DYNAMIC GRID

A New Storage Metric

Independent Levelized Cost
Of Storage

Comparing Technology: Performance of your next Energy Storage Project

Energy Storage System (ESS) technology choices are markedly different for a peak shaving or solar shifting application. There are many questions to ask about your storage project; how much? How long? How fast? And how deep? Common applications today include:

- **Demand Side Management/Peak Reduction:** Use energy storage to reduce electricity demand during peak demand periods to limit demand charges.
- **Fast Response Frequency Regulation**: Manage system frequency with tolerances on the grid for power quality purposes.
- **Electric Service Reliability/ Resilience:** Provide backup power during outages, including integration with distributed generation sources.
- **Renewables Firming:** Use energy storage in tandem with intermittent wind or solar to provide a steady power supply.
- **Transmission/Distribution System Deferral**: Defer and or reduce new distribution capacity by reducing peak system loads.
- **Energy Arbitrage:** Purchase low-cost off-peak electricity, charging the storage, so that stored energy can be used or sold at a later time when the price of purchased electricity is high.
- **Microgrids:** The use of dispatchable and non-dispatchable generation with

energy storage to produce stable energy for distribution to a local set of loads.

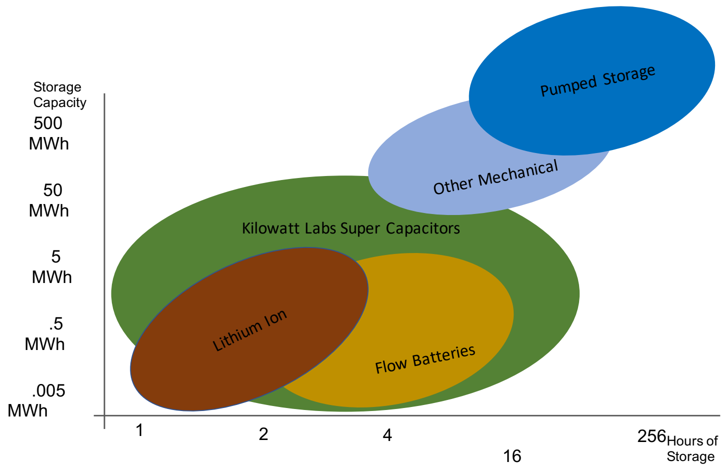
- **Off-grid systems:** Systems that are not connected to a utility grid fully powered by distributed energy, typically in remote or isolated areas.

Technology Choices

There are four major technology options to consider. The first is the electrolyte chemistries that include the five main lithium-Ion types (Lithium-Nickel Manganese Cobalt [NMC], Lithium-Iron Phosphate [LFP], Lithium Titanate [LTO], Lithium-Cobalt [LCO], Lithium Manganese [LMO) and the zinc hybrid technologies. The second type is the class of the various redox flow batteries (Iron, vanadium, bromide, and sodium). The third option is mechanical energy storage such as pumped hydro, compressed air and flywheel, and the fourth, are the electrostatic technologies such as supercapacitors.

For the different options described above, the answers to the questions of (how much, how long, and how fast) drive the asset choice and, in turn, determines the Levelized Cost of Storage (LCOS). While revenue or cost savings can vary and potentially make any ESS profitable, the first decision should focus on matching the application to the right ESS and determining the lowest cost system providing the needed services to the project.

For applications requiring shorter-term (<3 hours) energy storage such as demand management frequency regulation, reliability requiring storage under 4 hours, and minimal depth of discharge, lithium-ion technologies have certain advantages, including reliability and significant



commercial knowledge. However, they also have considerable disadvantages, including flammability and limited cycle life.

Historically mid-term (2 to 8 hours) energy storage applications such as renewables firming and distribution system deferral could utilize either the electrolyte or redox flow technologies.

Longer-term (over 6 hours) energy storage applications like energy arbitrage, microgrids, and off-grid systems are best served by more extended duration storage technologies with choices like redox flow and other emerging technologies.

Emerging Technology

New technology, just now being commercialized for energy storage applications, has significant implications for energy storage choices. Supercapacitor energy storage, to date, has been hampered by disadvantages like higher density and self-discharging that made them poor choices for grid energy storage. Today, with new advances in electronics and battery management systems, supercapacitors, like **Kilowatt Labs** can compete favorably in most applications. Their lifespan of greater than 40 years often makes them a financially advantageous choice. The following use case compared multiple ESS choices and found surprising results.

Use Case Independent LCOS

There has been an increasing number of LCOS studies, but there is not yet a common definition of this metric. Some studies neglect certain costs like replacement or disposal, while others exclude performance parameters, such as degradation. Most include revenue in the metric, making the LCOS highly dependent upon the use case and the cost of power into and out of the system. While the final choice of using storage or not is dependent upon the Net Present Value (NPV) of the system, making technology choices based upon the number does not inform the designer of the **cost efficiency** of transferring and storing electrons in an energy storage system independent of the use case. The key here is value engineering a project for the entire asset lifetime of the project, not just the investor's investment lifetime, which can be quite different.

There are challenges in expressing the levelized cost of stored electricity (LCOE) in a single measure. This is because traditional LCOS is dependent on economical storage characteristics and, unlike for the traditional LCOE, also depends on temporal characteristics of the electricity price profile for the energy being loaded into the storage. There are many cases where an analysis that includes revenue and not degradation will result in a poor selection or one that has positive cash flow but is not the best choice.

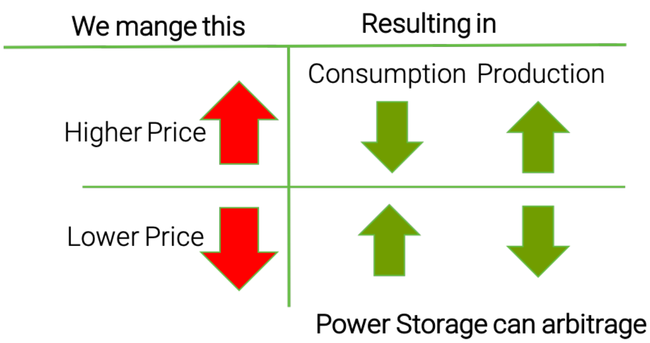
The Independent Levelized Cost of Storage (iLCOS) method accomplishes two things. One it pulls revenue out of the equation and only looks at the technological and performance characteristics of storage technology. Two, it looks at how our LCOS changes over time-based upon the different stakeholder perspectives and their view of the asset lifetime. So early in the lifetime of the asset, the LCOS (cost/energy throughput) may be increasing due to performance degradation of the storage asset but later will decrease. This method makes these changes clear graphically. The equation used is as follows.

$$\mathrm{LCOS}_t = \frac{\sum_{t=1}^{N} \mathrm{cost}_t}{\sum_{t=1}^{N} \mathrm{throughput}_t}$$

The method used here quantifies the discounted cost of discharged electricity (kWh) over the lifetime of the project but yearly. This is done to understand the differing viewpoints of system costs between the financier who may only have a 5-6-year window and the owner who may have a 25 to a 40-year view of the project. Because the storage system is financed (assumed rate of 10%), the project LCOS is high early in the project's lifetime because the fixed cost of purchase is amortized over limited amounts of discharged electricity. As energy storage is used more extensively, the LCOS decreases, and the value of long-life energy storage technologies are more pronounced.

Example: Isle au Haut Microgrid

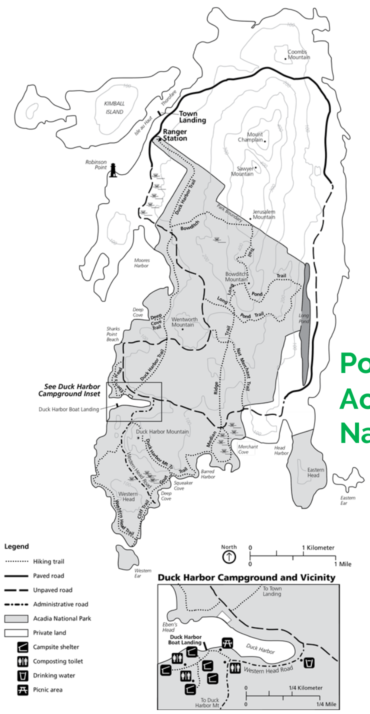
The proposed use case iLCOS analysis was done in the performance evaluation of various energy storage technology choices for a microgrid for the Isle au Haut (Maine) Electric Power Company. Power for Isle au Haut (IaH), Maine is supplied by an aging seven-mile undersea cable. Anticipating cable failure, the power company assessed many alternatives and concluded that migrating to a near-total reliance on solar is by far their best option. Peak electricity demand occurs in the summer when the island's population is largest. But, a solar project designed to match this seasonal pattern will generate excess power in the winter. Key aspects of the plan called for the installation of active demand-side management, air-to-water heat pumps with thermal storage using excess solar production at optimal times, and energy storage capacity of shifting daytime solar to nighttime, making a microgrid that meets 100% of the island's needs.



The Isle au Haut microgrid uses real-time pricing signals and controls to turn heating loads into a flexible (active) demand **resource that responds to changes in the abundance or scarcity of power**. This integrated solution uses Air to Water (A2W) heat pumps with thermal storage and machine learning algorithms allowing the heat pumps to respond, very flexibly, to a real-time Economic Dispatch Value signal (EDV), or in other words the value of electrical power at that moment. This thereby enables the load to follow the renewable generation power curve. When solar and wind production is high, A2W heat pumps "soak" up the extra renewable energy by heating thermal storage tanks located within the buildings, **reducing the necessary energy storage capacity** of the microgrid.

In conjunction with the active demand management features in the microgrid, the system engineering design was optimized, modeling the financial performance over the entire life of the deployed assets. This provided detailed estimates for the LCOS for the many energy storage choices.

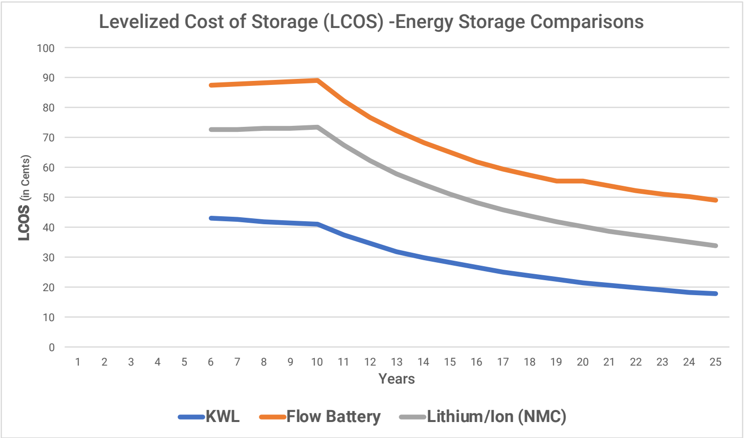
Levelized Cost of Storage



Portions of Acadia National Park

In this application at Isle au Haut, the storage system must move solar demand from midday to nighttime. This requires nearly 100% charge/discharge cycles every day, making the number of storage cycles and storage degradation (how quickly does the storage device lose capacity) very important considerations.

The comparison of the three technologies is shown here. Kilowatt Labs was a 500 kWh supercapacitor storage system that allows 100% Depth of Discharge (DOD) and the ability to cycle for as much as 1 million cycles. The flow battery was an Iron Phosphate redox battery that was sized at 800 kWh (standard size of this product). The Lithium-Ion system was produced by a major international manufacturer and consisted of 1000 kWh of Nickel-Manganese-Cobalt type. The system operation and sizing were optimized for each storage system, although the Lithium system was a bit oversized due to manufacturer size restrictions/inverter choices.



The iLCOS metric is not designed to calculate the value of particular storage technology in a specific use case but be able to compare storage technology based upon overall performance factors within classes of use cases. In this case, the long-term iLCOS over a 25-year project life the Flow Battery costs 49.2 cents per kWh, the Lithium-Ion 34.1 cents per kWh and the Super-capacitor is at 17.9 cents. If you include the revenue from that battery usage, all three technologies could be a good investment for this particular project.

Summary

The selection of the proper storage technology for a given project is a delicate balance of many factors, including revenue from the storage of energy. This analysis for LCOS provides a use case-independent metric for comparing the cost of transferring electrons in and out of the storage independent of revenue obtained by that transfer.

The analysis also determined on a use-case independent basis that the super-capacitors storage system developed by Kilowatt labs is a clear technology winner in most instances.

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