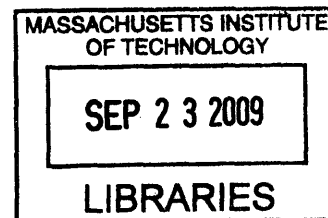


Status of Grid Scale Energy Storage and Strategies for Accelerating Cost Effective Deployment

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Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Engineering and Management
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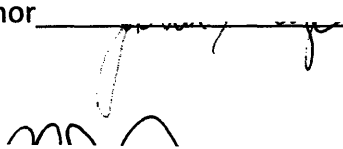
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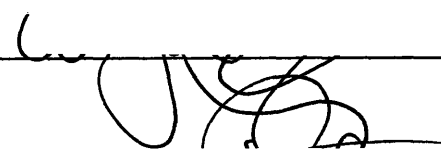
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Abstract

The development of emerging grid scale energy storage technologies offers great potential to improve the architecture and operation of the electrical grid. This is especially important in the face of increased reliance on clean, dependable electricity and with the influx of renewable generation and smart grid technology. However, at the present, grid scale energy storage is still in an early, developing stage.

This document brings together a broad overview of the sector, including rough revenue estimates for each individually possible application for energy storage, a high level overview including rough cost estimates of each technology and supplier, a more focused look at the actual or possible implementations in the market with rough estimates of the systems' economics in each implementation. Following this is a discussion of notable dynamics and potentially effective strategies, based on current industry conditions and existing academic management frameworks. The investigation was accomplished by leveraging prior research in existing literature, and extending it with first hand discussions with industry leaders and market analysis.

It was found that the economics of wholesale load shifting are unattractive for any of the emerging energy storage technologies, but that all of the other higher value implementations considered could be reasonably expected to at least break even financially given proper circumstances and the use of an energy storage technology which suits the implementation well. It was found that lithium ion and zinc-bromine flow batteries are well positioned for near term economically beneficial deployment on the grid. Many other technologies exist and are being developed to address these same markets, but are unlikely to be cost effective in the near term. It was also found that government regulation has played and will continue to play a major role in the deployment of energy storage on the grid.

Thesis Supervisor: Michael Davies
Senior Lecturer, Sloan School of Management

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1. Introduction and Motivation

The development of the modern electrical grid is one of the most impressive accomplishments of the 20th century. Its physical scale is incredible, stretching to most corners of the developed world and much of the developing world. It has become so ubiquitous and reliable in developed areas that it is hardly even considered until it is unavailable, as has been the case in major blackouts. One recent example of a region totally paralyzed due to loss of electricity was during the Aug. 14, 2003 blackout which affected power from Detroit to New York City to Toronto. The synchronization of its many interconnected parts over widely distributed areas creates great complexity but has been effectively managed by a web of interrelated organizations and companies.

However, the modern grid is still largely based on the original design which Westinghouse and Edison fought over in the late 1800's, and not designed for modern electrical loads, emerging distributed energy sources or optimal efficiency. Power quality is widely variable and, while acceptable for simple early devices like incandescent lights, the complex and demanding applications of the modern age require much higher quality, more stable power. Grid operators are unaware of blackouts until they receive a phone call from the victims due to the "open loop" control architecture of the grid. The grid is designed for central power plants to generate electricity and distribute it to distributed loads, without effective mechanisms in place to manage additional electricity injected into the grid at distributed locations. Energy produced must equal energy consumed at all times, adding to grid complexity, reducing efficiency and creating challenges to large scale adoption of renewable power sources, like wind and solar. Utilities only offer simple pricing models, frequently for consumers simply a constant rate at all times, which cannot exploit market forces to influence customer behavior and create efficiencies in the grid's operation.

Major steps need to be taken to modernize the grid including the implementation of a "smart" grid network to enable better management of grid assets and to incorporate mechanisms which improve the grid's capability to utilize power from non-dispatchable, distributed sources, like wind and solar, while improving quality of service for end users. Though early efforts at implementing aspects of a "smart" grid have already commenced, more work needs to be done.

This document will focus on one specific mechanism to improve the grid by allowing better integration of non-dispatchable, distributed power sources, and improving efficiency and quality of service. That mechanism is electrical energy storage. Energy storage is particularly interesting because there are many possible important applications on for it on the grid and there are a many widely differing technologies competing for use.

One energy storage technology, the electrochemical battery, has been the focus of a surge in development and commercial success in recent years, beginning with Lead Acid, NiCd, NiMH and Li Ion cells used in portable electrical devices and, more recently, descendants of these cells beginning to be used for driving energy in transportation. Recent development on a number of types of batteries which pump active material through a reaction chamber, instead of containing it all in a traditional cell, have

shown the potential to offer a useful set of capabilities as well. A number of other technologies are also being developed. Large banks of batteries for use on the grid are also being created to enable the many benefits previously discussed. This document will discuss potential applications for energy storage on the grid, technologies competing for use in these applications, how energy storage systems can be best implemented on the grid and make observations on strategies for accelerating the implementation of energy storage on the grid.

2. Individual Functions/Markets

Applications and markets will be discussed first because the widely varying requirements for applications will color the following discussion. It also presents the problem in a more “market pull” oriented light which offers a helpful mindset shift from a topic as technical as energy storage. Clayton Christensen and David Sundahl discussed the merits of a similar product marketing strategy which they referred to as hiring the right product to get the job done¹. In this way the customer identifies with the job they have to do and seeks a product that best fits it. This strategy is useful with energy storage on the grid because it focuses the discussion on ways in which energy storage can directly add value.

For each class of application, there are a number of specific applications mentioned; these vary between energy focused and power focused applications. This distinction is clearly delineated because it defines one of the most useful metrics for identifying applications with fundamentally similar physical activities and technical requirements. For many of these applications, a number of separate applications could be underway at the same energy storage unit. After a review of a number of ways to categorize applications, including those used by EPRI-DOE, ESA, Sandia, Baxter, NYSERDA and Kirby, the system from NYSERDA’s 2007 report was chosen because of its precision for independently identifying each primary cash flow source and making an estimate of it, for breaking down all the applications into sensible distinctions between power and energy applications, and for breaking down applications into major types including utility, end-user or renewables. The explanations in this section are based on that report.

To offer more context for the discussion of each application, Figure 1 is a graphical overview of the electrical grid. There are 4 main components, Generation, Transmission, Distribution and Customers. Figure 2 shows the same information in as value chain block diagram, which will be reused later in this document for graphically referencing what part of the value chain is relevant to an implementation.

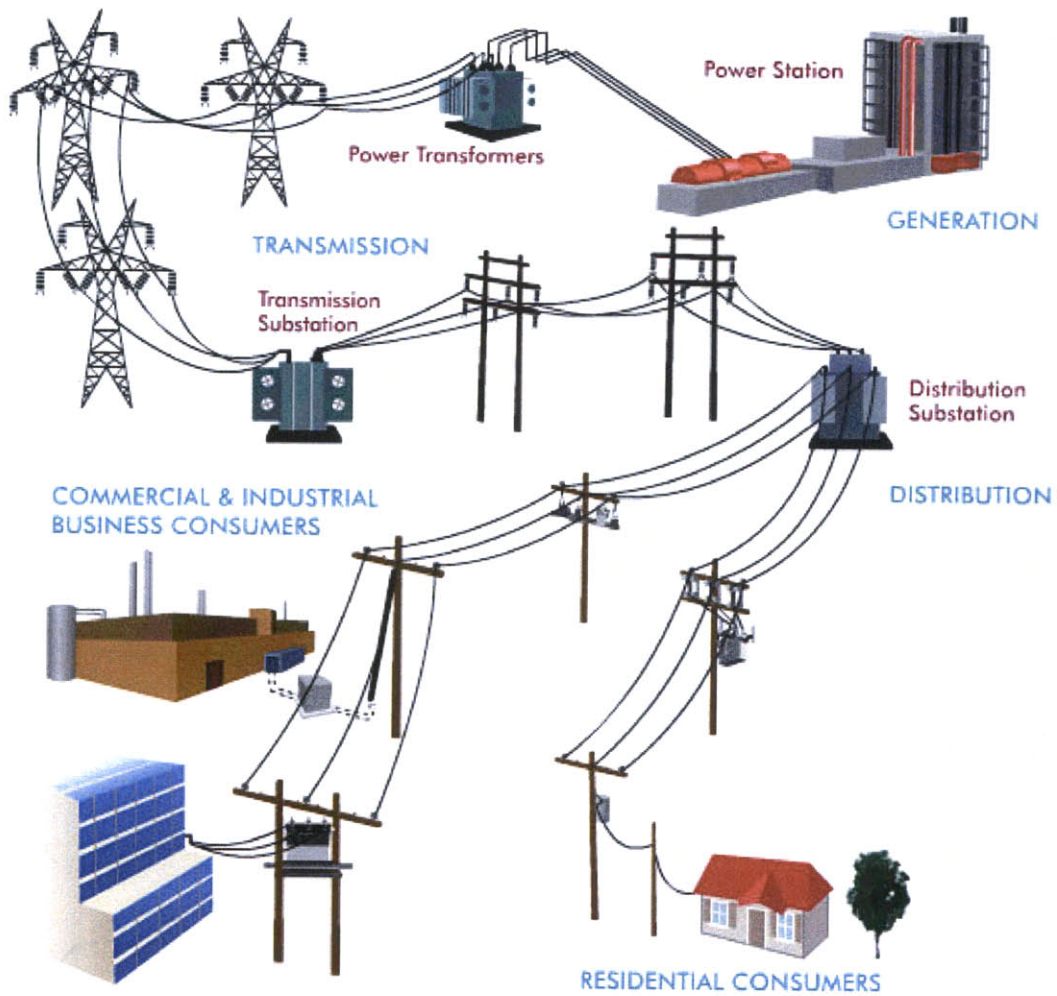


Figure 1: Electrical Grid (Oncor)

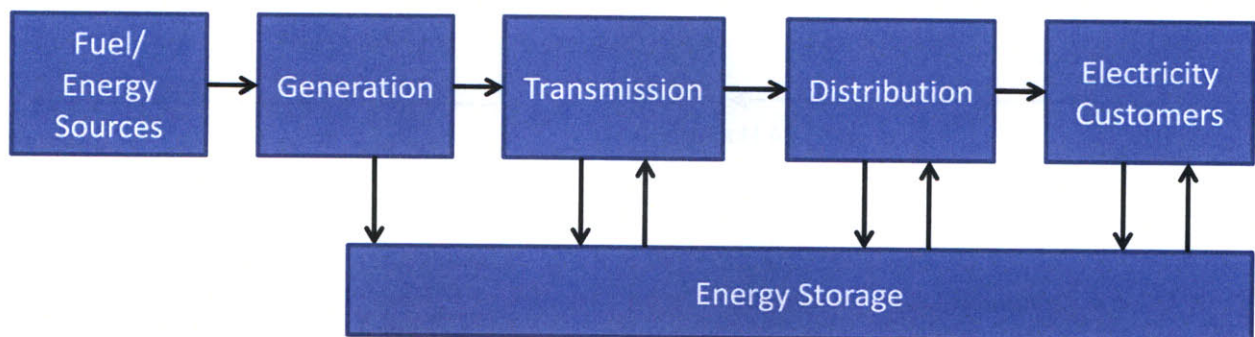


Figure 2: Electricity Value Chain

2.1. Utility Oriented Energy Applications

2.1.1. Bulk Electricity Time Shifting

This application refers to storing a large amount of low cost electricity during off peak times and delivering it back to the grid during peak times when higher rates can be charged. Alternatively, it can be viewed as powering peak load during the day with stored energy and making the electricity for that load at off peak times, basically shifting some of the peak load to off peak times. This increases the utilization of power plants, reduces the need for large capital expenditures on additional power plant generation capacity and allows existing plants to run at higher efficiency operating conditions for more time. The energy storage operator could enter into forward day ahead or real time hourly electricity contracts to sell the power from the off-peak to the peak times.

Since this application is only discussing balancing system level loads and not localized ones, the location of the energy storage in this application is not part of the value creation, so it could be sited near the load, near the generation or anywhere between. See Figure 3 for a graphical depiction of load time shifting.

Synergistic applications could include, depending on location and operation strategy, T&D deferral, reduce transmission congestion, reliability, PQ or ancillary services.

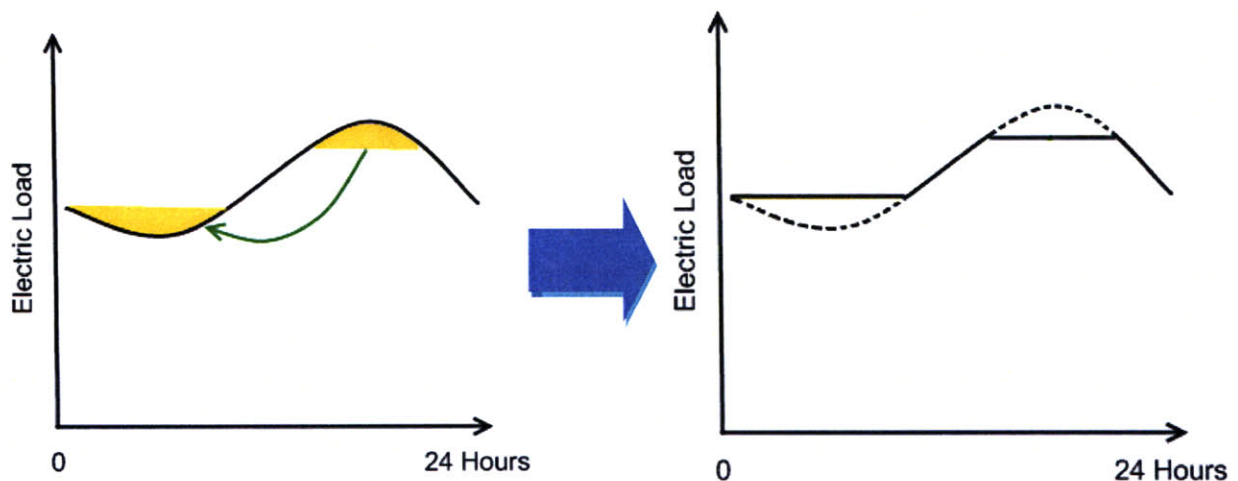


Figure 3: Flattening Load Profile by Shifting Load from Peak to Off Peak Time

2.1.2. Electric Supply Capacity

Load serving entities (LSE's) (including retail utilities) which purchase their power via the forward market (ie. day ahead contracts), not through the use of bi-lateral contracts with power producers, need to also purchase additional unforced capacity (UCAP) to ensure that there is sufficient electric supply capacity to serve demand.

The location of the energy storage in this application is not part of the value creation for this application, so it could be sited near the load, near the generation or anywhere between.

Synergistic applications could include, depending on location and operation strategy, T&D deferral, transmission support, reliability, PQ, and capacity reserves.

2.1.3. Reduce Transmission Capacity Requirements

This application refers to using energy storage to store electricity transmitted across transmission lines at off peak times for use locally at peak times and to reduce the operator's need for capacity at peak times, thereby freeing up additional transmission capacity to sell. This way the transmission lines will be able to transmit others' electricity during peak times. Also peak transmission rates can be avoided for the stored electricity in areas with variable transmission rates. In areas with fixed transmission rates and generation co-located with the load, one could also locally store off peak energy from the local power plant so that transmission rates are never paid.

The location of the energy storage in this application is a key part of the value creation for this application, so it should be sited downstream of a transmission bottleneck, likely near a load. The change in load profile looks similar to Figure 3, but the electric load of concern is just the load on the transmission line of interest, not the system as a whole.

Synergistic applications could include, depending on location and operation strategy, bulk electricity time shifting, T&D deferral, reliability, PQ, ancillary services and transmission support. There is some overlap with transmission congestion reduction and transmission upgrade deferral.

2.1.4. Reduce Transmission Congestion

This application refers to using energy storage to store electricity transmitted across transmission lines at off peak times for local use so that congestion on transmission line during peak times and the associated congestion fees can be avoided. This could also result in improved transmission efficiency.

The location of the energy storage in this application is a key part of the value creation for this application, so it should be sited downstream of a transmission bottleneck, likely near a load. The change in load profile looks similar to Figure 3, but the electric load of concern is just the load on the transmission line of interest, not the system as a whole.

Synergistic applications could include, depending on location and operation strategy, bulk electricity time shifting, T&D deferral, reliability, PQ, ancillary services and transmission support. There is some overlap with transmission capacity requirements reduction and transmission upgrade deferral.

2.1.5. Transmission and Distribution Upgrade Deferral

This application refers to using energy storage to smooth peak loads on substations, by storing electricity transmitted across transmission lines at off peak times and using it locally at extreme peak times (the one hottest day of the summer) which would otherwise require an upgrade of the T&D substation to deliver that power. This allows utilities to run their T&D assets closer to full utilization

more often and also allows them flexibility in the timing of upgrades. T&D upgrades are major, expensive undertakings and are implemented in large chunks of new capacity, which will be underutilized for years as system demand grows to fill the new capacity. Transmission investment has been falling for the past 25 years according to Edison Electric Institute even as electricity delivered has doubled, so this application is of particular importance as transmission upgrades become more urgent.

The location of the energy storage in this application is a key part of the value creation for this application, so it should be sited downstream of a transmission or distribution bottleneck, likely near a load. The change in load profile looks similar to Figure 3, but the electric load of concern is just the load on the transmission or distribution component of interest, not the system as a whole.

Synergistic applications could include, depending on location and operation strategy, bulk electricity time shifting, transmission congestion reduction, reliability, PQ, and ancillary services.

2.2. Utility Oriented Power Applications

2.2.1. Ancillary Services Overview

A number of electrical ancillary services are required to maintain electrical grid stability. These services are basically the injection or absorption of power at strategic moments to maintain proper grid balance and operation. They are currently provided by generators for the good of the whole grid system.

In deregulated areas, some of these ancillary services are traded as forward hourly contracts by each ISO (Independent System Operator, the organization which “administrates” a region’s grid, but does not own generation or T&D). They can be bid on by any certified provider. Ancillary services which are primary candidates for delivery with energy storage are frequency regulation and various types of operating reserves (such as spinning reserve, supplemental or non-spinning reserve and replacement reserve). A list of common ancillary services with additional information on each is included in Table 1. The hourly markets for these services could offer an existing utility the opportunity to provide these services with energy storage instead of varying the output of their existing power plant generators (an inefficient process) or a third party the opportunity to be a “merchant power plant”-like entity selling ancillary services. Energy storage technologies would have to be certified for bidding into these markets before it is possible to bid on these contracts. This certification will likely be a lengthy process, though progress on it is already being made in progressive ISO’s. In a few ISO’s, high-speed flywheel and lithium ion battery energy storage has already been certified for bidding into the frequency regulation market.

Instead of forward hourly contracts, other ancillary services are contracted via long term, negotiated agreements; one example is grid voltage control. It involves the injection or absorption of reactive power to maintain transmission-system voltages within required ranges.² Voltage at T&D substations is currently controlled by capacitors, inductors and variable ratio transformers to maintain voltage within the prescribed limits of the system, for instance, 120V +/-5% in the US and Canada. Though there have been energy storage installations using SMES and ultracapacitors addressing this market, this ancillary

service is not covered here in detail because it is served inexpensively by existing technologies and is focused on ultra high power, low energy systems which are beyond the scope of this document.

Table 1: Comparison of Key Ancillary Services' Characteristics, Price and Cost Requirements (Kirby³)

Type of Ancillary Service	Service Description	Response Time	Duration	Cycle Time	# Cycles (20 yrs)	Price (\$/MWh)	Price Description	Energy Storage Technologies
Frequency Regulation	Online Power. Tracks by-minute fluctuations in system load and corrects fluctuations in generator output. Frequency drops when load > generation & vice versa	< 1min	5 to 15 min	Minutes	350,000	Avg: \$35-40 Max: \$200-400; 10x Spinning Res.; < Energy prices	Relatively stable hourly costs	Flywheels, Supercapacitors, Batteries
Operating Reserve: Spinning Reserve	Online power. Provides immediate output increase in the event of a major generator or transmission outage. NERC requirement: can reach full output in 10 minutes	Seconds to < 10 min	15 sec to 10 min	Days	700 to 1,200	Avg: \$6-17 Max: \$100-300; 2x Supp. Res	Varies hourly; Corr. to daily flux of energy prices	Batteries, Pumped Hydro
Operating Reserve: Supplemental Reserve	Can be online or offline. Same as spinning reserve, but doesn't need to respond immediately. NERC requires it can reach full output in 10 minutes	< 10 min	10 min to 1 hr	Days	Less than Spinning Reserve	Avg: \$0.4-2 Max: \$2-36	Varies hourly; Corr. to daily flux of energy prices	Batteries, Pumped Hydro, CAES
Operating Reserve: Replacement Reserve	Offline. Same as supplemental reserve, but has 30 minute response time requirement. Used to restore spinning and supplemental reserves to pre-contingency status	< 30 min	1 to 2 hr	Days	Less than Supplemental Reserve	Avg: \$0.4-2 Max: \$2-36	Varies hourly; Corr. to daily flux of energy prices	Pumped Hydro

2.2.2. Ancillary Services – Frequency Regulation

This application refers to injecting or absorbing significant amounts of power to or from the grid on a minute to minute basis as needed by the grid operator to keep the electric flow on the grid stable and reliable, basically cancelling out unwanted electrical transients on the grid. For instance, if the load on the grid is consistently slightly larger than the amount of power supplied by the generators, the frequency of the power will begin to decrease as the power plants' turbines begin to spin more slowly. This needs to be boosted back up by frequency regulation ancillary services injecting power into the grid. This event can also happen in reverse where too much power is provided and the frequency speeds up, so the frequency regulation would absorb power to slow the frequency down. The requests for frequency up and frequency down regulation typically alternate between up and down requests on the order of minutes and current required response time is around 5 minutes. Rapid response frequency regulation is beginning to become available with new fast response technologies; contracting for it is still in flux.

Frequency regulation contracts are for delivery in a broad area of an ISO's territory, so the exact location of the energy storage in this application is not critical for this application. However, it should be connected to high voltage feeder lines which will allow it to inject/absorb power with minimal losses. Frequency reserve is constantly balancing out the minor fluctuations in generation versus load quantities throughout the day, as seen in the small oscillations in Figure 4. Frequency is tightly controlled to maintain functionality of devices on the grid, as shown in Figure 5.

Synergistic applications could include, depending on location and operation strategy, localized voltage support (an additional ancillary service not greatly discussed here), many other utility scale applications and local reliability and PQ.

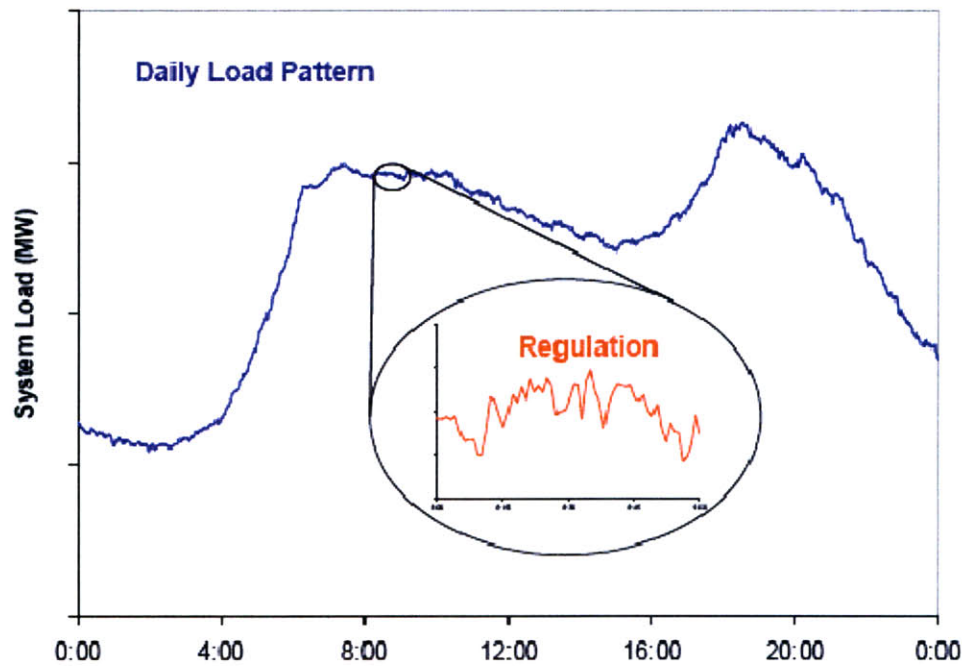


Figure 4: Frequency Regulation Compensates for Uncontrolled Minute-to-Minute Fluctuations in the Generation vs Load Balance (Kirby⁴)

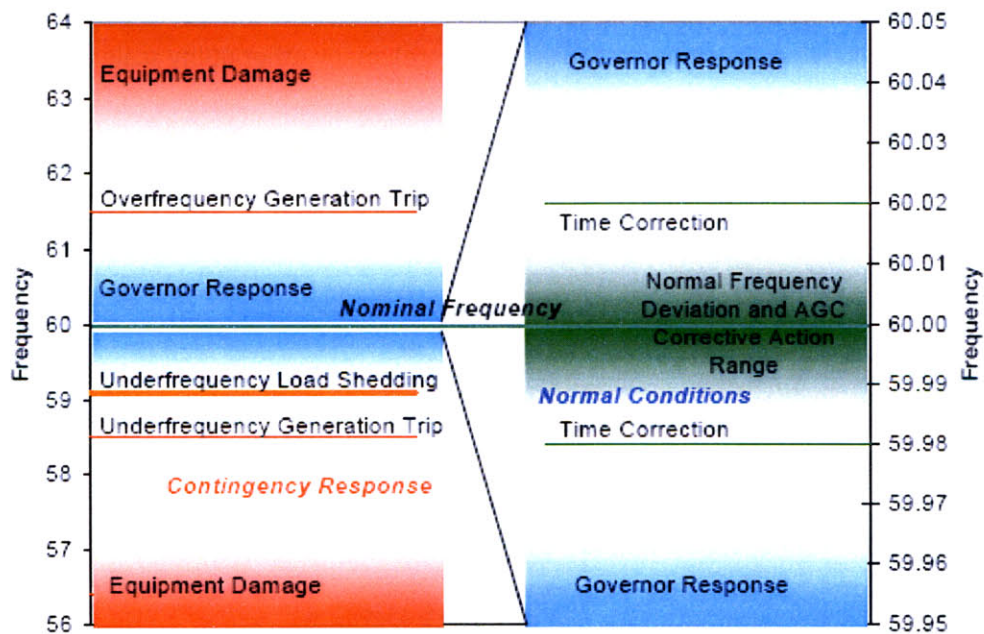


Figure 5: Power System Frequency is Tightly Controlled in North America (Kirby⁵)

2.2.3. Ancillary Services – Operating Reserve

This application refers to injecting significant amounts of power to or from the grid as needed by the grid operator when generation or transmission capacity is suddenly lost. When an event occurs which damages a utility's connection to a generation site, and backup power is needed for a short period of time to maintain the power on the grid while switches reroute power and/or additional sustaining generation comes online, Operating Reserves are the extra power supplying electricity during this transient. The required response time is on the order of minutes and it typically is in use for a few minutes before another long term power source comes online. Since this is only occasionally needed, but is paid for all the time, this is one way energy storage can produce revenue without cycling the storage system. Operating reserves include various types including spinning reserve, supplemental or non-spinning reserve and replacement reserve.

Operating reserve contracts are for delivery in a broad area of an ISO's territory, so the exact location of the energy storage in this application is not critical for this application. However, it should be connected to high voltage feeder lines which will allow it to inject power with minimal losses. Operating reserve comes online after a contingency while frequency regulation resources are supporting the grid, as shown in Figure 6.

Synergistic applications could include, depending on location and operation strategy, localized voltage support (an additional ancillary service not greatly discussed here), local reliability and PQ.

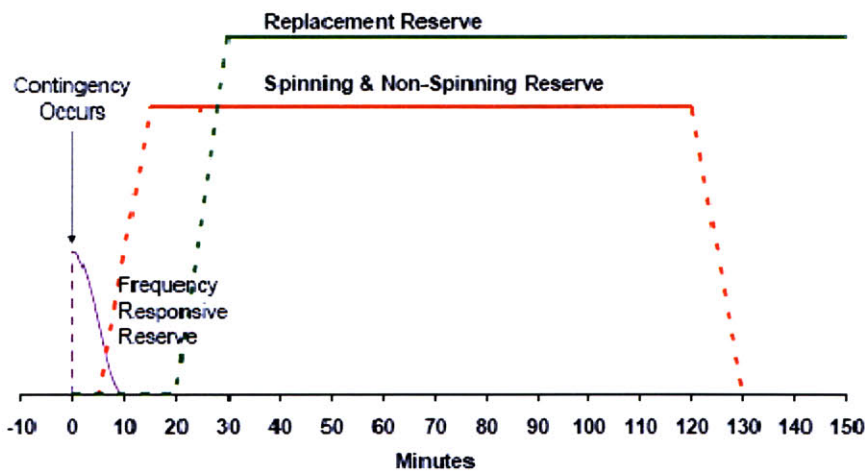


Figure 6: Coordinated Reserves Maintain Grid Power After a Contingency (Kirby⁶)

2.2.4. Transmission Support

This application refers to injecting or absorbing significant amounts of power to or from the grid with very high response rates (under 1 second) to maintain stability on particular transmission assets. Typical discharge durations for these services range from a few seconds to 20 seconds. There are a number of

services which are included in this set, such as voltage sag and sub-synchronous resonance. This application is very location specific and is also called “Network Stability” by FERC.

2.3. End User Oriented Energy Applications

Industrial and commercial customers have more complex electricity bill structures than common residential customers. It is common for them to be charged different rates for on-peak and off-peak electricity use and also to be charged additionally for the highest amount of power they demand in any 15 minute period over the course of a month. This offers opportunities for energy storage to reduce their electricity bills by time shifting the amount of electricity demanded from the utility. Some example rates for electricity service from across the US are shown in Table 2.

Table 2: Example Peak/Off-Peak Energy Prices and Demand Charges in the US (Sandia National Laboratory⁷)

Utility	State	Schedule	Summer			Winter		
			Demand (\$/kW)	On-peak (\$/kWh)	Off-peak (\$/kWh)	Demand (\$/kW)	On-peak (\$/kWh)	Off-peak (\$/kWh)
PG&E	CA	Medium General Service (Schedule A-10)	6.91	0.131	0.131	2.09	0.095	0.095
PG&E	CA	Medium General Service (Schedule A-10 TOU)	6.91	0.162	0.118	2.09	0.098	0.092
PSE&G	NJ	General Lighting and Power (Schedule GLP)	13.82	0.085	0.085	6.07	0.093	0.093
AEP (Texas Central)	TX	General Service		0.109	0.109		0.101	0.101
SRP	AZ	General Service (Rate E-36)	3.54	0.069	0.069	1.79	0.060	0.060
AEP (Ohio Power)	OH	General Service Non-demand (Rate GS-1)		0.048	0.048		0.048	0.048
AEP (Ohio Power)	OH	General Service Time-of-Day (Rate GS-TOD)		0.072	0.025		0.072	0.025
LADWP	CA	General Service Primary (Rate A-2 A)	16.49	0.051	0.051	15.33	0.051	0.051
LADWP	CA	General Service Primary TOU (Rate A-2 B)	11.34	0.059	0.046	10.61	0.059	0.046
CL&P	OH	Large Time-of-Day (Rate 58)	10.14	0.084	0.065	10.14	0.084	0.065
FP&L	FL	General Service Non-Demand (GS-1)		0.084	0.084		0.084	0.084
FP&L	FL	General Service Demand (GSD-1)	8.16	0.053	0.053	8.16	0.053	0.053
FP&L	FL	General Service Demand TOU (GSDT-1)	8.16	0.073	0.047	8.16	0.073	0.047

2.3.1. Electric Service Bill Reduction: Demand Charges

This application refers to reducing the maximum power a site draws over any 15 minute period from the grid to reduce the cost of the equipment required to transmit power to the site. It accomplishes this by locally storing power transmitted at off peak times for use at these peak times. Depending on tariff billing structure, the one highest peak demand of a period (ie. month) will determine a charge for the amount of distribution equipment necessary to support that demand. If that peak demand can be

reduced by using electricity transmitted and stored at an off-peak time, the demand charge will be reduced.

Energy Storage used for Demand Charge Bill Reduction is located on the customer's side of the meter at the customer's site.

Synergistic applications could include reliability and PQ. It may also benefit T&D deferral and, when charging, could provide reserve capacity by being able to be dropped as an optional load.

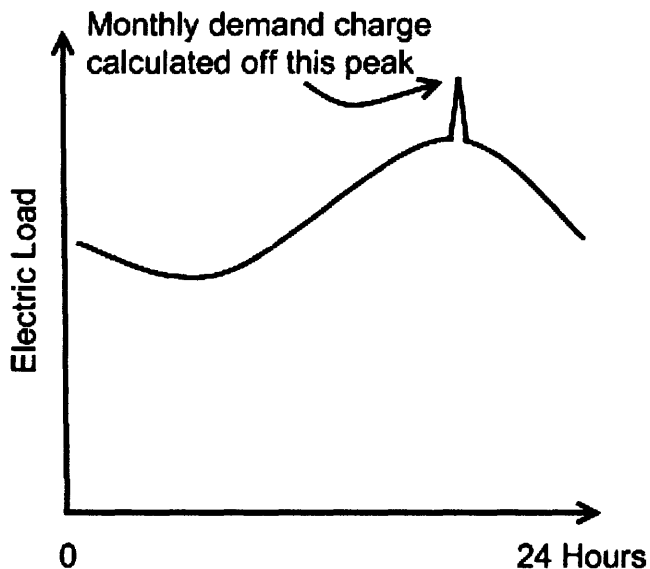


Figure 7: Unexpected Customer Load Spike Effecting Demand Charge

2.3.2. Electric Service Bill Reduction: Time-of-Use Energy Pricing

This application, useful for customers with time of use energy pricing, refers to reducing a customer's demand for electricity during peak times when electricity prices are high, by utilizing energy on site stored at low off peak prices. This has similarities to bulk electricity time shifting, however the electricity would not be sold back to the grid, and only used by the customer.

Gridpoint is proposing to do this on a residential level, however it appears that the stronger business cases can be made for peak shaving at a commercial/industrial site which have high peak energy demands for cooling or manufacturing and more complex electricity contracts, possibly including demand charges as well, which can be significantly reduced by limiting the site's usage during peak times. One non-electrical storage strategy which is also beginning to be implemented is off-peak ice production and storage for reducing cooling loads during peak.

Energy Storage used for Time-of-Use Energy Pricing Bill Reduction is located on the customer's side of the meter at the customer's site. This strategy mirrors the bulk energy time shifting strategy shown in

Figure 3, but the structure of the financial motivation in this case is to buy the power at a lower price off-peak for use on-peak when electricity will be expensive.

Synergistic applications could include reliability and PQ. It may also benefit T&D deferral and, when charging, could provide reserve capacity by being able to be dropped as a curtailable load.

2.4. End User Oriented Power Applications

2.4.1. Electric Service Reliability (Avoid Power Outages)

This application refers to maintaining electrical service to a customer when their grid power source is lost. Depending on how much equipment is to be supported and for how long (until switch over to on-site backup generation or until orderly shutdown completes) the power and energy requirements vary. These reliability assets can be owned and directly paid for by customers with exceptionally high electricity uptime requirements or in some cases owned and operated by utilities and paid for by state incentives for end user power reliability.

Energy Storage used for End User Electric Service Reliability is generally located on the customer's side of the meter at the customer's site. Generally the value is captured by the customer by avoiding downtime caused by power outages.

Synergistic applications could include PQ and electric service bill reduction.

2.4.2. Electric Service Power Quality (PQ) (Avoid Power Fluctuations)

This application refers to conditioning power delivered to end users to remove very short term transients (ie. momentary voltage sags/spikes, frequency variation, brief service interruptions). This is frequently useful for important electronics and for safety/security loads.

Energy Storage used for End User Electric Service Power Quality is located on the customer's side of the meter at the customer's site. Generally the value is captured by the customer by avoiding operational disruptions to critical devices which require clean power to function.

Synergistic applications could include reliability and electric service bill reduction.

2.5. Renewable Generation Energy Applications

2.5.1. Renewable Electricity Production Time-Shift

This application refers to time shifting power from a renewable source from its time of production to the time of its maximum value during peak times and selling it as dispatchable power, instead of the variable non-dispatchable power available directly from a wind turbine. Wind would particularly benefit from this as it generates its highest amounts of power at night (off peak time) and could be transmitted to the load region at off peak hours and stored for use during the coming day's peak times. In this way, multiple benefits can be obtained from one energy storage device.

Pilot operations with co-located storage at wind farms to stabilize their power production for improving its value to the grid are already underway. Though the bookkeeping is simplest when the energy storage is co-located with the wind farm, it actually requires less energy storage to accomplish the same task if the storage is located closer to the load and is able to balance the inputs of a number of wind farms at different locations (which will have less correlation in their power fluctuations, more stable power output in total and therefore less need for balancing). This application strategy can be visualized similarly to the time shifting portrayed in Figure 3.

Synergistic applications could include electric supply capacity, T&D capacity deferral, avoiding transmission congestion charges, reliability, PQ and ancillary services.

2.6. Renewable Generation Power Applications

2.6.1. Renewable Electricity Production Capacity Firming

This application refers to using a modest amount of storage to shift energy over short periods of time, for instance when PV solar output peaks and when electrical demand peaks (typically a few hours). It also may even out short term fluctuations in power delivery of renewables, so that they are a more dependable, higher value generation resource. The focus of this application is on power and not energy though, to maintain output from solar panels through fluctuations and not to shift the power to a time when solar is not producing at all (as in an off-grid PV situation). A source of cost savings for using storage on PV installations is that one electrical inverter could be used for both the PV and the energy storage system.

This Renewables Firming energy storage would be sited with the distributed renewable installation, for instance at a customer site behind their meter. This firming strategy would primarily reduce their on-peak energy demand, but also offer the potential for grid security and other benefits when utility to customer business protocols are defined and made operational.

Synergistic applications could include PQ, reliability, reduced demand for on peak electricity, reduced transmission capacity requirements, and reduced transmission congestion.

2.7. Overview of all applications:

Table 3 lists value estimates for each application discussed. The estimates of application value will be used in the remainder of this document as a reference point for how much value a multi-application implementation of energy storage could create.

Table 3: Estimated Benefits and Market Size for Each Application (NYSERDA⁸ & EPRI-DOE⁹)

#	Power or Energy App?	Application	NY Unit Benefit, \$/kW, over 10 Years**	NY Maximum Market Potential MW, 10 Years*	NY Total Benefit \$ Million, over 10 Years**	CA Unit Benefit, \$/kW, over 10 Years**	CA Maximum Market Potential MW, 10 Years*	CA Total Benefit \$ Million, over 10 Years**	US Maximum Market Potential MW, 10 Years***	US Total Benefit \$ Million, over 10 Years***
Utility Oriented Applications - Energy Focus										
1	Energy	Bulk Electricity Time Shifting	394	3265	1288	200 to 300	735	147 to 220	5880	1468
2	Energy	Electric Supply Capacity (NY)	753	3739	2815					
		Central Generation Capacity (Avoided Cost) (EPRI)				215	3200	688	25600	5504
3	Energy	Reduce Transmission Capacity Requirements	93	3759	350	72	3200	230	25600	1843
4	Energy	Reduce Transmission Congestion	72	2612	187	72	3200	230	25600	1843
5	Energy	Transmission and Distribution Upgrade Deferral (NY)	1200	411	494					
		Distribution Upgrade Deferral Top 10th. Percentile Benefits (EPRI)				1,067	160	172	1280	1373
		Distribution Upgrade Deferral 50th. Percentile Benefits (EPRI)				666	804	536	6433	4284
		Transmission Upgrade Deferral (EPRI)				650	1100	710	8800	5680
Utility Oriented Applications - Power Focus										
6	Power	Frequency Regulation	789	281	351	72	800	58	6400	461
7	Power	Operating Reserve	258	445	115	72	800	58	6400	461
8	Power	Transmission Support	169	70	47	82	1000	82	8000	656
End-User Applications										
9	Energy	Electric Bill Reduction: Demand Charges	1076	1,685	362	465	4000	1862	32000	14897
10	Energy	Electric Bill Reduction: Time-of-use Pricing	1649	270	2779	1004	4000	4021	32000	32166
11	Power	Electric Service Reliability	359	842	25	359	4000	1438	32000	11501
12	Power	Electric Service PQ	717	337	604	717	4000	2872	32000	22973
Renewables										
13	Energy	Renewable Electricity Production Time-shift	832	2700	2246	655	500	328	4000	2620
14	Power	Renewable Electricity Capacity Firming	323	188	61	172	1800	310	14400	2477

Note: Grayed out boxes indicate placeholder values from EPRI; the actual benefit was not estimated.

* MW of cumulative market potential over ten years.

** \$ present worth, over ten years, 2.5% inflation, 10% discount rate, mid year convention.

*** Ratio US to CA market potential is assumed to be 8 (EPRI estimate).

Assumption: Transportable storage could provide the same single year benefit at several locations.

Assumption: Existing resources/equipment, especially if it has useful life, will not be replaced with storage.

Figure 8 is a plot of technical requirements for various storage applications. Note that cost, though not included in this plot, is a critical additional piece of data and influences which technologies are economically viable for an application. It is nonetheless useful to compare this plot to the plot on similar axes in the technologies section, Figure 16, to see from this perspective which technologies match up with which applications.

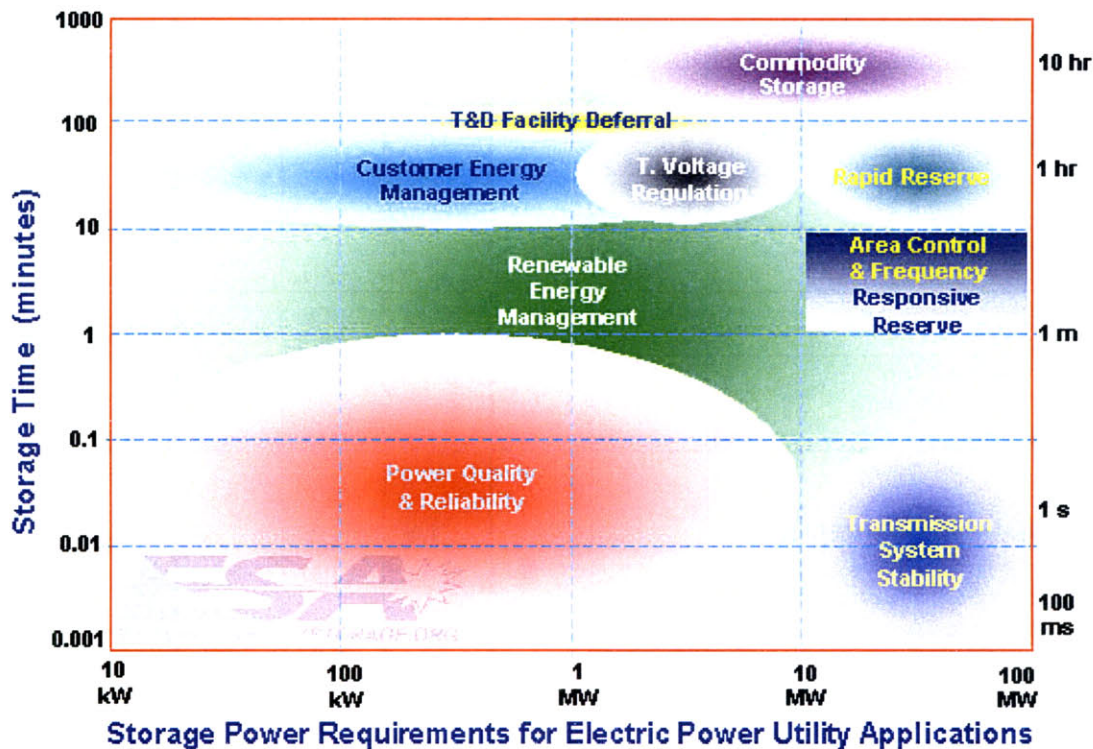


Figure 8: Power and Energy Requirements for Applications (Electricity Storage Association¹⁰)

2.8. Other Applications

These applications are mentioned for commentary, but are not pursued further in this document.

2.8.1. Load following

To keep electricity supply equal to demand at all times, additional supply must be dispatched throughout the day as load grows toward the daily peak. This allows the grid operator to track customer load changes on the fly, on the order of an hourly basis. This is currently done with gas turbine plants and hydro plants, in response to short term electricity market prices. For thermal power plants, like turbines, this requires cycling the equipment to follow the load, a costly and inefficient process. Energy storage could do load following and allow these plants to cycle less and run at optimum efficiency for more time, therefore reducing fuel costs and maintenance costs. However, to accomplish this, the energy storage system must store a great deal of energy and this is not cost effective at the current time.

2.8.2. Peak Shaving during Exceptional Loads

For a few dozen hours a year, the grid experiences its largest loads. Typically, this is a few hours at a time on the hottest few days of the year when cooling loads are high. Traditionally, in order to supply these highest demand spikes, additional generation capacity had to be built to supply the entire load, however these power plants are only run for a few dozen hours a year when the demand for power is exceptionally high. The remainder of the time they sit idle.

One business which has attracted a good deal of attention in this space is EnerNOC. EnerNOC operates a demand response network in which they organize customers onto the EnerNOC network and then occasionally direct them to curtail energy use (ie. reduce lighting) and/or turn on backup generators for a few hours to reduce the size of problematic demand peaks. This occurs only a few dozen hours a year to reduce the highest peaks, and does not follow demand hourly on a year round basis, so EnerNOC's demand response strategy does not compete directly with energy storage most of the time but it does sell power at the most profitable times. This is a specific market strategy which energy storage would not have an advantage in at this time, as to make profitable revenues with an ES system, it has to be cycled more frequently than a few times a year. However, ES systems could contribute to mitigating these occasional peak problems as part of other primary revenue producing activities.

2.8.3. Uninterruptable Power Supplies

Uninterruptable power supplies (UPS's) currently address power quality and reliability applications for industrial, commercial and residential applications. There is some overlap between the UPS market and the applications discussed here since they address related problems. However, due to their smaller distributed nature, UPS's are not discussed further in this document.

3. Energy Storage Technologies

3.1. Technology Overview

This technology overview will briefly discuss each relevant energy storage technology and its prominent manufacturers. For further detail on individual technologies, a number of good documents can be referenced, such as EPRI-DOE's Handbook of Energy Storage for Transmission and Distribution Applications.¹¹

A number of technologies which are included in charts later in this section are left out of this overview for various reasons. Low speed flywheels were left out as they do not have the energy capacity to accomplish grid scale tasks and have not been marketed as such. Traditional lead acid batteries were left out for cycle life and lifetime cost of ownership concerns. Nickel Cadmium (NiCd) batteries were left out for toxicity, challenges with further cost reduction concerns and lack of them being recently marketed for grid scale applications. Superconducting Magnetic Energy Storage (SMES) was left out due to extremely low energy density and specificity to VAR applications which are served inexpensively by

existing technologies. Ultracapacitors were left out due to low energy capacity; all current grid scale applications have discharge times of 30 seconds or less.¹²

This listing begins with energy oriented storage systems and moves toward power oriented storage systems. The first two bulk energy storage technologies, Pumped Hydro and CAES, are included for comparison, but are not deeply addressed after this section.

3.2. Pumped Hydro Storage

Pumped hydro storage (PHS) uses electricity to pump water uphill into an upper reservoir when there is excess power and allows water to run back down hill to generate power when it is needed. Typically there are two above ground reservoirs at different heights which are used for this. Technically it is possible to accomplish the same operation using an underground cavity for a lower reservoir, but this has not been implemented.

PHS is the most common electricity storage in use on the grid today and has over 90GW installed throughout the world, about 3% of global generation capacity. It is expensive to build initially, but inexpensive to cycle energy through, so it is a good solution for many applications, including peak shaving and ancillary services like frequency regulation and operating reserve. However, building a new PHS system requires appropriate geography and public approval for siting; in many developed parts of the world the potential locations for new PHS are extremely limited by these factors.

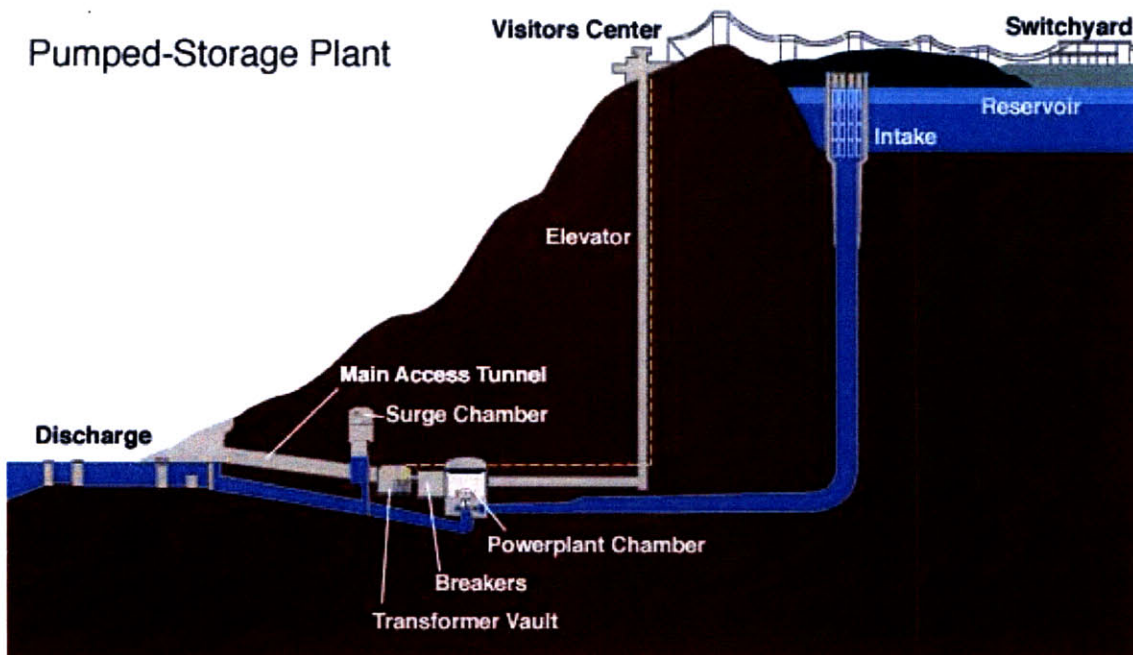


Figure 9: Pumped Hydro Storage Plant (Tennessee Valley Authority)

3.3. Compressed Air Energy Storage

Compressed Air Energy Storage (CAES) uses excess electricity to compress air into a cavity underground and then later use that compressed air as the input air to a gas-fueled turbine (similar to that of a regular power plant). Since a turbine spends more than 50% of its fuel to compress the intake air, having it pre-compressed allows the turbine to produce electricity when it is needed using much less fuel.

This technology has been used in two installations which continue to cooperate today, a 290 MW unit built in Hundorf, Germany in 1978 and a 110 MW unit built in McIntosh, Alabama in 1991. There are additional units currently proposed in Norton, Ohio and at the Iowa Stored Energy Park. Systems storing the compressed air in pipelines above ground have also been considered. Some market participants are General Compression, Ridge Energy Storage and Dresser-Rand.

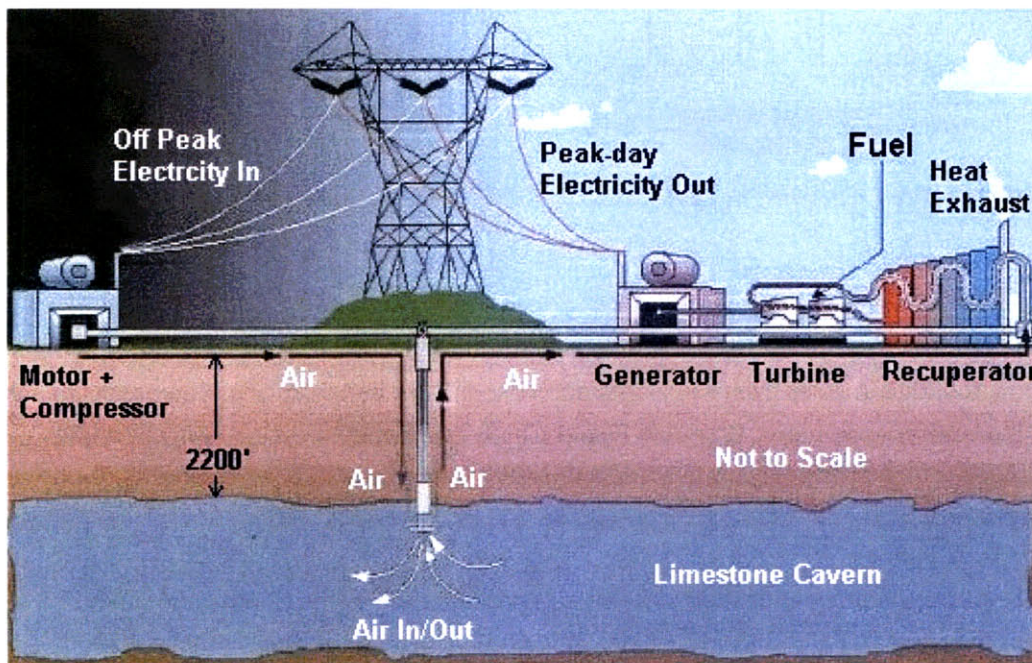


Figure 10: CAES Plant (CAES Development Company)

3.4. Flow Batteries

Flow batteries are a class of electrochemical energy storage, similar to a rechargeable fuel cell, which pumps two different liquid electrolytes across opposite sides of a membrane in a reaction chamber to produce or sink electrical current. The amount of power and energy a flow battery can produce is independently variable; the amount of power a flow battery can produce is defined by the area of the membrane it flows past and the amount of energy it can produce is defined by the size of its electrolyte tanks. There are a number of chemical pairs which are used in flow batteries with slightly different voltages produced.

The fundamental concepts for flow batteries have been developed since the 1970's. A number of flow batteries are currently in development and in prototype testing stages, however none are currently fully commercial products.

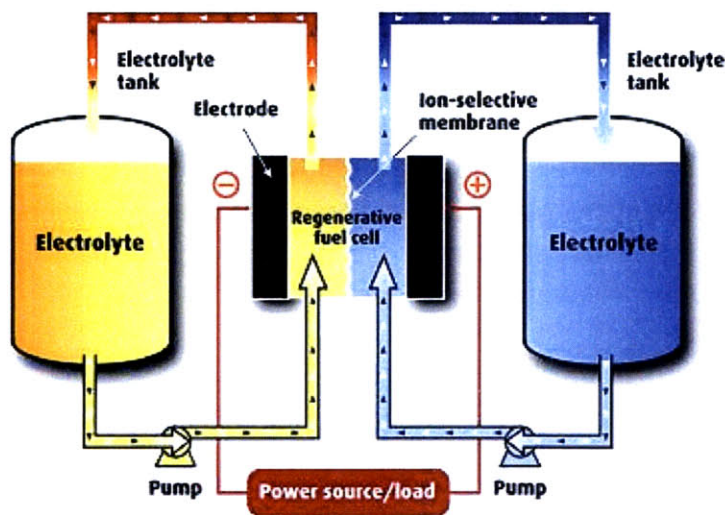


Figure 11: Flow Battery (Prudent Energy)

3.4.1. Premium Power

Premium Power (North Reading, MA) is a privately held, founder and VC backed, Zinc-Bromide flow battery company founded in 2002 from the assets purchased in the bankruptcy of Powercell, an earlier Zinc-Bromide flow battery company. Premium Power claims to be able to cycle energy at under \$.02/kWh,¹³ however they are very secretive and have not released any public documents on the results of their prototype projects.

Premium Power states the pricing for their systems as a combination of the energy and power requirements of the system: \$250-350/kW + \$200-300/kWh. The price of their Transflow 2000 0.5MW/2.8MWh unit has been conservatively estimated at about \$1M (\$2,000/kW and \$357/kWh on a system level).¹⁴ This system is integral to a semi-trailer which makes setup at a site and transfer between sites rapid. They have received a \$100M order for batteries from an unnamed Canadian utility and another \$100M order from Duke Energy.¹⁵ They do not market their systems very publicly, but appear to be well connected in the industry. They integrate a significant portion of the value chain in house at their manufacturing facilities in Massachusetts, from molding the plastic panels for the reaction chamber, to designing and assembling the power converter and controller boards, to assembling the whole system into a trailer for mobile use.

3.4.2. Prudent Energy (was VRB Power)

Prudent Energy (Beijing, China) acquired the assets of VRB Power (Richmond, BC, Canada) in early 2009 in VRB's bankruptcy. Prudent Energy is intending to continue commercializing Vanadium Redox batteries based on VRB Power's assets. VRB Power, which was a public company, was previously a

leader in commercializing Vanadium Redox battery technology and had released a number of white papers on installations they had completed or proposed. VRB was still in the prototype stage of development.

VRB's proposal to the Sorne Wind Farm included pricing guidance of €6,060,000¹⁶ (2007 €) for a 2MW/12MWh unit (€3,030/kW and €505/kWh or \$4154/kW and \$692/kWh using 2007 average conversion rates¹⁷).

3.4.3. ZBB Energy

ZBB Energy was formed in Australia in 1982 to commercialize Zinc-Bromide flow batteries. They created an operating subsidiary in Wisconsin to acquire the zinc-bromide technology assets of Johnson Controls in 1994. ZBB went public in 2005. They have released a number of white papers on prototypes and proposals, but their revenues to date have primarily been from engagements in research contracts with two utilities which include delivery of a prototype system. During the end of 2008 and beginning of 2009, they have released information on a handful of pilot sales and MOU's to customers.

ZBB has released a pricing estimate to an equity analyst in 2008 of \$362,500¹⁸ for their ZESS 500 unit, which is 250kW/500kWh (\$1450/kW and \$725/kWh). ZBB builds and assembles their flow batteries in house, but they have purchased their power converters from Satcon until this year when they have started including ZBB branded "ZESS POWR" power conditioning systems with some products.

3.4.4. Other Manufacturers

Company Name	Location	Chemistry
Cellennium	Thailand	Vanadium Redox
Cellstrom	Austria	Vanadium Redox
Deeya	California, US	Not public
Net Power Technology	China	Zinc Bromide
Plurion Systems	UK	Cerium Zinc
Redflow Energy	Australia	Zinc Bromide

3.5. Advanced Lead Acid Batteries

Advanced lead acid batteries refer to a number of innovations based on the venerable traditional lead acid battery which has been around for many decades. These innovations improve a variety of the characteristics of lead acid battery, particularly focusing on cycle life. Some of the companies making progress in this market are Axion (a very small public company based in New Castle, PA with a lead-acid-carbon battery supercapacitor hybrid in prototype stage), C&D Tech (a medium size public company based in Blue Bell, PA with a large format vented lead acid battery with low antimony/selenium grid in early production stage) and East Penn/Furukawa/CSIRO ("Ultrabattery" capacitor hybrid lead-acid battery technology licensed to East Penn of Lyon Station, PA for manufacturing). These innovations are still largely in the R&D phase or early, limited production phases.

The Ultrabattery has been implemented in a one-off HEV pack and one player, Axion, has is assembling a trailer full of their batteries for testing on grid applications. Sandia recently cycle life tested¹⁹ the C&D Tech and Ultrabattery at small discharges, a cycle profile which can be expected in grid scale ancillary services applications. They found that these batteries degraded much less slowly than the baseline lead acid battery, with the Ultrabattery retaining 80% of capacity for up to 6x as long (12,000 cycles) and the C&D Tech battery finishing testing at 6,000 cycles and still having much more than 80% of capacity remaining.

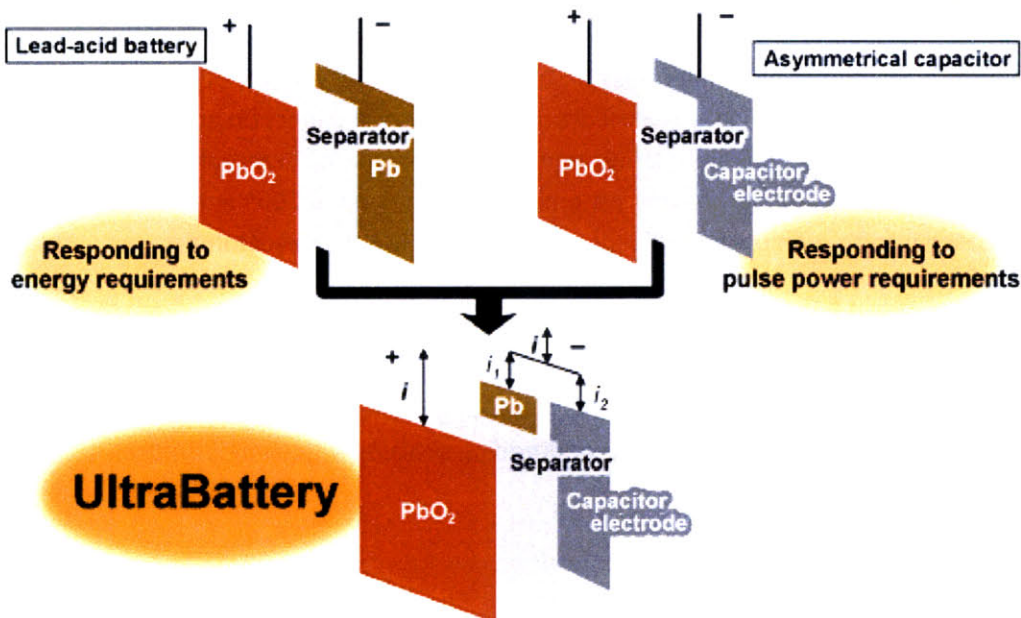


Figure 12: UltraBattery Advanced Lead Acid Battery (Furukawa Battery)

3.6. Sodium Sulfur Batteries

Sodium sulfur (NaS) batteries are kept at about 300°C and reversibly react molten sodium and sulfur across a solid ceramic electrolyte. Japan's Toyko Electric Power decided to focus on developing NaS batteries in 1983 after they were found to be attractive for grid scale energy storage as a result of Japan's "Moonlight Project". There have been prototype installations since the early 1990's and now NaS batteries are produced commercially by NGK Insulators. There is ongoing work underway in reducing the cost of the batteries.

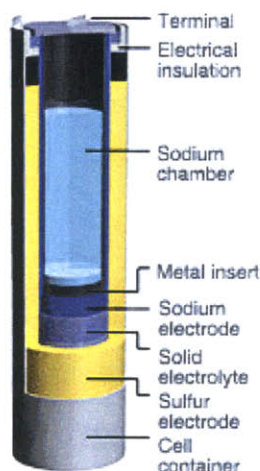


Figure 13: Sodium Sulfur Battery (NGK)

3.6.1. NGK Insulators

NGK Insulators is a medium size, publicly held company based in Japan and formed in 1919. NGK is the only company in the world which produces NaS batteries. They currently have 90MW of production capacity and plan to expand to 150MW in 2010.

The most clearly supported estimate available for a fully installed NaS system in the US is from a Sandia report written by Ali Nourai at AEP which estimates the fully delivered and installed cost of a new NaS system at \$2500/kW or \$347/kWh using NGK's PS-G50 NaS batteries (energy oriented battery module).²⁰

3.7. Lithium Ion Batteries

Lithium Ion Batteries are a class of batteries which use a lithium ion and an electron to transfer charge between the cathode and anode on charge and discharge. There are a number of different chemistries used for various types of these batteries each having different characteristics including different output voltage.

Li-ion batteries were first commercialized by Sony in 1991 for personal electronics and more recently advanced chemistries have been developed which yield more power, improved cycle life and improved safety at a lower cost. These improvements make Li-ion batteries fit the needs of plug-in hybrid vehicles, so a great deal of effort has been placed on their development in the last few years. A number of these new chemistries are in the beginning stages of commercial production, and there are more which are still in R&D stages. Some of these technologies are now being considered for the grid scale energy storage market. The biggest challenges facing the lithium ion battery for grid scale usage is cost per kWh and cycle life.

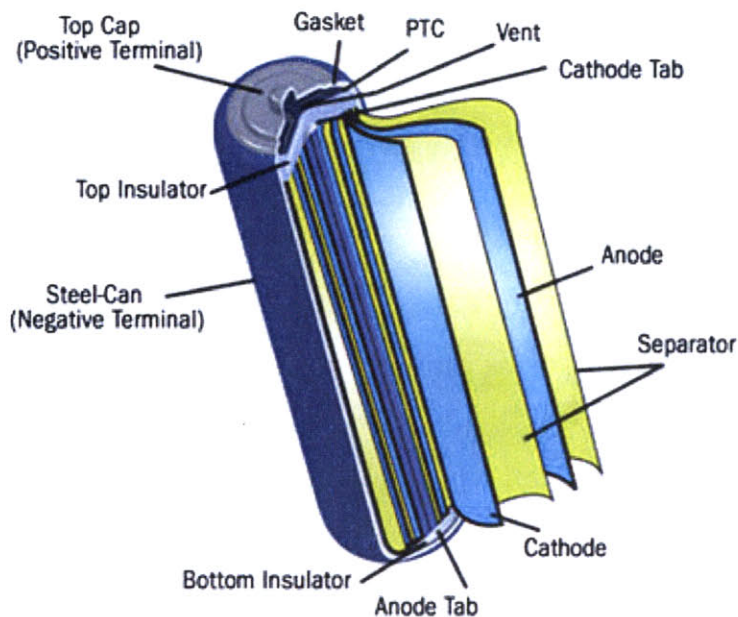


Figure 14: Lithium Ion Battery (HowStuffWorks)

3.7.1. A123 Systems

A123 Systems (Watertown, MA) is a privately held, VC backed late stage startup company that is commercializing their Nanophosphate technology based on a doped lithium iron phosphate (LFP) cathode. A123 Systems produces a 2MW/0.5MWh system built into a semi-trailer targeted at providing ancillary services including frequency regulation. A123 has multiple customers including AES. A123 has not released public pricing on their systems.

A123 has been producing cells in quantity for power tools since 2006, and now they are ramping up for PHEV's and grid scale storage. A123's vertically integrated cell manufacturing operations are currently in China and Korea. The company has also broken ground on a new \$2B plant in Michigan that will produce cells in North America. They assemble the grid scale systems in house at their Hopkinton, MA plant. A123 does not disclose their source for power inverters.

3.7.2. Altair Nanotechnologies

Altair Nanotechnologies (Reno, NV) is a small public company that specializes in nanotechnology research. They are commercializing an advance they have made in the optimization of nano-structured lithium titanate spinel oxide (LTO) anode material. Altair Nano has not released public pricing on their systems. Altair Nano has sold a 1MW/0.25MWh 53 foot trailer to AES for testing in Indiana. AES invested \$3M in Altair Nano in 2007.

Altair Nano has been working on related research since 2000, the fundamental LTO solution was devised in Feb 2005, and the first batteries were delivered in Sept 2006. Altair Nano is in a late R&D phase with their batteries. They have limited volume manufacturing capacity in Indiana and do not have a track record of battery production. A contract which they disclose with niche EV maker, Phoenix Motorcars,

which plans to release vehicles using Altair Nano cells in 2010. Altair Nano sources inverters for the grid scale storage trailer from Parker Hannifin.

3.7.3. Saft

Saft (Bagnolet, France) is a medium sized publicly held company founded in 1918 that makes many types of batteries. They make lithium ion batteries from a handful of chemistries for specialized applications like military, industrial and space, but not consumer electronics. They will be producing a 0.6MW/0.2MWh grid stabilization trailer based on Li-ion batteries (undisclosed type). EDF Energy in the UK will be testing this first deployment.

Saft has existing production facilities in place. They are using an inverter from ABB.

3.8. High Speed Flywheels

High speed flywheels store energy using the angular momentum of a composite rotor which is spun up to about 60,000 rpm. Typically the rotor is spun on magnetic levitating bearings in an evacuated container. High speed flywheels have an extremely high cycle life and very high power delivery. Low speed flywheel steel rotor systems exist as well, but they are only used in applications like bridging power for UPS's.

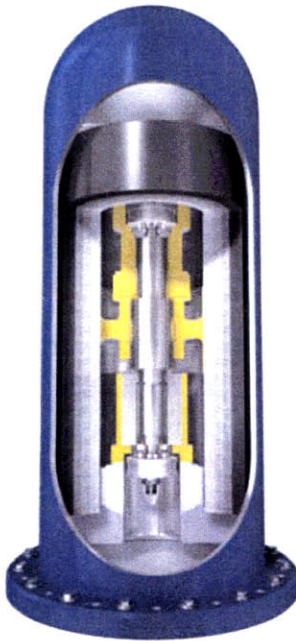


Figure 15: High Speed Flywheel (Beacon Power)

3.8.1. Beacon Power

Beacon Power (Tyngsboro, MA) is a small public company that has been developing high speed flywheels since its founding in 1997, and is now rolling out its 4th generation flywheel system. They now also produce solar inverter systems. Beacon estimates that the price for construction and installation of

its 20MW flywheel based Smart Energy Matrix will be \$50M for the initial one (\$2500/kW) and \$25M for the second (\$1250/kW).

Their strategy is to be a “vertically integrated utility” which means they are designing and building the systems as well as installing, operating and collecting revenue from them on the grid. They have been leading the charge on getting energy storage-favorable regulation enacted in many ISO’s. They are planning sites in NYISO, PJM and have a working site in MA on NE-ISO which they plan to expand.

3.8.2. Pentadyne

Pentadyne (Chatsworth, CA) is a VC backed company that produces high speed composite rotor flywheels for UPS and train regen applications. They shipped their first commercial production flywheel in 2004 and have shipped 500 since then.

3.9. Technology Comparisons

There are a variety of technologies vying for use in the many possible applications. Table 4 sorts the technologies loosely from bulk energy storage technologies to high power technologies. It includes information on *rough* capital expenditure estimates per unit energy and power from various sources (not including the effect of energy storage lifespan, maintenance or operating costs). When data was available directly from a specific company it was included separately in the quotes column. Representative strengths and weaknesses of each technology are also listed.

Quotes were gathered from a literature review and discussions with industry leaders with an effort to include all costs of the system, including power conversion, balance of plant, and installation costs. The capital expenditure estimates from EPRI and Sandia also claim to include most all of these components as well; however, the figures they identified were much different for some parameters.

Lithium ion battery based systems proved to be challenging to obtain *public* price quotes for. In order to identify another data point which could be used to reference Sandia’s \$1,333/kWh against, public pricing for the Chevy Volt’s lithium ion battery pack was used. GM has noted publicly that the price for the Volt’s 16kWh pack is “many hundreds of dollars per kWh” lower than \$1000/kWh, so \$700-800/kWh appears reasonable.²¹ Also, based on the electric motor size and generator size for the internal combustion engine, it is fair to say that the pack generates at least 58kW of power, a power to energy ratio of 3.625.^{22 23} These figures indicate a conservative pack cost of \$12,800 (\$800/kWh and \$220/kW). Since this system is cost optimized through much value engineering and expectations of mass production, it should be expected that grid scale energy storage, produced in smaller volumes and earlier in the value engineering cycle, will be somewhat more costly. However, since they will both use similar cells, probably not enormously so. From this rough estimate, it appears that Sandia’s \$1,333/kWh estimate, at about 2/3 more expensive, is reasonable. Also, the power to energy ratio of the produced systems identified (4, 4 and 3) are comparable with the power to energy ratio of the Volt’s pack, so the comparison is balanced in this fashion. For this analysis, grid scale lithium ion systems will

be assumed to be \$1,333/kWh and \$333/kW. These figures are rough and are expected to vary significantly between manufacturers.

In order to develop a complete estimate of the life cycle costs of energy storage technologies, further research about the operating cost in each implementation is needed.

Table 4: Technology Pricing and Characteristics

Technology	Capex \$/kW ¹	Capex \$/kWh ²	Quotes	Advantages	Disadvantages
Pumped Hydro	1500-2000	N/A		Low \$ per kWh cycled, large scale, long life	Siting, high capex
CAES	450	N/A		Low \$ per kWh cycled, large scale, long life	Siting, high capex
Zn-Br flow battery	639	400-500	\$2,000/kW, \$357/kWh (Transflow 2000) ³ ; \$1,450/kW, \$725/kWh ⁴	Potentially low \$/Wh cycled, high cycle life, pwr & energy decoupled, scaleable, low maintenance	Moderate efficiency, size, complexity
VRB flow battery	1828	600-1800	\$4,154/kW, \$692/kWh ⁵	Good cycle life, pwr & energy decoupled, scalable, low maintenance	Cost, company support, moderate efficiency
PSB flow battery	1094	160-185		Pwr & energy decoupled, scalable	No supplier exists, toxicity, cost, company support, moderate efficiency, maintenance
Lead-acid-carbon supercapacitor hybrid	N/A	500		High power density, high cycle life, low maintenance, existing mfging base	Low energy density, still in development, cost (expected to be reduced later),
NaS battery	810	450	\$2500/kW, \$347/kWh (Model PS-G50) ⁶	Good energy density, available, good cycle life, efficient, flexible, low maintenance	Cost, high temperature requirements, hazmat, monopoly supplier
NiCd	600	600		Good energy and power density, mature, low maintenance	Toxicity, cost, "memory effect"
Lead acid (traditional)	580	150-200		Low capex, available, mature	Short cycle life, low energy density, reliability, maintenance
Li ion	N/A	1333	\$333/kW, \$1,333/kWh ⁷	Excellent power density, good energy density, moderate cycle life, efficiency, safety improved	Cost, cycle life in some applications, concerns about lithium supply
High speed flywheel	N/A	1000	\$1,250-2,500/kW, \$5,000-10,000/kWh ⁸	High power density, excellent cycle life, low maintenance	Cost, low energy density
Low speed flywheel	459	380		High power density, minimal environ reqs, long life	Small scale kWh, more expensive than LA for kWh, standby losses
Supercapacitors	356-456	N/A		High power density, excellent cycle life, low maintenance	Low energy density, cost
SMES	509	N/A		Very high pwr, very high ramp	Very low energy density

¹ EPRI-DOE Handbook of Energy Storage 2003

² Ton, Dan; Sandia National Lab Report SAND2008-4247

³ Premium Power 2009 (\$250-350/kW + \$200-300/kWh)

⁴ Internal ZBB estimate; SMH Market & Liquidity 2008

⁵ VRB/SEI Feasibility Study 2007

⁶ Nourai, Ali; Sandia National Lab Report SAND2007-3580

⁷ Estimate discussed in Section 3.9

⁸ Beacon Power 2009

In order to understand which technologies are appropriate for an application, primarily the technology needs to be technically capable of accomplishing the task needed and able to deliver this performance in a cost effective way. The following two plots give an indication of how the technologies compare to one another in these ways. The first one, Figure 16, plots system power capability versus discharge time (energy stored). Comparison with the Figure 8 in the applications section allows one to find initial fits between technology and applications.

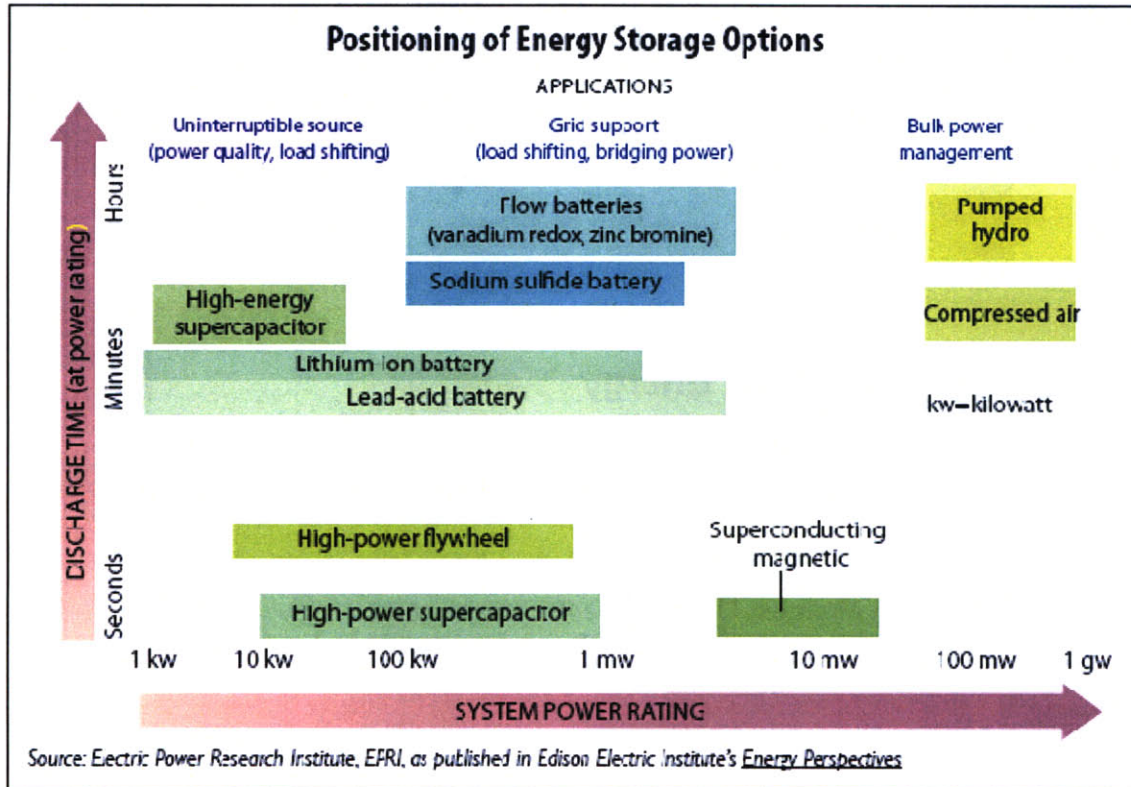


Figure 16: Power and Energy Positioning of Energy Storage Options (Climate Change Business Journal²⁴)

Figure 17 gives some indication of the rest of the picture from a financial perspective. This chart plots the technologies based on how much it cost to cycle a kWh through them (electricity round trip), based on capital cost, cycle life and efficiency, but not maintenance cost. This is a good way to view the cost of the system if one is willing to amortize the cost over the life of the system. This provides a first indication of when a technology can be competitive, as there are three technologies commonly in use today also plotted. It indicates that when natural gas peaker plants brought online and are setting the price of power, a number of emerging energy storage technologies could begin to be cost effective. See Figure 32 in the Appendix, Section 8.1, for a plot of the US power dispatch curve to observe when various plants are in use.

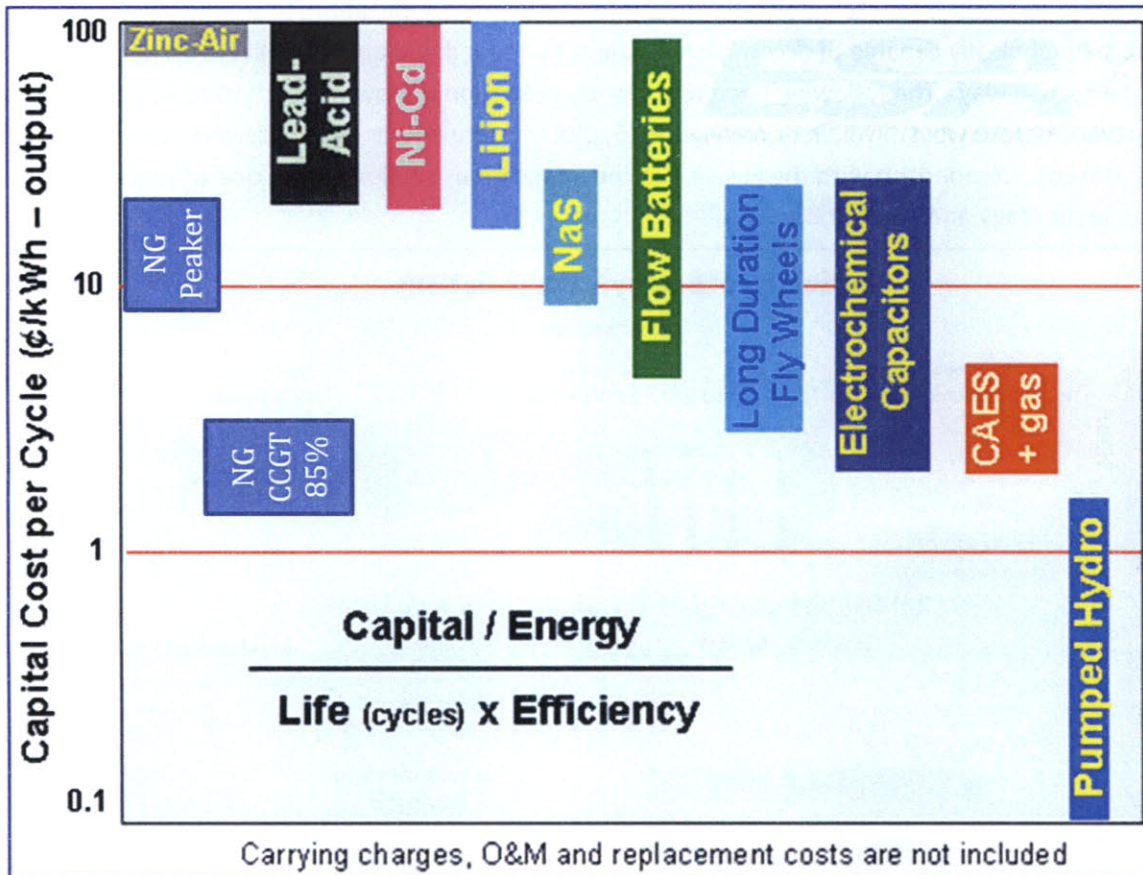


Figure 17: Capital Cost per kWh Cycled (Electricity Storage Association²⁵ and Credit Suisse Alt. Energy Review²⁶)

The following 2 tables are an overview of data on actual systems available on the market built by manufacturers noted in this section. Note that this includes only capital expenditure (capex) for the price, and does not attempt to account for operating expenses. The Variable Operating Cost (VOC) column only allocates a portion of the capex cost to each kWh cycled through the system using the same formula as in Figure 17.

Table 5: Overview of Installations of Various Technologies (Part 1)

Company	Technology	MW	MWh	Duration (hours)	\$ (Capex only)	\$/kW	\$/kWh
Premium Power	Zn-Br flow battery	0.50	2.80	5.60	1,000,000	2,000	357
ZBB Energy	Zn-Br flow battery	0.25	0.50	2.00	362,500	1,450	725
VRB Power	VRB flow battery	2.00	12.00	6.00	8,308,260	4,154	692
NGK Insulators	NaS battery	1.00	7.20	7.20	2,500,000	2,500	347
Example Li-ion	Li ion	1.00	0.25	0.25	333,000 (est.)*	333 (est.)*	1,333 (est.)*
Beacon Power	High speed flywheel	20.00	5	0.25	25,000,000-50,000,000	1,250-2,500	5,000-10,000

* Estimates for "average" lithium ion cells

Table 6: Overview of Installations of Various Technologies (Part 2)

Company	Efficiency w/o PCS (~10% less)	Cycle life (100% DOD)	VOC	Intended Implementation	Site	Source
Premium Power	80%	"Infinite"	.0408*	T&D - deferral	Expected Duke Power in PJM ISO	Premium Power 2009
ZBB Energy	80%	2,000+	0.4531	Industrial demand mgmt	Hypothetical	Internal ZBB estimate; SMH Market & Liquidity 2008
VRB Power	85%	10,000	0.0814	Renewables shifting	Proposed Donegal Ireland	VRB/SEI Feasibility Study 2007 pg 90
NGK Insulators	89%	2,500	0.1560	T&D - deferral	AEP in North Charleston, WV	Nourai, Ali; Sandia National Lab Report SAND2007-3580
Example Li-ion	90%	7000 (example)	0.2116	T&D - freq reg	Not Applicable	Author's Estimates
Beacon Power	85%	"Infinite"	.5372-1.0744*	T&D - freq reg	Beacon's site in Tyngsboro, MA	Beacon Power 2009 & Beacon grid freq reg white paper

* Assume cycle once a day for 30 yrs.

3.10. Common Trade offs

Some of the common tradeoffs with energy storage are as follows.

Energy capacity vs. Power capability

This is primarily notable in battery technologies like lead acid or lithium ion. In order to add more energy to the battery, one needs to add more active material to it to engage in the electrochemical

reaction. However, this additional active material creates more resistance to electricity flow in the battery and reduces its power capability. The inverse is also true when trying to design a high power battery. Flow batteries are interesting in this regard because the power and the energy of a system can be adjusted independently.

Capital expenditures (capex) vs. Operating expenditures (opex)

Some technologies are more expensive initially but require less ongoing cash outlays to maintain the ability to store the same amount of energy. A common example of a low capex, high opex technology is the lead acid battery pack commonly used in UPS's. Though they are inexpensive to buy, they need to be monitored by a technician for appropriate electrolyte levels, tested frequently since it is difficult to determine when they will fail otherwise, climate controlled since they only operate effectively in a narrow temperature range and replaced typically every 4 years. Many other technologies offer lower opex, but higher capex.

Cost vs. Performance

Another common tradeoff is between low cost and high performance. In all the energy storage systems, there are high performance versions and low performance versions. Inevitably the high performance ones cost more, and the analysis has to be done if the additional cost is offset in an improvement in performance which is relevant to the application. Performance parameters which commonly vary based on price are cycle life, energy stored in the system, power available from the system, energy density, power density, safety, toxicity, reliability, etc.

Core energy storage device vs. Energy storage system/pack

An energy storage system is only as good as the worst of the core energy storage device (battery/flywheel/etc) and the system surrounding it (power converters/cooling/safety/reliability). This means that there is a good deal of value to be added at the system level, and a good core energy storage device can be degraded by being part of a bad system.

3.11. Technology Trajectory

Energy storage has been improving since the first lead-acid battery was invented in 1859. However, compared to some technology trajectories which have become commonly referenced, like "Moore's Law", energy storage is progressing very slowly. Major advances in energy storage always require changing parts of a very tightly coupled system, which makes it hard to improve and optimize.²⁷ Additionally, advances come from novel manipulations of existing or new chemistries, which is very time intensive. The current interest in energy storage has sparked a great deal of research in the area which will surely push new solutions forward. However, the nature of the class of systems indicates that progress will be slow. This means that for near and medium term applications, the parameters of the technologies to be implemented will likely be similar to what they are today, or slightly improved.

Figure 18 shows the innovation trajectory of energy storage from an energy per unit cost (capex only) perspective, and Figure 19 tells a similar story of gradual innovation from a watt-hours per kilogram

perspective. For contrast, the impressive innovation trajectory of computer processing power per unit cost is shown in Figure 20. Note difference in log scales on the plots.

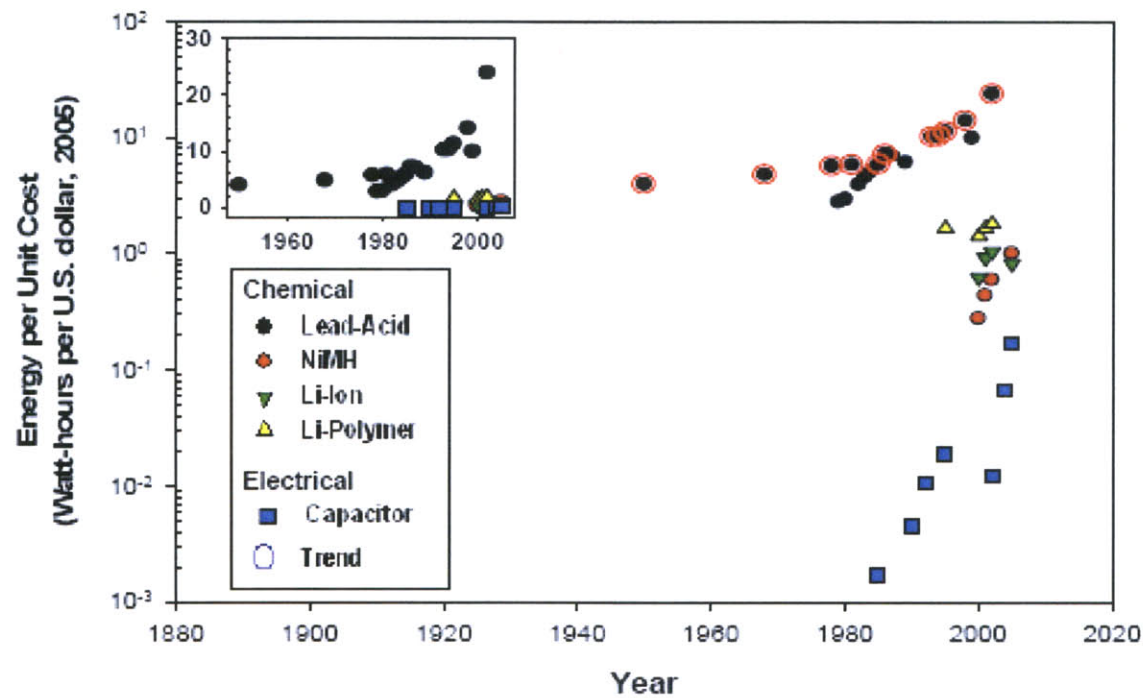


Figure 18: Battery Technology Trajectory in Energy Stored per Unit Cost (Koh and Magee²⁸)

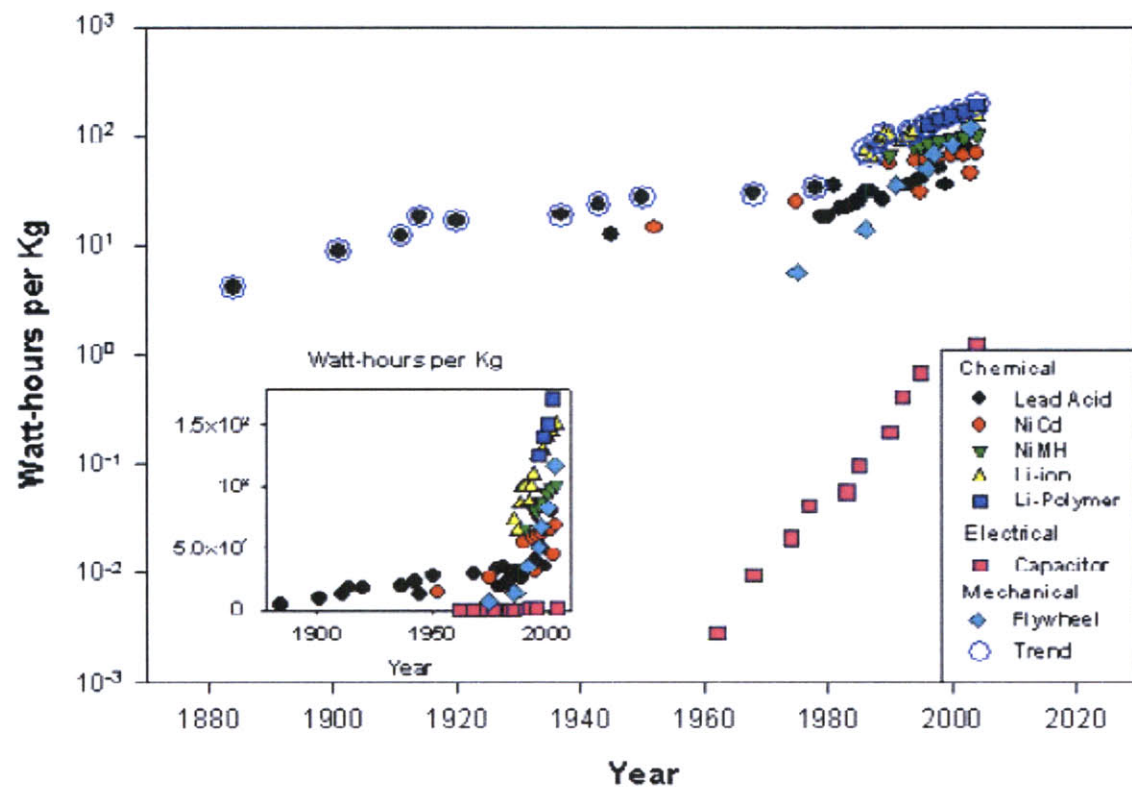


Figure 19: Battery Technology Trajectory in Watt-hours per Kg (Koh and Magee²⁹)

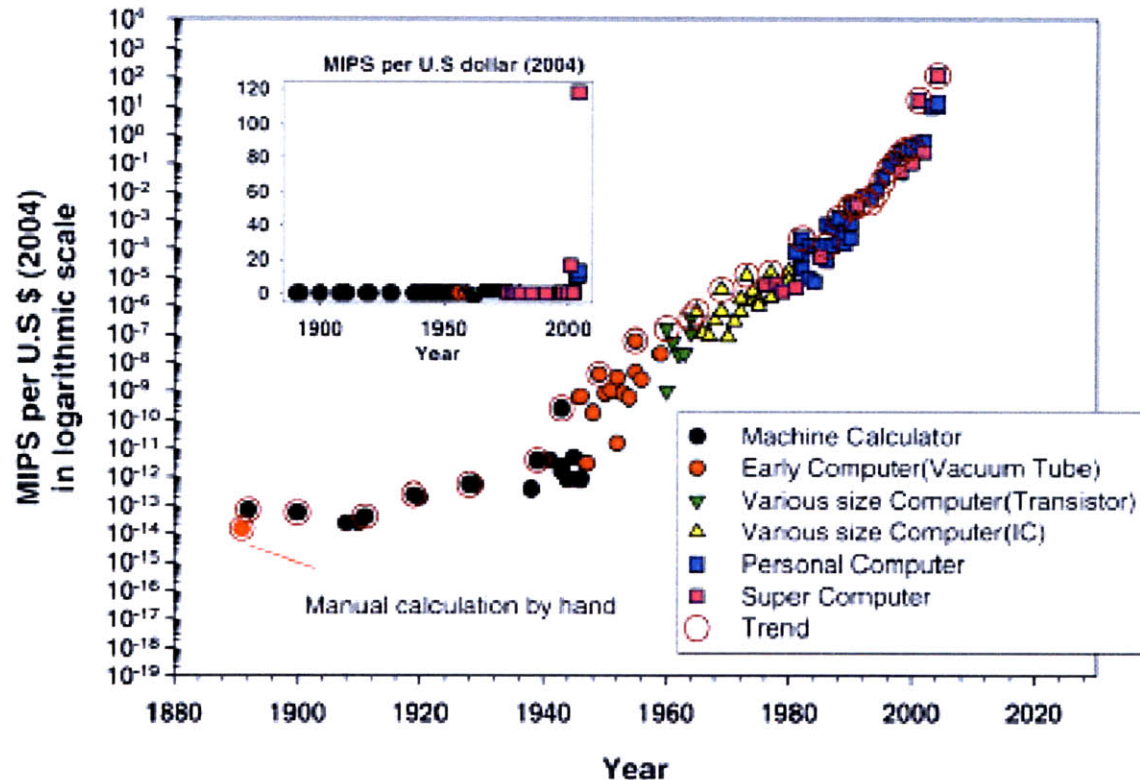


Figure 20: Microprocessor Performance Technology Trajectory in MIPS per US\$ (Koh and Magee³⁰)

3.12. System level competition

Energy storage technologies do not compete among themselves in a vacuum. There are a number of other ways in which some of these applications could be served. In order to be successful, energy storage will also have to successfully compete against a variety of alternatives with their own strengths and weaknesses. A full investigation of these additional competitive strategies is beyond the scope of this document, however some of them include:

- Construction of additional traditional infrastructure to transmit and manage power
- Efficiency
 - Improved efficiency could reduce further load growth and mitigate utilities needs to build new T&D
- Dynamic demand
 - Variable pricing via AMI influencing customer usage patterns
 - Appliances which individually manage demand based on signals from utility, like AMI or frequency reactive appliances
- Demand Response (DR)

- Aggregating energy consumption reduction during peak demand into a dispatchable load reduction service valuable to utilities
 - Commercialized by EnerNOC, Comverge, and others
- Thermal energy storage
 - Shifting cooling load by making ice at off-peak times and using that for cooling at peak times
 - Firming solar thermal generation's output with hot thermal storage
- Distributed Generation (DG)
 - Generating electricity from fuel at a number of non-centralized locations; can include heating or cooling at its location for increased system efficiency
 - DG technologies include: internal combustion engines, fuel cells, microturbines, even micro-sized nuclear power plants (Toshiba in Galena, Alaska, Hyperion)
- Electrolysis of water to produce hydrogen and oxygen
 - Xcel Energy and NREL are investigating this for a wind farm near Boulder, CO³¹

One point worth mentioning here is that information based technologies are likely to mature faster than ES technologies judging from the historical technology trajectory of information based technologies. Information based technologies, for instance enabling aggregation and fast response of distributed demand response, may be able to address some of the same applications as ES technologies at low cost and rapidly reduce the value which ES technologies can capture. A factor limiting their adoption is that the rollout of this technology is challenging because of the large number of nodes which need to be installed and integrated with a utility's system for it to be effective.

4. Implementations to Address and Combine Applications

There are a number of ways in which the applications previously discussed can be bunched together and addressed at a single ES installation. This section will briefly discuss a number of existing implementations of grid scale energy storage and briefly view them through technical, legal and economic lenses.

There are some general points which will influence the spectrum of implementations. For instance, the simplest strategy, initially expected by many observers, is to do energy arbitrage alone and sell it as a commodity product. However, this application, as can be seen in Section 4.1, does not generate large revenues for the energy storage asset. Most of these implementations are approaches to capturing more access to providing higher value applications. Frequently, a single implementation captures value from more than one application, however each implementation has been categorized with the type which is the most important to the individual implementation for revenue or experimental results.

This overview of implementations focuses on utility applications for next generation technology, so pumped hydro power, while incredibly valuable for many of these applications, is only mentioned in passing. Pumped hydro is currently the best solution to energy storage, however in most developed

parts of the world, the inability to site additional pumped hydro limits its usefulness for solving new challenges on the grid.

This overview views UPS and off grid markets as gateways to grid scale markets and so does not focus on them as ends in themselves.

As one reads through the listing of projects, there is a noticeable trend over the years from basic early engineering test stage, financially unsophisticated installations to economically motivated installations as technologies and strategies progress. The best use of energy storage on the grid is still being determined.

NYSERDA's revenue estimates include more applications and are more recent than the estimates from EPRI-DOE, so NYSERDA's are primarily discussed in this section, though both are displayed. The strategy of summing the high level benefit estimates is used here to get the total benefit for an implementation. It is intended to find an upper bound on benefits possible from an implementation. *It is not assured, or even likely, that this total benefit will actually be created.* However, the summed benefit does lay out a starting point for comparing technologies to implementations and seeing which combinations may be able to produce positive economic value. From that point more detailed modeling will be needed. Where available, case studies from company or research data are cited to give examples of economics found under specific operating conditions.

4.1. Wholesale Load Shifting

This type of implementation involves an energy storage system serving one application, to move electric power from one time of the day to another, typically from off peak to peak.

4.1.1. Example Implementations

- 1,080MW/(10,800MWh est.) Pumped-storage Hydroelectric plant at Northfield Mountain for FirstLight Power Resources in Northfield, MA 1972³²
- 100MW/(2,600MWh est.) CAES unit in McIntosh, AL 1991³³
- 1.2MW/1.4MWh GNB industrial Power/Exide Valve Regulated LA Battery on small village's island grid for Metlakatla Power & Light in Metlakatla, AK 1997^{34,35}
- 250kW/500kWh ZBB Zn-Br Flow Battery on a remote distribution feeder line for Australian Inland Energy (AIE) in New South Wales, Australia Sold in 2002³⁶

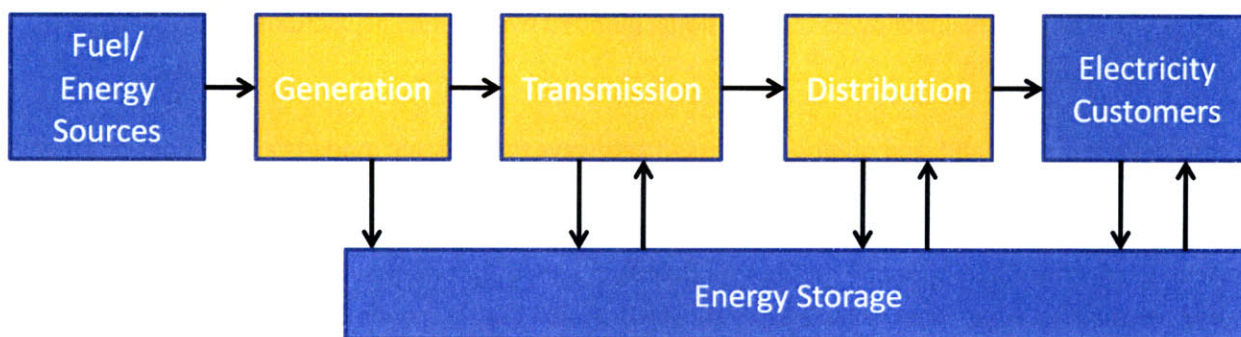


Figure 21: Primarily Sited with Generation, Transmission or Distribution

4.1.2. Considerations

Technical

Load shifting is technically feasible with a number of technologies at a variety of locations. To do this effectively, the installation will need to be close to transmission or major distribution lines.

Parameters that are important for this type of implementation are the ability to store a large quantity of energy and to cycle it inexpensively. Pumped Hydro is excellent at this application and typically dominates the market for load shifting wherever a facility is located. It also contributes heavily to other energy storage applications, like ancillary services, because it is able to respond to transients rapidly. However, the limit the scope of this document, pumped hydro is not extensively addressed here.

Legal

This implementation does not stretch the boundaries of regulation. For large scale plants, it is common for the systems to be owned by independent power producers in deregulated markets.

Economic – High Level Estimates

The estimated value from Table 3 of relevant benefits for this implementation is listed below. The required duration has been added, and the total benefit for this implementation is summed up to a total for comparison to possible methods of accomplishing this implementation, noted in Table 5. This total benefit is an upper bound on what is feasible from an implementation.

Table 7: Wholesale Load Shifting Benefits

Imp #	Implementation	App #	Applications Included	NY Unit Benefit, \$/kW, over 10 Years	CA Unit Benefit, \$/kW, over 10 Years	Duration Min (Hours)	Duration Max (Hours)
1	Wholesale Load Shifting	1	Wholesale load shifting	394	250	2	8
			TOTAL	394	250		

Upon comparison to Table 5, it is clear that none of the emerging technologies identified are likely to create positive value in this implementation, since to get the required duration of storage, they all cost far more in capital expenditure alone than is expected to be generated in revenue over 10 years.

Economic – Estimates from Individual Cases

Pumped hydro is typically the most competitive solution in these markets and is difficult for emerging energy storage system to compete with. For instance, though it is a large capital expenditure (pumped hydro's capital expenditure is listed by Sandia as \$1500-2000/kW, and Northfield Mountain's construction cost \$634/kW or roughly \$63.40/kWh in 1972 dollars, or \$3235/kW or roughly \$323.50/kWh in CPI adjusted 2009 dollars³⁷), it has an very long lifespan to amortize over and has the ability to provide additional electrical services with its fast response time, low cycled energy cost (based on very low non-energy variable operating cost), high energy capacity and high power.

Energy pricing is volatile on the wholesale market, more so than retail tariff structures. Since the high value times for energy resale are often just price spikes for an hour, it is important that the ES system be able to discharge at high power at those times. Typically, it can charge more gradually over the generally less expensive and less volatile off-peak times. Figure 22 shows example price data from the Cross Sound Cable connecting New York and Connecticut.

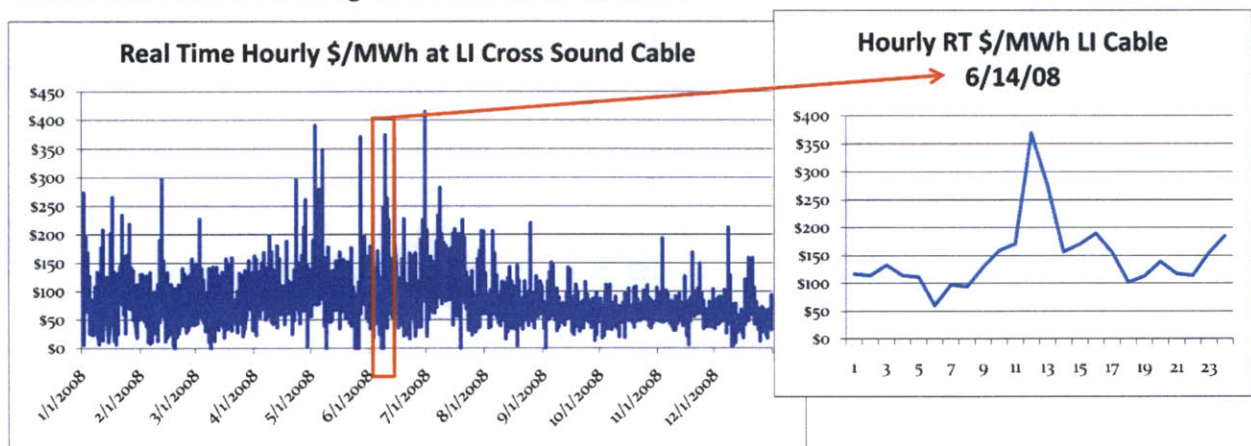


Figure 22: Real Time Hourly Data from Long Island Cross Sound Cable (NE ISO³⁸)

In unusual grid situations, if next best option is very expensive, like a diesel generator using fuel shipped in over long distances, the economics for using emerging energy storage technologies for load shifting can be quite good. This can be seen in the 3 year payback period for the \$1.5M LA battery in Metlakatla, AK where it was displacing a diesel engine which carried the peak load on the island. It displaced \$400,000 annually in fuel cost as well as displacing other operating costs and it was used for improving power quality on the island, which was previously very poor³⁹. It is these exceptional situations where emerging energy storage technologies may have a chance at near term acceptance for load shifting focused implementations.

4.2. Renewable Power Management

4.2.1. Example Implementations

- 2MW/12MWh VRB Inc. Vanadium Redox Flow Battery at Sorne Hill 39MW Windfarm for Tapbury Mgmt in Buncrana, Inishowen, Co. Donegal, Ireland. **Sale made** in 2007.^{40 41 42}
- .250MW/.5MWh ZBB Inc. Zinc-Bromide Flow Battery at Dundalk Institute of Technology's 850kW wind turbine for DkIT's Centre for Renewable Energy in Dundalk, Co. Louth, Ireland. **Sale made** Dec. 2008.⁴³
- 1MW/7.2MWh NGK NaS batteries at 11MW Wind farm for Xcel Energy and Minwind Energy in Luverne, MN. **Operational** in Q1 2009.⁴⁴
- Variety of previous installations in Japan using NGK NaS batteries.

Other information (technical economics paper)

- 1.5MW/1.5MWh ZBB Inc. Zinc-Bromide Flow Battery at hypothetical 20MW Windfarm. **Calculated** in 2002.⁴⁵

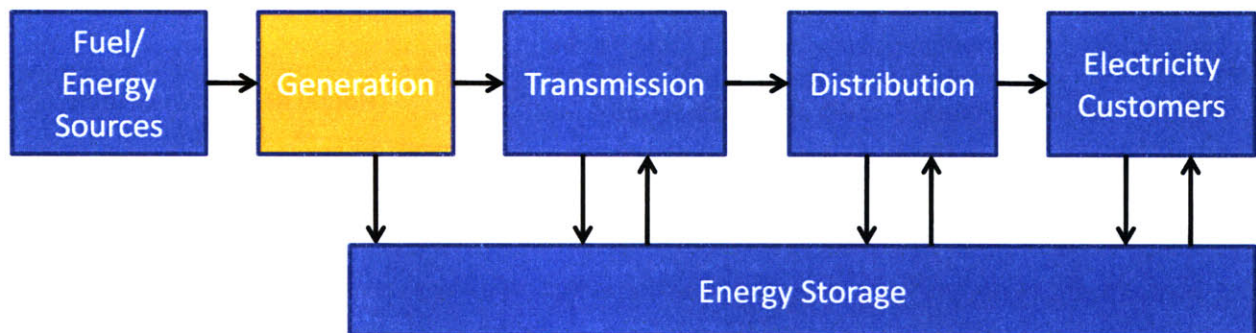


Figure 23: Primarily Sited with Generation

4.2.2. Considerations

Technical

This category of benefit focuses on damping instantaneous power fluctuations on wind farm output which allows reduced power “spillage” at high wind conditions, improved capacity factors for the wind farm installation and improved output power stability throughout the day. Since wind varies more dramatically than solar radiation, many of these installations focus on wind firming. However, PV could be an attractive application as well; one aspect in favor of adding storage for a solar PV farm is that PV’s output is DC so the power conversion system would be able to avoid the losses of an extra AC-DC conversion to get DC for the battery (as opposed to the AC output of a wind farm). The PV system and the battery system could also share the same output inverter as well for additional cost savings.

The location of the storage system for a given renewable power site is typically co-located with the renewable power site. This is because the limiting link in the system is typically the transmission capacity, and the smoothing effects of the storage system produces a less peaky output to the transmission line which will not require as large of a transmission line and makes transmission more

efficient. However, if transmission was not an issue and regulation allowed it, it could be beneficial to site the storage system with the load center, as then the storage system could be reduced in size because it would be balancing a number of less correlated inputs, such as load demanded and wind farm power from various sources, which would balance out some of the variability.

This tendency for co-location restricts the options for storage to systems which can be located conveniently next to the renewable power site. Therefore, pumped hydro is less likely to be a primary player in this arena. CAES is also challenging to site, though less so. There is work underway on building CAES near a wind farm in Iowa (Iowa Stored Energy Park⁴⁶), but this has not yet come to fruition. CAES using above ground compressed air storage in pipes may be a more flexible option for siting near wind power. If CAES can be sited, EPRI's 2004 study on storage paired with wind generation indicates that the economics could be very favorable.⁴⁷ The flexibility in location for many of the energy storage technologies based on batteries or flow batteries make them convenient choices for co-locating with wind farms.

Legal

The regulatory support for grid scale energy storage in any application varies from location to location, and renewables firming is no different. For instance, one cannot assume that an ES system can get paid for both firming and frequency regulation. The variation in the revenue expectations for each site mentioned in this implementation indicate some of the variability expected. ZBB's 2002 model for supporting a windfarm derives most of its financial benefit from avoided spillage of electricity in high wind conditions. VRB's revenue estimates for their wind farm co-located storage system include various types of ancillary services revenues including operating reserve payments, reactive power payments, black start payments and capacity payments. Xcel Energy's project, using NGK's NaS batteries focuses on the research they are doing and views the primary value they are gaining out of it as merely the data they will receive off the system for evaluation of its performance.

One other aspect which is likely to cause some uncertainty in how storage is deployed is the capacity factor allowed for ES systems that are integral to a renewable power plant versus those which are standalone. Currently, an ES system's capacity value can be derated when it is co-located with a renewable power plant. However, if the same ES system were sited alone, it would obtain a larger capacity value. The reduction in value of the ES system's revenues based on this factor will have to be compared against the amount gained by having the ES system available for firming.

Economic – High Level Estimates

There are a number of ways which an operator could produce revenue from a renewable power firming operation. Multiple applications could be bundled together into one implementation. The estimated value from Table 3 of relevant benefits for this implementation is listed below. The required duration has been added, and the total benefit for this implementation is summed up to a total for comparison to possible methods of accomplishing this implementation, noted in Table 5. This total benefit is an upper bound on what is feasible from an implementation.

Table 8: Renewable Power Management Benefits

Imp #	Implementation	App #	Applications Included	NY Unit Benefit, \$/kW, over 10 Years	CA Unit Benefit, \$/kW, over 10 Years		Duration Min (Hours)	Duration Max (Hours)
2	Renewables Management	7	Operating Reserve	258	NA		10 minutes	1
		13	Renewables shifting	832	655		4	6
		14	Renewables firming	323	172		1	3
			TOTAL	1413	827			

An alternative solution to valuing the benefits of storage is to look at the next best solution for transmitting peaky renewable power. This would be to enlarge the transmission lines, and this is estimated at \$500-1000/kW for the upgrade. This would not increase the value of the electricity generated by shifting it to valuable times, though, so it will not create as much value as the total an ES system could.

Upon comparison to Table 5, it can be seen that while no technology stands out as a clearly economically viable option, a few might be with some modification. For instance, if 4 hour discharge is assumed sufficient to generate all the benefit cashflow streams mentioned above, the Premium Power Zn-Br system at \$2,000/kW could be modified to reduce its duration to 4 hours, and its price would be approximately \$1,550/kW (system-level), based on Premium Power's pricing guidance. With that reduction in capex, it would be close to economically neutral. ZBB's Zn-Br system would benefit from the simplicity of changing the duration of a flow battery, which might allow them to extend the duration of their system from 2 hours to 4 hours without major capex increases over the current \$1450/kW, however the system's cycle life is not as attractive as Premium Power's and would likely not capture the full 10 years of value listed here, so it is not likely to be economical. If NGK reconfigured the 7.2 hour PS-G50 battery packs they sell to design for twice the power output and only 3.6 hours of output, their \$2,500/kW cost would drop considerably. There are more power oriented modules NGK builds which may be more appropriate for this application. It may still be challenging for a NaS battery to last for 10 years of cycling though since it is only rated for 2,500 100% DOD cycles, so it is unlikely to be economical. Though a typical lithium ion system has a low \$333/kW capex, it only offers about 15-20 minutes of discharge and would be prohibitively expensive if reconfigured to offer 4 hours of discharge. The other technologies are even less attractive.

Economic – Estimates from Individual Cases

A few of the companies installing ES systems for renewable power firming have released estimates on economics for specific projects. VRB estimated in 2007 that its proposed Sorne Hill project would produce a 11.7% project IRR before taxes or leverage and 17.5% project IRR after taxes while using a "commercially viable level of gearing", specifically 80%. This estimate includes 3.65 Euros per MW in enlarged capacity payments, which is an incremental improvement over capacity payments to the wind

farm without energy storage, about 57-58 Euros per MW, but not close to the full capacity payment for a fully dispatchable power plant of 86 Euros per MW. ZBB estimated in 2002 that the benefits of a hypothetical wind firming system to be an NPV of \$4.0M before tax and \$2.5M after tax, or an after tax IRR of 21.6%, including benefits primarily from avoided wind power spillage but including some smaller benefits from onsite backup power.

EPRI's 2004⁴⁸ estimated results for 5 different wind-firming-type applications and application combinations using NaS batteries and calculated NPV's on various strategies between -\$2.9M and \$13.1M each with initial costs of around \$18M for a 10MW system. They also estimated the NPV for 4 possible projects with VRB batteries with resulting NPV's of -\$5.5M to \$6.0M each with initial costs of around \$25M for a 10MW system. For CAES systems, EPRI estimated NPV's of -\$1.4M to \$23.2M with an initial cost around \$8.5M for 10MW systems with discharge times of 5hr to 12hr. They did not estimate for the Zn-Br system, as there were no suppliers at that time. The one with the best NPV in both battery cases combined 3 applications: forecast hedging to avoid varying from the amount of power contracted, frequency support on output of wind farm power and frequency regulation control on grid connected to wind farm. The best application combination for CAES was similar to that for the batteries, but included time shifting.

4.3. T&D Capacity Deferral Focused

4.3.1. Example Implementations

- 2MW/2MWh ZBB Zn-Br Flow Battery at Pacific Gas and Electric (PG&E) distribution substations in California 2004⁴⁹ Delivered system reduced to 0.25MW(continuous)/0.5MW(peak)/500kWh.⁵⁰
- 0.25MW/2MWh VRB Vanadium Redox Battery at Utah Power distribution substation in Utah, operational 2004⁵¹
- 1.0MW/7.2MWh NGK NaS Battery at Chemical Station substation for AEP in North Charleston, WV, operational 2006⁵²
- 2MW/14.4MWh NGK NaS Battery, 3 located at substations in OH, WV and IN for AEP, operational 2008.⁵³
- 4MW/24MWh NGK NaS Battery, substation in TX for AEP, proposed for 2009.⁵⁴
- 0.25MW/0.75MWh Axion Power Lead Acid Carbon hybrid battery/supercapacitor working with Gaia Power Technologies planned for use at a Delaware County Electric Cooperative (DCEC) site funded by New York State Energy Research and Development Authority (NYSERDA) site beginning in H1 2008. Deployment status as of Sept. 2008: install delayed to Q1 2009 partly due to Environmental Health and Safety assessment.^{55 56}
- 0.5MW/2.8MWh Premium Power Zn-Br Flow Battery at Duke Power in PJM ISO expected to be delivered H1 2009.⁵⁷ It may be used for capacity deferral.
- Additional installations based on traditional lead acid and nickel cadmium batteries however these systems are not expected to scale economically to future systems.⁵⁸

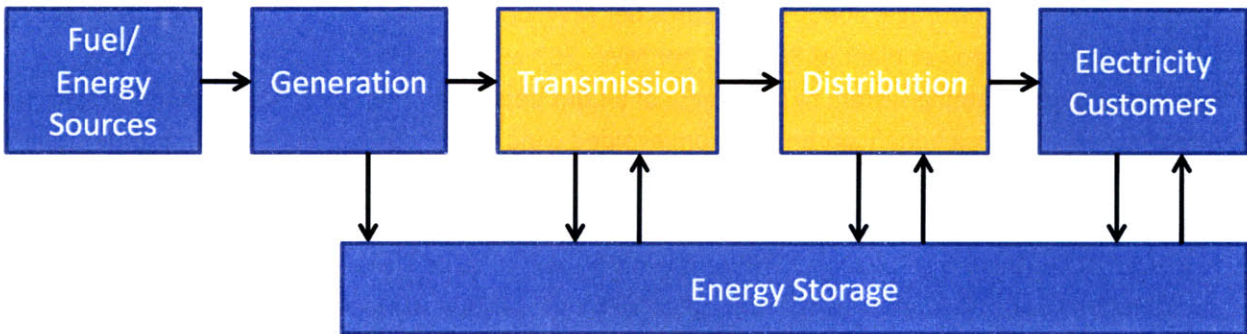


Figure 24: Primarily Sited with Transmission and Distribution

4.3.2. Considerations

Technical

There are a number of storage technologies competing for use in this type of implementation. All of the implementations claim to be technically successful, in that they can store energy and release it as needed for some benefit to the system operator. The primary benefit these implementations offer is to defer transmission or distribution build out for the utility. They can also be operated for benefits from short term load shifting, ancillary services, like frequency regulation and operating reserve, and benefits from improved system reliability.

These implementations are typically sited at existing distribution substations. This is done so that they can utilize the same switching hardware and high voltage connections, they can most easily obtain siting permits and they can be utilized to reduce the electrical burden on substation bottlenecks as well as line limitations. Since they are typically sited at substations with high voltage lines, they have good efficiency for providing ancillary services.

The characteristics of these implementations, including the need to discharge to support the substation's load for a number of hours, drives the use of energy storage systems with power to energy ratios in the range of 1/2 to 1/7. This ratio makes the higher energy ESS's the best choices for this kind of implementation and the choices of technologies observed for these implementations bears that out. Another useful characteristic when using these systems for capacity deferral is that the ESS be easily movable, so that once the upgrade to the T&D system is completed, the ESS can be utilized at another bottleneck substation. In this regard, some of the newer technologies which have been built into road-going semi-trailers, like the Premium Power Zn-Br flow battery and the Axion PbC hybrid battery, offer additional value from their mobility. In contrast, NGK's NaS batteries must be housed in a purpose-built stationary building.

Legal

Regulation differs across jurisdictions, frequently there are restrictions on a single entity accruing all the benefits of an ES system, especially when some benefits are market based (ie. load shifting or ancillary services), some are operational (ie. capacity deferral) and some are incentive based (ie. potentially reliability in some regions). For instance, though a T&D utility may be able to create value by using

energy storage for T&D deferral specifically, “a restructured T and/or D utility is typically not allowed to accrue the benefits from owning an energy storage facility related to load shifting, i.e. replacing high cost peak energy with low cost off-peak energy, or to sell ancillary services from such an energy storage facility. Either or both could make the difference in achieving attractive economics that are otherwise lacking if based only on deferring a more capital-intensive upgrade in the system.”⁵⁹

Also, because of the way the utilities are compensated based on a percentage of costs, reducing their costs for building the grid infrastructure may not be directly aligned with their interests, even though ratepayers would like to see the solution implemented which provides the required function for the least cost. For the capacity deferral revenue stream to work, the compensation of the utilities must be allowed to profit from energy storage as much as traditional methods, however their actual compensation structure will vary between jurisdictions.

Economic – High Level Estimates

There are a number of ways which an operator could produce revenue from a T&D capacity deferral focused implementation. Multiple applications could be bundled together into one implementation. The estimated value from Table 3 of relevant benefits for this implementation is listed below. The required duration has been added, and the total benefit for this implementation is summed up to a total for comparison to possible methods of accomplishing this implementation, noted in Table 5. This total benefit is an upper bound on what is feasible from an implementation. There are some additional applications noted but not included in the total because it is unlikely that full value could be captured for all applications at once.

Table 9: T&D Capacity Deferral Focused Benefits

Imp #	Implementation	App #	Applications Included	NY Unit Benefit, \$/kW, over 10 Years	CA Unit Benefit, \$/kW, over 10 Years	Duration Min (Hours)	Duration Max (Hours)
3	T&D Capacity Deferral	1	Load shifting	394	250	2	8
		5	T&D Capacity deferral	1200	1,067	2	6
		4	Reduce Transmission Congestion	72	NA	2	6
		11	Reliability	359	359	5 minutes	5
			TOTAL	2025	1676		
			(additional ways to create more value)				
		7	Operating Reserve	258	NA	10 minutes	1
		6	Frequency Regulation	789	NA	10 minutes	1
		12	Power Quality	717	717	10 seconds	1 minute

Upon comparison to Table 5, it can be seen that if a number of different value streams could be captured by one entity, it is possible that some of the emerging technologies could be cost effective for this. As mentioned in the legal section above, capturing all the value streams is very challenging and has not yet been accomplished though. Most of the technical requirements for this implementation are similar to that for renewables shifting and firming, but the potential benefit is quite a bit higher (\$2025 vs. \$1413 for NYSERDA's estimates). The one major additional technical requirement is mobility to allow it to be easily relocated to where the need is greatest.

Therefore, in this case, the same two technologies as for renewables shifting and firming are still interesting, however the mobility of semi-trailer mounted Zn-Br is very attractive and the permanent installation to a building nature of NaS is not attractive. This being the case, the Zn-Br system from Premium Power, especially with a reduced duration to 4 hours, is likely to be economically positive over a 10 year project lifespan. ZBB's system is less attractive than Premium Power's as it will need to be made more expensive than the baseline \$1,450/kW by adding duration and will also likely not last the full 10 years since it is only rated for 2,000 cycles (1 full cycle a day is 3,650 cycles over 10 years).

Economic – Estimates from Individual Cases

The most supported estimate available for the economics of a NaS installation is from a Sandia report written by Ali Nourai at AEP which estimates the fully delivered and installed cost of the next newly constructed NaS system at \$2500/kW.⁶⁰ The system AEP installed was 1MW (continuous), and because of temporary preferential pricing from NGK for the NaS batteries, the total capital cost was approximately \$2.3M. The report primarily focuses on technical knowledge gained in the installation and operation of the NaS ESS at North Charleston, WV, but it does also give some indication of the revenue such a project could produce. Assuming PJM Location Marginal Pricing and full utilization of the 1MW (continuous) system for first 11 months of its operation (July 2006 to May 2007), the ESS would have saved AEP \$57,000, which extrapolates out to \$62,182/yr and comes out to \$445,844 in total value over 10 years or \$446/kW over 10 yrs assuming 7.17 scale factor for 10 year present value (10% annual discount factor and 2.5% market growth). This matches up fairly closely to the estimate in Table 3 of the 10 year benefit of Application 1. AEP claims its figure could be improved had the system been operated for optimum energy arbitrage instead of system demand. This only includes one possible revenue stream, the market price of short term load shifting. Clearly, without some additional revenue streams, the installation of such a system is not economically sustainable. However, based on the value of the other applications mentioned in the table above, which could be addressed with the same storage system, a hybrid solution could be financially viable. The question still remains if the owner could accrue all that value though.

Another view of a similar issue is shown in Figure 25 from a presentation from Ali Nourai of AEP based on EPRI-DOE figures for the cost of storage versus the alternative infrastructure construction cost. When the cost of some ESS solutions are compared to using a bundle of applications similar to the applications accessible with a substation capacity deferral implementation, ESS solutions can theoretically be attractive. Figure 25's cost and benefit values are directly from EPRI estimates; the technology costs are also included in Table 4. The application benefits are simply the avoided infrastructure cost for the utility.

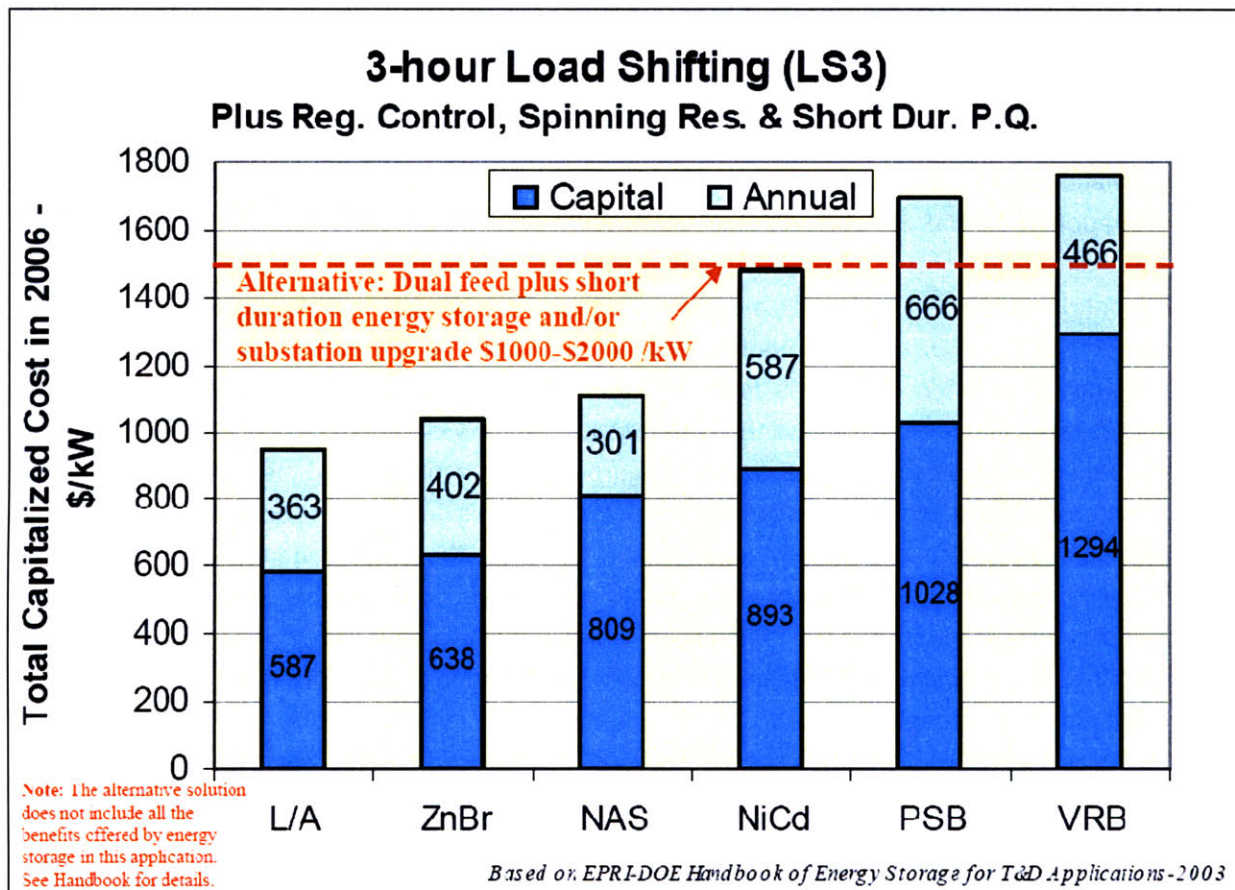


Figure 25: Cost versus Benefit of providing 3 hour Load Shifting with Other Services Using Various ES Technologies (AEP⁶¹)

4.4. Ancillary Services Focused

4.4.1. Example Implementations

- 0.6MW/0.2MWh Saft Lithium Ion battery at an EDF Energy site in the UK, announced 2008. Deployment status uncertain.^{62 63}
- 2MW/0.5MWh A123 Lithium Ion battery at AES power plant site in Southern California 2008.^{64 65}
- 1MW/0.25MWh AltairNano Lithium Ion battery at AES site in Indiana 2008.⁶⁶
- 1MW/0.25MWh Beacon Power flywheel smart energy matrix in NE ISO's Alternative Technologies Regulation Pilot Program in Tyngsboro, MA. Operating since Jan 1, 2009.⁶⁷
- 20MW/5MWh Beacon Power flywheel smart energy matrix as standalone frequency regulation power plant in NYISO in Stephentown, NY. Environmental assessment approved March 11, 2009.⁶⁸

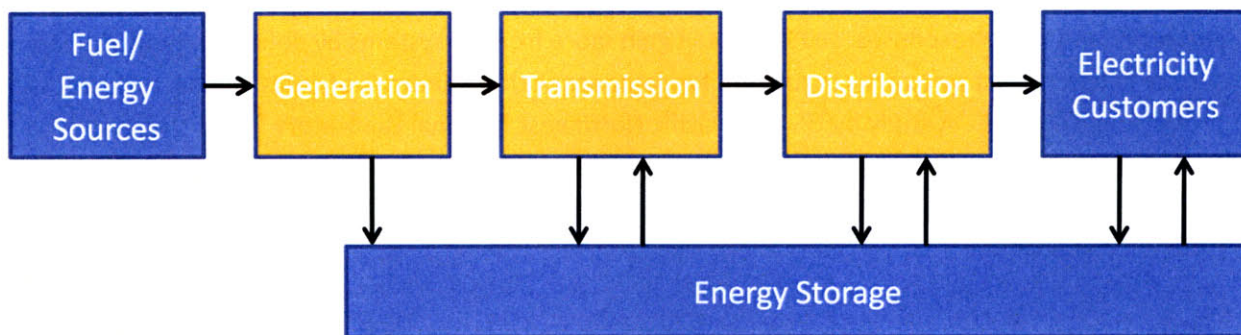


Figure 26: Primarily Sited with Generation, Transmission or Distribution

4.4.2. Considerations

Technical

For this type of implementation, there is a great deal of recent activity. The oldest systems have been installed in just the past few months so it is too early to have much data on the results, however, it appears that the systems will be able to technically accomplish their goals.

This implementation is currently focused exclusively on providing frequency regulation services to the grid and getting paid for them on the open market. This dictates that these are power oriented ESS installations, and would not be competitive for applications like T&D deferral. Both lithium ion and flywheel technologies are well suited in this regard. The cycle life of the technology is critical in this application as well, since frequency regulation requires the ESS to be almost constantly cycling at varying depths of discharge. In this regard, the flywheel based systems have an advantage, since they have an extremely long cycle life at all depths of discharge.

Various strategies for locating the first few installations have been attempted. A123/AES has sited theirs at a power plant, Beacon Power has sited their first one at their headquarters, and AltairNano/AES appears to have sited theirs in Indiana but is not clear on specifics. One factor driving siting considerations is the efficiency advantage for an ES system providing frequency regulation services via a high voltage line. There are also R&D operating considerations which have likely driven Beacon to site next to headquarters. For further roll outs, consideration of the legal implications of the location need to be optimized as well. For instance, siting a frequency regulation ES system with a thermal power plant, as A123 has, may allow the power plant to operate at a higher efficiency state of operation as well as enable the ESS to sell frequency regulation services which were previously provided by cycling the power plant. Beacon Power appears to be operating their systems as standalone sites and simply gaining revenue from the open market for frequency regulation. Beacon prefers to site near distribution substations to avoid interconnection charges.⁶⁹

A difference between ISO's is in the details of how frequency regulation is requested from the ISO. ISO's systems are commonly currently configured to request frequency regulation up or down and only demand a response within about a minute. Also, they commonly use trinary requests - that is "maximum regulation down", "no regulation" or "maximum regulation up". ES systems allow for much

smoother and faster responses, so ISO's could gain more from ES systems by defining a new ancillary service category, fast frequency regulation for response within hundreds of milliseconds, and also using proportional control. A study by US DOE Pacific Northwest National Laboratory found that fast frequency regulation was far more efficient than traditional frequency regulation with a time lag, such that CAISO could reduce its procurement of frequency regulation by up to 40% if it used only fast frequency regulation.⁷⁰

Legal

FERC Order 890 required the ISO/RTOs change their tariffs to permit "non-generation" resources to bid into the Ancillary Services markets. Some ISO's have changed their tariffs to comply with this ruling and changed their own tariffs to make the ISO compatible with grid scale energy storage on the open market for frequency regulation. Beacon Power has been lobbying hard for this to happen and their results enable all the players access to the market. Four ISO's have opened up their systems to intentionally allow and encourage energy storage onto their grids.⁷¹ For more information, see Appendix Section 8.2.

- ISO New England: Created an Alternative Technologies Regulation Pilot Program, commenced November 18, 2008
- Midwest ISO: Created new Stored Energy Resource (SER) category in their Ancillary Services Market tariff, approved by FERC on December, 2008; operation expected in June 2009
- New York ISO: A new Limited Energy Storage Resource (LESR) to provide Regulation Service, approved by FERC March 2009; operation expected in May 2009
- PJM (Pennsylvania, New Jersey and Maryland Interconnection): Ancillary services market open

CAISO has changed their tariff to comply with the FERC directive, but existing market rules and MRTU (Market Redesign and Technology Upgrade) market rules are a barrier to storage facilities. For instance, existing market rules for regulation require delivery of energy for a one hour period. Energy storage facilities have limited capacity and will have difficulty in meeting this requirement cost effectively.⁷²

CAISO is developing rules which encourage energy storage under the Integration of Renewable Resources Program (IRRP). Final tariff is expected to be filed with FERC in June 2009. A123 is siting their ESS with a power plant in California, possibly because of the current tariff arrangement, so that the power plant can back up the ESS as needed. Additionally, AES (A123's customer) is international and may be interested in deploying ESS's to other countries with ancillary services rules less amenable to energy storage.

Economic – High Level Estimates

There are a number of ways which an operator could produce revenue from a T&D capacity deferral focused implementation. Multiple applications could be bundled together into one implementation. The estimated value from Table 3 of relevant benefits for this implementation is listed below. The required duration has been added, and the total benefit for this implementation is summed up to a total for comparison to possible methods of accomplishing this implementation, noted in Table 5. This total benefit is an upper bound on what is feasible from an implementation. EPRI-DOE did not calculate CA

figures for these applications. Also, operating reserve is not currently an addressable market, but may be in the future.

Table 10: Ancillary Services Focused Benefits

Imp #	Implementation	App #	Applications Included	NY Unit Benefit, \$/kW, over 10 Years	CA Unit Benefit, \$/kW, over 10 Years	Duration Min (Hours)	Duration Max (Hours)
4	Ancillary Services	7	Operating Reserve	258	NA	10 minutes	1
		6	Frequency regulation	789	NA	10 minutes	1
			TOTAL	1047	0		

Upon comparison to Table 5, it can be seen that a lithium ion systems are attractive for this implementation. Since they are currently only able to address the frequency regulation portion of the opportunity, the theoretical revenue is \$789/kW over 10 years or \$110/kW per year. Because lithium ion batteries might not last 10 years in this abusive cycle environment, they would have to pay off quickly. The low capex of the system makes the payback rapid enough to fit within a reasonable expectation about the batteries cycle life. For instance, the total discounted revenue after 4 years is approximately \$379/kW, so if it could last for only 4 years, it would likely pay back. There is ongoing work to determine how long lithium ion cells will last in this environment, however, they are expected to last for 10 or more years in the less cycle intense electric vehicle application.

Alternatively, Beacon Power's initial 20MW flywheel implementation is expected to cost \$2,500/kW with future 20MW sites expected to cost \$1,250/kW, however their cycle life span is claimed to be infinite. If the Beacon's system can last for 20 years, it could make \$1,164/kW; if it can last for 30 years, it can make \$1,353/kW. From this simple analysis, it appears the initial implementation will not be economical, but the future ones could be if the long term risk can be mitigated.

Zn-Br systems have high \$/kW pricing and only limited potential for cost reduction on a per kW basis, so they are unlikely to be economical in this implementation. NaS batteries as currently built have high \$/kW pricing, but with a significant pack redesign, their \$/kW could likely be significantly decreased. It is unclear if it could be decreased enough to be cost efficient for this implementation, since it would have to be reduced by 60% just to be economically neutral; at this time they are not.

Economic – Estimates from Individual Cases

A key element of the value of frequency regulation service is the cost of operating the system. As shown below, the revenue produced by an ES system would increase rapidly as the operating cost goes down. The maximum revenue expected to be obtained is running a \$0 marginal operating cost system all day everyday at the NYISO 2005 annual average rate of \$40/MW-hr (Minimum is \$14/MW-hr, maximum is

\$250/MW-hr). See Appendix Section 8.2 for a plot of the fluctuations in one day's frequency regulation pricing.

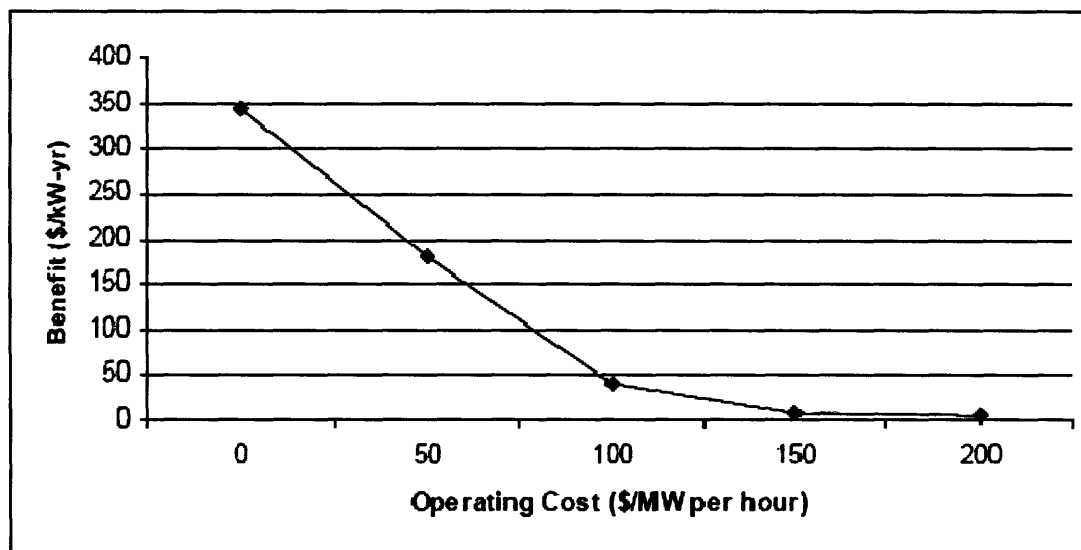


Figure 27: ES Marginal Operating Cost vs. Frequency Regulation Benefit (NYSERDA⁷³)

Beacon Power indicates that they expect their first 20MW frequency regulation plant to cost \$50M to build and install (\$2500/kW), and the second one would be \$25M (\$1250/kW). They expect \$10M in revenue annually at 70% EBITDA⁷⁴, which implies revenues of \$500/kW installed per year or \$3,585/kW over 10 years when viewed as NYSERDA does. This \$500/kW annually assumption appears to be quite optimistic and indicate an expectation of near \$0 marginal operating cost for the ES systems and also premium pricing for fast frequency regulation. The flywheels will likely be able to last more than 10 years. Beacon also mentioned that they will be able to gain some value from REC's based on the projected .75% to 1.5% improvement in power plant efficiency (net including flywheel losses) their product enables and this cash flow may be included in that \$10M estimate. Beacon intends to design, build, own and operate these systems for the near future, viewing them self as a "vertically integrated utility". Later on they may sell their ESS's to customers in a more traditional manner like other existing market players.

An interesting aspect to note is the lack of visibility on the elasticity of frequency regulation pricing. There will be significant variations in supply and demand in the coming years caused by additional wind on the grid and more storage on the grid. With the current boom in wind development and grid scale energy storage still emerging, it appears likely in the near term that wind will outpace storage and pricing will rise, however longer term pricing is less certain.

4.5. Community Support

4.5.1. Example Implementations

- 20-30kW/40-120kWh Storage supplier and technology are TBD but PHEV type Li-ion pack is likely. New concept from AEP, they plan to install a few prototypes in Columbus, Ohio in 2009, and 0.5MW worth in 2010.^{75 76}

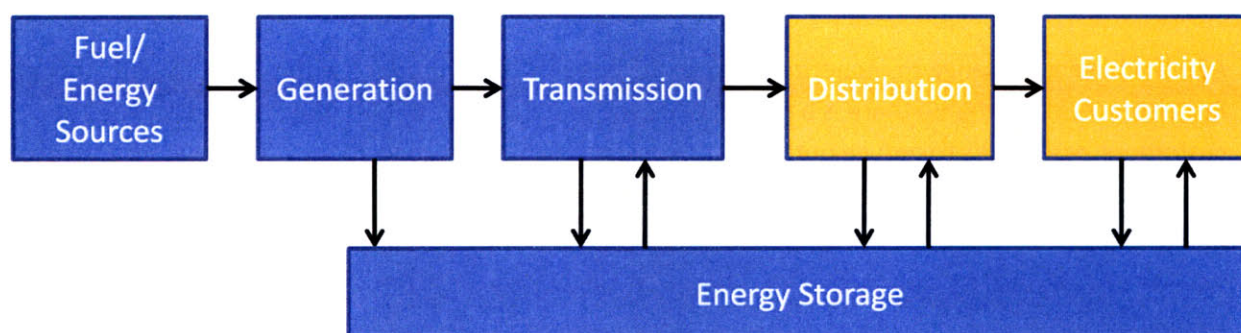


Figure 28: Primarily Sited at the End of a Distribution Line at Customer Site on Utility Side of Meter

4.5.2. Considerations

Technical

AEP is optimistic that stationary 20-30kW battery packs with 2 to 4 hour discharge duration will be useful for providing “community energy storage” by co-locating them with existing final step down transformers in residential neighborhoods. In this way, they envision being able to provide improved service reliability and efficiency to end customers while being able to derive some of the benefits of substation type storage without using batteries from a monopoly supplier (NGK). The pack they plan to use is similar to that used in PHEV’s, so they plan to leverage the synergies with PHEV’s for pricing and performance competition between suppliers. Siting the packs at these low voltage final step down transformers means the installation is not as expensive as for high voltage installations and each power converter is less expensive. Also, having many of them in the field means that maintenance is less time critical as well, since losing a pack or two is not critical the way losing a substation ESS is. They are starting out with CES units which provide about 3 hours of discharge based on their intuition about discharge requirements, but since this is early R&D and they have not done extensive modeling, they are still learning the optimum pack size to use.

AEP plans to offer improved reliability to customers and efficiency in transmitting power to customers, but they also expect to be able to aggregate the CES units using Advanced Metering Infrastructure (AMI) into a dispatchable resource they can use for applications previously done at the substation level, like T&D deferral and peak shaving. They also see benefits from having storage close to residences where PHEV’s may be plugging in and generating significant loads; with CES they claim the utility would not have to care when the customer charges their PHEV. CES would also allow AEP to deal more effectively

with distributed generation, like PV panels on homes. However, AEP points out that this would be an inefficient method to deliver frequency regulation so that would not be considered a source of revenue.

Legal

This is a new method and has not been significantly discussed in the legislative arena. However, since AEP intends to do this on their own grid infrastructure and not initially bid its services into any open markets, they may not have as many hurdles to initial implementations as if they did.

AEP will have a challenge to monetize many of the benefits it can produce with these CES units though. For instance, in Oklahoma there is a reliability incentive for utilities to bury the distribution lines to customers' residences to reduce outages. AEP might be able to receive money from that incentive for the system's reliability improvement. However, this would currently force them to forgo revenue from open markets and may influence how it is factored into their rate base.

Economic

Since this is a new idea without direct applicability to most of the commonly discussed applications, the revenues it would generate are unclear, even to AEP. However, a partial first order estimate might be made by selecting a handful of likely applications which could be bundled from the data from NYSERDA and EPRI-DOE. The estimated values from Table 3 of relevant benefits for this implementation are listed below. The required duration has been added, and the total benefit for this implementation is summed up to a total for comparison to possible methods of accomplishing this implementation, noted in Table 5. This total benefit is an upper bound on what is feasible from an implementation.

Table 11: Community Energy Storage Benefits

Imp #	Implementation	App #	Applications Included	NY Unit Benefit, \$/kW, over 10 Years	CA Unit Benefit, \$/kW, over 10 Years	Duration Min (Hours)	Duration Max (Hours)
5	Community - Opt.1	5	T&D Capacity deferral	1200	1,067	2	6
		11	Reliability	359	359	5 minutes	5
		12	Power Quality	717	717	10 seconds	1 minute
		14	Renewables Capacity Firming	323	172	1	3
			TOTAL	2599	2315		
	Opt. 2	11	Reliability	359	359	5 minutes	5
		12	Power Quality	717	717	10 seconds	1 minute
		13	Renewables Time shifting	832	655	4	6
		14	Renewables Capacity Firming	323	172	1	3
			TOTAL	2231	1903		

If AEP can combine and accrue the benefits of community energy storage in either of the ways shown, it could create a good deal of value. In this implementation, AEP expects the cycling on the pack to be similar to that experienced by a PHEV, and hopes that they will last 10 years as is expected in lithium ion PHEV's. AEP is targeting \$20,000-25,000 for the packs in quantity; the prototype bids are coming in around \$50,000-60,000 for 20-30kW units (\$1666-3000/kW). If these are capable of 10 years of life, then some of the more economical ones could produce positive economic value. It remains to be seen how much of this can be captured by AEP though.

Lithium ion batteries are attractive for this implementation because they do not require moving parts or hazardous substances, so they offer high reliability, low maintenance, low noise, and high potential customer acceptance devices. Beside these concerns, the other types of ES systems discussed at not available at similar power ratings so making a cost comparison is inappropriate.

4.6. Industrial Energy Management

4.6.1. Example Implementations

- 3MW/4.5MWh Valve regulated Lead Acid battery at a Lead Acid battery recycling plant in Vernon, California in 1996.⁷⁷ (power quality oriented)

- 3MW/1.5MWh SEI Vanadium redox battery for Totorri Sanyo Electric Company (LCD manufacturer) in Osaka, Japan in 2001.⁷⁸ (power quality oriented)
- 0.1MW/0.72MWh NGK NaS battery at commercial office building for American Electric Power (AEP) in Gahanna, Ohio in 2002.⁷⁹ (peak shaving oriented)
- 2MW/14.2MWh NGK NaS battery leased for use onsite at boat night racing facility, owned by Kyushu Electric Power in Japan in service before 2004.^{80 81} (peak shaving oriented)

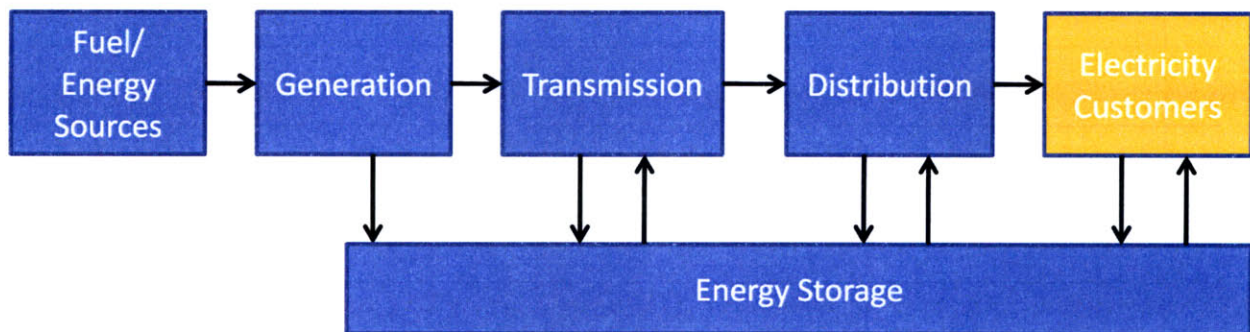


Figure 29: Primarily Sited at Customer Site on Customer Side of Meter

4.6.2. Considerations

Technical

This category of implementation is co-located with industrial or commercial facilities and often directly owned or leased by the end customer. Though these installations typically deliver UPS-type power quality and reliability services to the customer, the characteristic of note which sets them apart from the numerous existing UPS installations is that these are also intended to operate in a peak shaving mode to lower the customer's electric bills. In this way the customer can capture two value streams from the ESS, power quality/reliability and reduced electricity bills (based on time-of-use charge reductions or demand charge reductions).

Earlier installations of this type focused more heavily on the power quality part of the equation, largely because of the storage technology available at the time. Lead acid was the only realistic option and its limitations in cycle life did not make extensive peak shaving practical. More recently, new options with better cycling characteristics, like VRB and NaS batteries, have begun to be deployed and newer installations have begun to more aggressively target peak shaving applications which result in reduced electricity bills.

Legal

These installations are typically "behind the meter" at an end customer's site and owned or leased by the customer. This means that many of the regulations typically in place for grid scale energy storage are not applicable. However, permitting for the electrical installation at the customer site is still required. Additionally, retail tariffs will address storage differently in different areas, for instance, storage at a customer site could be seen as demand response and rewarded, in others, it might be ruled

an exiting load which incurs exit and standby charges of similar magnitude to the demand charge savings.⁸²

If the retail tariffs do not incur exit or standby charges for the ES system, the two primary benefits of storage are accrued to the end customer without needing to access open markets or interact with other rate payers, so they have minimal legal hurdles to collect this value. There is some additional value which the utility will gain by not needing to build infrastructure as quickly, but this should be largely reflected in the rates which the customer avoids paying. The secondary value which is created is directly accrued to the customer in the form of reliability and power quality. This union of value flows makes it likely that a customer can accrue the majority of the value out of this implementation, although some of them are non-cash.

Economic – High Level Estimates

There are a number of ways which an operator could produce revenue from an industrial energy management implementation. Multiple applications could be bundled together into one implementation. The estimated value from Table 3 of relevant benefits for this implementation is listed below. The required duration has been added, and the total benefit for this implementation is summed up to a total for comparison to possible methods of accomplishing this implementation, noted in Table 5. This total benefit is an upper bound on what is feasible from an implementation.

Table 12: Industrial Energy Management Benefits

Imp #	Implementation	App #	Applications Included	NY Unit Benefit, \$/kW, over 10 Years	CA Unit Benefit, \$/kW, over 10 Years	Duration Min (Hours)	Duration Max (Hours)
6	Industrial Energy Management - Opt. 1	9	Demand Charge Reduction	1076	465	4	6
		11	Reliability	359	359	5 minutes	5
		12	Power Quality	717	717	10 seconds	1 minute
			TOTAL	2152	1541		
	Opt. 2	10	Time-of-Use Reduction	1649	1004	4	6
		11	Reliability	359	359	5 minutes	5
		12	Power Quality	717	717	10 seconds	1 minute
			TOTAL	2725	2080		

Upon comparison to Table 5, it can be seen that if a number of different value streams could be captured by one entity, it is possible that some of the existing technologies could be cost effective for this. As mentioned in the legal section above, capturing all the value streams could be challenging though depending on jurisdiction. Most of the technical requirements for this implementation are similar to that for T&D capacity deferral and renewables shifting and firming, but the potential benefit is quite a bit higher than either (\$2,152/kW and \$2,725/kW for Industrial vs. \$2,025 or \$1,413 for the others from NYSERDA's estimates). This application does not stress mobility as much as T&D capacity deferral though, but it is still a useful bonus which makes installation inexpensive.

Therefore, in this case, the same two technologies as for renewables shifting and firming are still interesting. The Zn-Br system from Premium Power, especially with a reduced duration to 4 hours, is likely to be economically positive over a 10 year project lifespan. ZBB's system is less attractive than Premium Power's as it will need to be made more expensive than the baseline \$1,450/kW by adding duration and will also likely not last the full 10 years since it is only rated for 2,000 cycles (1 full cycle a day is 3,650 cycles over 10 years). The NGK NaS system which has been used for pricing quotes has a bit more duration than necessary for this implementation's minimum, so NGK could potentially reduce costs for this application by optimizing the packs for 4 hours instead of 7.2 hours. With a bit of cost reduction or with an installation strategy optimized for cost minimization, it appears that NaS ES systems will be economically neutral or slightly positive.

Economic – Estimates from Individual Cases

The Japanese boat racing facility installation provides load leveling and enhanced reliability and operates for 100 days a year. As stated by Kyushu in the ESA June 2004 newsletter⁸³, the system produces \$328,000/year in energy savings for the customer and the customer pays for it by a \$390,000/year service fee. Kyushu claims the difference is more than compensated for by the enhanced reliability, which has enabled races to continue during what would otherwise have been an outage.

AEP estimates that their installation in Gahanna, OH produced a 9.8% IRR and had an overall after tax NPV of \$116,335 for a \$604,500 initial investment (\$6045/kW of storage). The power quality benefits offered \$791,783 of pretax value, while the peak shaving benefits offered \$217,460 pretax. Since so much of the value for the installation was coming from the power quality benefits, which vary widely from customer to customer, it is important to find customers with high power quality needs for this type of installation to be cost effective. AEP assumed typical rates for electric service charge of:

Demand charge	\$10/kW-mo
On peak energy charge	\$.08/kWh
Off peak energy charge	\$.06/kWh

ZBB has released estimated economics for a ZEES 500 (250kW/500kWh) hypothetically installed in an industrial customer demand management implementation in a northeastern US area with tariffs favorable for their product's ROI. It indicates an after tax IRR of 20.21% on their system.⁸⁴ It indicates an annual savings of \$82,800 due to demand charge reduction and \$1,080 in reduction due to reduced

energy charges off a bill which was originally \$177,084. The assumed initial capex investment was \$362,500. ZBB assumed electrical rates as follows, which are noted as from Con-Edison NY:

Demand charge	\$27.04/kW-mo
On peak energy charge	\$.03/kWh
Off peak energy charge	\$.015/kWh

4.7. Other Implementations

There are a variety of other ways energy storage can be implemented which deliver value, however they are not the focus of this investigation. Some of them include vehicle to grid (V2G), battery packs in residences (one of Gridpoint's strategies), uninterruptable power supplies (UPS), off-grid support (ie. cell towers), provisions for other ancillary services like black start, and subway train energy recapture.

4.8. Implementation Profitability Comparisons

This section includes overview tables summarizing the profitability expectations from the discussion in Section 4. Likelihood of an economic loss on the project is denoted by a "-". Likelihood of close to neutral economics is denoted by a "0". Likelihood of profitable economics is denoted by a "+". Items which did not have data associated with them are denoted by "NA".

Table 13: Profitability Expectations Based on NYSERDA Benefit Estimates and Company Cost Quotes

		Zn-Br flow battery	VRB flow battery	NaS battery	Lithium Ion battery	High speed flywheel
1	Wholesale Load Shifting	-	-	-	-	-
2	Renewable Power Management	0	-	-	-	-
3	T&D Capacity Deferral Focused	+	-	-	-	-
4	Ancillary Services Focused	-	-	-	+	0
5	Community Support	-	-	-	+	-
6	Industrial Energy Management	+	-	0/+	-	-

Table 14: Profitability Expectations Based on Companies' Published Cost/Benefit Analysis

		Zn-Br flow battery	VRB flow battery	NaS battery	Lithium ion battery	High speed flywheel
1	Wholesale Load Shifting	NA	NA	NA	NA	NA
2	Renewable Power Management	NA	+	+	NA	NA
3	T&D Capacity Deferral Focused	NA	NA	-*	NA	NA
4	Ancillary Services Focused	NA	NA	NA	NA	+
5	Community Support	NA	NA	NA	NA	NA
6	Industrial Energy Management	+	NA	+	NA	NA

* Only including revenue from wholesale load shifting activities

5. Challenges, Opportunities and Strategies for Implementation

5.1. Market Drivers

The market for energy storage has many factors which influence its dynamics. A number of them are listed below.

Factors which encourage ES cost *reductions*:

- Economies of scale for production and research
- Economies of scale for certification of ES installations
- Simplified implementation & coordination of ES due to smart grid/AMI *(duplicated below)

Factors which encourage ES cost *increases*:

- Raw material limitations

Factors which encourage *increase* in value of ES service:

- Installation of more wind and solar power
- Carbon tax/trading scheme which gives credits to ES
- Reliability incentives or increased customer demand for reliability
- Increased difficulty of permitting of new power plants, transmission and other infrastructure

- Policy clarifying ES ownership and benefit capture
- Surplus base load power generation for demand decreases off peak electricity cost
**(duplicated below)

Factors which encourage *decrease* in value of ES services:

- Competition between new ES installs for same market share
- Less peaky electric use due to smart grid/AMI variable pricing *(duplicated above)
- Reduced electric demand reduces expensive peak pricing and T&D build up **(duplicated above)

Factors which favor alternatives to ES:

- Low fuel costs
- Improvements in competing non-storage technology (including thermal plant efficiency and life at variable loads)
- Demand side management

5.2. Insights based on Academic Literature on Innovation

5.2.1. Network and Scale Effects

Implementing energy storage on the grid involves interfacing with a highly complex network of equipment, regulations and stakeholders. Though energy storage is part of a large network, traditional network effects, as discussed by Chakravorti⁸⁵ where additional customers increase the value of each product, are not the primary dynamic influencing its adoption. Because energy storage systems supply a defined and finite market for services on the grid, like energy arbitrage, frequency regulation, or T&D deferral, the addition of greater quantities of energy storage on the grid will reduce the potential revenue of each energy storage system based on the laws of supply and demand.

Energy storage does create other advantages as it scales though. For instance, economies of scale in the production of ES will reduce its cost as more are produced. For some types of ES, this economy of scale may occur before the large scale rollout of ES on the grid, since for lithium ion battery packs, there are major synergies with the design and manufacture of plug in electric vehicle battery packs. This is a reason for optimism for community scale and even residential scale energy storage. There is still an unsettled debate over the availability of lithium which could limit the effects of this dynamic though, including opposing views stated most clearly by Tahil⁸⁶ and Evans⁸⁷.

Additionally, as more ES systems are implemented, they will become more common and therefore easier and less expensive to certify with utilities and ISO's. This will be particularly important as a dominant design for the systems emerges. The eventual dominant design and dominant architecture are still unclear however. It can be seen with all the varied implementations discussed in section 4 of this document that the grid level system architecture is still in flux. Another way it can be seen is the discussion of a new type of frequency regulation contract for suppliers which can respond to frequency regulation requests much more quickly than is currently required by existing frequency regulation

contracts which are targeted for thermal power plants. One physical ES system design does appear to be becoming dominant for small to moderate size implementations, with 5 suppliers identified using or proposing to use it. This design is the use of a standard semi trailer to house and transport the ES system. This trailer can be moved to the needed location, parked on a concrete pad and basically “plugged in” to the site where ES is needed with minimal installation cost and less than a day of work. It can also be relocated as electrical loads vary with little work. Siting is less challenging because fewer permits are needed since no permanent building housing the ES system has to be built.

5.2.2. Innovation Adoption and Resistance

Utilities are commonly known to be highly risk averse and change resistant entities. Given the high reliability requirements of the business and the quantity of long life equipment in the field to build and maintain this is hardly surprising. Besides this organizational aspect of utilities, a more fundamental human trait is also at play.

In a variety of research papers, including John T. Gourville’s “The Curse of Innovation: Why Innovative New Products Fail”⁸⁸, it is observed that people inherently resist behavior change by disproportionately valuing the status quo higher than a new product. In this way, even if a new product offers a superior alternative to the existing solution, the customer’s existing solution may still be more attractive to the customer than the innovation because the customer’s reference point is the existing solution. The developer of the innovation however views the situation from the reference point of the innovation and sees how much better it is, but does not account for all the resistance to the innovation the customer will put forth. In this way customer adoption of innovation is stifled.

With this in mind, one can imagine that the behavior changes required by most ES systems would significantly reduce a utility manager’s interest in deploying them, requiring a great deal of time and effort to have utilities adopt the innovation. This likelihood is diagrammed in the Figure 30 as the “long haul”.

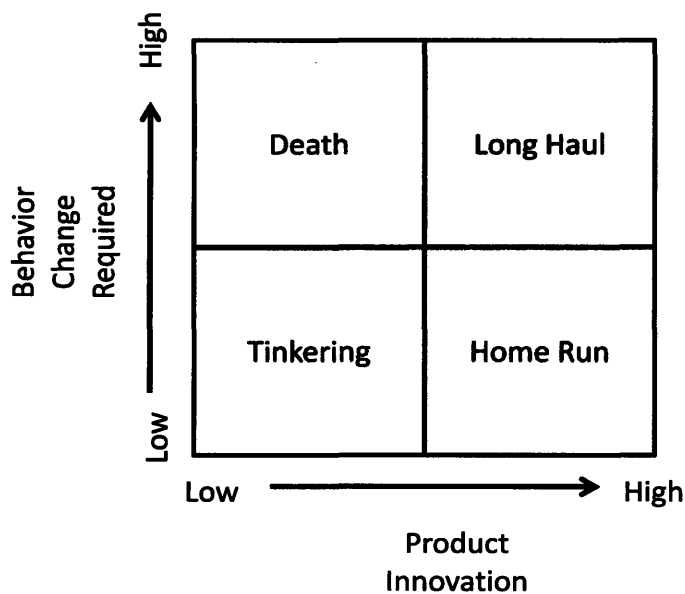


Figure 30: Product Innovation vs. Behavior Change Required (Gourville⁸⁹)

The more desirable square to be in would be “home run”. In order to get there, the supplier of the innovation will have to make the innovation require less behavior change for the same customers while maintaining the innovation’s benefits. Some of the more recent developments have begun to offer benefits with less behavior change. For instance, Beacon Power’s “vertically integrated utility” business model means it is delivering only frequency regulation services to grid operators via the open markets and not asking for any direct behavior changes. AEP’s community scale energy storage concept could allow utilities to incorporate ES with backyard transformers at relatively low voltage to make installation and maintenance very easy and shift most of the burden for managing them on a limited set of the utility’s grid operators and software programmers who might be more easily retrained than a large set of field employees. However, regardless of how the required behavior change effects are mitigated, some amount of behavior change will be required and a strong, clear, limited risk value proposition will have to be demonstrated for utilities to deploy ES.

Even as a handful of more innovative utilities tolerate the required behavior change and begin to deploy ES, many utilities with other priorities are not interested in it. This demonstrates the variation in types of customers discussed in literature such as Moore’s “Crossing the Chasm”⁹⁰. These current adopters are the innovators in the “Crossing the Chasm” innovation adoption model. One of these innovators, Ali Nourai at AEP, mentioned in his paper⁹¹ summarizing the results of the first “Distributed Energy Storage System” (DESS) installation at AEP that for the ES installation and deployment to be smoother (and more appropriate for early majority adopters), it would be helpful to have a single company which could assume the complete task of DESS delivery and system integration, instead of the 5 contracts AEP had to manage to deploy the DESS. Nourai also points out that improved logistics for the delivery and staging of the batteries themselves would have saved a great deal of money. These sorts of improvements to

the ES system are not technological or necessarily directly in the hands of the ES system developer, but need to be addressed to encourage adoption beyond a handful of utility innovators.

5.3. Key Observations from Discussions with Suppliers and Utilities

A number of themes came up during the course of research for this document, especially during conversations with ES suppliers and utilities, and also in reading relevant literature. The key points from these inputs on factors for success of an ES supplier have been captured and distilled in this section.

5.3.1. Cost Effectiveness

Electric utilities are in the business of delivering a low cost commodity. If energy storage cannot be implemented cost effectively, there can be no mass adoption of it. To minimize product cost, the successful ES supplier company will have to optimize their company in many common areas, like product development cost, cost versus performance tradeoffs in design, managing labor relationships, financially leveraging the firm and developing and defending their intellectual property portfolio.

In addition to these common issues, there are many specific issues for ES, some of which have been cleverly dealt with some market entrants. The technology must be developed from the start to make efficient use of resources against the metrics of interest for the targeted application, for instance, \$ per kWh, \$ per kW, operating expense or cycle life. The system's raw materials must be available in proper form in sufficient quantities to support large scale use while remaining inexpensive.

The purchased components for the system must be inexpensive, available and robust. Strategic decisions about system modularity and vertical integration of the supply chain are a way to manage this. For instance, since Premium Power has in-house expertise in electrics and power inverters, they have chosen to assemble their own power converters from off the shelf components and custom made boards, therefore saving themselves considerable money over buying from a third party.

The processes for manufacturing the system and its components must be scalable, high yield, low variance, inexpensive and within the company's core competency. For instance, A123 has decided to make all their own cathode powder and make it a core competency, since it is an expensive process and they can then focus on value engineering. It is also because a good deal of their IP lies in the powder and they can control the spread of that specialized knowledge more closely. Another way manufacturing cost can be managed is Premium Power's strategy of designing its systems to require only very common manufacturing machines and purchasing them second hand from other companies. They started the company by following this strategy to the extreme, by buying the company "secondhand" at a bankruptcy auction with IP and machinery already in place.

A well managed product line with standardized, platform products and no "one-off" units with high non-recurring engineering costs will help companies get products out to customers at the lowest cost possible. For instance, Satcon, a company which now focuses on making standardized power inverters for solar panels, used to make a wide variety of power conversion equipment, including some for grid

scale energy storage. After this conscious change in strategy and upgrading of product management skill in the company, they expect the cost of production to be significantly reduced.

Controlling cost in logistics and the supply chain by optimizing shipping packaging, arrival time coordination and bulk shipment discounts are major considerations for some types of ES systems. For instance, when AEP built its 1MW/7.2MWh ES system in North Charleston, WV, they found that they incurred \$140/kW in factory to site transportation costs. They identified a number of ways this could have been reduced with better coordination between parties, outdoor approved battery shipping containers and optimal bundling of overseas shipments.⁹²

5.3.2. Low Risk Product and Supplier

Utilities require high reliability, low risk solutions to ensure uninterrupted delivery of electricity to their customers. This means that ES companies and the products they produce must be reliable.

The product must offer reliable operation proven through a track record of operation or appropriate accelerated life cycle testing. When it does fail, it should be graceful and predictable. This is one reason why traditional lead acid batteries, which give little warning of impending total failures at the end of their lifespan, are not seriously considered for grid scale use. Lithium ion batteries, on the other hand, gradually fade over many cycles, so the end of their life is much more easily predictable and manageable.

The product also must not present an excessive safety risk and must be able to be produced consistently at high quality. This latter point is particularly important for “replicating” technologies like lithium ion batteries or flow batteries, which combine many cells into a single grid scale ES solution.

The supplier itself must inspire sufficient confidence in their customers to be credible about supporting the products and remaining in business to supply future orders. For this a small company needs cash reserves, strong backing from organizations with their own deep cash reserves and good earnings prospects to avoid needing to rely on cash reserves excessively. A123 applied a long term strategy of starting in a sector where supplier size was not as major a concern (power tool batteries) and used this to gain scale and earnings to approach other more profitable markets, like grid scale and automotive ES systems. Some companies may also have entirely separate sources of income to help fund the ES projects, like NGK’s diverse portfolio of non-ES products. This factor will be especially critical if the supplier is the sole supplier of the product.

The supplier must also make themselves low risk by building a strong relationship with their customers, especially with a key advocate at the customer, and then maintaining the trust with execution and communication. This advocate is taking a personal risk for the supplier and should be given as much information as is reasonable, ideally in a partnership type arrangement, to allow him to manage and minimize risk for the company and himself as much as possible in the endeavor of piloting an ES system.

One strategy which is being utilized to minimize risk to the utility and minimize the cost of supplying services to the grid has been implemented by Beacon Power. They have defined their company to be a “vertically integrated utility” so they design, build, install, operate and sell the services of their flywheel ES systems to collect revenue directly from open market frequency regulation operations. In this way they can integrate the whole value chain to capture as much value as possible and manage the cost the system. They also take the burden of the risk of the system on themselves and the utility simply receives the frequency regulation services they need. This makes it more attractive for the utility to allow Beacon’s flywheels on the grid, but this arrangement does require Beacon to bear a great deal of risk. It could also be an indication that Beacon was forced into this model because they could not capture enough value any other way to pay for the cost of the flywheel system.

5.3.3. Influencing Favorable Regulation

In order to encourage adoption of ES systems, suppliers must engage legislators in creating regulation favorable to ES. Current rules governing the grid assume and support the architecture of the grid which has been common in preceding decades and makes it challenging to incorporate new technology which does not directly fit into that architecture. Suppliers must join with other interested parties and motivate changes in these regulations and then take advantage of them.

ES systems do not fall neatly into common regulatory categories of utility infrastructure, like generation or wires. Therefore, though an ES implementation may generally make sense economically, it is not clear who has the right to install it, who can capture revenue from it, or if it can be included in a utility’s rate base. Without clear rules around who can own and be compensated for ES, there is little incentive for utilities to install it.

For ES systems owned and operated by customers on their side of the meter, the resulting rewards vary widely from jurisdiction to jurisdiction. For instance, in some areas, storage could be seen as demand response and rewarded, in others, it might be ruled an exiting load which incurs exit and standby charges of similar magnitude to the demand charge savings.⁹³

In order to monetize frequency regulation services of ES systems, the systems need to be certified with the local ISO to bid into the market. At the prompting of suppliers, like Beacon Power, some of ISO’s have started pilot programs which allow energy storage into the frequency regulation market, including ISO-NE’s Alternative Technology Regulation Pilot Program. Now other suppliers are also taking advantage of these regulations as well.

A number of other legislative aspects need to be addressed by successful suppliers as well. For instance, they need to make inspectors more comfortable with the technology to make siting and permitting simpler. They should lobby the ISO’s to create another category of frequency regulation which requires faster response times; this fast frequency regulation could meet the stability needs of the grid with fewer MW in use⁹⁴ and give ES improved pricing for the extra value it offers over thermal power plants. They should also lobby for incentives for grid reliability and security that ES can provide.⁹⁵

5.3.4. People and Relationships

A number of the small energy storage companies interviewed mentioned that they got their some of their first customers through their personal networks. Boston Power connected with their first major customer, Hewlett-Packard, because Boston Power's CEO had been friends for a number of years with the person running a part of HP's laptop program. Premium Power has applied their marketing and sales efforts almost exclusively through the power of the personal networks of a few key players at Premium Power and have been able to land a number of sizable contracts with the likes of Duke and others because of it. From these data points, it appears that the personal networks of the executives at a supplier company is critical.

Another strategy which has been observed, but appears to be less than optimal for suppliers, is using sales channel partners and other relationships with other players to gain distribution and recognition in the market at the cost of control and margins. ZBB Energy has entered into an MOU with Eaton Corporation to purchase products from them and also supply them with components for Eaton's Sustainable Energy Storage Solutions. Active Power, a low speed flywheel company from Austin, TX, sells to major OEM's like Caterpillar and Eaton, however they are actively reducing the volumes involved to focus on higher margin direct sales. Both of these companies were grappling with issues of survival when they originally agreed to these contracts.

In the market for grid scale energy storage, it does not appear that marketing to the public is necessary. Some of the leading suppliers release very few public communications. However, education of utilities and legislators is key, so suppliers tend to have significant presence in their targeted market area. Releasing public information can even be a detriment as competitors can bench mark against you more clearly. Also, publicly funded contracts, such as those through DOE/Sandia, require some public reporting and so outsiders can learn details of a company's failures, such as ZBB's inability to deliver a sufficient quantity of storage in their contract with the California Energy Commission.⁹⁶

5.3.5. Target Customers and Markets

One common piece of advice for new companies trying to sell their first product is to identify a fertile market to target and then focus intently on that market. With a product like grid scale energy storage, this adage still applies. Sometimes, the best way to start is to run company subsidized pilot projects with early adopter customers in the chosen market segment to further define the system requirements and develop a track record to reference with future prospective customers. Some points of interest for identifying the markets and customers which may be inclined to adopt ES systems are discussed below.

One way to begin the search is to identify geographical areas which have a large economic or technical need for energy storage. Some factors which may influence an area's attractiveness for energy storage are:

- High penetration of renewables relative to dispatchable generation
- Island grids with little "momentum" to absorb dynamics on the grid and limited options for generation, especially if they are using diesel fuel for generation

- Heavy industry with large or inductive intermittent loads
- Excessive penetration of slow to ramp baseload generation like nuclear and coal
- No pumped hydro storage available
- No natural gas or hydro generation
- High fuel costs
- Congested transmission/distribution and difficulty expanding T&D
- Presence of wide price spreads for peak to off peak power.

Another aspect to consider for target markets is the local regulations. This is challenging since regulations vary across different areas, and in the United States on a state to state basis. One of the first things to identify is if the local ISO has created complementary regulation to FERC Order 890, which opened the frequency regulation markets across the country to non-generation sources, like storage. Since Order 890 left many details critical for energy storage to the ISO's to define, like the required duration of continuous power injection into or withdrawal from the grid, ISO's have had to pass further regulation to allow energy storage. Many ISO's have complemented FERC's order with their own regulation or have plans to, including ISO-NE, NYISO, PJM, MISO, and CAISO. There are many other legislative issues to be aware of as well, some of which are also discussed for ancillary services in Section 4.4.2.

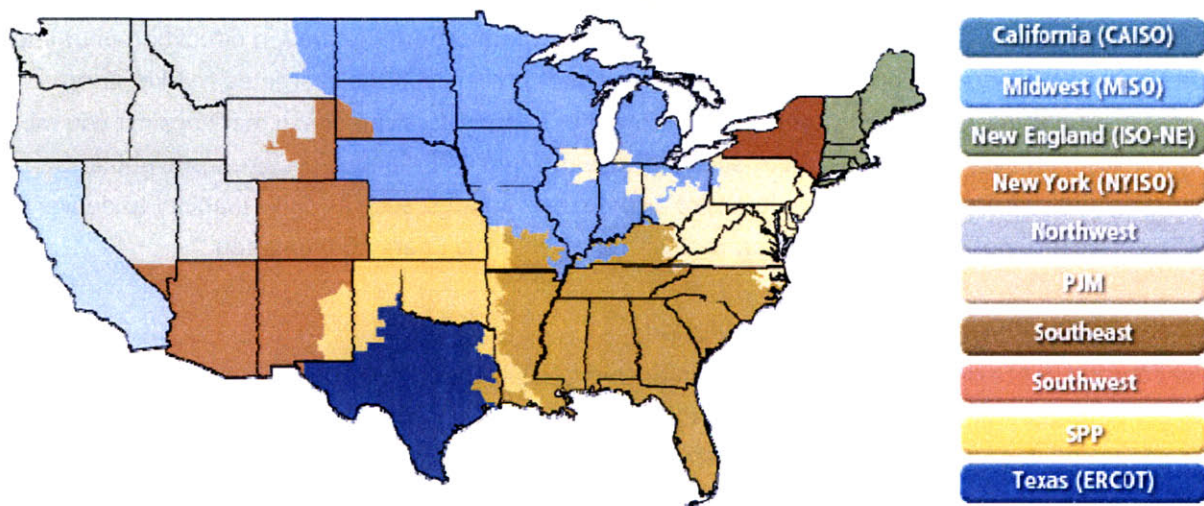


Figure 31: US Electric Markets (FERC⁹⁷)

Within these areas of interest, one also needs to identify target customers who can accrue much of the value created by the energy storage. Depending on local regulation and the application, this could be the utility or a customer. Depending on how the utility is compensated and what is allowed into their ratebase, a regulated utility may be able to capture a broader spectrum of benefits than a utility or merchant plant in a deregulated market.

A final aspect to investigate is the progressiveness of the utilities in the area. Some utilities stand out as early adopters. For instance, American Electric Power (AEP) is so interested in investigating energy storage based on executive direction that they are not currently concerned about economic payback on energy storage and are a good candidate for pilot projects. Experience with dispatchable distributed generation would give a utility good organizational knowledge to be a partner in piloting storage, such as DTE in Michigan. Other utilities are of interest for the favorable local economics of storage or a state level legislated motivation for storage.

5.3.6. Technology and Features

While the details of the technology used for energy storage are only a piece of the whole problem of getting energy storage on the grid, there are a few things which could be done to give a supplier an advantage, beside simply being low cost and low risk.

This is a situation where the end product electricity is a commodity, but the energy storage system itself has a number of ways it can be differentiated from other suppliers. Examining and defining what the boundaries of the business ought to be, including what functions the system should offer can be useful. In this way one can go beyond simply having a energy storage device in a box with a power converter attached to having a value added set of services and recurring cashflows to offer with your product. This could mean selling the ES system as a full solution which includes maintenance, and monitoring and control software. It could even be extended further as Beacon Power has to offer only the services of the system and not the system itself.

Savvy marketing and product development will allow suppliers to add value without adding significant extra cost. This has been seen in a number of ways. For instance, providing fast frequency regulation is more effective at maintaining grid stability and since it is an inherent characteristic of many of these energy storage systems, if it can be utilized and compensated, it is value for free. Another way this can be done is by making the ES system more mobile by building it into a semi-trailer, which reduces installation costs and also can be used and reused at many different locations as trouble spots arise. Identifying a standardized ES system configuration that fits as seamlessly into utilities system's will ease the cost of utilities adoption of ES as well by allowing them to deploy it at commercial customer sites or step it up to various feeder voltages. AEP proposes this configuration be 480V, 3 phase, 4 wire.⁹⁸

Also, in an effort to maintain one's advantages over competitors, suppliers should make their technologies as hard to imitate as possible. Premium Power has spent a significant amount of time implementing this strategy. For instance, they identified a way to avoid a significant maintenance issue with their technology by using a patent pending strategy⁹⁹ including an algorithm on their DSP to dither the charge and discharge of their cells, thereby making the zinc in the cell plate smoothly. Besides patenting the concept, they also obfuscated the algorithm from reverse engineering by programming the DSP to erase itself, if anyone connects a JTAG probe to the system to read the DSP's memory. This fits well with Premium Power corporate strategy of not releasing information publicly and also makes it challenging for competitors to copy their proprietary algorithm.

6. Conclusions

The development of emerging grid scale energy storage technologies offers great potential to improve the architecture and operation of the electrical grid. This is especially important in the face of increased reliance on clean dependable electricity and with the influx of renewable generation technology and smart grid technology. However, at the present, grid scale energy storage is still an emerging sector.

This document has brought together a broad overview of the sector, including a high level overview of the technology, a more focused look at the applicable markets and some estimates of the systems' economics. Analysis of this information offers insight into what the future of energy storage on the grid might be. This investigation was accomplished by leveraging prior research in existing literature, and extending it with first hand discussions with industry leaders and market analysis.

On a high level, some primary findings of this research include:

- Wholesale Load Shifting is not cost effective with emerging energy storage technologies.
- The remaining 5 higher value energy storage implementations could be accomplished with specific emerging energy storage technologies and potentially at least break even in good conditions. However, some of these include significant barriers for a single entity to own and accrue value from all the benefit streams an implementation creates.
- Li-ion batteries are economically attractive for dedicated Ancillary Services-Frequency Regulation implementations and possibly for Community Energy Storage in the future.
- Zn-Br flow batteries are economically attractive for Industrial Energy Management and T&D Capacity Deferral, and marginally for Renewable Energy Management.
- NaS batteries are marginally economically attractive for high value implementations like Industrial Energy Management, but may be difficult to further cost reduce and improve competitiveness with other technologies.
- High Speed Flywheels are very expensive and will not be economically attractive for the near future for their most suitable implementation, Ancillary Services-Frequency Regulation.
- Government regulation is a critical driver of or inhibitor to energy storage technology penetrating the market. Current trends in regulation are favorable for energy storage, especially in frequency regulation.

6.1. Energy Storage's Contribution on the Grid

Regarding the question, "Will energy storage become a significant contributor on the grid?", it was found that it is likely that use of grid scale energy storage will likely grow in specific implementations as long as regulations continue progressing forward and the current level of utility interest is maintained. Grid scale energy storage can create value in many ways and was found to have the most potential to be cost effective when one or more high value applications were combined into one implementation and served with the most appropriate technology. Applied in the proper way, energy storage was found to potentially be economically positive in the near term and even more economically beneficial as a number of factors, including energy storage prices, grid services value and regulations, converge to make energy storage more cost effective.

6.1.1. Implementation Attractiveness

A number of currently attempted implementations, which combine the revenues of various applications, were considered. The simplest one, which is the most commonly discussed in casual circles, is Wholesale Load Shifting and does not create enough value for emerging energy storage technologies to provide profitably. Pumped hydro or CAES may be able to do this cost effectively though. The remaining five implementations create a great deal more value through providing higher value services and combining multiple applications. All of these implementations could potentially be accomplished with energy storage and reasonably expect to at least break even financially given proper circumstances, the use of a particular energy storage technology which suits the implementation well and the ability of an single entity to own the unit and capture the value from all benefit streams it creates. These five implementations are Renewable Power Management, T&D Capacity Deferral, Ancillary Services, Community Support, and Industrial Energy Management.

6.1.2. Near Term Attractive Technologies

One technology which was identified as economically attractive was Li-ion batteries. For applications where a mix of low cost power capacity, moderate cycle life and ease of mobility/installation are keys for success, these systems are very promising. Currently, lithium ion batteries have found favorable economic use in dedicated frequency regulation implementations owing to their low cost and high power capacity, and the high value of frequency regulation services. In the future, they may also be useful for community energy storage implementations since all of their good characteristics can be easily scaled down to sizes suitable for small neighborhoods and synergies with PHEV packs may be found. Since there are many suppliers for lithium ion batteries, competition in the market will likely drive down prices as well.

Another technology which was identified as economically attractive was Zn-Br flow batteries, particularly those from Premium Power. For applications where a mix of low cost energy capacity, high cycle life and ease of mobility are keys for success, these systems are very promising. The two types of implementations which are best fits for this are Industrial Energy Management and T&D Capacity Deferral. Either of these appear to offer economics which should allow the Zn-Br battery to more than pay for itself over a ten year lifespan. Of the two, Industrial Energy Management is more attractive at this time since the majority of the benefits will be enjoyed by the same party who purchases it and there is less uncertainty about the legal treatment of the system. However, the benefits in this situation are largely non-monetary (improved reliability) so a very specific customer is needed. Additionally, Renewable Power Management offers economics which may allow a Zn-Br system to break even, but may not have much potential for upside. Especially if a site with needs and pricing particularly well suited to optimizing the implementation's value creation is used, it is likely that one can create economical projects with Zn-Br flow batteries.

6.1.3. Marginally Attractive Technologies

The NaS battery, which has the most extensive grid scale usage track record, remains still fairly expensive after many years of production. Even at this high price point, it is still somewhat attractive for the most high value stationary applications, particularly Industrial Energy Management. However, in order to be a truly competitive solution, the price will have to be reduced and it does not appear that this fairly mature and monopoly owned technology will be significantly cost reduced in the foreseeable future, limiting its potential for further use. If another competitor were to enter the market and drive innovation, there would be greater potential for this technology.

6.1.4. Potentially Attractive Technologies in the Future

There are a number of technologies which are not currently ready to economically contribute to grid scale applications, however they have the potential to do so in the future.

One technology that is still in R&D, but may be able to provide low cost energy storage with good power characteristics and cycle life is the lead-acid carbon supercapacitor hybrid. These devices leverage existing lead acid manufacturing infrastructure and have shown good cycle life performance in initial independent testing at Sandia National Lab. The most appropriate implementations for these systems will depend on the final characteristics of the devices.

A technology with potential for providing Ancillary Services is the high speed flywheel. However, currently it is a very expensive solution, and though it is projected to decline greatly in price over the next few installations, this price decline would only make it marginally economically attractive. These systems would still require a long amortization period to be profitable, so this would be a challenging sale for a very new and not entirely proven tech. Beacon Power claims the economics are very favorable with their next iteration installations (when they expect their costs to be half of their current level), but their estimates appear to be highly optimistic.

A final emerging technology is the VRB flow battery. It is currently not economical for any implementation and the primary developer of the systems, VRB Power, declared bankruptcy in early 2009. However, the company's assets were purchased by a Chinese company with strong financial backing. Given the reputation China has built for low cost production, significant cost reductions in these systems are not unlikely. However, becoming competitive with other flow batteries like Zn-Br will require going beyond low cost production and doing value engineering as well, which is potentially a more challenging task. Since there are a number of developers working on similar systems in various parts of the world, we may yet see the cost reductions needed.

6.2. Importance of Government Regulation

Government regulation plays a huge role in the deployment of energy storage on the grid. One of the reasons why the Ancillary Services Frequency Regulation implementation has blossomed with many market entrants in the last year is that regulation has recently changed, through a great deal of effort from energy storage developers like Beacon Power, to allow energy storage into that market in some

regions. However, for many other implementations, regulation is not nearly as amenable to allowing energy storage in, frequently based on a lack of clarity on how the financial benefits of an energy storage system are distributed. This creates fewer incentives for investment in the systems. If energy storage is going to meaningfully penetrate the market in implementations beyond Ancillary Services Frequency Regulation, large strides will have to be made in crafting government regulation which allows energy storage to play on an even footing with other solutions. As that happens, it is likely that energy storage will grow in importance on the grid considerably.

6.3. New Business Models and System Architectures

A new business model which is enabled by energy storage is the “vertically integrated utility” model which Beacon Power is currently using. This allows them to capture more of the value from the whole value chain by designing, producing, installing and operating the system and collecting revenues directly from the services the system provides to the grid. Currently, it appears that this model is being utilized out of necessity, as their systems are very expensive and to operate profitably there is no room for the margins required in selling the device to another party. One other beneficial aspect of the model is that it reduces the risk a utility has to take, which should increase the likelihood of adoption by utilities since they are generally very risk averse entities. Though this new model may or may not be enough to make Beacon Power a successful company, it demonstrates an option available to energy storage developers to improve their margins and drive deployment.

Energy storage has also developed new system architectures. For instance, over the past few years, many developers have converged on the solution of housing their energy storage systems in semi-trailers for ease of delivery, siting and installation. This has grown to be a dominant design in the industry.

Also, the architecture of the electrical grid itself is on the verge of a revolution, partially due to energy storage. Historically, the grid has been a centralized system with an elaborate network of high voltage transmission lines bringing electricity from large, centralized turbine based power plants to load centers and lower voltage distribution lines bringing electricity to individual customers. Now with energy storage and other smart grid technologies, the successful, scalable integration of distributed generation, micro grids, and islanding into the grid is possible.

7. Suggested Further Work

A number of interesting topics for further work were identified in the course of developing this document.

- Since frequency regulation is currently one of the hottest areas for energy storage developments, it would be useful to research the elasticity of ancillary services pricing based on the coming changes in the market. For instance, increased wind power will increase ISO’s demand for frequency regulation by some amount. However, as energy storage is deployed, the

supply of frequency regulation to the grid will increase. It is currently unclear what pricing expectations are reasonable.

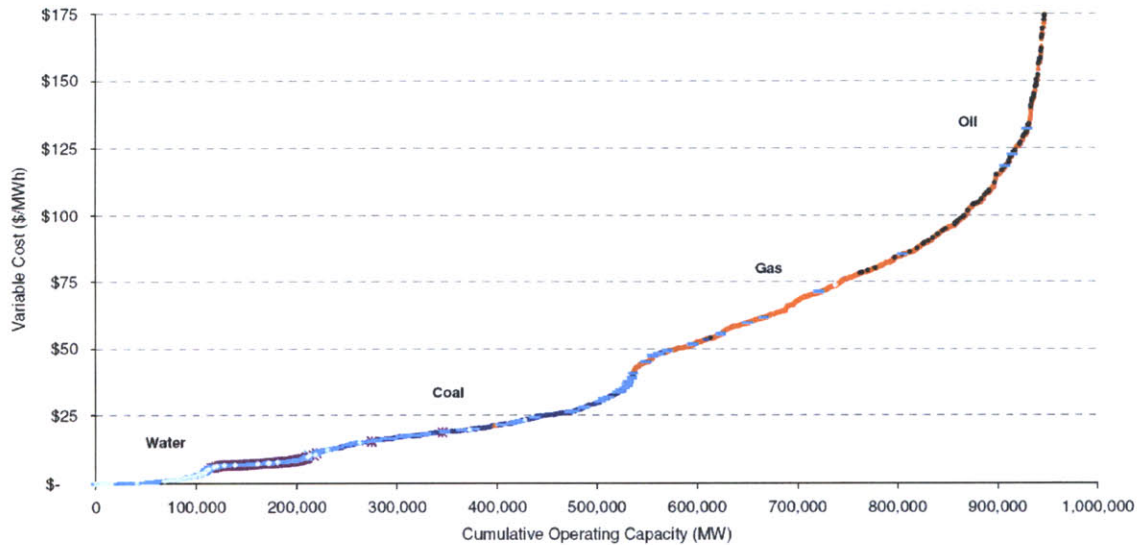
- One of the biggest factors in the entire grid scale energy storage system is the effect of regulation on the economics of energy storage. A further investigation of potential regulation and the effects on energy storage would be very useful. A number of details could potentially make a significant difference. For instance, if a price is put on carbon, can energy storage capture any carbon credits for the emissions it allows thermal power plants to avoid by letting them run at higher efficiency? Can energy storage be eligible for reliability incentives originally intended for other solutions, for instance incentives for installing below ground power lines? When can energy storage be added to whose rate base?
- One aspect of legislative factors could be clarified by assembling the relevant regulations for a variety of jurisdictions across the US and the rest of the world and then investigating the compensation systems for utilities and tariffs for customers and determining which are most friendly to energy storage.
- In order to investigate future scenarios, additional modeling of the grid to understand how to most efficiently and economically dispatch energy storage is critical.
- Researching the optimal siting of storage to balance wind projects would also be useful. Such a study should include both technical constraints and also regulatory/economic constraints to ensure that both aspects of the system are co-optimized.
- Also of interest would be to develop detailed operating cost models for each technology in each implementation. These operating costs will be needed to determine the true economics of an energy storage system in an implementation. EPRI-DOE has done good work on this in their "EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications" from 2003, which would serve as an excellent starting point.

8. Appendices

8.1. Dispatch curve

Depending how much power is needed in the system, different power plants are brought online. Plants that are expensive to run are only used when demand is high.

Exhibit 7: **U.S. dispatch curve**
All NERC Regions, 2007 Data



Source: SNL, Credit Suisse estimates.

Figure 32: Example Electrical Generation Dispatch Curve (Credit Suisse¹⁰⁰)

8.2. Background Information on Frequency Regulation

Table 15: Market Status for Frequency Regulation as of April, 2009 (Beacon Power¹⁰¹)

Market	Average MW Market Size	Average Pricing*	Market Developments and Status
ISO NE	130	\$48	Pilot program unanimously approved August 5, 2008, Began on November 18, 2008
NYISO	220	\$62	- Tailored market rules approved by stakeholders - Approved by FERC March 2009 - Market and software expected to be effective in May 2009
PJM	1000	\$61	Market open
MISO	Est. 1000 (new open market)	N/A (new open market)	- FERC ordered new tariff for Energy Storage Resources - MISO filed tailored tariff in May 2008, approved Dec08 - Expect open market by June 2009
CAISO	360	\$37	- California is market closed to fast-response storage - Stakeholder process to develop market rules for Energy Storage Resources derailed by MRTU priorities - Inability and/or unwillingness to comply with Order 890
ERCOT	Approx 100 and growing	N/A	- Not FERC regulated – less transparent - Highest wind penetration

* Average 12 month prices paid by ISO/RTO per MW service hour through July 08

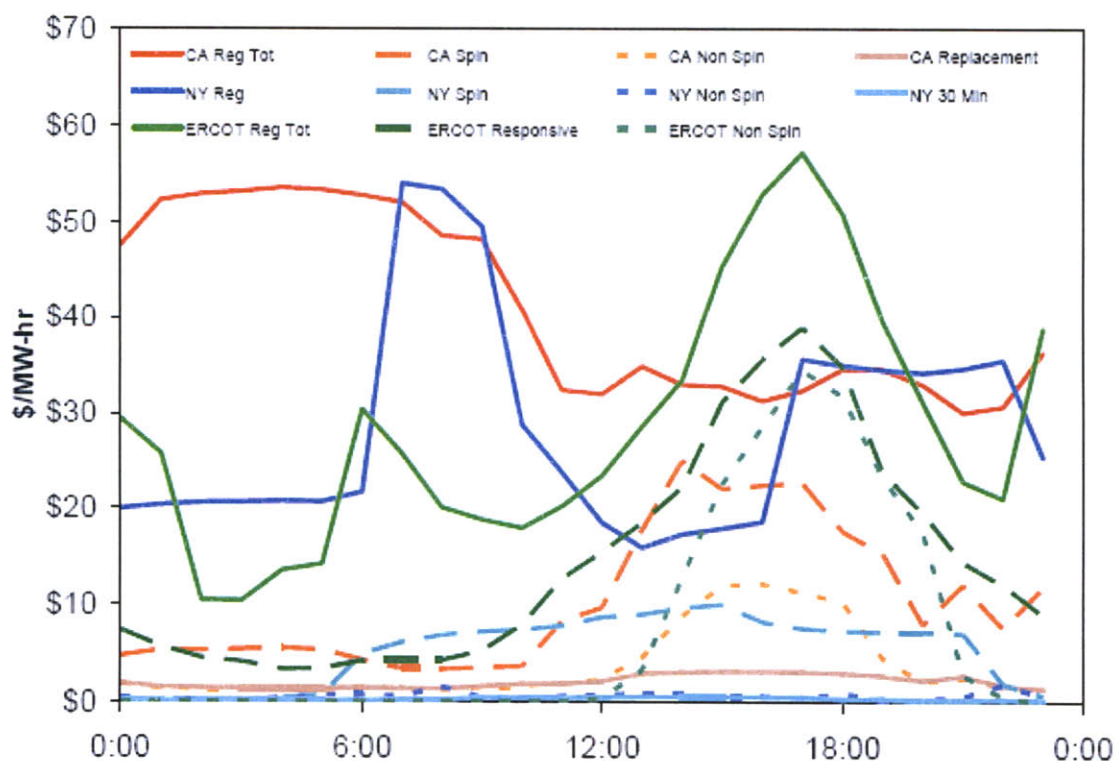


Figure 33: Average Ancillary Service Prices: June 2005 (Kirby¹⁰²)

8.3. Research Methodology

The research approach for this document was multi-pronged. One aspect of it was to identify and integrate the best existing public information on the topic, primarily from research reports written by national laboratories, non-profits, and industry analysts and consultants. It also involved obtaining a good deal of information from company websites, in press releases and recent industry articles. This information was frequently updated and allowed the document to include very current activity in the industry.

To complement this information, the research included a range of first hand interviews with many major firms in the sector on the supplier and customer sides of the business, and also analysts and related vendors making energy storage system subcomponents. A total of 18 companies were interviewed for this document using interview templates which were customized for each type of industry participant. Directly comparable information was included in spreadsheets of data on the industry and the entire content of the notes on each discussion was maintained electronically. The contribution of each interviewee is much appreciated.

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