Net Emissions Savings Benefit for a Battery Storage Facility in Wendell, Massachusetts

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Applied Economics Clinic

Prepared for: Borrego

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

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About the Applied Economics Clinic

Based in Arlington, Massachusetts, the Applied Economics Clinic (AEC) is a mission-based non-profit consulting group that offers expert services in the areas of energy, environment, consumer protection, and equity from seasoned professionals while providing on-the-job training to the next generation of technical experts.

AEC's non-profit status allows us to provide lower-cost services than most consultancies and when we receive foundation grants, AEC also offers services on a pro bono basis. AEC's clients are primarily public interest organizations—non-profits, government agencies, and green business associations—who work on issues related to AEC's areas of expertise. Our work products include expert testimony, analysis, modeling, policy briefs, and reports, on topics including energy and emissions forecasting, economic assessment of proposed infrastructure plans, and research on cutting-edge, flexible energy system resources.

Founded by Clinic Director and Senior Economist Elizabeth A. Stanton, PhD in 2017, AEC's talented researchers and analysts provide a unique service-minded consulting experience. Dr. Stanton has had two decades of professional experience as a political and environmental economist leading numerous studies on environmental regulation, alternatives to fossil fuel infrastructure, and local and upstream emissions analysis. AEC professional staff includes experts in electric, multi-sector and economic systems modeling, climate and emissions analysis, green technologies, and translating technical information for a general audience. AEC's staff are committed to addressing climate change and environmental injustice in all its forms through diligent, transparent, and comprehensible research and analysis.

1. Introduction

This Applied Economics Clinic white paper—prepared on behalf of Borrego—estimates the net change in carbon dioxide (CO_2) emissions resulting from Borrego's proposed battery storage facility located in Wendell, Massachusetts. The net emission savings of this proposed battery storage project is the sum of "positive" CO_2 emissions savings (less emissions) from the electric grid due to charging and discharging at specific times and "negative" CO_2 emissions (more emissions) due to land-use conversion from forestland to grassland.[1] Combined these two effects result in substantial net emissions savings (less emissions) resulting from the proposed Borrego facility: AEC's analysis shows that the facility's grid emissions reductions would be roughly 87 times greater than its added emissions due to site development.

These types of net emission estimates are used in permitting applications to assess the potential environmental impact of proposed projects in an effort to mitigate damage to the environment. Increasingly, states like Massachusetts and New York are asking for information on the lifetime and/or net emissions impacts of infrastructure projects. Renewable energy projects displace greenhouse gas emitting fossil-fuel-based electric generation but may also add some lifetime emissions from materials, construction, site preparation, or land use changes. Net emissions analysis clarifies the lifetime impact of a project, like a new battery facility, on greenhouse gas emissions.

Section 2 of this white paper summarizes the findings of the net emissions analysis for Borrego's proposed battery storage project in Wendell, Massachusetts. Sections 3 and 4 provide a closer look at the estimated net CO_2 emissions due to land-use conversion and CO_2 emissions savings from the electric grid, respectively.

2. Net Emissions Benefit and Summary of Findings

Borrego's proposed Wendell battery storage facility produces a net benefit to the grid: emissions savings (that is, reduced emissions) after netting out a small increase in emissions and sequestration losses from land-use changes. The emissions savings from charging and discharging at specific times informed by the Massachusetts Clean Peak Standard more than offset the greenhouse gas emissions impact from converting from forestland to grassland to make way for Borrego's proposed battery storage facility (see Table 1).

Table 1. Twenty-year net CO_2 grid benefit of Borrego's proposed battery facility in Wendell, Massachusetts

Project Site	Acreage	Grid Benefit (Emission Savings)	Emissions from Land Use Conversion	Net Benefit (Emission Savings)
		(cumulative metric tons CO_2, 2025-2044)		
Wendell Site	9.4	289,917	-3,338	**286,579**

Note: Negative values represent net CO_2 emissions from sequestration losses or CO_2 direct emissions. Positive values represent a reduction in CO_2 emissions or an emissions savings.

[1] For this study, AEC uses the term "grassland" to represent the non-developed areas of the project site that will be reseeded. The developed areas of the project site (i.e., concrete pads and gravel roads) are accounted for in the calculations.

At the Wendell site, the proposed battery facility displaces approximately 290,000 metric tons CO_2 from the electric grid over the 20 years between 2025 and 2044. Clearing trees and planting grass at the project site results in a net emission increase of roughly 3,300 metric tons CO_2 over the 20-year time period—equivalent to 1 percent of the battery facility's emission savings. The result is a net benefit of 287,000 metric tons CO_2 savings from the Wendell battery facility. Borrego's proposed battery facility offsets roughly 87 times more CO_2 emissions than what is emitted due to the site's development.

These calculations are likely conservative in that they do not include (i) new carbon sequestration resulting from the grass that will grow around battery facility and (ii) future sequestration that will occur when the forest regenerates after project decommissioning (young, growing forests sequester carbon at a considerably higher rate than mature forests). It is also important to note that this analysis does not consider the embodied carbon emissions associated with materials and construction processes of the battery facility itself.

3. Emissions from land-use conversion at Borrego's Wendell site

Borrego's proposed project in Wendell, Massachusetts would result in a net emission increase from biomass and soil due to the land-use conversion from forestland to grassland (with a portion of that land covered by built infrastructure such as concrete pads and access roads). The total emissions impact includes:

- CO_2 emissions from carbon sequestration losses in biomass and soil;
- End-use emissions from burning felled trees as firewood; and
- Net emissions savings from drained organic soils from changes in vegetation cover.

The Wendell site is currently forested land that would be cleared and converted to grassland to develop Borrego's proposed battery storage facility beginning in 2025. The twenty-year cumulative emissions impact (2025 to 2044) broken down by emissions type is shown in Table 2.

Table 2. Twenty-year cumulative emissions impact due to land-use conversion at the Wendell site

Project Site	Biomass Sequestration Losses	Biomass End-Use Emissions	Soil Carbon Sequestration Losses	Soil Carbon Emissions Savings	Total Emissions Impact from Land Use Conversion
	(cumulative metric tons CO_2, 2025-2044)				
Wendell Site	-639	-170	-2,754	225	**-3,338**

Note: Negative values represent net CO_2 emissions from sequestration losses or CO_2 direct emissions. Positive values represent a reduction in CO_2 emissions or an emissions savings.

3.1 Biomass sequestration losses and biomass end-use emissions

Borrego's proposed Wendell site is forested land containing a variety of tree species that currently provide carbon sequestration benefits. The removal of these trees would increase the amount of CO_2 in the atmosphere due to the loss of future carbon sequestration. The removed trees would no longer be able to store new CO_2 each year resulting in a net increase in annual greenhouse gas emissions. In addition, carbon that is currently stored in the existing trees (commonly referred to as "carbon stocks") would be released into the atmosphere if any of the felled timber were burned.

The estimated annual CO_2 net emissions due to future biomass sequestration losses are presented in Table 3. (Please see the Methodology section below for a more detailed discussion of the development of these estimates.) Tree removal at the proposed Wendell site would result in cumulative carbon sequestration losses of approximately 639 metric tons CO_2 from 2025 to 2044.

Table 3. Cumulative CO_2 emissions due to biomass sequestration losses at Borrego's proposed Wendell site

Project Site	Acreage	Biomass Carbon Sequestration Losses (*metric tons CO_2, 2025-2044*)	
		Annual Average	20-Year Total
Wendell Site	9.4	-32	-639

Note: Negative values represent net CO_2 emissions from sequestration losses or CO_2 direct emissions. Positive values represent a reduction in CO_2 emissions or an emissions savings.

Borrego assumes that 17 percent of the felled timber across the Wendell project site will be used as sawmill lumber, while the remainder will be chipped on-site (41.5 percent) or used as firewood (41.5 percent). The portion of the felled timber that will become firewood will release its stored carbon as CO_2 emissions once it is burned. The estimates of these end-use emissions are presented in Table 4. Burning 41.5 percent of the felled timber from the Wendell site as firewood would result in CO_2 emissions of 170 metric tons.

Table 4. CO_2 emissions from biomass end-use at Borrego's proposed Wendell site

Project Site	Weight of Burned Timber (*metric tons*)	Emissions from Biomass End-Use (*metric tons CO_2, 2025-2044*)	
		Annual Average	20-Year Total
Wendell Site	90	-9	-170

Note: Negative values represent net CO_2 emissions from sequestration losses or CO_2 direct emissions. Positive values represent a reduction in CO_2 emissions or an emissions savings. Emissions from biomass end-use occur when felled timber is actively burned as firewood. Although these emissions (represented by the "20-year total") are likely to occur within a few years of clearing the trees, AEC provides an "annual average" to allow for comparison with other components of this analysis.

3.1.1 Methodology

To estimate the total CO_2 emissions from biomass sequestration losses, AEC quantified the difference between initial and future carbon stocks of the forested land at the Wendell project site over a 20-year period from 2025 to 2044. AEC was provided with site-specific data by Licensed Forester Jeffrey D. Golay on tree characteristics for the Wendell project site broken down by tree species and diameter-at-breast height (DBH) measurements.[2] The Wendell project site contains the following tree species: beech, hemlock, red oak, red maple, white pine, and yellow birch.[3]

[2] Personal communication with Jeffrey D. Golay (Massachusetts Licensed Forester #399) accompanied with a forestry report and associated data tables for the Wendell project site dated October 4, 2021.

[3] Hemlock and white pine are both classified as softwood trees, while the other species are classified as hardwood trees.

To estimate the initial and future carbon stocks of the forested land at the Wendell site, AEC first estimated the rate of tree growth from the current year through 2025 and then through end of the 20-year analysis period and the relationship between DBH and biomass weight for each tree species (see below for further details on these steps in the methodology).

AEC converted the weight of living biomass (i.e., aboveground and belowground) from short tons to metric tons for each tree species at each DBH measurement, then calculated the standard dry weight of the trees by multiplying the total biomass weight (aboveground and belowground) by the dry weight ratio of 72.5 percent, an average calculated for temperate tree species.[4,5] Although the average dry weight ratio is for aboveground biomass, AEC applied it to both above- and belowground biomass as a dry weight ratio for the belowground carbon stock pool was not available. AEC used this average dry weight ratio across all species as species-specific dry weight ratios were not available for the trees located at the project site.

AEC calculated the carbon content of the trees by multiplying the dry weight of the trees by carbon factors of 0.521 and 0.498 for hardwood and softwood trees, respectively, then converted the carbon stock from C to CO_2 emissions by multiplying by the molar mass ratio of CO_2 to C (44 units CO_2/12 units C ≈ 3.67).[6]

Finally, AEC estimated the CO_2 emissions due to biomass sequestration losses at the Wendell site by subtracting the future carbon stocks in 2044 from the initial carbon stocks in 2025 (see Figure 1 below).

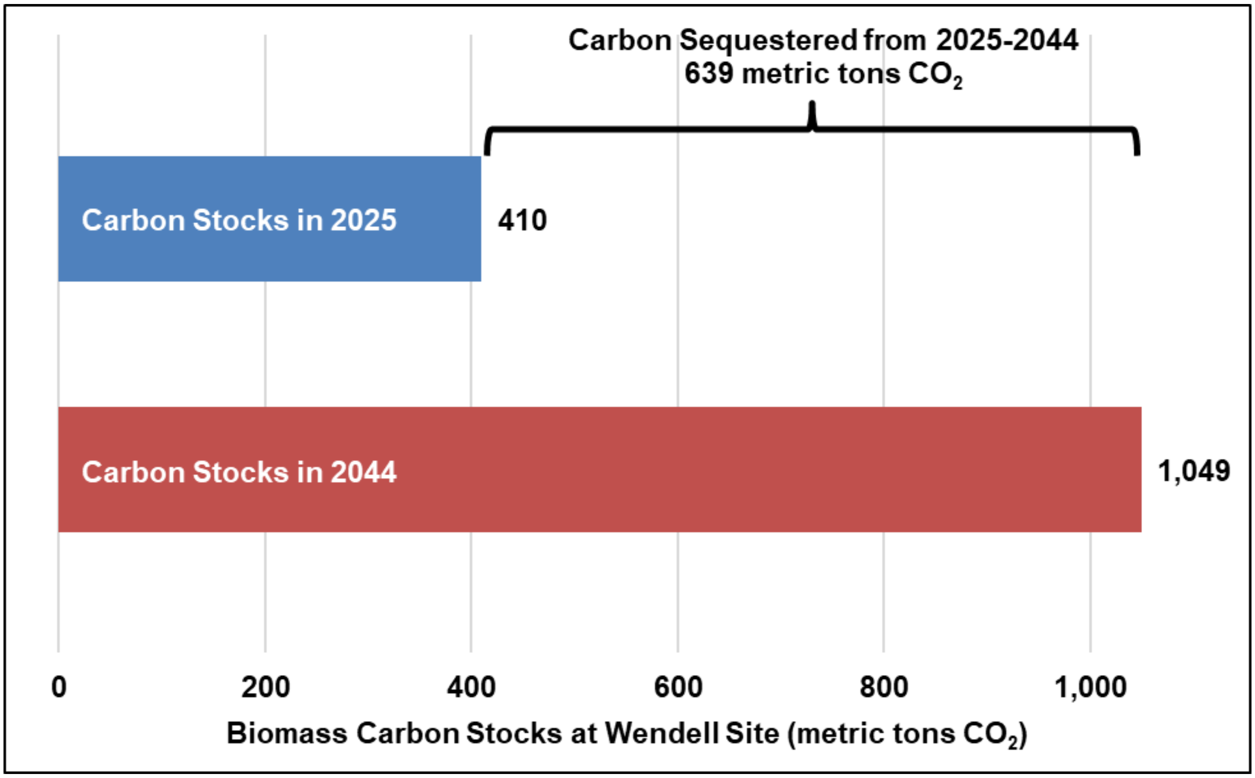
To estimate tree growth, AEC used a simplified, linear growth rate formula, where the rate of growth is a function of a tree's age and DBH. AEC estimated the average growth rate for trees located on the Wendell project site by dividing the mean DBH measurements of each species by the average age of each species, then (due to the small sample size) unweighted averaged across tree species resulting in an average growth rate of roughly 0.15 inches per year. AEC approximated the total tree growth over the analysis period by multiplying the average growth rate (0.15 inches per year) by twenty years to yield a total 20-year growth of approximately 3.1 inches in DBH. Since Borrego's proposed battery facility at the Wendell site is not anticipated to begin operations until 2025, AEC also approximated the tree growth between 2021 (i.e., when the site-specific data was collected) and 2025 to yield a growth of approximately 0.6 inches over the 4-year period.

[4] University of New Mexico. "How to calculate the amount of CO_2 sequestered in a tree per year". Available at: https://www.unm.edu/~jbrink/365/Documents/Calculating_tree_carbon.pdf

[5] DeWald, Scott J., Scott Josiah, and Becky Erdkamp. 2005. "Heating with wood: Producing, harvesting and processing firewood." Cooperative Extension, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln. Available at: https://outreach.cnr.ncsu.edu/ncwood/documents/NebraskaFirewoodGuide.pdf

[6] Earth Labs. November 11, 2019. "Living in a Carbon World – Part B: Carbon Storage in Local Trees". Available at: https://serc.carleton.edu/eslabs/carbon/1b.html

Figure 1. Initial and future biomass carbon stocks at Borrego's proposed Wendell site

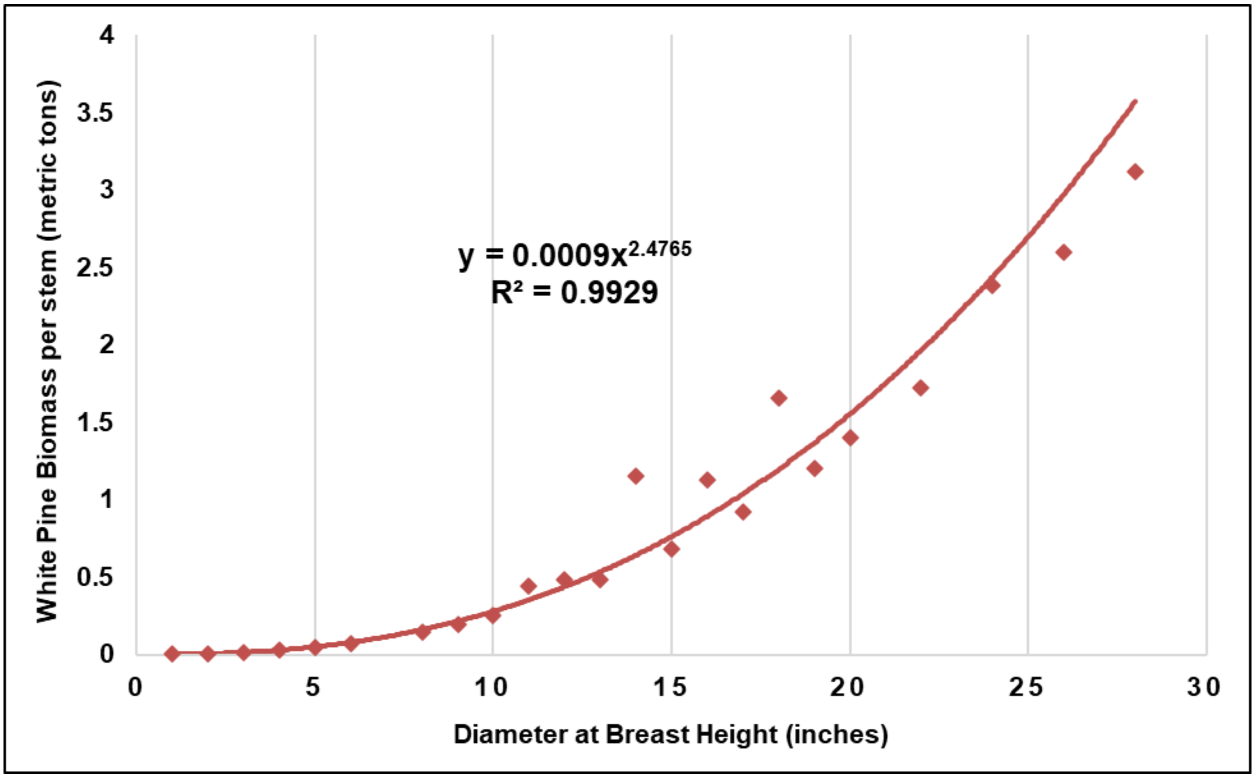


To estimate the relationship between total biomass and DBH, AEC conducted a regression analysis by tree species to construct species-specific allometric equations.[7] To determine this allometric relationship, AEC calculated the total biomass per stem across the Wendell site for each tree species by dividing the total biomass (in metric tons) by the total number of stems at each DBH measurement, then regressed that ratio against the DBH measurements.[8] The resulting equations measure the biomass-per-stem ratio as a function of DBH across for each tree species at the project site (see Figure 2 below for the white pine regression analysis).

[7] Allometric equations are commonly used in forestry to describe the relationship between tree characteristics. The allometric equations used in this analysis were in the form of a power function (i.e., $Biomass = a * DBH^b$). Source: Picard, Saint-André, & Henry. 2012. *Manual for building tree volume and biomass allometric equations: from field measurement to prediction.* Cirad; FAO. Available at: http://www.fao.org/3/i3058e/i3058e.pdf

[8] To determine the allometric relationship for each tree species, AEC supplemented the tree species data at the Wendell site with data received from Jeffrey D. Golay (Massachusetts Licensed Forester #399) for other Borrego project sites in Oakham and Wareham, Massachusetts. Since the heights, age, and DBH range is fairly consistent by species across the sites, AEC found that this supplemental data would be appropriate in these calculations. Sources: (1) Personal communication with Jeffrey D. Golay (Massachusetts Licensed Forester #399) on October 15, 2021; and (2) Castigliego, J.R., C. Lala, E. Tavares, and E.A. Stanton. 2021. *Estimating the Net Change in Carbon Dioxide Emissions for Solar Projects in Massachusetts.* White Paper for Borrego. Available at: https://aeclinic.org/publicationpages/2021/9/08/estimating-the-net-change-in-carbon-dioxide-emissions-for-solar-projects-in-massachusetts

Figure 2. Regression analysis of white pine for selected Borrego sites



Note: This regression analysis utilizes tree species data from Borrego's Wendell, Oakham, and Wareham project sites. Additional project site data was used to supplement the data collected at the Wendell site to better define the allometric relationship for each tree species.

To estimate the CO_2 emissions from timber end-use, AEC considered the expected end-uses for the felled trees from the Wendell project site. Borrego assumes that 17 percent of the felled timber across the Wendell project site will be used as sawmill lumber, while 41.5 percent will be chipped on-site, and 41.5 percent will be used as firewood. Since firewood is the only end-use that is likely to result in CO_2 emissions from burning, AEC multiplied the 2025 carbon stocks (in metric tons of CO_2) at each project site from Figure 1 above by 41.5 percent to calculate the maximum amount of CO_2 emissions that could be released from burning the felled trees allocated for firewood. These emission estimates represent the total amount of CO_2 that would be released under the conditions of "complete" combustion of the firewood.[9]

Incomplete combustion of the firewood would result in a small portion of the stored carbon to be released as carbon monoxide and other carbon-based pollutants. The ratio of CO_2 released during combustion relative to other carbon-based pollutants is known as the "combustion efficiency"—which is estimated to be greater than 90 percent but varies based on the type of wood burned and the conditions of the fire.[10] Due to this uncertainty, AEC made the conservative assumption that all carbon stored in the felled trees is released as CO_2 emissions, which provides a maximum estimate for end-use emissions.

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[9] Complete combustion of wood occurs when there are sufficient oxygen levels resulting in all stored carbon to be released as CO_2.

[10] Tsuchiya, Y. No date. *CO/C02 Ratios in Fire*. Institute for Research in Construction. p.519, 522. Available at: https://iafss.org/publications/fss/4/515/view/fss_4-515.pdf

3.1.2 Comparison to EPA methodology

EPA's "Greenhouse Gases Equivalencies Calculator" [11] provides a different, more generic methodology for calculating the net annual change in biomass carbon stocks. For purposes of comparison, AEC compared its biomass carbon sequestration methodology and results to that of EPA.

The EPA methodology produces a generic estimate of the change in annual carbon stocks for forestland anywhere in the United States of 0.55 metric tons carbon (C) sequestered per hectare per year.[12] EPA's estimate includes carbon sequestration from five different carbon pools: aboveground biomass, belowground biomass, dead wood, litter, and soil (including mineral and organic soil). As part of its analysis, EPA calculates carbon stocks for aboveground biomass, belowground biomass, and soil. AEC's analysis of soil CO_2 emissions is presented separately (in the next section of this white paper) and is thus excluded from this comparison. In addition, AEC excluded analysis of dead wood and litter due to lack of available data and the fact that that dead wood and litter do not actively sequester carbon like living biomass and soils.

For the purpose of comparison to AEC's biomass sequestration estimates above, AEC modified EPA's forest sequestration factor—0.55 metric tons of C sequestered per hectare per year—to only include carbon sequestered by living biomass (i.e., aboveground and belowground biomass). Although EPA does not provide a breakdown of the annual change in this forest sequestration factor by carbon pool source, the agency does provide the breakdown used in estimating its carbon stock density estimate as shown in Figure 3 below.

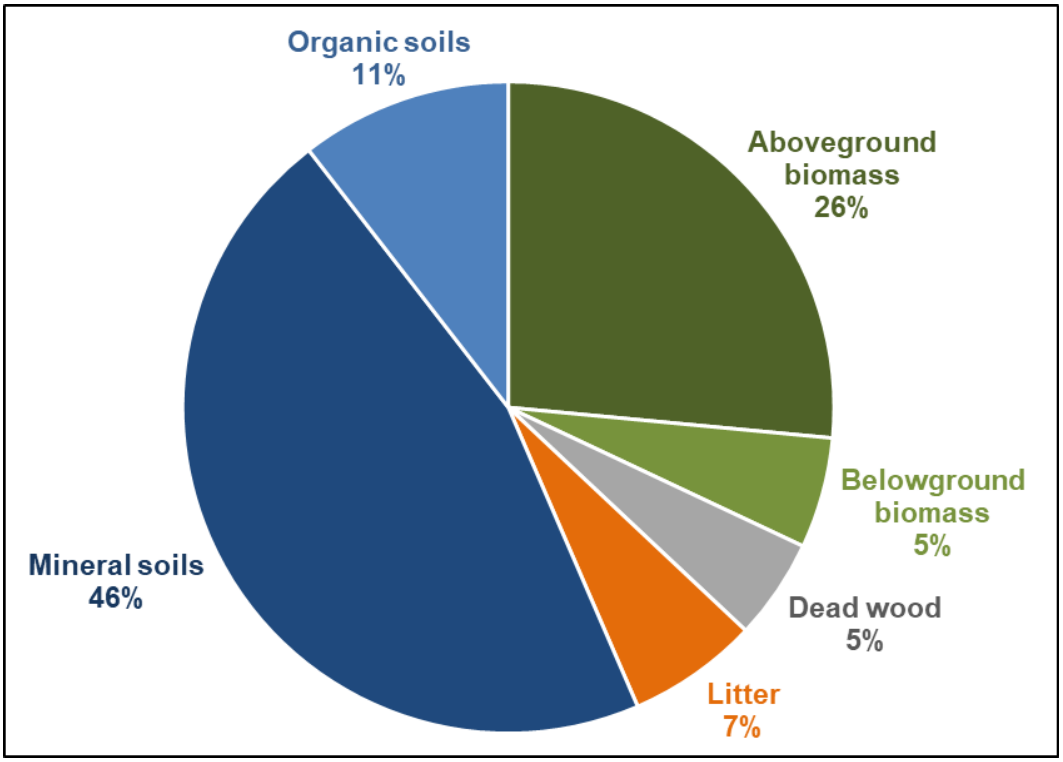
Using this breakdown as a proxy for the composition of EPA's forest sequestration factor, the total carbon density attributable to living biomass is 32 percent (the sum of aboveground and belowground biomass percentages in green in Figure 3 below). This proportion was multiplied by EPA's total forest sequestration factor (0.55 metric tons C per hectare per year) to result in a sequestration factor for living biomass in U.S. forests of 0.18 metric tons C per hectare per year, the amount that is directly comparable to AEC's biomass calculations.

AEC converted EPA's annual sequestration factor for living biomass (0.18 metric tons C per hectare) from C to CO_2 emissions by multiplying by the molar mass ratio of CO_2 to C (44 units CO_2/12 units C ≈ 3.67). Finally, AEC converted the annual CO_2 emissions factor (due to sequestration losses from living biomass) to a per acre basis, resulting in a sequestration factor of 0.26 metric tons CO_2 per acre.

[11] U.S. EPA. *Accessed November 1, 2021.* "Greenhouse Gases Equivalencies Calculator - Calculations and References." Available at: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

[12] EPA's estimate includes carbon sequestration from five carbon pools: aboveground biomass, belowground biomass, dead wood, litter, and soil (including mineral and organic soils).

Figure 3. Carbon stock density of U.S. forests in 2018 by carbon pool category



Source: U.S. EPA. Accessed November 1, 2021. "Greenhouse Gases Equivalencies Calculator - Calculations and References." Available at: *https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references*

The tons C per hectare values provided by EPA are a simple method of estimating a U.S. average annual change in biomass carbon stocks based on nationwide inventories that are tailored neither by region or tree species. The rate of carbon sequestration in trees varies greatly between different regions and tree species with climatic conditions playing a major role in carbon storage potential. AEC's estimates the Wendell-site's specific living biomass carbon sequestration rates to be 3.40 metric tons CO_2 per acre per year compared to the 0.26 metric tons CO_2 per acre per year derived from EPA's methodology (see Table 5). The difference between the AEC and EPA rates is likely attributable to geographical and temporal differences in tree species and climate. AEC's carbon sequestration estimates account for site-specific characteristics by utilizing data collected at the proposed site in Wendell, Massachusetts in late 2021, while EPA's methodology utilizes generic 2018 U.S. data.

Table 5. Comparison of AEC's biomass carbon sequestration rates to EPA's methodology

Project Site	Sequestered Carbon in Biomass (*metric tons CO_2 per acre per year*)		
	AEC Rate	EPA Rate	Difference
Wendell Site	3.40	0.26	3.14

3.2 Soil carbon sequestration losses and soil carbon emissions

The proposed project development on the Wendell site would affect soil emissions in two ways:

- *Soil carbon sequestration losses*: a decrease in carbon sequestration capability after development; and
- *Soil carbon emissions savings*: a reduction in emissions from drained organic soils due to changes in soil characteristics.

The project site is currently forestland and would be converted to grassland[13] during construction, with some areas hosting the battery storage equipment and other built infrastructure. When land is converted from one land use to another (e.g., forestland to grassland), the composition and characteristics of the soil also changes due to the differences in vegetation cover—resulting in a change in carbon sequestration potential and the CO_2 emissions that are released by the soils.

Estimated soil carbon sequestration losses at the project site are presented in Table 6, estimated as the change in carbon stocks from 2025 to 2044. The land-use conversion from forestland to grassland results in a decrease in carbon stocks at the project site, which is largely attributable to grassland soils holding less carbon than forestland soils.[14] (Please see the Methodology section below for a more detailed discussion of the development of these estimates.)

Table 6. CO_2 emissions due to soil carbon sequestration losses at Borrego's proposed Wendell site

Project Site	Acreage	Soil Carbon Sequestration Losses (*metric tons CO_2, 2025-2044*)	
		Annual Average	20-Year Total
Wendell Site	9.4	-138	-2,754

Note: Negative values represent net CO_2 emissions from sequestration losses or CO_2 direct emissions. Positive values represent a reduction in CO_2 emissions or an emissions savings.

The estimated change in CO_2 emissions from soil carbon emissions at the Wendell project site is presented in Table 7 below. Drained organic soils release CO_2 emissions from microbial processes, root respiration, as well as respiration of soil fungi and fauna in the soils.[15] Two factors interact to result in lower emissions: forestland soils emit greenhouse gases at a slightly lower rate than grassland soils; however, at the Wendell site the total acreage of emitting soils is reduced from this project.

[13] For this study, AEC uses the term "grassland" to represent the non-developed areas of the project site that will be reseeded. The developed areas of the project site (i.e., concrete pads and gravel roads) are accounted for in the calculations.

[14] Thompson, JR. et al. December 2020. *Land Sector Report: A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study*. Harvard Forest, Harvard University. Prepared for the Commonwealth of Massachusetts. Section 3.7. Available at: https://www.mass.gov/doc/land-sector-technical-report/download

[15] Oertel, Cornelius, Jörg Matschullat, Kamal Zurba, Frank Zimmermann, and Stefan Erasmi. 2016. "Greenhouse gas emissions from soils—A review." Geochemistry 76, no. 3: 327-352. Available at: https://core.ac.uk/download/pdf/82396671.pdf

The Wendell site would result in a reduction in soil emissions (or *emissions savings*) due to the land-use conversion. This emissions savings is primarily due to the greater percentage of land area covered built infrastructure (e.g., batteries, access roads, etc.). At the Wendell site, built infrastructure would cover approximately 33 percent, or 3.1 acres, of the converted land area. This ratio of built infrastructure at the Wendell site, in combination with the relatively small difference in emission factors of soil between forestland and grassland, results in lower soil emissions (i.e., an emissions savings) from the land-use conversion.

Table 7. CO_2 emissions from soil carbon emissions at Borrego's proposed Wendell site

Project Site	Acreage	Emissions from Drained Organic Soils (*metric tons CO_2, 2025-2044*)	
		Annual Average	20-Year Total
Wendell Site	9.4	11.3	225.1

Note: Negative values represent net CO_2 emissions from sequestration losses or CO_2 direct emissions. Positive values represent a reduction in CO_2 emissions or an emissions savings.

3.2.1 Methodology

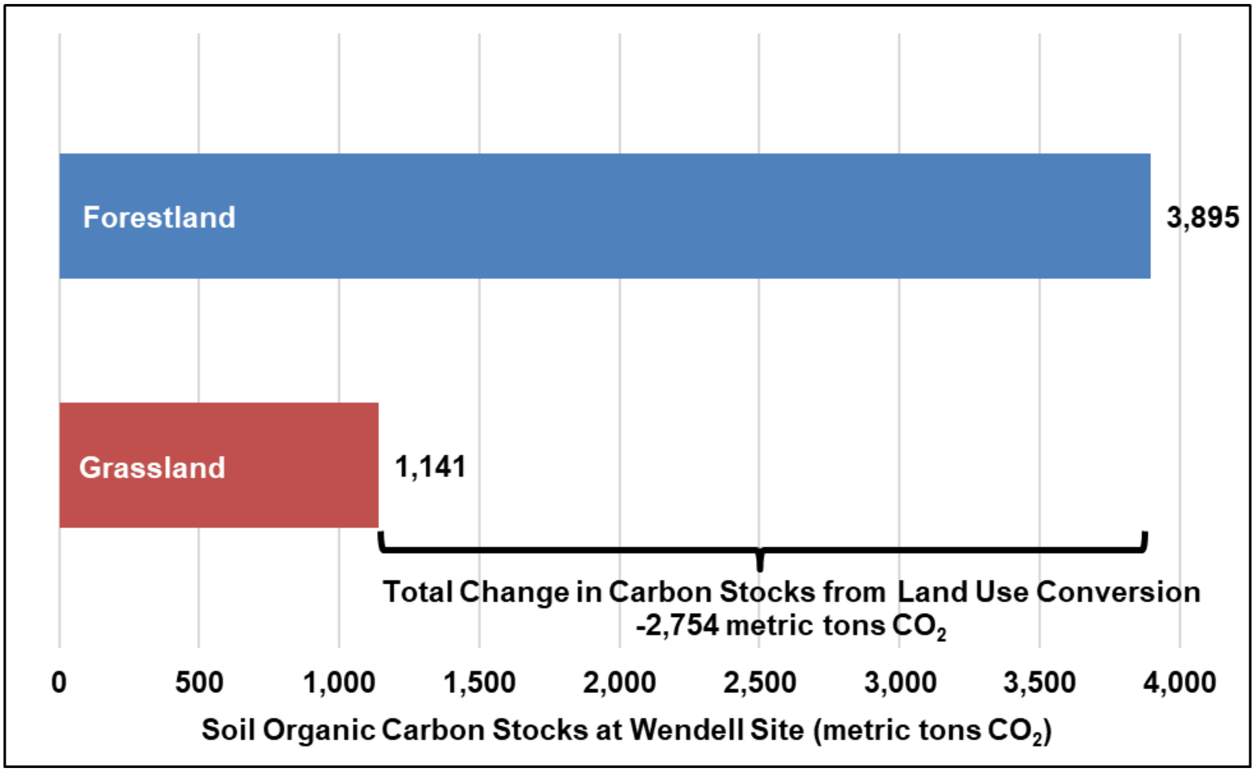
To estimate the change in soil carbon stocks following development of Borrego's proposed battery storage facility at the Wendell site, AEC modified EPA's "Greenhous Gases Equivalencies Calculator" methodology for calculating changes in soil organic carbon stocks from the conversion of forestland to cropland.[16] To better represent the Wendell project site, AEC replaced EPA's generic soil organic carbon factors (metric tons C per hectare) with those for forests and pasture/agricultural land taken from the *Land Sector Technical Report* prepared for Massachusetts' Executive Office of Energy and Environmental Affairs (MA EEA).[17] AEC multiplied MA EEA's soil organic carbon density for forests (279.0 metric tons C per hectare) by the *total acreage* of the project site (9.4 acres) to calculate the pre-conversion soil carbon stocks (i.e., in 2025). Post-conversion soil carbon stocks were calculated by multiplying MA EEA's soil organic carbon density for pasture/agricultural land (122.4 metric tons C per hectare) by the *net acreage* of each project site (i.e., total site acreage less the land area covered by built infrastructure).

The pre- and post-conversion soil carbon stocks were then converted from C to CO_2 emissions by multiplying by the molar mass ratio of CO_2 to C (44 units CO_2/12 units C ≈ 3.67). AEC subtracted the pre-conversion soil carbon stock of forestland by the post-conversion soil carbon stock of grassland to calculate the total 20-year change in soil carbon stocks due to land-use conversion (see Figure 4 below).

[16] US EPA. March 11, 2021. "Greenhouse Gases Equivalencies Calculator - Calculations and References." *Annual Change in Organic Carbon Stocks in Mineral and Organic Soils*. Available at: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

[17] Thompson, JR. et al. December 2020. Land Sector Report: A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. Harvard Forest, Harvard University. Prepared for the Commonwealth of Massachusetts. Section 3.7. Available at: https://www.mass.gov/doc/land-sector-technical-report/download

Figure 4. Initial and converted soil organic carbon stocks at Borrego's proposed Wendell project



To estimate the annual change in emissions from the soil due to land-use conversion, AEC modified EPA's "Greenhouse Gases Equivalencies Calculator" methodology for estimating emissions from drained organic soil.[18] To better represent the conditions at the Wendell project site, AEC replaced EPA's generic emission factor for cropland soils with an average emission factor for grassland soils in temperate climates (3.15 metric tons C per hectare per year) taken from EPA's *Inventory of U.S. GHG Emissions and Sinks*.[19] AEC kept the assumed emission factor for forestland soils (2.91 metric tons C per hectare per year) from EPA's Calculator since it is based on data for temperate climates derived from IPCC's 2013 supplement to their 2006 Guidelines for Natural Greenhouse Gas Inventories.[20]

[18] US EPA. March 11, 2021. "Greenhouse Gases Equivalencies Calculator - Calculations and References." *Annual Change in Emissions from Drained Organic Soils*. Available at: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

[19] US EPA. 2020. *Annexes to the Inventory of U.S. GHG Emissions and Sinks*. Table A-212. p.A-392. Available at: https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-annexes.pdf

[20] Intergovernmental Panel on Climate Change. 2013. *Methodological Guidance on Lands with Wet and Drained Soils, and Constructed Wetlands for Wastewater Treatment*. Table 2.1. Available at: https://www.ipcc-nggip.iges.or.jp/public/wetlands/pdf/Wetlands_Supplement_Entire_Report.pdf

AEC converted the soil emission factors for forestland and grassland from C to CO_2 emissions by multiplying by the molar mass ratio of CO_2 to C (44 units CO_2/12 units C ≈ 3.67). The emissions factors for each land use type were multiplied by the acreage of the project site to calculate total annual CO_2 emissions from soil pre- and post-conversion. As before, *total acreage* was used to calculate forest soil emissions and the *net acreage*—the total site acreage less the land area covered by built infrastructure—was used to calculate grassland soil emissions (see Table 8). Annual emissions were then multiplied by 20 years to estimate the total soil emissions due to land-use conversion over AEC's analysis period from 2025 to 2044.

Table 8. Pre- and post-conversion annual CO_2 emissions from soils at Borrego's proposed Wendell site

Project Site	Emissions Savings from Drained Organic Soils (*metric tons CO_2 per year*)		
	Forestland Organic Soil Emissions	Grassland Organic Soil Emissions	Total Change in Emissions from Land Use Conversion
Wendell Site	-40.6	-29.4	11.3

Note: Negative values represent net CO_2 emissions from sequestration losses or CO_2 direct emissions. Positive values represent a reduction in CO_2 emissions or an emissions savings.

4. Emissions savings benefit from the grid at the Wendell project site

The proposed battery facility at the site in Wendell, Massachusetts would draw power from the grid during periods in which clean, renewable energy sources are a high share of total New England generation, and discharge energy at times when mostly fossil-fuel-powered generators are displaced by this added energy. The 2020 Massachusetts Clean Peak Energy Standard is "designed to provide incentives to clean energy technologies that can supply electricity or reduce demand during seasonal peak demand periods."[21] The Clean Peak Standard rewards charging at periods of "typically high renewable energy production as a percent of the grid generation mix."[22] Energy discharged by the batteries would displace the dirtier, more expensive fossil fuel generators that are typically on the margin (that is, the most expense plant running and therefore the first to be displaced by added, lower cost energy).[23] By charging using low-emission generation and displacing fossil fuel generation while discharging power, new battery resources result in lower electric grid emissions.

4.1 Grid emissions savings estimates

The estimated grid emissions savings from Borrego's proposed Wendell project are presented in Table 9 and Figure 5 below (see the Methodology section below for a more detailed discussion of the development of these estimates). In total, the proposed Wendell project would result in nearly 290,000 metric tons CO_2 of emissions savings from the grid over the 20-year period between 2025 and 2044, or roughly 14,500 metric tons CO_2 annually. Annual emissions savings grow over time because ISO-New England's average resource mix is

[21] Massachusetts Department of Energy Resources. *Clean Peak Energy Standard*. Available at: https://www.mass.gov/clean-peak-energy-standard

[22] Massachusetts Department of Energy Resources. August 2020. *225 CMR 21.00: Clean Peak Energy Portfolio Standard (CPS)*. Available at: https://www.mass.gov/doc/clean-peak-energy-standard-final-regulation/download pg. 202.

[23] The margin is the point at which sufficient electricity is procured in the energy market. The last, and most expensive, generating resource procured to meet customer demand is the marginal resource (or "on the margin") and sets the clearing price for the market.

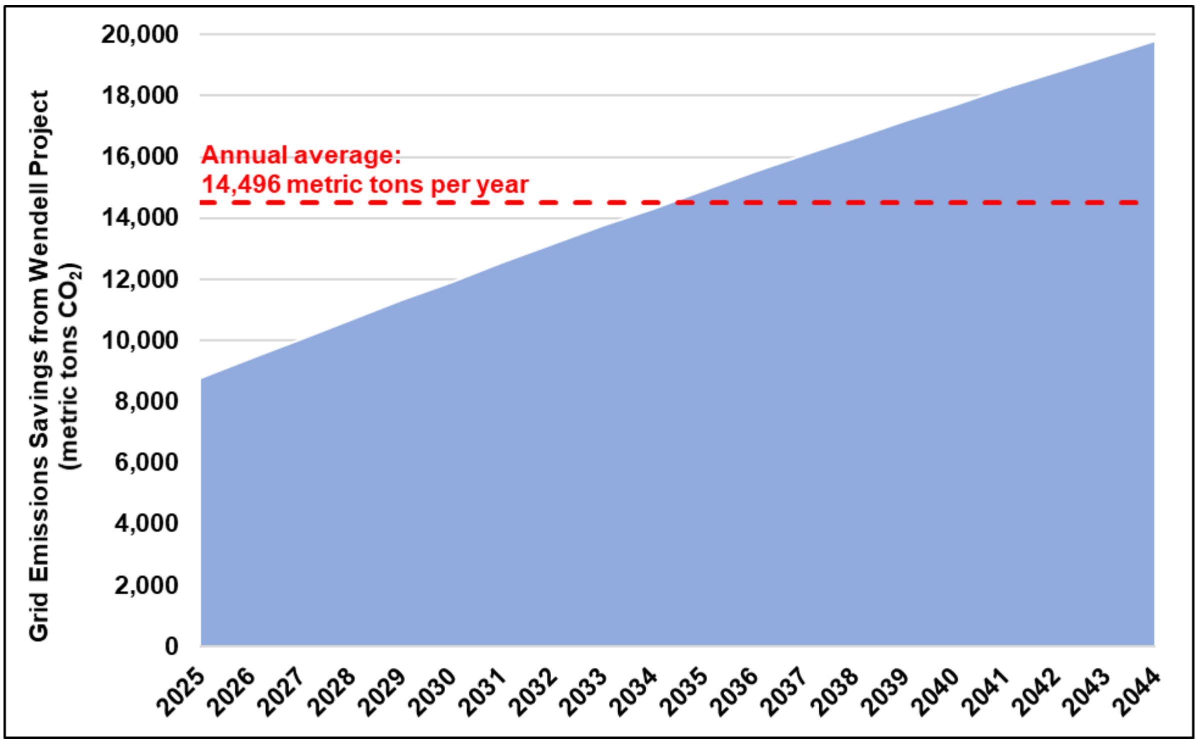
assumed to gradually get cleaner over time, which increases the difference in emissions between the charging and discharging time periods.

Table 9. CO_2 emissions savings from the grid due to Borrego's proposed battery facility in Wendell, MA

Project Site	Project Size (*MW DC/MWh*)	Grid Emissions Savings (*metric tons CO_2, 2025-2044*)	
		Annual Average	20-Year Total
Wendell Site	99.9 / 400	14,496	289,917

Note: Positive values represent a reduction in CO_2 emissions or an emissions savings.

Figure 5. Annual CO_2 emissions savings from the grid *due to* Borrego's *Wendell battery facility*, 2025-2044



4.2 Methodology

To estimate the total grid CO_2 emissions savings from the proposed Wendell battery facility, AEC quantified the greenhouse gas emissions that would be emitted in generating energy to charge the batteries and displaced as a result of discharging the proposed batteries. The CO_2 emissions savings result from charging at times of high renewable energy production as a percent of the grid generation mix and discharging during Seasonal Peak Periods as defined by the Massachusetts Clean Peak Standard (see Table 10).[24]

[24] Massachusetts Department of Energy Resources. August 2020. *225 CMR 21.00: Clean Peak Energy Portfolio Standard (CPS)*. Available at: https://www.mass.gov/doc/clean-peak-energy-standard-final-regulation/download

Table 10. Battery charging and discharging windows as defined by the Massachusetts Clean Peak Standard

Clean Peak Season	Season Dates	Charging Windows		Discharge Windows
		Wind-Based Charging Hours	Solar-Based Charging Hours	
Spring	Mar 1 - May 14	12am - 6am	8am - 4pm	5pm - 9pm
Summer	May 15 - Sep 14	12am - 6am	7am - 2pm	3pm - 7pm
Fall	Sep 15 - Nov 30	12am - 6am	9am - 3pm	4pm - 8pm
Winter	Dec 1 - Feb 28	12am - 6am	10am - 3pm	4pm - 8pm

Source: Massachusetts Department of Energy Resources. August 2020. 225 CMR 21.00: Clean Peak Energy Portfolio Standard (CPS). Available at: https://www.mass.gov/doc/clean-peak-energy-standard-final-regulation/download

4.2.1 Energy Flow

To estimate the proposed project's seasonal energy flow (MWh) in each year of the 20-year analysis period, AEC used the following specifications supplied by Borrego specific to the proposed battery facility in Wendell, Massachusetts:

- **System Size:** 99.9 MW/400 MWh
- **Annual Usage:** 300 cycles
- **Seasonal Usage:** Full operation/daily cycles during Winter and Summer; remaining cycles occur in Fall and Spring
- **Round-trip Efficiency:** 89.4 percent
- **Performance Level in 20 years due to degradation:** 90 percent

We assume a linear degradation in battery performance level across the 20-year analysis period—starting at 100 percent in 2025 and falling linearly to 90 percent in 2044. The assumed 300 annual cycles primarily occur every day in Winter (90 days) and Summer (123 days) according to dates defined in the Massachusetts Clean Peak Standard for each season (also shown in Table 10 above) with the 87 remaining cycles distributed evenly between Spring and Fall.

For charging, the seasonal energy (MWh) is equal to the system size (400 MWh) multiplied by the number of cycles in a given season (e.g., 90 for Winter, 123 for Summer, 43.5 for Spring, 43.5 for Fall) and the performance level in that year. For discharging, the seasonal energy (MWh) is equal to the system size (400 MWh) multiplied by the number of cycles in a given season, the performance level in each year of the analysis period, and the round-trip efficiency of 89.4 percent. (Only the amount of discharged energy is discounted by the efficiency loss; the undiscounted amount of energy is drawn from the grid for charging.)

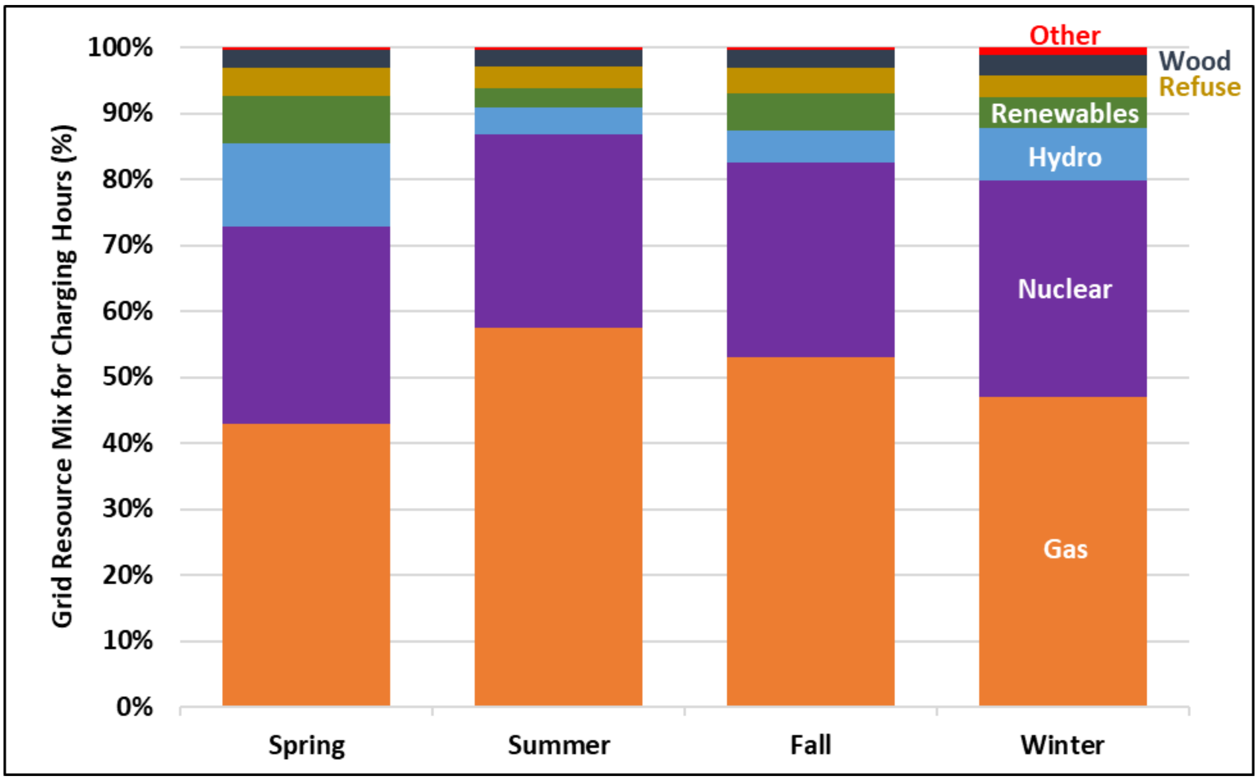
4.2.2 Emissions from Charging

To estimate the CO_2 emissions associated with charging, AEC multiplied the grid emissions rate (kg CO_2/MWh) by the charging energy flow (MWh) in each season for each year in the 20-year analysis period.

AEC estimated the seasonal average resource mixes on the grid for the charging time periods (as shown in Table 10 above) using ISO-New England's *Operations Reports for Dispatch Fuel Mix*[25] for the 2020 calendar year. When charging, batteries pull electricity from the grid and store it for later use. In our estimation of emissions from charging, we assume that the batteries utilize an average of all generating resources in operation during the charging hours.

To estimate the charging resource mix for each season (i.e., Spring, Summer, Fall, Winter), AEC first quantified the generation (MWh) by resource type (i.e., gas, coal, oil, refuse, wood, nuclear, hydro, solar, wind) for each hour in a day (i.e., 24 hours). AEC then calculated the resource mix percentages for each hour by dividing the generation (MWh) for each resource by the total generation (MWh) across resource types in that hour. Finally, AEC estimated the seasonal resource mix for the specified charging windows by averaging the resource mix percentages for each resource type across the specified hours (see Figure 6).

Figure 6. ISO-New England's grid resource mix in 2020 by season during Clean Peak Standard charging hours



Note: "Renewables" include both solar and wind resources. "Other" includes resources such as coal, oil, and landfill gas. Source: ISO-New England. 2020. Operations Reports: Dispatch Fuel Mix. Available at: https://www.iso-ne.com/isoexpress/web/reports/operations/-/tree/gen-fuel-mix

[25] ISO-New England. 2020. *Operations Reports: Dispatch Fuel Mix.* Available at: https://www.iso-ne.com/isoexpress/web/reports/operations/-/tree/gen-fuel-mix

AEC calculated the emissions associated with charging by multiplying each resource's emissions rate by its share in the total resource mix for the relevant hours. Individual emissions rates (kg CO_2/MWh) for each resource type are the product of the corresponding emissions factor (kg CO_2/MMBtu) from EPA's *Emission Factors for Greenhouse Gas Inventories*[26] and the average heat rate (MMBtu/MWh) for each resource in New England based on U.S. Energy Information Administration (EIA) 2020 data (see Table 11).[27] Average fuel input (MMBtu) for electric generators located in New England divided by average generation (MWh) of those same generators provides an estimate of the average heat rate (MMBtu/MWh) of each emitting resource (i.e., gas, coal, oil, refuse, wood).[28]

Table 11. New England emissions rates by resource type

	Gas	Refuse	Wood	Landfill Gas	Coal	Oil
Average Heat Rate (MMBtu/MWh)	8.0	18.7	14.4	13.3	11.8	14.2
Emissions Rate (kg CO_2/MMBtu)	53.1	90.7	93.8	52.1	95.5	74.2
Emissions Rate (kg CO_2/MWh)	427	1,698	1,355	693	1,129	1,057

Seasonal grid emissions rates (kg CO_2/MWh) in 2020 for the charging time periods are estimated as an average across resources individual emissions rate (kg CO_2/MWh) weighted by their resource mix percentages (see Table 12).

Table 12. Average grid emission rates in 2020 for charging time periods by season and resource type

(kg CO_2/MWh)	Resource Type Component Rates						Seasonal Emissions Rate
	Gas	Refuse	Wood	Landfill Gas	Coal	Oil	
Spring	183.3	74.1	36.2	2.4	0.1	0.3	296.5
Summer	245.1	55.0	34.9	1.6	0.3	0.8	337.8
Fall	226.3	66.2	36.2	1.8	0.7	0.9	332.1
Winter	200.2	57.8	40.9	1.8	5.9	3.8	310.4
Annual Average	**213.7**	**63.3**	**37.1**	**1.9**	**1.8**	**1.4**	**319.2**

[26] U.S. EPA. April 1, 2021. *Emission Factors for Greenhouse Gas Inventories*. Available at: https://www.epa.gov/sites/default/files/2021-04/documents/emission-factors_apr2021.pdf

[27] U.S. EIA. 2020. *Monthly Generation and Fuel Consumption, Form EIA-923 detailed data files.* Available at: https://www.eia.gov/electricity/data/eia923/

[28] AEC excluded electric generators that were classified as "combined heat and power plants" as well as those with fuel consumption and/or net generation equal to or less than zero.

AEC then forecasts New England grid emissions rates for 2044 charging hours and seasons, using the assumption that ISO-New England's grid resource mix would gradually transition towards clean, renewable energy sources (e.g., solar, wind, etc.) driven by each New England state's current Renewable Portfolio Standard obligations. AEC calculated the weighted average of New England's renewable portfolio standards in 2044 based on each state's electricity sales in 2020—resulting in a New England-wide minimum renewable energy share of 57 percent (see Table 13).

Table 13. New England Renewable Portfolio Standards in 2044

State	Electricity Sales in 2020 (MWh)	Renewable Portfolio Standard in 2044 (%)
Connecticut	27,113,673	48%
Massachusetts	50,009,341	60%
Maine	11,346,740	94%
New Hampshire	10,693,529	25%
Rhode Island	7,351,541	39%
Vermont	5,331,458	75%
Weighted Average for New England		**57%**

Sources: (1) Connecticut Public Utilities Regulatory Authority. "Connecticut Renewable Portfolio Standard." Department of Energy and Environmental Protection. Available at: https://portal.ct.gov/PURA/RPS/Renewable-Portfolio-Standards-Overview; (2) Massachusetts Department of Environmental Protection. 2021. 310 CMR 7.00: Air Pollution Control. Section 7.75 (4)(a). Available at: https://www.mass.gov/doc/310-cmr-700-air-pollution-control-regulations/download; (3) State of Maine. June 2019. Chapter 477 Public Law: An Act To Reform Maine's Renewable Portfolio Standard. Section 1-A. Available at: https://legislature.maine.gov/bills/getPDF.asp?paper=SP0457&item=3&snum=129; (4) New Hampshire Public Utilities Commission. Chapter PUC 2500: Electric Renewable Portfolio Standard. Available At: https://www.puc.nh.gov/Regulatory/Rules/Puc2500.pdf; (5) Rhode Island Public Utilities Commission. January 2018. RES Annual Targets. Available at: http://www.ripuc.ri.gov/utilityinfo/RES-Annual-Targets.pdf; (6) Vermont General Assembly. Title 30: Public Service, Chapter 089: Renewable Energy Programs, Subchapter 001: General Provisions. 30 V.S.A. 8005. Available at: https://legislature.vermont.gov/statutes/section/30/089/08005; (7) U.S. EIA. 2020. Retail sales of electricity to ultimate customers by sector, by state, by provider. Available at: https://www.eia.gov/electricity/data/state/sales_annual.xlsx

We assume all non-renewable generation (43 percent) is provided by gas-fired generators such that the annual grid emissions rate in 2044 for charging hours is equal to the individual emissions rate for gas (427 kg CO_2/MWh) multiplied by 43 percent. AEC estimated the seasonal grid emissions rates by multiplying the 2044 annual grid emissions rate by the ratio between each season's grid emissions rate in 2020 and the 2020 annual average. AEC assumes a linear trend between the 2020 and 2044 grid emission rates.

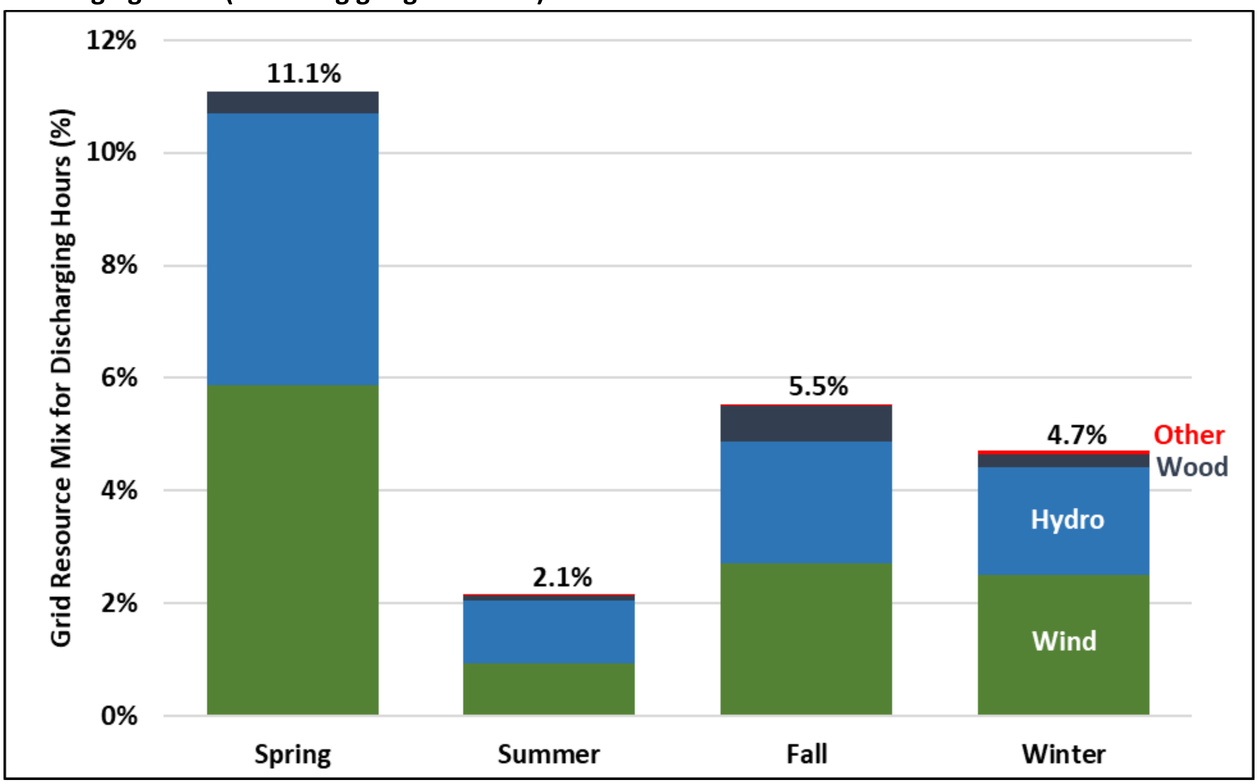
4.2.3 Emissions from Discharging

To estimate the CO_2 emissions associated with discharging, AEC multiplied the marginal grid emissions rate (kg CO_2/MWh) by the discharging energy flow (MWh) in each season for each year in the 20-year analysis period.

AEC estimated the seasonal average resource mixes on the grid for the discharging time periods (as shown in Table 10 above) using ISO-New England's *Operations Reports for Dispatch Fuel Mix*[29] for the 2020 calendar year. Because the proposed battery facility is very small in comparison to total grid energy flow, we assume that when batteries release the stored electricity back to the grid, the grid's marginal resource—the last, and most expensive, generating resource procured to meet customer demand—is displaced.

To estimate the discharging resource mix for each season (i.e., Spring, Summer, Fall, Winter), AEC first quantified the generation (MWh) for marginal resources by type (i.e., gas, coal, oil, refuse, wood, nuclear, hydro, solar, wind) for each hour in a day (i.e., 24 hours). AEC then calculated the resource mix percentages for each hour by dividing the generation (MWh) for each resource by the total generation (MWh) across resource types in that hour. Finally, AEC estimated seasonal marginal resource mixes during the specified discharging windows by averaging the resource mix percentages for each resource type across the specified hours (see Figure 7, which presents all resources other than gas).

Figure 7. ISO-New England's grid marginal resource mix in 2020 by season for Clean Peak Standard discharging hours (excluding gas generation)



Note: The resource mix percentages for gas were excluded from this figure to allow for other resources to be more easily compared between seasons. Gas makes up the remaining percentage in each season (e.g., gas accounts for nearly 89 percent of the grid's marginal resource mix in the Spring 2020 season, 98 percent in Summer, 94 percent in Fall, and 95 percent in Winter). "Other" includes emitting resources such as coal and oil. Source: ISO-New England. 2020. Operations Reports: Dispatch Fuel Mix. Available at: https://www.iso-ne.com/isoexpress/web/reports/operations/-/tree/gen-fuel-mix

[29] ISO-New England. 2020. *Operations Reports: Dispatch Fuel Mix.* Available at: https://www.iso-ne.com/isoexpress/web/reports/operations/-/tree/gen-fuel-mix

AEC calculated the emissions associated with discharging by multiplying each resource's emissions rate by its share in the total resource mix for the relevant hours. Average grid emissions rates (kg CO_2/MWh) in 2020 for the discharging time periods (by season) are estimated as an average across resources' individual emissions rates (kg CO_2/MWh) weighted by their resource mix shares (see Table 14).

Table 14. Marginal grid emission rates in 2020 for discharging time periods by season and resource type

(kg CO_2/MWh)	Resource Type Component Rates				Seasonal Emissions Rate
	Gas	Wood	Coal	Oil	
Spring	379.5	5.2	0.0	0.0	384.7
Summer	417.6	1.2	0.0	0.02	418.8
Fall	403.3	8.4	0.02	0.0	411.7
Winter	406.6	3.1	0.2	0.6	410.5
Annual Average	401.7	4.5	0.1	0.2	406.4

AEC then forecasted New England marginal grid emissions rates for 2044 discharging hours and seasons using the assumption that ISO-New England's marginal emissions rate would be equal to the weighted average of each New England state's marginal emissions rate in 2044 as reported in the National Renewable Energy Laboratory's (NREL) Cambium model. [30] AEC estimated seasonal marginal emissions rates by multiplying the 2044 annual rate by the ratio between each season's grid emissions rate in 2020 and the 2020 annual average. AEC assumes a linear trend between the 2020 and 2044 grid emission rates.

Cambium is a new model from NREL designed specifically to project avoided marginal emissions from the electric sector over time. NREL's results are state-specific and show projected marginal emissions shrinking over time as more renewables are added to the grid due to current renewable portfolio standards and emission reduction laws (as shown in "orange" in Figure 8). [31]

AEC's forecasts annual marginal emissions for the purposes of this analysis as a linear trend between the ISO-NE-based 2020 marginal emissions and NREL's "short-run" marginal emissions for 2044 (in purple). The result is a slight increase in emissions over time, suggesting that New England's marginal emissions will change very little over the next 25 years (i.e., 2020 through 2044), whereas the region's average grid emissions (discussed above) will reduce significantly over this same period.

[30] AEC uses NREL's "short-run" marginal emission projections, which offer a long-term forecast of marginal emissions based on current renewable portfolio standards and emission reduction laws. (A second NREL forecast called "long-run" adds market forces to these projections but is still under development.) Source: National Renewable Energy Laboratory (NREL). 2020. *Cambium Viewer*. Available at: https://cambium.nrel.gov/

[31] Gagnon, P. et al. 2020. "Cambium Documentation: Version 2020." National Renewable Energy Laboratory (NREL). Available at: https://www.nrel.gov/docs/fy21osti/78239.pdf

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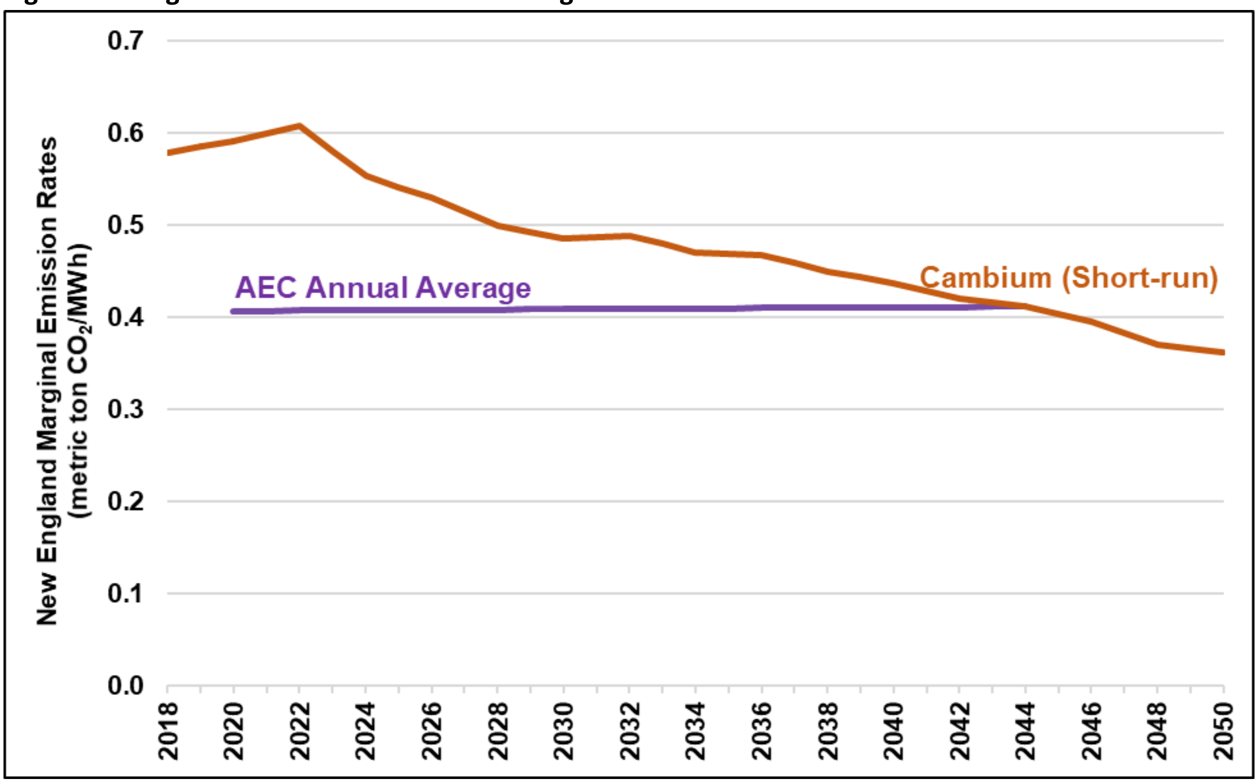
Marginal emissions based on ISO-New England's 2020 data, on which we rely to establish current average and marginal resource mixes by season and hour, is lower than Cambium estimated marginal emissions for the same year: AEC estimates 406 kg CO_2/MWh compared to Cambium's 591 kg CO_2/MWh. Our interpretation of this substantial difference is that New England is further ahead on the renewable transition curve expected by NREL than the national lab anticipated.

An alternative explanation is that our 2020 New England data is accurate but skewed; that is, it may represent a singular year in which higher emission resources were not needed rather than representing a longer-term rolling average.

Figure 8. Marginal emissions rates for New England



Sources: (1) National Renewable Energy Laboratory (NREL). 2020. Cambium Viewer. Available at: https://cambium.nrel.gov/; (2) ISO-New England. 2020. Operations Reports: Dispatch Fuel Mix. Available at: https://www.iso-ne.com/isoexpress/web/reports/operations/-/tree/gen-fuel-mix; (3) U.S. EPA. April 1, 2021. Emission Factors for Greenhouse Gas Inventories. Available at: https://www.epa.gov/sites/default/files/2021-04/documents/emission-factors_apr2021.pdf; (4) U.S. EIA. 2020. Monthly Generation and Fuel Consumption, Form EIA-923 detailed data files. Available at: https://www.eia.gov/electricity/data/eia923/