Stacking Up the Benefits of Storage for New England

A White Paper in Support of Integrating Energy Markets and Public Policy

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ABOUT THIS WHITE PAPER

In August 2016 the New England Power Pool (NEPOOL) held its first meeting in the Integrating Markets and Public Policy (IMAPP) stakeholder discussion. This process intends to explore and propose changes to the New England energy, capacity, and ancillary markets for the purpose of better reconciling them with state-specific public policy goals. Synapse Energy Economics (Synapse) represents several end-users and alternative resource providers in this process. This paper, based on the research and thesis of guest author Sam Hill-Cristol, is a contribution from Synapse to the overall IMAPP discussion. It outlines how battery storage systems located at substations can provide a range of important services for the grid that reduce carbon intensity, increase reliability, and provide savings to consumers. Battery storage systems are successfully operating today elsewhere in the United States and there are substantial opportunities in New England to capture the benefits they can provide.

The study began with a survey of battery storage projects in the United States in order to determine how widespread they were, where they were located, how much they cost, and what services they were providing. From here, the study focused on a few projects that seemed particularly successful and assessed the main drivers behind their development. Through this came the concept of '"revenue stacking," which informs many of this paper's recommendations.

Acknowledgements

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CONTENTS

1. INTRODUCTION

The accelerating development of renewable energy generation in the United States is likely to force massive changes to our electricity systems. Policymakers, regulators, business leaders, and other stakeholders will need to reorganize electricity markets, utility business models, and even the electrical grid itself. The variable nature of renewable resources requires us to rethink a system that is currently based upon dispatchable energy derived from fossil fuels. The New England region is no different, and, in some respects, it is amongst those leading this change. In August 2016, the New England Power Pool (NEPOOL) held the first of several stakeholder meetings intended to reconcile New England's regional electricity markets with its states' public policy goals. To achieve this, the stakeholders involved in this discussion, referred to as Integrating Markets and Public Policy (IMAPP), are investigating and proposing changes to the region's energy, capacity, and ancillary services markets. These changes are intended to incorporate the climate and clean energy goals of public policy into the market framework. Regardless of the outcome of this specific proceeding, IMAPP represents the beginning of a larger, nation-wide trend of re-designing the electricity markets and systems across the country to accommodate and encourage the growth of renewable energy. Battery storage has a pivotal role to play in this transition, but unless it's integrated and valued properly the technology may be unnecessarily held back. This paper explores the services batteries can provide and lays out several market-rule changes that would support the necessary development of battery storage.

1.1. New England Public Policy Landscape

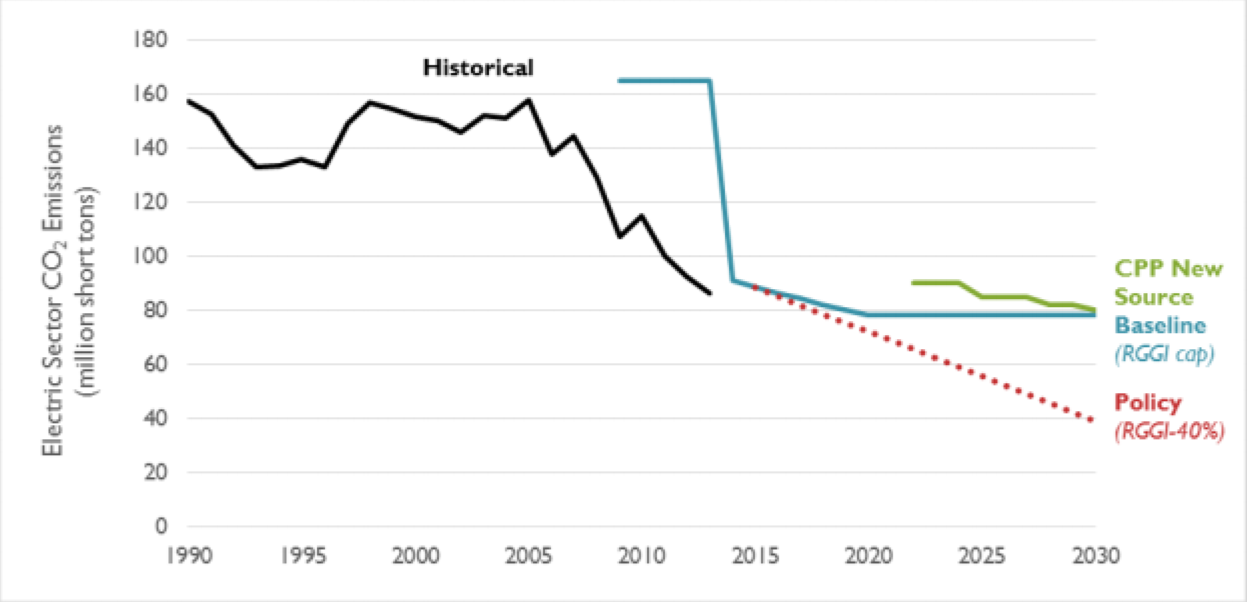
While national efforts to pass or enforce comprehensive climate legislation have stalled or failed, the New England region has committed to emission-reducing measures and targets time and again, setting a national benchmark for regional efforts to address climate change. The efforts undertaken by the six New England states are varied and wide-ranging, touching all industries in the region. However, the electric sector is the second largest historical emitter of carbon in the region, prompting multiple efforts to address and decrease the carbon impact of the electric sector in New England. In addition to signing onto a region-wide governor's mandate to reduce emissions 35–45 percent below 1990 levels by 2030, each of the six New England states has passed public policy directives to reduce the carbon intensity of its energy system and economy as a whole, as seen in Table 1.

Table 1. New England states emissions reduction goals

Carbon Emissions Goals	2030 Target	2050 Target	Stringency	Timeline	Legality
Connecticut	35-45% below 1990	80% below 2001	Mandate	1990 levels in 2010, 10% below 1990 levels in 2020, and 80% below 1990 levels in 2050	Legislation
Maine	35-45% below 1990	75-80% below 2003	Goal	1990 levels in 2010, 10% below 1990 levels in 2020, and 75-80% below 2003 levels in 2050	Statute
Massachusetts	35-45% below 1990	80% below 1990	Mandate	10-25% below 1990 levels by 2020; 80% below 1990 levels by 2050	Statute
New Hampshire	35-45% below 1990	80% below 1990	Goal	20% below 1990 levels by 2025, 80% below 1990 levels by 2050	Recommendation from climate task force
Rhode Island	35-45% below 1990	80% below 1990	Mandate	10% below 1990 levels by 2020, 45% below 1990 levels by 2035, 80% below 1990 levels by 2050	Executive order -> legislation
Vermont	35-45% below 1990	75% below 1990	Goal	25% below 1990 levels in 2012, 50% below 1990 levels by 2028, 75% below 1990 levels by 2050	Legislation

Further, at a regional scale, each New England state participates in the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade program established in 2009 that includes all of the New England states as well as Delaware, New York, and Maryland. It sets a regional carbon emissions budget for the power sector and holds auctions that allow stakeholders to buy and sell permits to meet their emissions levels. The 2017 RGGI review recently concluded and the updated goal is now an additional 30 percent reduction from 2020 levels by 2030.

Figure 1. RGGI states' historical emissions relative to RGGI baseline, Clean Power Plan cap and state public policy reductions



Source: Synapse Energy Economics.

Figure 1 is from the Synapse 2016 report *RGGI 2030: Roadmap for 40 Percent Emission Reductions in RGGI States*, which detailed the least-cost methods for reducing carbon emissions in states participating in RGGI to 40 percent below 1990 levels by 2030. It shows historical emissions for RGGI states in comparison with emissions levels required under the RGGI cap, the Clean Power Plan (CPP), and the emissions required to achieve the stated goal of "RGGI-40%." In the context of this report, this figure illustrates that, while RGGI and its subsequent reviews represent a significant step in emission reduction legislation, it is only a single component of the public policy landscape in New England that includes other policies needed to achieve more substantial emissions reductions.

Additionally, every state has legislation establishing a Renewable Portfolio Standard (RPS), requiring a certain percentage of the state electrical load to be served by renewable energy sources. Table 2Table 1illustrates each state's current RPS goal, interim schedule, final goal and, importantly, the primary renewable resources that are eligible to satisfy the RPS.

Table 2. New England state renewable portfolio standards

State	Current	Interim Targets or Rate of increase	Final Goal	Resources	Notes
Massachusetts	9%	Increasing 1% per year		Wind, hydro, solar	Massachusetts' RPS explicitly requires the development of offshore wind.
Connecticut	21%	1.5% per year	27% by 2020 (20% Class I resources, 3% Class II and 4% Class III)	Class I (new wind, solar, run-of-river hydro) Class II (trash incineration, biomass) Class III (combined heat and power)	
Maine	30% (currently satisfied)	10% new Class I resources (wind and solar) by 2017	40% by 2017	Class I (new resources) Class II (existing resources)	The 40% goal is artificially high because it includes considerable existing hydro resources.
Rhode Island	10%	Increasing 1.5% per year	38.5% by 2035	Wind, solar, tidal energy, geothermal, small hydro	
New Hampshire	9.2%	20% by 2020	25% by 2025	Class I (new wind, methane, tidal energy, geothermal) Class II (new solar) Class III (Existing biomass) Class IV (existing hydro)	New Hampshire's RPS is delineated explicitly between many different types of resources.
Vermont	55%	Increasing 4% every 3 years	75% by 2032	Wind, solar, hydro, geothermal, biomass resources if the fuel is sourced from waste	

In August 2016, Massachusetts passed an energy bill entitled *An Act Concerning Energy Diversity,* which requires utilities to procure 1,200 MW of clean energy resources in the form of new hydro imports from Canada plus in-state wind and solar and an additional 1,600 MW of offshore wind. These procurements are "out of market" requirements. Utilities are required to procure electricity from these resources regardless of whether or not price signals from the capacity market indicate that it would be the lowest cost solution. These resources have the potential to increase consumer costs above what they would have otherwise been, had the utilities procured electricity only with respect to market signals.

From a public policy perspective, there is a clear focus on carbon emissions reductions in New England, despite the possible higher costs. The region has committed to these reductions irrespective of capacity market pricing signals. The overwhelming support for public policy goals focused on clean energy creates a conflict with the current wholesale market structures that claim to be fuel neutral, but are designed to accommodate new gas-fired generators. The IMAPP process seeks to address this conflict.

1.2. Current Market Status

The Independent System Operator of New England (ISO-NE) runs the Forward Capacity Market (FCM) in New England. To ensure a reliable system, ISO-NE procures enough generating capacity to meet future demand. If the current regional resource mix will be insufficient to cover system needs in the future, the FCM provides price signals to prompt development of potential new generation. The primary auctions are held three years ahead of when the electricity will be delivered, in order to give new resource providers enough time to build their generation facilities. The auctions are intended to foster competition amongst resources and provide customers with the least-expensive resource mix that will still ensure a reliable system. While the FCM allows for participation of traditional fossil-fired generators, renewable resources, energy efficiency, and demand response resources, it does not include any direct consideration of public policies that require carbon reductions or the development of renewable energy. Current market structures are ostensibly fuel neutral, but the price signals provided by the FCM are set based on net cost of new entry (CONE) figures. Net CONE is calculated using a reference unit that is either a new combined cycle gas turbine or a new single cycle gas turbine, depending on the current market conditions. In either case, net CONE is not based on new wind, solar, or storage units. Important market parameters are intentionally set to attract new fossil fuel generation, thereby establishing a market system that hinders the achievement of public policy goals from New England states that focus on specific, non-fossil, resource types.

The carbon intensity of electricity generation from natural gas, while generally about half that of generation from coal plants, is not low enough to meet states' carbon reduction goals on its own. Rather, the region will need to develop more renewable sources of generation to achieve the deep emission reductions called for by every New England state. To date, however, the FCM has not adequately procured the renewable energy required to achieve the level of greenhouse gas emissions required under public policy goals.

The proliferation of RPS policies is another indication that the FCM is not providing adequate incentives to build the renewable generation needed to meet state carbon emissions reduction policy goals. An

RPS is a policy instrument used to directly stimulate development and build renewable energy projects. Emissions goals only stimulate development of renewable energy projects indirectly, if at all. If the FCM resulted in enough renewable energy to satisfy the states, there would be no need for the RPS policies.

ISO-NE also operates energy and ancillary service markets to procure the daily and hourly generation, reserves, and regulation necessary to ensure smooth operation of the region-wide electric grid. However, these markets make no effort to incentivize the types of generation required by state policy goals. Although each New England state clearly places an emphasis on electricity generated from renewable resources, current energy market designs do not provide sufficient incentives for renewable resources in the energy market. Further, reserve and regulation requirements—the two primary services procured through ancillary service markets—are established based upon the current resource mix on the grid. This bases regulation and reserve requirements for maintaining reliability upon the inflexibility of large, old generators with long lead times to start and slow ramp speeds. It places less emphasis on the fast-response resources (such as storage) required to maintain reliability on a system that includes many newer, more flexible, and variable renewable energy resources.

In this way, the markets are not currently aligned with region-wide, and state-specific public policy. IMAPP is an exploration of methods to bridge this gap and create forward-looking energy markets that work in tandem with public policy.

1.3. IMAPP Proposals

Throughout the first few IMAPP stakeholder meetings, various stakeholders in the NEPOOL process presented proposals that they believe would better integrate markets with public policies. These proposals fall roughly into three categories: creating a Forward Clean Energy Market (FCEM); incorporating a carbon price/adder into the market; and other miscellaneous proposals. Table 3, Table 4 and Table 5 outline the specific proposals included in each category.

Table 3. Initial IMAPP proposals: Forward Clean Energy Market

Forward Clean Energy Market	
Organization	**Proposal**
National Grid	**Forward Clean Energy Market (FCEM):** Clean energy could be procured 3.5 years in advance through an ISO-NE competitive auction. Charges from Load Serving Entities (LSEs) are collected when energy is provided. Payments/charges are governed under FERC tariff. *Note: National Grid proposed a Forward Renewable Capacity Market in 2011; this new program is essentially the same but it could include hydro and nuclear.*
NRG	**First Proposal:** Two-tiered pricing mechanism in current Forward Capacity Market. This would maintain existing resources and build new fossil resources. Renewables would be financed through second proposal. **Second Proposal:** A 3-year forward market for renewable attributes (defined by each state as close to uniform as possible) that has 10- to 20-year fixed prices for new resources.
NextEra	**An FCEM distinct and in addition to the existing markets:** All clean energy sources (including nuclear) are eligible. Payments are monthly and tied to MWh performance, meaning it would be better for nuclear. A carbon adder would work in this approach—nothing in the FCEM prevents it, but with existing clean energy policy and the FCEM a carbon price would be unnecessary.
RENEW[22]	**Principles:** Long-term time periods are key with regard to contracts and financing. An ISO mechanism to ensure long-term revenue would complement state-mandated Power Purchase Agreements (PPAs). **Possible Reforms:** Competitive market for long-term contracts between ISO and chosen resources. Another possible reform is long-term commitments that cover annual revenue requirements (assuming production is met)—essentially using market to simulate long-term contracts.
FirstLight	FirstLight proposed an FCEM as well, with one difference. It proposed to have multiple commodities in market, off-peak, midday and late-day peak. It also highlighted the need for storage. It noted that a Carbon Shadow Price (CSP) might not be sufficient to meet carbon goals and the FCEM offers “price discovery for the cost of carbon used in a CSP design.” The CSP model alone does not account for carbon intense baseload generation.

Table 4. Initial IMAPP proposals: carbon price

Carbon Price	
Organization	**Proposal**
Conservation Law Foundation (CLF)	CLF has a two-part solution consisting of changes to both the energy and the capacity markets. The first part is a real carbon price that affects Local Marginal Prices (LMP). Revenue from the price is collected by the ISO and returned to load through the Load Serving Entities (LSEs). The second part of the proposal is two, sequentially clearing capacity markets, with the first being for a newly established Zero Emission Credit (ZEC) market for *new* non-emitting resources and the second being the current capacity market. Resources that clear the ZEC market are obligated to clear the traditional market or they will lose their ZEC revenue. This ensures that ratepayers do not "pay twice" for the same non-emitting resource.
Acadia Institute	Acadia proposed strengthening RGGI as a starting point because of the appeal of market-based, flexible appeal of a cap and invest carbon-pricing system. The goals of IMAPP can be achieved simply by strengthening RGGI.
Exelon	A price on carbon in the real wholesale market will enable states to meet policy goals, while attracting new and retaining existing zero emissions sources (possible nuclear subsidies). A carbon price would also recognize the benefit of low carbon gas. A phase-in period where existing clean energy incentives continue may be needed. Suggested starting price was the social cost of carbon, or $42/ton.

Table 5. Initial IMAPP proposals: miscellaneous

Miscellaneous	
Organization	**Proposal**
Public Power (Municipalities)	**Improvements to existing market:** Revisit multiple pricing tiers in the Forward Capacity Market (FCM). Use "Texas-style" energy market with an operating demand curve. Impose substantially higher carbon price. **New Proposal:** Institute a Voluntary-Residual Market Structure. Consumers/States procure power voluntarily, and the ISO makes up residual needs to meet reliability standards.
High Liner Foods	**Proposal for existing zero emissions generator (primarily nuclear) subsidies**: Plants awarded payment for operating costs minus revenues. Generators give back subsidy as energy prices increase. Payments would be established through ISO-NE in deals lasting 3-7 years.
Environmental Defense Fund (EDF)	**Proposal on how to harmonize the gas and electric wholesale markets**: EDF identified need for prices and trends in each market to send strong signals to the other market. It wants to financially reward existing gas pipeline operators for their ability to flow gas at key times, rather than just for building additional capacity. If natural gas plants are the key bridge to integrating more renewables, rewarding gas pipeline operators for their ability to deliver gas when needed will give them incentives to innovate towards that end.

At the initial IMAPP stakeholder meeting, Synapse presented three specific topics for further review that could potentially alleviate the inconsistencies between markets and public policies:

1. A carbon price in dispatch
2. Long-term power purchase agreements for generators that meet public policy needs
3. Integrating battery storage at substations

The initial two proposals are similar to proposals by other stakeholders and, as a result, have been more fleshed out in NEPOOL discussions and written documents. However, the proposal to incentivize and install storage at substations across the grid in order to better align how markets are able to operate and integrate public policy demands is uniquely Synapse's.

This report discusses the considerable benefits that battery storage provides to the grid. It then outlines possible market design changes that will catalyze battery development, allowing the region to capture these benefits. Specifically, it discusses the scenario of placing battery storage systems at utility substations, drawing upon examples from elsewhere in the country where storage installations are operational. These case studies illustrate why utility substations are ideal sites to locate utility-scale battery storage. Importantly, the policy proposals outlined in this report are intended to complement, not replace, the proposals presented throughout the IMAPP process by other stakeholders.

1.4. The Role of Storage

Battery storage systems are unique because they can act both as electricity supply resources and as electricity demand resources. When the battery system charges, it functions as a demand resource; when the battery system discharges, it acts as a supply resource. Although a battery can shift load on the system and provide some regulation on the system while charging, a battery's main benefits to the electrical grid arise when the system is acting as a supply resource. When a battery acts as a supply resource, it can provide four distinct benefits to the grid:

- **Capacity**—the ability to produce electricity.
- **Energy**—putting electricity onto the grid, the same as any generation resource in ISO-NE.
- **Reserves**—as a resource that can be dispatched quickly, a battery can function as a reserve resource: it can maintain a charge in case something else on the system fails or can no longer function, and it can respond quickly and provide energy to the system until the problem is fixed.
- **Regulation**—automatically responding to changes in the frequency of the electrical system second-to-second, maintaining the reliability of the system (regulation service can be provided both while discharging and charging).

Placing battery storage systems at substations throughout the ISO-NE system is particularly advantageous because it allows for many co-benefits beyond the four operational benefits listed above. For instance, when a storage resource is fully (or even partially) charged, it can offset the need for other, more expensive forms of capacity. With enough storage facilities on the grid, the ISO could offset the need for whole power plants—either by avoiding a new fossil-fired unit, or by allowing an older, higher-emitting unit to retire. Further, by charging in hours when wind and solar are producing excess energy, a battery can store this clean energy for a later period when that energy could offset the need for generation from a fossil-fired unit.

As a result, placing battery storage systems at substations throughout ISO-NE would help meet broader objectives of the IMAPP process, such as integration of large-scale renewables, deferral of transmission and distribution upgrade costs, congestion relief, and reserve capacity. Locating battery storage systems at substations greatly expands the capabilities of both the electric grid and battery system with the potential to generate savings for electrical consumers, increase grid reliability and flexibility, and concurrently reduce carbon emissions in the energy sector. In light of this, it is clear that battery storage development has an important role to play for New England's integrated electric grid.

2. TYPES OF STORAGE

While Synapse has chosen to focus this report on battery storage specifically, electricity storage technologies vary widely and the type of technology drives the services that a particular storage system can provide. Storage technologies that can provide small amounts of *power* with a quick response time, for example, are best suited for frequency regulation. Storage technologies that can provide larger amounts of *energy* over a long period of time, but may have a slower response time, are best suited to act as a capacity supply resource. Flywheel storage systems exist on one end of this spectrum: they are capable of providing quick frequency regulation through mechanical processes. And pumped hydro systems sit on the other end: they are capable of providing long-term energy generation through the stored potential energy from hydropower. Depending on their size and capabilities, battery storage systems exist somewhere in the middle. Table 6 defines the major types of storage systems that currently exist in the market. Table 7 provides an overview of their primary uses, lifespans, and their comparative advantages and disadvantages.

Table 6. Storage technology descriptions

Storage Type	Description
Flywheel	Flywheels store mechanical energy by rotating at high speeds. They provide quick bursts of energy at a high power rating when they are decelerated.
Compressed Air (CAES)	CAES systems store energy as air forced into underground geological formations that can store air under high pressure. The compressed air is released and converted to electricity by powering a generator similar to a natural gas turbine.
Flow Battery	Flow batteries consist of two electrolyte solutions separated into different tanks. When the battery is connected to a load, electrons flow between the two solutions creating an electrical current.
Battery (various chemistries)	These are traditional battery types most commonly used in utility scale storage systems, consisting of various chemistries such as lead-acid, lithium ion, zinc, and sodium. Generally, these batteries function as the chemical reactions within the battery create a build-up of electrons, which is then released as a current when the battery is connected to a load. All of the storage project case studies in this report describe installations of this type of storage.
Pumped Hydro	Pumped hydro is a system of two reservoirs at different elevations. Water is pumped into the higher reservoirs during times when electricity is inexpensive and then is released into the lower reservoir when electricity is expensive. The water spins turbines similar to those used in a traditional hydropower plant.

Table 7. Storage technology comparison

Storage Type	Use	Life time	Advantages	Disadvantages
Flywheel	Frequency regulation	20+ years	• High power and quick discharge capability	• Relatively low energy density • Generates large amounts of heat during operation
Compressed Air	Transmission system replacement	15-20 years	• Uses existing gas turbine technology • Well-established technology • Relatively large scale	• Relatively inefficient • Requires specific, suitable geology
Flow Battery	Capacity, distribution services, renewables integration	15-20 years	• Storage capacity does not degrade over time • Power and energy capabilities are independently and highly scalable	• Less mature technology • Relatively expensive system costs
Battery (various chemistries)	Capacity, frequency regulation, renewable integration, transmission system replacement, distribution services	5-15 years	• Well established technology with multiple chemistries for different use cases • A flexible range of costs • Highly scalable enabling them to provide different services	• Highly efficient chemistries are still relatively high cost • Cheaper chemistries can lack in energy density or life span • Some chemistries operate at high temperatures raising safety concerns
Pumped Hydro	Capacity	20+ years	High power capacity • Mature technology (utilizes existing hydro technology) that is integrated into the grid	• Limited suitable sites because water availability is required • Low energy density

While pumped hydro still accounts for the majority of storage capacity in the United States, battery storage systems are gradually becoming the dominant storage technology in new installations because of the maturity of the technology, the scalability of the resource, the flexibility of types of batteries within the technology and the rapidly falling costs of new resources. Unlike pumped hydro or compressed air storage, battery storage does not require specific geology and thus can be located wherever it is needed. The most important characteristic of battery storage is its ability to be scaled up or down to the necessary size, unlike pumped hydro or compressed air storage. For instance, while pumped hydro is only suitable for large-scale capacity and flywheels are only suitable for frequency regulation, batteries can be scaled up to provide capacity, scaled down to provide frequency regulation or scaled somewhere in between to provide any number of services. For these reasons, this paper focuses only on the development of battery storage systems.

3. SUMMARY OF EXISTING BATTERY STORAGE PROJECTS

While the storage industry lags behind that of other clean energy technologies such as wind and solar, there is substantial recent development throughout the country, particularly in the Pennsylvania-Jersey-Maryland (PJM) regional transmission operator service area and in California. Despite the region-wide commitment to renewable energy in New England, energy storage is not widespread here. Massachusetts is the only state that includes storage in its public policy and the largest grid-connected utility scale battery storage system in New England is a 2 MW project currently under construction in Sterling, Massachusetts. Beyond this, there are two small projects in Vermont and two in Maine. Thus, we must look to regions beyond New England to illustrate the services that battery storage can provide to the grid.

Additionally, it is important to consider that storage development varies across states and regions due primarily to public policy and market-based factors. State policy and regional transmission operator (RTO) market design have large impacts on the economic viability of location-specific storage development. We examine these mechanisms briefly in this section and more fully in the case studies.

3.1. Distribution of Projects

There are currently 116 grid-tied utility-scale (rated power of 500 kW or larger) battery storage systems operational in the United States. Of those in RTO service areas, 29 projects are located in CAISO, 26 in PJM, five in New York, three in ISO-NE, four in Texas, four in the Mid-continent Independent System Operator (MISO) service area, and three in the Southwest Power Pool (SPP). The remaining projects are not in RTO control areas but are scattered throughout the United States, with clusters in Washington and the Southwest. The projects range in size from 500 kW to 36 MW. Lithium-ion is the dominant battery chemistry, with over 50 percent of the current total battery storage projects utilizing this technology. Notably, it was the chosen battery chemistry for 99 percent (by MW) of grid-tied storage capacity deployed in 2016. The projects are fairly evenly distributed across three distinct ownership models: customer-owned, utility-owned, or third-party ownership such as merchant storage projects owned by developers or investors.

3.2. System Costs

When thinking about system costs, it is important to recognize that cost estimates and predictions will vary based upon several factors: the use case, battery chemistry, and key assumptions made in the estimation process. Overall, the prevailing belief is that battery storage system costs are falling rapidly and will continue to do so in the next five years and beyond. Generally, capital expenditures are confidential for battery storage projects, but for projects with data available the total project costs ranged widely from $1.1 million to $68 million, with a median cost of about $6.1 million. Given the variation, it is much more useful to examine costs on a per kilowatt-hour (kWh) basis. In 2014, estimates for the current cost of a four-hour battery system were 720–2,800 $/kWh. The battery itself cost 500–700 $/kWh, with the rest of these costs due to system installation. Another estimate from the same year, but for various battery chemistries put lead-acid at 150–500 $/kWh, lithium-ion at 500–1500 $/kWh, and sodium-sulfur at 125–250 $/kWh. That same year, Brattle Group forecasts put battery system costs at ~350 $/kWh by 2020. Morgan Stanley estimated that battery-only costs would fall to 125–150 $/kWh by 2020, which is consistent with the Brattle Group's estimates for total system costs. These projections are proving accurate, with Lazard putting the low end of capital costs for lithium-ion systems at 422 $/kWh in 2015.

3.3. Development Patterns

CAISO and PJM are the regions that have supported the most storage development in the United States. Combined, they are responsible for 82 percent of storage projects deployed since 2013. This is due to two factors; an attractive fast-response frequency regulation market in PJM and a resolution by California Public Utilities Commission (CPUC), expanding California state bill AB-2514 to require the California utilities to procure 1,325 MW of storage by 2020.

In response to Federal Energy Regulatory Committee (FERC) order 755, which required RTOs to remedy compensation models for frequency regulation to fairly reward fast-response regulation resources such as battery storage systems, PJM established a so-called "RegD" fast responding frequency regulation market. This sparked an influx of storage projects in the region, so much so that in April 2015 PJM temporarily suspended the RegD market in order to study the market effects of high levels of storage on the system before re-opening the RegD market.

While the RegD market in PJM created a strong market opportunity for energy storage, California's legislation created a direct mandate for energy storage procurement that sparked development. Southern California Edison has already contracted with AES Energy Storage for a 100 MW project that is expected to grow to 300 MW, which would make it the largest in the country. In May 2016, the California Public Utilities Commission adopted a second resolution expediting the procurement of some of this storage because of reliability concerns relating to the retirement of the Aliso Canyon Gas Facility. This resolution resulted in at least five additional projects being contracted by Southern California Edison and San Diego Gas & Electric.

The levelized cost of battery storage is falling, and it is projected to continue falling to economically attractive levels in many states by 2021. But until that point any significant penetration of storage into the grid will rely on public policy or specific market design and opportunities. And as the above examples from PJM and CAISO imply, a slight market incentive may be enough to begin to incentivize significant development of these resources.

4. SUBSTATION SITE ADVANTAGES

As battery storage development grows in New England, it will be important for this development to be carried out efficiently and in a way that is most beneficial to the region’s electrical grid, economy, and ratepayers. This section outlines the myriad services that battery storage can provide to the region, discusses the amount of value associated with these services, and details how locating battery storage projects at substations enables the capture of all of these benefits.

The IMAPP process is concerned only with possible changes to align energy and capacity markets with public policy at a regional level. Thus, front-of-the-meter applications for storage are most applicable to the process. Locating batteries at utility substations will allow the New England energy system, and by extension its ratepayers, to capture the most value and have the best return on investment from battery storage development. Batteries located at utility substations can capture all of the benefits at the ISO/RTO level *and* at the utility level of the electric system. The case study from Minster, Ohio, for example, provides frequency regulation at the ISO/RTO level while also providing power factor correction and peak shaving benefits at the utility level.

In addition, deferral of transmission and distribution upgrade costs, one of the most significant value adds provided by battery systems, is only available if the battery system is located at a utility substation. We discuss the value of these services in Section 4.2 and, while the exact value of these services varies, examples from elsewhere in the United States suggest that it could be quite high.

The frequency regulation market change and resulting development in PJM, discussed in Section 3.3, is an example of the limits that exist when battery storage systems are only able to provide one service. When PJM expanded its market design to reward fast-responding regulation, it sparked rapid development. An early actor, Invenergy, entered the market in 2012. According to Maggie Pakula, the commercial analytics manager at Invenergy, by 2015 the RegD market became saturated and all of the market opportunities from frequency regulation disappeared. If these projects had been located at substations, they would not have been as limited by the size of the frequency regulation market in PJM. Instead, they could have captured multiple revenue streams and avoided dependence on a single stream from frequency regulation. More development could have been achieved, yielding more benefits for PJM ratepayers.

4.1. Revenue Stacking

In the absence of the rare specific market or policy incentive, utility scale battery storage development requires revenue stacking to be economically viable. Revenue stacking is a development strategy where a battery system is designed to receive multiple revenue streams to make it profitable. It does this by taking advantage of the flexible nature of a single battery system to provide multiple sources of revenue to the system owner. This development strategy can make otherwise unrealistic projects cost-effective by increasing revenue gained, as well as by decreasing revenue lost due to opportunity cost. Batteries used for a single service are often underutilized, leaving the battery system idle for much of its useful life. A system providing multiple services, and thus receiving multiple revenues, will be idle less frequently. This will lead to a better overall return on investment.

The idea of revenue stacking can be expanded beyond direct streams of revenue flowing to the owner of a given battery system, to services provided that add value for the owner or to the grid indirectly. For instance, beyond revenues from the energy, capacity, and ancillary services markets, a battery can generate several additional benefits. If appropriately valued and compensated, these benefits would improve the overall economics of a storage system. This is particularly applicable to a system located at a substation.

In a 2015 study, the Rocky Mountain Institute identified 13 services that battery systems can provide that add value to the grid. Table 8 outlines those various services; what they are and at what part of the grid they are applicable. Many of these services have been discussed earlier in this paper, but presenting them here concisely will inform the discussion of revenue stacking, grid services, and possibly market design changes to further storage development.

Table 8. Battery storage system grid services

Service	Service Level	Description
Energy Arbitrage	ISO/RTO	Energy arbitrage is the practice of charging a battery when electricity is cheap and selling the energy when electricity is more expensive, thus creating a profit.
Spinning/Non-Spinning Reserves	ISO/RTO	Spinning reserve is reserve capacity that is online and being used to maintain system stability during unexpected demand changes or emergency situations. Non-spinning reserve is the same capacity when it is offline, or coming from an alternative source.
Black Start	ISO/RTO	Black start is the act of restoring power to a substation or grid after a blackout without the assistance of the larger transmission network.
Frequency Regulation	ISO/RTO	Frequency regulation is the provision of short-term power that helps maintain the ideal operating frequency of the grid at 60 Hz.
Voltage Regulation	ISO/RTO	Similar to frequency regulation, voltage regulation provides short-term power in order to maintain a consistent voltage on a power line.

Service	Service Level	Description
Flexible Capacity/Resource Adequacy/Peak Shaving	ISO/RTO or Utility	This service refers to when a battery storage system is treated as capacity similar to any other power plant, and supplies energy to the grid to meet demand. Peak shaving refers to the specific instances where a system is charged during low demand times and discharged during times of peak demand, in order to reduce the need for newly generated electricity. These systems generally have a higher nameplate capacity and longer duration than one being used only for frequency regulation.
Renewable Integration Assistance	ISO/RTO or Utility	A battery system can smooth the output from renewable energy sources, reducing wear and tear on a substation transformer.
Transmission Cost Deferral/ Distribution Cost Deferral	Utility	A battery system allows utilities to avoid the cost of transmission upgrades in a certain part of the grid that result from large interconnection requests. A battery system allows utilities to avoid the cost of distribution upgrades in a particular neighborhood or at a particular substation, at least until there is sufficient demand beyond a few peak times each year, to truly warrant those upgrades.
Congestion Relief	Utility	A battery system provides an outlet for excess energy that would otherwise create congestion in the electricity grid, resulting in higher prices.
Power Factor Correction	Utility	A power factor is the ratio of the real power of a circuit to the apparent power. Power factor correction is needed when an electrical system is supporting a load with a low power factor (most commonly an industrial customer). A low power factor means that a larger amount of current is needed to transfer the same amount of power. Larger current requires system upgrades to maintain safety and reliability. Power factor correction helps to avoid this situation.
Time-Of-Use Cost Savings	Residential/ Commercial (Behind the meter)	In places where residential or commercial ratepayers are charged more for using electricity at certain times, a battery storage system can help avoid these costs by providing energy during times when prices are high.
Back-Up Power/Islanding	Residential/ Commercial (Behind the meter)	A battery storage system can provide back-up power during blackouts or in times of emergency. A large enough storage system can serve to isolate an entire section of the grid, independent of the larger system.
Increased PV Self-Consumption	Residential/ Commercial (Behind the meter)	A battery storage system allows a residence or business with a rooftop solar installation to consume more of the power they generate by storing it, instead of having to put it back on the grid.

Table 8 illustrates the wide array of value adding services that a battery storage system can provide to the grid. As discussed above, these services vary between being direct revenue streams (i.e., flexible capacity or frequency) and indirect value adds (i.e. distribution cost deferral). The indirect value added is likely a substantial revenue stream and is primarily available at the utility service level. The specific proposal of locating battery storage systems at substations allows benefits at multiple levels of the electricity system to be captured, thus allowing the substantial indirect benefits discussed above to be captured as well.

4.2. Amount of Value Added

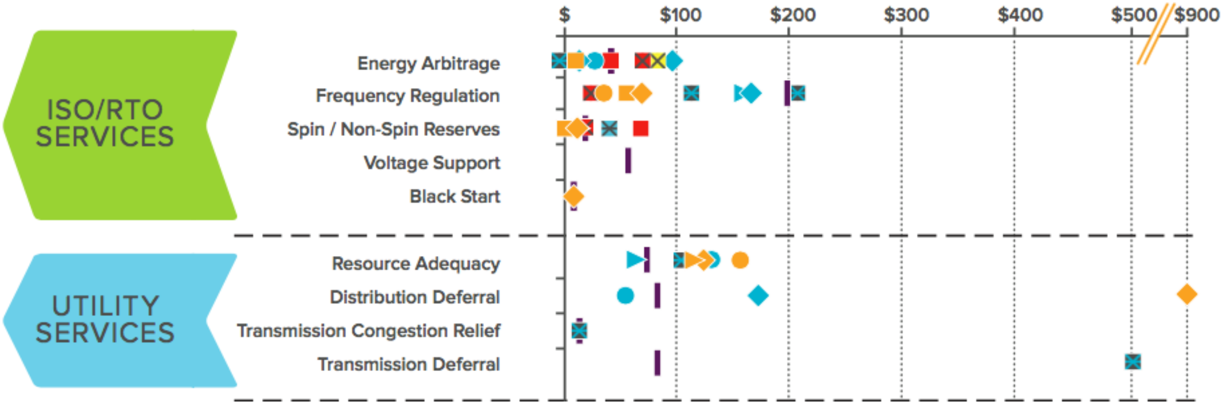
Similar to the cost estimates presented earlier, estimates of the value added to the grid by battery storage systems vary depending on many factors. These include use case, location, year, and key modeling assumptions such as fossil fuel prices and battery efficiency. The following table presents a sampling of industry studies calculating estimates for the value of battery storage systems on the grid.

Table 9. Service value of battery storage systems

Modeling Entity	Services Provided in Model	Value ($/kw-yr)	Revenue Stacking Scenario
Sandia National Laboratory	Energy	35.9–71	No
Sandia National Laboratory	Spinning Reserve	5.7–22.5	No
Sandia National Laboratory	Regulation	78.5–201	No
Sandia National Laboratory	Transmission and Distribution Cost Deferral	75.9–107.9	No
National Renewable Energy Laboratory	Spinning reserve, Energy, Regulation	114.5–127.7	Yes
National Renewable Energy Laboratory	Spinning reserve, Energy, Regulation (restricted case)	54.0–63.4	Yes
Sandia National Laboratory	Energy and regulation	117–161	Yes

Figure 2 shows the service value for battery storage systems used for various services at the ISO/RTO level and the utility level, including many of the studies presented in Table 9 as well as some additional data from in-house Rocky Mountain Institute analyses.

Figure 2. Service value of battery storage systems



Source: Rocky Mountain Institute. Values in $/kW-yr. Note: the break in the x-axis demonstrates just how big of a potential benefit Distribution Deferral can be to the system, especially for first-movers.

Finally, a recent analysis of the potential for storage deployment in Massachusetts found that large-scale deployment of storage (600 MW system-wide) has the potential to bring $800 million in benefits to the state's ratepayers. This modeling effort identified possible substations and locations for battery storage systems, optimized the size of these systems, and used a cost-benefit analysis to quantify the benefits of the optimal amount of storage development. The $800 million in potential benefits are likely the most important to consider in the context of IMAPP given its timeliness and specificity to the New England region.

5. CURRENT TREATMENT OF STORAGE IN ISO-NE

In March 2016, ISO-NE released a memo detailing the ways in which storage could participate in the wholesale electricity markets in New England. It mentioned the unique ability of storage to act as load, generation, or both. However, there is currently no market structure in ISO-NE designed to address and compensate storage systems that act as load and generation at the same time. Instead, storage assets must participate in the markets as two separate assets, one when it is acting as load and another when it is acting as generation. While such a framework is appropriate for pumped-hydro storage assets, as there is a small delay when the resource is transitioning between generation and load, it fails to capture the unique advantage of battery storage systems: their ability to respond immediately to dispatch signals and transition between generation and load.

The memo states that batteries can participate in all three of ISO-NE's main markets: the energy market, the forward capacity market, and the ancillary service market (which includes the locational forward reserve market, real time reserve market, and the regulation market). The memo implies that, with the exception of the ancillary services market, battery storage systems would act as any other asset. In other words, they would participate in the markets under the current rules used by all other assets, including the interconnection and transmission processes. In light of the binary treatment of battery storage systems detailed above, it is not clear how this would be done in practice. If a single storage system functions as two separate systems with regards to the markets, depending on whether it is acting as load or generation, battery developers and operators would need more information on how that process would occur. Presumably, a method would be needed to tie together a single battery system being treated as two separate projects as it moves through the auction, interconnection, and dispatch processes. A method would also be needed to determine how to compensate a single system providing multiple services at different times.

The only instance in which battery storage systems are treated as unique resources is in the Alternative Technology Regulation Resource (ATRR) program. Created in response to FERC Order 755, ATRR is a designation for batteries participating exclusively in the frequency regulation market. This market recognizes a battery's ability to respond more quickly and accurately to frequency regulation signals than traditional resources, and it rewards storage resources accordingly by allowing them to realize increased compensation. Systems must be at least 1 MW to participate, but there is no limit on how many ATRRs can participate in the frequency market.

However, as mentioned above, a battery system can only receive an ATRR designation if it is participating *solely* in the frequency regulation market. This places a limit on the services that an ATRR can provide. For example, an ATRR-designated battery system cannot provide both dispatchable generation and frequency regulation. In the context of revenue stacking, this limitation decreases both the likelihood that the project will be economically viable and the value that the battery can provide to the electrical grid.

There are important changes planned to address these shortcomings in the treatment of battery storage. On December 1, 2018, ISO-NE plans to adjust and expand the treatment of ATRR-designated resources. ATRR resources will be treated as a dispatchable generator (currently they are deemed non-dispatchable) that can provide reserves and set prices in the energy market. This will create economically attractive revenue stacking opportunities for battery storage system owners. A single system, for example, will be able to act as a generator while also being properly compensated for the regulation services it can provide. ISO-NE noted that the details are yet to be worked out. Thus, while these changes are likely to improve the development climate for storage projects, it is important that ISO-NE execute the changes in a manner that will make the concept behind the change a reality.

As currently designed, however, the wholesale electricity markets in New England do not provide effective pathways for battery storage systems to participate. The small number of battery storage systems that exist in the region is proof of this. We can identify two major shortcomings. First, as battery storage is a new resource for New England's markets, ISO-NE has yet to clearly define the pathways for participation for battery storage systems. Second, the pathways for participation currently in place are not designed to fully realize the multiple benefits available from a battery storage system. The following market design recommendations begin to address these concerns.

6. MARKET DESIGN RECOMMENDATIONS

As part of the IMAPP process, it is necessary to recommend changes to the ISO market design that will provide incentives and opportunities for revenue stacking. This will allow the region to realize the full benefits of grid-wide battery deployment. Revenue stacking and the ability of battery storage systems to provide multiple services to the grid will maximize the net benefits of storage deployment while minimizing inefficiencies. This paper provides a suite of recommendations that, taken together, can catalyze substantial storage development in New England.

The IMAPP stakeholder process described in the introduction has been underway since August 2016, and thus it is also important to frame these market design recommendations, where appropriate, within proposals already put forth by other stakeholders.

6.1. Recommendation 1: Establish a market classification for battery storage technologies

As noted above, a primary challenge for battery storage systems is their treatment as two separate resources, depending on how they are acting. To remedy this, ISO-NE should adopt a separate classification for battery storage systems (and likely other advanced storage systems such as flywheels).

ISO-NE's treatment of demand resources is a successful example of the classification of a non-traditional resource. Demand resources help to maintain system reliability by reducing the demand for electricity. ISO-NE created their first demand resources programs in 2001 and the asset class has been fully incorporated in the FCM since 2010. Active demand resources, or demand response resources, are currently being integrated into the energy markets and will be eligible to fully participate in 2018.

Another successful example of this technique, specific to storage, is demonstrated by CAISO. CAISO classifies advanced storage systems as non-generation resources (NGR). NGRs can participate in all of CAISO's daily markets—energy, ancillary services, and reserves. The minimum capacity requirement for participating storage resources in CAISO is 0.5 MW. To participate in these markets, NGRs must follow the bid requirements for whichever market in which they intend to participate on a given day. These requirements include continuous energy duration requirements for participation in the regulation and reserve markets. They also include a "state of charge" update to inform CAISO of the operating parameters of the asset and to avoid infeasible dispatches. This specific classification allows for the performance of the battery storage system to be co-optimized across the daily energy, regulation, and reserve markets based on its characteristics and the needs of the grid on a given day.

Importantly, CAISO allows NGRs that clear in the capacity market to participate in the daily energy and ancillary services markets, based upon the system of co-optimization described above. Creating a special asset class, such as NGRs, clarifies outdated and often confusing market rules. It also encourages participation in multiple markets by removing any barriers to entry for storage resources that are capable of immediately and seamlessly transitioning between providing various services. As a result, it allows the grid to capture the full benefits provided by battery storage systems while incentivizing storage development through opportunities for revenue stacking.

ISO-NE’s planned changes to its ATRR designation are a notable step in this direction. This shift indicates that the ISO is recognizing the capabilities of battery storage. To fully embrace battery storage, ISO-NE should make an entirely new resource designation for storage instead of expanding a current and limited designation.

6.2. Recommendation 2: Establish clear rules for battery storage participation in the Forward Capacity Market

It will be essential to have clear rules that describe how a battery storage system could participate in the FCM with regards to bidding and acquiring a capacity supply obligation. The participation in the FCM referred to in the ISO-NE memo will only be theoretical unless these specific rules are established.

ISO-NE should delineate what capacity requirements are necessary for a battery storage system to qualify for the FCM and how those will be determined. This would likely be in the form of a duration (MWh) requirement. Once the ISO settles upon the capacity requirements specific to storage, the ISO needs to clearly describe what the offer obligations are, and how they would be achieved by a battery storage system that receives a capacity supply obligation through the FCM.

In conjunction with these new updates to market rules, ISO-NE should establish an offer review trigger price (ORTP) for battery storage. ISO-NE calculates an ORTP for every other type of resource. This is an essential piece of information for storage resources if they plan to participate in the FCM.

Numerous proposals in the IMAPP proceeding suggest a change in the design of the FCM. The details vary. But generally, these proposals suggest either changes to the capacity market intended to buoy the development of renewables by recognizing their value as a zero-emission resource or a change to the day-ahead and real-time energy market that creates a separate market for zero-emission resources. The capacity market would be called the Forward Renewable Capacity Market (FRCM) and the energy market would be called the Forward Clean Energy Market (FCEM). Battery storage systems should be allowed to participate fully in both the FRCM and the FCEM concepts as they are further developed.

Participation by storage systems in the FRCM could occur in two ways. The first would simply be for a battery storage system to enter the auction as a stand-alone resource, similar to any other market participant. A concern here may be that, while batteries have no direct emissions, they have indirect emissions if the energy used to charge them is coming from a fossil fuel resource. Determining what exactly qualifies as a zero-emission resource, thus qualifying for participation in the FRCM, will be an important and necessary consideration as the details of the market design evolve.

The second way battery storage systems could participate in the FRCM would be through pairing a battery storage system directly with a renewable energy project. Battery storage systems greatly increase the reliability of renewable energy sources by smoothing their output. Allowing paired projects to participate in the FRCM would create a valuable source of clean and reliable capacity and assuage any concerns about a battery storage system being eligible to participate as a zero-emission resource. This would also allow the battery system to participate in the FCEM because it could bid clean energy from the renewable source into the energy market. One downside to this restriction—the required pairing of storage with renewables—is that it may limit the number of battery storage projects built, and it would not necessarily harness all of the benefits associated with siting batteries at substations in particular.

6.3. Recommendation 3: Remove limits on services provided by ATRR and change the minimum capacity requirement for systems to participate

ISO-NE should amend the ATRR designation by removing the limit on the services that an ATRR can provide. This could be done in multiple ways. One way is to mirror the method used in PJM, which has an asset designation called Energy Storage Resource (ESR). While these assets are primarily used for frequency regulation, they are allowed to participate in the energy and reserve markets as well.

Alternatively, given the establishment of an NGR classification for advanced storage systems (discussed in *Recommendation 1*), the ATRR designation could be removed entirely. NGRs would provide the frequency regulation previously provide by the ATRRs. The compensation mechanism for ATRRs would be transferred to the NGRs that are providing the frequency regulation to maintain compliance with FERC Order 755.

Regardless of the method chosen, it is important to remove the minimum capacity requirement of 1 MW. PJM's ESR asset designation has a requirement of only 0.1 MW. ISO-NE had the same requirement in the ATRR pilot program, but it was raised to 1 MW when the program was officially included in the ISO tariff. This change put many of the battery storage systems that had been providing frequency regulation for the duration of the pilot program suddenly out of business. Re-evaluation and eventual removal of the 1 MW requirement will encourage development. It will also allow entities that only need small systems, such as municipalities, to reap the benefits of fast-response regulation.

6.4. Recommendation 4: Encourage ISO-NE to create a working group to work with utilities and examine siting challenges at substations specific to New England

The considerable benefits of locating storage at substations were detailed earlier in this paper, but to enable this development it will be necessary to work with the distribution utilities. ISO-NE has many stakeholder working groups that assist them in organizing the wholesale electricity markets, operating the power grid, and system planning. Thus, there is precedent for ISO-NE to create a working group that encompasses the New England distribution utilities to examine any challenges associated with locating battery storage systems at substations. These might include ownership structure or interconnection considerations. The Distributed Generation Forecast Working Group (DGFWG) and the Energy Efficiency Forecast Working Group (EEFWG) are two examples of ISO-NE working groups that have been quite successful in planning for and working through the challenges associated with important grid modernization topics.

6.5. Recommendation 5: Include battery storage as a possible solution when ISO-NE performs system assessments as part of its system planning

As a part of its RTO responsibilities, ISO-NE releases Regional System Plans (RSPs) biennially. These reports look over a 10-year horizon to ensure that the system has the resources and transmission it needs to operate reliably and efficiently in the future. ISO-NE utilizes the Planning Advisory Committee (PAC), an open forum for stakeholder participation, to identify areas to conduct resource needs assessments or economic studies, and to identify competitive solutions for those needs. At the request of NEPOOL, ISO-NE conducted its 2016 economic study to analyze the effect of public policy on energy markets and the electric system. While no specific policies were considered, ISO-NE modeled five scenarios for the future mix of resources in the region, only one of which included battery storage. Given the expected storage procurement target in Massachusetts, and in light of the other recommendations suggested in this paper, ISO-NE and the PAC should include battery storage in all their various planning studies going forward—both needs and economics studies—as well as in their studies that identify competitive solutions to the challenges facing the system.

Additionally, the PAC and ISO-NE evaluate the transmission needs for the region. Battery storage should be considered in that process, as a way to meet future transmission needs by deferring development of new lines where applicable.

7. CONCLUSION

The IMAPP process began with the goals of exploring and identifying changes that would align regional wholesale electricity markets with regional clean energy and climate policies. Energy storage has an important role to play in achieving IMAPP's goals: battery storage is a flexible technology that provides myriad benefits to the system, and whose integration could be easily encouraged by simple market rule changes. The services provided by battery storage systems increase reliability and would likely save ratepayers money, all without causing any additional carbon emissions.

To achieve the development required to capture the full benefits that battery storage can provide to the grid, we suggest the five market design recommendations below:

Table 10. Market design recommendations summary

Market Design Recommendations	
1.	**Establish a market classification for battery storage:** Create a specific classification for battery storage systems to clarify, streamline, and optimize how these systems can participate in the regional capacity, energy, and ancillary services markets.
2.	**Establish clear rules for battery storage participation in the Forward Capacity Market:** Create specific rules to govern how battery storage systems can participate in the Forward Capacity Market. These rules should include clarification on, but not be limited to, capacity requirements, offer obligations, and the establishment of an ORTP. In the event that a Forward Renewable Capacity Market is established, it too should have clear rules for battery storage participation.
3.	**Remove limits on services provided by ATRR and change the minimum capacity requirement for systems to participate:** Reorganize the regulation market and compensation structure to better reward fast-responding regulation assets. Additionally, the current minimum capacity requirement to participate in the regulation market as a fast-responding resource should be removed.
4.	**Encourage ISO-NE to establish working group to work with utilities and examine siting challenges at substations:** ISO-NE should create a working group intended to work with utilities to address the challenges associated with battery storage development and installation at substations, as well as the challenges of widespread integration of battery storage into the electricity grid and the wholesale markets.
5.	**Include battery storage when ISO-NE performs system assessments as part of its Regional System Plans:** ISO-NE should consider the effect that increased deployment of battery storage will have on the grid, as well as the possibilities for battery storage to act as a flexible, efficient solution to the challenges facing the grid. Additionally, ISO-NE should include battery storage development in its future transmission planning.

The implementation of these recommendations could be an important catalyst for the rapid uptake of storage throughout New England. Development patterns throughout the country indicate that stakeholders are prepared to engage in significant development. Notably, a few market changes are all that is needed to make battery storage systems economically attractive and create ample opportunities for development.

APPENDIX A: CASE STUDIES

This appendix outlines various storage projects that could be used as guidance for New England. We selected projects based on the service(s) that they provide, a unique ownership structure, or a particularly successful revenue stacking strategy. Since there is no significant precedent for utility scale battery storage development in New England, these case studies of existing projects are intended to illustrate successful project designs that could be applied to developing projects in the region.

Grand Ridge Energy Storage

Location: Illinois
Capacity: 31.5 MW (12.2 MWh)
Duration: ~23 minutes at full power
Services Provided: Frequency regulation

Grand Ridge Energy Storage is a utility scale energy storage project owned by merchant developer Invenergy. It began commercial operation in November 2015. Invenergy wholly owns the project but the revenue of the project is shared with battery provider BYD America. BYD America provided the lithium-ion system used by Invenergy. Grand Ridge is an example of a storage system being able to take advantage of a clear market opportunity. As discussed previously, in October 2012, PJM redesigned its frequency regulation market to better compensate fast-response regulation, such as that provided by battery systems, compared to slower regulation from fossil fuel plants. The new fast-response frequency regulation market offered attractive pricing that made a project like Grand Ridge profitable. Invenergy continues to take advantage of this pricing by providing reliable regulation and operates anywhere from 13–24 hours per day. The system is normally discharged 40–50 percent before it is recharged. PJM bases eligibility to clear in the market upon a performance score assigned to the resource, which consists of three measures: delay, precision, and accuracy. If the resource clears, it becomes obligated to provide power for two hours. The resource can be punished for any intra-hour faults, such as technological failures. Thus, it is important for Grand Ridge to maintain enough power and flexibility to meet these demands.

Grand Ridge and Invenergy's successful participation in the PJM frequency regulation market is an example of what could be achieved by changes in ISO-NE regulation market. Despite this success, however, and due to the PJM market saturation discussed earlier in this paper, any new development in PJM done by Invenergy will require strategies to stack revenues by providing multiple services.

Village of Minster (Half Moon Ventures and S&C Electric)

Location: Village of Minster, Ohio
Capacity: 7 MW (3MWh)
Duration: ~25 minutes
Services Provided: Frequency regulation, power factor correction, and peak shaving

In May 2016 the Village of Minster, Ohio, in conjunction with renewable energy developer and investor Half Moon Ventures (HMV) and battery storage company S&C Electric, opened a joint solar and electricity storage facility. The storage facility uses lithium ion batteries manufactured by LG chem. It is the first municipal “solar plus storage” project in the United States.

Initially, the Village of Minster municipal utility only intended to build a solar array for the purposes of diversifying its energy portfolio. In 2014, however, just as that project was being finalized, the Ohio legislature passed a bill that ended all solar incentives in the state and Minster’s solar project was no longer economically attractive to investors. The addition of a battery storage system allowed the developer to stack revenue streams. HMV uses the system to bid into the frequency regulation market in PJM and the Village uses it for power factor correction and peak shaving.

Overall, the economics of the project proved extremely attractive to both the Village and HMV. The total cost of the project was $14 million, all of which was invested by HMV. While no exact figures are available, HMV states that it is earning a healthy return on its investment. The Village of Minster benefits from lease payments paid to the Village by HMV and the municipal utility benefits from avoided transmission and capacity expansion costs.

The Village of Minster battery storage project illustrates the value added to the grid by the flexibility of battery arrays. It highlights the creative ways in which revenue stacking can make a project economically viable and it provides evidence that battery projects can be financially attractive for developers in the right environment. Finally, it illustrates how creative siting of battery storage resources—in this case next to a solar PV installation—can lead to improved overall economics of a project.

Los Alamitos (AES Storage)

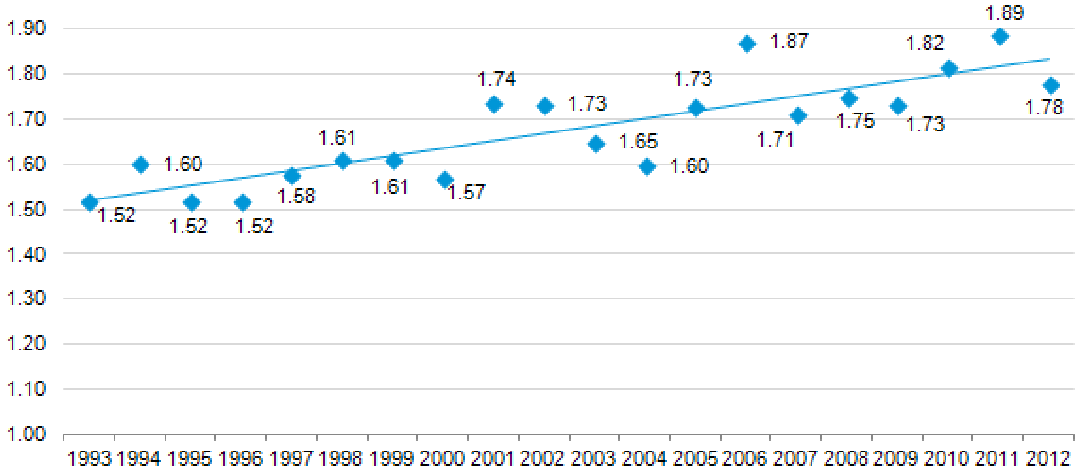
Location: Long Beach, California
Capacity: 100 MW (400 MWh)
Duration: 4 hours
Services Provided: Peak power shaving, peaking plant replacement

The Los Alamitos storage project, being developed by AES with a power purchase agreement from Southern California Edison Company (SCE), is the largest battery energy storage project in the world. AES describes the project as 200 MW of “flexible resource” because the system can be used as 100 MW of storage capacity during off-peak times and then as 100 MW of flexible capacity during times of peak demand. The project is intended to eventually add another 200 MW, however the additional capacity has not yet been built or contracted. The initial 100 MW that is under construction targets an online date of 2021. Its primary use will be to replace a gas peaking plant. The storage project will be located at the Alamitos Energy Center and is being developed in conjunction with a higher efficiency gas plant to replace the older gas plant that exists there currently.

The project is particularly notable for two reasons. First, it is the first battery project in the country that will be directly involved in meeting a "resource adequacy" requirement each day. This, combined with its long duration of four hours, will make it a prime example of the full capabilities of lithium-ion battery storage. Second, SCE chose the project through a competitive solicitation because of its cost-effectiveness. John Zahurancik, the President of AES, stated that in grid reliability and adequacy planning for the area, CAISO, the California Public Utility Commission, and SCE all determined that energy storage was more cost-effective than other future possibilities. This project shows that battery storage can be a cost-effective option for peaking plant replacement, while also causing no emissions and using minimal water.

This project is particularly applicable to New England because of the opportunities that the region has to replace its gas peaking plants with cleaner technologies. Largely variable temperatures between the summer and winter in New England mean that electrical demand has high peaks in each season. In 2015, the peak demand was 24,437 MW, about 1.6 times the average daily load on the system for that year of 14,480 MW. Figure 3 shows the average to peak demand ratio in New England from 1993–2012.

Figure 3. Peak-to-average Demand Ratio in New England



Source: U.S. Energy Information Administration.

The ratio has steadily risen since 1993, and as it rises the system becomes more inefficient because the gap between the energy generation during peak demand and an average day continues to grow. According to the Energy Information Administration, this inefficiency is the most pronounced in New England of any region in the country. Increasing the storage capacity on the grid by deploying batteries would help to alleviate this inefficiency by decreasing the need for newly generated electricity during peak demand. The Los Alamitos project could be a useful example to apply to battery storage development in New England.

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