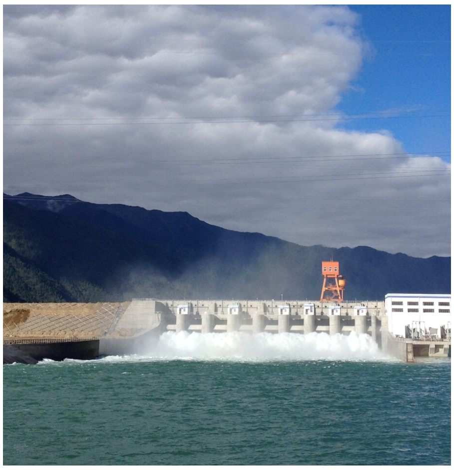
DECEMBER 2019

THE STATE OF GRID ENERGY STORAGE IN MASSACHUSETTS



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ASSOCIATED INDUSTRIES OF MASSACHUSETTS

DECEMBER 2019

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EXECUTIVE SUMMARY

The State of Grid Energy Storage in Massachusetts

Grid-scale energy storage is often described as a game changer because of its potential to revolutionize the design and operation of electrical grids while enhancing the viability of renewable energy generation systems. Today, electrical grids require demand and supply of electricity to be balanced in real time to avoid power disruption and blackouts. This is already a challenging task, and growing efforts to integrate intermittent renewable energy sources, like wind and solar, create additional complications for the electrical grid. The current grid system tolerates the existing level of fluctuations in energy supply by utilizing spinning reserves and plants that can quickly respond to demand, commonly known as "peaker" plants. However, substantial growth of intermittent sources in coming years will create further issues for grid resilience and energy security, underlining the critical need for widespread utilization of grid-scale energy storage.

"Going forward, the need for utility-scale energy storage will be more critical for the Commonwealth."

The Commonwealth of Massachusetts is planning to add thousands of megawatts of new renewable energy sources in the next decade, primarily offshore wind, even as many nuclear-, coal-, and oil-powered resources have been shut down in recent years and many more are slated to be retired in the next decade. For the maximum cost savings and environmental benefits of these billions of dollars in ratepayer investment in renewable energy to be fulfilled, cost-effective, grid-scale energy storage will need to be deployed and developed for Massachusetts, alongside quick-response storage solutions to solve short-term and highly localized electric grid efficiency challenges.

With this critical need, the Commonwealth of Massachusetts launched the Energy Storage Initiative in 2015, which aims to establish the state as a national leader in the emerging energy storage market. Through the Advancing Commonwealth Energy Storage (ACES) Program, 20 million dollars of funding has been provided to 25 demonstration projects across the state. All these activities associated with utility-scale energy storage establish the basis and need for this comprehensive study on the status, challenges, and outlook of grid energy storage in the Commonwealth of Massachusetts.

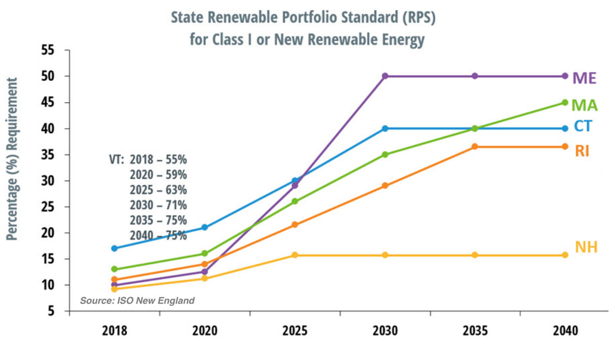
This report explains why utility-scale energy storage is needed and what benefits it can deliver; which technologies are available today and which will be in the near future; the current state and federal incentives affecting energy storage development; and the key remaining barriers to implementation of wide-scale grid storage. The report concludes with recommendations for how policies and incentives should be adjusted and refocused for the future, including the need for additional studies to specify how much energy storage Massachusetts will need within various timeframes and renewable energy generation scenarios, how much the usage of existing underutilized storage resources can be increased, and whether long-term contracts should be considered, or if they may be necessary, to secure adequate utility-scale storage at cost-effective prices for ratepayers.

EXECUTIVE SUMMARY

Key Findings

1 The need for energy storage is primarily driven by economic factors because the regional grid operator, Independent System Operator New England (ISO-NE), is by design energy-agnostic and by design and assigned to identify the lowest-cost generation sources while maintaining system reliability. **The three most significant factors driving demand for additional energy storage include:** (1) Occasions when system demand exceeds power generation capacity; (2) Price volatility in wholesale markets that creates arbitrage opportunities for energy storage to be profitable; (3) Promotion of renewable energy to mitigate the effects of climate change by reducing carbon emissions, which in the future is likely to be driven by carbon pricing and tax incentives.

2 Construction of new utility-scale energy storage systems remains expensive from an investment and operational perspective, and **systems are in most cases far from economically feasible without stacking of policy incentives and revenue opportunities from ancillary services**. As with other nascent technologies, the market does not yet drive the incentive, so state and federal initiatives that recognize the full value of storage will drive additions of new storage while the price of these technologies becomes more competitive.



> **"Without utility-scale energy storage, the Commonwealth's commitment to carbon emission reduction will likely fall short."**

3 The Commonwealth of Massachusetts is home to two pumped hydro storage facilities with a total capacity of about 1,800 MW. However, **less than 30% of their capacity is currently utilized**, largely because of the lack of competitive-market incentives for producing carbon-free electricity outside of state-directed contracts (as opposed to bilateral contracts for wind and hydro power required by state carbon-reduction policies).

4 Without utility-scale energy storage, the Commonwealth's commitment to carbon emission reduction will likely fall short. Even in scenarios with high penetration of renewable energy, the overall emissions of the grid could remain unacceptably high. Research by Anbaric Group, for example, has found that moving to an 80% renewable grid, without energy storage, would lead 30% of the clean energy being wasted or curtailed, producing a grid that is only 20% "clean" at times of peak demand [1].

[1] Clean Peak Analysis and Recommendations, Anbaric Development Partners, May 21, 2019

EXECUTIVE SUMMARY
Recommendations

1 Massachusetts needs both short-term, highly responsive energy storage systems that operate for seconds or minutes in specific geographies with grid constraints and transmission congestion, and longer-term, baseload-like energy storage released over hours. However, **how much and what kind of energy storage will be necessary and most cost-effective for utility ratepayers, and in which timeframes, is still to be determined and critically important information** for the Commonwealth's policymakers and utility regulators, ISO-NE, prospective energy storage developers, investors, and other stakeholders. Furthermore, other important questions to explore include: How can the Commonwealth's existing pumped-hydro storage systems be better utilized beyond their current 30 percent capacity? How do the costs of increased operation of these existing assets compare to construction of new energy storage systems, primarily batteries? How much energy storage does the Commonwealth really need, and in what timeframes, as the renewable energy generation portfolio grows over time?

2 A large variety of viable, grid-scale energy storage technologies are available in the marketplace today. While some of these technologies are currently operational in Massachusetts, such as pumped hydro and lithium ion batteries, others are in a more developmental stage, such as flow batteries. No one technology provides the optimal combined solution for all applications. **A diverse portfolio of technologies will be necessary to realize all the benefits of energy storage for various services.**

3 Expected revenues for investors based on the benefits provided by storage systems are difficult to predict. Quantifying the value streams of energy storage would substantially increase the incentives for procuring, owning, and operating energy storage. This can be done by **setting a clear methodology for allocating all costs and benefits at each level of the energy market, and providing long term certainty about compensation and access to markets** by supporting investment choices through programmatic and policy development.

4 The power grid is a low-salience issue for most individuals. As such, building political and public will for policy change will **require increased educational and outreach programs that connect the benefits and impact of energy storage to ratepayers' everyday lives.** We recommend developing public information and awareness programs that increase public appreciation of the benefits that energy storage can provide and its vital role in maximizing the impact of the Commonwealth's commitment to renewable energy generation and greenhouse gas reduction.

I. THE STATE OF ENERGY FOR THE COMMONWEALTH

A. Energy Generation

Currently, the most prevalent approach to electric generation in New England is the use of natural gas, which comprises about 40% of the overall generation capacity (see Fig. 1). A significant trend over the past two decades has been a decreased reliance on coal and oil, which have decreased from 15% and 19% respectively to around 1% each [1]. Due to increased concerns around global warming, these fossil fuel sources are being phased out in favor of other energy generation approaches that have a reduced impact on climate change. Over the same timeframe, renewables and hydro power have marginally increased (3% and 1%, respectively), but a significant portion of renewable sources are expected to be added within the next 5-10 years [1]. Nuclear energy has stayed fairly constant and has only varied by 2% in the past two decades and imports have only changed by 3% [1]. From a broad perspective, the composition of energy generation is in a different place than it was 20 years ago - and there will be even more changes in the next decade that will change the breakdown from what it is today.

Capacity is the maximum power output an electricity generator or asset can physically produce. Along with large grid-scale power plants, as of 2017, there were 224 cogeneration installations in MA with a total capacity of about 1700 MW [2]. The largest capacity was in the chemical industry, which accounted for about 38% of the overall capacity followed by district energy generation (15%) and electronics manufacturing (10%). The vast majority (88%) of this capacity is powered by natural gas, followed by oil and waste, which both make up about 4% of the total power sources [2]. Most of the capacity comes from sites that are greater than 20 MW of energy capacity, contributing 85% of the total capacity in only 6% of the total sites. There is a potential for about 1,000 new sites that could have a potential combined heat and power capacity of 780 kW.

Nuclear power provides approximately 25% of the electricity used across New England [1], but Massachusetts' only nuclear plant, Pilgrim Station in Plymouth, was decommissioned in May of 2019 because it had become economically uncompetitive. While it was operational, it produced about 16% of the state's total energy while emitting essentially zero greenhouse gases. It had a total capacity of about 680 MW [3]. The plant closed because it was no longer cost effective to operate compared to other energy sources and because a substantial investment was necessary to bring the plant into compliance with new codes. Even though there are no longer any nuclear plants in Massachusetts, the state still gets power from nuclear resources in other New England states. According to ISO-NE, about 25% of the electricity for the region is still from nuclear sources, which Massachusetts still gets a part of, which still makes it a relevant energy source for the state [1].

Traditional steam plants are a fairly simple way to generate electricity that has been used for many years. There are a few different types of traditional steam plants that use different sources to create heat to generate steam. Coal traditional steam plants used to be the most common way to generate electricity, but once coal was recognized to be a large pollutant and because of operating cost, many plants switched over to using natural gas. About a decade ago, coal plants produced about a quarter of the total energy in MA, but by 2018, after the closing of Brayton Point in Somerset and Mount Tom in Holyoke and the replacement of the Salem Harbor coal-burning power plant with a new unit that runs on natural gas, Massachusetts had no utility-scale coal plants in operation. Plants running on oil continue to operate in the Commonwealth, including "dual fuel" units that can switch between natural gas and distillate oil, but use of oil for electricity generation in the Commonwealth has decreased from about 20% of total generation in the early 2000's to less than 2% today [4]. A recent increase of about 1% in total usage from these plants is due to concerns with overall grid reliability and the decreased availability of nuclear and coal plants [4].

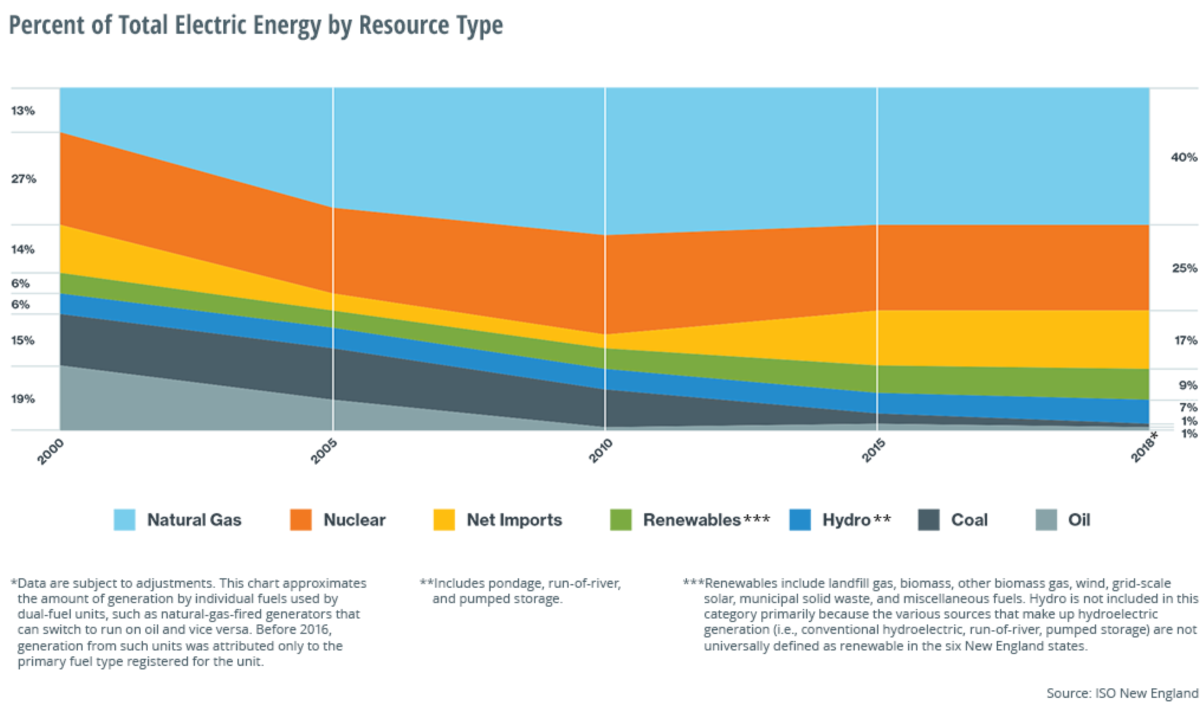


Fig. 1. Percent of total electric energy by resource type in New England. Retrieved from https://www.iso-ne.com/about/key-stats/resource-mix/

Hydroelectric power is arguably one of the cleanest ways to harvest energy (after installation) and is a renewable energy source. Unlike other renewables (i.e. wind and solar), hydroelectric generation is not generally subject to intermittency, which is limited to daylight operation and wind, which is dependent on a sufficient wind resource at any given moment. There is however a possibility in areas where droughts are common that there is not a reliable source of water to generate energy, but this risk can be mitigated by studying the area where the hydroelectric dam is going to be installed. The main limitation for hydroelectric power is geographical since it is reliant on the presence of water resources. MA currently has 30 hydroelectric power facilities, including a plant that was built in 1893 in Holyoke. The Connecticut river, which cuts through a large part of MA, has 12 dams along it that produce hydropower. Last year, hydroelectric power accounted for about 4% of the Commonwealth's overall power generation [5].

Within the U.S., onshore wind turbines are abundant in areas such as the Midwest and Great Plains states having a strong wind resource, with installed capacity growing to over 100 GW in 2019 [6]. MA has procured more than 1,600 MW of offshore wind to be developed in coming years, and more utility-scale offshore wind generation is being evaluated along both coasts of the U.S. and the Great Lakes. New England's first utility-scale wind farm (30 MW) went into service in 2016 off the coast of Block Island.

Although wind energy is intermittent, wind energy generation is fairly reliable and can occur at all times of the day, unlike solar. Concerns associated with wind energy include aesthetics, noise pollution, and impacts on animal species (e.g. birds, bats, and aquatic life). As of 2018, there was about 113 MW of wind infrastructure built in MA with 5 MW of planned additional power for the coming year. Wind power makes up about 1% of MA overall energy generation and makes up about 38% of the Commonwealth's renewable energy portfolio [7].

Solar energy will play a significant role in renewable energy generation for the foreseeable future. PV modules are used both at dedicated solar farms and rooftop solar installations across the Commonwealth. Most rooftop solar is classified as "behind the meter" (BTM), meaning the energy it generates directly serves demand within the home or building it is mounted on, reducing demand for utility-provided electricity. As of March 2019, there were about 160,000 BTM solar systems installed in New England that amounted to about 3,000 MW of capacity [8]. On the other hand, "in front of the meter" installations contribute to the utility's energy portfolio. There are currently about 2,500 MW of solar energy generation installed in MA from about 96,000 separate projects, which has already surpassed the state's goal of 1.6 GW by 2020 [9].

Waves in the ocean have the potential to generate about two-thirds of the energy needed to power the U.S. per year [10]. There are a variety of different technologies that are being used to harvest wave energy, some of which float on top of the water and some of which are submerged in the water. One of the more popular forms of wave energy generation is an underwater turbine that uses flowing water to generate power. These devices, like wind turbines, can pivot to face the direction of flow to optimize energy generation, but eliminate the above ground noise and visual aesthetic issues associated with wind turbines. There are also other devices that sit on top of the water and harvest the kinetic energy generated from the up and down motion of waves. There are some concerns with these technologies in that they need to be kept in place using underwater mounts and cables, which have some siting, mooring, and engineering concerns. On top of that these devices need to be able to withstand strong currents and saltwater corrosion. Hydro-kinetic energy generation is an area of increased research but does not currently have a significant impact on energy generation for MA.

In the next decade there will be a large increase in renewables that will completely change the energy generation landscape of MA. Currently, the energy system in the Commonwealth has a lot of centralized energy generation with steam plants, since that has been the main energy generation system in the US for decades. With the recent increase in renewables, the system has started to get more and more decentralized as there are various farms and other sources spread around the state. This trend does not look to be changing soon as there are many more planned renewable installations, mostly solar and offshore wind, alongside plans for shutdowns of centralized plants. This increase in renewables will cause an increase in energy intermittency. In order to offset this intermittency, there is a need for storage to be added into the system so that energy can be stored when the energy production is higher than demand. Along with helping solve intermittency issues, storage can help with both peak shaving and load leveling by injecting that stored energy during times of high demand to help decrease the amount of energy needed from other sources in order to be more economical and decrease demand.

I. THE STATE OF ENERGY FOR THE COMMENWEALTH

B. Energy Consumption

Demand for energy peaks both during the day and during the year. During a 24-hour cycle, there are two different energy consumption peaks, the first in the morning from about 5:00 to 7:00 am (as people wake up, turn on lights, and use energy for cooking, bathing, and other purposes) where electricity demand picks up from the baseload. From 7:00 am till about noon, the demand increases slightly, and then from noon until about 5:30 pm the demand decreases slightly. This fairly stable time is while most people are at work, so most of the demand is coming from industry and residential climate control. At 5:30 pm, the demand starts to greatly increase until demand peaks at about 6:30 pm and decreases onwards till midnight [11]. This trend is fairly consistent throughout the year, with the major peak slightly shifting throughout the year depending on when the sun rises and sets. Consumption over a typical day can been seen in Fig. 2.

Throughout a calendar year, much like a day, there are two main peaks that occur. The first peak occurs during winter months when the weather is the coldest (i.e. for home heating). The second peak comes during summer months, for air conditioning and refrigeration.

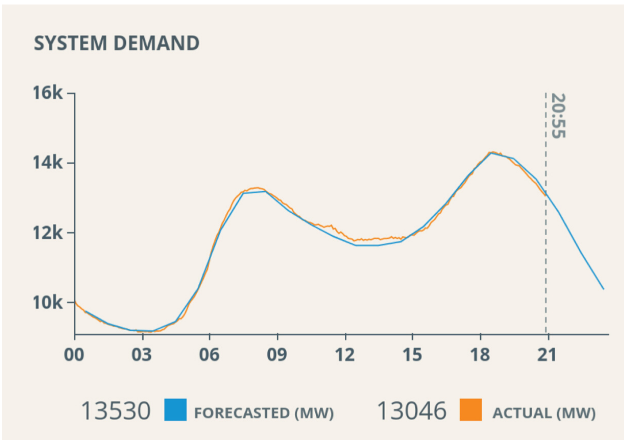


Fig. 2. System demand real time data retrieved on October 23, 2019 for forecasted system demand (blue) and actual system demand (orange). Retrieved from www.iso-ne.com

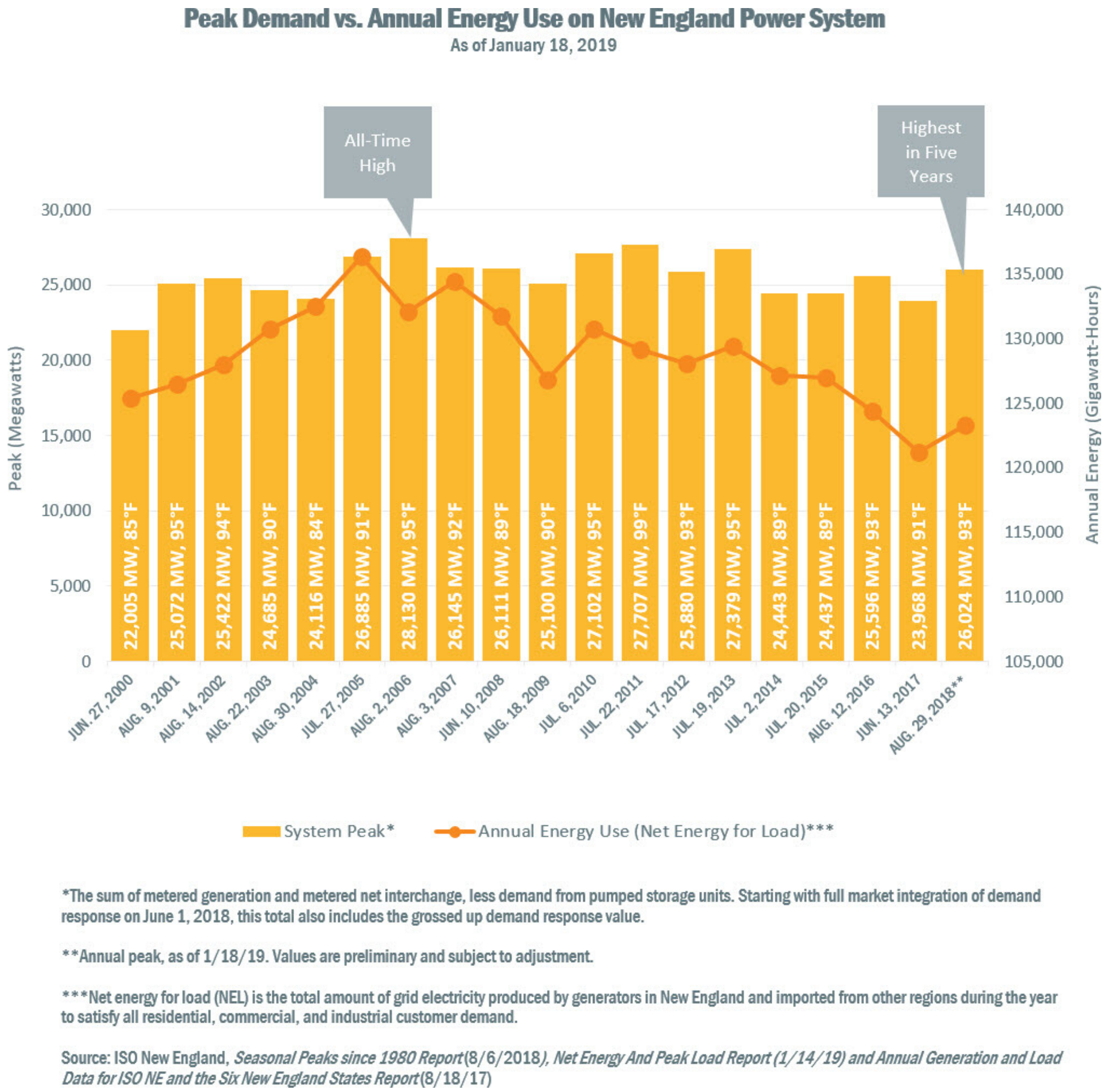


Fig. 3. Peak demand and annual energy use on New England Power System between years 2000-2018. Retrieved from https://www.iso-ne.com/about/key-stats/electricity-use/

In 2006, the energy use in MA peaked at ~ 28,000 GWh and has trended downward in subsequent years (see Fig. 3) primarily due to improvements in energy efficiency and behind the meter renewable energy installations. Year-to-year fluctuations are caused by changes in weather, fuel costs, economic conditions and levels of business and industrial activity, and MA's investment in energy efficiency programs.

There are several programs that have contributed to the Commonwealth's energy efficiency. One of the largest initiatives in Massachusetts is the Mass Save program, which helps customers in both the residential and business sectors save energy through different services. They provide energy assessments, construction consultation, financing, rebates, and incentives for the purchase of energy efficient appliances or infrastructure upgrades [12].

Additionally, the Affordable Access to Clean and Efficient Energy Initiative addresses barriers to entry for lower income households [13]. The Home Energy Market Value Performance (Home MVP) Program helps residents reduce their carbon footprint while improving the comfort and value of their home by providing a list of contractors that can help address customer goals and assess potential solutions [14]. After the assessment, they will give a custom scorecard with measures that can be taken to improve the home and will explain incentives related to potential improvements as well as potential 0% loans. The Peak Demand Reduction Grant Program has allocated money to try and improve the state's demand response infrastructure, thus reducing the reliance on fossil fuel sources while decreasing energy prices [15].

I. THE STATE OF ENERGY FOR THE COMMENWEALTH

C. Future Projections

According to ISO-New England, there are five major power plants in New England that have already or are about to retire: Mt. Tom (Holyoke), Mystic (Charlestown), Salem Harbor (Salem), Pilgrim Station (Plymouth), and Brayton Point (Somerset) [1]. These plants primarily use coal and oil, with the exceptions of Pilgrim (nuclear) and Mystic that partially utilize natural gas. Two additional oil power plants that are at risk of shutting down in coming years, Canal Station located in Sandwich and West Springfield.

There is currently some concern about backup power during cold winter months, as the best back-up resources are traditionally coal and oil plants, which have largely been replaced with natural gas plants. Massachusetts has experienced high-emission spikes in use of oil and coal to generate electricity during periods of peak demand in winter, when constrained supplies of natural gas were inadequate to meet demand for both heating and power generation. The issue with natural gas plants during cold weather is that it is used for both heat and electricity generation, which affects prices and accessibility. All of these factors potentially make backup power risky during winter months. In all of New England, oil-based power plants are expected to decrease by 32%, providing only 4,400 MW of energy by 2027 (see Fig. 4) [1]. Nuclear is expected to decrease by 18% to a total capacity of 3,300 MW [1]. Coal is expected to decrease 100% so that there will be no coal generation resources left in the New England region.

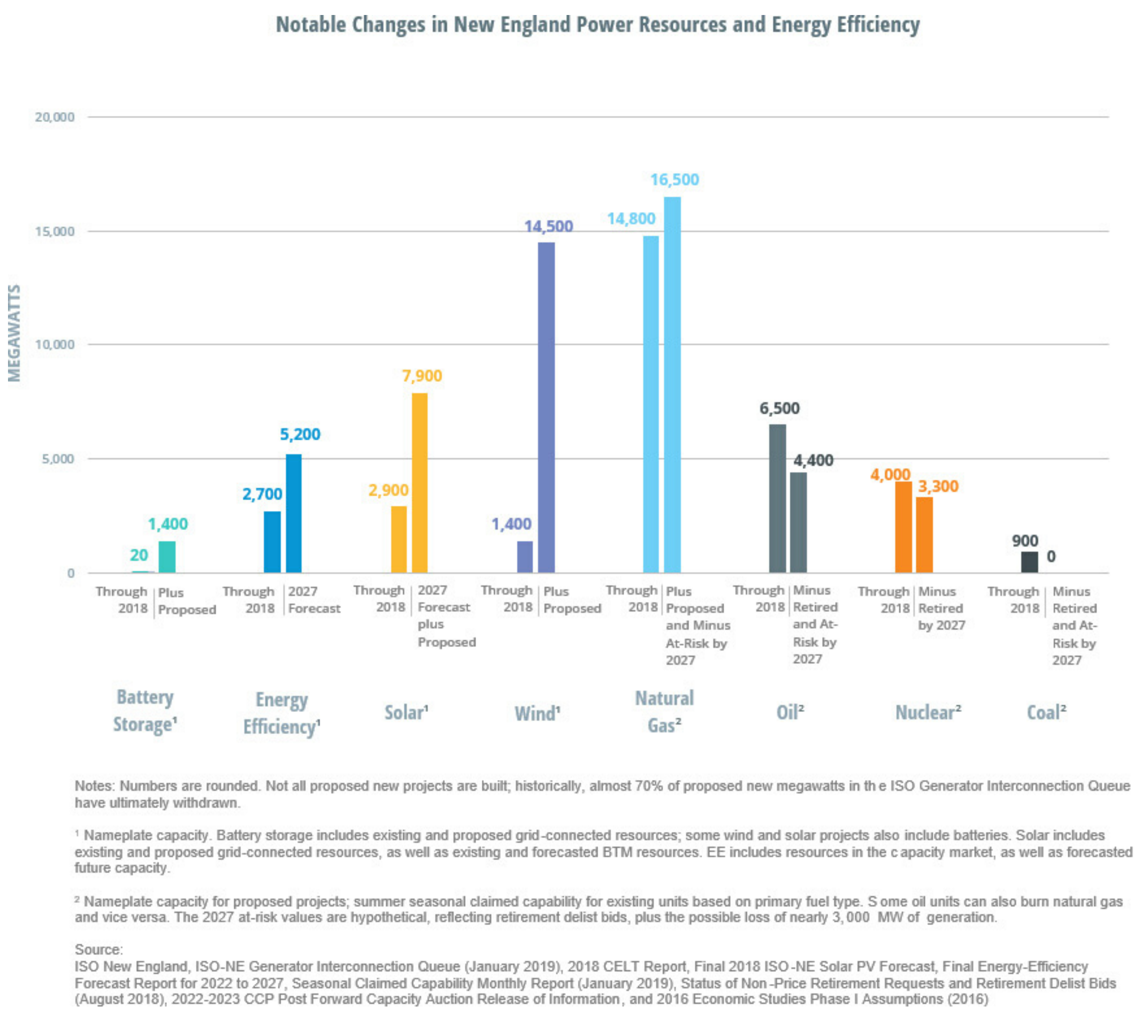


Fig. 4. Notable changes in New England Power Resources and Energy Efficiency. Retrieved from https://www.iso-ne.com/about/what-we-do/in-depth/power-plant-retirements

There are three new natural gas plants that have already, or are going to, come online by 2020 in MA (Footprint, Medway, and a new Canal plant). In New England, these plants, along with a couple other projects, lead to an expected increase of 11% in natural gas plants to a total of 16,500 MW [1]. Overall, the planned retirements, increased variability, the desire to reduce greenhouse gas emissions, and need for a resilient energy infrastructure provides an opportunity for renewable energy coupled with energy storage technologies. The following statistics consider proposed projects minus retirements expected by 2027 for all of New England. It is predicted that battery storage will increase by 8000% to 1,400 MW (see Fig. 4), which includes existing and proposed grid-connected resources [1]. Energy efficiency is expected to increase by 193% to 5,200 MW, which includes resources in the capacity and future capacity markets. Solar energy is expected to increase by 272% to 7,900 MW while wind energy is projected to increase by 1,036% to 14,500 MW of energy.

II. REVIEW OF GRID ENERGY STORAGE

A. Types

The most commonly utilized renewable sources, such as solar and wind are intermittent. Since there is expected to be a significant increase and reliance on renewable energy sources, the power generation ability and grid will become less stable due to intermittency. To accommodate the increase in renewable energy generation, energy storage is necessary and will help to alleviate intermittency issues by creating an additional source of energy that increases the robustness and stability of the grid. Energy can be stored in systems during off-peak times or when there is low consumption. Later, that stored energy can be reinserted into the grid during times of high demand (i.e. peak times). Implementing such a strategy, will allow for stored renewable energy to be better utilized by shifting from times of low demand to times of high demand.The characteristics of the available energy storage technologies are shown in Fig. 5.

1. Pumped Hydro

Pumped hydro uses one of the most abundant resources on earth, water, to store energy, by moving it up to an elevated reservoir. When the stored energy is needed, the water is released to a lower reservoir or river through a turbine that generates electricity, typically for several hours at a time. Energy is able to be generated until all of the water flows out of the top reservoir into the lower reservoir. When energy needs to be stored, water is then pumped back up to the higher reservoir where the process repeats. Pumped hydro currently makes up about 94% of all energy storage within the U.S., but opportunities to develop more are limited by geography and availability of large amounts of water near topography with significant elevation differences.

2. Compressed Air

Compressed air energy storage works by storing air in underground caves or disused wells. Air is forced into this underground area and is pressurized and stored. When the energy needs to be released it is let out through a turbine, which is rotated by the flow of air, and generate electric power through a coupled generator. When energy needs to be stored, air is pressurized back into the cavern until energy needs to be released again. There is not a large amount of compressed air energy storage throughout the U.S., but it is a viable technology that is growing in popularity using old oil drilling wells. Like pumped hydro, compressed air can store a large amount of energy, but its use is restricted geographically to areas with available caverns or wells. Some other companies are exploring hydro pneumatic energy storage, but these technologies are still at the research stage and have not been implemented at a utility-scale [16].

Grid energy storage allows increased stability while decreasing energy prices during peak times.

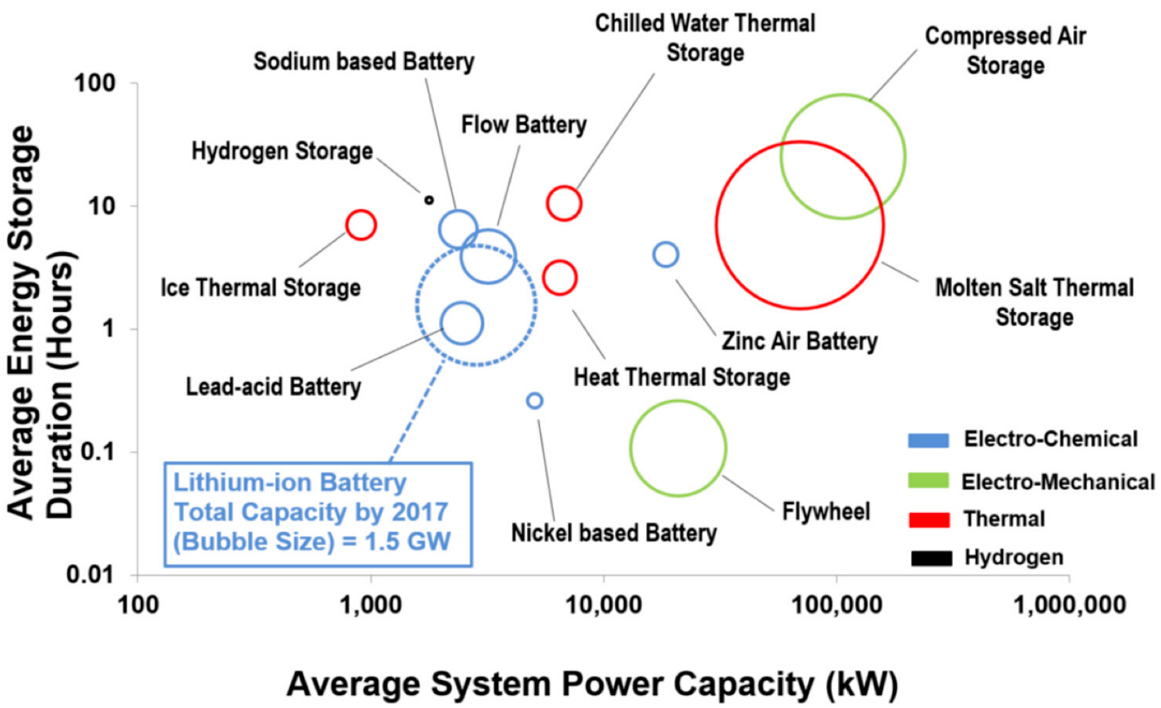


Fig. 5. Average characteristics of energy storage systems built worldwide between 1958 and 2017. Retrieved from https://www.nrel.gov/docs/fy19osti/71714.pdf

3. Lithium-ion Battery

Li-ion batteries are the most common type of battery technology that is currently being used. These batteries use three main components; the positive electrode, the negative electrode, and the electrolyte. The positive electrode is usually made of lithium cobalt oxide or lithium iron phosphate, the negative electrode is usually made of graphite, and the electrode varies by manufacturer. When the battery is charging, the positive lithium ions move from the positive electrode, through the electrolyte and onto the negative electrolyte where they stay. When the battery discharges, the lithium ions move from the negative electrode to the positive electrode where they stay. Li-ion batteries usually have controllers in them that prevent overcharging so that the battery does not catch on fire, which is still a major concern for deployment of this technology. In the vast majority of large-scale energy storage implementations, Li-ion batteries have been used. While a proven and flexible technology, Li-ion batteries are less cost-effective than many other forms of energy storage.

4. Flow Batteries

Flow batteries are a newer technology that is still developing in the commercial marketplace and is the subject of a lot of research. Flow batteries have a unique setup in that they decouple energy and power by separating the electrolyte into two separate exterior storage tanks that pump the electrolyte into the cell stack where all of the redox reactions take place. The energy density can be increased by increasing the size of the storage tanks and the power density can be increased by increasing the active area in the cell stack. Flow batteries have not been widely deployed to this point as they are a fairly new and unproven technology.

There are many different chemistries that have been used in flow batteries, but the most commonly used one is the all vanadium chemistry, since vanadium has four different stable oxidation states which negates contamination issues in each of the tanks. These batteries have great potential for long-duration grid-scale applications, but currently are not considered as proven enough to be widely deployed. When considering the levelized of cost of energy storage analysis, their pricing can be competitive with peaker plants as well as Li-ion batteries.

II. REVIEW OF GRID ENERGY STORAGE

A. Types

5. Thermal Energy Storage

Thermal energy storage includes many different approaches but most commonly ice is used as the storage medium. Often, this technology is used to make air-conditioning more effective as ice is created during the night produced with inexpensive electricity, and during the day and uses the cooling capacity of the stored ice to decrease the amount of energy that is needed during the day to cool the space. Ice-based storage can also be used as the lower temperature source for heat pump systems, which allows them to work for longer amounts of time and handle heavier loads. These systems are not terribly common, but there are some systems that have been implemented around the country. Deployment of these systems is not common and is constrained by the space required for storing ice.

Federal funding is also supporting forms of thermal energy storage including Molecular Solar Thermal (MOST) Systems, which store solar energy in the form of molecular bonds. Another technology in this category is molten salt energy storage, which uses the energy of the sun to heat salt to a molten state and pump it through a heat exchanger to create steam that powers a turbine to create energy. Molten salt technology continues to be heavily researched, with a few installations of this technology operational. [17].

There is not one singular technology that provides a broad solution for all applications.

6. Flywheel

Flywheel energy storage differs from conventional batteries in that it stores energy as kinetic energy as opposed to chemical energy. Electricity driving a very low friction shaft with a flywheel disk mounted on it gets the disk spinning at high speeds for minutes or hours until the flywheel's energy is tapped to generate electricity. These systems are not yet able to store large amounts of energy but leveraged in parallel, they can make a storage plant of sorts that are scalable for different applications [18]. For example, Beacon Power created a proprietary carbon fiber rim, which they claim can help them produce energy more efficiently by allowing a maximum speed of 16,000 rpm. They claim their system can sustain more than 175,000 full depth charge and discharge cycles without any system maintenance [19]. These systems have not been widely deployed to this point, but there have been some larger projects that have proven the technology.

7. Other Technologies

In addition to these energy storage systems, there are many other technologies that are being considered as potential energy storage solutions. Hydrogen energy storage is one of these technologies, which uses electrolysis to generate hydrogen which is then stored until it is re-electrified when needed. Hydrogen storage works very similar to compressed air energy storage in that it is stored in large vessels or underground caves and is released when needed to power a turbine. It is advantageous over air as it is a smaller molecule, so more gas can be stored in the same amount of space. Additionally, once the hydrogen is released, it can be used in electrochemical systems such as fuel cells in order to chemically generate electricity. An added benefit of using hydrogen for combustion is that it generates only water as a byproduct [20].

Gravity energy storage is a technology that has recently been making headlines, which uses many of the same basic physics principles that pumped hydro energy storage has been using for years. The system uses a six-arm crane that lifts 5,000 concrete blocks up and down a 33-story building to store and release energy. This crane is operated by automation software that operates the system mechanically to best store and release power when needed [21]. There is a similar technology from a company called Gravitricity who uses a singular large weight in a shaft that is raised or lowered to release or store energy. They claim efficiences of 80-90+ percent and a 50-year life of their technology with a less than one second response rate. Their storage systems can store up to 20 MW of power with up to 15 hours of storage [22]. These technologies are still being heavily researched, but there are some companies, such as Gravitricity, that are already producing them.

In summary, many viable energy storage technologies have been deployed in Massachusetts to date, particularly pumped hydro and lithium ion batteries, and more are in development, such as flow batteries. For example, while workable in other parts of the U.S., compressed-air energy storage is unlikely to be feasible for installation in Massachusetts. No single technology is likely to provide the broad solution. Rather, a portfolio approach leveraging various technologies where they provide the most cost-effective benefits is likeliest to meet Massachusetts' needs for energy storage.

Fig. 6. Northfield Mountain pumped hydro storage facility. Retrieved from https://www.firstlightpower.com/facilities/

III. CURRENT STATUS OF ENERGY STORAGE DEPLOYMENT IN MASSACHUSETTS

A. Technologies in Use

Placement of energy storage can generally be described as front of meter, which is always linked to the electric grid, or behind the meter (BTM), which is always connected to commercial building or residential electricity infrastructure. The size and placement of storage systems is used to qualify the best use cases. In general, front of meter systems are employed by utilities and commercial and industrial (C&I) customers for demand management, participation in ISO-NE wholesale market programs, increased dispatch flexibility, avoiding upgrades in transmission infrastructure, and to reduce the effects of intermittent generation on the grid. BTM systems are widely used to minimize demand charges, firming capacity of on-site renewables, facility resiliency (backup power), and energy arbitrage.

The key issues that project sponsors face are related to operation and compensation. Regarding the operation for BTM storage, host customers and the utility may disagree on the usage priorities (i.e. demand charge reduction, backup power, arbitrage), which are often used by the project sponsor to finance the system. A mild change in law may have a large effect on a project's financeability. For example, if the revenue from the customer is based on the reduction of demand charges, any change in regulation could jeopardize the viability of the contract.

Utilities are increasingly seeing energy storage as the most cost-effective way to capture compensation for ancillary benefits. However, some challenges exist regarding the implementation of viable energy storage. The need for energy storage is primarily driven by economic factors since most ISOs are energy agnostic and choose to bring on energy power generation assets that are the least expensive.

There are currently three primary factors that provide motivation for additional energy storage: (1) An increase in demand above the capacity of the available power generation systems drives a demand for energy storage. For example, as more electric vehicles are operated, there is a higher need for additional electric power generation because the energy required for vehicle transportation is now being sourced from the electric grid instead of fuel. (2) Wholesale energy markets with higher volatility create a need for having more energy storage. The volatility can be attributed to the increase of renewables that possess energy intermittency or local and global political or energy market variations. For example, having low natural gas and oil prices do not incentivize the use of renewables and the need for energy storage. (3) To mitigate the effects of climate change, there is an increasing awareness of the need for more renewable energy to move to low carbon emission forms of energy generation. In the future, this will be largely be driven by carbon tax incentives and pricing. As more renewables are brought on line to help reduce greenhouse gas emissions, the coupling of energy storage with renewables will become more important. Ultimately, policy and economic incentives drive the current wholesale market for energy storage. Storage projects will become more commercially viable as states set targets for storage and allow them to participate in ISO-NE's capacity markets and get compensated for stacking services and benefits. By employing smart energy management systems (EMS), batteries can be charged and discharged in an economically optimized way, maximizing returns. With improved forecasts of prices, scheduling and bidding into marginal energy markets, energy storage can conduct efficient arbitraging to reduce consumer electricity prices and peak demand charges.

1. Pumped Hydro

Historically, pumped hydro has been the predominant grid-scale source of energy storage in Massachusetts. It was originally developed in the 1960s and 1970s to capture surplus energy from nuclear power plants overnight and refill reservoirs to provide on-demand energy in daytime and evening hours of peak demand.

Only less than 30% of the available pumped hydro capacity is utilized on a regular basis.

Pumped hydro storage makes its profit from the capacity market and price differential/arbitrage. The economics of pumped storage benefited from the availability of extremely low-cost nuclear baseload power overnight and wholesale market prices that rose to multiples of overnight prices during the day and evening.

The massive untapped potential of pumped hydro facilities for storing and moderating the intermittent nature of renewable electricity needs to be recognized as it offers over 4 times the capacity and discharge over 2 times the duration of standard Li-ion systems. There are two pumped hydro stations currently in use in the Commonwealth of Massachusetts with the total capacity of about 1,800 MW. However, only less than 30% of the capacity is utilized on a regular basis since there currently is no strong incentive to utilize carbon-free energy sources. For the utilization level to change, changes in policy or to the market structure (e.g. greater energy volatility, intermittency, increased energy demand, increased fossil fuel prices, or carbon pricing) would have to take place. Within Massachusetts there are currently two pumped-hydro storage facilities:

- Bear Swamp Hydroelectric Station: Can provide up to 600 MW of power for up to ~ 6 hours of operation with a ramp up in under 3 minutes.
- Northfield Mountain (see Fig. 6): Can provide up to 1,168 MW of power for up to ~ 8 hours of operation with a ramp up in under 10 minutes. Northfield Mountain was created to store energy from the Vermont Yankee Nuclear Power Plant, and Bear Swamp was created in the 1970's to help meet increasing peak loads
- These two facilities are currently operating at only 25-30% of capacity for a variety of reasons, including reduced volatility in wholesale prices and the lack of market incentives for utilities or offshore wind developers to contract for large-scale energy storage.

2. Electrochemical Systems - Municipal Utility Energy Storage Projects.

Ten municipal utility energy storage projects have been installed or are under development in the state. The Sterling Municipal Light Department was the first "muni" to deploy a storage system that saved ratepayers $1 million in one year of operation, inspiring other municipal utilities to follow suit. The Sterling project, in partnership with Origis Energy, pairs a 1 MW community solar project with a 1 MW, 2-MWh Li- ion battery charged exclusively by the solar system. Use of stored energy at periods of peak demand when wholesale prices are highest directly reduced bills for ratepayers. Other examples of municipal energy storage projects include:

- The Templeton Municipal Light and Water Plant's 1.6-MW/3.2-MWh Li-ion battery commissioned in May 2019 as part of a microgrid with projected annual ratepayer savings of approximately $310,000.
- The Wakefield Municipal Gas & Light Department's 3-MW/5-MWh Li-ion battery interconnected through Wakefield's Beebe Substation. The $3.2 million project was completed in January 2019 and is delivering monthly savings of approximately $25,000 monthly savings, or $300,000 annually.

3. Electrochemical Systems - ACES Program

Additionally, with the Advancing Commonwealth Energy Storage (ACES) Program, 26 energy storage projects (23 Li-ion battery, 2 flow batteries and 1 flywheel) are currently under development (see Fig. 7). Some of these projects are among the 10 municipal utility storage projects. More details regarding the ACES Program, awarded projects and the awardees can be found on https://www.masscec.com/advancing-commonwealth-energy-storage-aces.

Fig. 7. Host site types of the awarded ACES Projects. Retrieved from https://www.masscec.com/advancing-commonwealth-energy-storage-aces

III. CURRENT STATUS OF ENERGY STORAGE DEPLOYMENT IN MASSACHUSETTS

B. Future Projections

As of October 2019, ~ 21,100 MW have been proposed in the ISO Generator Interconnection Queue in New England as seen in Fig. 8.

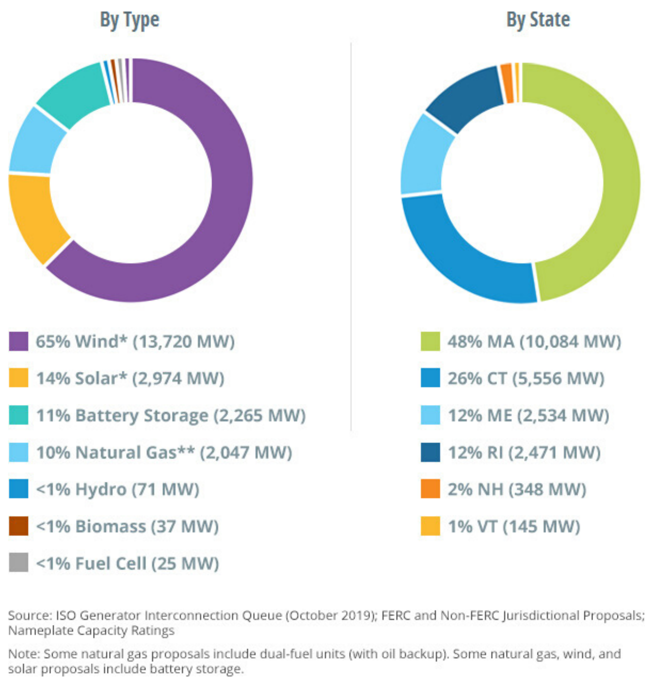
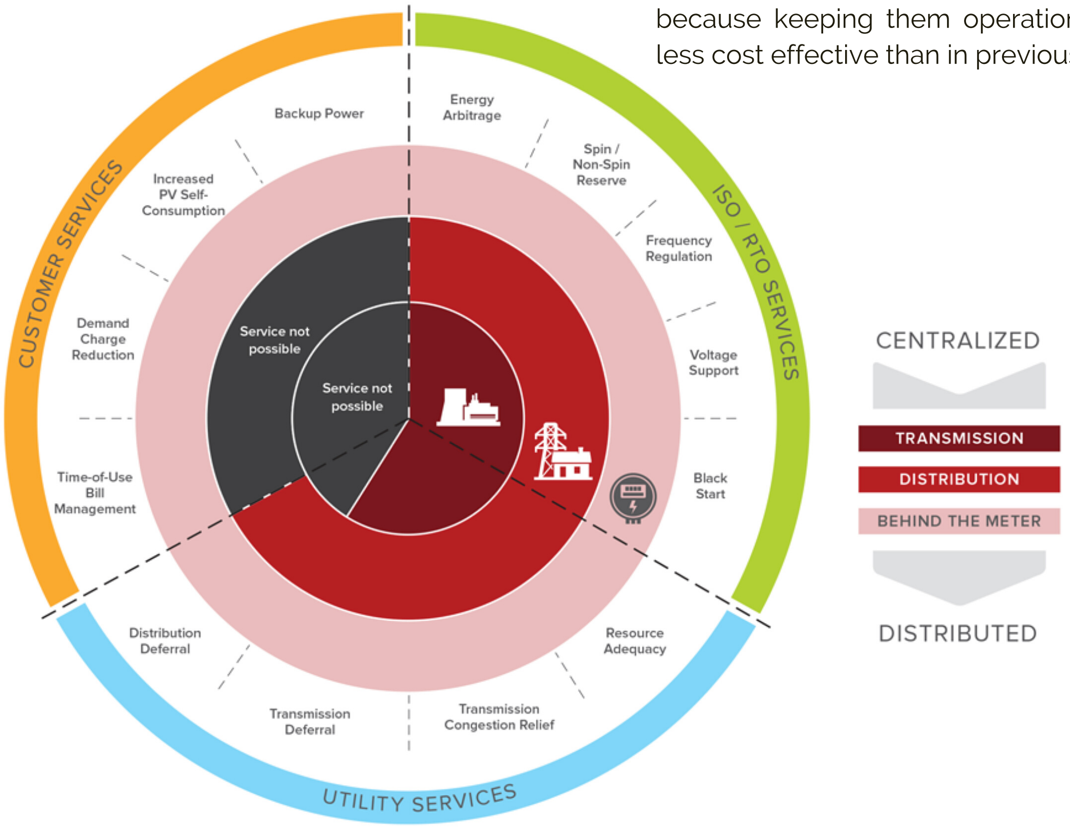


Fig. 8. ISO New England generator interconnection queue (October 2019). Retrieved from https://www.iso-ne.com/about/key-stats/resource-mix#on-the-way-in

IV. GRID ENERGY STORAGE APPLICATIONS AND SERVICES

From an ISO perspective, grid energy storage can provide up to 13 different benefits among stakeholder groups, including utilities, independent system operators (ISOs) and regional transmission organizations (RTOs), and customers (see Fig. 9). One of the primary and most widely advertised applications of energy storage is time shifting. Energy storage allows for cheap excess energy to be stored during low demand periods, which is later released at times of peak demand. During times of high demand, there are often auxiliary sites that are asked to power on in order to meet the demand of the grid. Energy storage could replace these plants (e.g. more expensive to operate or having higher greenhouse gas emissions) by using the energy that it stored when there is low demand during these times of high demand to meet grid demand while additionally



Energy storage also complements intermittent renewable energy by capturing surplus power during times of low demand, reducing the risk wind and solar generators are ordered to curtail production by ISO-NE or that they face conditions of negative pricing, in which they have to pay the grid to take their energy as an alternative to the disruption of shutting down operations. Therefore, energy storage has the potential to eliminate energy production curtailments and mitigate negative power pricing. Energy storage has the ability to perform energy arbitrage such that low cost energy is used to store energy and then utilize that energy when prices or demand are higher. This helps for energy producers to maintain revenues, decrease the payback period of the power system, and keeps energy prices lower for consumers.

Energy storage also improves grid resiliency by providing stored energy for emergencies and replacing the need for "peaker plants" fueled by natural gas, or jet fuel that can be ordered to fire up on short notice. Currently, during emergencies when the power goes out, there are small gas or oil plants called mid-level plants that switch on when they are called on by ISO-NE. Several of these plants have recently been shutting down because keeping them operational has become less cost effective than in previous years.

Fig. 9. Grid energy storage can provide up to 13 services three stakeholder groups, including utilities, independent system operators (ISOs) and regional transmission organizations (RTOs), and customers. Retrieved from The Economics of Battery Energy Storage Report by Rocky Mountain Institute: https://rmi.org/insight/economics-battery-energy-storage/

Not having these power generation plants available can cause an issue because there are fewer options for backup power generation during outages and emergencies. Energy storage can address this issue as it allows for a reliable backup power supply that can cost effectively be switched on at a moment's notice. Since several of the peaker plants have recently shut down, ISO-NE is using a strategy of keeping the two pumped hydro facilities (Bear Swamp and Northfield Mountain) as a critical source of backup power for grid emergencies, which adds stability to the grid.

The voltage in the grid can also be supported by storage technologies if there is an infrastructure failure. Sometimes if a plant has an issue or there is an issue with wiring or other infrastructure, the available voltage on the grid will decrease. This voltage loss continues until either the issue is resolved or another plant comes online. However, the plant typically coming online is likely to be one of the peaker plants, so it is either not environmentally friendly or cost effective. If the voltage decreases due to an infrastructure failure, an energy storage resource could come online and supply the necessary voltage, negating the need for peaker plants to on. This also has the potential to save money as releasing energy that was stored during a low demand time may be more cost efficient than turning on a peaker plant during a grid failure.

Renewable sources, especially solar, can be unpredictable and so sometimes there is an excess amount of energy on the grid. Normally this excess energy would just be dissipated as heat, or the power generating assets would be curtailed, or the electricity pricing would go negative. If energy storage was added, this energy could be utilized and not wasted since it can be stored for later use. This allows for a reduction in the curtailment of renewables and results in greater profit for the energy producer as they are able to operate their assets and sell energy that would otherwise be wasted.

Energy storage can also be used to assist in eliminating issues associated with transporting energy from one location to another. Many newer renewable resources are not central to where the demand is, so the energy needs to be transported to energy users.

Grid Energy storage enables intermittent renewables to operate with more stability and robustness.

Power transmission is typically done by using a long network of power lines that transmit the energy from the source throughout the grid. An alternative to this methodology is to add energy storage as both a way to transmit and regulate the energy that comes from these sources. Localized or distributed solar or wind energy systems could be hooked up to the energy storage system, also known as co-location, and the energy produced would flow to the storage system or battery. In cases where transmission capacity is constrained from locations where wind and solar generation is in operation to locations of electricity demand, co-located energy storage at the generation site can capture surplus energy for injection into the grid when transmission is less constrained. Co-located systems also have the benefit of qualifying for many federal and state incentive programs. Likewise, if needed, the energy could go straight to the grid, but if there wasn't a current need for energy, it could be stored until it needs to be transmitted elsewhere. The energy storage system can be located right next to the source, a short distance away from the source, or many miles from the sources depending on the geography and need. By storing this excess energy, the load on the grid is able to be reduced, therefore alleviating the strain on the power generation system and adding stability and resiliency.

All energy sources have at least some carbon footprint, both from the energy used to build them and from emissions associated with burning natural gas, oil, or coal for power. Renewables paired with storage, however, have much less impact than traditional sources and enable greater use of solar panels and wind turbines that generate zero emissions when operating.

V. REVIEW OF INCENTIVES FOR ENERGY STORAGE

Massachusetts energy policymakers have identified energy storage as critical for achieving the state's clean energy goals and mitigating intermittency and surplus generation from renewables. Storage adoption has been driven by state legislative procurement targets and a growing awareness of the technology's benefits to the grid. States have been looking at how to best incentivize energy storage and major growth in utility-scale storage has been thus far primarily due to state level energy policies, incentivizing adoption through procurement targets, and tax incentives.

The Federal Energy Regulatory Commission's (FERC's) Order 841, or so-called "Storage Rule", directs operators, utilities and ISOs to allow battery systems to participate in and get compensated by wholesale energy, retail capacity, and services markets. FERC and the states recognize the importance of improving the competitiveness and financeability of energy storage to support a more dynamic and cleaner grid, store intermittent renewables, cover winter and summer peaks and times of fuel scarcity, and promote grid resilience. Further, extreme weather and growing societal concern exacerbated by climate change increase the importance of grid resiliency, mainly providing relief to the energy grid during peak hours and fuel scarcity.

MA supports the rapid adoption of energy storage as a part of a cost-effective clean energy agenda.

According to Energy Storage Association, the Northeast will account for slightly over one-quarter of capacity installed by 2025 (see Fig. 10) [23]. Key drivers for such large growth in the Northeast include aggressive greenhouse gas (GHG) reduction policies or renewable deployment targets implemented by states.

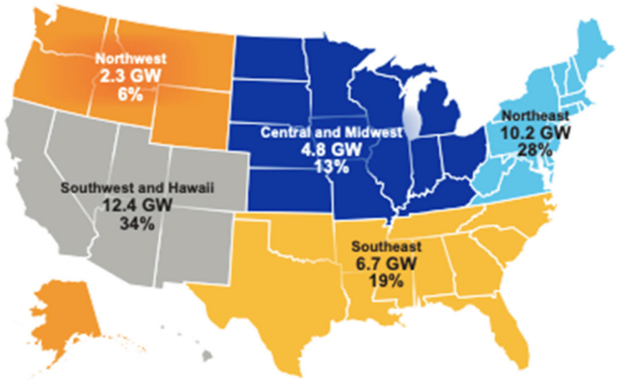


Fig. 10. Cumulative U.S. Energy Storage Energy Capacity Additions Region, Vision case (2017-2025). Retrieved from https://energystorage.org/wp/wp-content/uploads/2019/06/esa_vision_2025_final.pdf

A. Active Federal Programs

- FERC Order 784: FERC revised market regulations in ways that should favor energy storage. Pay-for-performance tariffs allow for public utilities to account for speed, flexibility, and accuracy for fast response services.
- FERC Order 841: This ruling was critical to removing many regulatory barriers, allowing for more efficient, rapid deployment. FERC instructed Regional Transmission Organizations (RTOs) to open wholesale markets to allow energy storage to participate. It is required for RTOs and Independent System Operators (ISOs) to enforce participation models for energy storage that allows compensation for all the services they are capable of providing.
- Tax Incentives: Storage collocated with renewables qualify for federal investment tax credit (ITC). The ITC supports solar plus storage systems that are charged by renewables 75% of the time, rather than the grid. Until 2019, the ITC credits 30% of the cost of the system. This credit drops to 26% for 2020, 22% for 2021, and permanently to 10% starting in 2022.

B. Active State Programs

- Renewable Energy Portfolio Standard (RPS): RPS requirements promote the adoption of renewable energy resources by mandating electricity providers to serve their retail area with a required minimum percentage of renewable energy. Currently, MA has one of the highest percentage requirements within ISO-NE territory, set at 45%, which increases 2% between 2020 and 2030, and 1% thereafter (with no expiration date set), thereby 85% of retail load must be met with renewables by 2050 (see Fig 11).

- Energy Storage Initiative: Resulted in a state funded comprehensive study of energy storage opportunity in MA (State of Charge, 2016) and funding for demonstration projects generating data to inform future policy around new technologies. The energy storage procurement target was first put into effect August 2016. In the target, the MA Department of Energy Resources (DOER) encourages utilities to meet a voluntary target of 200 MWh of energy storage by 2020. Each electric utility in Massachusetts is required to submit a report to the DOER by Jan. 1, 2020 detailing how it has complied with the energy storage target. Regulatory obstacles may have disheartened a more aggressive target. Others have suggested that the target should have set aside fractions of the target for specific types of storage (i.e. behind the meter storage). Finally, the mandate only focused on utilities, without opening up involvement to a wider range of entities, there is less opportunity for different market players to participate.

- Advancing Commonwealth Energy Storage (ACES): MassCEC and DOER award $20 million to support 26 energy storage demonstrations.

- Statewide Energy Efficiency Plan for 2019-2021: MA abundant energy-efficiency budget of $2.8 billion to promote electrification of buildings, industries, and transportation. The plan also outlines new consumer demand reduction and response programs. It is expected to deliver $8.56 billion in benefits to customers. Load management initiative involves a first in the nation energy efficiency measure, where funds are made available to BTM battery storage projects. This makes MA the first state to recognize energy storage as a cost-effective energy-efficiency measure.

- Pay-for-performance: This incentive pays MA utility customers who dispatch from battery systems during peak events. National Grid and Eversource are currently offering commercial and industrial customers who participate in the Daily Dispatch Program up to $200/kW per event in the summer. The incentive would be $20,000 per year for a customer dispatching an average of 100 kW over the summer. National Grid's Winter Dispatch Program offers incentives of up to $25/kW per event in the winter. The Incentives are paid on performance, with some of the rates locked in for the first five years of the program.

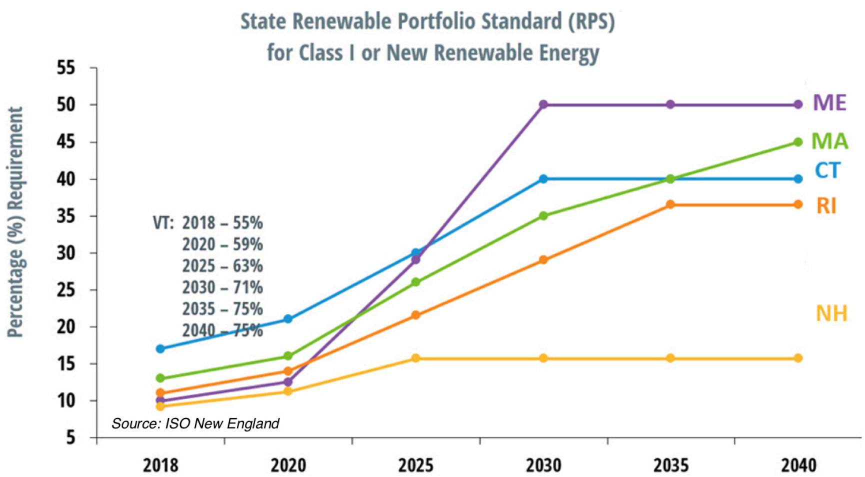


Fig. 11. Renewable energy standards for six New England states. Retrieved from https://www.iso-ne.com/about/key-stats/resource-mix/

- Solar Massachusetts Renewable Target (SMART): Storage systems that qualify at least 25% of solar PV system's capacity and with a capacity of 2-6 hours are eligible for SMART energy storage adder incentives of up to $0.0763/kWh. The SMART interconnection queue already includes more than 130 megawatts and has attracted national solar plus storage specialists to migrate to MA. An unintended consequence of the incentive is that it has been disincentivizing people to participate in demand response programs.

- Utility-Based Demand-Management Pilots: Active demand response programs to aid in peak shifting, offsetting expensive hours of the day and year to work alongside the Clean Peak Standard and other demand charges.

- Peak Demand Reduction Grant Program: A $4.68 million DOER initiative for testing novel strategies for reducing Massachusetts' energy usage at peak demand times. $1.975 million was awarded to fund projects designed to defer investment in energy transmission and distribution systems. An additional $2.71 million will be used to fund projects designed to address all aspects of peak demand reduction including transmission and distribution investment, wholesale capacity markets, and customer demand charge. Many awards for battery storage systems performing ancillary benefit of load management/shifting, as well as exploring new capabilities.

- Alternative Energy Portfolio Standards (APS): DOER requires meeting 5% of the state's load with qualified "alternative energy", including combined heat and power (CHP) projects, flywheel energy storage, energy efficient steam technology, and renewable technologies that generate useful thermal energy by 2020.

- Energy Storage Safety - Moon Island: Solar plus storage or storage only system installed to provide energy security for the Boston Fire Department's training location in Quincy, MA. This site is being used for energy storage safety training to first responders.

MA strives to push the boundaries of energy and climate policy and create more opportunities for the energy storage industry.

- Capacity Substitution Auctions by ISO-NE: Forward capacity substitution auctions allow new clean energy resources to take the place of capacity resources that wish to retire. This market-based incentive accommodates the entry of storage into the forward capacity market and protects the market's competitive pricing mechanism to help avoid cost shifts.

- An Act to Advance Clean Energy **(under development):** Governor Baker signed An Act to Advance Clean Energy, which includes raising the energy storage target to 1 GW/1,000 MWh by 2025.

- Clean Peak Standard (CPS) **(under development):** Resources that move clean energy to peak demand period are extremely valuable. In August 2018, Governor Baker signed into law An Act to Advance Clean Energy, requiring that DOER issues a program requiring retail providers to meet a minimum percentage of sales with appropriate clean peak resources. The Clean Peak Standard is designed to incentivize clean energy technologies that can supply electricity or demand during seasonal peak demand periods, motivating new, fast and flexible distributed energy storage resources. Any resource that generates or discharges energy during seasonal peak period generates clean peak certificates; electricity suppliers will be required to buy a certain number of certificates annually. The novelty is with forging new business opportunities without huge market/rate reforms and ensures that a growing fraction of peak electricity will be met by clean rather than fossil fueled sources. CPS can clean the MA peak, eliminate dirty peakers encourage colocation of clean generation and storage, and help MA use all the clean energy it produces.

VI. KEY BARRIERS TO IMPLEMENTATION OF GRID STORAGE

A. Cost

The capital cost of energy storage remains high and a barrier to development. The lack of suitable and available land and the challenge of contemporary environmental regulations means it is unlikely Massachusetts will every build another pumped storage facility the size of Northfield Mountain or Bear Swamp. Compressed air energy storage is another technology that is expensive to create but is less expensive if there is an existing cave that can be used as an air reservoir. Massachusetts lacks pre-existing facilities (i.e. disused oil wells or mines) that could support compressed air energy storage.

Beyond increasing the utilization of existing pumped storage hydro above the current 25-30 percent level, batteries and flywheel technologies represent the most immediately deployable and cost-effective technologies in the marketplace. These storage technologies can range from levelized costs of about $100/MWh to as high as $1250/MWh for battery technologies and as low as $58/MWh for 100 year pumped-hydro facilities [24] (see Fig. 12). The cost competitiveness of a technology very much depends on the application that it is used for. For example, most battery storage technologies at the utility scale that are coupled with a renewable energy source in front of the meter cost from about $100/MWh to about $225/MWh. For storage coupled with renewable energy sources behind the meter in a residential setting, costs range from about $475/MWh to $750/MWh. Currently, for utility-scale in front of the meter applications, Lithium batteries are one of the most cost-effective storage technologies. In the near future further cost reductions are expected from new technology and by companies that consider adding energy storage coupled with a renewable energy generation project.

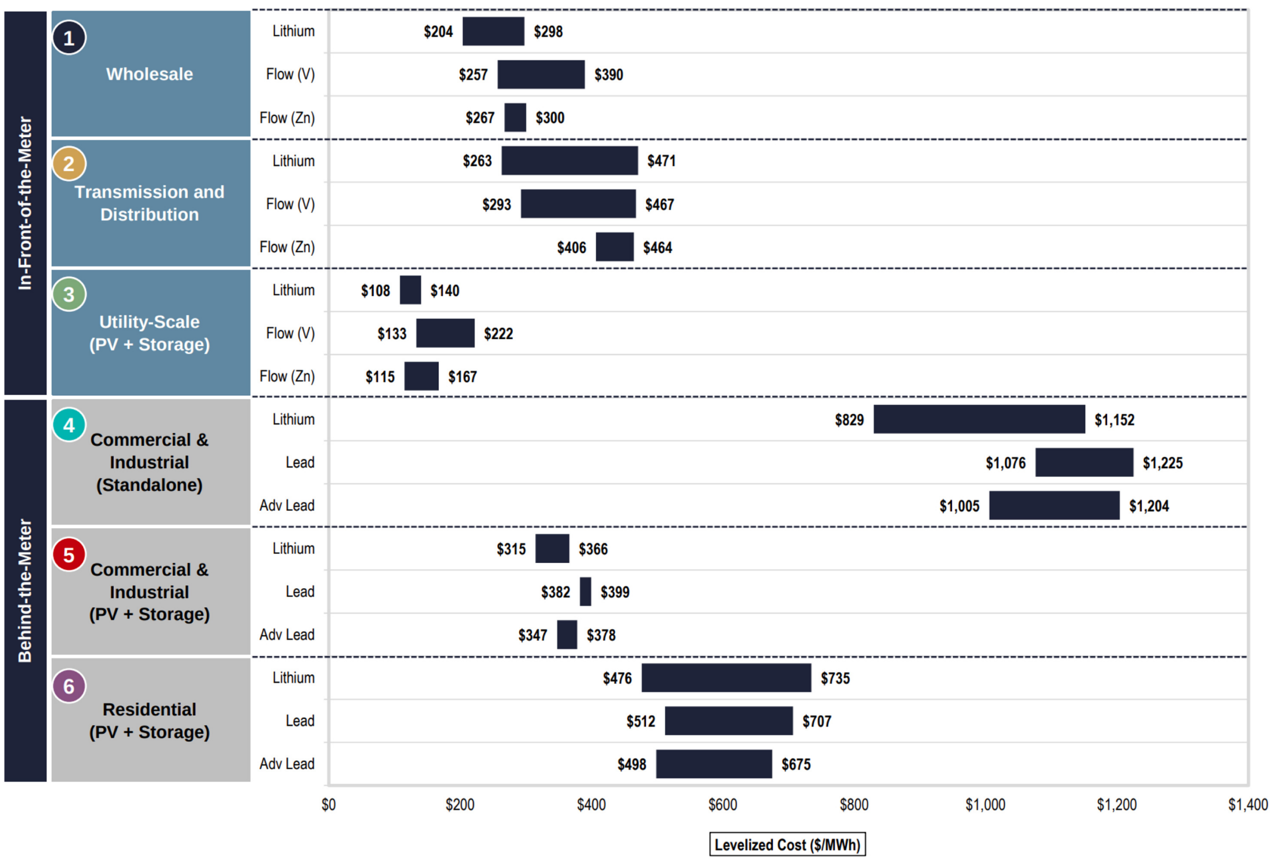


Fig. 12. Unsubsidized levelized cost of energy storage comparison for various grid-scale electrochemical energy storage technologies. Retrieved from Lazard's LCOS Analysis: https://www.lazard.com.

B. Technical Challenges Regarding Grid Integration

Today's New England power grid, originally built for one-way transmission of electricity from central generating stations to customers, will continue to require complex, costly, and ongoing modifications to support two-way flows of renewable energy and storage. The current grid system is not prepared for the addition of energy storage systems and needs to be modified before it can adopt newer technologies. Recently, with so many renewable sources being added, the grid is moving to a bi-directional power flow model where there are many different distributed power sources. With many new power sources being built that need to be connected to the grid, there needs to be new controllers and systems added to regulate how much energy is flowing through the grid. This will take a lot of work and investment of electrical grid companies, since they are the ones that own and must modernize their distribution infrastructure. It will also take large amounts of investment from the renewable energy generation developers who have to build these systems and create the proper hookup to the grid. Both of these stakeholders will have to allocate a substantial amount of resources to update the grid, but it is necessary for the next generation of energy generation paired with energy storage. Utilities such as Eversource, National Grid, Unitil, and the state's municipal utilities have begun the work on creating the "smart grid" of the future, and we can expect these upgrades to continue for decades.

C. Resource Availability

For some energy storage technologies, there needs to be substantial geographical features in order for them to be built. For example, pumped hydro needs to have two large reservoirs at varying elevations for the technology to work. There, at the very least, needs to be a difference of elevation for the reservoirs to be on, such as a mountain, a plateau, or raised structure, where the two reservoirs need to be built. These are some major geographical restrictions that either make it difficult or extremely costly to create these systems in places without the required elevated terrain, which is a large barrier to entry. For compressed air energy storage, there needs to be a large underground space for the air to be stored.

The already existing resources could accommodate some if not all of the new energy that is coming online without having to build new construction.

Some systems use natural caves that were formed underground, and stores air in them, which means they have to buy the rights to the cave. Some systems use old natural gas or oil wells that are no longer active, which is cost effective since there are likely to be cheap or free since they are unused. There are a few that create their own spaces, but this process is expensive and takes a lot of surveying and careful mining. There are some areas where creating a space would not be allowed due to environmental and stability concerns, so this technology is not viable in some areas. Since these spaces are necessary for this technology to be viable, and there are no preexisting wells or many existing caves to use in Massachusetts, it would be very costly to create a space for air to be stored and is therefore a barrier for widespread implementation of this technology.

There are currently two existing pumped hydro systems in Massachusetts, Northfield Mountain and Bear Swamp that were created to store energy from the Vermont Yankee Nuclear Power Plant and to help meet increasing peak loads in the 1970's, respectively. The grid system looks very different now from when they were created, and they are utilized much less now. These days the pumped hydro plants are only being used for ~ 25-30% of their capacity since the current energy market does not compensate resources for being carbon free. If only 30% of these resources are being used, there is still about 1300 MW of available energy storage that is not being fully utilized. An increase in renewables would cause a need for energy storage, and it is presently unclear if the already existing energy storage assets can fully accommodate state's new renewable energy requirements or not. This fact points to the need for additional research to determine: How much the energy storage does Massachusetts really need, if the state converted its energy generation portfolio to 100% renewable energy?

D. Policy

Mastering the complex rules for how energy storage can interconnect with the ISO-NE grid and qualify for energy and ancillary services markets revenue is a challenge for developers. Clearer, simpler rules from ISO-NE could make projects more financeable and viable. Future carbon pricing efforts would clarify the value of storage that supports renewables deployment and obviates the need for high-emissions coal and oil generation during peak winter electric demand. **While the cost of storage continues to drop and its economic value in energy markets becomes clearer, state and federal policies and incentives will remain the most important drivers in the near term for expanded storage.**

Information about market participation, financeability, and revenue opportunities for proposed storage systems is provided by ISO-NE during the interconnection process. Per their role in the energy market, ISO-NE has advised owners on how market rules dictate the opportunities for integration and ancillary services, and how systems should demonstrate capabilities to provide ancillary services or participate in energy markets. While this provides guidance for investors who take the time to navigate the market and ask questions, market operation and financeability may not be comprehensible otherwise, limiting the number and compensation for proposed storage systems.

The opportunities should be simplified in order to raise investments in storage and keep the interconnection queue growing with storage that actually benefits and is compensated by multiple state and federal incentives, at every level of the grid and energy market that is relevant to storage (i.e. services, capacity, and distribution). These recommendations will obviously need to consider the location of the system relative to areas of congestion and high demand charges, where storage would be most beneficial, since the market will dictate the need for certain ancillary services in lieu of large capacity. This will guide the storage interconnection queue towards system qualities that best serve localities, ultimately, working to achieve ISO-NE critical roles. There are different value propositions per the amount of storage capacity provided by a system and other qualities including the rate of discharge.

Large capacity systems, especially pumped-hydro, are ideal for arbitraging. These resources benefit from price volatility, however, a problem identified for MA's pumped hydro is low utilization rate due to the lack of market incentive for emissions-free generation. In general, the market dictates the need and value of storage. For this reason, some of the benefits of storage cannot be valued unless they are explicitly valued in policy and adoption targets and in terms of GHG emission goals.

Carbon pricing may present an opportunity to internalize environmental detriment of fossil fuel resources. ISOs often perform out of market action, especially when dealing with posture resources—resources with limited supply that needs to be preserved. This scenario is relevant during severe winter weather, when oil and coal are still used to maintain reliability. Since pumped-hydro facilities are not likely freeze, these systems can be called upon to provide winter reliability without burning limited resources of fossil fuels.

ISO-NE is technology agnostic, meaning they are not concerned with what technology is employed to meet energy needs, but are service and performance specific, since their role is to provide energy along with services to maintain reliability and resiliency in the region. ISO-NE would like to see additional reactive power resources and a value on alternative (out of market) actions, but requirements and systemic policy are required at the state or federal level. Finally, technologies are changing rapidly, therefore, these opportunities and requirements should also change.

Construction of new storage remains expensive from an investment and even operational perspective; systems are in most cases far from economic without one or stacked policy incentives and revenue opportunities from ancillary services. Common to other nascent technologies, **the market does not drive the incentive, it is state and federal programs that can anticipate the largest additions of new storage that is cost-effective, at least, while the price of these technologies drops.**

E. Acceptance

While approximately 100 million households in the U.S. have some type of non-analog electrical meter, only about 50% those meters operate in a two-way fashion, known as Advanced Metering Infrastructure (as opposed Advanced Meter Readers (AMR), those simply sending consumption information to the utility for billing). However, in MA, according the Energy Information Administration, this penetration was significantly lower, as there were only about 156,254 electrical meters installed in the Commonwealth that were categorized as advanced metering infrastructure (AMI or SMART meters). Overall, the level of installed AMI in MA is only slightly more than 10% of all existing meters.

This represents an area of potential interest for policy makers, as AMI is a necessary technology to allow for the realization of maximum value that distributed energy storage represents to consumers and electrical services that can be made available to the grid [25]. In fact, in 2018, the MA Department of Public Utilities postponed approval of Eversource and National Grid's AMI plans [26] and Eversource's plan relied on customers to "opt-in" to the purchase of AMI meters, which could mean it takes 10 years or more before smart meters are widely adopted [27].

The need for AMI capability to achieve maximum benefits from distributed energy storage is complicated by the fact that the existence, not to mention the benefits of SMART meters is generally lacking, with only 1/3 of Americans having even heard of the technology [28]. Boudet suggests that this lack of familiarity makes garnering political support difficult, particularly because upgrade costs are immediate, and any benefits are largely unknown and contingent upon future conditions. **This lack of salience surrounding SMART meters is indicative of the overall complexity and low-priority that many residents of MA place on the issue of the climate change.** A June 2017 WBUR Poll indicates that the public in MA strongly believes that climate change is occurring and while a majority of those surveyed (72%) indicated they would be willing to pay up to $10 a month more in energy costs if it cut CO_2 emissions, the issue didn't rank among their top issues of concern [29].

The current approach, authorized by the Green Communities Act and Global Warming Solutions Act to incentivizing renewable energy generation (especially PV systems) has resulted in 40,000 PV projects currently operating in MA [30]. **While there is no doubt this represents a considerable public policy success story, but one that should be complemented by system-designed distributed electrical storage both by customers behind the meter and by utilities, municipalities, and corporate aggregators at utility scale.**

In short, the growth of distributed electricity generation by renewables has presented major approaches that have been advanced with energy storage. The first, is a behind-the-meter approach to storage, which anticipates residential, commercial, and industrial electricity consumers identify cost- savings and operational efficiencies that can be achieved by installing on-site energy storage solutions. Another approach to energy storage is corporate entities, municipalities, and other collective actors that make investments in small- to moderately-scaled energy storage projects, as seen most prominently by the Sterling Municipal Light Department to provide the energy storage for their stakeholders, providing electrical power in the event of severe weather events while reducing "demand charges by about $17,000 for the month of December" [30]. Further examples such as this would help to raise the political salience and awareness of energy storage.

Three factors, when combined, lead to a path forward that establishes a case for the development of policy that promotes grid-level energy storage solutions. **First,** the solutions to grid-level storage are myriad, and policy support should recognize that a successful storage approach, may include pumped-hydro, lithium-ion batteries, flow batteries, flywheels, and other storage approaches. **Second,** each of these technologies will require the establishment of varying types of policies to ensure that an over-reliance on policy tools focused on economic incentives (and the underlying calculations prioritizing raw economic efficiency), when coupled with the low-salience of the energy storage issue among consumers, does not result in the development of a storage capacity that is too small to maximize the benefits afforded by future renewable energy generation.

Third, the government has a duty to ensure the operation of a sustainable, effective and reliable electrical grid which will require energy storage if a large percentage of the generated electricity comes from renewables. That policy and policymakers should recognize the diversity of technologies available now and in the near future that will lead to successful storage as well as the benefits of storage that the current competitive market may not yet recognize and value.

VII. CONCLUSIONS & RECOMMENDATONS

A. Issues

- The Massachusetts electric grid will continue to have high emissions even with a high renewables penetration, producing a 20% clean peak. For example, according to a recent study by the Brattle Group [18]: 80% renewables cause up to 30% clean energy to be wasted or curtailed while producing a 20% clean peak.
- Because carbon is not priced into the energy market, ISO-NE is under-incentivized to call on clean, stored generation, including significantly underutilized pumped hydro storage
- Non-market incentives that reward storage and improve its financeability are underdeveloped and inefficient.
- Investors' and municipalities' expected revenues based on the benefits provided by storage systems are challenging to predict, making it difficult to secure financing for them.
- Policies which create affordable financing opportunities and incentives for municipalities and other local government units to cut municipal energy use and decrease the economic losses do not provide clear revenue opportunities tied to the benefits of energy storage.
- Policy development which recognizes that rationales behind the adoption of distributed energy generation and storage are not uniform, and that multiple strategies should be employed to raise awareness about the value that energy storage can deliver, particularly in partnership with renewable generation.

B. Call to Action

1) Further Studies on Energy Storage:

It is clear that deployment of thousands of megawatts of new renewable energy generating capacity, particularly offshore wind, will require thousands of megawatt-hours of storage capacity, including both increased use of the Commonwealth's now-underutilized pumped storage hydro facilities, and the development of new storage systems of the types described in Section II of this paper. MA is certain to need both short-term, highly responsive energy storage systems that operate for seconds or minutes in specific geographies with grid constraints and transmission congestion, and longer-term, baseload-like energy storage released over hours (< 30 minutes provides regulation; ~ 1 hour provides reserves; > ~2 hours provides capacity). **Just how much of these different kinds of energy storage will be operationally necessary and most cost- beneficial and -effective for utility ratepayers, and in which timeframes**, would be critically important information for the Commonwealth's policymakers and utility regulators, ISO-NE, prospective energy storage developers and investors, and other stakeholders to obtain. **Why the Commonwealth's proven, built-and-paid- for pumped storage systems now operate at less than 30 percent of their capacity, and what could be cost-effective ways to increase the use of these available resources**, would be an important question for others to explore in such an exercise. Additionally, because of the challenges posed to the ISO-NE competitive electric market by the increased quantity of "out of market" power procurements such as the "83C" offshore wind contracts and the "83D" hydroelectric contracts, we recommend rigorous exploration of the question of whether the Commonwealth's ratepayers and emissions-reductions goals would be best served by carefully structured long-term contracts for large-scale energy storage.

2) Improved Policy and Incentives:

As Massachusetts continues to rely on energy storage to support decarbonization, it is important to address where policy fails to encourage and reward energy storage deployment. Storage should be able to qualify for multiple value streams if and when it provides grid and pricing benefits. Establishing the cost of externalities associated with power generation, particularly emissions, will improve the incentives for developing renewables and energy storage over the long term. Today, energy system operators are only motivated to provide the cheapest supply. This is largely done when operators ask for bids, reflecting the lowest price that a generator will sell its electricity. It is crucial to reduce the risk and improve the return of procuring, owning, and operating energy storage. This can be done by setting a clear methodology for allocating all costs and benefits at each level of the energy market, and supporting long term certainty about compensation and access to markets by supporting investment choices through programmatic and policy development.

Without utility-scale energy storage, the Commonwealth's commitment to carbon emission reduction will likely fall short. Even in scenarios with high penetration of renewable energy, the overall emissions of the grid could remain unacceptably high. To avoid this scenario, power system planners must optimize for high reliability, reasonable cost, and environmental performance, incorporating societal value of low-carbon. All resources, both generation and demand-side, should be properly valued for their useful attributes. Energy only markets are not always sufficient to provide signals to encourage investments. Distributed resources can play a crucial role in the transition to a renewable electricity future by reducing intermittency limitations of renewable supply, reducing or shaping demand, and enabling the integration of variable renewable resources. Forward capacity market opportunities, revenue opportunities, and valuing of system qualities provide out-of-market incentives.

Massachusetts has been leading with comprehensive energy plans, and large-scale procurements, attracting and supporting storage companies, improving financeability through state incentives, and accelerating the development of early commercial storage technologies. **Systemic valuations and policies to advance energy storage need to be employed within the rapidly growing market for energy storage presents an important opportunity for investors, and society at large.** However, in order for these benefits to be realized, policy changes to address specific component of energy storage systems are needed.

Our suggestion is to expand markets for storage technologies, valuing storage benefits (allowing for stacking) to clean energy integration, grid reliability, system wide efficiency, and peak demand reduction. Moving forward, it is important to recommend targeting new regulations and programs to help achieve these objectives including expanding on economic, workforce, and societal benefits.

Similar to a system impact study currently provided under ISO-NE's interconnection review, streamlined value stacking would make information available to investors offering granularity about fixed return, incentives, and revenue opportunities. This requires differentiating and acknowledging the different services that systems can provide and provide value for these benefits in the wholesale market. Storage has a unique ability to simultaneously participate in multiple markets, such as retail, services, and arbitrage markets. FERC is in a position to clarify participation, however, New York has proposed their own "Value Stack" approach to value distributed energy resources. These systems are compensated for energy, capacity and environmental value of their stored electricity. It also outlines additional compensation paid for demand reduction and location system relief value. From this information and the needs of the grid, investors can decide the storage technology and system size for cost-effective and productive systems.

Moreover, it's important to acknowledge the shortcomings or failures of current and proposed policy. Assets, such as batteries and other forms of storage, that shift clean energy to a demand peak that does not coincide with clean generation, are valuable during a transition to clean energy, as proposals are made to eliminate dirty peakers. Before we face a major issue regarding curtailment and overinvestments in renewables that cannot serve peak demand, it is crucial that storage is considered as a least-cost method to shift clean energy to peak periods. Investments should be made now, before we face serious issues marked by the intermittency of renewables. Clean peak incentives can be reinforced by valuing carbon. Then, clear price signals will favor storage that provides the benefits of demand charge reduction and reducing curtailment.

3) Perception:

The power grid is a low-salience issue for most individuals. As such, **building political and public will for policy change will require better educating ratepayers and stakeholders about the full value of a lower-cost, lower-emission, higher-reliability, more-resilient grid supported by increased energy storage.** With municipalities' economies depending on the rise of tele-work, e-commerce, trade, transportation, and manufacturing, building and maintaining a secure energy storage solution to support local business and emergency services might be a good approach, especially as climate change is likely to increase the number and severity of storms. Having an energy storage solution would be a proactive preparedness strategy. **Drawing on New England's heritage of town-meeting governance, community/municipal/co-op-owned storage could be promoted as a wise form of stewardship by cities and towns to ensure reliable, affordable, environmentally responsible electricity.**

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