Massachusetts Battery Storage Measures: Benefits and Costs

July 2018 – White Paper

Applied Economics Clinic

Prepared for:

Clean Energy Group

Author:

Elizabeth A. Stanton, PhD

www.aeclinic.org

July 31, 2018

[AEC-2018-07-WP-02]

Applied Economics Clinic
Economic and Policy Analysis of Energy, Environment and Equity

Table of Contents

Acknowledgements

This report was commissioned by Clean Energy Group in support of its efforts to expand the benefits of energy storage and clean energy technologies. This work is generously funded by Barr Foundation and The Merck Family Fund. CEG wishes to thank the following organizations and individuals for their input and comments: Janet Besser and Jamie Dickerson of Northeast Clean Energy Council, and Michael Kleinberg and Chandler Miller of DNVGL.

About Clean Energy Group

Clean Energy Group (CEG) is a leading national, nonprofit advocacy organization working on innovative policy, technology, and finance strategies in the areas of clean energy and climate change. CEG promotes effective clean energy policies, develops new finance tools, and fosters public-private partnerships to advance clean energy markets that will benefit all sectors of society for a just transition. CEG assists states and local governments to create and implement innovative practices and public funding programs for clean energy and resilient power technologies. CEG manages the Clean Energy States Alliance (CESA), a national nonprofit consortium of public funders and agencies working together to accelerate clean energy deployment. Learn more at www.cleanegroup.org.

About Applied Economics Clinic

The Applied Economics Clinic is a 501(c)(3) non-profit consulting group housed at Tufts University's Global Development and Environment Institute. The Clinic provides expert testimony, analysis, modeling, policy briefs, and reports for public interest groups on the topics of energy, environment, consumer protection, and equity, while providing on-the-job training to a new generation of technical experts.

1. Introduction

Lithium-ion batteries for electric storage are considered in Massachusetts' energy efficiency program administrator's 2019-2021 draft plan, released April 30, 2018,[1] and addressed, partially, in the "BCR Model" spreadsheets (publicly released in June 2018) used to calculate cost-effectiveness in the April draft plan. Massachusetts' assessment of the cost-effectiveness of electric demand and peak-reducing measures' depends on the "BCRs"—or benefit-cost ratios—estimated in these spreadsheets. For measures to be included in the funding allocation and program implementation described in the 2019-2021 plan they must receive a benefit-cost ratio of 1.0 or higher; that is, a measure's benefits must have a higher value than its costs.

This Applied Economic Clinic white paper provides the calculations and assumptions necessary to estimate complete 2019 benefit-cost ratios for battery storage measures in Massachusetts, using a methodology identical to that of the program administrator's own "BCR Model" spreadsheets for the 2019-2021 and previous three-year efficiency plans. The resulting Massachusetts benefit-cost ratios for battery storage in 2019 are:

- 2.8 for a single-family home battery under the low-income efficiency program
- 3.4 for a multi-family apartment complex battery under the commercial and industrial efficiency programs

The benefits of electric battery storage outweigh their costs, and, therefore, must be offered by Massachusetts electric program administrators to their customers, in accordance with the Green Communities Act.[2] This white paper reviews the calculation of a value for battery storage of the cost and each type of benefit included in Massachusetts' cost-effectiveness assessment: avoided energy, avoided energy demand reduction induced price effects (DRIPE), summer generation capacity, winter generation capacity, electric capacity DRIPE, transmission, distribution, and reliability, non-energy benefits, and non-embedded environmental costs. Of these benefits, avoided capacity costs are by far the most substantial.

[1] Massachusetts Program Administrators. 2018. "Massachusetts Joint Statewide Electric and Gas Three-Year Energy Efficiency Plan: 2019-2021". http://ma-eeac.org/wordpress/wp-content/uploads/2019-2021-Three-Year-Energy-Efficiency-Plan-April-2018.pdf

[2] The General Court of the Commonwealth of Massachusetts. 2008. Acts 308-80: An Act Relative to Green Communities. Chapter 169. https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter169.

2. Engineering Assumptions

Lazard's *Levelized Cost of Storage 3.0* report outlines two behind-the-meter energy storage use cases: Case 4, commercial, and Case 5, residential.[3] Case 4, commercial, represents storage "designed for behind-the-meter peak shaving and demand charge reduction services for commercial energy users" while Case 5, residential, represents storage "designed for behind-the-meter residential home use," that "provide backup power, power quality improvements and extend the usefulness of self-generation".[4] This analysis adopts the lithium-ion assumptions for both Cases.

Figure 1 presents the technical parameters of all cases, with Cases 4 and 5 highlighted.

Figure 1. Energy storage use cases—operational parameters

		Project Life (Years)	MW[(1)]	MWh of Capacity[(2)]	100% DOD Cycles/Day[(3)]	Days/ Year[(4)]	Annual MWh	Project MWh
In-Front-of-the-Meter	1 Peaker Replacement	20	100	400	1	350	140,000	2,800,000
	2 Distribution	20	10	60	1	350	21,000	420,000
	3 Microgrid	10	1	4	2	350	2,800	28,000
Behind-the-Meter	4 Commercial	10	0.125	0.25	1	250	62.5	625
	5 Residential	10	0.005	0.01	1	250	2.5	25

= "Usable Energy"[(5)]

Source: Reproduced from Lazard's Levelized Cost of Storage Analysis – Version 3.0, page 9. https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf. *Emphasis added by Applied Economics Clinic.*

Figure 2 below presents Lazard's levelized cost of storage for Cases 4 and 5 according to their "high" component costs: capital, operations and maintenance (O&M), charging, taxes and other costs. In the calculations presented in this white paper, the following changes are made to Lazard's treatment of the components:

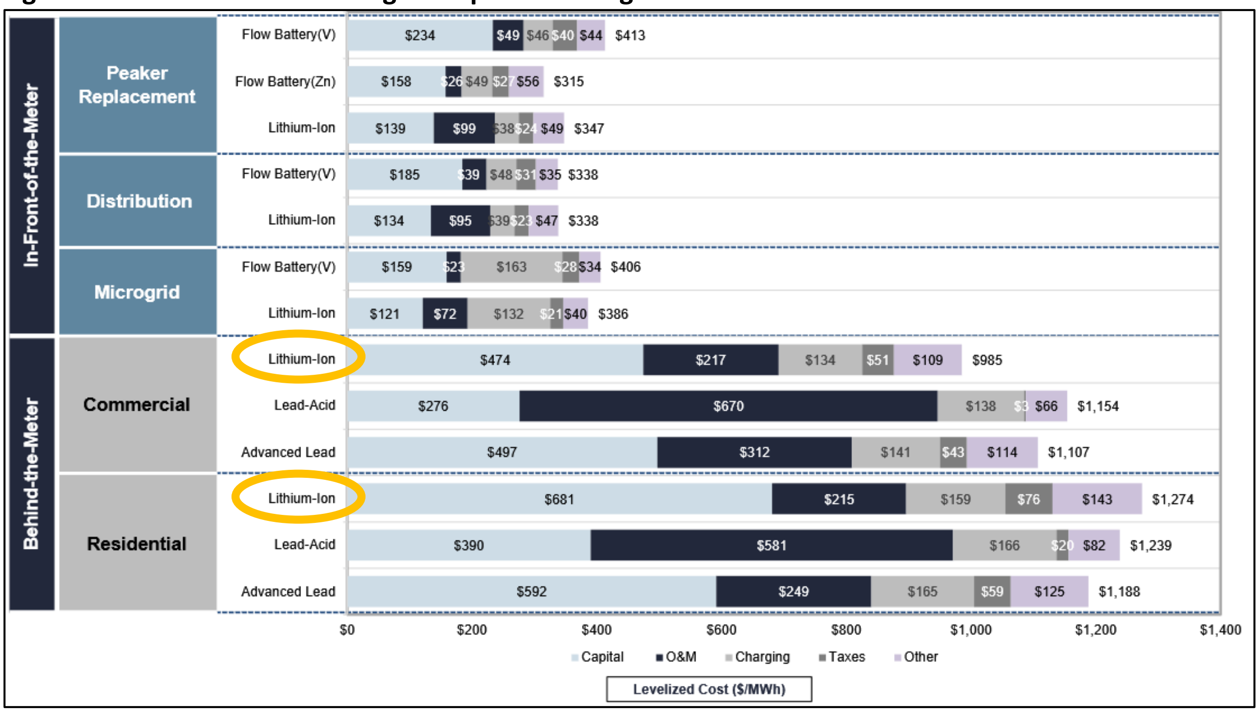
- Capital costs are de-escalated by 20 percent from the 2017 cost, following Lazard's assumption, to estimate the 2019 capital cost.

---

[3] Lazard. November 2017. *Lazard's Levelized Cost of Storage Analysis – Version 3.0*, page 8. https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf
[4] Ibid.

- Capital costs per MWh of battery capacity are adjusted to instead reflect capacity costs per MWh of use based on 52 days of use per year (that is, 52 full cycles per year—on average, one cycle per week) instead of the frequency of use shown in Figure 1.
- Charging costs are removed because, in Massachusetts, costs and savings related to the use of electricity are included in the benefits calculations of benefit-cost ratios. For measures—like storage—where on an annual basis megawatt-hours (MWhs) are lost instead of saved the net costs of charging are considered negative benefits. To include charging in these measures' levelized cost would be double counting.

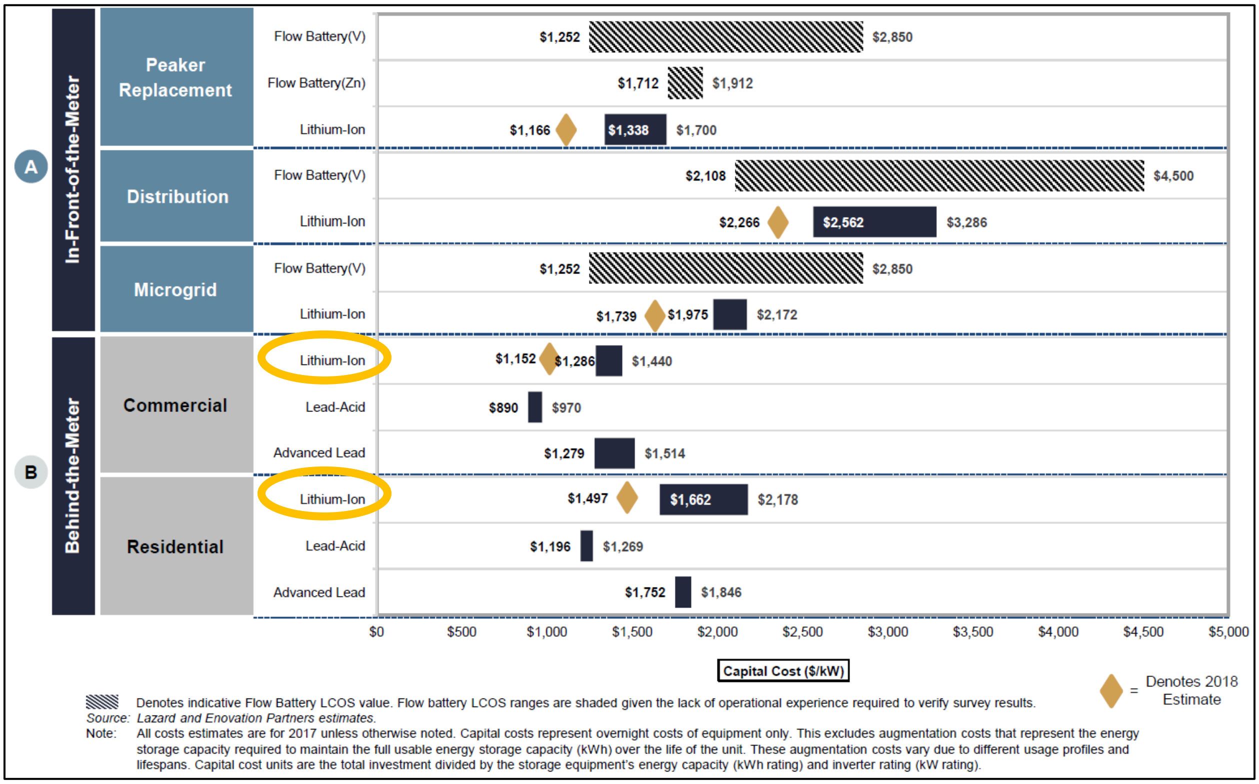
Figure 2. Levelized cost of storage components—high



Source: Reproduced from Lazard's Levelized Cost of Storage Analysis – Version 3.0, page 29. https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf. *Emphasis added by Applied Economics Clinic.*

Figure 2 and Figure 3 together show that Lazard's levelized capital costs of $474/MWh for commercial multi-family and $681/MWh for low-income single-family represent 1,440/kW for commercial and $2,178/kW for residential. When we reduce these costs by 20 percent for 2019, the per kW capital costs are $1,152/kW for multi-family and $1,742/kW for single-family.

Figure 3. Capital cost comparison: $/kW



Source: Reproduced from Lazard's Levelized Cost of Storage Analysis – Version 3.0, page 15. https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf. *Emphasis added by Applied Economics Clinic.*

3. Total Resource Cost

The total resource cost is calculated as the product of the measure or system life in years, the annual production in MWh, and the levelized cost in dollars per MWh, scaled proportionately to the kW size of the system being analyzed. These kW system sizes used in this report are: 6 kW for a single-family battery in the low-income efficiency program, and 30 kW for multi-family battery in the commercial and industrial efficiency program. In their "BCR Model" spreadsheets, National Grid assumes 2.5 kW for residential batteries, and Cape Light Compact assumes 5 kW for residential and 5 kW for commercial and industrial batteries. Eversource and Unitil do not include any system size measures in their "BCR Model" spreadsheets. Because technical assumptions regarding battery performance and cost are proportional to system size throughout these calculations, system size does not impact on cost-effectiveness.

For simplicity, a single system of each kind of measure (residential and commercial) is assumed for the calculations presented in this white paper. This should not be interpreted as a recommendation for how many measures the program administrators should strive to provide.

Using this method, total resource costs for each measure are $13,163 for low-income measures and $46,322 for commercial and industrial measures (see Table 1 below). It is important to note that these total resource costs represent levelized costs per MWh of battery discharge, not capital costs, and are estimated for the 10-year lifetime of the measures.

Table 1. Total resource cost

Parameter for 2019	Low-Income	C&I	Source
Quantity	1	1	
Measure Life	10	10	Lazard's Levelized Cost of Storage Analysis v.3.0 November 2017, p.9
Maximum Load Reduction (kW)	6	30	
Annual kWh Production (kWh)	624	3,120	Lazard's Levelized Cost of Storage Analysis v.3.0 November 2017, p.9
2019 Levelized Cost ($/MWh) without capital costs	$434	$377	Lazard's Levelized Cost of Storage Analysis v.3.0 November 2017, p.12, 14, 29; "high" cost of storage components; 2017 total cost per MWh less capital and charging costs
2019 capital cost ($/kW)	$1,742	$1,152	Lazard's Levelized Cost of Storage Analysis v.3.0 November 2017, p.15, "high" cost of storage components; 2017 capital cost less 10% per year per Lazard
Total Resource Cost ($)	**$13,163**	**$46,322**	**Calculation; multiplied by measure life**

Source: Applied Economics Clinic calculation

4. Energy Use by Time Period

The program administrators' "BCR Model" methodology has traditionally been used to estimate the benefits and costs of energy efficiency measures that reduce annual energy demand. While the methodology includes the apparatus and assumptions necessary to estimate benefits from peak shifting measures—such as batteries—that change the pattern of energy demand but do not lower the annual total, this is not the way these spreadsheets have typically been used. For a typical energy efficiency measure, the gross annual kWh savings would be a positive value, but for the battery storage measures shown here, they are negative, due to round-trip efficiency losses inherent in batteries. Batteries are typically charged at times of low demand or low energy price and discharged at times of high demand or high energy prices. If batteries had perfect round-trip efficiency (no energy was lost in storing and discharging the battery), then gross annual kWh savings would equal zero. Energy out would equal energy in. However, Lazard assumes 15 percent efficiency losses for commercial batteries and 14 percent efficiency losses for residential batteries.[5] For this reason, gross annual kWh saved shows a loss, or negative value: negative 87.4 kWh for low-income and negative 468 kWh for commercial and industrial (see Table 2 below).

Table 2. Energy use by time period

Parameter for 2019	Low-Income	C&I	Source
EE: Gross Annual kWh Saved	(87.4)	(468.0)	Assume 15% efficiency loss for commercial; 14% for residential Lazard's Levelized Cost of Storage Analysis v.3.0 November 2017, p.31
Summer Peak Energy (%)	33.3%	33.3%	By assumption: representing a peak shifting measure
Summer Off-Peak Energy (%)	-33.3%	-33.3%	
Winter Peak Energy (%)	66.7%	66.7%	
Winter Off-Peak Energy (%)	-66.7%	-66.7%	
Summer Coincident (%)	100.0%	100.0%	MA PAs assumption
Winter Coincident (%)	100.0%	100.0%	By assumption
Summer Peak Energy MWh Net Lifetime	2.1	10.4	Changed PA calculation to refer to total peak MWh instead of total annual MWh savings/losses
Summer Off-Peak Energy MWh Net Lifetime	-2.4	-12.2	Changed PA calculation to refer to total off-peak MWh instead of total annual MWh savings/losses; off peak calculated as 100%/(1-efficiency rate)
Winter Peak Energy MWh Net Lifetime	4.2	20.8	Changed PA calculation to refer to total peak MWh instead of total annual MWh savings/losses
Winter Off-Peak Energy MWh Net Lifetime	-4.8	-24.5	Changed PA calculation to refer to total off-peak MWh instead of total annual MWh savings/losses; off peak calculated as 100%/(1-efficiency rate)

Source: Applied Economics Clinic calculations

5 Lazard. November 2017. *Lazard's Levelized Cost of Storage Analysis – Version 3.0*, page 31. https://www.lazard.com/media/450338/lazard-levelized-cost-of-storage-version-30.pdf

The program administrators' "BCR Model" takes the annual kWh saved and divides it into four time-periods—summer peak, summer off-peak, winter peak, winter off-peak—totaling 100 percent. For example, National Grid's new residential buildings high-rise lighting measure is assumed to have annual savings allocated as follows: 12.9 percent summer peak, 15.2 percent summer off-peak, 36.3 percent winter peak, and 35.6 percent winter off-peak.

Alternatively, for a storage measure, the assumption used in this white paper is that energy is subtracted from energy demand during summer and winter peak (a negative percentage) and added on to demand during summer and winter off-peak (a positive percentage), adding up to zero across the four time-periods. (Efficiency losses are included in the calculation of gross annual kWh saved and are therefore not included in these shares to avoid double counting.) The values use in these calculations (shown in Table 2) are 33.3 percent summer peak and 66.7 percent winter peak, negative 33.3 percent summer off-peak and negative 66.7 percent winter off-peak, and 100 percent summer and winter coincident.[6] This is equivalent to assumption an equal use of the battery in every month of the year (where summer is assumed to last for four months, and winter for eight months).

Based on these assumptions, the avoided energy over a ten-year system life from a 6 kW low-income single-family battery is: 2.1 MWh of summer peak energy and 4.2 MWh of winter peak energy, and negative 2.4 MWh of summer off-peak energy and negative 4.8 MWh of winter off-peak energy. The avoided energy over a ten-year system life from a 30 kW commercial multi-family battery is: 10.4 MWh of summer peak energy and 20.8 MWh of winter peak energy, and negative 12.2 MWh of summer off-peak energy and negative 24.5 MWh of winter off-peak energy (see Table 2 above).

5. Avoided-Energy Benefits

Avoided-energy benefits are the product of avoided energy (in MWh) and avoided energy prices, as calculated in the *Avoided Energy Supply Components in New England: 2018 Report* (AESC 2018).[7] Avoided energy prices are calculated on an hourly basis in AESC 2018 and then aggregated to summer peak, summer off-peak, winter peak, winter off-peak. The average energy prices for these time periods, by year, are very sensitive to changes in the assignment of hours as peak or off-peak. AESC 2018 follows the definition of peak as 9 am to 11 pm each weekday (excluded holidays) for both summer (four months) and winter (eight months). This broad definition of "peak" is not useful in representing the strategic use of batteries to relieve tight energy markets in periods of high energy demand or high energy prices.

---

[6] Program administrators hard-code a winter coincidence to peak of 0 percent (see "BCR Model" spreadsheets, 'ADMYr1 tab, AE4:AE123).
[7] Synapse Energy Economics. June 1, 2018. Avoided Energy Supply Components in New England: 2018 Report. http://www.synapse-energy.com/sites/default/files/AESC-2018-17-080-June-Release.pdf

As shown in Table 3, redefining peak as those hours with the highest energy prices or highest MWh sales results in a very different allocation of hours between summer peak, summer off-peak, winter peak, winter off-peak. By energy price, all but one of the highest priced hours are in the winter months, and 43 percent of these are off-peak. By demand, 28 percent are in winter and 48 percent of these are off-peak.

Table 3. Peak/Off-peak hours for 2019

	Total Count	Highest 10% by	
		Energy Price	MWh
Summer peak	1,260	0	317
Summer offpeak	1,668	1	313
Winter peak	2,565	502	128
Winter offpeak	3,267	373	118

Source: Applied Economics Clinic calculations

Table 4 demonstrates how average energy prices change based on each of these definitions. The average avoided energy price for winter peak is $47 under the AESC 2018 definition of peak, $80 under the definition of peak as those hours with the highest energy prices, and $73 under the definition of peak as those hours with the highest MWh sales. The average avoided energy price for winter off-peak is $42 under the AESC 2018 definition of peak, $78 under the definition of peak as those hours with the highest energy prices, and $75 under the definition of peak as those hours with the highest MWh sales.

The average avoided energy price for summer peak is $31 under the AESC 2018 definition of peak and $37 under the definition of peak as those hours with the highest MWh sales. The average avoided energy price for summer off-peak is $27 under the AESC 2018 definition of peak, $69 under the definition of peak as those hours with the highest energy prices, and $36 under the definition of peak as those hours with the highest MWh sales.

Table 4. Peak/Off-peak energy prices for 2019

	Total Count	Highest 10% by	
		Energy Price	MWh
Summer peak	$31	n/a	$37
Summer offpeak	$27	$69	$36
Winter peak	$47	$80	$73
Winter offpeak	$42	$78	$75

Source: Applied Economics Clinic calculation

Table 5 and Table 6 below present avoided-energy benefits using two different definitions.

Table 5 presents avoided-energy benefits using the AESC 2018 definition of peak; benefits are negative for both storage measures, meaning a cost to the electric system: -$22 for low-income single-family and -$138 for commercial multi-family.

Table 5. Avoided energy benefits: AESC 2018 definition of peak

Parameter for 2019	Low-Income	C&I	Source
Summer Peak Energy Benefits ($)	$113	$563	Changed PA calculation to refer to total peak MWh instead of total annual MWh; corrected erroneous cell reference to wrong avoided costs
Summer Off-Peak Energy Benefits ($)	(113.0)	(572.0)	Changed PA calculation to refer to total off-peak MWh instead of total annual MWh; off peak calculated as 100%/(1-efficiency rate); corrected erroneous cell reference to wrong avoided costs
Winter Peak Energy Benefits ($)	$288	$1,440	Changed PA calculation to refer to total peak MWh instead of total annual MWh; corrected erroneous cell reference to wrong avoided costs
Winter Off-Peak Energy Benefits ($)	($310)	($1,569)	Changed PA calculation to refer to total off-peak MWh instead of total annual MWh; off peak calculated as 100%/(1-efficiency rate); corrected erroneous cell reference to wrong avoided costs
Total Avoided Energy Benefits ($)	**($22)**	**($138)**	**Sum**

Source: Applied Economics Clinic calculation; cell references corrected in "BCR Model" spreadsheets, 'ADMStrategies' tab.

Table 6 presents avoided-energy benefits using the percent of hours by energy price definition that is consistent with discharging an average of one time per week: the highest 2.2 percent of hours by energy price in winter and the highest 5.0 percent of hours by energy price in summer. Following this method, batteries would have time to charge in between each discharge. In addition, discharges occur during times of highest energy prices. With just 52 discharges per year, it is possible to select times of very high energy prices, and still have time to charge between each discharge. Using this definition, benefits are positive for both storage measures—meaning a positive benefit to the system: $162 for low-income single-family and $787 for commercial multi-family.

Table 6. Avoided energy benefits: Discharging 52 times per year

Parameter for 2019	Low-Income	C&I	Source
Summer Peak Energy Benefits ($)	$136	$682	With peak definition adjusted to match 52 discharges per year
Summer Off-Peak Energy Benefits ($)	($119)	($602)	
Winter Peak Energy Benefits ($)	$461	$2,305	
Winter Off-Peak Energy Benefits ($)	($316)	($1,598)	
Total Avoided Energy Benefits ($)	**$162**	**$787**	**Sum**

Source: Applied Economics Clinic calculation

6. Avoided-Energy DRIPE Benefits

Demand reduction induced price effects (DRIPE) are defined in AESC 2018 as "the reduction in prices in the wholesale markets for capacity and energy, relative to the prices forecast in the Reference case, resulting from the reduction in quantities of capacity and of energy required from those markets due to the impact of efficiency and/or demand response programs. Thus, DRIPE is a measure of the value of efficiency in terms of the reductions in wholesale prices seen by all retail customers in a given period."[8] Avoided-energy DRIPE benefits are the product of avoided energy and avoided-energy DRIPE as presented in AESC 2018.

The avoided-energy DRIPE benefits presented in Table 7 have been adapted to the definition of peak as the highest 10 percent by energy price, although this change makes relatively little difference to the resulting benefits. Benefits are positive for both storage measures, meaning a positive benefit to the system: $38 for low-income single-family and $185 for commercial multi-family.

[8] Synapse Energy Economics. June 1, 2018. "Avoided Energy Supply Components in New England: 2018 Report". Page 13. http://www.synapse-energy.com/sites/default/files/AESC-2018-17-080-June-Release.pdf.

Table 7. Avoided-energy DRIPE benefits

Parameter for 2019	Low-Income	C&I	Source
Summer Peak Energy DRIPE Benefits ($)	$41	$206	Changed PA calculation to refer to total peak MWh instead of total annual MWh saved/lost; corrected erroneous cell reference to wrong avoided costs
Summer Off-Peak Energy DRIPE Benefits ($)	($33)	($165)	Changed PA calulation to refer to total off-peak MWH instead of total annual MWh saved/lost; off-peak calculated as 100$/(1-efficiency rate); corrected erroneous cell reference to wrong avoided costs
Winter Peak Energy DRIPE Benefits ($)	$126	$631	Changed PA calculation to refer to total peak MWH instead of total annual MWh saved/lost; corrected erroneous cell reference to wrong avoided costs
Winter Off-Peak Energy DRIPE Benefits ($)	($85)	($429)	Changed PA calculation to refer to total off-peak MWH instead of total annual MWh saved/lost; off-peak calculated as 100$/(1-efficiency rate); corrected erroneous cell reference to wrong avoided costs
Energy Electric Cross DRIPE Benefits ($)	($11)	($58)	
Total Energy DRIPE Benefits ($)	**$38**	**$185**	**Sum**

Source: Applied Economics Clinic calculations

7. Avoided-Capacity Benefits

The program administrator’s “BCR Model” awards measures with benefits based on avoided costs of summer generation capacity, winter generation capacity, electric capacity DRIPE, transmission, distribution, and reliability—together referred to as “avoided-capacity benefits.” The benefits shown in Table 8 are calculated following the program administrator’s methodology exactly with one important change: the program administrator’s assumption of a winter capacity value of $0/kW for storage measure has been adjusted to the AESC 2018 un-cleared capacity value by year.[9] The sum of all avoided-

[9] Un-cleared capacity chosen as a proxy to replace zero values. Program administrators hard-code a winter capacity value of $0/kW (see “BCR Model” spreadsheets, ‘Avoided Cost’ tab, O9:O40), which applies to both energy efficiency and advanced demand management measures.

capacity benefits for the two storage measures is positive, $30,861 for low-income single-family and $154,300 for commercial multi-family.

Table 8. Avoided-capacity benefits

Parameter for 2019	Low-Income	C&I	Source
Summer Generation Capacity Benefits ($)	$2,586	$12,928	
Winter Generation Capacity Benefits ($)	$2,586	$12,928	Changed PA calculation to use uncleared capacity value per kW instead of $0. Note that PAs assign winter generation a value of $0/kW for all measures.
Electric Capacity DRIPE Benefits ($)	$14,362	$71,810	
Transmission Benefits ($)	$2,491	$12,454	
Distribution Benefits ($)	$8,342	$41,708	
Reliability Benefits ($)	$494	$2,472	
Total Electric Capacity Benefits ($)	**$30,861**	**$154,300**	**Sum**

Source: Applied Economics Clinic calculations

8. Avoided-Non-Energy Benefits

The program administrators' "BCR Model" assigns non-energy benefits to numerous energy efficiency measures based on the *Massachusetts Program Administrators' Massachusetts Special and Cross-Sector Studies Area, Residential and Low-Income Non-Energy Impacts Evaluation*.[10] Table 9 lists non-energy benefits for which monetary values were provided in the 2011 Evaluation; marked in green are the subset of these benefits assigned to measures in the program administrator's 2019-2021 April draft plan.

[10] Massachusetts Program Administrators. 2011. *Massachusetts Special and Cross-Sector Studies Area, Residential and Low-Income Non-Energy Impacts (NEI) Evaluation*. http://ma-eeac.org/wordpress/wp-content/uploads/Special-and-Cross-Sector-Studies-Area-Residential-and-Low-Income-Non-Energy-Impacts-Evaluation-Final-Report.pdf

Table 9. Avoided-non-energy benefits

NEI	Duration
UTILITY PERSPECTIVE	
Arrearages	Annual
Bad debt write-offs	Annual
Terminations and reconnections	Annual
Rate discounts	Annual
Customer calls	Annual
Collections notices	Annual
Safety-related emergency calls	Annual
Insurance savings	—
SOCIETAL PERSPECTIVE	
National Security	Annual
NON-RESOURCE BENEFITS	
Appliance Recycling – Avoided landfill space	One time
Appliance Recycling – Reduced emissions due to recycling plastic and glass, reduced emissions	One time
Appliance Recycling – Reduced emissions due to incineration of insulating foam	One time
PARTICIPANT PERSPECTIVE (OWNERS OF LOW-INCOME RENTAL HOUSING), PER HOUSING UNIT	
Marketability/ease of finding renters	Annual
Reduced tenant turnover	Annual
Property value	One time
Equipment maintenance (heating and cooling systems)	Annual
Reduced maintenance (lighting)	Annual
Durability of property	Annual
Tenant complaints	Annual
PARTICIPANT PESPECTIVE (OCCUPANT)	
Higher comfort levels	Annual
Quieter interior environment	Annual
Lighting quality & lifetime	One time
Increased housing property value	One time (Annual for NLI RNC)
Reduced water usage and sewer costs (dishwashers)	Annual
Reduced water usage and sewer costs (faucet aerators)	Annual
Reduced water usage and sewer costs (low flow showerheads)	Annual
More durable home and less maintenance	Annual
Equipment and appliance maintenance requirements	Annual
Health related NEIs	Annual
Improved safety (heating system, ventilation, carbon monoxide, fires)	Annual
Window AC NEIs	Annual

**** Green cells showing the Benefits in April Draft of 2019-2021 Plan**

Source: Massachusetts Program Administrators. 2011. Massachusetts Special and Cross-Sector Studies Area, Residential and Low-Income Non-Energy Impacts (NEI) Evaluation. *Emphasis added by Applied Economics Clinic.*

While storage may provide many non-energy benefits, our literature review did not turn up any valuations of these benefits (see Table 10).

Table 10. Non-energy benefits sources reviewed

Eichman et al. December 2015. "Operational Benefits of Meeting California's Energy Storage Targets." National Renewable Energy Laboratory.
Edmunds et al. February 2017. "The Value of Energy Storage and Demand Response for Renewable Integration in California." Lawrence Livermore National Laboratory.
Edmunds et al. June 2013. "The Value of Energy Storage and Demand Response for Renewable Integration in California." Prepared for the California Energy Commission by Lawrence Livermore National Laboratory.
Energy Storage Association. 2018. "Incidental and Other Benefits." http://energystorage.org/energy-storage/energy-storage-benefits/benefit-categories/incidental-and-other-benefits
Hledik, et al. 2017. "Stacked Benefits: Comprehensively Valuing Battery Storage in California." Prepared for Eos Energy Storage.
Lazard. 2017. "Lazard's Levelized Cost of Storage Analysis – Version 3.0."
Massachusetts Department of Energy Resources and Massachusetts Clean Energy Center. 2016. "State of Charge: Massachusetts Energy Storage Initiative."
Massachusetts Program Administrators. 2011. "Massachusetts Special and Cross-Sector Studies Area, Residential and Low-Income Non-Energy Impacts (NEI) Evaluation." NMR Group, Inc.
Medina et al. 2014. "Electrical Energy Storage Systems: Technologies' State-of-the-Art, Techo-Economic Benefits and Applications Analysis." 47th Hawaii International Conference on System Sciences.
New York Department of Public Service. July 2015. "Staff White Paper on Benefit-Cost Analysis in the Reforming Energy Vision Proceeding." Paper No. 14-M-0101.
NMR Group, Inc. August 2011. "Massachusetts Special and Cross-Sector Studies Area, Residential and Low-Income Non-Energy Impacts (NEI) Evaluation." Prepared for Massachusetts Program Administrators.
ReOpt Web Tool User Manual. https://reopt.nrel.gov/tool/REopt%20Lite%20Web%20Tool%20User%20Manual.pdf
Stark et al. February 2015. "Renewable Electricity: Insights for the Coming Decade." Prepared by Joint Institute for Strategic Energy Analysis for the National Renewable Energy Laboratory.
U.S. Energy Information Administration. 2018. "U.S. Battery Storage Market Trends." U.S. Department of Energy.
Woolf et al. September 2014. "Benefit-Cost Analysis for Distributed Energy Resources." Advanced Energy Economy Institute and Synapse Energy Economics.

Therefore, the calculations presented in this white paper include only one non-energy benefit: a one-time increase to property values of adding a storage system. These values are calculated using the "low-income" benefit from the 2011 Evaluation for a heating retrofit: which was reported to be $949 in the *Massachusetts Program Administrators' Massachusetts Special and Cross-Sector Studies Area, Residential and Low-Income Non-Energy Impacts Evaluation*. The sum of all avoided-non-energy benefits for the two storage measures is positive, $5,235 for low-income single-family and $510 for commercial multi-family (see Table 11).

Table 11. Avoided-non-energy benefits

Parameter for 2019	Low-Income	C&I	Source
One time per Unit (Net)	**$5,235**	**$510**	Massachusetts' Program Administrators' Special and Cross-Sector Studies Area, Residential and Low-Income Non-Energy Impacts Evaluation August 15, 2011; p.1-6, 1-8: Increased housing property value is $949 for LI; for multi-family property owners (marketability/ease of finding renters, property value; equipment maintenance) is $17.03 per unit Electric State-wide Cost and Savings Table for 2011: LI 1-4 family heating retrofit TRC for one measure is $1,895; for multi-family $1,155 Resulting assumption: LI housing property value increase by 1/2 of measure capital cost for single-family and 1% for owners of multi-family

Source: Applied Economics Clinic calculations

Avoided-non-energy benefits are the only benefit category in this cost-effectiveness assessment that would change if these batteries were offered in a residential efficiency program, and not in a "low-income" or means-tested program.

9. Avoided Non-Embedded Environmental Costs

Avoided non-embedded-costs are the product of avoided emissions and the avoided cost of emissions from AESC 2018. These avoided costs are "non-embedded" in the sense that they are externality costs: costs that are not included in market prices but have value to Massachusetts. In the program administrators' "BCR Model" spreadsheets' non-embedded costs are set to zero; the benefit-cost ratios present below adopt this same assumption of zero non-embedded environmental costs.

The section presents the benefits that would occur if non-embedded costs instead included a $100 per metric ton cost of carbon dioxide (CO_2), the lower of two non-embedded CO_2 costs provided in AESC 2018. Here, AESC 2018's definition of peak is important in two ways.

First, AESC 2018 assumes (as a result of its modeling of the hourly dispatch of New England electric generation resources) that CO_2 emissions rates (lbs/MWh) are higher in off-peak hours than they are in peak hours (see Table 12).

Table 12. Electric-sector CO_2 and NO_x emissions rate (lbs/MWh)

	Winter		Summer	
	On Peak	*Off Peak*	*On Peak*	*Off Peak*
CO_2	978	999	952	959
NO_x	0.212	0.241	0.173	0.180

Note: Emissions rates do not vary substantially across years.
Source: EnCompass modeling outputs for main 2018 AESC case

Source: Avoided Energy Supply Components in New England: 2018 Report by Synapse Energy, Inc. Table 150. *http://www.synapse-energy.com/sites/default/files/AESC-2018-17-080-June-Release.pdf.*

This finding runs counter to the more common assumption that, in New England, CO_2 emissions rates are lower in off-peak hours and higher in peak hours. ISO-New England reported higher peak than off-peak emissions in is its 2016 annual emissions report (see Table 13), which has held true in the last two years (see Figure 4).

Table 13. 2016 LMU Marginal Emission Rates—All LMUs (lb/MWh)

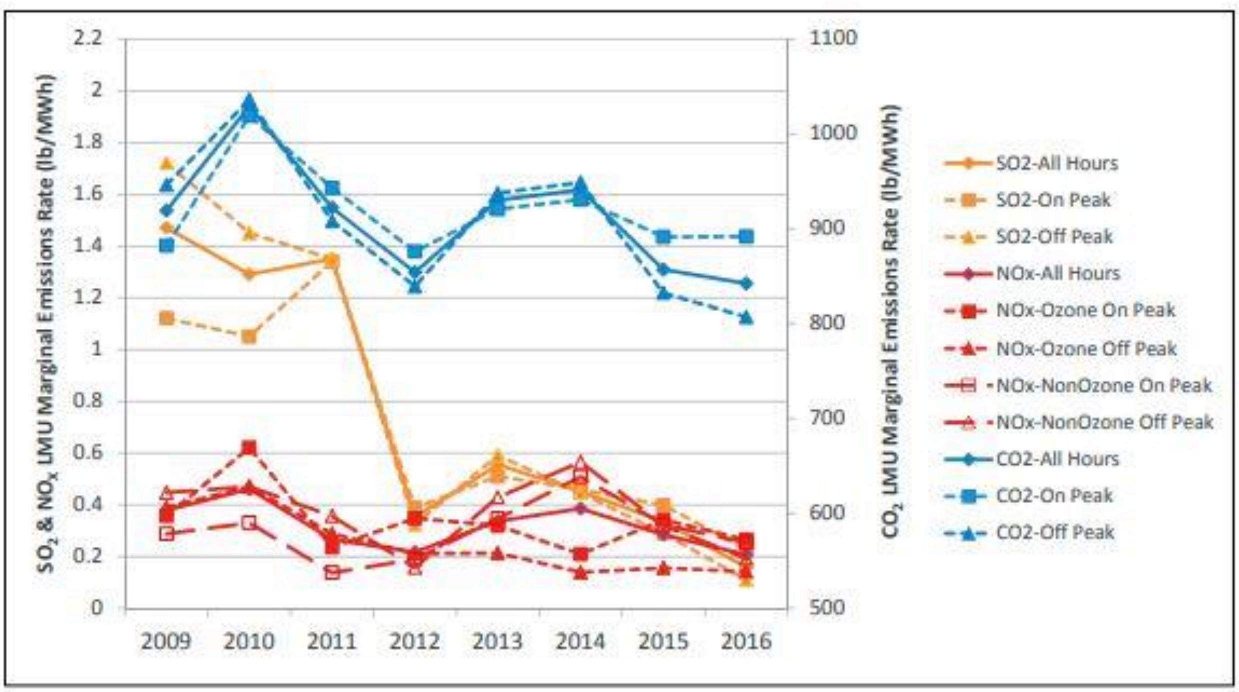
Ozone / Non-Ozone Season Emissions (NOx)					
Air Emission	Ozone Season		Non-Ozone Season		Annual Average (All Hours)
	On-Peak	Off-Peak	On-Peak	Off-Peak	
NO_X	0.26	0.14	0.25	0.19	0.21
Annual Emissions (SO_2 and CO_2)					
Air Emission		Annual			Annual Average (All Hours)
		On-Peak	Off-Peak		
SO_2		0.22	0.11		0.16
CO_2		892	807		842

(a) The ozone season occurs between May 1 and September 30, while the non-ozone season occurs from January 1 to April 30 and from October 1 to December 31.

(b) On-peak hours consist of all weekdays between 8:00 a.m. and 10:00 p.m. Off-peak hours consist of all weekdays between 10:00 p.m. and 8:00 a.m. and all weekend hours.

Source: ISO-NE 2016 Emissions Report, Table 5-3. https://www.iso-ne.com/static-assets/documents/2018/01/2016_emissions_report.pdf.

Figure 4. 2009-2016 Marginal Emissions Rates, all LMUs (lb/MWh)



Source: ISO-NE 2016 Emissions Report, Table 5-9. https://www.iso-ne.com/static-assets/documents/2018/01/2016_emissions_report.pdf.

Second, the definition of peak impacts not only energy prices (see Table 3 and Table 4 above) but also the average emissions rates for these periods. The calculations presented in this white paper do not include any correction or revised definition with regards to emission rates. The necessary data are not available in the AESC 2018 report or user interface.

Both Table 14 and Table 15 present avoided non-energy-costs using AESC 2018's definition of peak. Table 14 presents avoided non-embedded costs using the AESC 2018 peak and off-peak emission rates; benefits are negative for both storage measures—meaning a cost to the system: -$51 for low-income single-family and -$270 for commercial multi-family.

Table 14. Avoided-non-embedded costs: AESC 2018 peak and off-peak emissions rates

Parameter for 2019	Low-Income	C&I	Source
Summer Peak Energy Benefits ($)	$90	$452	Changed PA calculation to refer to total peak MWh instead of total annual MWh; changed peak and off-peak CO2 emissions rates
Summer Off-Peak Energy Benefits ($)	($106)	($535)	Changed PA calculation to refer to total off-peak MWh instead of total annual MWh; off peak calculated as 100%/(1-efficiency rate); changed peak and off-peak CO2 emissions rates
Winter Peak Energy Benefits ($)	$186	$930	Changed PA calculation to refer to total peak MWh instead of total annual MWh; changed peak and off-peak CO2 emissions rates
Winter Off-Peak Energy Benefits ($)	($221)	($1,117)	Changed PA calculation to refer to total off-peak MWh instead of total annual MWh; off peak calculated as 100%/(1-efficiency rate); changed peak and off-peak CO2 emissions rates
Total Avoided Non-Embedded Benefits ($)	**($51)**	**($270)**	**Sum**

Source: Applied Economics Clinic calculations

Table 15 presents avoided non-energy-costs using the peak and off-peak emission rates for ISO-New England's 2018 emissions report; benefits are negative (but smaller) for both storage measures, meaning a cost to the system: -$12 low-income single-family and -$83 for commercial multi-family.

Table 15. Avoided-non-embedded costs: ISO-New England peak and off-peak emissions rates

Parameter for 2019	Low-Income	C&I	Source
Summer Peak Energy Benefits ($)	$85	$423	With peak / offpeak emission rates changed to 2016 ISO-NE values: 2016 ISO New England Generator Air Emissions Report, January 2018, Table 5-3, https://www.iso-ne.com/static-assets/documents/2018/01/2016_emissions_report.pdf
Summer Off-Peak Energy Benefits ($)	($89)	($451)	
Winter Peak Energy Benefits ($)	$170	$848	
Winter Off-Peak Energy Benefits ($)	($178)	($903)	
Total Avoided Non-Embedded Benefits ($)	**($12)**	**($83)**	**Sum**

Source: Applied Economics Clinic calculations

In the total benefits and benefit-cost ratios presented below, non-embedded environmental costs are set to zero, following the program administrators' "BCR Model" assumption.

10. Total Benefits

Table 16 sums up total benefits for these two storage measures assuming the peak definite of highest 10 percent of hours by energy price for energy benefits, non-energy impacts for low-income households, and zero non-embedded environmental costs. For low-income single-family measure, $36,296; for commercial multi-family measure, $155,782.

Table 16. Total benefits

Parameter for 2019	Low-Income	C&I
Total Avoided Energy Benefits ($)	$162	$787
Total Energy DRIPE Benefits ($)	$38	$185
Total Electric Capacity Benefits ($)	$30,861	$154,300
Total Non-Energy Impacts ($)	$5,235	$510
Total Avoided Non-Embedded Benefits ($)	$0	$0
Total Electric Benefits ($)	**$36,296**	**$155,782**

Source: Applied Economics Clinic calculations

11. Benefit-Cost Ratio

Based on the assumptions and methodology presented in this white paper, the benefit-cost ratio for the low-income single-family measure is 2.8 (that is, the value of benefits is nearly three times that of the costs, see Table 17) and the benefit-cost ratio for the commercial multi-family measure is 3.4. Both measures pass the cost-effectiveness test for Massachusetts.

Table 17. Total benefits and costs

Parameter for 2019	Low-Income	C&I
Total Electric Benefits ($)	$36,296	$155,782
Total Resource Cost ($)	$13,163	$46,322
Benefit-Cost Ratio	**2.8**	**3.4**

Source: Applied Economics Clinic calculations

If avoided-non-energy benefits were removed from these calculations, their benefit-cost ratios would be reduced to 2.4 for the single-family battery and 3.4 for the multi-family battery.