill savings), but it also may limit ability to provide other grid services (e.g., capacity).

2.2.4.6 Cost Reductions over Time

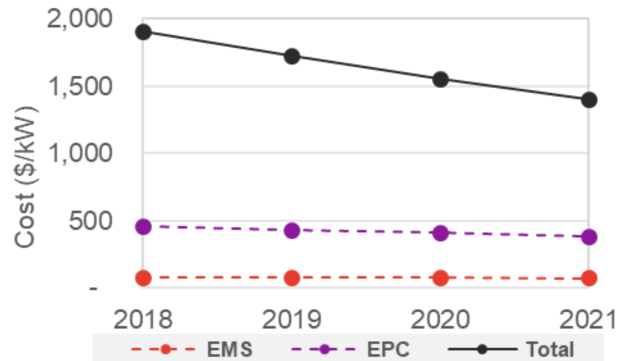
As shown in Figure 6, a rapid decline in hardware costs is observed between 2017 and 2018. The same rate of decline, however, is not expected to continue in the future. Instead, future annual cost declines are expected to be similar to those observed prior to 2017. Total costs reductions are also projected to be similar to hardware cost reductions (Figure 7). Annual cost reductions by component are in shown in Table A-1 in the appendix.

Figure 6. Cost by Year (Li-ion, Utility-scale, 4-hr, Hardware components)



Source: Evaluator Analysis

Figure 7. Cost by Year (Li-ion, Utility-scale, 4-hr, Non-hardware components)[22]

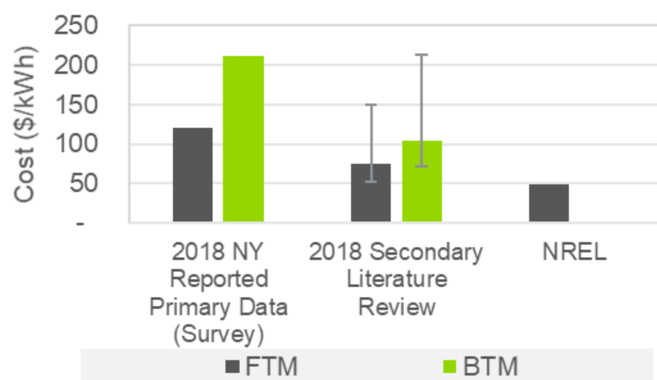


Source: Evaluator Analysis

2.2.4.7 Comparison of Primary Data and Literature Review Results

Figure 8 provides a comparison of the soft costs from the 2018 NY reported primary data and literature review, as well as a data point from the NREL report *2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark*, as this provides a reference for utility-scale soft costs that is consistent with the scope of the survey analysis. Soft costs from the survey data appear to be higher than calculated soft costs from the literature review, as well as from NREL specifically. This may be partially attributable to higher reported costs in New York State. The significantly lower costs for the

Figure 8. Soft Cost Comparison (2018, Li-ion, 4-hr)



Source: Evaluator Analysis

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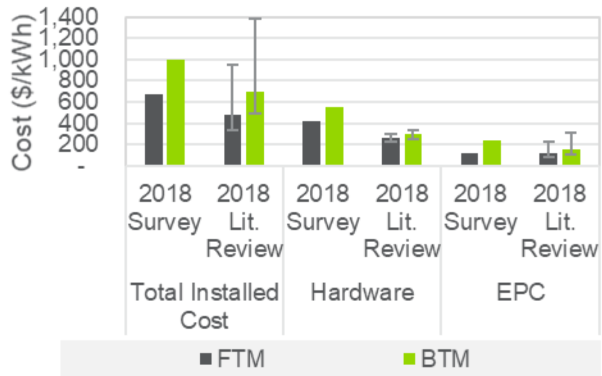
[22] Dashed lines represent costs at the component level while solid line represents cost for non-hardware components.

NREL data may also be partially attributable to economies of scale (i.e., 60 MW basis).

Figure 9 provides a comparison of the total installed, hardware and EPC costs from the survey and literature review. The literature review generally finds lower average costs than the survey, though costs from the survey are generally within the range of error from the literature review. The exception is hardware costs. The reason for this discrepancy is unclear but the discrepancy may be due in part to high labor costs for upstream hardware providers being built into the hardware price and/or to more stringent technical requirements for permits and interconnection (e.g., additional containerization).

Figure 9. Comparison of Literature Review and Survey Results (2018, Li-ion, 4-hr)[23]



Source: Evaluator Analysis

2.2.5 Performance

The performance review focused on the following three key metrics:

- **Efficiency:** System efficiency (including auxiliary power)
- **Energy density:** Usable energy (MWh) on a gravimetric, volumetric, and areal basis
- **Lifetime:** Calendar (year) and cycle life basis

As with the cost analysis, the evaluators evaluated the impact of duration, size, use case, and variation over time on each performance metric. Results were generally consistent with those presented in 2017 report with no significant change in performance and dependencies being observed.

[23] *2018 Survey* refers to 2018 NY Reported Primary Data while *2018 Lit. Review* refers to 2018 Literature Review

2.2.5.1 Variability in Performance

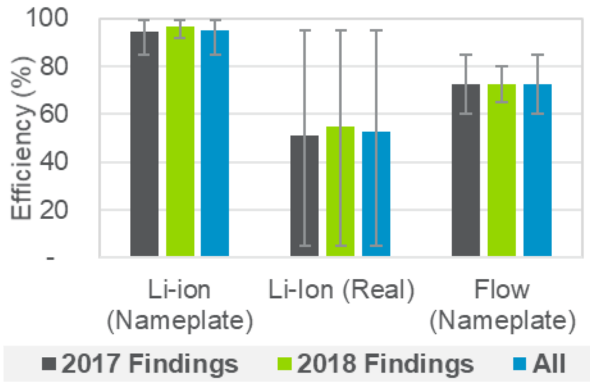
Results from both the 2017 report and analysis of the new data demonstrated that system performance is largely driven by technology selection, but variability in performance data is driven by a number of other factors:

- **Current basis:** Stated efficiencies do not always indicate whether it is on an alternating current (AC) or direct current (DC) basis.
- **Density basis:** Performance data does not consistently indicate whether the basis for the data is at the cell, module, rack, or system level.
- **Lifetime basis:** Cycle life data does not consistently report underlying assumptions of whether partial or full cycles are assumed, and both cycle and calendar life data do not consistently report assumptions regarding oversizing and augmentation.

2.2.5.2 Efficiency

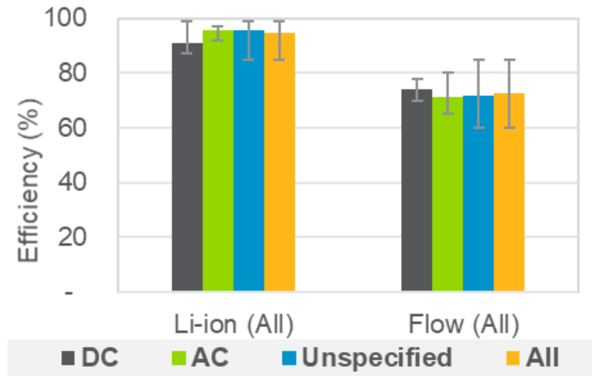
As shown in Figure 10, there is no significant difference in efficiency between the new dataset and the data presented in the 2017 report. Consistent with the 2017 report, nameplate efficiency primarily depends on technology. For example, flow batteries tend to have significantly lower efficiencies than Li-ion and a greater range of efficiency. As noted in the 2017 report and illustrated in Figure 11, uncertainties in the AC vs. DC basis for reported data do not have a significant impact on the magnitude of the nameplate efficiency.

Figure 10. Efficiency Ranges by Technology



Source: Evaluator Analysis

Figure 11. Efficiency (AC vs. DC, nameplate)

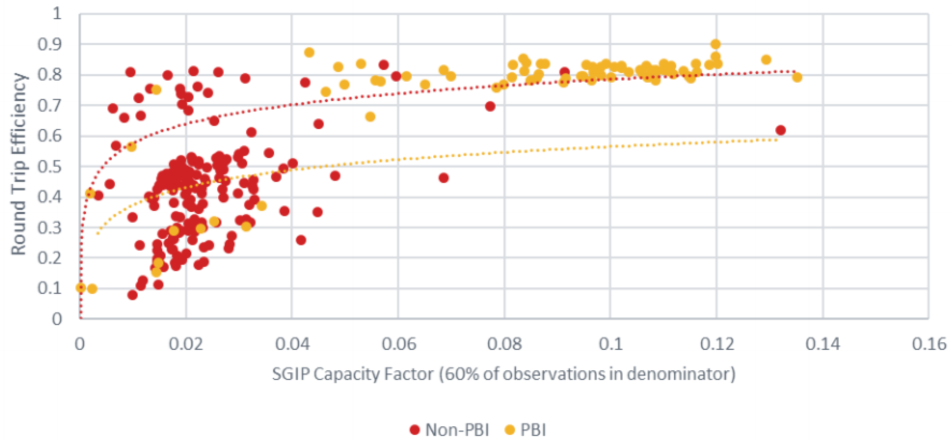


Source: Evaluator Analysis

Nameplate efficiencies, however, typically do not reflect expected standby and auxiliary losses, which drive down real efficiencies of energy storage systems. Performance data from energy storage systems funded by California's Self-Generation Incentive Program (SGIP) provides valuable data on real system efficiencies (Figure 10 and Figure 12). As shown in Figure 10, real efficiencies tend to be lower and more highly variable than nameplate efficiencies. The two key driving factors for lower system efficiencies are low capacity factor and high parasitic losses (e.g., self-discharge and powering of auxiliary components). As illustrated in Figure 12, low capacity factors generally resulted in low real system efficiencies due to a high amount of parasitic losses relative to total energy throughput. Notably, the SGIP data indicates that batteries with a Performance Based Incentive (PBI) tended to have higher capacity factors and lower parasitic loads than those without a PBI.[24]

[24] Performance-Based Incentive (PBI) is an incentive structure in which projects 30 kW and larger receive half of the incentive up-front and the remainder as annual payments.

Figure 12. Real System Efficiency vs SGIP Capacity Factor[25]



Source: California Public Utilities Commission (CPUC). 2017. 2017 SGIP Advanced Energy Storage Impact Evaluation

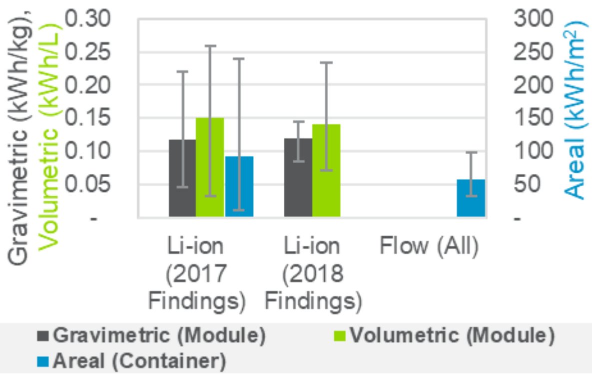
2.2.5.3 Energy Density

Assessing the new dataset that became available since the 2017 literature review was conducted for energy density yielded similar results to the 2017 report. As illustrated in Figure 13, changes in density between the 2017 findings and 2018 findings are not significant, and any variations are likely due to limited data rather than changes in performance. Both indicate that energy density depends as much on system-level design as it does on technology, leading to significant variability within a technology. For example, Li-ion battery systems tend to have higher energy density than flow battery systems, but the ranges of both significantly overlap.

As noted in the 2017 report, energy density significantly varies between cell, module, rack, and container levels. As illustrated in Figure 14, gravimetric and volumetric densities tend to decrease at each step, while areal density increases from the module to rack level, but decreases going from rack to container.

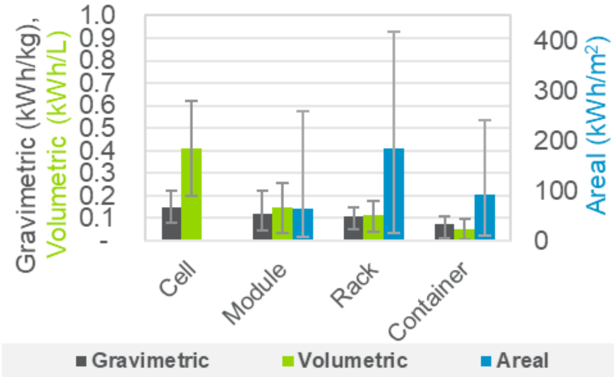
[25] Trendlines for Non-PBI (red) and PBI (yellow) appear to be erroneously reversed in the image.

Figure 13. Density (by technology)



Source: Evaluator Analysis

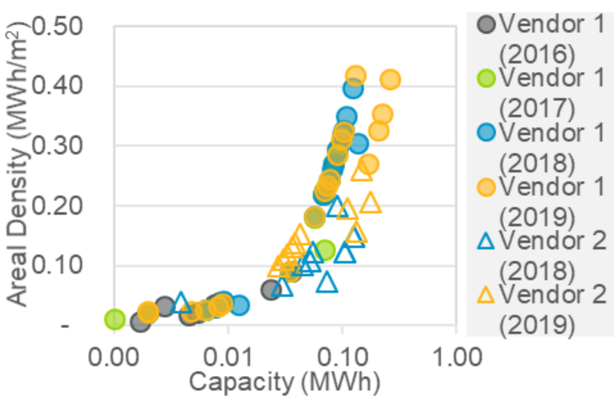
Figure 14. Density (Li-ion by basis)



Source: Evaluator Analysis

Data in Figure 15 suggest that there have not been significant improvements in energy density at the rack level over the past two years. Data from one leading Li-ion battery vendor (Vendor 1) over multiple years all falls along consistent trendlines. Another vendor (Vendor 2) appeared to demonstrate some improvements in areal density from 2018 to 2019, but it did not exceed the benchmark of Vendor 1. Thus, although some vendors may show improvement over time, the industry benchmark does not appear to be shifting significantly.

Figure 15. Areal Density vs. Size



Source: Evaluator Analysis

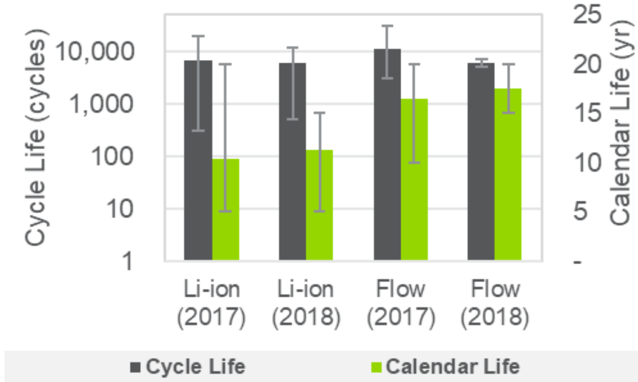
2.2.5.4 Lifetime

No significant change in lifetime was observed relative to the 2017 report, as illustrated in Figure 16. This Figure supports the observation that calendar and cycle life vary significantly within and between technologies.

Several challenges exist in evaluating lifetime:

- Limited data exists for real lifetime and system degradation from actual systems
- Lifetimes are often based on warranty period or financial life of system
- Limited information is available comparing energy augmentation to counteract capacity fade
- Limited information is available regarding whether reported cycle life is on full or partial cycle basis

Figure 16. Lifetime (by Technology and Analysis Year)[26]



Source: Evaluator Analysis

[26] Year noted in the chart refers to the year in which analysis was conducted.

3 Findings

Finding 1

Total installed average system cost and proportional percent of soft costs increased in 2018 compared to 2017. However, the evaluator acknowledges that both years' analyses are based on a limited number of respondents and may not reflect larger market trends. NYSERDA tracks operational projects in New York State and has confirmed the survey responses collected by the primary research activities are representative of the market and capture the companies implementing most projects in New York State.

Finding 2

Survey respondents were asked to provide average total cost and soft costs for their New York State energy storage projects in 2018 but did not report costs on a project-specific basis. Future evaluations should include collection of project-specific cost data by either program staff or the evaluator. This includes cost data for all projects located in New York State, such as utility-owned projects not previously surveyed, in order to most accurately reflect market evolution.

Finding 3

Updated 2018 costs are lower than projected 2018 costs presented in the 2017 report. Although rapid decline in hardware costs was observed between 2017 and 2018, the evaluators do not expect the same rate of decline to continue in the future. Future annual cost declines are expected to be similar to those observed prior to 2017.

Finding 4

System performance was generally consistent with that presented in the 2017 report. No significant change in performance and dependencies was observed. Future improvements in round-trip efficiency may be limited for Li-ion (already above 90% in many cases), though significant improvements may be possible for other technologies. Energy density improvements are difficult to observe due to a wide range of variability. Lifetime improvements will be difficult to observe unless real system data is obtained and/or typical warranty periods become longer.

Finding 5

System costs derived from the primary data collection appear to be higher than system costs derived from the literature review across all components, including hardware. This is likely due at least in part to relatively high labor costs in New York State, some of which may be built into supplier costs for hardware components, as well as more stringent requirements for permitting and interconnection, which may result in greater hardware and non-hardware costs.

4 Recommendations

Recommendation 1

For the 2020 survey, the evaluators recommend asking survey respondents for system size information (e.g., kW and kWh). and adding additional questions to better understand the breakdown of hardware costs (e.g., across battery, PCS, and BOS).

Recommendation 2

For the projects NYSERDA is funding through these efforts, the evaluators recommend defining data collection requirements and establishing terminology standards to address gaps and inconsistencies in the data. The terminology standards would help to address issues specified in Sections 2.2.4.1 and 2.2.5.1 above and enable more consistent evaluation and comparison of data (e.g., distinguishing between nominal usable energy versus total energy).

Recommendation 3

The evaluators recommend that programs focused on energy storage technologies concentrate more on driving costs down than driving performance up, given that performance parameters indirectly have an impact on cost and that the variability in performance has as much to do with system design as it does the performance of the underlying storage technology.

5 Methods

5.1 Primary Data Collection Methods

This section describes the methods the evaluator used to complete the primary data collection activities.

5.1.1 Survey Design and Data Collection

NYSERDA fielded a survey to 85 energy storage companies in February and March 2019. Due to a low initial response rate, the evaluator collaborated with NYSERDA to target key respondents for enhanced communication including email follow-up, outbound phone calls, and personal messaging via LinkedIn. The evaluator closed the survey in the second week of March. The survey instrument gathered data on the following items:

- Key selling points for DES projects
- Characteristics of DES projects in New York State
- Characteristics of each company's primary DES use case
- Percentage of DES project costs spent on hardware, engineering and construction, and soft costs
- Length of DES project sales and implementation cycles
- Differences between the DES market in New York State and other markets
- Company characteristics

Twenty-six companies responded to the survey (31% response rate) with nine companies answering all questions in the survey, including providing cost information. Several companies cited confidentiality concerns as a reason for not answering all questions in the survey. One company installed thermal energy storage projects, which the evaluator removed from the analysis due to the differences between thermal storage and battery systems. The remaining 16 companies did not install, commission, or have any projects in the pipeline with an executed contract in New York State in 2018 so they indicated that many questions were not applicable to their business.

5.1.2 Analysis

The evaluator fielded the survey using Qualtrics and downloaded the data for analysis in Excel. The evaluator conducted all data analysis, excluding all instances where missing information could not be resolved. The evaluator also excluded responses from companies that indicated they did not install, commission, or have any projects in the pipeline with executed contracts in New York State in 2018, except those related to respondent characteristics. Results were not weighted due to a concern that weighting would add additional bias.

5.1.3 Respondent Characteristics

Companies were asked what roles they filled in the energy storage market. Mirroring 2017, developer (n=14) was the most common role fulfilled by companies in 2018 followed by integrator (n=5) and manufacturer (n=5). Results are shown in Table 5.

Table 5. Company roles in energy storage market (multiple response)

Company Type	Number of Companies (2017, n=20)	Number of Companies (2018, n=23)
Developer	13	14
Integrator	8	5
Installer	8	4
Manufacturer	6	5
Sales	4	3
Financier	4	1
Distributor	3	2
Other	3	2

5.1.4 Statewide DES Projects

In addition to providing metrics on their primary and secondary use cases, energy storage companies were asked to report on all projects installed, commissioned, or in the pipeline with an executed contract in New York State in 2018. On average, companies (n=7) reported that 47% of their North American (i.e., U.S. and Canada) energy storage portfolio was located in New York State and 31% of their New York State energy storage portfolio was located in New York City.[27]

Respondents (n=7) reported that 18 total projects were installed, commissioned, or had a contract signed in New York State in 2018. The majority of reported projects (n=12) were BTM. All projects were electrochemical projects, with three lead-acid projects and 15 Li-ion projects. Thermal projects in New York City were reported by one developer; however, the evaluator

[27] These percentages are based on energy storage system capacity.

removed this data from the analysis due to the differences between thermal storage and battery systems. Nineteen companies indicated that they did not implement any projects in New York State in 2018.

Seven companies provided information on the sectors they most frequently served, with two reporting that they served the utility sector and five reporting that they served commercial facilities.

5.2 Literature Review Methods

The literature review was based on data gathered in both 2017 and 2018 analyses. Individual data points were filtered for accuracy and consistency, as described in the following sections. Due to limited data specific to New York State, the numbers are representative of national averages.

5.2.1 Sources

See Table A-2 in Appendix A for details regarding the types of data points extracted from each source.

5.2.2 Data Cleaning

The evaluators cleaned the data by excluding individual data points with unclear assumptions, limited relevance, and/or questionable accuracy. Reasons for exclusion of data include: lack of specified system duration (for cost data), not based on batteries for stationary and grid-connected systems, questionable accuracy for significant outliers, and unclear assumptions from which to interpret the scope and applicability of the data.

5.2.3 Data Selection and Trend Evaluation

The evaluators tagged and manipulated data points to provide a direct comparison between like data points. Individual data points were tagged by parameters including source, size, duration, grid location, use case, technology, component, and year. Cost data was converted to $/kW values for a specified duration. To support evaluation of cost as a function of duration, some data points were extrapolated across multiple durations (e.g., 1-, 2-, and 4-hour durations, assuming constant $/kW cost for PCS and constant $/kWh cost for batteries). If the grid location was not specified, it was assumed, as appropriate, to be based on utility-scale data. In some cases, calculated values are based on a limited number of data points when applying multiple filter criteria (e.g., duration, technology, component, year, and grid location).

The evaluators calculated costs by duration based on the costs of individual components as a function of duration. Where insufficient 2018 data was available, cost data from 2017 and 2019 were considered as well. PCS costs were assumed to be independent of duration. Li-ion battery costs were assumed to scale only with energy for systems less than 1 hour, which excluded the cost of high performing batteries such as lithium iron phosphate (LFP) and lithium titanate oxide (LTO). For battery costs of 15-minute and 30-minute systems, LTO and average cost for LTO and standard Li-ion chemistry were assumed, respectively. Soft costs were calculated based upon the difference between total installed costs and sum of all component costs, based upon the premise that EPC component costs may not include all soft costs. The range for soft costs provided in Figure 8 is based upon the same relative range as for total costs (Figure 1), given that total costs demonstrated more significant variability than any component, and soft costs are expected to have a relatively high range of variability in comparison to other components.

Performance data was generally assumed to be nameplate unless otherwise specified. Areal density data includes only the direct footprint and does not include necessary clearances, which can further reduce the effective areal energy density.