# Energy Storage Cost Summary for Utility Planning: Executive Summary

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# Abstract

This an executive summary of a report that was prepared as a utility resource for planners and others involved in evaluating energy storage. As grid-connected energy storage installations transition from the demonstration phase to commercial deployment, it becomes increasingly important to understand the cost and valuation of storage. This is especially true when comparing to conventional generation or “wires-based” alternatives. This report provides projected installed costs for energy storage systems assuming installation and start of commercial operation in 2017 and discusses various cost metrics used for storage and their applicability. Additionally, this report illustrates importance of pre-determining energy storage value as well as cost. Due to a multitude of energy storage sizes, locations, and uses, comparisons based on simplified duty cycle assumptions have potential to mislead planners and investors.



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# Table of Contents





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# Description of Contents

This cost summary was developed to support utility resource planners in their understanding of energy storage costs, cost metrics and provide a brief introduction to valuation. This executive summary includes the following section and contents:

- **Cost Methodology** – The scope of the cost study is to provide installed cost for technologies with commercial deployment track records. This section describes the technology section and data collection process. Additionally, since energy storage is an energy limited resource unlike conventional generation, there is some discussion to highlight that costs can not simply be communicated on a $/kW or $/kWh basis for a given technology, the power and energy rating must be factored in.

- **Cost Results** – This section includes total installed costs contemplating project configurations for the various technologies and an example of a detailed breakdown of lithium ion system costs that were also collected in this study. The costs are based on a 2017 reference year for installation. Future cost projections (beyond 2017) were not included in this study, but EPRI research in both the energy storage and transportation programs, indicate that battery and system costs will continue to decrease in the next few years.

- **Cost Metrics** – There are several different cost metrics used in evaluating energy storage. This section contains an overview of those metrics and their applicability.

- **Cost-Benefit Analysis** – This section presents an example of cost-benefit analysis for a resource adequacy or capacity use case with the key message that cost is only one part of the equation and benefits must be included for a complete evaluation.





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# Cost Study Methodology

Description and discussion of approach to generate current energy storage cost estimates



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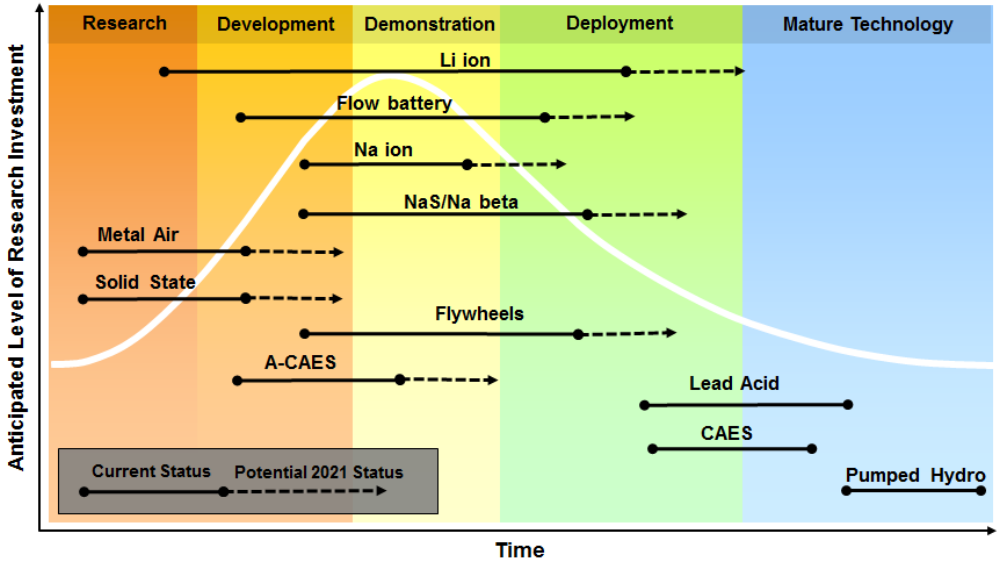
# Technology Selection for Cost Study

- To support depth of analysis, technology scope was limited.
- Technologies were prioritized based on the following criteria
  - Maturity of technology and derivative products
  - Substantial recent changes in cost/price due to recent technical or business developments
- Selected Technologies:
  - Compressed Air Energy Storage (CAES)
  - Pumped Hydro
  - Lead Acid Batteries
  - Lithium Ion Batteries
  - Sodium Sulfur (NaS) Batteries
  - Flywheel





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# Scope of Energy Storage Costs Considered

- Scope consistent with other technologies included in EPRI Technology Assessment Guides, except contingencies are not included [1]
- Energy Storage Integration Council (ESIC) Cost Tool and Template was used to identify scope of installation costs. [2]
  - Tool was developed to provide exhaustive list of project cost components and help facilitate clear communication in a request for proposal/quote
  - Screen shot shown to right shows this project scope (i.e. inclusions/exclusions).
  - Not all cost items in the template are shown. Operations and Maintenance, replacement, and other recurring costs were not included in this study.

| Cost Line Item | Cost Input Options |
|---|---|
| **Total Project Development** | **Excluded** |
| Project Development Oversight | |
| Site Selection | |
| Permitting - Land Use | |
| Power system feasibility / interconnection study (e.g. WDAT, Rule 21) | |
| Specification Development | |
| Solicitation Development | |
| Proposal Evaluation, Negotiation, & Contracting | |
| Other Project Development Costs | |
| **Total Energy Storage Product** | **Included-Not Itemized** |
| Battery / Energy Storage Medium | |
| Power Conversion System (PCS) | |
| Control Software | |
| Control Equipment | |
| UPS & Other Electronics | |
| ESS Thermal Management System | |
| Pre-Engineered ESS Structural Components (e.g. containers & racks) | |
| Security Equipment | |
| Safety Equipment (e.g. fire suppression) | |
| Other ESS Purchases | |
| **Total ESS Shipping** | **Included-Not Itemized** |
| **Total Project Management** | **Included-Not Itemized** |
| **Total Engineering Study** | **Included-Not Itemized** |
| **Total Grid Integration Equipment** | **Included-Not Itemized** |
| Transformer(s) | |
| Protection Equipment | |
| Switchgear | |
| Other Integration Equipment | |
| **Total Metering & Telemetry** | **Included-Not Itemized** |
| **Total Grid Integration Site Manager Software Purchase & Certification** | **Included-Not Itemized** |
| **Total ESS Data Storage Computer & SCADA Software or Data Historian** | **Included-Not Itemized** |
| **Total Site Installation** | **Included-Not Itemized** |
| **Total ESS Installation** | **Included-Not Itemized** |
| **Total Commissioning and Acceptance Testing** | **Included-Not Itemized** |
| **Total Training** | **Included-Not Itemized** |
| **Total Upfront Financing Fees** | **Excluded** |
| **Total SG&A** | **Included-Not Itemized** |
| **Total Upfront ESS Program Costs** | **Excluded** |





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# Data Collection Approach and Process

- Initial cost ranges developed by EPRI project experience and previous studies. Ranges refined by industry input from ESS vendors, integrators, developers, and general contractor/engineering, procurement and construction firms.
- Detailed lithium ion estimates were obtained for three example use cases. These were used to validate associated summary ranges and provided further insight to the break down of project costs by major component/category.
- Pumped Hydro estimates are based on a 2010 EPRI Study [3] and escalated by 2% per year
- CAES estimates were validated internally within EPRI by subject matter experts with experience deploying CAES systems




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# Scaling Factors for Energy Storage Costs

- Installed costs for energy storage scale two dimensions:
  - Power-related costs ($/kW or $/MW) scale by the rated capacity of the storage plant, similar to conventional generation
  - Energy-related costs ($/kWh or $/MWh) scale by the size of the energy storage reservoir.
- Total cost ranges therefore depend on the scale of the energy storage in each dimension as well as variations in site-specific costs.
- Expression of costs on a $/kW basis is preferred for improved comparison with other generation options for integrated resource planners. However, to highlight the impact of scale, in both power rating and energy rating, different project reference sizes are presented to incorporate impacts of power- and energy-related scaling factors.
- System sizes selected for study are based on similar-sized projects that have been built recently or are under current development, in order to access more up-to-date data than are available at present for other technologies. Also, sizes help to provide some comparative insight on how duration impacts costs.




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# Summary of Cost Results

Cost ranges and illustrative examples for energy storage technologies


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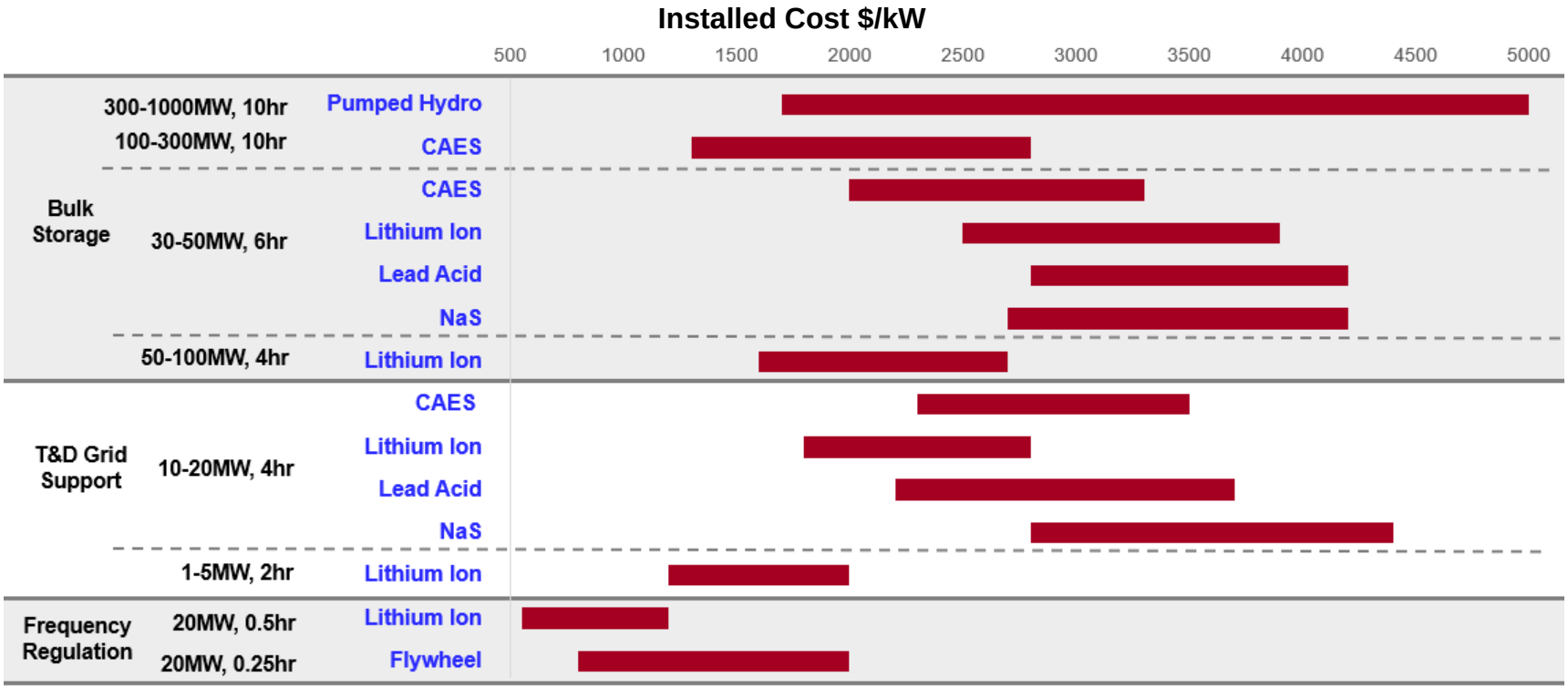
# Energy Storage Installed Cost Summary: 2017




- Costs are for 2017 installation reference year only and assumes overnight installed costs.
- Suppliers and publicly available studies indicate continuing trend of cost decline for battery-based storage technologies, particularly lithium-ion.
- Installed costs exclude land costs, owners costs, and contingency. Detailed list of inclusions and exclusions is provided in previous section.
- Average is not necessarily mid-point of the range





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# Energy Storage Installed Cost Summary: 2017

| Application | Technology | Rating (MW) | Duration (hours) | 2017 Cost ($/KW) |
|---|---|---|---|---|
| Bulk Storage | Pumped Hydro | 300-1000 | 10 | 1700 - 5100 |
| | CAES | 100-300 | 10 | 1300 - 2800 |
| | CAES | 30-50 | 6 | 2000 - 3300 |
| | Lithium Ion | 30-50 | 6 | 2500 - 3900 |
| | Lead Acid | 30-50 | 6 | 2800 - 4200 |
| | NaS | 30-50 | 6 | 2700 - 4200 |
| | Lithium Ion | 50-100 | 4 | 1600 - 2700 |
| T&D Grid Support | CAES (Above Ground) | 10-20 | 4 | 2300 - 3500 |
| | Lithium Ion | 10-20 | 4 | 1800 - 2800 |
| | Lead Acid | 10-20 | 4 | 2200 - 3700 |
| | NaS | 10-20 | 6 | 2800 - 4400 |
| | Lithium Ion | 1-5 | 2 | 1200 - 2000 |
| Frequency Regulation | Lithium Ion | 20 | 0.5 | 550 - 1200 |
| | Flywheel | 20 | 0.25 | 800 - 2000 |


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# Breakout costs for Lithium Ion

- Lithium ion costs were further broken down into the costs of major system components
  - ESS Product includes the battery, PCS, control software, ESS thermal management systems, ESS safety systems, pre-engineered racks and containers
  - Site and Grid Integration encompasses remaining costs such as grid integration equipment, installation, engineering and project management
  - Fees, General and Administrative (G&A) costs were assumed to be 10% of total project cost. This is based on typical Fees and G&A included for other technologies in the Technology Assessment Guide [1]
- Example cost in the table are based on a 20MW, 4 hour system
- Additional breakouts of balance of plant costs and full breakout costs for 2MW, 2 hour and 20MW, 0.5 hour lithium ion systems are included in the full report [4]

| Technology Description | | Li-ion |
|---|---|---|
| Rating | MW | 20 |
| Duration | Hours | 4 |
| Commercial Start Year of Service | Year | **2017** |
| ESS Product | $/kW | 1420 |
| ESS Shipping | $/kW | 645 |
| Grid Integration Equipment (up to high side of step up transformer) | $/kW | |
| Metering and Telemetry | $/kW | |
| Grid Integration Site Manager Software Purchase and Certification | $/kW | |
| ESS Data Storage Computer and SCADA Software or Data Historian | $/kW | |
| Site Installation | $/kW | |
| ESS Installation | $/kW | |
| Commissioning and Acceptance Testing | $/kW | |
| Project Management | $/kW | |
| Engineering Study | $/kW | |
| Training | $/kW | |
| Project Development | $/kW | not included |
| Extended Warranty Option | $/kW | not included |
| Upfront ESS Program Costs | $/kW | not included |
| **Subtotal Installed Plant Cost** | **$/kW** | **2085** |
| Tax for ESS Product and Grid Integration Equipment (7%) | $/kW | 145 |
| Fee and G&A (10%) | $/kW | 210 |
| Process Contingency | $/kW | not included |
| Project Contingency | $/kW | not included |
| **Total Installed Plant Cost** | **$/kW** | **2440** |





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# Cost Metrics

Discussion of metrics and applicability for expression and comparison of energy storage costs



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# Metrics Used for Storage Cost Comparison

There are currently several metrics for measuring the cost of energy storage systems. Due to the distinguishing characteristics of energy storage relative to traditional generation, it is important to understand the various cost metrics and the scenarios under which it would make sense to apply them. The table below provides a summary of the commonly-used cost metrics and their broad applications.

| Metric | Expressed as: | Applications and *caveats:* |
|---|---|---|
| **Installed Cost** | $/kW | Comparisons with reliability-based capacity resources, such as CT<br><br>Used as an input to more-detailed cost-benefit analyses |
| **Levelized Cost of Capacity** | $/kW-Year | Primarily used for comparing to reliability-based capacity resources, such as CT<br><br>Cost of New Entry (CONE) assessment |
| **Present Value of Life-cycle Costs** | PV $/kW<br>or<br>PV $/kWh | Used for storage technologies, typically not for conventional generation<br><br>Compared with PV of revenue for cost-benefit evaluation<br><br>*Specific to a given technology and use case and not for direct comparisons with alternatives.* |
| **Levelized Cost of Electricity (LCOE)** | $/MWh | Used to normalize generation cost between different installed costs and capacity factors.<br><br>Primarily of interest for energy resources such as baseload fossil generation<br><br>*Misleading for energy storage because storage is not a net energy producing device, and LCOE does not capture the value of storage capacity and flexibility.* |





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# Metrics (Continued)

***Installed Cost ($)*** includes all equipment, delivery, installation, interconnection and step-up transformers. This metric assumes a site is available; so does not include the cost of land or project planning costs. It does not account for ongoing costs, replacement costs, or any income or benefits obtained from storage.

***Levelized Cost of Capacity*** is a lifecycle measure of fixed and variable costs. The objective is to identify a value for the revenue per kW of capacity that the generator needs to produce, on a time-discounted basis, to cover those lifecycle costs. For storage, the variable costs include off-peak charging costs which may change over time. Consistent with usage when applied to conventional generation, this metric does not incorporate any benefits or revenue obtained from storage operation.

***Present Value of Life-Cycle Costs*** similarly accounts for fixed and variable costs over time. This metric includes installed costs, ongoing fixed O&M, variable O&M, and replacement equipment costs (including battery replacement) over the useful life of the plant. Costs are aggregated over time in present-value terms, using the selected discount rate. The resulting total present-valued cost is then divided either by rated output (kW) or by estimated total lifetime energy generation (kWh). Again, the variable costs include off-peak time-varying charging costs but do not incorporate any benefits or revenue obtained from storage operation. ESIC's Cost Tool provides this calculation in $/kWh terms and refers to the metric as Total Cost of Energy Storage (TCOES). [2]

***Levelized Cost of Electricity*** **(LCOE)** is the cost per unit of energy delivered, defined formally as the present value of all costs over the life of a project (including initial capital costs, all operational costs including fuel and O&M, and disposal costs) divided by the total energy delivered over the life of the project, and has units $/kWh or $/MWh delivered. "Present value" means that costs accrued and energy delivered in future years are "discounted" into present day equivalent values. LCOE is a simple and attractive metric when operationally equivalent generation technologies are being compared and when the only value under consideration is the delivered energy.





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# Cost-Benefit Analysis

Discussion of value and “net cost” considerations



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# Comparison of Net Cost of Capacity

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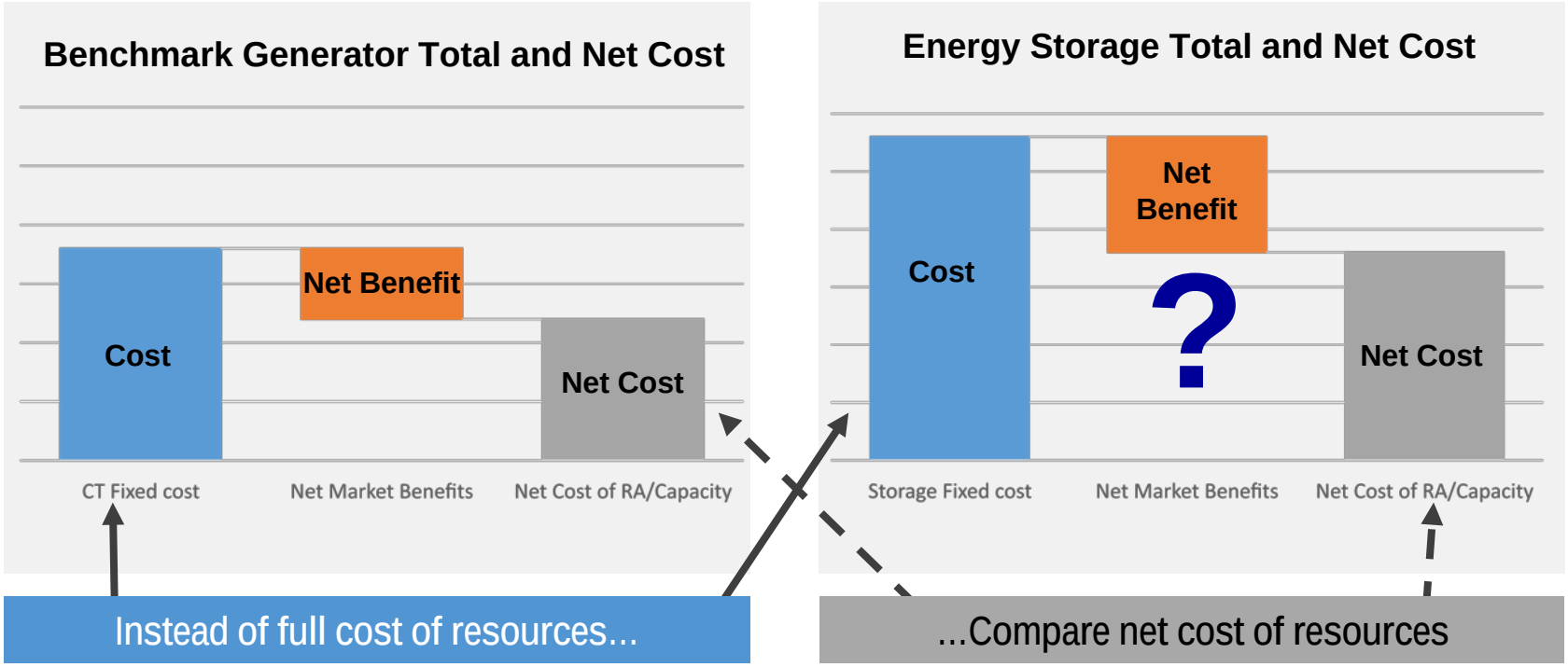


- When analyzing the economics of an energy storage plant, it is important to understand not only the upfront installed costs, but the net market value. Energy storage differs from conventional generation in operating cost and market benefits. New tools are required for storage valuation.
- The economic analysis needs to capture costs and benefits during charging and discharging and also the multiple services an energy storage plant can provide to the grid: consuming and storing relatively low-cost (i.e., off-peak) electricity, displacing higher-cost (i.e. on-peak) generation, providing ancillary services, and supporting grid resiliency and security.

**Cost of new capacity is full installed cost net lifetime operational benefits**





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# EPRI publicly available resources for further information on benefit and cost analysis for energy storage

- Storage Value Estimation Tool (StorageVET™) [forthcoming December 2016, more information at www.storagevet.com]
- "Cost-Effectiveness of Energy Storage in California." [EPRI 3002001162]
- ESIC Cost Template and Tool [EPRI 3002006072]




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# Full Report Forthcoming

*Energy Storage Cost Summary for Utility Planning*. EPRI, Palo Alto, CA, 2016. 3002008876.

For more information visit www.epri.com



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# References

[1] *Technical Assessment Guide (TAG®)-Power Generation and Storage Technology Options: 2012 Topics.* EPRI, Palo Alto, CA: 2013. 1024063.

[2] *Energy Storage Cost Template and Tool: Guidelines Developed by the Energy Storage Integration Council for Distribution-Connected Systems (ESIC Cost Tool) v1.0*, EPRI, Palo Alto, CA 2016. 3002006072.

[3] *Electric Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits.* EPRI, Palo Alto, CA, 2010. 1020676.

[4] *Energy Storage Cost Summary for Utility Planning*. EPRI, Palo Alto, CA, 2016. 3002008876.



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