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Behind-the-Meter Battery Storage:

Technical and Market Assessment

Final Report

December 2014

Report Number 15-02

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Behind-the-Meter Battery Storage: Technical and Market Assessment

Final Report

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Table of Contents

List of Figures

List of Tables

Summary

This report details the findings of research into the technical characteristics and market potential of behind-the-meter battery storage systems in end-user facilities in New York State. ERS performed this research in collaboration with NYSERDA staff. The primary goal of the research was to understand the potential of battery storage technologies under NYSERDA's Technology and Market Development Plan (T&MD plan). This potential includes input on how battery storage might fit into NYSERDA's Emerging Technologies and Accelerated Commercialization (ETAC) program, but is also intended to support both the joint NYSERDA and Con Edison Demand Management Program (DMP) and NYSERDA's Research & Development (R&D) program.[1]

This report builds on the findings of an interim deliverable, *Customer-Sited Battery Storage: Phase I Research*, provided to NYSERDA by ERS on December 18, 2013. This report supplemented the interim deliverable with a range of research activities. The research included an exhaustive examination of secondary resources as well as interviews with a range of stakeholders: battery storage vendors, battery storage customers, rate engineers, demand response (DR) aggregators, program administrators, and others. The research was performed primarily in the spring of 2014, with updates and revisions in the fall of 2014 to reflect changes in the marketplace resulting from DMP.

Key observations, conclusions, and future considerations are provided in this summary. Additional supporting detail is provided throughout the main report and its appendices.

S.1 Battery Technologies, Systems, and Costs

Batteries are electrochemical systems that convert energy between chemical energy and electric energy. They are measured and described in the following dimensions:

- Power capacity - the maximum power output (kilowatts [kW]) the battery can provide.
- Energy capacity - the energy (kilowatt-hours [kWh]) that the battery can discharge.
- Discharge duration - the maximum time, measured in hours or minutes, that a battery can discharge at its power capacity.

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[1] This report was initiated prior to the commencement of New York State's Reforming the Energy Vision (REV) initiative. REV could have significant impacts on battery economics because it is calling for utilities to change the way they procure and operate Distributed Energy Resources, which REV defines to include storage. If, as part of REV, utility rate structures and demand response programs change, the economics for batteries will change as well.

- Maximum depth of discharge - the percentage of a battery's technical energy capacity that can safely be discharged.
- Roundtrip efficiency - a measure of the energy retained/lost during the combined charge and discharge cycle.
- Cycle life and lifetime - measures of a battery's useful life, in charge-discharge cycles and years, respectively.

Power capacity, energy capacity, and discharge duration are related concepts that are achieved by combining electrochemical cells in series or parallel to achieve the desired kW and kWh capacities. Energy capacity is the product of discharge time multiplied by power capacity.

Notably, *technical* energy capacity may differ from *usable* energy capacity as a result of depth-of-discharge limitations and efficiency losses. It is common practice, though not universal, to quote the usable energy capacity of a battery as opposed to technical energy capacity.

Relatedly, as batteries age, their energy capacity degrades.[2] A battery's useful life is commonly, though not universally, defined as the number of cycles or years before it reaches 80% of its original technical capacity. Some vendors quote their energy capacities *net* of this degradation, as a sort of guarantee or warranty; that is, they oversize the battery to deliver the quoted energy capacity for the life of the battery. Battery purchasers should always clarify that a vendor's proposed capacity is net of these factors - i.e., is usable over the life of the battery - and will meet the customer's capacity needs for the number of years the battery is expected to last. For greater detail on these and other aspects of the fundamental characteristics of batteries, see Appendix A.

S.1.1 Technology Comparison

Different battery technology types will vary in their characteristic efficiencies, discharge limitations, lifetimes, and so forth. They also vary in size, weight, and - importantly - cost. Table S-1 and Table S-2 summarize the qualitative and quantitative aspects of those battery technologies that we have identified to be either mature and commercially available or near-commercial. Appendix B compares each of these technologies in much greater detail, with further discussion on pre-commercial technologies.

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[2] Flow batteries, which degrade in the efficiency dimension, are an exception to this general rule.

Data in Table S-2 represents the ERS team's judgment and synthesis of a variety of sources, including U.S. Department of Energy survey data, academic studies, and interviewee responses. It is presented for batteries in the 100 kW to 1 megawatt (MW) range. Cost parameters represent whole-system, first costs, including power electronics, conditioning equipment, safety equipment, installation, permitting, and design, but excluding battery replacement costs and annual maintenance or software costs. Costs/kWh are for *usable* energy capacity (i.e., net of depth of discharge, etc.), not technical energy capacity. Lifecycle costs are significantly affected by the expected lifetime of a battery, because battery replacement costs are between 15% and 40% of the initial system purchase depending on the technology. Tables S-1 and S-2 provide more background on cost considerations.

In Table S-2, volume refers to the volume of the battery itself as represented by standard refrigerator equivalents (i.e., 44 cubic feet). Footprint is the estimated footprint of the total battery system including power electronics, conditioning equipment, and walkways. The size and weight constraints imposed by batteries are significant. It is often difficult to identify suitable space within a building that is both safe and which can accommodate, for example, the roughly 2,000 square feet necessary for a 2-megawatt-hour (MWh) lead acid battery installation, which is the most popular technology to date. Space constraints are exacerbated by the weight of batteries, which is too much for most standard-construction commercial floors. Section 3.2 examines project siting issues in detail.

Table S-1. Summary of Qualitative Characteristics

Market	Battery Type	Technology summary	Key Advantages	Practical Challenges	Hazards
Commercial Technologies	Lead acid	Mature and widely used technology; the market leader	Modular; low cost; proven; highly recyclable	Deep discharges, extreme conditions shorten cycle life; heavy and large	Hazardous (Pb); corrosive; fire risk
	Lithium ion	Most rapidly growing technology with potential to become market leader	High energy and power density; long life; high DOD and efficiency	Very high cost	Fire risk
	Sodium sulfur	Mature technology with some limitations and narrow applicability	Cost-effective for long discharge times; long life; relatively low cost	Typically come as 1 MW unit; limited manufacturers	High temperature (300°C+); hazardous (Na); explosion and fire risk
	Nickel cadmium	Mature, but uncompetitive technology	High energy density; modular; solid life	High cost; memory effect	Hazardous (Cd)
Near Commercial	Advanced lead acid	Based on existing technology integrating carbon into electrodes	Improved life, durability, and recharge rates	Many advanced architectures that are proprietary and less proven	Hazardous (Pb); corrosive
	Vandium redox (flow)	Most mature flow battery	Long life; no self-discharge; scales well in energy dimension	Large, complicated system	Corrosive
	Zinc bromine (flow)	Promising second-generation flow technology	Very long life; modular; scales well in energy dimension	Large, complicated system; lack of established manufacturing process	Hazardous (Br); corrosive
	Sodium nickel chloride	Evolution of high temperature sodium batteries	Long life; low cost	Lack of established manufacturing process	High temperatures (350°C+)

Table S-2. Summary of Key Technical Parameters

Market	Battery Type	Installed Energy Cost ($/kWh)		Roundtrip Efficiency (%)	Useful Life		Size and Weight (Using 500 kW/2,000 kWh Example)			
		Suburban (Outdoors)	Urban (Indoors)		Cycle Life	Expected Lifetime (Years)	Battery Volume (Standard Refrigerators)	Total Footprint (Sq ft)	Weight (Lbs)	Pressure (Lbs/sf)
Commercial Technologies	Lead acid	$700 – $1,000	$800 – $1,200	70% – 80%	500 – 1,500	3 – 5	25	1976	110,231	558
	Lithium ion	$1,000 – $2,000	$1,500 – $2,500	85% – 98%	2,000 – 5,000	10 – 15	5	367	32,067	874
	Sodium sulfur (salt)	$750 – $900	$1,000 – $2,000	70% – 80%	2,500 – 4,500	10 – 15	8	642	22,611	352
	Nickel cadmium	$1,000 – $1,500	$1,250 – $2,000	60% – 70%	800 – 3,500	15 – 20	15	1223	70,548	577
Near Commercial	Advanced lead acid	$900 – $1,500	$1,200 – $1,800	80% – 90%	1,000 – 2,000	5 – 7	25	1976	110,231	558
	Vanadium redox (flow)	$1,000 – $1,500	$1,500 – $2,000	60% – 70%	10,000+	5 – 15	66	5242	220,462	421
	Zinc bromine (flow)	$750 – $1,250	$1,250 – $1,750	60% – 70%	10,000+	5 – 10	36	2854	110,231	386
	Sodium nickel chloride	$1,000 – $1,500	$1,300 – $1,800	80% – 90%	2,500 – 4,500	10 – 15	10	778	40,084	515

S.1.2 Whole-System Considerations

Batteries themselves are only one part of the overall energy storage system. The battery system includes the battery, controls, conditioning equipment, safety equipment, and power electronics such as inverters, meters, and bus bars. For outdoor installations, these components come packaged together in an enclosed housing, commonly a shipping container. For more mature suppliers, they often offer both the battery itself or a self-contained battery system in a shipping container. Indoor installations will have to construct a controlled-access room within a building in order to house all of these items. Greater detail on whole-system considerations is in Section 1.1.

S.1.3 Battery System Costs

Battery system costs depend on a variety of factors including:

- The battery itself typically represents half or less of the total installation costs. For some technologies, it can be as little as 20% of total cost.
- Labor and design, power electronics, controls, conditioning equipment, and safety equipment are a significant cost driver and typically represent more than 50% of the cost.
- For indoor locations in an urban setting, the costs increase, in some cases dramatically; labor costs are higher, and the amount invested in safety and conditioning increases in order to deal with the indoor location. Urban construction can require a premium typically representing 10-50% over standard outdoor installation costs.
- Another aspect of cost is the cost of replenishing the battery's capacity at the end of its useful life; longer-lasting batteries may cost more upfront, but they will save money down the line. These replacement costs are quoted in Table S-3 as a percentage of the total first cost of the entire installed system.
- Finally, annual operations and maintenance costs are typically between 2%-4% of total installed cost and will vary by technology. These costs include inspections, repairs, and software services.

Table S-3 summarizes the different components of costs. Section 1.2 details factors surrounding costs.

Table S-3. Battery Lifecycle Costs by Technology[3]

Battery Type	Whole-System First Costs ($/kWh)		Battery Replacement Costs	Battery Replacement Cycle (years)	Yearly O&M Costs	NPV Lifecycle Costs (500 kW, 2,000 kWh)	
	Suburban	Urban				Suburban	Urban
Lead acid	$700 – $1,000	$800 – $1,200	25%	3 – 5	2%	$ 3,392,461	$ 3,923,810
Lithium ion	$1,000 – $2,000	$1,500 – $2,500	40%	10 – 15	2%	$ 4,212,077	$ 5,716,390
Sodium sulfur (salt)	$750 – $900	$1,000 – $2,000	20%	10 – 15	2%	$ 2,207,372	$ 3,815,210
Nickel cadmium	$1,000 – $1,500	$1,250 – $2,000	40%	15 – 20	2%	$ 4,306,388	$ 5,562,418
Advanced lead acid	$900 – $1,500	$1,200 – $1,800	25%	5 – 7	2%	$ 3,959,175	$ 5,001,063
Vanadium redox (flow)	$1,000 – $1,500	$1,500 – $2,000	15%	5 – 15	4%	$ 4,193,075	$ 5,940,190
Zinc bromine (flow)	$750 – $1,250	$1,250 – $1,750	15%	5 – 10	4%	$ 3,319,518	$ 5,066,633
Sodium nickel chloride	$1,000 – $1,500	$1,300 – $1,800	40%	10 – 15	2%	$ 3,610,352	$ 4,512,940

Per-kilowarr-hour costs decrease as the battery's energy dimension increases. Because energy is a function of power, it is also true that economies of scale exist in the power dimension so long as the discharge duration is fixed. Based on interviews and limited empirical data, these economies of scale were estimated to represent roughly half the variation in cost represented in the ranges previously described, while the rest is attributable to vendor- and site-specific factors. This information can be interpreted as saying that smaller batteries (e.g., 50 kW/200 kWh) will tend to incur costs in the upper half of the ranges shown, while larger batteries (e.g., in the 500 kW/2 MWh and larger range) will tend to experience costs in the lower half of the ranges shown.

Overall, battery costs are decreasing and are expected to continue to decrease. The price drops for lithium ion are expected to be the most significant, with some forecasts estimating their costs to halve by the end of this decade. Lead acid, sodium sulfur, and nickel cadmium battery costs are unlikely to experience such dramatic reductions because they have been in use for a long time.

Importantly, non-battery system costs - which represent from half to three-quarters of total installed cost in a typical installation - are not typically included in battery cost forecasts. These costs may decrease as experience with installations grow, but should be expected to do so at a lower rate than the cost of batteries themselves. This fact will represent a drag on whole-system cost reductions because greater than 50% of costs are dedicated to non-battery aspects of the project.

Greater detail on costs and cost forecasts can be found in Section 1.2.

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[3] Replacement and yearly O&M costs are presented as a percentage of total installed cost. Total installed cost spans all components of cost (e.g., labor, permitting, power electronics, battery, and so forth) and are first costs only. They are not lifetime costs. Costs are examined in greater detail in Section 2.2.

S.2 Value Streams, Project Models, and Economic Analysis

Batteries create value in a variety of ways, in the form of both avoided costs and direct revenues. The value streams' characteristics - the magnitude of their value and the costs and technical challenges borne to realize that value - shape today's project models and their associated economics. This section explores those value streams, contemporary project models, and the economics of those models.

S.2.1 Value Streams

Behind-the-meter projects in use today are primarily energy-bill-management projects. They derive their economic value from three principle value streams:

- **Demand-charge reduction** - Reducing peak demand charges on a customer's utility bill. Peak clipping, peak shaving, demand limiting, and load smoothing are all strategies aimed at demand-charge reduction.
- **Demand response** (DR) - Receiving payments in exchange for providing reliable demand reduction in response to calls from the Independent System Operator or the utility during times of high grid congestion or during energy shortages.
- **Energy-cost savings** - Buying relatively inexpensive off-peak energy to power on-peak loads. Savings are the difference between the on-peak and off-peak rates, less efficiency losses. Energy cost arbitrage, load shifting, and energy shifting are all synonyms for activities aimed at energy-cost savings.

Other value streams noted in the literature and by interviewees included resiliency applications, targeted demand-side management (TDSM) programs, and renewables integration. None of these streams were key components of behind-the-meter projects that have occurred in New York State to date. Resiliency applications have the most promise as there is interest in using batteries managing targeted loads (e.g., allow one elevator to run for 10 minutes at the top of each hour), though this has not been done yet.[4] TDSM programs have not historically paid for battery projects, but may provide a revenue source in the future. Finally, renewables do benefit from batteries, but neither is essential for the other, and the benefits are primarily realized by the grid and at grid scale.

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[4] New York City Department of Buildings' regulations require that all voluntarily installed emergency generators provide power to emergency lighting, fire alarm systems, and at least one elevator serving all floors. Batteries are not considered emergency generators. http://www.nyc.gov/html/dob/html/codes_and_reference_materials/tppn0107.shtml

Among the value streams that behind-the-meter projects in New York have accessed, demand-charge reduction is far and away the most lucrative value stream. Demand response can also be lucrative, but to a lesser degree. Energy-cost savings, while a non-negligible source of income, are the least lucrative, and are typically pursued as a secondary goal to demand-charge reduction and demand response. Detail on the derivation and maximization of value streams is provided in Appendix C. Table S-4 summarizes average associated revenues.

Additionally, incentives are available for batteries through the Demand Management Program (DMP). DMP offers $2,100/kW for batteries that are able to discharge for 4 hours from 2 p.m. to 6 p.m. on nonholiday weekdays from June through September. Additionally, the program offers $800/kW for DR projects. Projects cannot claim both incentives. These incentives contribute positively to the economics of the project models discussed in this report, and they are included in economic modeling within this report. However, the report does not treat them as "value streams" because they are one-time payments and because they are only applicable to projects installed prior to June 1, 2016.

S.2.2 Project Models

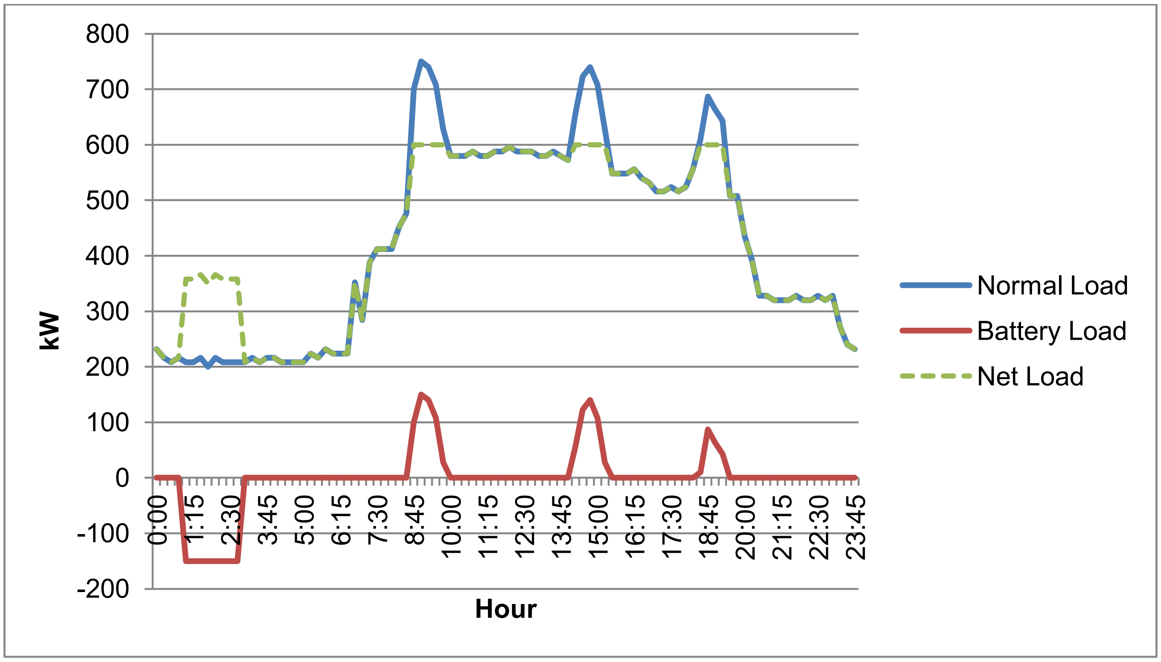
Customers have pursued the previously described value streams as part of different project models, all of which depend on a night-day, charge-discharge cycle (i.e., charge at night, discharge during the day):

- **Peak clipping** – This model targets demand-charge reduction with a low-energy solution (e.g., 2 hours or less discharge duration) that uses smart control technology to discharge energy coincident with intermittent spikes in load from using equipment such as elevators and water pumps. By limiting the discharge duration of the battery, this model can keep the cost of the battery down relative to revenues. This model is, broadly speaking, the most cost-effective investment in the absence of incentives, but requires a load curve with intermittent spikes that can be clipped. Figure S-1 shows a hypothetical daily load curve for a building engaging in peak clipping.
- **Demand response/peak clipping hybrid** – This model extends the discharge duration to 4 hours to participate in DR programs, while still targeting demand-charge reduction on days that DR events are not called. The larger battery raises costs, which can be partially offset by the additional revenues offered by DR. Typically, DR revenues are less significant than those offered by peak clipping, and, thus, in the absence of additional incentives, this project model garners less market attention.

- **Permanent load reduction (PLR)** – This model assumes a 4-hour discharge duration and is designed to fulfill the requirements of the DMP battery incentive. DMP requires that participating batteries discharge for 4 hours from 2 p.m. to 6 p.m. on nonholiday weekdays from June through September. During non-DMP days (October through May and weekends and holidays from June through September), the system is used to peak clip; from October through May, the battery participates in winter DR programs. As with the hybrid model, PLR battery costs are more significant than in the case of peak clipping. The model attempts to overcome those increased costs by maximizing demand charge reduction and DR payments within the rules of the DMP program while leveraging the significant DMP incentives. Note that DMP requires that batteries discharge in the described manner for 10 years; after 10 years, they are allowed to operate in other ways and would likely convert to a hybrid model approach to operation. For all economic analysis, it was assumed that in year 11 the battery will achieve revenues consistent with a hybrid model.

Detail on each of the project models is discussed in Section 2.1, including representative load curves for each of the models.

Figure S-1. Load Curve for a Peak-Clipping



S.2.3 Economic Analysis

This section analyzes the economics of the three project models previously identified and examines the key drivers of economics: project model, upstate v. downstate[5], urban v. suburban installations[6], technology costs, and project size. These topics are approached sequentially in order to isolate and clearly illustrate the impact of each major variable. Note that the project economics require assumptions, which are detailed for each analysis.

Table S-4 summarizes the realized value, both upstate and downstate, for each value stream within each project model assuming a 500 kW battery and includes estimated return on investment (ROI) and simple payback (SPB). All ROI calculations assume a discount rate of 5%. In Table S-4, the ROI is calculated for each project model, using Upstate and Downstate rate structures and revenue assumptions.

Table S-4. Summary of Economics by Project Model and Region

Revenue Category	Peak Clipping (500 kW/1,000 kWh)		Hybrid (500 kW/2,000 kWh)		PLR (500 kW/2,000 kWh)	
	Downstate	Upstate	Downstate	Upstate	Downstate	Upstate
Demand Charge Reduction	$205,000/yr	$30,000/yr	$182,500/yr	$25,000/yr	$146,000/yr	$20,000/yr
Demand Response Programs	n/a	n/a	$64,000/yr	$10,000/yr	$11,925/yr	$3,375/yr
Energy Cost Savings	$5,750/yr	$6,200/yr	$17,500/yr	$12,400/yr	$17,500/yr	$12,400/yr
DMP Incentive	n/a	n/a	$240,000	n/a	$1,050,000	n/a
ROI	59%	-66%	19%	-78%	19%	-81%
SPB	6	64	9	165	9	∞

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[5] Downstate is considered Con Edison service territory (i.e., New York City and Westchester County) and Long Island, while Upstate is the rest of New York State. This division is used throughout the report.

[6] Throughout the report, suburban installations will refer to those that are installed outside using a containerized solution. Urban installations are those installed indoors and which require the construction of controlled-access rooms.

A variety of assumptions go into the cost and value stream estimates and are documented in detail in Appendix C, and summarized here:

- Peak clipping assumes a 2-hour discharge duration and hybrid and PLR assume a 4-hour discharge duration.
- For reasons of simplicity, *suburban costs* (i.e., outdoor installations) are assumed in Table S-4. Such costs are unlikely to be experienced in the urban core of New York City. Figure S-2 examines the impact of urban costs.
- Costs are averaged for lead acid, lithium ion, sodium sulfur, and nickel cadmium technologies in order to isolate location and project model differences. Later in this section, technology-based ROIs are presented, which do vary significantly to make certain technologies appear more attractive than others.
- Demand charge reduction assumes "Standby Rates" from Con Edison for downstate and National Grid for upstate. Standby Rates are necessary to achieve the greatest demand charge reduction savings.
- Demand response revenues are estimated using posted rates or historical averages where appropriate.
- Energy cost savings are estimated using historical energy rates in New York City and Albany for Downstate and Upstate, respectively.
- DMP incentives are included: $800/kW available for the hybrid case and $2,100/kW available for PLR projects.

Table S-4 plainly shows that peak clipping projects have higher ROIs than hybrid or PLR projects. This is true, however, only in cases where a building's existing load profile is well suited - i.e., includes substantial, intermittent, and predictable spikes in load that can be offset using a battery with a discharge duration of 2 hours or shorter. The majority of facilities will not have this sort of profile and may be forced to consider hybrid or PLR projects as a consequence of their having a smoother load profile or a load profile with a peak that surpasses 2 hours in duration.[7]

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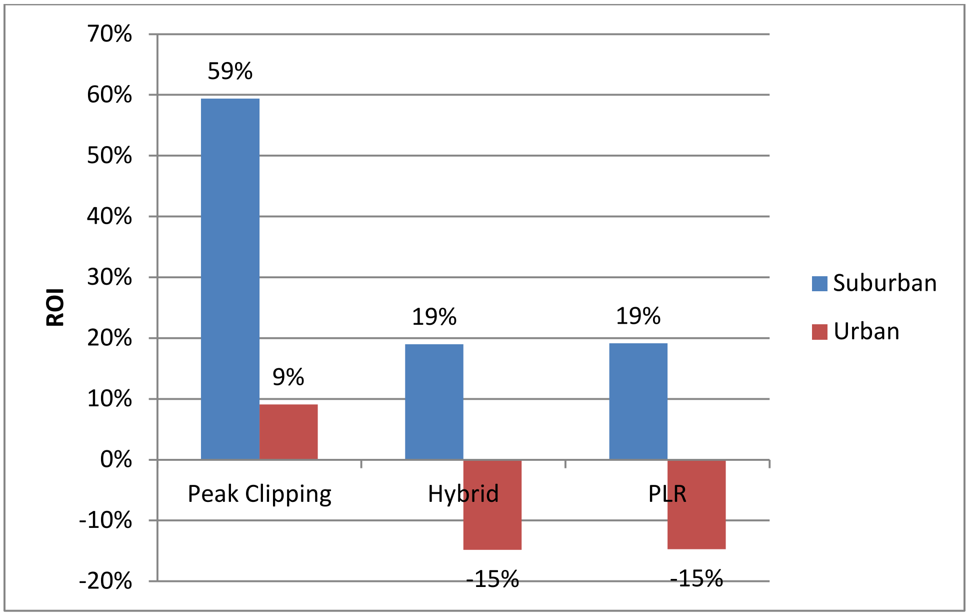
[7] Note that the similarity in ROI between hybrid and PLR projects is purely coincidental.

Table S-4 also clearly demonstrates that the Upstate value streams are so much lower than those available Downstate that Upstate projects are not economical. The focus of the market and NYSERDA should be on the Downstate region, in particular Con Edison territory and New York City, where the demand charges are the highest and DR programs are the most lucrative.[8]

Unfortunately, New York City projects will, by and large, occur in highly urbanized settings. Figure S-2 shows how the downstate ROIs change in response to urban costs. Urban costs include increased construction costs from indoor installation, higher labor rates, permitting costs, and increased delivery costs. Excepting the urban v. suburban cost dimension, the same assumptions in the previous section are applied in the next section, including battery capacity.

Figure S-2. Impact of Urban Costs on Project ROIs, Downstate



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[8] This analysis is based on existing rate structures. NYSERDA should collaborate with utilities to create storage-specific rate classes that reward users for investing in and properly operating a storage system. In jurisdictions outside of New York State, these rate classes have been employed instead of or as a supplement to incentive programs aimed at promoting storage technologies. This topic is addressed briefly in Appendix C.

Urban costs - and more specifically indoor installations - impose a significant barrier to project economics, driving the average project into the red. Downstate projects can partially avoid these costs by finding outdoor or outdoor-like settings within New York City such as parking lots and garages, loading docks, and yards. Although these sorts of spaces are limited in the city, utilizing these spaces can avoid the costs of building a controlled access room within the building.

The preceding analyses showed the economics of upstate v. downstate and urban v. suburban construction using an average of technologies. Investment economics, however, vary by technology. Table S-5 summarizes those variances by technology using the same assumptions as for the Downstate region.

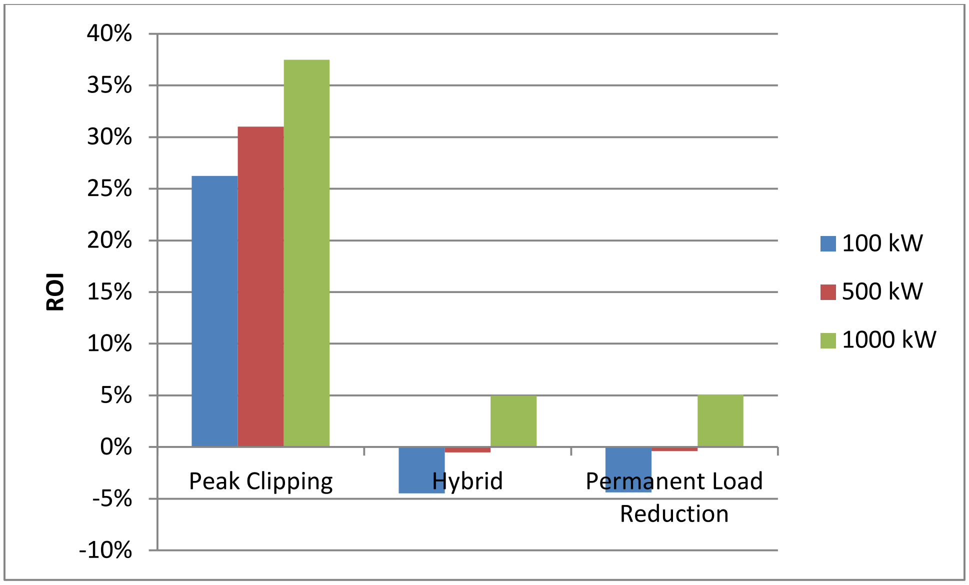
Table S-5. Comparison of ROI by Technology and Project Model, Downstate

Project Model	Lead Acid		Lithium Ion		NaS		NiCad		Adv Lead Acid		Vanadium Redox		Zinc Bromine		NaNiCl	
	ROI	SPB	ROI	SPB	ROI	SPB	ROI	SPB	ROI	SPB	ROI	SPB	ROI	SPB	ROI	SPB
Peak clipping	31%	6	-10%	12	26%	9	-11%	10	5%	9	-13%	14	1%	11	18%	9
Hybrid	-1%	8	-29%	18	2%	13	-32%	15	-20%	13	-36%	28	-25%	20	-11%	13
PLR	0%	7	-29%	26	2%	16	-32%	21	-20%	15	-36%	102	-25%	43	-11%	17

Lead acid, sodium sulfur, and sodium nickel chloride appear to be the most promising. Lead acid is currently the market leader, representing the vast majority of behind-the-meter installations to date. Sodium sulfur is not viable in urban situations due to size and safety concerns, so its economic performance should be discounted except in those cases where the battery can be sited outdoors. Sodium nickel chloride is an up-and-coming technology that is the basis of GE's flagship battery technology; it has a high first cost, but longer life than lead acid. Lithium ion, at time of research in early 2014, was still too expensive to be viable in most cases, but it has been noted elsewhere in this report that the greatest cost reductions are being seen with this technology, and many experts believe that it will overtake lead acid in the next few years as a consequence of those cost reductions.

As previously noted, project size can also influence project economics. Figure S-3 shows how economies of scale can influence projects using a lead acid project as an example.

Figure S-3. ROI by Project Model and by Project Size, Lead Acid, Downstate



Scaling up battery sizes from around 100 kW to around 1 MW can improve project ROI by roughly 10%. Further cost economies of approximately 10% – not shown in this graph – can be achieved by bundling projects across a portfolio of buildings to streamline permitting, contracting, and other transaction costs.

S.3 Non-Energy Barriers

The topics in this section include considerations that are neither purely technical nor purely economic, but which have an influence on battery project viability and profitability. Further detail on these topics is provided in Section 3.

S.3.1 Health and Environmental Hazards

All battery technologies include inherent risks. These risks are documented in detail by battery type in Appendix B, but in general stem from toxicity of the materials and their potential to leak, melt, catch fire, or explode. The actual safety risks are well understood, and fairly well-worn methods to counter them, such as constructing controlled-access rooms with sunken floors to contain spills, have been employed. However, the downstream impact of the potential for hazard on construction siting, permitting, cost, and customer perceptions act as an impediment to the adoption of batteries.

S.3.1 Construction and Siting Limitations

Installation of a battery storage system requires careful consideration of where the system will be installed, particularly when the installation is indoors. Considerations include:

- Batteries are, first and foremost, heavy, which means they need to be installed on concrete or reinforced floors. A standard office floor is required by the International Building Code to accommodate 50 pounds per square foot, whereas batteries can apply pressures ranging from 350 to nearly 1,000 pounds per square foot depending on the technology.
- Batteries are also large in volume. A 500-kW, 2-MWh lead acid battery will be roughly equivalent to 25 standard size refrigerators and require nearly 2,000 square feet of space including access aisles and support equipment. Certain technologies like lead acid or lithium ion are highly modular, which means they can counter this issue by being divided up into cabinet-sized components and fit into odd shaped spaces. Others, notably sodium sulfur batteries, come as large blocks that will require a large uniform shape and create building-access issues (e.g., will require walls to be knocked down).
- Given the inherent hazards posed by batteries, they cannot be put in flood-prone basements or near boilers.
- Finally, because they require ventilation and conditioning, they must be positioned such that these functions are available, which for indoor installations may require expensive ductwork.

The best solution to these issues is to install the battery outside, e.g., in parking lots or garages or on loading docks. Alternatively, interested customers could seek input from battery vendors who can help them identify optimal locations within a building. That said, there are buildings that simply cannot accommodate batteries either because they do not have a safe area for the battery (e.g., in flood zone or only have space next to the boiler) or because remediating the building to accommodate the battery would be cost prohibitive (e.g., would have to knock down walls to get it in or reinforce upper floors to accommodate the weight). Unfortunately, such factors are site-specific, cannot be broadly generalized by market segment, and can only be assessed definitively by actually visiting a building.

S.3.3 Permitting and Codes

Battery projects are required to get the necessary permits in line with the governing jurisdictions' building and fire codes. The New York State code permits lead acid, lithium ion, and nickel cadmium batteries, and a recent change to the New York City code expanded the allowable technologies to lead acid, lithium ion, lithium metal, and nickel cadmium, but both codes only support uninterrupted power supply(UPS)-style projects. ***Importantly, variance applications are required for all energy-management functions even with the recent code change.*** Example experiences in New York City include:

- One interviewee claimed to have established a blanket variance with the NYC Department of Buildings (DOB) and FDNY for all lead-acid energy management applications.
- The Brooklyn Army Terminal was forced to pursue lead acid because their application for variance with a lithium ion battery was rejected.
- The Barclay Tower installed their battery *without* appropriate permits and was only allowed on variance after the fact.

The variance process is a lengthy, effort-intensive process that offers no certainty of success, as evidenced by the Brooklyn Army Terminal's experience. Lead acid batteries have received variances for energy-management projects. Once a variance has been approved, it can be cited as precedence in future projects, which would still be subject to project-specific approval. However, these variances are not published and are considered in some ways to be a proprietary advantage.

S.3.4 Utility Interconnection

Utility interconnection is a necessary component of energy-management battery projects. Con Edison has had to streamline their process in order to accommodate the volume of requests they receive for combined heat and power (CHP) and solar projects, and that the same streamlined process is available for battery projects. This process is similar in other parts of the country.

S.4 Target Market Sectors

The market for batteries is limited by a series of practical considerations that impact the feasibility and economic viability of a project. Realizing value from a project depends a great deal on the electricity rates and DR programs available to a customer, both in terms of service territory and rate structure. The profitability of a project is also highly dependent on the customer having a load profile that enables them to take advantage of demand charge reduction at a relatively low cost. Finally, the facility must be capable of accommodating the physical battery structure without imposing impractical costs. A project is likely to be most cost effective:

- In Con Edison territory because demand charges and demand response rates Upstate are insufficient to economically justify battery projects.
- With a low-tension service[9] customer and have access to the Standby Service[10] and Hourly Pricing[11] rate structures to maximize revenue streams.
- Where spikes in load are intermittent, short in duration (ideally less than 2 hours in aggregate duration), and large enough[12] to be worth the effort of following through on the project. These characteristics align a building's load to demand charge reduction. Demand charge reduction is a key component of project economics for all three project models noted earlier in this report. As a rule-of-thumb, an appropriate load shape will be associated with demand charges that are greater than 40% of the total electric utility bill.
- With space sufficiently large and safe enough (e.g., conditionable and neither flood prone nor near a boiler or other hazard) to accommodate the necessary battery. Ideal locations will be outdoors, in a parking lot or parking garage, on a loading dock, or in an unused portion of the basement.

A viable battery project will fulfill all of these criteria, each of which is described in greater detail in Section 4.1.

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[9] High-tension service is offered at lower demand charge rates, which diminishes the savings potential from demand charge reduction; nearly all customers, with the exception of some large industrials, are on low-tension service.

[10] Switching to Standby Rates increases the proportion of a customer's bill that is dedicated to demand charges, thus increasing the demand charge reduction savings potential. This rate structure is available to all customers.

[11] Switching to Hourly Pricing is necessary to reap any energy cost savings from day-night arbitrage. This rate structure is available to all customers.

[12] In outdoor settings, customers have followed through on projects as small as 8 kW. In indoor settings, where the installation is more disruptive and costly, vendors suggest that a project must be at least 100 kW to be worth the trouble.

Even having identified these criteria, it is difficult to generalize about battery feasibility from a market perspective. Variations in load shape and available space make go-no-go decisions on batteries a highly building-specific question; for example, multiple vendors noted that they will not move forward on any project without seeing a year's worth of interval data.[13] However, some generalizations can be made regarding a sector's alignment with the necessary site characteristics. In Section 4.2, these criteria were analyzed in a market-by-market context to illuminate pockets of opportunity for batteries in New York State and suggest that:

- Multifamily and retail, particularly refrigerated retail, are the sectors best aligned with the criteria and are most suitable to peak clipping.
- The industrial sector offers some exciting potential, but faces certain challenges, most notably the variability of workloads and electric loads and their relative scarcity in Con Edison territory.
- Office, hotel, and other commercial loads are generally too smooth to align with peak clipping objectives, but they may be more amenable to longer-duration project models, such as the hybrid or PLR models.
- Hospitals and educational facilities are generally poorly aligned with the criteria, with exceptions.

Table S-6 summarizes the analysis of each market sector. Note that the analysis is aligned most closely to peak clipping projects, but applies to hybrid and PLR projects as well because they also depend on demand charge reduction to make project economics work.

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[13] This is necessary to identify the intermittency and predictability of demand spikes for demand charge reduction. Given that all the models depend significantly on revenue from demand charge reduction, the requirement for a year's worth of interval data can be thought of as a universal requirement.

Table S-6. Market Sector Analysis

Market Sector	Overview	Opportunities	Challenges	Assessment
Multifamily residential	Multifamily applications target common-area loads, which are more consistently prone to spikes	Intermittent load spikes in from elevators, water pumps, HVAC ramping Available space in garage or storage rooms Green image marketing	No HVAC ramping during winter diminishes winter revenues Elevator duration may not align with Con Edison demand charge calculations[14] Common area only	Feasible
Commercial retail	Large retail facilities that are standalone or separately metered within mixed-use commercial, especially refrigeration loads	Mid-morning peak in large retail stores Refrigeration loads in grocery & convenience stores can spike during deliveries/high usage	No HVAC ramping during winter diminishes winter revenues Limited space for batteries	Feasible
Industrial	Load profiles vary greatly depending on production processes and cycling	Huge equipment loads that are often intermittent Available space within existing facilities	Most facilities upstate Peak loads often already managed Variable production	Hit or miss
Other commercial	Includes office buildings, hotels, restaurants, and mixed-use commercial buildings without individual metering	Elevator loads in office buildings Evening peaks in restaurants/other commercial	Load shapes too smooth/ not conducive to demand charge reduction No HVAC ramping during winter diminishes winter revenues Limited space within NYC	Limited/longer duration feasibility (e.g., hybrid or PLR)
Hospitals	Hospitals have large overall loads due to 24-hr occupancy and air cycling requirements	Available space on campus Individual spiking loads	Administrative process High utilization; flat demand	Less feasible
Educational facilities	Schools, campuses, and related buildings	Available space on campus Demonstration projects Labs may have spiking equipment	Relatively flat loads Often master metered	Less feasible

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[14] Con Edison calculates peak demand by averaging the highest consecutive 15-minute periods of demand during the billing period. If elevator rush-hour is shorter than half an hour, then the opportunity presented by spiky elevator loads can be diminished.

S.5 Program Precedents and Future Considerations

California's Self-Generation Incentive Program (SGIP) is the only incentive program in the U.S. other than DMP specifically targeting battery storage for commercial deployment (as opposed to R&D or emerging technology programs). Its structure and experience provide a useful model for how to design battery programs here in New York State. Additional programs throughout the country encourage broader energy storage – typically thermal storage – and other permanent load reduction strategies. These other programs are summarized in Section 5.1.

Observations from program precedents, as well as the analyses presented throughout this report, lead to the following future considerations for the DMP program design:

- The proposed DMP battery storage **base incentive rate** of $2,100/kW is nominally aligned with similar programs, notably SGIP. However, the $/kWh are lower when the implications of required discharge duration are considered (2 hours vs. 4 hours for SGIP and DMP, respectively).
- The **rated capacity** (both kW and kWh) of the battery should be measured in terms of the usable energy delivered on the AC side of the inverter and this capacity should be requiring for a set number of years.
- Incorporating a **measurement and verification (M&V)** period, such as the 1-year program currently planned by NYSERDA and Con Edison, is a fair compromise between the needs of project developers and Con Edison. Battery project developers would receive the majority of the incentive upon project completion, while the M&V period encourages projects to perform as designed, helping verify load reductions.
- A minimum **roundtrip efficiency** of 65% for DMP projects. This value is based on empirical research in California that ensures no net greenhouse gas emissions.[15] It is also well within the range of commercially available technologies, and it pushes less-efficient technologies toward the higher end of their capabilities.

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[15] CA SGIP program requires minimum 63.5% roundtrip efficiency. The SGIP program manager at CPUC reported verbally that this value was selected to ensure no net increase in greenhouse gas emissions.

Future considerations specific to the ETAC program include:

- **Near-commercial technologies** – A set of technologies identified in Appendix B are not widely deployed, but could be solid candidates for demonstration projects through ETAC.
- **Hybrid projects** – Although peak clipping is gaining traction, hybrid projects are much less common. ETAC could support a series of these projects to speed their adoption and to establish data on revenue retention when layering DR and peak-clipping functions.[16]
- **Managed, critical-load backup** – During interviews, multiple battery vendors identified that they are exploring using the battery in a managed fashion as backup to critical loads during power outages. This type of application has never been done, and it would increase the cost of the battery, but it could really get the attention of the market if done successfully.
- **Flow batteries –** Flow batteries have not yet been proven in an urban location. Identifying a project to prove their capability in such an environment could go a long way to smoothing their adoption in the downstate region, where their long-duration characteristics would be most valuable.

ERS also suggests that the future considerations for the pre-commercial technologies identified in Appendix B be noted for NYSERDA's R&D program.

All of these future considerations are discussed in further detail in Section 5.2.

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[16] Regarding "revenue retention", on days when DR events may be called, peak-clipping will not be possible since peaks often occur outside of the DR event window. On those days, the battery will not have sufficient charge to both fulfill DR obligations and peak clip completely. This deficit leads to an erosion of demand charge reduction savings. Without empirical examples, the extent of the reduction in savings is unknown.

1 Battery Systems and Costs

This section discusses batteries as an energy storage system and covers cost considerations. For battery basics, refer to Appendix A. In addition, Appendix B provides details on different battery technology types.

1.1 Whole-System Considerations

Energy storage systems are composed of more than just a battery. These other components provide critical functions for the battery equipment and are typically included in the costs of a battery storage system. Total systems will include the following equipment:

- **Battery management system (BMS) or controls** – This software is necessary to control battery operation. It keeps tabs on battery charge status and other critical indicators such as temperature. It dictates charge and discharge cycles based on other equipment loads or energy prices. It includes both the user interface, which is typically Web-based, and the physical measurement equipment. Most battery manufacturers also offer their own proprietary BMS, which can operate on a standalone basis or can integrate with existing controls systems.
- **Meters** – Vendors typically install their own meters inside of the utility meter to capture the interval data needed to calibrate the advanced control systems that predict peak loads and control the operation of the battery systems. If switching to a new rate class, such as Standby Service, a new utility meter may also be required; this is an added cost as part of the interconnect process, but is only a small fraction of the cost of a system.
- **Power electronics** – This refers to critical ancillary equipment such as inverters and relays to integrate the DC battery signal with the facility's AC system. Inverters must meet UL 1741 architecture standards to receive utility approval. This standard means they are capable of automatically isolating the battery from the grid in the event of an outage. Inverters often come with inefficiencies that contribute to overall system inefficiency.
- **Housing** – Many manufacturers package energy storage systems in shipping containers, which provide a strong and durable housing for the equipment. Within a facility they may be provided as modular cabinets in a sealed room with controlled access.
- **Physical support** – Large battery systems are very dense and can exceed local floor support specifications requiring additional support to be installed before the battery. Outdoor installations are usually installed on poured concrete foundations.
- **HVAC** – Batteries are sensitive to operating temperature and often have specific requirements for ventilation. The ventilation requirements are typically dictated by the manufacturer, but can also be influenced by code. Modular units typically come with built-in HVAC systems.

1.2 System Costs

System costs will vary by technology, but they include similar components, including:

- Battery.
- Power electronics.
- Controls equipment.
- Conditioning equipment.
- Housing.
- Design.
- Labor.

During interviews with manufacturers and system designers, cost breakdowns were discussed. Batteries are typically responsible for only one-third to one-half of the project costs with power electronics, while other components, design, and installation account for the rest of the cost.

1.2.1 Cost Influences and Lifecycle Costs

Various factors must be considered when estimating the total lifecycle costs of a system, including:

- **Installation** – The equipment costs for battery systems are fairly constant project to project, and generally the biggest unknown factor is the cost of installation, which can be dramatically different depending on the location. Factors like installation in a high-rise building in New York City will increase the cost of installation compared to an outside installation in a suburban environment by between 10% and 50%. Typically, urban installations would be indoors, but not exclusively. Indoor urban installations would be the most expensive installation type for a number of reasons, ranging from difficulties in transporting the equipment to the space and meeting building code requirements.
- **Economies of scale –** Battery systems tend to experience economies of scale in the energy dimension. Because energy is a function of power, it is also true that economies of scale exist in the power dimension so long as the discharge duration is fixed. Some aspects – design, administration, etc. – are amortized in both dimensions, while power electronics costs scale with power but can be spread across the energy capacity of the battery (e.g., the cost of the inverter is the same if it has a discharge duration of 2 hours or 8 hours). Additionally, many manufacturers offer modular batteries that are combined to create larger power capacities, but they do not offer significant discounts when ordering multiple modules. The economies of scale were estimated to represent roughly one half of the variance in per-kWh cost in the cost ranges presented. This information can be interpreted as saying that smaller batteries (e.g., 50 kW/200 kWh) will tend to incur costs in the upper half of the ranges shown in Table 1-1, while larger batteries (e.g., those in the 500 kW/2 MWh and larger range) will tend to experience costs in the lower half.

An alternative formulation is to consider economies of scale as a "discount". Vendors who were interviewed quoted economies of scale that varied, but which centered around an approximately 10% discount from scaling by roughly a factor of 10. That is, if a 50-kW, 200-kWh battery costs $200,000, a 500 kW/2 MWh battery will cost $1.8 million - a 10% discount from $2 million ($200,000 x 10 = $2 million). Vendors also believe that another roughly 10% savings can be achieved in administrative economies of scale by bundling 5-10 projects together (for example with a portfolio of buildings), by streamlining permitting, contracting, and other administrative transaction costs.

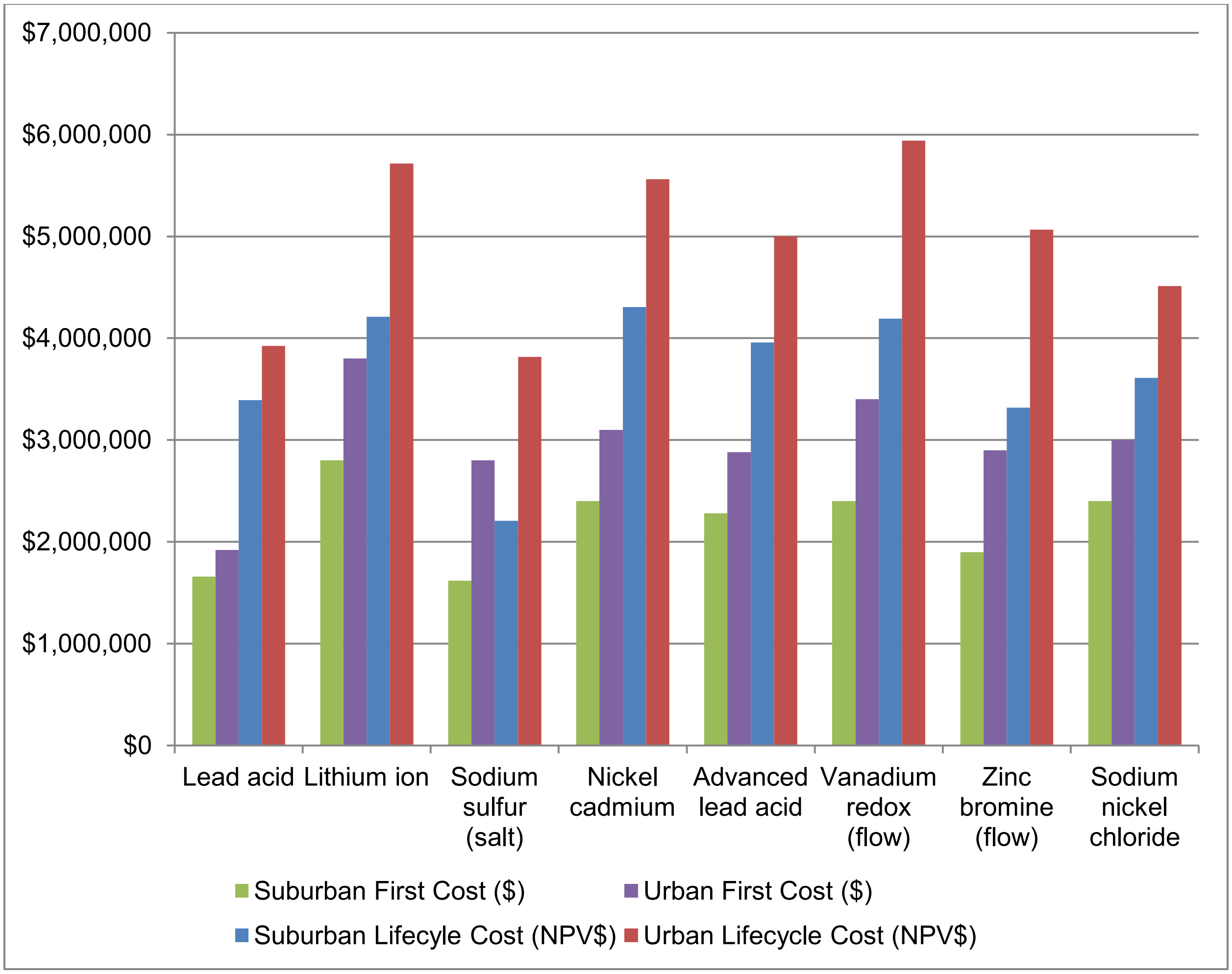
- **Battery useful life and replacement** – Generally, the batteries in an energy storage system will have shorter lifetimes than the power electronics, controls, conditioning equipment, and equipment housing. Costs of replacing the battery will depend on the battery type, but are between 20% and 40% in most cases. As such, the useful life of the battery itself is a significant determinant of overall lifecycle costs because short lives mean repeated purchases. Power electronics and other supporting equipment are estimated to have a useful life of 25 years. Details on the lifetimes of batteries and their expected replacement costs are shown in Table 1-1.
- **Operations and maintenance** – Operations and maintenance (O&M) costs will also vary to some extent depending on the battery type. Flow batteries have the highest O&M costs, but overall annual O&M is less than 5% of original capital expenditure for the total system. Sometimes it is included as part of the project contract.

Table 1-1 summarizes battery costs by technology for the mature and near-commercial technologies. Figure 1-1 shows those costs in graphical form. Replacement costs and O&M costs are quoted as a percentage of original expenditure. Net present value of total costs uses a 5% discount rate.

Table 1-1. Battery Lifecycle Costs by Technology

Battery Type	Total Installed Energy Cost ($/kWh)		Battery Replacement Costs	Battery Replacement Cycle (years)	Yearly O&M Costs	NPV Lifecycle Costs (500 kW, 2,000 kWh)	
	Suburban	Urban				Suburban	Urban
Lead acid	$700 – $1,000	$800 – $1,200	25%	3 – 5	2%	$ 3,392,461	$ 3,923,810
Lithium ion	$1,000 – $2,000	$1,500 – $2,500	40%	10 – 15	2%	$ 4,212,077	$ 5,716,390
Sodium sulfur (salt)	$750 – $900	$1,000 – $2,000	20%	10 – 15	2%	$ 2,207,372	$ 3,815,210
Nickel cadmium	$1,000 – $1,500	$1,250 – $2,000	40%	15 – 20	2%	$ 4,306,388	$ 5,562,418
Advanced lead acid	$900 – $1,500	$1,200 – $1,800	25%	5 – 7	2%	$ 3,959,175	$ 5,001,063
Vanadium redox (flow)	$1,000 – $1,500	$1,500 – $2,000	15%	5 – 15	4%	$ 4,193,075	$ 5,940,190
Zinc bromine (flow)	$750 – $1,250	$1,250 – $1,750	15%	5 – 10	4%	$ 3,319,518	$ 5,066,633
Sodium nickel chloride	$1,000 – $1,500	$1,300 – $1,800	40%	10 – 15	2%	$ 3,610,352	$ 4,512,940

Figure 1-1. Battery First Cost and Lifecycle Costs by Technology for 500-kW, 2,000-kWh System



1.2.2 Cost Forecasts

Costs are expected to continue to drop for all developing technologies as manufacturing processes become cheaper and systems mature. Lithium ion offers the most exciting prospect for cost reductions. Costs are reaching the point where value streams can exceed costs making for economical projects in certain applications as described previously and expanded upon throughout this report. As costs come down, especially for the less commercial technologies, market penetration can be expected to increase.

Importantly, non-battery system costs are not typically included in these forecasts and may decrease as experience with these sorts of installations grows, but should be expected to do so at a lower rate than the cost of batteries themselves. This fact will represent a drag on cost reductions due to the relatively large portion of costs dedicated to non-battery aspects of the project, particularly in urban settings.

2 Value Streams, Project Models, and Economic Analysis

The market for behind-the-meter battery storage depends on projects' ability to monetize the load management capabilities of the technology. Load management is a broad term encompassing a range of activities: load shifting, peak shaving, peak clipping, demand limiting, load smoothing, energy-cost arbitrage, DR, and many more. Monetizing the range of these activities comes down to a handful of value streams that take the form of either avoided costs or direct revenues. The relative profitability and technical challenge of each value stream has shaped the market for batteries and led to a set of typical project models.

The value streams fall into six categories, presented in descending order from most to least relevant to today's viable project models:

- **Demand-charge reduction** – Batteries can act as a tool to reduce peak demand and thus reduce peak demand charges on a customer's utility bill. Peak clipping, peak shaving, demand limiting, and load smoothing are all synonyms for activities aimed at demand-charge reduction. Demand-charge reduction is currently the most lucrative value stream and requires a relatively low-energy and comparatively inexpensive battery to realize its value; consequently, the market is currently biased toward short-duration batteries that are a poor fit with DMP objectives.[17] For customers to maximize their bill-based savings, they must switch to Standby Service rates or similarly demand-oriented rates.

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[17] Through the course of interviews, ERS found that there was a mild preference for the term "peak clipping" among vendors. While some had no preference, others were concerned that "peak shaving" connoted energy management as opposed to power management. Since the low-energy nature of the battery is so important in the current market context, the term "peak clipping" will be used when referring to demand-charge reduction activities in this report.

- **Demand response (DR) –** DR programs offer to pay for reliable DR during certain windows, or events, commonly (though not always) called during peak hours of the summer and usually lasting at least 4 hours. Layering DR revenues with demand-charge reduction is not especially popular because it has two consequences: 1) it will typically require a battery with double the discharge duration (and cost) of one employing only a peak-clipping strategy and 2) by partaking in both peak clipping and DR, a customer is incapable of realizing the full value of either value stream due to competing claims on the same discharge capacity. [18] An important development that may increase the market for DR-capable batteries is the recent rate increase for Con Edison DR programs.
- **Energy-cost savings** – Energy-cost savings accrue from buying relatively inexpensive off-peak energy to power on-peak loads. Savings are the difference between the on-peak and off-peak rates, less efficiency losses. Energy-cost savings are far less significant than those accrued through demand-charge reduction. As a result, contemporary battery projects tend to be power-sized, not energy-sized, and rarely pursue this value stream as a primary target. Energy-cost savings are commonly accrued as an afterthought to peak clipping or hybrid peak clipping/DR projects. [19] To realize this value stream, customers must participate in hourly supply pricing.
- **Soft revenues and avoided costs from resiliency** – Resiliency applications can avoid costs associated with unplanned shutdowns or allow landlords to charge a premium for the peace of mind offered by resilient building functions. None of today's projects provide true back-up power – nor will any project soon – because cost-effective battery storage project capacities are massively undersized to meet total building load. However, there is interest for future projects in hard-wiring critical loads (including elevators) and meting out power in a managed way during grid disruptions. Such an application is feasible and could be a marketing differentiator with meaningful impacts on rental or lease revenues.
- **Targeted demand-side management** – In the past, Con Edison has offered customers incentives for load reduction commitments in specific areas of the grid experiencing localized congestion. None of today's projects tapped these funds.
- **Integration with renewables** – The integration of battery storage with renewable energy generation projects, primarily wind and solar, is an increasingly common practice that provides some important benefits such as intermittency relief and frequency regulation. However, these benefits, where quantifiable, are largely accrued to the grid with greater importance at utility scales; the primary driver for behind-the-meter battery projects is their energy management functionality, not the integration with on-site renewable generation.

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[18] Engaging in peak clipping will preclude a project from realizing 100% of potential DR revenues. Peak-clipping year-round will lower the baseline load measured by the DR program, thus reducing the amount of capacity that can be offered to DR programs. The history of such hybrid projects is short and, to date, no one has reported having their DR projects impacted in such a way. However, it is likely to happen. For the purposes of revenue projections, 60% retention is estimated, though this is a rough educated guess, equivalent to saying that one-half of the peak clipping discharge overlaps with the DR window. An additional consequence of using the same battery for both peak clipping and DR is that the battery will be too drained on event days to perform peak-clipping duties. A loss of 10% of revenues is estimated for peak clipping as a result of participating in DR events.

[19] Because energy cost arbitrage activities are rarely the focus of the project, less attention has been paid to their nomenclature. Activities aimed at accruing energy cost savings were referred to in a variety of ways in interviews including energy cost arbitrage, load shifting, energy shifting, and sometimes load shaving. These activities will be referred to as energy cost arbitrage in this report.

The following subsections expand upon the summaries of the six value streams. The details of each subsection will focus on the most relevant and common elements of value as opposed to surveying all possible options.

Three project models were observed that illuminate how the above value streams are realized in practice and how they shape market dynamics. Two of those project models are in use today:

3. **Peak clipping** – This model focuses on delivering a power-oriented,[20] low-energy solution (e.g., 2 hours or less discharge duration) that uses smart control technology to discharge energy coincident with intermittent spikes in load from using equipment such as elevators and water pumps. The goal is a reduction in peak demand charges. Load-shifting revenues are realized, but they are less significant than the demand-based savings. By limiting the discharge duration of the battery, this model can keep the cost of the battery down relative to revenues. This model is, broadly speaking, the most cost-effective investment and the most widely employed.
4. **Demand response/peak clipping hybrid** – This model delivers a power-oriented, medium-energy solution (e.g., 4 hours discharge duration) to accomplish the same peak clipping previously described above while garnering DR revenues. The discharge duration of the battery is expanded in order to accommodate DR events. This raises costs, which can be offset by the revenues offered by DR. Typically, DR revenues are less significant than those offered by peak clipping.

The IPEC DMP is requiring a discharge duration minimum of 4 hours, with the full battery energy discharged during the system peak (noon to 8 p.m. from May to October). This has led to discussion of a new project model that would draw on available value streams while satisfying program criteria:

1. **Permanent load reduction** – This model would deliver a power-oriented, high-energy solution (e.g., 5–6 hours discharge). This discharge capacity would allow the battery to fulfill program requirements surrounding permanent load reduction, which is a 4-hour bulk discharge during summer peak hours.[21] The additional discharge capacity would enable the system to peak clip during off-peak summer hours. During off-peak months the system could be utilized to peak clip and participate in winter DR programs. This would require a significantly more expensive battery. There are no examples of a project model like this in use today.

Table 2-1 outlines the details of the most common value streams is shown in Table 2-1, with estimated annual revenues for each of the three project models. Appendix C provides further detail on value streams including expanded discussion on the underlying rate structures and DR payments that contribute to them.

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[20] "Power-oriented" in this context means that the battery's power capacity is sized to match the curtailable power spikes of the building's load. Some buildings' load shapes will be too flat to be feasible for such an application. The key is that the above-baseload spikes are drawing power for a total of less than a few hours per day (the fewer the better). The target building's load spike will vary as a percentage of total load, but typical examples have been between 5% and 20% of total load.

[21] This load reduction is considered "permanent," per the IPEC program, in that it involves a commitment to do this every day during summer peak hours in perpetuity.

Table 2-1. Summary of Value Streams and Estimated Annual Revenues by Project Model

Category	Sub-category/Activity	Description	Revenue Structure	Revenue Rule-of-Thumb	Example Revenues by Project Model					
					Peak Clipping (500 kW/1,000 kWh)		Hybrid (500 kW/2,000 kWh)		PLR (500 kW/2,000 kWh)	
					Downstate	Upstate	Downstate	Upstate	Downstate	Upstate
Demand Charge Reduction	Peak Clipping	Curtails short duration spikes in load through battery discharge in order to reduce demand charges. "Load smoothing"	(Old peak kW - new peak kW) x demand charge Varies by rate structure. Standby rates used to show maximum possible benefit.	Downstate: Average $/kW/day of ~ $1.72 in summer Average $/kW/day of ~ $1.02 in winter Upstate: $/kW/day of $0.2543 year-round in National Grid territory	$205,000/yr	$30,000/yr	$182,500/yr	$25,000/yr	$146,000/yr	$20,000/yr
Demand Response Programs	NYISO SCR/ICAP	Most widely used NYISO program (94.9% of particpants) due to lower barriers to entry and reservation-based payment. Participation organized by aggregator. Events are typically 4 hour windows with a minimum of 2 hours notice. Can be called year-round, though off-peak events are uncommon.	Reservation payment for kW capacity. Additional revenue based on energy reduction observed during events. Aggregators take between 10%-40% of revenue.	$150/kW/year in NYC $53/kW for winter in NYC $43/kW/year in upstate $15/kW for winter in upstate	N/A	N/A	$33,750/yr	$9,675/yr	$11,925/yr	$3,375/yr
	ConEd CSRP	Participation organized by aggregator. Events have standard 4 hour windows with a minimum of 21 hours notice. Runs May through September. Can participate in DLRP simultaneously.	Reservation payment for kW capacity for each month. Additional revenue based on energy reduction observed during events. Bonus dependant on large number of events or unplanned events. Incentive for those who sucessfully complete three years.	$10/kW/month for 4 or fewer events $15/kW/month for 5 or more events $1/kWh during events $6/kWh during unplanned events $10/kW/month for long term participation	N/A	N/A	$13,275/yr	N/A	N/A	N/A
	ConEd DLRP	Participation organized by aggregator. Events have standard 4 hour windows with 2 hours or less notice. Runs May through September. Can participate in CSRP simultaneously.	Reservation payment for kW capacity for each month, based on network Tier. Additional revenue based on energy reduction observed during events. Bonus dependant on large number of events or longer event periods. Incentive for those who sucessfully complete three years. Aggregators take between 10%-40% of revenue.	$6/kW/month for Tier 1 Networks $15/kW/month for Tier 2 Networks $2/kW for 7-9 events/month $3/kW for 10 or more events/month $1/kWh during events $6/kWh during extended performance $5/kW/month for long term participation	N/A	N/A	Tier 1 : $6,975/yr Tier 2: $17,100/yr	N/A	N/A	N/A
Energy Cost Savings	Energy Cost Arbitrage	Arbitrage through purchasing energy at lower rates during the evening to discharge during the day, avoiding peak rates.	(Discharge kWh rate - Charge kWh rate / roundtrip efficiency) x kWh shifted Varies by rate structure and market pricing. Must have hourly pricing to take advantage of this structure.	Average arbitrage net of efficiency: Downstate - $0.024/kWh Upstate - $0.017/kWh	$5,750/yr	$6,200/yr	$17,500/yr	$12,400/yr	$17,500/yr	$12,400/yr
IPEC	Permanent Load Reduction	One-time payment for the installation of equipment to provide permanent load reduction for four-hour periods during peak hours.	Different $/kW depending on technology.	$2,100/kW for Downstate projects.	N/A	N/A	N/A	N/A	$1,050,000	N/A
	Demand Response	One-time payment for the installation of equipment to provide demand response service as needed during peak hours.	$/kW of demand response capabilities.	$800/kW for Downstate projects.	N/A	N/A	$240,000	N/A	N/A	N/A

2.1 Project Models

Three project models illuminate how the above value streams are realized in practice and how they shape market dynamics.

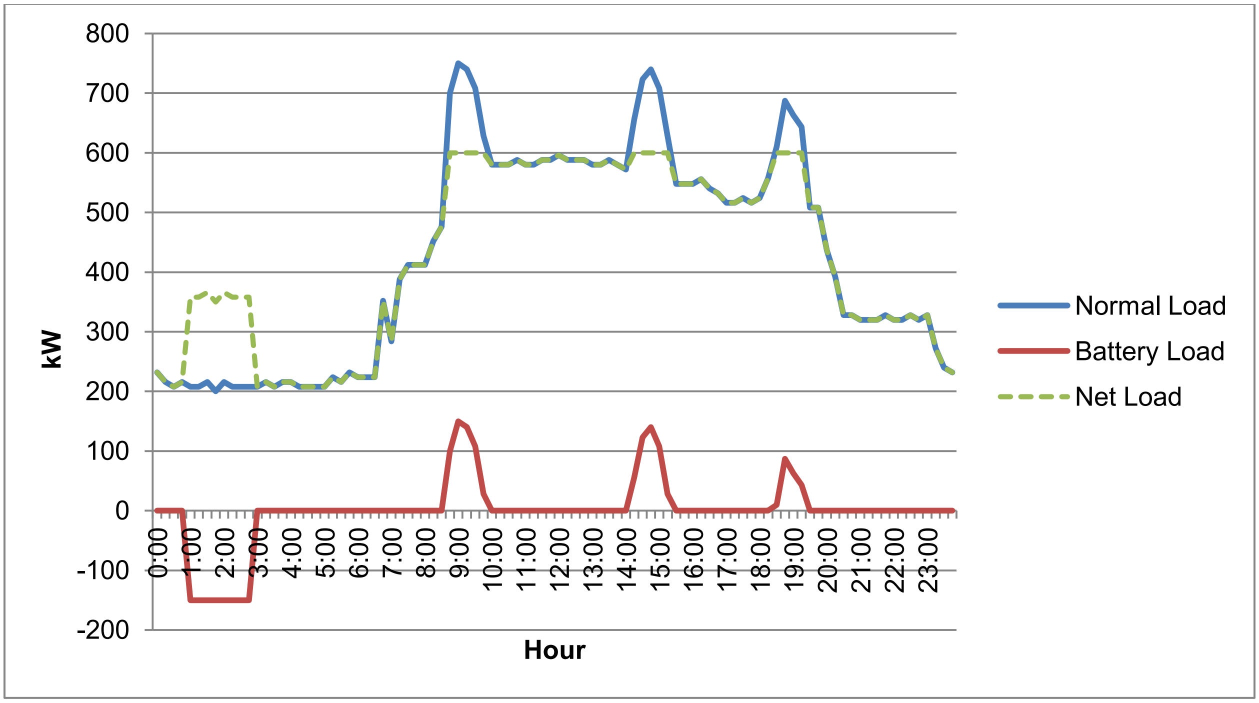
2.1.1 Peak Clipping Projects

This model focuses on delivering a power-oriented, low-energy solution (e.g., 2 hours or less discharge duration) that uses smart control technology to discharge energy coincident with intermittent spikes in load from using equipment such as elevators, water pumps, etc. The goal is a reduction in peak demand charges.

- Power-oriented in this context means that the battery's power capacity is sized to match the curtailable power spikes of the building's load. Some buildings' load shapes will be too flat to be feasible for such an application. The key is that the above-baseload spikes are drawing power for a total of less than a few hours per day (the fewer the better). The target building's load spike will vary as a percentage of total load, but typical examples have been between 5% and 20% of total load.
- Load-shifting revenues are realized, but they are less significant than the demand-based savings.
- By limiting the discharge duration of the battery, this model can keep the cost of the battery down relative to revenues.
- This model is, broadly speaking, the most cost-effective investment and the most widely employed. It is the underlying business model for most energy management projects.

Figure 2-1 shows how a building load profile is impacted by peak clipping and how the battery is charged and discharged in practice on a representative day. This project is for a 150 kW battery with roughly 300 kWh energy capacity.

Figure 2-1. Peak Clipping Project – Building and Battery Load Profile



The battery is deployed like an HVAC system with the controls acting as a thermostat to limit demand. In this case, the peak "setpoint" is 600 kW. The peak setpoint may vary by the day or time of year. The system will use weather forecasts and historic-use patterns to determine the optimal setpoint on a given day. The goal is to maximize deployed demand, within the bounds of the battery's power capacity, while not deploying so aggressively that the battery runs out of energy and is unable to respond to a late-day spike.

Anecdotally, interviewees reported that mistakes are sometimes made, either because a battery is deployed too aggressively or not aggressively enough. In the context of standby service where peak demand is measured daily, this is not a huge deal, as it will mean that only one day's worth of demand charge savings are forgone and perhaps only a fraction of them at that. If peak demand is measured on a monthly basis, this can be bigger issue as it will impact a whole month's savings. For standby service customers, we estimate that the net of these issues is a 10% reduction in savings from the theoretical maximum.

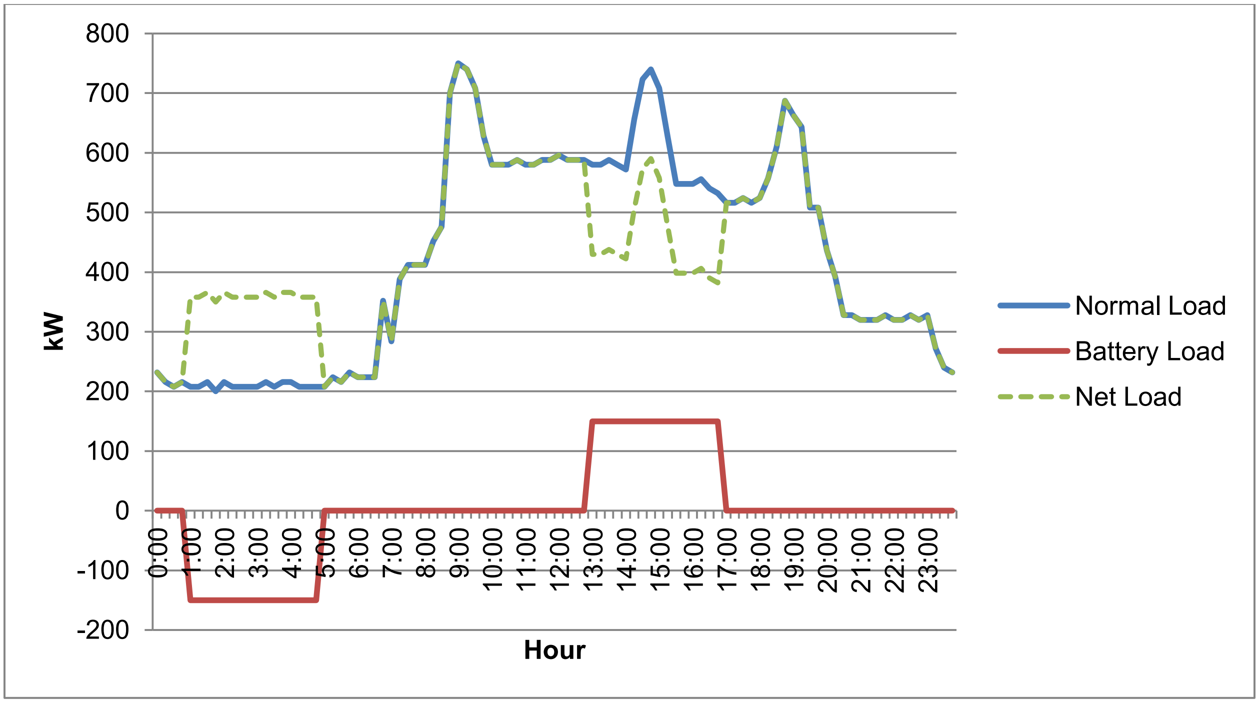
2.1.2 Peak Clipping-Demand Response Hybrid Projects

This model delivers a power-oriented, medium-energy solution (e.g., 4 hours discharge duration) to accomplish the same peak clipping described above while also garnering DR revenues.

- The discharge duration of the battery is expanded from around 2 hours to 4 hours or more in order to accommodate DR events.
- Expanding the battery's energy capacity raises costs, which can be offset by the revenues offered by DR.
- Typically, DR revenues are less significant than those offered by peak clipping so these projects tend to be less cost-effective and have fewer operational and in-construction examples. Barclay Tower is one example.
- During DR event days, the battery goes into DR mode and forgoes peak clipping. This leads to a small reduction in annual peak clipping savings, except to the extent that the peak happens to coincide with DR event hours.
- During most days, when no DR events are planned or called, the battery is in peak clipping mode and acts exactly as it would in the previous example, although with greater energy capacity at its disposal.
- Deploying a battery with 4-hour discharge duration expands the pool of buildings that can be targeted for demand charge reduction at a given power capacity. The characteristic load shape requirements (e.g., spikey, intermittent loads) can be relaxed somewhat, with more rounded peaks in demand accommodated by the longer discharge duration of the battery. This has no impact on the level of savings – those are dictated by power capacity, not energy capacity – but does expand the pool of buildings capable of achieving those savings (albeit with a battery that is twice as expensive).

Figure 2-2 shows how a building load profile is impacted as a consequence of a hybrid battery project that participates in DR.

Figure 2-2. Hybrid Project in DR Mode – Building and Battery Load Profile



By comparing the net load (the dotted green line) in Figure 2-2 to that in Figure 2-1, a few observations can be noted:

- Hybrid battery projects will not always be able to achieve demand charge reduction on DR event days, as shown in Figure 2-2. The morning and evening spikes are not responded to and will register as a higher peak demand than in Figure 2-1. As a result, we estimate that demand charge savings will be reduced by 10% relative to the peak clipping model, for a total of 80% of savings retained.
- During the DR event, the battery, although it is discharging fully, spikes to 600 kW at one point. The average coincident load – the DR program baseline – is likely to reflect the net load shown in Figure 2-1. Thus, the area between those two curves for the period of the DR event is less than the total energy capacity of the battery. This will manifest itself in terms of payment as a less than expected DR payment, as described in the preceding section on DR. It is difficult to predict the impact, but we assume that only 60% of nameplate-predicted DR revenues will be retained as a result of this phenomenon.

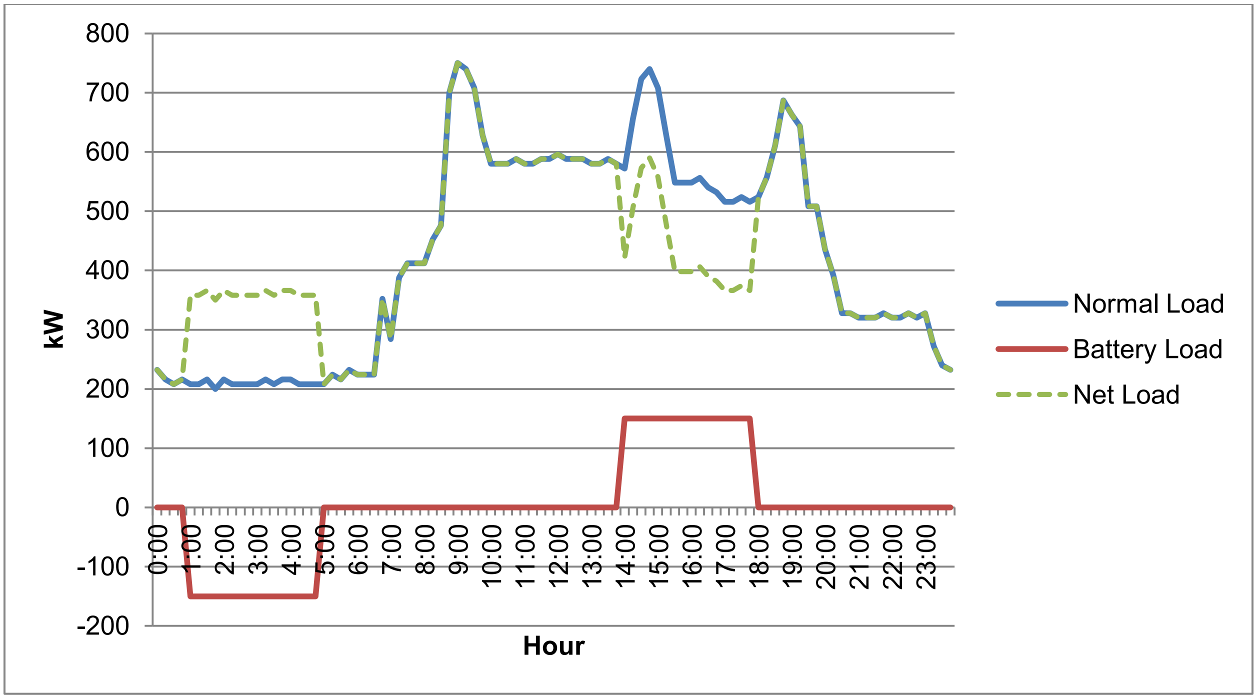
2.1.3 Permanent Load Reduction Projects for DMP

The DMP is requiring a discharge duration minimum of 4 hours, with the full battery energy discharged during the system peak (2 p.m. to 6 p.m., June through September). This has spurred a project model – the permanent load reduction (PLR) model – that draws on available value streams while satisfying program criteria. The PLR model delivers a power-oriented, medium-energy solution (e.g., 4 hours discharge).

- This project model is driven entirely by DMP incentives. It does not make economic sense without those incentives as it does not directly optimize DR revenues or demand charge reduction.
- The 4-hour discharge duration allows the battery to fulfill the requirements of the DMP program, thus enabling it to take advantage of the $2,100/kW incentive.
- During off-peak days – weekends, holidays, and days in October through May – the system is utilized for demand charge reduction. Like the hybrid model, the PLR model can successfully apply demand charge reduction to a wider range of load profiles due to its increased energy capacity.
- During off-peak months (October through May) the battery participates in winter DR. The payments are significantly less than the summer payments, but are still a worthwhile value stream.
- DMP requires that buildings perform the bulk discharge for 10 years. In year 11, the battery operator would be free to use it as they like. The most economical choice given current rate structures would be to operate as a hybrid model.

Figure 2-3 shows an example of how the PLR project model would work in practice at shifting and shaping a building's load profile during the peak summer months.

Figure 2-3. PLR During Summer Months – Building and Battery Load Profile



The figure shows how the battery's energy is discharged in bulk during the afternoon hours, but some peaks are outside of this window. As such, during DMP days, the battery will result in either marginal or no demand charge reduction unless the building load shape is well-aligned to the DMP hours. Weighting by the value of demand charges throughout the year, performing bulk discharge for DMP is equivalent to conceding about one third of the annual potential demand charge reduction that can be achieved by performing peak clipping alone.[22]

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[22] By examining the load shapes of buildings participating in DMP, it was determined that buildings achieve on average about 8.5% of potential demand reduction by simply discharging during the DMP period. In 2014, there were 85 days that would have required discharge within the rules of DMP. Demand charges are higher in the summer, so these 85 days represent a significant loss in revenue opportunity. Considering that 8.5% of demand charge reduction occurs "incidentally," the net result is that DMP projects will achieve an estimated 64% of their theoretical demand charge reduction potential as a result of performing bulk discharge for DMP.

2.2 Economic Analysis

ERS constructed an economic spreadsheet model to estimate the lifecycle return on investment (ROI) and simple payback (SPB) of projects with various parameters. This tool has been submitted separately as an excel file. The parameters of the model that can be externally manipulated are:

- **Region** – This will impact the utility rates charged to the building and DR programs available to the project. For upstate, National Grid rates were used. Downstate is considered Con Edison territory.
- **Location** – This refers to the location of the construction and is either urban or suburban. Urban construction is indoors and involves greater expense.
- **Project type** – Each of the above three project types can be examined. This will impact the size and cost of the battery, the magnitude and type of available value streams, and the availability of incentives. There is also the option of entering custom values.
- **Power capacity** – This is the power capacity of the battery in kW. It will not impact cost-effectiveness, but will scale other variables.
- **Battery technology** – The mature and near-commercial technologies are in the model. Each technology comes pre-coded with default efficiencies, costs, sizes, lifetimes, etc. There is also the option of entering custom values.
- **Interest rate** – This is the rate at which future value streams are discounted for the purpose of calculating ROI.

The below sections leverage this model to observe trends in the economics of these projects. ERS ran a series of comparative tests in order to compare the impact of major variables.

IMPORTANT: The model is based on average costs. Many variables outside the scope of the model – such as physical installation particulars that impact costs and load shape aspects that impact the ability to glean revenue – will affect project economics. Returns on investment are intended to be illustrative of broad market trends and are primarily used for comparative purposes among project models, regions, and technologies.

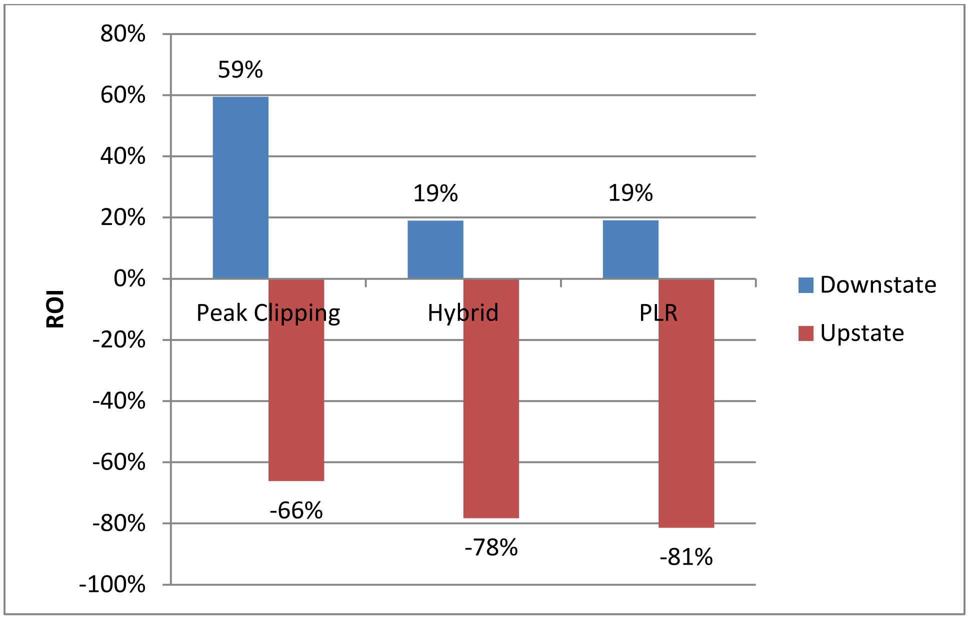
2.2.1 Project Models and Regions

Region and project model type have a significant impact on revenues and the profitability of a project. Table 2-2 and Figure 2-4 show a summary of results for the average of the four mature technology types: lead acid, lithium ion, sodium sulfur, and nickel cadmium. We have assumed suburban costs (i.e., outdoor installations) in order to compare economic performance by project model and by region.

Table 2-2. Regional and Project Model ROIs and SPBs, Suburban Costs

Project Model	Downstate		Upstate	
	ROI	SPB	ROI	SPB
Peak Clipping	59%	6	-66%	64
Hybrid	19%	9	-78%	165
PLR	19%	9	-81%	∞

Figure 2-4. Impact of Regional Revenue on Profitability and ROI



First, in the regional dimension, it can be seen that upstate projects will not be profitable under even the most favorable of circumstances. Downstate values show significantly more favorable profitability because revenues from demand charge reduction, demand response, and energy cost arbitrage are all significantly higher downstate. *For the balance of the analyses in the section, we assume only downstate projects because upstate projects are not viable in the current environment.*

Second, profitability varies widely by project model, with the shortest-duration batteries and project model – peak clipping – performing most favorably. This is because, although costs scale with the duration of the battery, the project value streams are driven primarily by demand charge reductions, which do not scale with discharge duration. For downstate, outdoor installations, peak clipping is a cost-effective and profitable project model, while hybrid projects and PLR have positive ROIs. However, these projects assume *suburban-style outdoor installations* and the reality is that most downstate projects will be indoors.

It is important to understand that peak clipping will not be appropriate for most buildings because they lack a load profile that includes substantial, intermittent, and predictable spikes in load that can be offset using a battery with a discharge duration 2 hours or shorter. As such, most facilities starting point will be to consider hybrid or PLR projects as a consequence of their having a smoother load profile or a load profile with a peak that surpasses two hours in duration.[23]

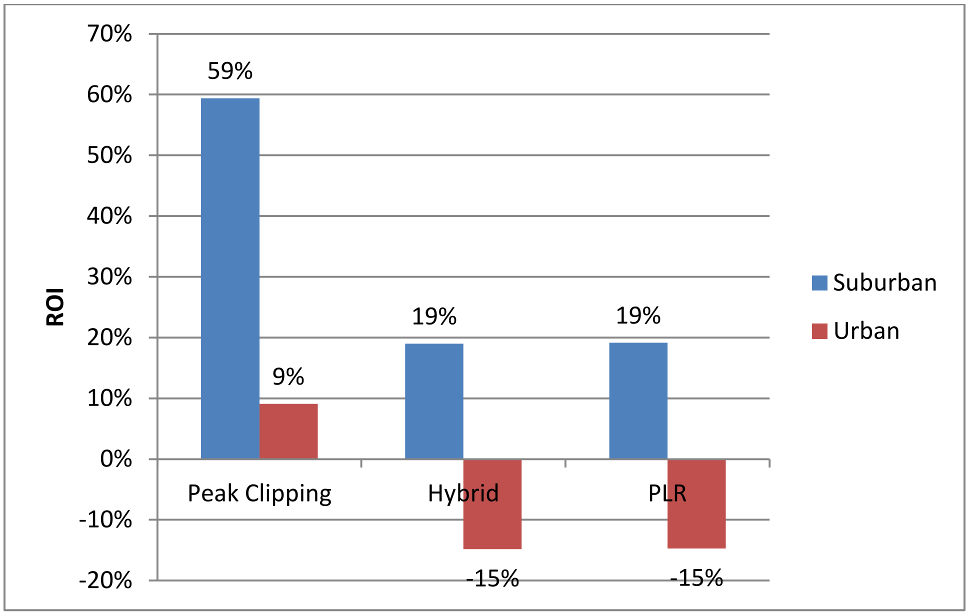
2.2.2 Construction: Urban Indoor vs. Suburban Outdoor

Table 2-3 and Figure 2-5 show a comparison of suburban and urban costs and their impact across project models in the downstate region.

Table 2-3. Suburban and Urban ROIs and SPBs, Downstate

	Suburban		Urban	
Project Model	**ROI**	**SPB**	**ROI**	**SPB**
Peak Clipping	59%	6	9%	9
Hybrid	19%	9	-15%	14
PLR	19%	9	-15%	17

Figure 2-5. Impact of Urban Construction Costs on ROI, Downstate



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[23] Note that the similarity in ROI between hybrid and PLR projects is purely coincidental.

The increased costs that are imposed in an urban setting have a major negative impact on project profitability. The table shows that SPBs lengthen by 3 to 8 years depending on the project. Moreover, the projects appear generally unprofitable on an ROI basis in an urban environment, with the exception of peak clipping just barely climbing into profitable territory.

These numbers represent "average" project dynamics – project-specific values will range, and widely so. One major variable is technology type, which is examined in the next section. Even within a technology category, project-specific construction costs will vary by 25% or more. Those buildings that can physically accommodate a project in a parking garage, on a loading dock, or in some other similarly ideal location could avoid the brunt of urban costs and perform profitably.

2.2.3 Technologies

The above tables are predicated on the average of the four technologies deemed mature and commercially available. Table 2-4 shows ROIs and SPBs by technology for all eight commercial or near-commercial battery technologies. These values are for urban installations in the downstate region. The four leftmost technologies are the mature and commercially available ones; the rightmost four are near-commercial technologies.

Table 2-4. ROIs and SPBs by Technology, Urban, Downstate

	Lead Acid		Lithium Ion		NaS		NiCad		Adv Lead Acid		Vanadium Redox		Zinc Bromine		NaNiCl	
Project Model	**ROI**	**SPB**	**ROI**	**SPB**	**ROI**	**SPB**	**ROI**	**SPB**	**ROI**	**SPB**	**ROI**	**SPB**	**ROI**	**SPB**	**ROI**	**SPB**
Peak clipping	31%	6	-10%	12	26%	9	-11%	10	5%	9	-13%	14	1%	11	18%	9
Hybrid	-1%	8	-29%	18	2%	13	-32%	15	-20%	13	-36%	28	-25%	20	-11%	13
PLR	0%	7	-29%	26	2%	16	-32%	21	-20%	15	-36%	102	-25%	43	-11%	17

A few observations on the above table:

- There is a wide range in outcomes by technology. For peak clipping applications, for example, the ROIs range from -13% up to 31%.
- Although multiple technologies show success in the peak clipping category, none yields substantially positive ROIs for hybrid or PLR projects.
- The mature technologies as a group do not perform substantially better than the near-commercial technologies. This is encouraging, since the near-commercial technologies show promise as profitable technologies. On the other hand, this observation should be taken with a grain of salt: the near-commercial cost data is more academic and more speculative, whereas the mature technologies' data was provided more by experienced interviewees or through empirical case studies.

- Lead acid is the best performing technology from a cost-effectiveness perspective. This is unsurprising as it is far and away the market leader.
- Sodium sulfur (NaS) and its close cousin sodium nickel chloride (NaNiCl) also perform respectably. In particular, NaS batteries are the only technology with positive ROIs in the hybrid and PLR context. Unfortunately, NaS batteries face other non-energy barriers such as their inherently large modules and their high-temperature design that impede their adoption in an urban environment. Those factors are not captured by this model and help to explain the lack of adoption of this technology. In addition, NaS and NaNiCl also impose substantial first costs, which may push customers in the direction of lead acid batteries.
- Lithium ion shows up as very cost-ineffective. This finding is consistent with lithium ion's status as the most costly mature technology. It should also be treated with some skepticism. Lithium ion's costs are falling fast, much faster than any other technology. As these estimates are inherently backward-looking, it would not surprise the ERS team to find that lithium ion costs are lower than the modeled values suggest.
- Differences in lifetime lead to divergent outcomes for ROI, which is based on lifecycle costs, and SPB, which is based on first cost only. For example, lead acid and NaS have similar ROIs for hybrid projects. However, the lead acid battery has a much more favorable SPB – 8 years vs. 13 years. This is because the NaS battery is long-lasting and has a high first cost, whereas lead acid is the opposite.

Overall, project economics are challenging, with SPBs ranging upwards from 6 years. However, pockets of opportunity exist. Section 4 discusses the key site and customer characteristics that lead to positive ROIs.

3 Non-Energy Barriers

There are a variety of barriers that must be taken into account when installing a battery system. These challenges have the potential to significantly impede the adoption of behind-the-meter battery systems. These barriers are described below along with the role that NYSERDA can play to aid customers in overcoming them.

3.1 Health and Environmental Hazards

Most battery technologies, including all commercially viable technologies, come with inherent risks to human and environmental health and safety. They are composed of toxic chemicals and have the potential to overheat, catch fire, and explode. Though this section details these risks, it is important to understand that for all commercially viable technologies, these risks are well understood and can be mitigated, even within an urban environment. The hazards do, however, have downstream effects on permitting and construction that are detailed in subsequent sections of this memo. Technology-specific risks are also described above in the System Technology and Costs section.

3.1.1 Toxicity

The most prevalent battery storage technologies, including lead-acid, sodium sulfur, lithium ion, vanadium redox, and nickel cadmium, all contain toxic and hazardous chemicals. Key risks caused by exposure to the batteries' fluids include:

- Irritation to skin and eyes (including severe burns and blindness)
- Damage of the respiratory system through inhalation of dangerous vapors
- Damage to the digestive tract if swallowed

Exposure tends to occur when the battery system has been compromised, damaged, or tampered with. Operating the battery systems under normal and manufacturer-recommended conditions reduces the risk of harm due to exposure to hazardous chemicals. One interviewee noted that people are a battery's worst enemy; properly maintained and operated batteries do not pose these risks unless tampered with or damaged. As a result, toxicity risks have an effect on construction and siting issues, described in subsequent sections.

3.1.2 Fires, Explosions, Melting, and Leaking

All commercially viable battery technologies pose a risk of melting, leaking, catching fire, and exploding. Damage caused by excessive heat, lack of ventilation, or physical damage can lead to leaks and explosions. These failure modes are caused by improper conditioning, improper ventilation, unsafe activity around the battery, or seismic activity.

As with battery chemical toxicity, fire risks are well documented. Well-maintained and properly-operated equipment can reduce these risks. It should also be noted, that these risks have implications in regard to permitting, construction, and siting issues. These effects are detailed in subsequent sections.

3.1.3 Battery Disposal

Though often considered to be of concern, the disposal of batteries has historically been a safe and systematized process. One interviewee noted that lead acid batteries are the most successful recycling project in the history of the world: 98% of all lead acid batteries are recycled due to the value of the lead. Other batteries have a lesser track record, but overall this is not a significant concern with commercially viable technologies.

3.1.4 NYSERDA’s Role

The risks of batteries are well documented and commonly understood as an aspect of battery storage projects. The risks are mitigated by proper battery storage and operation. Ultimately, the end user will have to make an informed decision on these risks, and NYSERDA can share accurate information and successful risk mitigation strategies. Popular media coverage of dramatic cases of explosion or fire may leave some potential customers concerned, but NYSERDA can help assuage doubt in the market through education.

3.2 Construction and Siting Issues

All else equal, the ideal location for a battery from a construction and siting perspective is close to the switch gear, as this will reduce the complexity and cost of construction. Outdoor installations, typically in dedicated shelters or shipping container-type enclosures, are common in suburban or exurban settings. Indoor installations have also been done – there are lead-acid UPS systems in just about every major building in New York City – but the requirements of siting a long-duration (2+ hours) battery indoors are more limiting, complex, and costly. Choosing the right site can limit the associated costs. Generally speaking, the batteries themselves can be made safe such that they pose a minimal (as to be negligible) risk to the building and its occupants. On the flip side, proper siting can minimize the risk of the building and its occupants posing a hazard to the battery.

3.2.1 Battery Weight and Size

Batteries are heavy, which means they need to be installed on concrete or reinforced floors. A standard office floor is required by the International Building Code to accommodate 50 pounds of uniform distributed live load per square foot, whereas batteries can apply pressures ranging from 350 to nearly 1,000 pounds per square foot depending on the technology.

Other technologies are not as dense, but even the lightest systems will exceed safe weights for normal floors. Thus, unless there is an upper floor that is already reinforced (e.g., for an elevated mechanical room), the basement becomes the de facto place to put a battery system. The cost to reinforce a floor is prohibitive.

The size of batteries ranges widely and can be considerable. Table S-2 in the Summary shows the size of representative 500 kW systems with 4 hours discharge duration by technology. This table illustrates the sheer size of certain battery technology. Considering floor limitations and general safety, it can become difficult to find a location that is both safe and provides enough room for the batteries and their associated equipment. One interviewee felt that finding the right space was almost as difficult as finding a willing customer. However, other interviewees emphasized that certain battery technologies are modular and can make use of varying container sizes or rack systems to fit a customer’s needs. Lithium ion in particular is compact. Suffice to say that the size and weight of batteries make finding an appropriate location for them a serious and limiting challenge, but one that can be overcome in most situations.

3.2.2 Modularity

While most technologies are composed of modular cells – meaning they could be walked into a building and lowered via a freight elevator – sodium sulfur batteries are not perfectly modular. NGK is the primary source for this technology and they do not offer any size smaller than a 1 MW, 6 MWh battery. This presents a challenge for indoor installations to leverage this technology in anything other than a new-construction context. Given that alternative technologies such as lead acid and lithium ion can be produced modularly, this lack of modularity has heretofore precluded large sodium sulfur technologies from the urban environment in the US, although they have reportedly been installed in Tokyo.

3.2.3 Basement Siting and Flood Risks

The threat of major flooding to certain buildings in Manhattan as well as parts of the outer boroughs precludes the placement of batteries at or below ground level in those buildings, particularly in lower Manhattan. According to New York City's report on resiliency planning after Sandy, approximately 35,000 buildings in New York City lie within the 100-year floodplain, which is defined as the areas that have a greater than 1% chance of flooding in a given year. This accounts for more than 376 million square feet of space that effectively cannot support a battery. ERS knows of no "flood-proofing" methods that have been tried that can isolate a battery room from the rest of the building in the event of a flood. However, most of midtown Manhattan, which is a prime target for such projects, is not exposed.

3.2.4 Ventilation, Conditioning, and Fire Suppression

All commercially viable batteries require ventilation and conditioning, although the specific needs vary by technology. Indoors, ventilation and conditioning requirements will consequently imply a dedicated, sealed, and controlled-access space with dedicated equipment. For outdoor projects, many battery products come in pre-packaged, self-contained units that include conditioning, ventilation, and fire suppression. General requirements include the following:

- Lithium ion batteries do not require dedicated ventilation per the New York State fire code. However, due to thermal runaway concerns and efficiency losses, dedicated conditioning equipment is required in order to keep the batteries at room temperature and sustain peak performance.

- Lead acid batteries have minimum associated ventilation requirements (1 cfm/ft^2 per the New York City code). Within the family of lead acid batteries, even more stringent requirements can occur (e.g., a dedicated stack that must be bored upward through the building and dumped outside 20 feet above pedestrians); these requirements have effectively precluded those sub-technologies from the urban market. Moreover, HVAC equipment is necessary for lead acid batteries to maintain cool temperatures, both to avoid thermal runaway, but perhaps more importantly to extend the life of the system since they degrade more quickly in warm conditions.
- Sodium-based batteries are high heat (300°C) and thus require thermal monitoring and conditioning. NGK's representatives said sodium sulfur, being hermetically sealed, requires no ventilation, but described the conditioning requirements as being similar to those of other batteries.
- Though batteries are typically placed in the basement, they should be kept out of the boiler room (or other heated spaces) due to heat concerns.
- Conversely, placement in air shafts is not ideal because it will require dedicated heating equipment in winter. This has been described as a prohibitive expense.
- All systems will need to come equipped with dedicated fire alarm and fire mitigation equipment. These costs are well understood and included in most project quotes.

3.2.5 NYSERDA's Role

The physical siting of these systems is dictated by the risks and hazards posed by these battery technologies as well as their weight and size. It is fair to say that, at least in New York City, the above considerations will shrink the potential market considerably – either by making projects technically nonviable or economically nonviable. NYSERDA can play an informational role in helping developers understand the successful construction approaches and the best battery locations within and around buildings.

3.3 Permitting and Codes

Local codes and the associated permitting are a significant hindrance to the adoption of specific technologies. Code requirements for battery storage systems are designed to ensure safe installation and operation of battery systems. Their focus is on safety precautions to mitigate impacts of spills, fires, natural disasters, and unauthorized access.

Unlike with health, safety, construction, and technical constraints, these issues cannot be surmounted by the project team directly – it takes the consent of individuals at the code and permitting authorities who are, with good reason, hesitant to embrace emerging and potentially dangerous technologies. On the bright side, this fact also means that if the minds of these individuals can be changed, then it may open the door for certain technologies.

3.3.1 Relevant Code Specifications

Codes require that permits be obtained for any stationary storage battery system installation. For both New York City and New York State, both the fire code and mechanical code detail battery storage requirements. In general, these codes are modified from versions of the International Code Council's (ICC) International Building Codes (IBC). Table 3-1 shows which battery technologies are allowed by a selection of different state and city codes. Table 3-2 details the code requirements by technology.

Importantly, both the New York City and New York State codes specifically indicate that they apply to batteries "used for facility standby power, emergency power, or uninterrupted power supplies." Energy management projects are *not* allowed in under this provision.[24]

Table 3-1. Battery Technologies Allowed by Code

	New York City	New York State	California
ICC Code basis	2012 IBC	2006 IBC	2012 IBC
Flooded lead-acid	X	X	X
Flooded nickel-cadmium	X	X	X
Valve regulated lead-acid (VRLA)	X	X	X
Lithium-ion	X	X	X
Lithium metal	X		X

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[24] The New York City Fire Code was updated (effective March 30, 2014) to allow additional battery storage technologies, including lithium-ion and lithium metal polymer batteries. Although energy management projects are not currently allowed under this new version, it is expected that an additional revision will be made later in 2014 to incorporate energy management storage projects into the code.

Table 3-2. Code Requirements for Battery Storage Systems in NY

Requirement	Flooded Lead-Acid Batteries	Flooded Nickel-Cadmium (Ni-Cd) Batteries	Valve Regulated Lead-Acid Batteries	Lithium-Ion Batteries	Lithium Metal Polymer
Allowed per NY City code?	Yes	Yes	Yes	Yes	Yes
Allowed per NY State code?	Yes	Yes	Yes	Yes	No
Battery size applicability	Liquid capacity greater than 50 gallons (189L)	Liquid capacity greater than 50 gallons (189L)	Liquid capacity greater than 50 gallons (189L)	Greater than 1,000 pounds (454 kg)	Greater than 1,000 pounds (454 kg)
Safety cap	Venting caps	Venting caps	Self-resealing flame-arresting cap	No cap required	No cap required
Thermal runaway management	Not required	Not required	Required method to predict, detect, & control	Not required	Required
Spill control	Required	Required	Not required	Not required	Not required
Neutralization	Required	Required	Required	Not required	Not required
Ventilation	Continuous ventilation of at least 1 $ft^3/min/ft^2$ of floor area Limit maximum hydrogen concentration to 1% of total room/cabinet volume			No ventilation required	No ventilation required
Signage	Signage must state that room contains energized battery system and energized electrical circuits, and that battery electrolytes, where present, are corrosive liquids.				
Seismic protection	Required	Required	Required	Required	Required
Smoke detection	Required	Required	Required	Required	Required

3.3.2 Code Variance Process

All deviations from code – including all energy management projects – require the project to submit an application for a variance:

- Applying for a variance requires gathering and synthesizing available research studies on the safety aspects that concern the relevant departments.
- Applying for a variance does not guarantee a permit and it can take a year or more to receive approval.
- Once a variance has been granted for a specific application, it can, in certain circumstances, be used as a "blanket variance" that applies to all similar installations. These will be subject to individual inspection and approval, but the same data collection and persuasion process is no longer necessary. These blanket variances are not public, but they can be leveraged by any firm that is aware of their existence.

ERS collected the following instances of project developers working with the variance process in New York City:

- One interviewee claimed to have established a blanket variance with the NYC Department of Buildings (DOB) and FDNY for all lead-acid energy management applications.
- Supposedly, the Brooklyn Army Terminal was forced to pursue lead acid because their application for variance with a lithium ion battery was rejected.
- However, interviewees reported that lithium ion batteries are near acceptance within the NYC DOB and FDNY. Timelines were not specified, and it was unclear whether this would be a formal code amendment or a blanket variance. It is also unclear whether this included energy management or simply lithium ion UPS applications.
- One interviewee reported that a very small sodium sulfur battery had supposedly been allowed in Queens, but that this may not represent much of a precedent for larger installations due to its size. He did not expect further variances to be granted for these particular technologies.
- The Barclay Tower installed their battery *without* appropriate permits and was only allowed on variance after the fact.

3.3.3 NYSERDA's Role

NYSERDA's main objective with regard to permitting and codes should be to lobby the city and state to adopt the battery-related provisions of the 2012 IBC as soon as possible. NYSERDA can also play an informational role for the market by:

- Informing prospective battery storage customers about which technologies are permitted in the code in which jurisdictions.
- Aiding project developers who are applying for variances by organizing and supplying research materials that demonstrate the safety of these technologies.
- Collecting information on successful variance applications and redistributing that safety material to other parties interested in pursuing similar technologies.

3.4 Utility Interconnection

Utility interconnection is a necessary component of nearly all energy management battery projects. The proliferation of CHP and solar has rendered this process relatively painless, as Con Edison has had to streamline their process in order to accommodate the volume of requests they receive. Understanding is this process is similar in other jurisdictions.

Con Edison's distributed generation team oversees the interconnection process for technologies such as solar, wind, CHP, and battery storage. They require any battery storage system that represents greater than 15% of a building's load to go through the interconnection process.

The process for approval includes the following:

- Filing project paper work and processing (10 days).
- Basic engineering review (15–20 days).
- Projects where the battery load exceeds the peak demand of the building require a longer review process (60 days). If the battery is smaller than a building's load, this step can be skipped. This is almost always the case, and skipping this step saves time and the significant cost of the study.
- Study results review (10–25 days).
- Project installation.
- Verification testing.
- Final paperwork.

Con Edison requires a UL 1741-certified inverter. This is required to avoid larger grid problems and safety issues. The inverter prevents the battery from back-supplying the grid when it goes down. Back-supplying can be unsafe for utility workers, can damage equipment, and can cause problems for other customers.

The process for battery interconnection with Con Edison's grid is well established since the utility uses the same process for connecting other distributed generation technologies (e.g., solar, wind, CHP systems) with the grid. Discussions with Con Edison's distributed generation team indicated that this process is fairly straightforward. Interviewees also agreed that what was needed was well understood and streamlined.

4 Target Market Sectors

The market for batteries is limited by a series of practical considerations that impact the feasibility and economic viability of a project. Realizing value from a project depends a great deal on the electricity rates and DR programs available to a customer, both in terms of service territory and rate structure. The profitability of a project is also highly dependent on the customer having a load profile that enables them to take advantage of value streams at a relatively low cost. Finally, the facility must be capable of accommodating the physical battery structure without imposing impractical costs. These observations lead to the following project criteria – a building must:

- Be located in Con Edison territory.
- Be a low-tension service customer and have access to the Standby Service and Hourly Pricing rate structures.
- Experience spikes in load that are intermittent, short in duration (ideally less than 2 hours in aggregate duration), and large enough[25] to be worth the effort of following through on the project. As a rule-of-thumb, an appropriate load shape will be associated with demand charges that are greater than 50% of the total electric utility bill.
- Have space sufficiently large and safe enough to accommodate the necessary battery.

A viable battery project will fulfill all of these criteria, each of which are described in greater detail below.

Even having identified these criteria, it is difficult to generalize about battery feasibility from a market perspective. Variations in load shape and available space make go-no-go decisions on batteries a highly building-specific question; for example, multiple vendors noted that they will not move forward on any project without reviewing a year's worth of interval data. However, some generalizations can be made regarding a sector's alignment with the necessary site characteristics. In Section 4.2, we analyze these criteria in a market-by-market context to illuminate pockets of opportunity for batteries in New York State and suggest that:

- Multifamily and retail, particularly refrigerated retail, are the sectors best aligned with the criteria above.
- The industrial sector offers some exciting potential, but it faces certain challenges including the relative dearth of locations in Con Edison territory and the often unpredictable nature of loads.

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[25] In outdoor settings, customers have followed through on projects as small as 8 kW. In indoor settings, where the installation is more disruptive and costly, vendors suggest that a project must be at least 100 kW to be worth the trouble.

- Office, hotel, and other commercial loads are generally too smooth to align with peak-clipping objectives, but may be more amenable to longer-duration, peak-shaving projects.
- Hospitals and educational facilities are generally poorly aligned with the above criteria, with exceptions.

Section 4.2 includes a detailed discussion of each sector.

4.1 Criteria for Success

ERS has identified site characteristics that correlate strongly to successful projects, both in terms of revenue and feasibility. The key site characteristics are described in the sections that follow.

4.1.1 Region

A customer's region will impact the utility bill rates a customer experiences and limit their access to DR programs.

- Con Edison's demand charge rates are significantly higher than those in the rest of New York. During the summer, Con Edison's demand charges are almost seven times as much as those in the Albany area for National Grid customers.
- The cost of supply is higher, generally, downstate than it is upstate, by about 20% to 40%.
- Upstate customers do not have access to the most lucrative DR programs. NYISO ICAP/SCR payments in New York City (Zone J) are roughly three times higher than upstate (Zones A through I) and two times higher than on Long Island (Zone K). Moreover, upstate and Long Island customers cannot access the Con Edison DR programs. All in, customers in Con Edison territory can receive roughly six times as much in DR payments as upstate customers.

The net of all these differences is that value streams – demand charge savings, energy cost arbitrage, and DR – are currently so much less lucrative outside of Con Edison territory that upstate projects will not be profitable except in niche circumstances.

4.1.2 Rate Structure

Within the Con Edison SC8 and SC9 rate classifications, choosing certain rate structures enables customers to maximize value from peak clipping and energy cost arbitrage. Similar choices are available for upstate customers in the case of some utilities, but the overall scale of the opportunity is so small upstate that those choices are moot.

- **Standby service** – For Demand Charge Reduction, Standby Service (Rates IV & V) presents the best opportunity to maximize demand charge savings. This service assesses as-used peak demand charges on a daily basis and does not have energy charges or minimum monthly charges; customers on this service can thus achieve greater demand charge savings than in Standard or Time-of-Day Services.
- **Hourly pricing supply** – To maximize energy cost savings, it is essential for customers to volunteer for the hourly pricing supply model. This enables customers to take advantage of the "spark spread" between less expensive energy purchases at night and avoided daytime prices, which maximizes energy cost arbitrage savings.
- **Low tension** – Facilities with low tension service pay higher demand charges, so peak clipping can be more lucrative. The vast majority of facilities receive low tension service, though industrial facilities are occasionally the recipient of high tension service.

4.1.3 Load Profile and Load Spikes

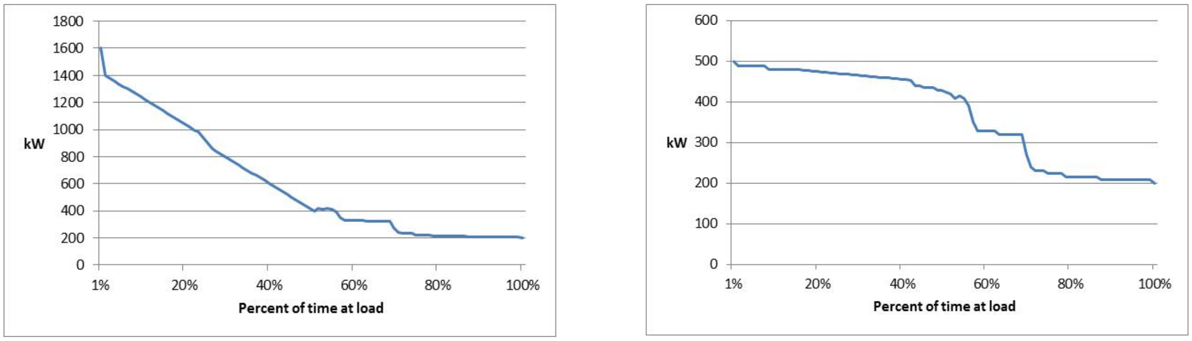
Batteries are most lucrative in the power dimension (i.e., reducing peak demand charges) and are expensive for long discharge durations. As such, the best opportunities for battery storage are in facilities that have intermittent spikes in load that persist for a short duration. As a general rule-of-thumb, the most attractive facilities will experience spikes in load that can be addressed with discharge durations of 2 hours or less over the course of a day and will experience more than half of their energy bills in demand charges. As an additional rule-of-thumb, good load-shape targets will be associated with demand charges that are greater than 50% of a customer's total electric utility bill. There are more limited opportunities for longer discharge duration batteries that encompass DR revenues, but the general rule is that the shorter the spike lasts, the more cost-effective the project will be. The magnitude of the spike will impact the size of the opportunity, but will have only a marginal impact on cost-effectiveness.

- **Common intermittent loads** – Conversations with industry experts and battery vendors identified common intermittent loads likely to be good candidates for peak clipping.
    - For large office and multifamily buildings, elevator loads are often cited as ideal candidates due to their power-intensive, short duration operation cycles.
    - Other candidates for these facilities include water pumps, as well as the initial ramp-up of HVAC systems for heating and cooling.
    - Industrial equipment offers a wealth of opportunity – injection molding equipment, air compressors, mixers, and the ramp-up of process motors in general are examples of intermittent loads.
    - Refrigeration is a potentially appealing opportunity, particularly in the context of retail facilities like groceries or convenience stores.

Identifying this equipment is a helpful first step, but understanding how it is staged and scheduled relative to other building loads is necessary to understand whether the equipment creates the sort of load spikes that are of interest to battery projects.

- **Identifying intermittent load spikes** – The best method for identifying buildings that are well-suited for peak clipping – and the one method treated as essential by vendors intending to qualify projects – is to analyze historical 15-minute interval data. A load duration curve (LDC) can be calculated from this data, showing the frequency of load magnitudes over the course of a set period. An annual LDC is a useful initial indication of potential candidates, but more detailed analysis on the consistency of spikes in daily LDCs must be performed to confirm the opportunity. A good daily load duration profile (left graph below) has a small percentage of time with high demand and large percentage with lower or flat demand, while a poor profile will be relatively flat at the highest demand values (right graph below).

Figure 4-1. Good (Left) and Bad (Right) Sample Daily Load Duration Profiles



4.1.4 Physical Available Space

Commercially available battery systems range broadly in size and weight, and finding available space to site projects can be a challenging and limiting factor in Con Edison territory. First, batteries are heavy, which means they need to be installed on concrete or reinforced floors, which limits the places they can be put. Moreover, within Manhattan, where costs per square foot are high, there is a lack of unused space, and there are competing priorities for any available space. However, the modular nature of many battery chemistries provides some flexibility in installation. While permitting, code, and conditioning requirements certainly apply, industry experts highlighted the feasibility of installing battery storage systems in parking garages, bicycle and general storage rooms, or even in enclosed cabinets within hallways. These solutions offer ways around this barrier, but availability of space will sometimes limit the potential technology types that can work in a building or even preclude an installation overall.

4.2 Viable Market Sectors

The above analysis leads to the conclusion that the ideal battery storage prospect will:

- Be in Con Edison territory
- Be a low-tension service customer and have access to the Standby Service and Hourly Pricing rate structures

- Experience spikes in load that are intermittent, short in duration, and large enough to be worth the effort of following through on the project – as a rule-of-thumb, an appropriate load shape will be associated with demand charges that are greater than 40% of the total electric utility bill
- Have space sufficiently large and safe enough to accommodate the necessary battery

Every building is unique, particularly when it comes to load profiles, but by applying these criteria to different market sectors, it is possible to offer some sense of where the opportunities lie. Table 4-1 summarizes our reading of the relative market opportunities by sector. The following subsections discuss the alignment of market sector characteristics to the criteria above in greater detail.

Table 4-1. Market Sector Summary

Market Sector	Overview	Opportunities	Challenges	Assessment
Multifamily residential	Multifamily applications target common area loads, which are more consistently prone to spikes.	Intermittent load spikes in from elevators, water pumps, HVAC ramping Available space in garage or storage rooms Green image marketing	No HVAC ramping during winter Elevator duration may not align with Con Edison demand charge calculations Common area only	Feasible
Commercial retail	Large retail facilities that are standalone or separately metered within mixed use commercial, especially refrigeration loads	Mid-morning peak in large retail stores Refrigeration loads in grocery & convenience stores can spike during deliveries/high usage	No HVAC ramping during winter Limited space for batteries	Feasible
Industrial	Load profiles vary greatly depending on production processes and cycling.	Huge equipment loads that are often intermittent Available space within existing facilities	Most facilities upstate Peak loads often already managed Variable production	Hit or Miss
Other commercial	Includes office buildings, hotels, restaurants, and mixed-use commercial buildings without individual metering	Elevator loads in office buildings Evening peaks in restaurants/other commercial	Generally round load shapes No HVAC ramping during winter Limited space within NYC	Limited/longer duration feasibility (e.g., hybrid or PLR models)
Hospitals	Hospitals have large overall loads due to 24 hr occupancy and air cycling requirements	Available space on campus Individual spiking loads	Administrative process High utilization; flat demand	Less feasible
Educational facilities	Schools, campuses, and related buildings	Available space on campus Demonstration projects Labs may have spiking equipment	Relatively flat loads Often master metered	Less feasible

4.2.1 Multifamily Residential

High-rise multifamily buildings represent a potential early adopter segment for battery storage. The opportunities are typically limited to the common-area loads of the building, as individual apartments are generally metered separately (with the exception of master-metered buildings).

Opportunities – There are many high-rise multifamily buildings within Con Edison territory that are potential candidates for battery projects. Within common-area load profiles, elevators and water pumps are likely to be ideal intermittent loads for peak clipping. Additionally, the daily ramp-up of HVAC systems may also be subject to spikes depending on the facility. Multifamily buildings often are equipped with parking garages, storage, or bicycle parking facilities, and they may therefore have available unused space for battery projects. There may be additional non-energy incentives for batteries within multifamily buildings, as owners seek to advertise their sustainability practices and also provide resiliency services during outages.

Challenges – While elevator loads are often cited as prime targets, they operate on short (less than 15-minute) cycles and their loads may not be truly reflected in Con Edison's demand charge calculation. HVAC loads may spike during summer months for cooling, but winter heat load is typically gas, reducing this peak-clipping revenue stream.

Assessment – The high volume of multifamily buildings downstate and the relative spikiness of their load profile present the most feasible current opportunity for battery storage. Multiple battery project developers have explicitly identified this market as a ripe opportunity for peak clipping storage projects and are actively recruiting multifamily customers. The primary downside of multifamily projects is that their scope is limited to the common-area loads, which brackets the overall load reduction the grid might experience.

4.2.2 Retail Outlets

Retail outlets include both standalone facilities and large, separately metered retail within commercial high-rise buildings. Standalone facilities are more common upstate and in the outer boroughs, while separate meters within Manhattan can be found in large retail and grocery stores. Retail peak usage varies from general commercial (office) peaks, both in timing and in the spikes created by key loads such as refrigeration, thus warranting separate discussion of market characteristics.

Opportunities – While office buildings ramp up building conditioning processes early in the morning to prepare for daily occupancy, often before 7 a.m., large retail outlets often demonstrate peak spikes later in the morning, as retail stores generally open mid-morning. This aligns well with Con Edison peak demand charges, and presents greater magnitudes for peak clipping savings. Within commercial retail, facilities such as grocery stores and convenience stores with high refrigeration demand are great candidates. During daily deliveries and after-work shopping periods, cooling cases are often left open or are opened frequently, resulting in spikes as additional short-duration cooling capacity is needed.

Challenges – Available space is a key challenge for retail outlets, especially when they are sited within mixed-use commercial buildings in Manhattan. Smaller retail outlets may also not have enough demand to warrant the trouble of a battery installation.

Assessment – Refrigeration demand is one primary driver for the viability of battery projects in retail outlets. ERS interviews identified a number of existing and proposed battery projects explicitly targeting refrigeration loads within grocery and convenience stores. Large retail stores also see spikes in demand as a result of store startup that are not already managed at the facility level, presenting an opportunity for peak clipping. Commercial retail and, in particular, refrigerated retail present a good opportunity for battery storage projects.

4.2.3 Industrial Facilities

The load profiles of industrial facilities vary greatly; facilities such as foundries with intensive electric melting processes are likely to have very large intermittent load spikes, while other facilities running constant production cycles (24/7 or 24/5) tend to have flat loads. The absolute best candidates for peak clipping will be found in this segment, but they will be sprinkled among facilities that look similar, but which are poor candidates for battery projects. This combination makes the sector a great opportunity and a great challenge as well.

Opportunities – Within industrial facilities, equipment prone to demand spikes is commonplace. Examples of these types of equipment include air compressors, induction furnaces, and blending and injection molding equipment. Available, safe space for a battery is not a large concern as most industrials have parking or large concrete areas in which they could put a modular battery storage system. Most industrial facilities also have experience with large, complex capital projects such as battery installations. Smaller industrial facilities may be ideal candidates if they are not currently actively managing their loads.

Challenges – The primary challenge for industrial facilities is that they are located in the wrong region: upstate. This fact alone greatly diminishes – by a major amount – the potential targets for battery storage. Also, industrial facilities often receive high tension service due to the requirements of their equipment, thus reducing the magnitude of peak clipping opportunities. Additionally, custom "job shops" may run variable production cycles, making their load spike magnitudes and durations inherently unpredictable, a major practical challenge for battery storage controls. Many large facilities also have staff dedicated to managing facility loads, scheduling starts to reduce peaks, which may eat into the opportunity for batteries.

Assessment – Industrial facilities located downstate, with predictable production cycles, represent the single best opportunity for battery projects. However, these facilities are few and far between, since most industrial facilities are upstate and many downstate facilities are job shops with variable production. Overall this market is "hit or miss," depending on the specific facility.

4.2.4 Other Commercial Buildings

Other commercial buildings include office buildings, hotels, restaurants, and mixed-use commercial facilities that are not individually metered. Typical office building load profiles reflect a more rounded peak, with load relatively flat during normal business hours (i.e. 8 a.m.–5 p.m.) and significantly less during nights and weekends, but it is worth noting that restaurants and other businesses operating within mixed-use buildings can cause peak spikes during evening hours as well.

Opportunities – The prevalence of large commercial office buildings within Con Edison territory makes this market sector a common target for battery project developers. Common intermittent spikes for commercial buildings include elevator operations and spikes during summer when HVAC systems ramp up to provide cooling capacity at the start of operations; these ramps are often scheduled to mitigate peaks, but there may be opportunities within smaller facilities and where scheduling is absent.

Challenges – The rounded peak profile requires batteries with longer discharge durations, closer to 4 hours; additional costs to provide this duration can significantly hurt project cost-effectiveness. Additionally, while cooling load ramping is an attractive summer spike, most facilities run gas heating during winter, diminishing or eliminating this peak clipping application for half of the year. There are many competing priorities for any available space in such a building, requiring that project developers get creative in their siting approach.

Assessment – The rounded load profile commonly found within this market sector is a significant challenge for peak clipping applications. These buildings are more likely to find success with hybrid or PLR models. In certain instances where low-cost construction siting opportunities exist, these models already be viable, but overall the high costs related to providing additional discharge duration hurts the feasibility within this market sector, even while the sheer volume of buildings makes it one that can't be ignored.

4.2.5 Hospitals

Hospitals by nature have many critical loads necessary to provide health and emergency care. Load profiles tend to be relatively flat due to 24-hour occupancy and large air cycling requirements. There may be some intermittent spikes within hospital load profiles due to individual equipment, but these spikes are difficult to predict and may not affect the overall load profile.

Opportunities – There are many power-intensive loads within hospitals, but they tend to operate consistently to meet air quality and safety requirements. Hospitals are often clustered as campuses, and therefore finding available space may be feasible for battery projects.

Challenges – The relatively flat load of hospitals presents a challenge to the viability of battery projects. Additionally, most hospitals have significant administrative processes for safety reasons that would likely delay the project approval process. While certain machines such as MRI systems have large load spikes, they are often paired with a dedicated power supply (generator) and are made cost-effective by scheduling many cycles per day, which would require longer discharge duration to offset with batteries.

Assessment – The flat load profile for most hospitals is not a good match for the demand reduction functionality provided by battery projects. Intermittent spikes on an individual-facility basis may present a small opportunity, particularly in highly specialized or day-use outpatient facilities. As a market sector, however, this is a below-average opportunity for batteries.

4.2.6 Educational Facilities

Educational facilities include schools, university campuses, and related buildings. These facilities are spread throughout the state and, even downstate, campuses may have more available space to accommodate battery projects than some other market sectors.

Opportunities – As with the majority of market sectors, there are summer cooling loads where ramping processes may be candidates for peak clipping. Additionally, laboratories and other specialty buildings may have individual equipment with large power demand subject to spikes. Additionally, as educational institutions, these facilities may have marketing and other incentives to install battery storage aside from pure economic value streams. Campuses are also likely to have available space for installations.

Challenges – Educational facilities generally have a relatively flat load profile. The dominant components of the electrical loads within these facilities are lighting and space conditioning. Individual peaking equipment is unlikely to be predictable or consistent.

Assessment – The relatively flat loads and inconsistent spiking equipment present significant challenges for battery storage to generate value for educational facilities. Overall, educational facilities are below average candidates for battery storage, but there may be opportunities for research or demonstration projects.

5 Program Precedents and Future Considerations

This section provides an overview of existing energy storage and load reduction programs throughout the country, as well as future considerations for NYSERDA's programs, with an emphasis on IPEC DMP design.

California's Self-Generation Incentive Program (SGIP) is the only incentive program specifically targeting battery storage. Its structure and experience provide a useful model for how to design battery programs here in New York State. Additional programs throughout the country encourage broader energy storage – typically thermal storage – and other permanent load reduction (PLR) strategies. These other programs are summarized in Section 5.1.

Observations from program precedents, as well as the analyses presented throughout this report, lead to the following future considerations for the IPEC DMP program design:

- The proposed IPEC DMP battery storage **base incentive rate** of $2,100/kW is nominally aligned with similar programs, notably SGIP. However, it is less generous when the implications of required discharge duration (2 hours versus 4 hours for SGIP and IPEC DMP, respectively) are considered.
- The **rated capacity** (both kW and kWh) of the battery should be measured in terms of the usable energy delivered on the AC side of the inverter and this capacity should be required for a set number of years.
- Required **discharge duration** should reflect the load reduction goals of the overall IPEC DMP as much as possible. In practice, imposing a 4-hour discharge duration window will limit the cost-effectiveness of IPEC DMP projects. However, limiting the window to accommodate participation will cause misalignment between project outcomes and Con Edison's reduction goals.
- Incorporating a short **measurement and verification (M&V)** period, such as the 1-year program currently proposed by NYSERDA and Con Edison, is a fair compromise between the needs of project developers and Con Edison. Battery project developers would receive the majority of the incentive upon project completion, while the M&V period encourages projects to perform as designed, helping Con Edison verify permanent load reductions.
- A **roundtrip efficiency requirement** of 65% for IPEC DMP. This value is based on empirical research in California that ensures no net increase in greenhouse gas emissions. It is also well within the range of commercially available technologies, and pushes less-efficient technologies towards the higher end of their capabilities.

Future considerations specific to the ETAC program include:

- **Near-commercial technologies** – A set of technologies identified in Section Appendix B are not quite commercially available, but could be solid candidates for demonstration projects through ETAC.
- **Hybrid projects** – Although peak clipping is gaining traction, hybrid projects are much less common. ETAC could support a series of these projects to speed their adoption and to establish data on revenue retention when laying DR and peak clipping functions.
- **Managed, critical-load backup** – During interviews, multiple battery vendors identified that they are exploring using the battery in a managed fashion, as backup to critical loads during power outages. This type of application has never been done and it would increase the cost of the battery, but could help vendors get the attention of the market if done successfully. ETAC could examine this as a special-case application worthy of demonstration funding.
- **Flow batteries** – Flow batteries have not yet been proven in an urban location. Supporting projects that prove their capability in such an environment could go a long way to smoothing their adoption in the downstate region, where their long-duration characteristics would be most valuable.
- **Industrial controls** – One aspect of peak clipping that is challenging in industrial contexts is predicting load levels and spikes. Finding a "job shop" type location and working with a vendor to develop production-based load prediction algorithms could open up a challenging segment of the market.

Finally, the pre-commercial technologies identified in Appendix B are recommended for consideration for NYSERDA's R&D program.

All of these future considerations are discussed in further detail in Section 5.2.

5.1 Program Precedents

A number of relevant energy storage and load reduction programs exist throughout the country. Only one program, California's Self-Generation Incentive Program (SGIP), provides explicit incentives for battery storage; the majority of existing programs provide incentives specifically for Thermal Energy Storage (TES) or for other approaches to achieve load reductions. This section provides an overview of the SGIP program as it pertains to battery incentives and summarizes incentive program designs including thermal storage programs, as well as Con Edison's specific Targeted Demand Side Management program.

5.1.1 California Self-Generation Incentive Program (SGIP)

The California SGIP provides incentives for distributed energy systems on the customer side of the meter. Traditionally, this program has been used primarily to provide incentives for CHP generation facilities, but the program has reallocated incentive funding toward renewables and emerging technologies over the last 5 years. Relevant details on the SGIP program include the following:

- SGIP 2014 budget: $77,190,000, split across California's IOUs and the California Center for Sustainable Energy.
    - 75% of budget for renewable & emerging technologies (including batteries).
    - 25% of budget for non-renewable conventional CHP.
- Planned incentive decline – Starting in 2014, the SGIP battery incentive is scheduled to decline at a rate of 10% per year.
    - Prior to 2013, incentive was $2,000/kW.
    - In 2013, incentive reduced 10% to $1,800/kW.
    - In 2014, incentive reduced 10% to $1,620/kW.
- SGIP incentive details for advanced energy storage are available at www.cpuc.ca.gov/PUC/energy/DistGen/sgip/.

Table 5-1 summarizes the key aspects of the program.

Table 5-1. Summary of Key SGIP Aspects

SGIP Program Parameters	Advanced Energy Storage (Battery)
SGIP program size cap	3 MW
Maximum AES project size	Up to host customer's previous 12-month annual peak demand. Projects coupled with renewable generation cannot be sized larger than rated generation capacity.
2014 base incentive rate	$1,620/kW
Base incentive annual decline	10% per year
Project size <1 MW	100% of base incentive
Project size 1 MW – 2 MW	50% of base incentive
Project size 2 MW – 3 MW	25% of base incentive
Additional provision for >30kW systems	50% of incentive paid upon project completion & verification, remaining 50% paid as performance incentive (5 yr performance)
Project incentive cap	60% of total project cost
Rated capacity definition	Average discharge power output (kW) over 2 hr period
Discharge requirements	1. Must have capability to discharge rated capacity for minimum 2hr 2. Must have capability for full discharge at least once per 24hr
Roundtrip efficiency requirement (GHG emission standards)	Greater than or equal to 63.5%, measured on annual basis
Interconnection requirements	Must be connected to local utility AND be configured to operate in parallel with grid
Additional incentive for CA supplier	20% of base incentive

5.1.2 National Thermal Storage & Time-Of-Use Incentive Programs

Various storage programs offered by utilities around the country that provide incentives for thermal energy storage (TES). TES programs tend to consist of dollars-per-kilowatt incentives based on peak demand shifted, and many programs have additional incentive caps, time of use (TOU) rates, and other monitoring and verification parameters.

The TOU rates that are associated with these programs present an interesting model, catalyzing projects by promoting rate structures that reward users who invest in technology capable of shifting load and also rewarding them for operating them properly. NYSERDA can point to these programs' rate structures as examples of storage-friendly rates that the utilities in New York could adopt to promote storage technologies.

Table 5-2 provides a sample of TES program designs around the country.

Table 5-2. Summary of Select TES Programs Nationwide

Name of Program	Program Description	Incentive Rate ($/W)
California Permanent Load Shifting (PLS) Program (www.pge.com/en/mybusiness/save/energymanagement/pls/index.page)	Incentive program to offset capital investment costs for Thermal Energy Storage (TES) systems.	$875/kW Incentive capped at 50% of project cost
Anaheim Public Utilities Thermal Storage/Time-of-Use (http://www.anaheim.net/article.asp?id=4132)	TES & TOU program for C&I customers in Anaheim.	Up to $21,000 per customer towards purchase of TES system. Performance-based TOU rate available if TES system shifts >20% of on-peak demand to off-peak.
Austin Energy TES Power Saver Program (http://powersaver.austinenergy.com/)	TES program providing tiered rebates based on kW peak shift. Additional TOU rates & feasibility incentives available.	Feasibility incentive – 50% of study cost up to $7,000. TES Tiers: 0 - 100 kW shift – $350/kW 101 - 500 kW shift: $200/kW 501 kW or greater: $100/kW Must shift lesser of 20%–50% of facility demand or 1,000 kW
Burbank Water & Power TES Program (https://www.burbankwaterandpower.com/incentives-for-businesses/energy-solutions-business-rebate-programs)	Program provides incentive as $/kW of demand saved by TES installation.	$800/kW of peak demand saved Total rebate capped at 25% of installed system cost.
Riverside TES Program (http://riversideoed.com/)	Thermal Energy Storage (TES) program for Riverside, CA	$200/kW incentive for peak shifting due to TES Incentive cap of $25K/yr, no more than 25% of project cost Incentive payment of 50% when agreement is signed, 50% upon confirmation that system is operational

5.1.3 Con Edison's Targeted Demand Side Management Program

Con Edison's Targeted Demand Side Management (TDSM) program is designed to defer Transmission and Distribution (T&D) infrastructure upgrades by offering incentives to commercial (daytime peaks) and residential (evening peak) customers for energy efficiency measures that result in PLRs. The TDSM program targets specific near-term (less than 5 year) substation load relief needs throughout the Con Edison service area. Although the program is not currently accepting project bids, if a new round is launched and an RFP is issued, it is likely that battery storage technologies would be eligible for TDSM incentives; at least one industry expert with experience developing battery projects in New York City identified the TDSM program by name as a potential future revenue source.

5.1.3.1 Current Program Status

In 2012, Con Edison began issuing an annual report on its TDSM program to provide an overview of forecasting and load relief needs; in both 2012 and 2013, due in large part to the economic downturn, Con Edison forecasts identified improved load power factors at substations and reduced load forecasts, alleviating the need to issue new TDSM rounds. However, as acknowledged in Con Edison's 2013 annual report, the potential IPEC shutdown, combined with high demand experienced during the summer of 2013, has resulted in the preliminary 2014 forecast including 20 projects with load relief needs within the 5-year prioritization window (PSC Case No. 09-E-0115, Proceeding on Motion of Commission to consider Demand Response Initiatives, Targeted Demand Side Management Program Annual Report, No. 2. December 2, 2013). Concurrently, Con Edison is currently funding an "Integrated DSM Market Research Project" to analyze the economics and market potential for a host of energy efficiency technologies, explicitly including energy storage, to be included in future TDSM offerings.

5.1.3.2 TDSM Program Summary

There have been four rounds of TDSM to date. Phase I was a pilot program, contracting 47 MW of load reduction, while Phases II through IV targeted an aggregate reduction of 148 MW. The following bullets highlight some key features of the TDSM program:

- **RFP process & load reduction term** – For each TDSM round, Con Edison issued an RFP soliciting bids for load reduction within specifically identified networks. Phase I required vendors to maintain measures for 10 years following installation; however, Phases II through IV required maintenance through the duration of the planned load deferral, generally 2 to 5 years.

- **Incentive amounts and program revenue** – Incentives vary for the program and are prioritized based upon network megawatt relief need. Phase I incentives were largely negotiated per project, with awarded incentives up to $2,000/kW. For Phases II through IV, specific bid price guidelines were provided for each network within the Request for Proposal (RFP). As an example, the Phase II RFP listed price guidelines ranging from $775/kW to $1,345/kW. The average target incentive per kW for Phases II through IV was estimated at approximately $1,000/kW.
- **M&V requirement and incentive payment timing** – Previous TDSM rounds have required 100% M&V, with pre- and post-installation visits to verify existing baseline equipment and confirm that replacement equipment achieves load reduction targets. Vendors receive 90% of the incentive after post-installation inspection is completed, and the remaining 10% is paid in equal increments throughout the duration of the targeted 2- to 5-year load deferral.
- **Historical installed measures** – Historically, over 95% of installed measures through TDSM have been lighting retrofits. These projects align well with TDSM's needs of reliable load reductions within short timeframes, and are easily compatible with both residential and commercial installations.

5.2 Future Considerations for IPEC DMP Design

The following discussion presents ERS's synthesis of the existing storage and load reduction programs, the preceding analyses, and a series of conversations with industry experts and NYSERDA staff. It includes conditional suggestions for how to proceed with the IPEC DMP rollout.

5.2.1 Base Incentive Rate

The SGIP, the program most similar to the IPEC DMP, currently provides an incentive of $1,620/kW. This rate has been declining over the past two years – it was $2,000/kW through 2012 and $1,800/kW in 2013. On the surface, NYSERDA's proposed rate of $2,100/kW aligns fairly well with SGIP. However, differences in required rated capacity and discharge duration will dramatically alter the percentage of project costs covered by this incentive. A $1,620/kW incentive that requires a 2-hour discharge duration covers a greater portion of project costs than a $2,100/kW incentive with a 4-hour required discharge duration as discussed in the next section.

5.2.2 Rated Capacity

The definition of battery system rated capacity, in both kW and kWh, for purposes of incentive calculation, is as important to program design as defining the incentive rate itself. There are different ways of quoting power capacity and energy capacity that can obscure actual performance.

Additionally, vendors sometimes quote energy capacity as technical energy capacity, not usable energy capacity. Depth of discharge, efficiency losses, and degradation can all limit usable energy capacity.

ERS recommends that the rated capacity of the battery reflect the usable energy that will be provided during operation. This approach will keep vendors from claiming a greater benefit than they are actually delivering to the grid, and consists of two main components:

- Capacity should be measured on the AC side of the inverter net of efficiency losses and depth-of-discharge maximums.
- The battery should be able to deliver the rated capacity over a pre-defined period of years. Battery performance degrades over time, so requiring that the battery deliver the rated capacity for at least 3 years would help Con Edison realize the load reductions they target. This component doesn't necessarily require M&V, just that Con Edison use industry-standard, technology-specific degradation curves to determine capacity over time.

5.2.3 Discharge Duration Requirements

NYSERDA has proposed a 4-hour discharge duration that intends to reflect peak reduction objectives. In California's experience, a 4-hour requirement was too long. Only three projects more than 50 kW went through the SGIP during the time when the required discharge window was 4 hours. In 2012, when the discharge window had been changed to 2 hours, more than 20 projects went through SGIP.

This data and the economic analysis in Section 2.2 suggest that NYSERDA and Con Edison PLR projects will face challenges. However, it should be noted that California's rate environment is less lucrative than Con Edison's, and the economic modeling represent average conditions, not best case. As such, ERS expects the 4-hour duration to be viable and preliminary applications to DMP suggest that the market agrees.

5.2.4 Measurement and Verification

Incorporating an M&V component into the incentive paid to battery projects reduces opportunities for gaming while providing additional confidence to program administrators that the actual performance of the systems reflects their rated capacity. However, tying too much of the incentive into M&V effectively reduces the incentive in the eyes of project developers and can present program participation and project financing challenges.

ERS's conversations with industry experts highlighted the common practice of oversizing the inverter and "de-rating" in execution in order to garner a higher incentive rate. For example, SGIP's 2-hour discharge duration requirement allows a participant who has an objective need for 500 kW of power over 4 hours (i.e., a 2-MWh battery) to install a 1-MW battery that can be discharged over 2 hours. This project will collect 1-MW-worth of incentives, but de-rate in practice to 500 kW of delivered power. Interestingly, it may be the opposite issue that occurs with IPEC DMP. The long discharge duration requirement may lead to vendors de-rating for the purposes of IPEC DMP qualification, installing a 1-MW, 3-MWh battery, for example, but claiming a 500 kW incentive. M&V could help prevent this de-rating from happening.

It is ERS's understanding that NYSERDA and Con Edison intend to require a full season of M&V, similar to what is done for performance-based projects through EFP. Given the potential for gaming, ERS supports some kind of M&V to verify actual field performance. However, this support comes with two significant concerns:

- Withholding significant portions of the funding will diminish program participation at the margins. Although performance-based withholdings are necessary for the reasons discussed, ERS advises against lengthy M&V windows.
- Without some sort of ongoing, more-permanent contract between Con Edison and the battery owner, bulk peak load shifting operations may partially or completely revert to peak clipping/load smoothing at the conclusion of the M&V period. They will no longer have any incentive to offer the load reduction that is most valued by the grid and will respond to the price signals provided by their energy bills.

Ultimately, Con Edison will have access to customer load data and should threaten repercussions in the event that the IPEC DMP participants deviate from expected load shifting over the course of some number of years (10, for example). The recourse could be vague, but the threat alone would likely be enough to keep people from gaming the system.

5.2.5 Roundtrip Efficiency

None of the TES programs included explicit roundtrip efficiency requirements, while SGIP requires a roundtrip efficiency of at least 63.5%. This value was the result of local greenhouse gas emissions (GHG) standards which limit the amount of efficiency losses that the unit can experience. Analyses calculated that on average, GHG emissions are reduced even down to this level of efficiency since peaking resources are so much more GHG-intensive than off-peak resources.

At this level of efficiency, the most developed technologies (lead acid, sodium sulfur, and lithium ion) have minimum roundtrip efficiencies in the 70%+ range, with each of them capable of pushing into the 80% range, sometimes higher. For flow batteries and nickel cadmium/metal hydride, their roundtrip efficiencies can be lower (as low as 60%), but are capable of higher levels.

ERS recommends a roundtrip efficiency of 65%, which would be achievable by all the commercially viable technologies, leverages the SGIP standards as an objective precedent, and would push less efficient technologies to reach the higher end of the efficiencies of which they are capable.

5.3 Future Considerations for ETAC

While the majority of this research effort focused on commercially available technologies for deployment to achieve load reduction benefits for the grid, a few technologies and implementation strategies would benefit from programs within the Emerging Technologies and Accelerated Commercialization (ETAC) program.

5.3.1 Near-Commercial Technologies

A set of technologies identified in Appendix B are too mature for the R&D program and not quite commercially available, so they could be solid candidates for demonstration projects through ETAC. These technologies include:

- Advanced lead acid.
- Vanadium redox flow.
- Zinc bromine (ZnBr) flow.
- Sodium nickel chloride.

5.3.2 Hybrid Projects

Generally speaking, peak clipping is a commercially viable project model that is being executed in different sectors using different technologies. Hybrid projects are not nearly as common, with only one project in operation and only one other reportedly considering the model. ETAC could support a series of these projects to speed their adoption. Given the uncertainty surrounding the impact that layering peak clipping and DR has on both value streams, it would be useful to the market for a long-term demonstration to prove out the levels of revenue retention.

5.3.3 Managed, Critical-Load Backup

During interviews, multiple battery vendors identified that they are exploring using the battery in a managed fashion, as backup to critical loads during power outages. These vendors are looking to market resiliency benefits as a potential differentiator and “hook” alongside economic benefits. This would be especially valuable in multifamily building applications. Such project applications would be directly tying in emergency loads to the battery, such as elevators and water pumps, and dispense power in a managed way. They would also likely include the ability for tenants to charge cellphones, flashlights, and emergency radios. This type of application has never been done and would increase the cost of the battery, but could help vendors get the attention of the market if done successfully. ETAC could examine this special-case application to see if it is worthy of demonstration funding.

5.3.4 Urban-Sited Flow Batteries

Flow batteries have not yet been proven in an urban location. Their large size makes them a challenge to install indoors. Supporting projects that prove their capability in such an environment could go a long way to smoothing their adoption in the Downstate region. This is important because they have other characteristics that lend themselves to the long-duration load management that benefits the grid.

5.3.5 Industrial Controls

One aspect of peak clipping that is challenging in industrial contexts is predicting load levels and spikes. Other sectors are more schedule or weather driven. Industrial may vary quite a bit depending on production levels. Finding a “job shop” type location and working with a vendor to develop production-based load prediction algorithms could prove a real boon, opening up a challenging segment of the market.

5.4 Future Considerations for R&D

ERS recommends the following promising, pre-commercial technologies be considered for R&D:

- Iron chromium
- Zinc air
- Polysulfide bromide

These technologies show promising characteristics in the lab, but they must be moved to field testing.

Appendix A: Battery Basics

Batteries are electrochemical systems that convert energy between chemical energy and electric energy. They are measured and described in the following dimensions:

- **Power capacity** – Also known as rated power, this is the maximum power output (kW) of the battery.
    - For the vast majority of behind-the-meter projects, power capacity is specified and measured across the terminals on the AC side of the inverter, which is how we define it for the rest of this report unless otherwise noted.
    - Battery systems are highly modular and can be assembled to provide a range of power capacities. Almost all battery technologies can be configured for any power capacity that might be encountered for a facility-scale project.
    - Battery systems are rated for a certain maximum power, but are generally capable of operating at any power level lower than their maximum power.
- **Energy capacity** – The amount of energy (kWh) a battery can discharge.
    - Charging inefficiencies mean that it always takes more energy to charge a battery than it is capable of discharging. Thus, batteries are, by definition, not an energy efficiency technology.
    - The practical energy capacity of a battery will often differ from the technical energy capacity because of depth of discharge limitations (defined further below). However, project reports and industry participants commonly – *though not universally* – refer to energy capacity as the actual usable energy capacity, net of depth of discharge and other factors, as measured across the terminals on the AC side of the inverter.[26] For this report, when the term energy capacity is used it should be considered the actual usable energy capacity of the battery unless otherwise noted.
    - Although batteries are largely modular, certain batteries are more conducive to larger energy capacities than others because their modules tend to be inherently larger, such as sodium sulfur, or are well-suited to scaling, such as flow batteries. Other batteries are better suited to lower energy capacities because their modules are inherently smaller, such as lead acid and lithium ion batteries.
- **Discharge duration** – The maximum amount of time, measured in hours or minutes, that a battery can discharge at its power capacity.
    - It is useful to compare batteries to a car to understand these terms. If power capacity is the “top speed” of the battery, energy capacity is the “gas tank,” and discharge duration is the “miles” that the battery system can travel without refueling.
    - $Discharge\ duration =$

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[26] It is important to clarify this definition when specifying projects, interviewing vendors, or setting program requirements because of its lack of universality.

- **Depth of discharge (DOD)** – The percentage of a battery's technical energy capacity (as opposed to practical energy capacity, as defined above) that has been discharged.
    - Different battery technologies are capable of cycling to different DODs without significantly reducing cycle life. The maximum DOD will define the practical energy capacity of the battery.[27] Additionally, deeper DOD will diminish cycle life, particularly for lead acid, which is most susceptible to DOD concerns among commercial batteries.
    - Most batteries have circuitry to prevent them from discharging past their maximum DOD.
    - $Technical\ energy\ capacity \times Maximum\ DOD = Energy\ capacity$
- **Cycle life** – The number of cycles a battery can be expected to operate before reaching end of useful life (EUL).
    - Cycle life varies greatly by technology.
    - For most battery technologies, diminished energy capacity is the primary symptom of the aging process. Batteries are commonly considered at EUL when they reach 80% of their original energy capacity. This is *not* a universal definition and vendors should be asked to specify their EUL criteria.[28]
    - Unlike most technology categories, flow batteries do not lose energy capacity over time, but do experience diminished roundtrip efficiency. The definition for EUL for a flow battery is less defined and will vary by economic use case (i.e., efficiency is more important for energy cost arbitrage than other use cases).
    - A battery's cycle life varies greatly depending on the use characteristics of the battery. Greater DODs, short discharge times, discharges closer to full power, and high operating temperatures are the most common factors that contribute to diminished cycle lives.
- **Lifetime** – Life of the battery as a measure of time, typically in years.
    - $Lifetime =$
    - Although degradation is primarily a function of the number of cycles and DOD that the battery runs, there is typically a maximum "shelf life" of a battery due to capacity degradation that occurs as the result of continuous contact between the electrolyte and the electrodes. This rate differs between chemistries.

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[27] Different manufacturers sometimes report different maximum DODs for the same technology, which may reflect a more durable construction, or they may simply be rating for a shorter cycle life.

[28] Energy capacity degradation tends to occur linearly, at least up to a point. For some technologies such as lithium ion, the battery never truly dies. However, for others, such as lead acid, they experience rollover at the end of their useful life; their capacity, having degraded slowly for years, suddenly begins to reduce rapidly, and the battery soon becomes inoperable.

- **Roundtrip efficiency** – A measure of the energy lost during the combined charge and discharge cycle.
    - Roundtrip efficiency is the ratio of the energy capacity to the energy necessary to charge the battery to energy capacity.
    - $Roundtrip\ efficiency =$
    - Efficiency losses are generally manifested as heat and come from inherent resistances in the battery and power electronics.
- **Self-discharge rate** – The rate at which the battery loses stored energy while idle, typically measured on a per-day basis.
    - This varies by technology and is usually less than 2% of system capacity.

Appendix B: Battery Technologies

This section introduces the primary battery technologies available as commercial systems and the leading cell chemistries emerging from research and development into mature, commercial endeavors. These technologies are presented below:

- **Mature and commercially available technologies** – These are technologies that can be bought "off the shelf," have demonstrated a clear path to market through deployments, and are likely to be viewed as options by DMP participants.
- **Near-commercial and successfully demonstrated technologies** – These technologies have proven themselves outside the lab in a small number of deployments. Their path to market is emerging, and they could be considered for the ETAC program.
- **Pre-commercial and undemonstrated technologies** –These technologies show promise in controlled laboratory testing, but have not been demonstrated and third-party validated in the field.

Tables B-1 and B-2 summarize the key qualitative and quantitative characteristics of the commercial and near-commercial technologies. The three following subsections correspond to the categories above with decreasing levels of detail provided for the less commercially available technologies.

The following technical data is based on information from the US Department of Energy (DOE) Energy Storage Handbook produced by Sandia National Laboratories (SNL), the DOE Global Energy Storage Database, scientific and academic sources, and interviews with manufacturers, designers, and customers.

Table B-1. Summary of Qualitative Characteristics

Market	Battery Type	Technology summary	Key Advantages	Practical Challenges	Hazards
Commercial Technologies	Lead acid	Mature and widely used technology; the market leader	Modular; low cost; proven; highly recyclable	Deep discharges, extreme conditions shorten cycle life; heavy and large	Hazardous (Pb); corrosive; fire risk
	Lithium ion	Most rapidly growing technology with potential to become market leader	High energy and power density; long life; high DOD and efficiency	Very high cost	Fire risk
	Sodium sulfur	Mature technology with some limitations and narrow applicability	Cost-effective for long discharge times; long life; relatively low cost	Typically come as 1 MW unit; limited manufacturers	High temperature (300°C+); hazardous (Na); explosion and fire risk
	Nickel cadmium	Mature, but uncompetitive technology	High energy density; modular; solid life	High cost; memory effect	Hazardous (Cd)
Near Commercial	Advanced lead acid	Based on existing technology integrating carbon into electrodes	Improved life, durability, and recharge rates	Many advanced architectures that are proprietary and less proven	Hazardous (Pb); corrosive
	Vandium redox (flow)	Most mature flow battery	Long life; no self-discharge; scales well in energy dimension	Large, complicated system	Corrosive
	Zinc bromine (flow)	Promising second-generation flow technology	Very long life; modular; scales well in energy dimension	Large, complicated system; lack of established manufacturing process	Hazardous (Br); corrosive
	Sodium nickel chloride	Evolution of high temperature sodium batteries	Long life; low cost	Lack of established manufacturing process	High temperatures (350°C+)

Table B-2. Summary of Key Technical Parameters[29]

Market	Battery Type	Installed Energy Cost ($/kWh)		Roundtrip Efficiency (%)	Useful Life		Size and Weight (Using 500 kW/2,000 kWh Example)			
		Suburban (Outdoors)	Urban (Indoors)		Cycle Life	Expected Lifetime (Years)	Battery Volume (Standard Refrigerators)	Total Footprint (Sq ft)	Weight (Lbs)	Pressure (Lbs/sf)
Commercial Technologies	Lead acid	$700 – $1,000	$800 – $1,200	70% – 80%	500 – 1,500	3 – 5	25	1976	110,231	558
	Lithium ion	$1,000 – $2,000	$1,500 – $2,500	85% – 98%	2,000 – 5,000	10 – 15	5	367	32,067	874
	Sodium sulfur (salt)	$750 – $900	$1,000 – $2,000	70% – 80%	2,500 – 4,500	10 – 15	8	642	22,611	352
	Nickel cadmium	$1,000 – $1,500	$1,250 – $2,000	60% – 70%	800 – 3,500	15 – 20	15	1223	70,548	577
Near Commercial	Advanced lead acid	$900 – $1,500	$1,200 – $1,800	80% – 90%	1,000 – 2,000	5 – 7	25	1976	110,231	558
	Vanadium redox (flow)	$1,000 – $1,500	$1,500 – $2,000	60% – 70%	10,000+	5 – 15	66	5242	220,462	421
	Zinc bromine (flow)	$750 – $1,250	$1,250 – $1,750	60% – 70%	10,000+	5 – 10	36	2854	110,231	386
	Sodium nickel chloride	$1,000 – $1,500	$1,300 – $1,800	80% – 90%	2,500 – 4,500	10 – 15	10	778	40,084	515

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[29] Data in this table represents the contractor's team's judgment and synthesis of a range of data, including DOE survey data, academic studies, and interviewee responses. Cost parameters represent full system cost, including power electronics, conditioning equipment, safety equipment, installation, and design. Costs/kWh are for *practical* energy capacity (i.e., net of DOD, etc.). Volume refers to the volume of the battery itself as represented by standard refrigerator equivalents (i.e., 44 cubic feet). Footprint is the estimated footprint of the total battery system including power electronics, conditioning equipment, and walkways. Greater detail on these parameters and their driving factors are in the following subsections.

B.1 Mature and Commercially Available Technologies

Battery systems that have reached mature, commercial status have demonstrated a clear path to market through a series of behind-the-meter deployments and are currently available from energy storage system vendors. Installations of these technologies are primarily funded by the client instead of an outside source, such as government research grants. Only four technologies have reached this point, and each has its own advantages and drawbacks. Different technologies are better suited to different projects depending on a large number of factors, including daily and annual discharge profile, desired lifetime, installation location, and others. These factors have been called out within the sections, as appropriate.

The commercially viable, facility-scale energy storage technologies available today in order of their relevance[30] to NYSERDA's goals are:

- Lead acid
- Lithium ion
- Sodium sulfur
- Nickel cadmium

It should be noted that within these primary technology groups, there are further sub-chemistries that have slightly different characteristics.

Table B-3 provides a summary of their comparative performance. A greater level of detail on each technology – their chemistry, advantages and disadvantages, applications and market evolution – is described in subsequent sections.

Table B-3. Key Parameter Comparison Matrix[31]

Parameter	Worst-->			<--Best
Cost/kWh	Lithium ion	Nickel cadmium	Sodium sulfur	Lead acid
Expected lifetime	Lead acid	Nickel cadmium	Sodium sulfur	Lithium ion
DOD	Lead acid	Sodium sulfur	Nickel cadmium	Lithium ion
Efficiency	Nickel cadmium	Sodium sulfur	Lead acid	Lithium ion
Replacement costs	Lithium ion	Nickel cadmium	Lead acid	Sodium sulfur
Hazards	Lead acid	Nickel cadmium	Sodium sulfur	Lithium ion

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[30] This was defined as applicability to facility scale storage in key areas of interest (notably New York City) inclusive of cost, performance, size, and safety.

[31] Akhil, Abbas, et al. DOE/EPRI. 2013. Electricity Storage Handbook in Collaboration with NRECA. Livermore, CA: Sandia National Laboratories; Rastler, D. 2010. "Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits." Electric Power Research Institute and the U.S. Department of Energy.

B.1.1 Lead Acid

Lead acid batteries are the oldest, the most widely commercialized, and the most mature battery technology available. They are used in vehicles worldwide and nearly all uninterruptible power systems employ them.[32] They are also the most popular choice for energy management batteries in buildings. Traditional lead acid batteries come in two types, vented and valve regulated. Valve regulated batteries are more suitable for highly dynamic applications (e.g., cars) because the electrolyte is utilized in a gel form; they are also more expensive.

Lead acid batteries are typically the standard by which other batteries are measured due to their low cost and reliability, but they offer only mediocre energy or power density and lifetimes in comparison to the other three mature technologies. Importantly, they are capable of only a limited DOD (as little as 50% DOD in traditional lead acid batteries); full discharges will damage the battery and shorten its life.

These batteries can easily be linked together in parallel or series for an essentially infinite combination of voltages and energy capacities[33]. They are currently manufactured worldwide by dozens of manufacturers including GNB Industrial Power, Axion Power, Exide, and Leoch Battery.[34]

Important Characteristics and Considerations

- **Cost –** Lowest cost per kW and kWh, compared to all other batteries at any scale.
- **DOD –** Lead acid batteries, no matter what type, have a more limited depth of discharge than any other battery. Discharging past 50% on traditional lead acid batteries will result in reduced cycle life (by as much as half or more). Deep-cycle lead acid batteries are designed to withstand regular cycling to 80% DOD and have even greater cycle lives at lower DODs.
- **Roundtrip Efficiency –** Typically between 70% and 80%.

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[32] Akhil, et al. *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA,* 75.

[33] Chen, Haisheng, Thang Cong, Wei Yang, and et al. 2009. "*Progress in Electrical Energy Storage System: A Critical Review*." Progress in Natural Science (S), no. 19 (2008): 297.

[34] Klein, A, and T Maslin. 2011. *US Utility Scale Battery Storage Market Surges Forward*. IHS Emerging Energy Research.

- **Degradation/lifecycle –** Their cycle life is low under optimal conditions (<2,000 cycles), and under high temperatures or especially deep depth of discharges (>80%), their cycle life is greatly reduced to the order of 500 cycles.[35] Lead acid battery's cycle lives are more sensitive to DOD, temperature, and discharge rate than any other battery. This makes conditioning and close control imperative. Lead acid batteries are usually considered dead after 80% capacity degradation because rollover (the phenomenon whereby linear degradation gives way to rapid deterioration and, shortly, inoperability) typically takes effect beyond this point.
- **Size/Space –** Lead acid and advanced lead acid batteries are heavier and more space consuming than any other of the battery types covered in this report except for flow batteries, which makes them challenging to install in urban contexts.
- **Hazards –** Lead is toxic, and gasses resulting from the reactionmust be vented. They are capable of catching fire if mishandled or improperly conditioned or vented.

Applications and Market Evolution

For the size range between 100 kW and 1 MW, lead acid batteries are typically the most cost-effective battery energy storage technology available, especially for power applications that do not have rigorous size and weight requirements. Although they are the current market leader and may represent the bulk of installations under the DMP, traditional lead acid batteries are likely to be replaced in the next 2 to 5 years by developing battery technologies – including lithium ion and advanced lead acid chemistries – primarily due to lead acid's limited cycle life under deep DOD and sensitivity to operating conditions. Their primary advantages at this point are that they are relatively inexpensive and, importantly, a known entity in a risk adverse permitting environment.

B.1.2 Lithium Ion (Li-Ion)

Lithium ion batteries are typically constructed of carbon and metallic electrodes with a lithium-based electrolyte. There are a variety of subtly different cell chemistries that can be used to construct these types of batteries that are often proprietary to a specific manufacturer. Lithium iron phosphate batteries are the most commonly reported chemistry for use in energy storage applications by manufacturers because of their extended cycle life and reduced fire hazards[36].

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[35] G. Albright, *A Comparison of Lead Acid to Lithium-Ion in Stationary Storage Applications. White paper*, 8.

[36] Everyone interviewed preferred this lithium ion chemistry, i.e., BYD, Samsung, GSA, and A123.

Lithium ion batteries can be purchased at facility scale from any number of manufacturers such as A123, Xtreme Power, Tesla, BYD, AES Energy Storage, and Samsung.[37]

Important Characteristics and Considerations

- **Cost –** Highest cost per kW and kWh compared to other batteries. More than any other battery technology, lithium ion batteries are experiencing reductions in cost from growing market volumes across a range of applications.
- **DOD –** Typically capable of any DOD, but rated to approximately 2,000 cycles at 100% DOD. Shallower cycles will greatly extend life in excess of 5,000 cycles at 50% DOD.
- **Roundtrip Efficiency –** Very high, approaching 100%
- **Degradation/lifecycle –** High temperatures will decrease the lifetime for most batteries, and the same is true for lithium ion. Most manufacturers recommend storing at a cool temperature of about 15°C or 60°F.[38] Also, as noted above, DOD will impact cycle life significantly.
- **Size/Space –** Lithium ion batteries are the most compact and one of the lightest batteries available. However, their compact nature makes their weight per square foot very high, which can be a challenge for some floor types.
- **Hazards –** Exceeding the assessed charge/discharge rate causes excessive heat and potential for fire, and discharging beyond a certain depth can lead to the formation of lithium metal at the electrodes, which is potentially a fire hazard. Although circuitry for these batteries is designed to prevent this kind of hazardous operation, lithium ion batteries are perceived to be a greater fire risk than other battery technologies. However, fire risks have decreased over time as use of metallic lithium in the battery has given way to ionic lithium. Lithium ion batteries are as safe as lead acid at this point.

Applications and Market Evolution

The market for lithium ion batteries continues to grow because of their excellent energy and power densities, which makes them lighter and more compact than any other commercial battery technology. These characteristics give them an edge in situations where space or weight might be valued over capital cost (e.g., cell phones and laptops). They are also hyper efficient and typically rated for full discharge/charge cycles, unlike lead acid batteries; this helps most for energy cost arbitrage where efficient, repeated cycles are necessary. They last about twice as long as lead acid batteries, if both are operated under optimal conditions, which is a significant advantage. However, the batteries themselves are currently two to three times the cost of lead acid and *perceptions* of safety issues and regulatory issues

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[37] Klein, A, and T Maslin. *US Utility Scale Battery Storage Market Surges Forward.*

[38] Buchmann, Isidor. Is lithium-ion the ideal battery. Battery University, Cadex Electronics 20 http://batteryuniversity.com/learN/Article/is_lithium_ion_the_ideal_battery

due to their newness in building applications. These issues are likely to diminish with familiarity and costs are expected to come down in cost in the coming years, which makes them a likely candidate to become the dominant battery technology in 2 to 5 years. Advanced chemistries are in the making, which will build on the strong characteristics of this technology.

B.1.3 Sodium Sulfur (NaS)

Sodium sulfur batteries were commercialized in the 1980s by NGK Insulators, Ltd., the primary manufacturer of the technology, and Tokyo Electric Power Co. Except for requiring a very high operating temperature, sodium sulfur batteries have favorable characteristics for larger-scale energy storage. They are often referred to as molten salt batteries because during operation they are composed of molten sulfur and liquid sodium separated by a ceramic electrolyte.[39]

Sodium sulfur batteries have been established as a commercial technology by offering longer discharge times (6+ hours) than most other technologies and reliable operation at cost-competitive rates. These batteries require a heat source to maintain their temperature, which results in a parasitic energy loss, but they have lifetimes up to 15 years.[40,41]

NGK claims they are the only manufacturers commercially offering this technology, and they have 20 MW currently installed in the US. [42] Eagle Picher and American Electric Power are currently in the process of commercializing their own versions of this technology. The “GE Battery” is a derivative of sodium sulfur: sodium nickel chloride. That technology is not as mature and is discussed in the next section.

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[39] Rastler, D. 2010. “Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits". EPRI Report., page 4–9.

[40] Ibid.

[41] Haisheng Chen et al.. 2009. “Progress in Electrical Energy Storage System: A Critical Review.” *Progress in Natural Science* no. 19: 307–308.

[42] Klein, A, and T. Maslin. 2011. *US Utility Scale Battery Storage Market Surges Forward.* Emerging Energy Research LLC Report.

Important Characteristics and Considerations

- **Cost –** Sodium sulfur batteries are comparable in cost to lead acid batteries in large-scale, long-discharge, outdoor applications, but are not cost competitive with lead acid in other situations including, notably, indoor applications
- **DOD –** Established cycle life at 2,500 for 100% DOD and 4,500 at 90% DOD. Cycling at lower DODs will greatly increase usable cycle life[43]
- **Roundtrip Efficiency –** 70% to 80%. Requires a parasitic heat source to keep electrodes in liquid state or at approximately 300°C
- **Degradation/lifecycle:** Typical lifetimes of 15 years, but if electrodes are not maintained at temperature, the molten salt solidifies, and it's not clear yet how this affects cycle life
- **Size/Space –** One of the lightest and most compact batteries, but they are not commonly manufactured at small capacities (less than 1 MW)
- **Hazards –** These operate at an extremely high temperature, but they come in a hermetically sealed package, which mitigates ventilation or leakage issues. Sodium is hazardous. These batteries could also pose fire and explosion risks. In 2011 a sodium sulfur battery in Japan exploded, and the resulting fire took 8 hours to extinguish. GreenTech Media[44] and Scientific American[45] featured articles about this incident.

Applications and Market Evolution

Sodium sulfur batteries are primarily installed in controlled outdoor locations because of their high operating temperatures, and they are used typically in energy cost arbitrage or other uses that require long discharge times.[46] They have not been looked upon favorably by building- and fire-code departments, limiting their urban-scale deployment potential. For certain niche applications requiring lengthy discharge duration, but with ample outdoor space available, this technology is a competitive solution; downstate and in urban settings it is *not* competitive.

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[43] Z. Wen, J. Cao, Z. Gu, X. Xu, F. Zhang and Z. Lin. 2008. "*Research on sodium sulphur battery for energy storage*," Solid State Ionics, vol. 179, pp. 1697-1701.

[44] http://www.greentechmedia.com/articles/read/Exploding-Sodium-Sulfur-Batteries-From-NGK-Energy-Storage

[45] http://www.scientificamerican.com/article/battery-fires-risks-storing-lareg-amounts-energy/

[46] Poullikkas, Andreas. 2013. A comparative overview of large-scale battery systems for electricity storage. Academic, Nicosia, Cyprus: Renewable and Sustainable Energy Reviews.

B.1.4 Nickel Cadmium (NiCd)

Nickel cadmium batteries are almost as old as lead acid batteries and were developed over a hundred years ago. They are built from nickel and cadmium electrodes with an alkaline electrolyte. Nickel metal hydride is a closely related, second-generation technology of this type.

Because of their robust build, reliability, low maintenance requirements, and high energy density they have been favored in portable tools and devices for years but are being phased out in favor of newer technologies because of their high cost and tendency to have a memory effect. Memory effect is used to describe the tendency of nickel cadmium and nickel metal hydride batteries to lose apparent power capacity if shallowly discharged several times in a row. Capacity can be recovered through several full charge/discharge cycles, but capacity can also be permanently lost if too many shallow cycles are performed.

Nickel cadmium batteries are still available from a range of manufacturers worldwide, and it's notable that they were used in the world's most powerful battery (40 MW) installed in Fairbanks, Alaska. That battery is used to keep the town supplied with power while generators come online in the event of power loss.[47]

Important Characteristics and Considerations

- **Cost –** Nickel cadmium batteries are not cost competitive and unlikely to become cheaper as they are a rather mature technology
- **DOD –** Can be fully discharged; shallow DOD causes memory effect. Deep DOD diminishes cycle life
- **Roundtrip Efficiency –** 70% to 80%
- **Degradation/lifecycle –** Durable battery with very long shelf lives of up to 20 years, but cycle lives of only 800–3,500
- **Size/Space –** Medium weight and footprint
- **Hazards –** Cadmium is very toxic

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[47] Haisheng Chen, *Progress in Electrical Energy Storage System: A Critical Review*, 297.

Applications and Market Evolution

Nickel cadmium batteries are still used in UPS systems, but they are being phased out due to high costs from the manufacturing process, above average self-discharge rate (~ 4%/day), and depth of discharge concerns.[48] Though they are capable of being used for facility-scale storage, they are unlikely to compete successfully with the alternatives listed above.

B.2 Near Commercial and Successfully Demonstrated Technologies

A few battery types have not yet developed a clear path to market or shown repeated deployments, but have been demonstrated successfully in the field. These near-commercial technologies may lack the validation necessary to gain traction in the market and could be a target for ETAC. The near-commercial battery technologies are:

- Advanced lead acid
- Flow batteries (vanadium redox [VR] and zinc bromine [ZnBr])
- Sodium nickel chloride

Of these three types, advanced lead acid and sodium nickel chloride are based on the chemistries of their commercial system's counterpart (lead acid and sodium sulfur, respectively) and can be considered second-generation technologies.

B.2.1 Advanced Lead Acid

Advanced lead acid batteries employ carbon in different ways to improve the performance of traditional lead acid batteries. Companies researching this type of battery include Ecoult/EastPenn, Axion Power International, Xtreme Power, GS Yuasa, and Hitachi. Each company has its own proprietary take on the technology, but they all seek to overcome the shortcomings of traditional lead acid batteries, improving cycle life and depth of discharge capability.[49]

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[48] Akhil, et al. *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA,* 109.

[49] Ibid.

B.2.2 Flow Batteries – Vanadium Redox and Zinc Bromine

Flow batteries rely on the flow of a liquid electrolyte to provide power. In comparison to other battery types, the charge is stored in the electrolytes instead of at the electrodes. Sumitomo Electric Industries and Imergy are the main investors in vanadium redox (VR) batteries, and ZBB Energy Corporation is the primary manufacturer of ZnBr batteries. Both have packaged options available for purchase, though the number of deployments is limited.[50]

VR and ZnBr batteries are fundamentally different chemistries, which lead to some differences in function.[51] At the same time, they share certain important characteristics that are common to flow batteries as a family. First, the pumps and moving parts associated with these systems leave them with low energy densities, large footprints, and operations and maintenance responsibilities that exceed those of other technologies including servicing the pumps necessary to make the batteries flow. Flow batteries also have poor roundtrip efficiencies of less than 70%. On the other hand, they look to be more cost-effective for long discharge times (>6 hours) than traditional battery types because you can simply add more electrolyte (i.e., install larger tanks). Vanadium battery types in particular, have potential for very long lifespans, but ZnBr batteries are slightly cheaper.[52]

Flow batteries do not lose energy capacity over time, but instead lose efficiency as the electrode plates in the battery degrade and the effective surface area diminishes. Relatedly, in order to “refresh” the battery to its original state, an owner must only replace the plate as opposed to replacing the entire battery. This gives flow batteries a lifecycle cost advantage over traditional battery types, although their upfront costs are still significant.

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[50] Klein, A, and T Maslin. *US Utility Scale Battery Storage Market Surges Forward.*

[51] VR, unlike ZnBr and other flow batteries, relies on only one element (vanadium) that can reach multiple electron states.

[52] Ibid. 14; Rastler, D. Electricity *Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits*". 4-13; Chen, *Progress in Electrical Energy Storage System: A Critical Review*, 301.

B.2.3 Sodium Nickel Chloride

Sodium nickel chloride batteries are high-temperature (300+ °C) batteries and are also called the ZEBRA battery. They are similar to sodium sulfur technologies, but with better safety characteristics. Only two manufacturers are making these batteries currently (notably, General Electric is one of them), but it is anticipated that they will have long lifetimes and generally better performance characteristics than traditional lead acid batteries without some of the safety concerns associated with sodium sulfur batteries.[53]

B.3 Pre-Commercial and Undemonstrated Technologies

Several other promising technologies are on the horizon for the rechargeable battery market that promise performance beyond what is currently available. These include iron chromium, zinc air, and polysulfide bromide. These technologies may be worth supporting through R&D grants.

B.3.1 Iron Chromium

Iron chromium batteries are flow batteries that propose a low-cost solution to energy storage. The technology is promising for a variety of applications (both power and energy oriented) and is progressing steadily towards field demonstrations.[54]

B.3.2 Zinc Air

Air-type batteries have the potential for very high energy densities, up to three times those of lithium ion, but researchers have struggled to overcome many technical difficulties such as electrolyte management and susceptibility to environmental conditions, like humidity and dust.[55]

B.3.3 Polysulfide Bromide

Polysulfide bromide batteries are flow-type batteries. Like other flow batteries they promise long lifetimes, but low energy or power densities.

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[53] Akhil et al. *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA,* 109.

[54] Ibid.

[55] Ibid.

Appendix C: Value Streams

The following sections expand on the detail provided in the value-stream summary table presented in Section 3 of the report and show how the savings and revenue estimates are calculated. The appendix addresses 6 topics:

2. Demand-charge reduction
3. Demand response revenues
4. Energy-cost savings
5. Soft revenues and avoided costs from resiliency
6. Targeted demand side management revenues
7. Integration with renewables

C.1 Demand-Charge Reduction

Demand-charge reduction applies primarily to delivery charges. In general, delivery charges are composed of both demand-based charges (i.e., $/kW) assessed on peak demand[56] and energy-based charges (i.e., $/kWh). The structure and magnitude of charges vary by utility, by rate class, and, in some cases, by time of day and time of year.

In order to illustrate the principles of demand-charge reduction and peak clipping, ERS will focus on the utility and service classifications most relevant to this analysis: Con Edison's Multifamily Dwellings (SC8) class, which covers multifamily buildings on a master meter, and General Large Commercial (SC9) class, which includes commercial and industrial customers and the common areas of multifamily buildings where apartments are separately metered.

Research into upstate utility rate structures revealed that they are broadly similar in structure, though the rate classes are called different things, are organized differently, and – importantly – charge at lower rates. Detail is provided following the Con Edison discussion.

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[56] The peak demand for a customer is the maximum capacity required during a given period. Energy demand is typically monitored at 15-minute intervals. Most utilities use a single 15-minute interval to set peak demand. For Con Edison, the peak demand is calculated by taking the highest rolling 30-minute interval. Con Edison's 30-minute window in effect results in smoother peaks, reducing opportunities for peak clipping.

C.1.1 Rate Class Structures

There are five rate classes – representing three billing structures – that are available to customers within either the Con Edison SC8 and SC9 classifications. Across the board, they have seasonal variability, with higher rates for the summer months (June through September), and lower rates during the rest of the year. Besides that similarity, they have key differences in rate structures and are applied for different types of customers:

- **Standard Service** (Rate I) – This is for customers with demand from 10 kW to 1,500 kW. The rate class includes $/kW assessed on the peak demand over the course of the month. This rate class includes energy-based charges and a minimum monthly charge based on the highest peak measured over the last 18 months and billed at 40% of the applicable rate.
- **Time-of-Day Service** (Rates II & III) – This rate structure is required for standard customers with demand greater than 1,500 kW (Rate II) and is voluntary for customers with demand less than 1,500 kW (Rate III). The structure includes time-variant demand charges assessed on the peak demand over the course of a month. The base rates are lower than standard rates, but they include premium charges for on-peak periods.[57] This rate class includes energy-based charges and a minimum monthly charge based on the highest peak measured over the last 18 months and billed at 40% of the applicable rate.
- **Standby Service (Rates IV & V)** – This rate structure is required for customers with on-site generation capacity greater than 15% of the customer's maximum potential demand (Rate IV) and is available on a voluntary basis for customers with less than 15% on-site generation (Rate V). Standby Service includes no energy-based charges and is thus more demand-based. As-used demand charges are assessed on peak demand on a daily basis with premiums during on-peak periods. There is a monthly flat charge called a contract demand charge that is negotiated and represents the maximum possible demand that the building could draw; this is similar in function to the minimum monthly charge, but in practice represents a smaller portion of the applicable rate (between 15%–25%).

Table C-1 presents a high-level overview of these rate classes' structures and applicability.

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[57] On-peak periods are defined as weekdays between 8 a.m. and 10 p.m., with additional premiums assessed for summer weekdays between 8 a.m. and 6 p.m.

Table C-1. Con Edison SC8 & SC9 Sub-Rate Characteristics

Rate Class	Applicability	Demand Charge Structure ($/kW)	Peak Demand Charge Cycle	Energy Charges ($/kWh)	Minimum Monthly Charge
Standard Service (Rate I)	10 kW to 1,500 kW peak demand	Flat rates for different levels of demand	Monthly	Yes	Yes
Time of Day Service (Rate II & III)	Required if demand >1,500 kW Optional if demand <1,500 kW	Premiums during peak periods (8 a.m.–10 p.m. and 8 a.m.–6 p.m.)	Monthly	Yes	Yes
Standby Service (Rate IV & V)	Required if on-site generation >15% of maximum demand Optional if on-site generation <15%	Monthly flat rate for maximum possible demand; premiums during peak periods (8 a.m.–10 p.m. and 8 a.m.–6 p.m.)	Daily	No	No, replaced with “contract demand charge”

There are a few key differences between the rate classes that make Standby Service the best available rate class for peak clipping projects in Con Edison territory. For Standard Service and Time-of-Day Service, peak demand is applied on a monthly basis, whereas for Standby Service the peak demand is applied daily. Thus, a one-day lapse in peak-clipping activities (as the result of, for example, poor planning on the part of the battery control software or participation in a DR event) would result in a forfeiture of the demand-charge savings for an entire month for Standard and Time-of-Day Service, but only one day’s savings for Standby Service.

Because the rates across Standby Service and Standard service are engineered to provide equivalent revenue to Con Edison for an “average” customer load shape and because the Standby Service does not include energy charges, more of Standby Service charges are based on peak demand charges. This increases the opportunity for and magnitude of peak-clipping savings.

Customers in Standard and Time-of-Day Service rates incur a Minimum Monthly Charge, below which their peak demand charges cannot go regardless of their actual peak demand. The customer’s Minimum Monthly Charge will be equal to that customer’s highest registered demand within the previous 18 months. Thus, historical peak demand can have long-lasting implications on current and future demand pricing. The Contract Demand Charge in Standby Service does not operate as a “floor” for demand charges. It is a fixed price that represents roughly 20% of a customer’s overall per-kW demand charges (compared with 40% for the Minimum Monthly Charge); the balance of charges can float according to the customer’s ability to lower their peak demand.

The combination of the above factors makes Standby Service a good match for peak clipping, which makes it the best rate structure for battery customers. Customers can maximize their demand charge reduction savings by switching to Standby Service or other similar rate structures.

C.1.2 Estimating Savings from Peak Clipping

By peak clipping, customers can reduce their peak demand, which results in reduced demand charges on their bills. The below example shows how those annual savings are calculated:

$$Savings = [(Summer\ days \times Summer\ rate) + (Nonsummer\ days\ \times Nonsummer\ rate)] \times Peak\ reduced \times Success\ rate$$

Where,

- $Summer\ days$= The number of days June through September
- $Summer\ rate$= The maximum $/kW charge incurred during summer months
- $Nonsummer\ days$= The number of days in the other months of the year
- $Nonsummer\ rate$= The maximum $/kW charge incurred during nonsummer months
- $Peak\ reduced$= The kW reduced; this is equivalent to battery power capacity
- $Success\ rate$ = The percentage of peak clipping potential actually achieved net of mistakes, variations in load peaks and valleys, and DR events; for purposes of calculation, we assume 90% in general and 80% for batteries participating in DR

Thus, for a 500 kW battery that is not participating in DR and which is charged through the Standby Service rates, the expected annual savings are: [58]

$$Savings = [(122 \times \$1.72) + (243\ \times \$1.30)] \times 500\text{ kW} \times 90\% = \$236{,}580\text{/year}$$

Peak-clipping savings are the largest single value stream for a typical battery installation.

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[58] Con Edison rate classes distinguish pricing between low tension and high tension service based upon service voltage. All quoted figures are for low tension service based upon the understanding that the vast majority of customers interested in battery storage are low tension customers. As a rule-of-thumb, high tension costs tend to be lower by about 25%, which eats into the potential savings.

C.1.3 Other Utility Rate Structures and Charges

All New York utilities offer some kind of standby service rate structure for use with on-site generation. The other rate structures tend to make use of similar constructs: daily, per-kW peak demand charges, sometimes with variations depending on time of day or time of year. Across the board, though, the charges are lower and often significantly lower. Table C-2 summarizes the standby service rate for each of the major utilities in New York.

Table C-2. Summary of New York State Standby Service by Utility

Utility	Con Edison	Orange & Rockland	Central Hudson	Rochester Gas & Electric	National Grid	NYSEG	PSEG/LIPA
Rate Class	SC 9 Rate V - Standby Rate	SC 25 Standby Service Rate 3	SC 14 Standby Service	SC 14 Standby Service	SC 7 Standby Service	SC 11 Standby Service	Supplemental Service
Peak Charge Cycle	Daily	Daily	Daily	Daily	Daily	Daily	Monthly
Summer Charge	$1.72/kW	$0.5168/kW	$0.3549/kW	$0.3234/kW	$0.2543/kW	$0.1425/kW	$22.50/kW
Summer Peak Window	June - Sept 8 AM to 10 PM	June - Sept 24 hours	Mon - Fri 7 AM to 11 PM	Mon - Fri 7 AM to 11 PM	Mon - Fri 8 AM to 10 PM	Mon - Fri 7 AM to 10 PM	June - Sept Noon to 8 PM
Winter Charge	$1.02/kW	$0.3399/kW	Same as summer	Same as summer	Same as summer	Same as summer	$0/kW
Winter Peak Window	October - May 8 AM to 10 PM	October - May 24 hours	Same as summer	Same as summer	Same as summer	Same as summer	n/a
Expected Annual Savings from 100 kW Battery	$41,193	$13,108	$8,327	$7,588	$5,967	$3,344	$8,100

Table C-2 shows that demand charge savings for Con Edison customers vastly exceed those realized by customers of other utilities. This makes the environment for battery projects outside of Con Edison territory very inhospitable.

In jurisdictions outside of New York State, energy storage programs offered by utilities have been coupled with special rates that were specifically designed to reward users for shifting load off peak. These rates differed from typical rates and were available only to those who participated in the programs. Although standby rates are a step in this direction, it is clear from the above table that not all standby rates are created equal. NYSERDA could encourage the utilities to develop storage-specific rate structures in order to create a more storage-friendly environment.

C.2 Demand Response Revenues

Demand response (DR) programs incentivize users who are able to reduce their load on the grid during periods of congestion. DR programs offered by both NYISO and Con Edison provide an opportunity for battery owners to monetize their investment by discharging stored energy to reduce their loads. A few notes about DR participation:

- The NYISO programs are offered statewide, though payments in New York City (Zone J) are roughly three times higher than upstate (Zones A through I) and two times higher than on Long Island (Zone K).[59]
- Con Edison's programs are only available to customers reliant upon Con Edison delivery, but eligible customers can and are recommended to participate in both Con Edison and NYISO programs.
- Customers are only able to select one NYISO program, but can enroll simultaneously in both programs offered by Con Edison (for a total of 3 programs in Con Edison territory).
- Enrollment is commonly handled by an aggregator who takes a proportion of the payment as an administrative fee. These fees are negotiated, but range from 10%–40% of the total revenue offered by the programs. The larger the customer's demand response bid is, the smaller the fee.

Table C-3 summarizes the characteristics of the programs offered.[60]

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[59] The NYISO recently proposed a redrawing of the grid zones that may have an impact on the relative profitability of DR in the various zones. Their presentation to FERC can be seen here.

[60] Major changes to Con Edison's DR programs were recently approved that make them significantly more lucrative. All tables and calculations show the new features and rates.

Table C-3. Demand Response Programs

Provider	Program	Uptake	Season	Event Structure	Revenue Structure
NYISO	SCR/ICAP	94.9% of enrolled MW in NYISO DR	Year-round, events outside of the summer are uncommon.	Events are typically 4 hour windows with a minimum of 2 hours notice.	Reservation payment for kW capacity. Additional revenue based on energy reduction observed during events.
NYISO	EDRP	Low participation	Year-round, events outside of the summer are uncommon.	No obligation for participation during events. Events are typically 4 hour windows with a minimum of 2 hours notice.	Revenue based on energy reduction observed during events.
NYISO	DADRP	No activity in 2012 summer.	Year-round	Based on purchased offers for the day ahead.	Revenue based on energy reductions purchased off of markets similar to day-ahead clearing house for generation sources.
NYISO	DSASP	No participation in 2012 summer.	Year-round	Based on purchased regulation offers. Offers must be accepted a minimum of 75 minutes before scheduled hour.	Revenue based on ancillary service rates similar to those provided to generation sources.
ConEd	CSRP	High participation	May-September	Events have standard 4 hour windows with a minimum of 21 hours notice.	Reservation payment for kW capacity for each month. Additional revenue based on energy reduction observed during events. Bonus dependant on large number of events or unplanned events. Incentive for those who sucessfully complete three years.
ConEd	DLRP	High participation	May-September	Events have standard 4 hour windows with 2 hours or less notice.	Reservation payment for kW capacity for each month, based on network Tier. Additional revenue based on energy reduction observed during events. Bonus dependant on large number of events or longer event periods. Incentive for those who sucessfully complete three years.

A few comments on the table:

- The most popular programs are “reservation” based, which refers to the fact that the participants are paid by the month simply to be available for events. Although payments are tied to performance, if no events are called – which is typically the case in a given month – the participants still receive revenue based on their “reserved” capacity.
- The SCR/ICAP program is the most popular NYISO program; it is 94.9% of NYISO DR enrollment.
- For Con Edison, CSRP and DLRP both receive robust participation.
- Notably, the Con Edison programs are summer only, whereas the NYISO programs are year-round.
- For the NYISO programs, summer payments are more lucrative than winter payments by as much as a factor of 2.
- DR events are 4 hours in length and are called with a range of notice: between 2 and 21 hours.

C.2.1 Measuring Participant Demand Reduction

Demand reduction during a DR event is measured as the amount of demand, in kW, below a participant's baseline, or typical, load. The baseline load is commonly referred to as the average coincident load (ACL), and it is determined differently by NYISO and Con Edison. The methodologies for determining the peak load during an event are shown in Table C-4.

Table C-4. Methodologies for Determining Peak Load

Provider	**Peak Load Level Measurement**
NYISO	Average of customer's highest 20 hours of kW demand during the grid's 40 highest hours of kW demanded during the preceding year.
Con Edison	Average of peak demand of 5 highest days during the 10 days leading up to the event.

These methodologies may prevent battery storage projects from participating in DR programs at the full level of their installed capacity if they also partake in peak clipping. In theory, peak clipping will reduce the ACL (i.e., measured baseline demand) relative to the actual building load. When the battery switches from peak clipping mode to DR mode, only the portion of discharge over and above what is necessary to peak clip will register as true demand reduction with the DR program. The impact will differ by methodology:

- The NYISO's top 40 hours, which determine NYISO ACL, all occurred between 1 p.m. and 6 p.m. during days in June, July, and August. If the building's peaks happen to occur outside those hours then they would not impact the ACL or could only partially impact it.
- Con Edison's program ACL is based on *daily* peak demand in the lead up to the event, as opposed to specific hourly demand. As a result, peak clipping will have a much greater impact on Con Edison program revenues.

If peak clipping impacts either program ACL, then the customer will experience DR payments below what might be expected if judging by the nameplate power capacity of the battery alone. The amount of lost payment is very difficult to estimate, and there are no real empirical examples on which to base an estimate.[61] Since the system of payments is reservation-based and since the number of events is few, this limits the exposure of battery projects to failure, but also elevates the importance of the test event. The ability to deliver full nameplate power capacity will vary with the building load profiles and is a function

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[61] The Barclay Tower project reports receiving full DR revenues from its participation in the NYISO SCR/ICAP. However, for NYISO programs, it will take a year before the effect on ACL kicks in, which explains why this is the case. There are no other empirical cases of battery storage providing DR in New York City of which the contractor knows.

of the typical intensity and duration of their load spikes during the days and hours that set the ACL for the program, but the precise dynamics are very difficult to predict. For the purposes of revenue projections, it is assumed that 60% of revenues are retained, though there is no empirical data on which to base this calculation at this time.

C.2.2 Estimated Savings from a DR Program

The available DR programs offer capacity reservation payments, compensating participants whether events are called or not. Participation in these programs is predicated upon a battery that will be able to provide demand reduction for a 4-hour period, as in the hybrid project model described in the introduction to this section.

Table C-5 shows the available revenue from the three most relevant programs. NYISO programs offer smaller payments outside of Con Edison territory, as congestion issues are less significant in the rest of the state.[62] Tier 2 networks are those deemed high priority by Con Edison.

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[62] Major changes to Con Edison's DR programs were recently approved that make them significantly more lucrative. All tables and calculations show the new features and rates.

Table C-5. Demand Response Program Value Streams

Program	Revenue Structure	Revenue Rule-of-Thumb	Example Revenue (500 kW/2,000 kWh)
NYISO SCR/ICAP	Reservation payment for kW capacity. Additional revenue based on energy reduction observed during events. Aggregators take between 10%-40% of revenue.	$150/kW/year in NYC $53/kW for winter in NYC $43/kW/year in upstate $15/kW for winter in upstate	$33,750/yr in NYC $9,675/yr upstate
ConEd CSRP	Reservation payment for kW capacity for each month. Additional revenue based on energy reduction observed during events. Bonus dependant on large number of events or unplanned events. Incentive for those who sucessfully complete three years. Aggregators take between 10%-40% of revenue.	$10/kW/month for 4 or fewer events $15/kW/month for 5 or more events $1/kWh during events $6/kWh during unplanned events $10/kW/month for long term participation	$13,275/yr Assuming 1 test event Assuming 2 events
ConEd DLRP	Reservation payment for kW capacity for each month, based on network Tier. Additional revenue based on energy reduction observed during events. Bonus dependant on large number of events or longer event periods. Incentive for those who sucessfully complete three years. Aggregators take between 10%-40% of revenue.	$6/kW/month for Tier 1 Networks $15/kW/month for Tier 2 Networks $2/kW for 7-9 events/month $3/kW for 10 or more events/month $1/kWh during events $6/kWh during extended performance $5/kW/month for long term participation	Tier 1 - $6,975/yr Tier 2 - $17,100/yr Assuming 1 test event

Revenue structures for the three DR programs are calculated similarly and are primarily based off of a capacity reservation payment. Calculation of the revenue stream from the CSRP program is shown below as an example:

$$\begin{aligned} Savings = {} & (Capacity\ \times Participation\ capacity\ \times\ Months\ \times DR\ rate) \\ & + ((Capacity\ \times Participation\ capacity) \times (Test\ events + 4(events))) \end{aligned}$$

Where:

- $Test\ events$ = Number of test events, assumed to be one per year with 1 hour of duration
- $Events$= Number of events called, assumed to be two per year with 4-hour durations
- $Participation\ capacity$= Capacity at which battery can be used for DR, assumed to be 60% of total capacity to account for ACL issues discussed above
- $Capacity$= Installed battery’s capacity, assumed to be 500 kW.
- $Months$= Duration of the program, 5 months
- $DR\ rate$= $/kW/month reservation payment, it is assumed that there will be few enough events to come in at the lower incentive level.

$$Savings = (100\ kW\ \ \times 60\% \times 5\ Months\ \ \times \$10/Month) + \big((500\ kW\ \ \times 60\%) \times \big(1 + 4(2)\big)\big)$$
$$= \$17{,}700/yr$$

Note that the end user would only realize between 60% and 90% of this value as a result of aggregator's fees. One DR program's revenues are not especially large, but customers can aggregate revenue from the three most popular programs. The total is not quite as much as peak clipping, but is still significant.

C.3 Energy-Cost Savings

Energy-cost savings are accrued by reducing supply charges, typically by purchasing off-peak power to offset consumption when prices are higher. Supply charges represent the costs paid to suppliers for the energy that a customer uses. Supply charges vary based on supplier, service classification, rate structure, and energy demand. For Con Edison customers there are two categories of supply charge rate structures, which mirror those offered by other utilities:

- **Standard market supply charges –** For most small commercial Con Edison customers (<500 kW), the market supply charge (MSC) is comprised of the following three components:
    - Energy charge – cost of energy ($/kWh) based upon NYISO market prices
    - Capacity charge – cost of power ($/kW) determined by service classification, rate class, and NYISO market prices; in the relevant rate classes, this charge is converted to a $/kWh charge according to General Rule 25.1, thus excluding it as an opportunity for demand-charge reduction
    - Ancillary service charge – an additional charge ($/kWh) for additional supply services

Customers in this rate structure cannot save money on their energy supply using a battery.

- **Mandatory hourly pricing** – Con Edison's mandatory hourly pricing provision applies to customers with demand greater than 500 kW and is voluntary for everyone else. The energy charge component of the MSC for these customers is derived based on the NYISO day-ahead location-based marginal pricing (LBMP) market for each billing period. A weighted average price is calculated by multiplying the hourly customer load by the corresponding hourly NYISO Day-Ahead LBMP price. LBMP prices fluctuate throughout the day and throughout the year.
    - Customers have the option to choose an energy service company (ESCO) to provide their supply. Con Edison Solutions is the default ESCO for customers, but customers may prefer to go with an alternate company for a variety of reasons. Assuming that prices are indexed to the day-ahead LBMP, the choice of ESCO will not impact the battery-based savings.

- Nighttime, off-peak prices are lower than daytime, peak prices.[63] An analysis of historical data shows great fluctuations across years, seasons, and days. Over the course of last year in New York City, on-peak prices (8 a.m. to 10 p.m.) averaged slightly more than \$0.02/kWh higher than off-peak prices.[64] This difference represents the bare minimum of the true arbitrage opportunity experienced by customer. On any given day, the spread can be much higher: as much as \$0.50/kWh or more. Anecdotally, the Barclay Tower project reported experiencing a \$0.06/kWh spread during the same period by charging and discharging during select hours of the day in order to maximize this spread.

It is imperative for any customer hoping to take advantage of energy-cost arbitrage to move to the hourly pricing supply model because standard MSC do not vary. Whether or not they choose to pursue an ESCO alternative makes much less of a difference.

C.3.1 Estimating Savings from Energy-Cost Arbitrage

By charging the battery when energy is inexpensive at night and discharging during the day, buildings can save money on their energy supply costs through energy-cost arbitrage. Savings will be a function of the difference in prices as well as the roundtrip efficiency of the battery. An example of how to calculate the estimated annual savings.

$$Savings = \left(Discharge\ price - \frac{Charge\ price}{Roundtrip\ efficiency}\right) \times Energy\ shifted \times Annual\ cycles$$

Where:

- $Discharge\ price$ = The average price, in \$/kWh, that would have been paid during discharge periods if not for the battery; this is typically equivalent to the peak price and will represent a weighted average
- $Charge\ price$ = The average price, in \$/kWh, paid while charging the battery
- $Roundtrip\ efficiency$ = The percentage of energy retained through the charge-discharge cycle
- $Energy\ shifted$ = The average energy, in kWh, charged and discharged in a given day; typically this is the total energy capacity of the battery
- $Annual\ cycles$ = The number of charge-discharge cycles during the year

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[63] The difference between peak and off-peak prices is sometimes called the “spark spread.” This is not universal terminology, but it is common enough to be worth noting.

[64] The difference between peak and off-peak was 20%–40% higher in New York City than in the capital region. Further detail on regional variations is provided below.

As previously noted, calculating the actual experienced price differential for a given customer is difficult. For representative purposes, the contractor used last year's LBMP data to calculate:

- The average annual spread between peak and off-peak over the course of the year.
- The spread between the highest and lowest priced hours on each day, averaged over the course of the year.

The average of these two values, net of efficiency losses at an assumed roundtrip efficiency of 83.5%, came out to \$0.024/kWh. Thus, for a 2,000 kWh battery, the expected annual savings are:

$$Savings = \frac{\$0.024}{kWh} \times 2{,}000 \text{ kWh} \times 365 = \$17{,}520\text{/year}$$

Energy-cost arbitrage savings are non-negligible, but they are a less significant value stream than peak clipping or DR.

C.3.2 Other Utility Rate Structures and Charges

The DPS requires that all New York utilities allow customers to solicit supply from an ESCO. As such, all the utilities have some form of hourly pricing rate structure that is similar in nature to the one offered by Con Edison. The biggest determining factor of energy cost arbitrage profitability is thus the spread between peak and off-peak prices experienced by the customer as determined by the regional LBMP. Table C-6 shows regional LBMP spreads for representative areas. Note that all values are \$/kWh and are *not* net of efficiency losses; actual realized revenue per-kWh will be less as a result of efficiency losses.

Table C-6. Regional LBMP Prices

Time Period		NYC	Long Island	Albany	Buffalo
Peak	Winter	\$0.101	\$0.119	\$0.100	\$0.072
	Summer	\$0.059	\$0.084	\$0.049	\$0.047
	Year-round	**\$0.080**	**\$0.101**	**\$0.075**	**\$0.060**
Off	Winter	\$0.059	\$0.065	\$0.063	\$0.040
	Summer	\$0.029	\$0.031	\$0.027	\$0.025
	Year-round	**\$0.044**	**\$0.048**	**\$0.045**	**\$0.032**
Spread		**\$0.036**	**\$0.053**	**\$0.030**	**\$0.027**

The values differ, but not by enough to change the end result, making energy-cost arbitrage a relatively minor value stream.

C.4 Soft Revenues and Avoided Costs from Resiliency

Batteries, like other grid-independent generation sources, can serve as a back-up power system (or a component of one) in the event of a grid outage. The two main instances of this value stream include the following:

- Batteries with short discharge durations can serve as uninterruptible power systems (UPSs), which bridge the gap between the outage and the more long-term generation source (typically a gas-fired generator).
- Large, standalone batteries can serve as the long-term generation source, but their relatively high costs make them a poor alternative to a UPS-generator combination system. Standalone battery backup is so rare that it is effectively irrelevant.

For both of these examples, one fact alone places them outside the scope of this analysis: for a battery to truly serve as back-up power, it must always be full and ready to discharge, which precludes it from performing energy management functions, which are the primary driver of project economics.

Although batteries do not typically serve as full-system back-up power, there are opportunities for energy management batteries to serve, in a managed fashion, as backup to critical loads. Typically speaking, the battery's power capacity will be a fraction (e.g., 20%) of the total building load. Moreover, the discharge duration would allow it to cover that load for less than half of one day. However, by hardwiring certain critical loads, such as elevators, emergency lighting, water pumps, etc., to a dedicated battery-connected circuit, the battery may be able to provide limited support in the event of a predictable outage, such as one caused by inclement weather. Unexpected outages may occur at an inopportune time (e.g., late afternoon after the battery has just fully discharged for DR reasons), but if a storm is forecast, the building could forego peak clipping or DR activities and leave the battery in reserve.

Critical loads will often represent a significant portion of the battery's power capacity; a typical elevator or large water pump motor could be 50 kW alone. The energy management team at the building would have to deploy these loads selectively on a scheduled basis to avoid overloading the battery or damaging equipment, but it is possible to maintain these basic building functions in the event of an extended outage using a standard energy management battery. One vendor also noted that this arrangement could allow tenants to come to the basement and charge their phones.

Dispensing power to critical loads and electronics in a managed way is not the same as running the full building, but could represent a differentiator in a market where finding ways to rent space quickly and decrease vacancy is incredibly important. This is particularly true for residential buildings in lower Manhattan, which were affected by the outage caused by Superstorm Sandy and where the average monthly rental price per is around $55/sq ft.[65] For a building with 500,000 square feet of rentable space, a decrease in average vacancy of just one-tenth of one percent (0.1%) can represent $330,000 in increased revenues annually.

As of yet, no building has implemented such a strategy. However, multiple vendors discussed this strategy as a potential value proposition, one which might provide the sort of intangible value that piques developers' interest.

C.5 Targeted Demand Side Management Revenues

Con Edison's Targeted Demand Side Management (TDSM) program is designed to defer transmission and distribution (T&D) infrastructure upgrades by offering incentives to commercial (daytime peak) and residential (evening peak) customers for energy efficiency measures that result in permanent load reductions. The TDSM program targets specific near-term (less than 5 years) substation load relief needs throughout the Con Edison service area. While the program is not currently accepting project bids, if a new round is launched and an RFP is issued, it is likely that battery storage technologies would be eligible for TDSM incentives. At least one industry expert with experience developing battery projects in New York City identified the TDSM program by name as a potential future revenue source.

C.6 Battery Integration with Renewables

The integration of battery storage capacity with renewable energy generation projects, primarily for wind and solar, is an increasingly common practice that provides important benefits to the grid. The fast response time of batteries presents an attractive pairing with renewables; batteries can provide frequency regulation services and can bridge gaps in production due to the intermittency of renewables, while also time shifting the load to periods of high demand. However, individual customers with renewable generation can use the grid itself to bridge their intermittency gaps, negating the need for batteries to perform this function. The benefits of batteries integrated with renewables are thus primarily relevant at utility scale and are almost entirely accrued to the grid.

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[65] http://www.elliman.com/pdf/ee9140b7b493eaae44ed15375427419e583574f3

Aside from individual projects seeking to achieve net zero energy consumption and function entirely off-the-grid, the primary driver for behind-the-meter batteries, even when integrated with on-site renewable generation, is for energy management functions as outlined in the value streams discussed previously. Integration with renewables, while important, is not a relevant value stream on its own, especially within Con Edison territory where facilities are grid connected and the urban, New York City buildings are less likely to have on-site renewable generation.

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