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Energy Storage Benefit-Cost Analysis

A Framework for State Energy Programs

Prepared by Applied Economics Clinic
for the Clean Energy States Alliance

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

CleanEnergyStatesAlliance

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About this Report

This report was prepared by the Applied Economics Clinic on behalf of the Clean Energy States Alliance. The purpose of this report is to help states in conducting benefit-cost analysis of energy storage for inclusion in state clean energy programs.

The concept of benefit-cost analysis is hardly a new one for state energy agencies; practically every clean energy program that requires an expenditure of ratepayer dollars, from renewable portfolio standards to customer rebate programs, is predicated on the idea that the benefits of a program will outweigh its costs. However, in weighing costs and benefits, details matter. Getting the right result at the end of the process depends heavily on numerous decisions about inputs, assumptions, valuation and methods. In the case of energy storage, a relatively new technology for most state energy agencies, these decision points can be challenging.

This report is intended to help state energy officials and program administrators conduct benefit-cost analysis of energy storage in a way that fully accounts for and fairly values its benefits as well as its costs.

Acknowledgments

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TABLE OF CONTENTS

Forward

When considering whether to invest in a new technology, the first thing anyone wants to know is will the benefits outweigh the costs?

Costs are usually pretty straightforward. Benefits, on the other hand, can be tricky to assign a dollar value to; nevertheless, it's important to do so. If you can't compare costs to benefits, you're investing blindly. Most people will therefore do their best to assess the benefits they expect to receive as a result of their investment. After all, nobody wants to pay more for something than the thing is worth.

States, when they consider spending public funds, go through a similar comparison of costs and benefits, to ensure that the people are getting their money's worth. The process is called a benefit-cost analysis (BCA). This report provides a framework for state energy agencies contemplating a BCA for battery storage.

Battery storage, it turns out, is not one of the easier technologies to assess where BCAs are concerned. There are several reasons for this.

For one thing, batteries are a multi-use resource, meaning that they can do lots of different things depending on decisions made by the user. Solar, by contrast, does just one thing—it generates power when the sun is shining; but batteries can act as a generator or as a load, or as a transmission or distribution grid resource. Batteries can provide backup power to a home, a business, or a critical community facility when the grid goes down. Batteries can shift a business's power consumption from high-demand to low-demand times; provide grid operators with critical services like frequency regulation; bid capacity into regional wholesale energy markets; make variable generators like solar PV and wind turbines more reliable and thus more valuable; replace fossil-fueled peaker power plants; and about a dozen other things. This is good news for battery owners, but it creates challenges for state energy agencies, utilities, and program administrators—because if you don't know exactly how people are going to use batteries, it's difficult to put a value on that technology.

Even where the intended uses of batteries are well understood, the value of these uses may be difficult to determine. For example, everyone recognizes that backup power is valuable – that's why there's a market for backup generators. But it's hard to pin down exactly what that value is, in dollars and cents, both for individual customers and for society at large. Being uncertain about the value of battery services can lead to overly conservative estimates, or even to no value being assigned at all. Faced with uncertainty, it's tempting to shrug and move on to something easier. But this means that the value of resilience, and of other hard-to-value battery services, frequently defaults to zero in storage BCAs, making costs appear higher relative to benefits.

Complicating the situation further, many battery services are difficult to monetize in power markets, either because markets for these services do not yet exist (for example, for battery systems that provide energy resilience) or because storage doesn't qualify to enter the market (for example, in jurisdictions where distributed resources cannot easily bid into wholesale capacity markets). In these cases, it may be tempting to wait for a market to develop so that pricing occurs naturally. Yet, the current lack of a market for energy storage services does not mean that no value exists, and market failures should not be a reason to omit benefit values from storage BCAs.

Aside from these issues, there are many nuts-and-bolts questions to be answered: Which of the many available cost-effectiveness tests are most appropriate to use when assessing battery storage? What discount rate should be used to value future costs relative to present costs? And how should states conduct a BCA process to ensure the results are both fair and equitable? States may be uncertain about how to answer these questions for the simple reason that batteries are not a technology with which they have much prior experience.

This report, prepared by Applied Economics Clinic, is intended as a guide for state energy agencies preparing to conduct cost-effectiveness evaluation for battery storage programs. It presents a BCA framework for battery storage and attempts to address many of the uncertainties state energy agencies may encounter by drawing on the experience of public agencies across the country. The Applied Economics Clinic has many years of experience conducting storage valuation and cost-effectiveness tests, and the report is based on that experience, plus best practices gleaned from numerous BCAs undertaken by early adopter states, as well as related literature about how to value battery services.

It is our hope that this report will provide guidance that will be useful for many state and municipal energy agencies across the United States.

Todd Olinsky-Paul
Senior Project Director
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Executive Summary

Prepared on behalf of the Clean Energy States Alliance, this Applied Economics Clinic (AEC) report lays out a framework for the execution of a thorough and robust benefit-cost analysis (BCA) of battery energy storage systems based on AEC's review of 29 battery storage BCAs and related analyses from a variety of reputable sources including utilities, utility commissions, state energy agencies, green banks, and research groups from around the country.

AEC's set of best practices addresses all aspects of a battery storage BCA including cost-effectiveness tests, discount rates, benefits, costs, sensitivity analyses, and stakeholder process (see Table ES-1).

Table ES-1. Summary of AEC recommendations

AEC Battery Benefit-Cost Analysis Recommendations	
Cost-effectiveness tests	Use the SCT as a primary cost-effectiveness test and the UCT and RIM as secondary tests
Discount rates	Use a 0.1 to 2.5 percent social discount rate and each utility's own WACC as a financial discount rate
Benefits	Include all 25 benefits listed in Section VI for a thorough consideration of a full range of battery benefits
Costs	Use up-to-date battery-specific engineering references to establish correct program costs
Sensitivity analysis	Conduct several sensitivity analyses, falling in two categories. Sensitivities recommended for model calibration are analyses that can be used to fine-tune model results based on adjustments to input assumptions; and sensitivities recommended for full results presentation are analyses that capture the uncertainty inherent in particular assumptions to arrive at a range of BCR values
Stakeholder process	Conduct an inclusive, diverse, and equitable stakeholder process from start-to-finish of a BCA assessment and include representatives from state agencies, utilities, consumer and environmental advocates, low-income representatives, ratepayers, regulators, environmental justice communities, non-governmental organizations, government, renewable energy developers and battery companies

A battery storage BCA conducted as recommended in this report can help states determine the energy storage policy priorities and program decisions most conducive to reaching the state's policy goals at the greatest benefit for the least cost.

Introduction

Many states have adopted statutory mandates to deploy energy storage, while others have adopted 100 percent clean energy targets, aggressive renewable energy targets, and/or grid modernization, electrification and resilience efforts. Development of new energy storage policy and programs will be integral to achieving all these goals; and because most state energy programs include cost effectiveness requirements, development of new policies and programs to achieve state clean energy and energy storage targets will require careful assessment of the relative benefits and costs of storage technologies across various programs and in numerous applications.

Benefit-cost analysis (BCA) is a frequently used tool in state policy analysis and program evaluation, especially in the energy sector. BCAs identify and quantify all relevant benefits and costs of a given program or initiative to determine a benefit-cost ratio. A benefit-cost ratio greater than 1.0 indicates that the sum of all benefits outweighs the sum of all costs; that is, that the measure, program or policy is "cost effective." In contrast, a benefit-cost ratio less than 1.0 indicates that costs exceed benefits. The results of a BCA substantially influence major policy decisions and technological investments in the electric sector in states throughout the country; in the case of battery storage, the results of BCAs are used to make key decisions regarding how to meet state energy storage and climate-related policy goals. As such, it is critical that BCAs be carried out with care and rigor.

In this Applied Economics Clinic report, developed on behalf of the Clean Energy States Alliance, AEC lays out a framework for the execution of a thorough and robust BCA of battery energy storage systems.[1] Drawing upon insights and methodologies from 29 battery storage-specific BCAs and related studies from throughout the United States, this report presents a cohesive analytic framework that can be used as a guide for states in conducting (or in contracting outside experts to conduct) a BCA of battery storage options. The recommendations contained in this report are essential for soliciting input to be used in developing, refining, and finalizing a BCA and developing recommendations based on BCA conclusions. They are backed up by the studies referenced and many are utilized in public processes throughout the country. A BCA conducted as recommended in this report can help a state determine which policy priorities and decisions will be most conducive to reaching the state's clean energy and energy storage goals, providing the greatest benefit at the least cost. A BCA conducted in this manner also informs the rates and structure of incentive programs that may be developed to advance the expansion of energy storage capacity in the state.

The remainder of this report details AEC's recommendations for a battery-specific BCA (Table 1). The sections are as follows, each including AEC's recommendations: Sections II and III summarize the key elements of the 29 battery storage BCAs and closely related sources from a variety of reputable sources including utilities, utility commissions, and research groups reviewed by AEC; Section IV provides a discussion of the different cost-effectiveness tests that can be employed in a BCA; Section V reviews the different discount rates employed in different battery-related BCAs; Section VI provides detailed descriptions of the different benefits to be included in a battery-related BCA; Section VII discusses the costs to be accounted for in a battery storage BCA; Section VIII presents the sensitivity analyses

[1] While other types of energy storage (i.e., thermal storage, compressed air, pumped hydro, etc.) may be developed to help meet the state's target, this report only addresses battery storage.

conducted as part of a battery-related BCA; and Section IX summarizes AEC's suggestions for an inclusive, diverse, and equitable stakeholder process.

Table 1. Summary of AEC recommendations

AEC Battery Benefit-Cost Analysis Recommendations		
Cost-effectiveness tests	Use the SCT as a primary cost-effectiveness test and the UCT and RIM as secondary tests.	
Discount rates	Use a 0.1 to 2.5 percent social discount rate and each utility's own WACC as a financial discount rate.	
Benefits	Include the following 25 benefits for a thorough consideration of a full range of battery benefits:	
	Consumer benefits	Lower ratepayer bills Lower customer energy use Resilient power during outages and value of lost load Job creation Higher property values Enhanced value and capacity of renewables
	Avoided system costs	Avoided operations and maintenance costs Avoided costs of environmental compliance Avoided capacity costs Avoided fuel costs Reduced ancillary services costs Avoided transmission and distribution costs Avoided collections and disconnections Reduced costs to integrate renewable generation Wholesale market price effects
	Environmental benefits	Smaller land footprint than generation facilities Reducing greenhouse gas emissions and air pollution Reduced water consumption
	Grid reliability	Fewer power outages Avoided emergency calls Peak shaving and shifting Black start capability Reduced grid congestion
	Difficult-to-monetize benefits	Participant non-energy benefits Societal non-energy benefits (including public health and EJ benefits)

AEC Battery Benefit-Cost Analysis Recommendations	
Costs	Use up-to-date battery-specific engineering references to establish correct program costs.
Sensitivity analysis	Conduct several sensitivity analyses, falling in two categories. Sensitivities recommended for model calibration are analyses that can be used to fine-tune model results based on adjustments to input assumptions; and sensitivities for full results presentation are recommended analyses that capture the uncertainty inherent in particular assumptions to arrive at a range of BCR values.
Stakeholder process	Conduct an inclusive, diverse, and equitable stakeholder process from start-to-finish of a BCA assessment and include representatives from state agencies, utilities, consumer and environmental advocates, low-income representatives, ratepayers, regulators, environmental justice communities, non-governmental organizations, government, renewable energy developers and battery companies.

Best Practices in Battery Storage BCAs

AEC reviewed 29 battery storage BCAs, methodologies, and related analyses from a variety of reputable sources—including utilities, utility commissions, state energy agencies, green banks, and research groups from around the country—to develop a set of best practices that address all aspects of a battery storage BCA. Based on these best practices, a set of recommendations includes the following topics:

- **The cost-effectiveness tests to use** to best evaluate and compare the benefits and costs of policies, programs, or measures to arrive at a benefit-cost ratio—that is, the value of benefits divided by the value of costs.

- **The discount rates to use in valuing future benefits.** Discount rates are used to convert future dollars to present-day terms and are used to account for the fact that a dollar today is more highly valued than a dollar in the future. An appropriate discount rate is important to fairly assess the financial risk of an investment, and/or make current and future dollar values more comparable.

- **The benefits of battery storage to consider when conducting a BCA.** Benefits include those conferred to battery storage program participants and electric ratepayers, reduced costs experienced by utility customers and the electric system overall, benefits to the natural environment and the human communities that rely on natural resources, improvements to the reliability of the grid, and benefits that are difficult to monetize, such as participant non-energy benefits, public health benefits, and environmental justice benefits.

- **The costs of battery storage to include in a BCA.** Costs can include administrative, capital, labor, and operational costs for utilities or other program administrators and, depending on the program design, capital and labor costs for customers that host battery storage resources.

- **How to conduct sensitivity analyses** that account for the uncertainty inherent in many of the input assumptions to a BCA analysis. Sensitivity analyses can test the robustness of BCA results to changes in given input assumptions, calibrate and/or refine a BCA model in its development, and/or determine a range of values for a final BCA result.

- **How to structure stakeholder processes** that are inclusive, diverse, and equitable, and will support a robust battery storage BCA analysis. Stakeholder processes are an important opportunity for information sharing as well as essential for soliciting input to be used in developing, refining, and finalizing a BCA and developing recommendations based on BCA conclusions.

AEC's sources are listed in Table 2 and described in detail in Appendix A. These sources include proposals to accelerate the deployment of storage systems, assessments of battery storage costs and benefits, assessments of storage market trends and potential, utility climate plans, and detailed benefit-cost methodologies of batteries and related technologies. The sources cover states and territories including California, Connecticut, the District of Columbia, Massachusetts, Minnesota, New Jersey, New York, and Rhode Island, as well as studies of the United States as a whole. Represented institutions include the US Department of Energy, the National Energy Screening Project, the Energy Storage Association, various utility or public service commissions, and other public interest organizations.

Each source was examined for the benefits, costs, or avoided costs it described, values calculated, and the methodology used to conduct the BCA—including the cost-effectiveness tests and discount rates utilized, as well as sensitivity analyses conducted and information about stakeholder engagement. The report uses these sources to catalog and categorize the methods, benefits, and costs for battery storage BCAs and to form the basis for our recommendations. Table 2 provides a brief summary of each source reviewed and introduces a short-form citation for each source that is utilized throughout the remainder of this report.

Table 2. List of sources in annotated bibliography (see Appendix A)

Source	Description
CA Brattle 2017	The California Brattle Group's Assessment of the economics of battery storage initiatives in California.
CA CPUC 2020	The California Public Utilities Commission's approach to calculating avoided-supply side resource costs and how that relates to the resource planning process.
CT PURA 2021	The Connecticut Public Utilities Regulatory Authority's report outlining the adoption of the Connecticut Green Bank's electric storage program, including a residential-level BCA and a commercial and industrial level BCA.
CA SGIP 2021	The California Center for Sustainable Energy's outline of California's procedures and policies associated with incentives for on-site distributed energy resources.
DC CEAIWG 2021	The District of Columbia Clean Energy Act Implementation Working Group's stakeholder comments and recommendations on metrics and reporting requirements to be included in a BCA framework.
DC Pepco 2021	Hledik, R. et al.'s summary, prepared for the District's Public Service Commission on behalf of Pepco, of Pepco's *5-Year Action Plan*, including the utility's near-term initiatives and programs and a BCA designed by the utility.
HI GE Energy 2017	GE Energy Consulting's report quantifying the net benefit of energy storage systems for the Oahu, Hawaii system, using a BCA with an extensive list of benefit categories.
NJ AEC 2022	The Applied Economics Clinic's evaluation of economic outcomes of a transition to clean energy in New Jersey in comparison to a business-as-usual scenario.
MA AEC 2019a	The Applied Economics Clinic's white paper discussing the cost-effectiveness of battery storage using the Massachusetts efficiency program evaluation methodology.
MA AEC 2019b	The Applied Economics Clinic's white paper in which valuations of non-energy benefits of battery storage are calculated.
MA DOER 2016	An analysis by the Massachusetts Department of Energy Resources of economic benefits and market opportunities for energy storage in Massachusetts, as well as potentially resourceful programs and policies.
MA PAs 2021	The Massachusetts Energy Efficiency Program Administrators report explaining the benefit-cost ratio model spreadsheets used to calculate the values in the "Massachusetts Joint Statewide Electric and Gas Three-Year Energy Efficiency Plan: 2022-2024."
MA NEI 2011	The Massachusetts Program Administrators report quantifying non-energy impacts from utility programs.
MN E3 2019	The Minnesota Department of Commerce and Division of Energy Resources' analysis, prepared by E3, of costs and benefits of deploying energy storage systems in Minnesota.
NE AESC 2021	Synapse Energy Economics' report that develops projections of electric and gas sector costs that would be avoided by improvements in energy efficiency in New England.
NJBPU 2020	The New Jersey Board of Public Utilities' order adopting the interim New Jersey Cost Test for use in assessing the cost-effectiveness of energy efficiency and peak demand reduction programs.
NYDPS 2015	The New York Department of Public Service's proposed BCA framework within New York's Reforming Energy Vision (REV) proceedings.
NYS Roadmap 2018	The New York Department of Public Service's report that provides a strategic roadmap for New York State to achieve it's 1,500 MW energy storage target by 2025.
NYSEG and RG&E 2020	The New York State Electric and Gas Corporation and the Rochester Gas and Electric Corporation's *Benefit Cost Analysis (BCA) Handbook* describing the framework and methodology used in New York's program evaluation of four categories of utility expenditures.
RI DPUC 2021	Synapse Energy Economics' report estimating the cost and benefits of the Community Remote Net Metering Program using Rhode Island's benefit-cost test.

Source	Description
RI SEPA 2020	Smart Electric Power Alliance's report examining the Rhode Island BCA framework and how it is being used to assess utility investments, as well as recommendations for improving the framework.
US DOE 2020	The United States Department of Energy's report documenting the roadmap for accelerating the development, commercialization, and utilization of energy-storage technologies in the United States.
US EIA 2021	The United States Energy Information Administration's analysis of survey responses to document trends in battery storage capacity installations in the United States through 2019.
US ESA 2017	The Energy Storage Administration's report describing opportunities to deploy more than 35 GW of new energy storage systems by 2025 in the United States.
US NESP 2020	The National Energy Screening Project's manual providing a nation-wide framework for cost-effectiveness tests.
US NESP 2022	The National Energy Screening Project's handbook acting as a companion resource to the US NESP 2020 manual; it provides a glossary of frequently used terminology in BCAs, steps to follow, and important metrics and formulas.
US NRECA 2019	The National Rural Electric Cooperative Association's overview of stationary electrochemical battery energy storage system technology and applications.
US RAP 2019	The Regulatory Assistance Project's paper that evaluates changes to traditional regulatory models in light of developments in advanced energy technologies.
Western FER 2020	A study by Frontiers in Energy Research that investigates the system level services and associated benefits of long duration storage on the 2050 Western Interconnection.

Cost-Effectiveness Tests

Cost-effectiveness tests evaluate and compare the benefits and costs of policies, programs, or measures to arrive at a benefit-cost ratio—the value of benefits divided by the value of costs. The specific costs and benefits included in each type of cost-effectiveness test, however, differ depending on perspective and the ultimate use of the test. For example, *cost savings* for an electric ratepayer may be *added costs* for an electric utility. To address how costs and benefits differ depending on perspective, BCAs typically employ one or more of six primary cost-effectiveness tests, each of which quantifies costs and benefits from a different perspective (see Table 3). The National Standard Practice Manual (NSPM) 2022 Methods, Tools, and Resources Handbook explains the appropriate use of each cost-effectiveness test and the implications of using them.[2]

[2] US NSPM 2022 at https://www.nationalenergyscreeningproject.org/national-standard-practice-manual.

Table 3. Primary cost-effectiveness tests and their perspectives

Typical benefits included		Typical costs included
Societal Cost Test (SCT): Perspective of society overall		
Avoided energy Avoided generation capacity Avoided transmission and distribution capacity Reliability DRIPE energy impacts DRIPE capacity impacts	Non-embedded emissions Market revenue Avoided ancillary services Job creation benefits Net societal non-energy benefits Net participant non-energy benefits	Upfront incentive administration Performance incentive administration Participant incremental DER costs
Total Resource Cost Test (TRC): Perspective of utility system plus host customers		
Avoided energy Avoided generation capacity Avoided transmission and distribution capacity Reliability	DRIPE energy impacts DRIPE capacity impacts Market revenue Avoided ancillary services	Upfront incentive administration Performance incentive administration Participant incremental DER costs
Participant Cost Test (PCT): Perspective of host customers only		
Net participant non-energy benefits Net avoided outage benefits Participant bill savings	Upfront program incentives Performance incentives Non-program incentives	Lease value Participant incremental DER costs
Utility Cost Test (UCT): Perspective of utility system		
Avoided energy Avoided generation capacity Avoided transmission and distribution capacity	Reliability DRIPE energy impacts DRIPE capacity impacts	Program incentives Program administration costs
Program Administrator Cost Test (PACT): Perspective of program administrator (only if a distinct agency from utility)		
Avoided energy Avoided generation capacity Avoided transmission and distribution capacity Reliability	DRIPE energy impacts DRIPE capacity impacts Market revenue Avoided ancillary services	Upfront program incentives Performance incentives Upfront incentive administration Performance incentive administration
Ratepayer Impact Measure (RIM): Perspective of all utility ratepayers		
Avoided energy Avoided generation capacity Avoided transmission and distribution capacity Reliability	DRIPE energy impacts DRIPE capacity impacts Market revenue Avoided ancillary services	Participant bill savings Upfront program incentives Performance incentives Upfront incentive administration Performance incentive administration

In addition to these six main cost-effectiveness test frameworks, some BCA analyses used in evaluating battery programs have developed and employed less common or entirely idiosyncratic tests. For example:

- Pepco's 2022 BCA of its five-year electrification plan for Washington, DC, utilizes a cost-effectiveness test designed by Pepco for this purpose—the Climate Policy Enablement Test (CPE), which is a hybrid of the SCT and UCT.[3]

- NESP's 2020 *National Standard Practice Manual* for BCAs of distributed energy resources, suggests the use of jurisdiction-specific cost-effectiveness tests, which synthesize elements

[3] DC Pepco 2021.

of the other cost-effectiveness tests tailored to jurisdictional conditions and policy aims. These tests take a regulatory perspective and aim to evaluate benefits and costs for all actors in the jurisdiction.[4]

An example of a jurisdiction-specific test is the Rhode Island benefit-cost test, which was developed in Rhode Island Public Utilities Commission Docket 4600 in order to evaluate the cost-effectiveness of new energy resources, including batteries. The Rhode Island Test has been used in DPUC's 2021 BCA for Rhode Island and reviewed by a SEPA case study in 2020.[5]

A second example of a jurisdiction-specific test—that is still in development—is the New Jersey Cost Test,[6] which will be a test guided by the Resource Value Framework, a method employed in the *National Standard Practice Manual* for BCAs for energy efficiency resources, to allow states the flexibility to develop screening tests that are aligned with their interests and energy policy goals.[7] Its objective is to assess the cost-effectiveness of energy efficiency and peak demand reduction programs. For the first three years of the program cycle—which began on July 1, 2021—a modified TRC test is in use, along with the continued reporting of results from five other cost-effectiveness tests: an SCT, the existing TRC test, a PCT, a PACT, and a RIM test. After the New Jersey Cost Test is prepared for use by utilities and state administrators, it will be used instead of the current set of tests.

AEC Recommendation

Use the SCT as a primary cost-effectiveness test and the UCT and RIM as secondary tests, unless a state-specific test is required.

This recommendation is consistent with the approaches employed in several similar BCAs and analytic frameworks, including the Connecticut Green Bank's 2020 BCA adopted by PURA, the District of Columbia's Clean Energy Act Implementation Working Group's 2021 Framework, and New York State Electric and Gas Company's BCA handbook.[8] The CT PURA's BCA notes the importance of using a RIM as a way of evaluating the net present value of their energy storage program to all electric ratepayers and the allocation of costs between utilities and ratepayers, and it recommends the use of a UCT to weigh the benefits and costs of an energy storage program to utilities as program administrators for ongoing performance-based incentives.[9]

The DC CEAIWG Framework notes that the use of an SCT allows for specific identification of impacts on low-income customers and communities, in addition to adopting a broader scope than other tests, making it a good primary test; the Framework also advocates for the use of a RIM as a secondary test

[4] US NESP. 2020.
[5] (1) RI DPUC 2021; (2) RI SEPA 2020.
[6] NJBPU 2020.
[7] National Energy Screening Project. 2017. *National Standard Practice Manual for Assessing Cost Effectiveness of Energy Efficiency Resources*. Available online: https://www.nationalenergyscreeningproject.org/wp-content/uploads/2017/05/NSPM_May-2017_final.pdf.
[8] (1) CT PURA 2021; (2) DC CEAIWG 2021; (3) NYSEG and RG&E 2020; (4) DC Public Service Commission. 2021. "Third Joint Metrics and BCA Framework Committee Meeting Minutes." *DC PSC.* Page 16.
[9] (1) CT Green Bank 2020. Pages 2 and 74. (2) CPUC. n.d. "Developing Cost-Benefit Models According to Perspective." Avalable online: https://docs.cpuc.ca.gov/published/FINAL_DECISION/105926-03.htm.

because it captures customer impacts, particularly on low-income customers.[10] The Framework identified the RIM as a test separate from the central BCA for the purpose of informing rate and bill impacts; other BCAs, such as that on distributed energy resources conducted by the Regulatory Assistance Project (RAP) in 2019, include RIM calculations within their BCA framework.[11]

NYSEG's BCA handbook employs the SCT as the primary test because it measures the impact on society overall; the New York handbook also advocates for the use of UCT and RIM as secondary tests to measure the preliminary impact on utility costs and ratepayer bills from the benefits and costs that pass the SCT.[12]

Discount rates

Discount rates convert future dollars to present-day terms and are used to account for the time value of money (a dollar today is more highly valued than a dollar in the future), to account for the riskiness of an investment, and/or to make current and future dollar values more comparable. The NSPM 2022 handbook explains the procedure for incorporating discount rates into a BCA and the implications of choosing a particular rate.[13]

Discount rates used in energy-sector BCA analyses fall into two main categories based on the types of costs and benefits being discounted (see Table 4). For social benefits and costs, such as future costs associated with present-day greenhouse gas emissions or the social cost of carbon (SCC), a **"social discount rate"** is used, with values typically ranging from 1 to 3 percent, valuing future costs and benefits as very similar in importance to current costs and benefits. Social discount rates are often used to value costs and benefits tens and sometimes even hundreds of years into the future.

When calculating the financial costs and benefits associated with funding a battery storage program, a **"financial discount rate"** is used to evaluate the financial cost (and potential return) of an investment in battery storage. A financial discount rate, typically represented by a firm's own weighted average cost of capital (WACC), reflects the rate the company must pay its investors and/or lenders, and thus the minimum rate that must be returned on its investment. Financial discount rates are usually used to value market-based costs and benefits in the near term.

[10] DC CEAIWG 2021. Page 78.
[11] (1) DC CEAIWG 2021; (2) US RAP 2019.
[12] NYSEG and RG&E 2020. Page 30.
[13] US NSPM 2022. Page 147.

As an example of how different social discount rates and WACC can be, for New Jersey utilities Jersey Central Power and Light (JCP&L) and Public Service Electric and Gas Company's (PSE&G), their respective pre-tax WACC values are 9.16 percent and 6.99 percent.[14]

By contrast, Massachusetts energy efficiency program administrators' 2021 (benefit-cost ratio model spreadsheets used to calculate the values in the "Massachusetts Joint Statewide Electric and Gas Three-Year Energy Efficiency Plan: 2022-2024") include a nominal discount rate of 1.98 percent and a real discount rate of 0.21 percent.[15] Table 4 summarizes the discount rates utilized in battery storage BCAs from AEC's review of recent literature.

Discount rates must be chosen very carefully in BCAs, based on the context in which they are used, as seemingly small variations in the chosen discount rate can alter a calculation substantially. For illustrative purposes: Using a 1 percent discount rate, a cost worth $100,000 incurred in 20 years is worth $82,000 in today's terms; under a 3 percent discount rate, the present value of the same future cost drops to $55,400, and with a 10 percent discount rate, the present value of the cost is only $14,900.

AEC Recommendation

Use a 0.1 to 2.5 percent social discount rate and each utility's own WACC as a financial discount rate.

[14] (1) New Jersey Board of Public Utilities Docket Nos. EO18060629 and GO18060630. September 2019. *In the matter of the petition of Public Service Electric and Gas Company for approval of the second Energy Strong program.* Submitted by Public Service Electric and Gas Company. Available online: https://www.nj.gov/bpu/pdf/boardorders/2019/20190911/9-11-19-2F.pdf. Page 7; (2) New Jersey Board of Public Utilities. September 2020. *In the Matter of the Verified Petition of Jersey Central Power and Light Company for approval of JCP&L's Energy Efficiency and Conservation Plan including energy efficiency and peak demand reduction programs*. Submitted by Jersey Central Power and Light Company. Available online: https://www.firstenergycorp.com/content/dam/customer/OpCoHome/files/JCPLRegulatory/JCPL-EEC-Plan-Verified-Petition.pdf. Page 18.

[15] MA PAs 2021. Note: "Energy Efficiency Guidelines 3.4.6 requires that 'Benefits and costs that are projected to occur over the term of each Energy Efficiency Program shall be stated in present value terms, using a discount rate that is equal to a twelve-month average of the historic yields from the ten-year United States Treasury note, using the previous calendar year to determine the twelve-month average.' The Program Administrators calculated the discount rate used in their 2022-2024 Plan consistently with this methodology, but averaged interest rates over the previous three years (instead of the previous one year) to account for the anomalous impact of the COVID-19 pandemic on interest rates." Source: Massachusetts Program Administrators. 2021. "Massachusetts Joint Statewide Electric and Gas Three-Year Energy Efficiency Plan: 2022-2024." Available online: https://ma-eeac.org/wp-content/uploads/Exhibit-1-Three-Year-Plan-2022-2024-11-1-21-w-App-1.pdf. Exhibit 1, Appendix C.1, Page 2.

Table 4. Discount rates utilized in battery storage BCAs

Discount Rate	Applications	Reference
Social discount rates		
0.81%	Real discount rate for energy price levelization	NE AESC 2021
1%, 2%, 3%	NYS SCC guidelines	NYDPS 2015
1-2.5%	Intergenerational discount rate for SCT	DC CEAIWG 2021
2.5%, 3%, 5%	EPA discount rates for SCC	NYDPS 2015
3%	Residential solar PV	CT Green Bank 2020
3%	PACT, SCT, TRC	CT Green Bank 2020
3%	SCC (real discount rate)	NYSEG and RG&E 2020
3%	Real discount rate	NJBPU 2020
Financial discount rates		
6.81%	NYSEG WACC for 2018	NYSEG and RG&E 2020
7%	RIM	CT Green Bank 2020
7.18%	WACC for utility-scale solar	MN EEE 2019
7.18%	WACC for BTM solar financing	MN EEE 2019
7.48%	RG&E WACC for 2018	NYSEG and RG&E 2020
8%	After-tax nominal WACC	MA DOER 2016
9.13%	WACC for front-of-meter Li-ion battery financing	MN EEE 2019
9.13%	WACC for BTM storage financing	MN EEE 2019
10%	PCT	CT Green Bank 2020
10%	Battery energy storage system (BESS)	HI GE Energy 2017

Benefits

AEC's review of the literature generated a list of 25 benefits for inclusion in battery storage BCAs including the following:

- **Consumer benefits:** benefits conferred to battery storage program participants and electric ratepayers more broadly as a result of new battery energy storage system
- **Avoided system costs:** reduced costs experienced by utility customers and the electric system overall due to the implementation of battery storage programs

- **Environmental and health benefits:** benefits to the natural environment and the human communities that rely on natural resources by developing battery storage and avoiding some of the worst impacts of business-as-usual energy infrastructure investments,
- **Grid reliability benefits:** battery energy storage systems can improve the reliability of the grid, offering benefits to customers, utilities and the entire energy system, and
- **Benefits that are difficult to monetize:** some benefits—such as participant non-energy benefits, health benefits, and environmental justice benefits—are especially difficult to quantify, but, because leaving them unquantified is equivalent to assigning them a value of zero in a BCA, new or novel measurement techniques should be utilized to assign values to these benefits.

AEC Recommendation

Include all 25 benefits of battery storage, listed in Table 5, for a thorough consideration of a full range of battery benefits.

Table 5. Benefits of battery storage

Benefit Category	Benefit
Consumer benefits	Lower ratepayer bills
	Lower customer energy use
	Fewer power outages and value of lost load (VOLL)
	Job creation
	Higher property values
	Enhanced value and capacity of renewables
Avoided system costs	Avoided operations and maintenance costs
	Avoided costs of environmental compliance
	Avoided capacity costs
	Avoided fuel costs
	Reduced ancillary services costs
	Avoided transmission and distribution costs
	Avoided collections and disconnections
	Reduced costs to integrate distributed renewable generation
	Wholesale market price effects
Environmental benefits	Smaller land footprint than generation facilities
	Reducing greenhouse gas emissions and air pollution
	Reduced water consumption
Grid reliability	Fewer power outages
	Avoided emergency calls
	Peak shaving and shifting
	Black start capability
	Reduced grid congestion
Difficult-to-monetize benefits	Participant non-energy benefits
	Societal non-energy benefits (including public health and EJ benefits)

The following section organizes battery storage benefits into the following six categories: Consumer Benefits, Avoided System Costs, Environmental Benefits, Grid Reliability, and Difficult-to-Monetize Benefits where each category contains multiple benefits (see Table 6 below). Each benefit section below provides the following:

- An explanation of the benefit—that is, how battery storage provides the benefit in question and why that benefit ought to be included in a battery storage BCA
- References to utility BCAs and related guidance documents that use or discuss the benefit, and, when available
- Values provided for that benefit from AEC's review of the literature.

It is important to note that many of the benefits included in Table 5 above are not exclusive to one benefit category or another, and some of the "benefits" listed are actually multiple benefits that are closely related: For example, non-energy benefits like enhanced grid reliability, job growth, and increased safety are all captured in other categories, while reduced greenhouse gas emissions and air pollution are distinct benefits that are closely related to one another.

Consumer Benefits

Consumer benefits are the benefits conferred to battery storage program participants and electric ratepayers more broadly as a result of new battery energy storage systems. While electric ratepayers are represented at all levels of society, different groups of ratepayers will experience different sets of benefits from battery storage implementation. The benefits that ratepayers can accrue as a result of battery energy storage systems include financial gains by way of reduced electric bills and increased property values (of particular benefit to low-income communities), reduced power outages, lower energy use, and the creation of new jobs.

Lower ratepayer bills

Battery storage provides electric supply during times of peak demand, collects energy during times of lower demand, and reduces congestion on the transmission and distribution systems. Together, these battery functions make customer bills more affordable[16] by:

- Reducing congestion and demand charges.[17]
- Reducing the need for costly new peaker plants.[18]
- Providing frequency response and load management.[19]
- Lowering the energy and capacity costs that are passed onto ratepayers.[20]

Ratepayers' cost savings from battery storage can be further enhanced when battery storage is paired with other kinds of resources and/or rate structures, such as when:

[16] US NESP 2020. Pages 4 to 19.
[17] CA Brattle 2017. Page 6.
[18] MA AEC 2019a. Page 19.
[19] US ESA 2017. Page 8.
[20] MA DOER 2016. Page xii and 89.

- Battery storage is paired with renewable energy generation sources and is used to better align variable supply with demand[21] and/or
- Incentives are made available via performance payment programs such as demand response programs and Massachusetts' ConnectedSolutions program;[22] and/or
- Customers are offered time-of-use rates that make it possible to charge battery storage when rates are low and dispatch energy stored in batteries when rates are high.[23]

Lower ratepayer bills are of the greatest benefit to low-income customers, who are more likely to be energy-burdened (that is, pay a larger share of their income in energy costs than higher-income customers) and to fall behind or default on their energy bills[24] and face utility disconnections.[25]

Table 6. Estimates of lower ratepayer bill benefits from battery storage measures

Sources	Justification for benefit inclusion	Value
MA DOER 2016 (pages xii, 89)	- Peak shifting leads to energy price suppression - Utilization of battery storage within the transmission system reduces congestion and transmission losses, also lowering energy prices	$275 million (over 10 years starting in 2020, for 1,776 MW of storage)
CT Green Bank 2020 (pages 77, 79)	- Ratepayer bills are reduced when customers are on time-of-use rates as batteries shift energy consumption from higher priced hours to lower priced hours	$3.53 million over 4 years ($270K in 2022, $480K in 2023, $920K in 2024, $1.7M in 2025 for 50 MW of storage)
US RAP 2019 (pages 25, 45)	- Customers using distributed energy resources (including batteries) for water/space heating typically see bill reductions as compared to fossil fuels	Net bill savings equal 10 to 40 percent under current rate structures

Estimates of lower ratepayer bills as a result of battery storage measures vary substantially, depending on the amount of battery storage and the timeframe under consideration, but AEC's review of the literature indicates that this benefit is substantial (see Table 6, additional customer price impacts from wholesale market changes are discussed in the section on *Avoided System Costs* above).

Lower customer energy use

Customer-sited batteries have the potential to lower electric customers' overall energy use (and, therefore, further lower customer bills) by facilitating the integration of more efficient residential technologies, like rooftop solar[26], electric heat pumps, and electric hot water heating systems.[27]

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[21] Ibid. Page 13.
[22] (1) RAP 2019. Page 85. (2) Clean Energy Group. 2021. *ConnectedSolutions*. Available online: https://www.cleanegroup.org/ceg-resources/resource/connected-solutions-policy/. Page 14.
[23] (1) CT Green Bank 2020. Page 77; (2) CA Brattle 2017. Page 3.
[24] US NESP 2020. Pages 4-14.
[25] (1) MA AEC 2019b. Page 11; (2) MA PAs 2021.
[26] While some states categorize solar PV as an efficiency measure, others do not, finding that a reduction in grid demand does not always correlate with an increase in energy efficiency.
[27] US RAP 2019. Page 25.

Customer-sited batteries enable households to manage their own energy use more efficiently and can reduce their overall energy requirements.[28] For example, research published in the journal in *Energy and Buildings*[29] has shown that a home with solar panels could reduce its electric demand from the power grid by 14 percent with battery storage as opposed to just 5 percent without battery storage.[30] Table 7 presents an estimate of the value of lower customer energy use from AEC's review of the literature.

Table 7. Estimate of lower customer energy use benefit from battery storage measures[31]

Source	Justification for benefit inclusion	Value
US RAP 2019 (page 28)	- Battery storage reduces customer energy and demand charges by shifting evening energy loads to daytime hours	Average monthly demand charge reduction of 42 percent for battery plus rooftop solar (compared with 8 percent for rooftop solar only or 23 percent with battery only)
CT PURA 2021 (page 25)	- Battery storage reduces the need for marginal generation capacity during peak load hours.	The implementation of 50 MW of battery storage capacity from 2020 to 2025 would result in a total of $30,010,000 in net present value avoided generation capacity savings (per CT green Bank, see fn. 36)

Resilient power during outages and the value of lost load (VoLL)

Battery storage can reduce the frequency and duration of power outages[32] by providing a source of emergency power to customers[33] in the event of service interruptions[34] and reducing the costs of power outages on ratepayers.[35] Nationally, power outages cost residences and businesses between $30 and $130 billion each year.[36] For residential consumers, the damages of power outages include increased discomfort; morbidity or mortality from loss of electric appliances, medical devices, and/or

[28] Ibid.

[29] Vossos, Vagelis, Karina Garbesi, and Hongxia Shen. 2014. "Energy savings from direct-DC in US residential buildings." *Energy and Buildings*, 68, 223-231.

[30] Department of Energy. September 2015. "Chapter 5: Increasing Efficiency of Building Systems and Technologies." *Quadrennial Technology Review: An Assessment of energy Technologies and Research Opportunities.* Available online: https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter5.pdf. Page 172.

[31] Connecticut Green Bank. July 31, 2020. *Solarize Storage—A Proposal of the Connecticut Green Bank Under Docket No. 17-12-03(RE03)—Electric Storage*. Available online: https://www.ctgreenbank.com/wp-content/uploads/2020/08/PURA-Docket-No.-17-12-03RE03-%E2%80%93-Solarize-Storage-Proposal-from-the-Green-Bank.pdf

[32] MA AEC 2019a. Page 21.

[33] CT Green Bank 2020. Page 86.

[34] US ESA 2017. Page 11.

[35] (1) MA AEC 2019a. Page 11; (2) CT Green Bank 2020. Pages 82-86, 89.

[36] MA DOER. Page 26.

loss of heating or cooling; the loss of perishable foods; and the loss of labor income when work is interrupted. For businesses, the costs of power interruptions include decreased production; damage to equipment, inventory, material inputs, or products; and the costs of maintaining and operating backup power.[37] Resiliency in the face of power outages will especially benefit hourly workers who might otherwise lose wages, medical patients whose equipment might otherwise be unable to function, and providers and recipients of essential services that might otherwise be disrupted due to losses of service.[38]

A reduction in the number and duration of power outages is a benefit for both customers and electric distributors, but valuing this benefit is made difficult by the fact that there is no market for the avoidance of energy interruptions. As a result, most valuation exercises seek to estimate the costs of energy interruptions[39] by estimating the cost to customers of a power outage on a per kilowatt-hour (kWh) basis[40]—an estimate that is referred to as the "value of lost load," or VoLL.

VoLL is a measure of the costs that families and businesses face when they lose load (i.e. experience power outages), and is estimated in various ways, including willingness-to-pay values from survey data (customers are asked how much they would pay to avoid power outages), direct damage costs, revealed preferences (using spending on back-up generators and batteries to infer the value placed on avoiding outages), and macroeconomic production-function techniques (involving large data sets and advanced statistical methods).[41]

Whatever the estimation method, VoLL is simultaneously a measure of (1) the cost to customers of power outages *and* (2) the benefit to customers of **avoided** power outages. The estimated VoLL varies, depending on the estimation method, location, or customer class (see Table 8).

[37] Hamachi, LaCommare, Eto. 2004. " Understanding the Cost of Power Interruptions to U.S. Electricity Consumers." Lawrence Berkeley National Laboratory. Available online: https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/Understanding_Cost_of_Power_Interruptions.pdf.

[38] Castigliego, J., T. Stasio, and E. Tavares. 2021. *Conditional Benefits of sustainable Community Microgrids.* AEC. Available online: https://aeclinic.org/publicationpages/2021/5/20/conditional-benefits-of-sustainable-community-microgrids. Page 3.

[39] van der Welle, A. and van der Zwaan, B. 2007. An Overview of Selected Studies on the Value of Lost Load (VoLL). Energy Research Centre of the Netherlands. Page 2.

[40] Schröder and Kuckshinrichs. December 24, 2015. "Value of Lost Load: An Efficient Economic Indicator for Power Supply Security? A Literature Review." *Frontiers in Energy Research*. Available online: https://www.frontiersin.org/articles/10.3389/fenrg.2015.00055/full.

[41] NE AESC 2018. Page 218.

Table 8. NE AESC 2018 results of reported values of recent lost load literature review (2018$/kWh)

Report year	Author	Region	Small C&I	Large C&I	Residential	Weighted average across sectors
2015	LBNL[a]	US	$280	$16	$2	$37[d]
2014	London Economics[b]	ERCOT	$7	$4	--	$12[d]
2014	London Economics[b]	US	$46	$31	$2	--
2010	Centolella[c]	Midwest	$56	$28	$5	--

[a] Sullivan et al. 2015. Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States. Prepared for Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy. Lawrence Berkeley National Laboratory (LBNL). [b] London Economics International LLC. 2013. Estimating the Value of Lost Load. Prepared for the Electric Reliability Council of Texas, Inc. [c] Centolella, P. 2010. Estimates of the Value of Uninterrupted Service for The Mid-West Independent System Operator. Harvard Electricity Policy Group. [d] AESC 2018.

AEC's review of the literature—including one of our own publications[42] from 2019 that explains VoLL and its valuation in detail—indicates that VoLL estimates range from roughly $20 to $25 per kWh while estimates of the value of avoided outages for the State of Connecticut topped $14.5 million over five years (see Table 9). The Dallas Federal Reserve estimates the VoLL of the 2021 Texas blackouts at $6.73 per kWh for firms and $0.12 per kWh for households; the amount of power lost (a total of 70.5 hours and an average load loss of 14,000 MW) resulted in a total power outage cost of $4.3 billion.[43]

It is also important to note that reliability can and does provide many distinct benefits, and VoLL accounts for some, but not all, of these benefits. For example:

- More resilient power enables providers of safety and health services—like hospitals or community health centers—to continue to provide services that are extremely valuable to society during outages (which often coincide with and are caused by natural disasters). While many health facilities own large back-up generators, their operation is costly and is typically limited by the store of fuel at the onset of an emergency. In addition, many other critical facilities (i.e., public shelters, health clinics, fueling stations, etc.) do not have backup generators of any kind on-site. The added value of being able to continue to provide emergency services to the community during a natural disaster and/or power outage is not captured by VoLL.

[42] MA AEC 2019b.
[43] Golding, G., A. Kumar, K. Mertens. 2021. *Cost of Texas' 2021 Deep Freeze Justifies Weatherization*. Federal Reserve Bank of Dallas. Available online: https://www.dallasfed.org/research/economics/2021/0415.aspx.

- The value of avoided power outages for customers who are elderly, disabled or reliant on electronic devices for serious health conditions[44] is greater than for other kinds of customers because to be without power could be harmful or life threatening.[45]

Table 9. Estimates of VoLL from battery storage measures

Sources	Justification for benefit inclusion	Value
MA AEC 2019a (pages 11, 21)	- Avoiding power outages is beneficial for customers because it reduces costly and potentially dangerous disruptions to life and work	$26/kWh VoLL (across all customer classes in New England)
NE AESC 2018 (page 227) MA PAs 2021	- There are costs to customers when they are unable to take power from the system, including direct and indirect damages	$25/kWh VoLL (across all customer classes in New England)
US RAP 2019 (page 98)	- Storage can be used to avoid costly power outages, which provides benefits for customers	$20/kWh commercial and industrial, $3/kWh residential VoLL (in Texas)
CT Green Bank 2020 (page 89)	- There is value in emergency backup power to customers due to greater energy reliability	$14,710,000 net avoided outage benefits (50 MW battery storage between 2021-2025)
US ESA 2017 (page 11)	- Storage can be used to avoid costly power outages, which provides benefits for customers	$29.5 billion VoLL (between 2017-2025 for 35 GW of battery storage)

These are distinct non-energy and non-market benefits of greater energy reliability that may not be adequately accounted for in VoLL. (VoLL is also used as a proxy to represent the savings from avoided outages to utilities or the system as a whole; see the section on *Grid Reliability* below.)

Job creation

Investing in battery storage creates jobs along the entire value chain, including in planning, developing, managing, manufacturing, constructing, installing, and operating and maintaining battery systems.[46] In addition, though these services have not yet been developed for lithium ion batteries, there will be new jobs in battery recycling, decommissioning and disposal as the first generation of Li-ion batteries

[44] (1) Molinari, N.A.M., Chen, B., Krishna, N., and Morris, T. March 2017. "Who's at Risk When the Power Goes Out? The At-home Electricity-Dependent Population in the United States, 2012." Journal of Public Health Management and Practice, 23(2), 152-159. Available online: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5007208/; (2) Mango, M. 2019. *Home Health Care in the Dark.* Prepared for Clean Energy Group. Available online: https://www.cleanegroup.org/wp-content/uploads/Home-Health-Care-in-the-Dark.pdf. Page 4.

[45] See: Code of Massachusetts Regulations Title 220. January 27, 2017. 220 CMR 19.00: Standards of Performance for Emergency Preparation and Restoration of Service for Electric Distribution and Gas Companies. Available online: https://www.mass.gov/files/documents/2016/08/rr/220cmr1900.pdf.

[46] MA DOER 2016. Appendix B, page 223.

ages.[47] Battery storage also creates indirect jobs[48] in industries that supply and support battery storage, such as from the demand for materials used to make batteries or related manufacturing of battery components and other equipment.[49] Job creation in turn generates additional benefits for customers, including easily monetized benefits such as labor income.[50] According to the National Association of State Energy Officials and the Energy Futures Initiative's *U.S. Energy and Employment Report*, there were nearly 66,000 people directly employed in the battery storage jobs nationwide in 2019, 8,500 employed in pumped hydro, and 3,500 in other storage jobs.[51]

Estimates of job creation from battery storage development are presented in Table 10. A recent study conducted by AEC on the *Economic Impacts of a Clean Energy Transition in New Jersey* found that, by 2050, a clean energy transition would result in the net creation of 5,506 jobs in energy storage within the State of New Jersey.[52] Massachusetts' *State of Charge* report estimates that installing 1,776 MW of energy storage over a five-year period (2016-2020) could create 5,911 job-years (where 1 job-year is defined as one job for one year) and $550 million in labor income.[53] These benefits are equivalent to approximately 3.3 jobs per MW and $334,000 per MW over the battery storage deployment period (2017-2020).[54]

Table 10. Estimates of job creation benefit

Sources	Justification for benefit inclusion	Value
MA DOER 2016 (Page 22)	- Battery storage creates jobs in manufacturing, research and development, engineering, and installation	5,911 job-years and $550 million in labor income (2016-2020, for 1,776 MW of storage)
MA AEC 2019b (Pages 22-23)	- Battery storage creates jobs, including in: battery manufacturing, research and development, engineering, construction, operations and maintenance, sales, marketing, management, and administration	3.3 jobs/MW (2017-2020) 0.05 jobs/MW (2021-2025) $334,522/MW (2017-2020) $4,500/MW (2021-2025)
NJ AEC 2022 (Pages 34-36)	- Battery storage creates direct, indirect, and induced jobs in research and development, construction, installation, and elsewhere in the energy sector	5,506 new jobs (in 2050) 60,541 added job-years (by 2050) $540 million in labor income (in 2050)

[47] NREL. 2021. *A Circular Economy for Lithium-Ion Batteries Used in Mobile and Stationary Energy Storage*. Page 7.
[48] US NESP 2020. Pages 4 to 22
[49] MA DOER 2016. Appendix B, page 223.
[50] CEAI 2021. Page 11.
[51] National Association of State Energy Officials and the Energy Futures Initiative. 2020. *2020 U.S. Energy and Employment Report.* Available online: https://static1.squarespace.com/static/5a98cf80ec4eb7c5cd928c61/t/5ee78423c6fcc20e01b83896/1592230956175/USEER+2020+0615.pdf
[52] NJ AEC 2022. Page 9.
[53] MA DOER 2016. Pages 23 and 103.
[54] MA AEC 2019b. Page 22-23.

Higher property values

When batteries are installed in a residence or commercial property, they increase the value of that property to the extent that buyers or renters are willing to pay more for the benefits that on-site batteries can provide, such as:

- Increased energy resiliency during power outages.[55]
- The ability to participate in wholesale energy markets, demand response programs, and incentive programs where available.
- Reduced operating costs from optimized energy usage.[56]
- The perception of batteries as property upgrades, apart from their direct financial benefits.[57]

AEC's review of the literature indicates that battery storage can lead to significant property value increases (see Table 11).

Table 11. Estimates of higher property value benefit

Sources	Justification for benefit inclusion	Value
US RAP 2019 Page 26	- Battery storage systems increase property values by making energy management more flexible, making a property more marketable, and, when paired with rooftop solar, reducing energy expenses	$15,000 (Increased residential property value from average array (3.6 kW) of rooftop solar)
MA AEC 2019b Page 17	- Battery storage systems increase property values by providing energy during outages, by making buildings' thermal control more comfortable, and by making a property more marketable	$5,325 per low-income single-family homes and $510 per unit for owners of multi-family housing

Enhanced value and capacity of renewables

The use of battery energy storage systems can augment the capacity of existing variable renewable energy resources, thereby enhancing their value to customers by deferring investments in new renewables.[58] Likely due to the nascency of research in this specific area, AEC's review of the literature did not yield any sources that quantified the monetary value of enhanced renewables capacity. A potential avenue for estimating the enhance value and capacity of renewables is the value of deferred investment.

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[55] ACEEE. 2012. Measuring Participant Perspective Non-Energy Impacts (NEIs). Available online: https://aceee.org/files/proceedings/2012/data/papers/0193-000046.pdf.
[56] MA NEI Evaluation 2011; AEC 2019. Page 17.
[57] Hoen, et al. 2013. "Exploring California PV Home Premiums." Berkeley National Laboratory - Environmental Energy Technologies Division. LBNL-6484E. Available online: http://emp.lbl.gov/publications/exploring-california-pv-home-premiums.
[58] MIT. 2020. "Long-run system value of battery energy storage in future grids with increasing wind and solar generation." *Applied Energy*. Available online: https://www.sciencedirect.com/science/article/abs/pii/S0306261920309028?via%3Dihub.

Avoided System Costs

The implementation of battery storage programs will result in reduced costs experienced by utility companies and the electric system overall. In addition to the arbitrage opportunity presented by the capability of battery storage systems to charge energy at times of low cost for use at times of high cost, batteries can reduce system costs by lowering the costs of operations, maintenance, renewable energy integration and ancillary services and avoiding the costs of environmental compliance, capacity, fuel, and transmission and distribution.

Avoided operations and maintenance costs

Battery storage provides electric supply during times of peak demand, a critical balancing service that avoids the need to operate expensive fossil fuel "peaker" power plants.[59] Discharging batteries at strategic times reduces energy system operations and maintenance (O&M) expenditures by:

- Preventing the need to start and stop.[60]
- Preventing the need to ramp generation up and down.[61]
- Reducing the need to build new, additional fossil fuel peaker plants.[62]
- Reducing the cost to provide frequency regulation and spinning reserve services.[63]
- Reducing equipment failure rates.[64]

In addition to the issues discussed here, peakers emit local criteria pollution that results in environmental and human health impacts. Because peakers are often sited in densely populated areas (close to electric load) and because they are more often in low-income neighborhoods, this leads to equity issues.[65]

By charging and discharging battery storage to meet changing electric demand in lieu of deploying peaker plants, utilities can operate fossil fuel-fired plants at constant generation output, reduce their heat rates, and improve their efficiency,[66] thereby minimizing load fluctuations and reducing O&M costs.[67] Table 12 presents estimates of the value of avoided O&M costs from AEC's review of the literature.

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[59] MA DOER 2016. Page 95.
[60] Ibid. Page 94.
[61] Ibid. Page 94.
[62] (1) Ibid. Page 33; (2) Robbins, S. H., and Mango, M. *The Peaker Problem.* Prepared for Clean Energy Group. Available online: https://www.cleanegroup.org/wp-content/uploads/The-Peaker-Problem.pdf. Page 18.
[63] US ESA 2017. Page 9.
[64] NYDPS 2015. Page 24.
[65] (1) Castigliego, J. R., Stanton, E. A., Alisalad, S., Stasio, T., Tavares, E. 2021. *PJM's Capacity Market: Clearing Prices, Power Plants, and Environmental Justice.* Available online: https://aeclinic.org/publicationpages/2021/10/29/pjms-capacity-market-clearing-prices-power-plants-and-environmental-justice?rq=pjm; (2) Mango, M. 2019. *Home Health Care in the Dark.* Prepared for Clean Energy Group. Available online: https://www.cleanegroup.org/wp-content/uploads/Home-Health-Care-in-the-Dark.pdf. Page 20.
[66] MA DOER 2016. Page 94-95.
[67] Ibid.

Table 12. Estimates of avoided O&M costs benefit

Sources	Justification for benefit inclusion	Value
MA DOER 2016 (pages 94-95)	-Energy storage improves the efficiency of generators by preventing them from turning on or off and ramping up and down rapidly during peak periods. This reduces O&M, including environmental compliance costs - Plants operating at constant generation see increased efficiency, reduced heat rates, and decreasing O&M costs	\$197 million (over 10 years)
US ESA 2017 (page 9, Chart 3.1)	- Reduced cost of spinning reserves and frequency regulation - Operational cost savings to households	\$4.05 in cumulative savings by 2025 (for 3 GW of storage in 2025)
NYSEG & RG&E 2020 (page 93-94)	- Reduced expenses such as reductions in customer service phone calls or savings from advanced meter functionality - Reduced expenses not tied to avoided distribution system investments	Fixed O&M: 3% of CapEx per year inflated annually Variable O&M: \$2/MW

Avoided costs of environmental compliance

Batteries are often charged from emission- and pollution-free renewable energy generation sources like wind and solar because storage balances these resources' intermittency (that is, that wind- or solar- generated power is only "available" when the wind is blowing or the sun is shining).[68] Adding battery storage to the energy grid, therefore, offers increased reliability to wind- and solar-generated power and enables the addition of further wind and solar to the grid, which in turn lowers the cost of environmental compliance—such as the cost of CO_2 and other emissions allowances.[69]

AEC's review of recent literature found that New England's 2021 *Avoided Energy Supply Components* estimated the benefit of avoided environmental compliance costs at \$2.67 to \$16.81 per MWh across the six New England states (see Table 13). As renewable energy and emission reduction targets increase and state policymakers develop stronger enforcement mechanisms, the cost of compliance and the benefit of avoided compliance costs will increase as well.

Table 13. Estimates of avoided costs of environmental compliance benefits from battery storage

Source	Justification for benefit inclusion	Value
NE AESC 2021 (pages 143-144) MA PAs 2021	- Energy efficiency, demand-side measures, and clean energy sources reduce the cost of compliance with renewable energy standards across the New England states	\$2.67 to \$16.81 per MWh (across 4 scenarios, \$2021, levelized 2021-2035)

[68] C. Katz. 2020. "In Boost for Renewables, Grid-Scale Battery Storage Is on the Rise." *YaleEnvironment 360*. Available online: https://e360.yale.edu/features/in-boost-for-renewables-grid-scale-battery-storage-is-on-the-rise.

[69] (1) AESC 2021; (2) CA CPUC 2020; (3) DC Pepco 2021.

Avoided capacity costs

By charging when electric demand is low and discharging when demand is high, battery storage helps lower peak electric demand and utilities require less generation capacity to satisfy their capacity obligations, thereby avoiding capacity market purchases.[70] Each utility must maintain enough generation capacity to meet peak electric demand plus a "reserve margin" as mandated by its regional grid operator, or as mandated by their own set capacity requirements. These reserve margins are subject to change; for example, PJM expects to raise its summer peak reserve margins from 28.8 percent in 2022 to 38.0 percent in 2026.[71]

Developing battery storage resources lowers peak demand and avoids the need to generate electricity at the margin (i.e., at high cost) during times of peak demand: a benefit for the energy system as a whole. Table 14 summarizes estimates of the benefit of avoided capacity costs from AEC's review of the literature—in Massachusetts alone, the benefit of reduced peak capacity costs (for 1,776 MW of storage) is estimated at over $1.8 million (see discussion of "DRIPE" below).

Table 14. Estimates of avoided capacity costs benefit from battery storage[72]

Sources	Justification for benefit inclusion	Value
MA DOER 2016 Page 125	- Electric producers can avoid the cost of maintaining sufficient generation capacity to meet peak demand (plus a reserve margin) by discharging batteries during periods of high demand, and charging them during periods of low demand	$150/kW-yr (for 1MW/1MWh storage)
CT Green Bank 2020 Page 170, Table 6	- Reducing system peak loads also reduces the marginal generation capacity required during system peaks	$170/kW-yr (sum of weighted average retail cost of capacity, distribution and transmission costs)

Avoided fuel costs

Battery storage can reduce system fuel costs by:

- Reducing peak demand and thereby lowering the need for on-site fuel storage and/or high fuel prices at times of peak. [73]

[70] (1) US ESA 2017. Page 10; (2) CT Green Bank 2020. Page 75-6; (3) NYSEG and RG&E 2020. Page 37; (4) NYDPS 2015. Page 13; (5) US EIA 2021. Page 113; (6) CA Brattle 2017. Page iv; (7) MA DOER 2016. Page 33.
[71] PJM 2022. "Forecasted Reserve Margin." Available online: https://www.pjm.com/-/media/planning/res-adeq/20220119-forecasted-reserve-margin-graph.ashx.
[72] MA DOER 2016 estimates the value of avoided capacity payments at approximately $0.6 million for a 1-MW storage project, or (by AEC's calculation) approximately $150/kW-yr.
[73] MA DOER 2016. Page 33.

- Increasing the fuel efficiency of fossil fuel generators by adjusting their "fuel flow set point" (i.e. how much fuel the generator requires for operation).[74]

AEC's review of the literature found one estimate of the benefits of energy storage by way of avoided fuel costs from increasing the efficiency of gas generators (see Table 15). According to the source's modeling results, the value of these benefits in 2050 for a 2,000-MW long-duration battery system, under different assumptions of round-trip battery efficiency between 40 and 80 percent, ranges from $29 to $74 million.[75]

Table 15. Estimate of avoided fuel costs benefit from battery storage

Source	Justification for benefit inclusion	Value
Western FER 2020 (page 11)	- Long-duration battery storage reduces fuel costs by improving generator efficiency	$29.1 million at 40% round-trip efficiency to $73.9 million at 80% round-trip efficiency

Reduced ancillary services costs

Battery storage enables generation to follow load more closely thereby reducing the overall cost of system ancillary services required by the grid by:[76]

- Reducing the need for frequency regulation.[77]
- Reducing the need for spinning reserves.[78]
- Reducing the need for voltage stabilization.[79]

AEC's review of the literature found one estimate for reduced ancillary service costs, although this estimate is for ratepayer rather than utility savings (see Table 16). In addition, distributed energy resources providers can benefit if they qualify to provide ancillary services to their grid operator at lower cost than conventional generators.[80]

[74] Ibid. Page 5.
[75] Western FER 2020. Page 11.
[76] NYDPS 2015. Page 18.
[77] MA DOER 2016. Page 92.
[78] Ibid.
[79] Ibid.
[80] NYSEG and RG&E 2020. Page 45.

Table 16. Estimate of reduced ancillary services cost benefit

Source	Justification for benefit inclusion	Value
MA DOER 2016 (pages 94-95)	Battery storage reduces: frequency regulation, spinning reserves, voltage stabilization and VAR support	$200 million to ratepayers (over 10 years starting in 2020, for 1,776 MW of storage)

Avoided transmission and distribution costs

Battery storage reduces system transmission and distribution (T&D) costs by:

- Reducing load growth and the degree to which existing T&D infrastructure is utilized, extending that equipment's life span[81] and delaying the need for significant T&D replacement.[82]
- Reducing the need for investment in new feeder lines and substations.[83]
- Avoiding congestion-related costs and charges on T&D equipment.[84]

Siting storage (and distributed generation) close to customer load or transmission-constrained locations on the grid further enhances T&D cost saving benefits because it results in less electricity transmitted from centralized generation sources and reduced demand during times in which capacity is constrained.[85] AEC's review of the literature found two estimates for reduced T&D costs (see Table 17).

Table 17. Estimate of reduced T&D cost benefit

Source	Justification for benefit inclusion	Value
MA PAs 2021	Battery storage reduces T&D costs	$99.16/kW transmission $83.07/kW distribution (both in 2021$)
NYS Roadmap (Page 5)	Avoided distribution infrastructure	$505/kW distribution (NPV $1.4B savings from 2,795 MW storage by 2030)

Avoided collections and disconnections

Battery storage reduces customers' electric bills, which results in residences and businesses being better able to pay their bills and lowers utilities' costs by decreasing the need to make safety-related calls and send disconnection notices.[86]

[81] MA DOER 2016. Page 42.
[82] CT Green Bank 2020. Page 76.
[83] US NRECA 2019. Page 22.
[84] US EIA 2021. Page 14.
[85] (1) CA Brattle 2017. Page 5; (2) US NESP 2020. Pages 8-10.
[86] MA AEC 2019a. Page 19.

Table 18 provides estimates of the benefit (on a per customer basis) of avoided safety-related emergency calls and disconnection notices from a 2011 report by Massachusetts' energy efficiency program administrators.[87]

Table 18. Estimates of fewer safety-related calls and disconnection notices benefit

Sources	Justification for benefit inclusion	Value
MA NEI Evaluation 2011 (page D-5)	- When ratepayers pay bills on time, utilities make fewer safety-related calls	$1.03/year/customer (2010$)
MA NEI Evaluation 2011 (page D-6)	- When ratepayers pay bills on time, utilities send fewer disconnection notices	$0.96/year/customer (2010$)

Reduced costs to integrate distributed renewable generation

Battery storage reduces the cost of integrating utility-scale and distributed renewable energy resources by:

- Reducing the cost of reverse power flow at substations—a phenomenon in which the generation of distributed power exceeds local customer demand, causing power to flow in the opposite direction.[88]
- Avoiding feeder upgrades at substations to accommodate increased capacity from distributed generation.[89]
- Shifting electric loads to accommodate larger amounts of intermittent renewable generation, which benefits ratepayers through avoided energy, capacity and ancillary costs.[90]
- Enhancing the cost savings from distributed renewable resources.[91]

The estimated benefits of battery storage for renewable integration from AEC's review of the literature are presented in Table 19 below.

[87] MA NEI 2011.
[88] (1) MA DOER 2016. Page 86; (2) J. P. Holguin, D. Celeita Rodriguez, and G. Ramos. 2020 "Reverse power flow (RPF) detection and impact on protection coordination of distribution systems." *IEEE Transactions on Industry Applications* 56, no. 3. Available online: https://ieeexplore.ieee.org/document/8972583. Pages 2393-2401.
[89] (1) MA DOER 2016; (2) K. A. W. Horowitz, F. Ding, B. A. Mather, and B. S. Palmintier. 2018. *The cost of distribution system upgrades to accommodate increasing penetrations of distributed photovoltaic systems on real feeders in the United States*. No. NREL/TP-6A20-70710. National Renewable Energy Lab. (NREL). Available online: https://www.nrel.gov/docs/fy18osti/70710.pdf.
[90] US RAP 2019. Page 28.
[91] Ibid.

Table 19. Estimate of reduced renewable integration cost benefit

Source	Justification for benefit inclusion	Value
MA DOER 2016 (page 87)	- Battery storage reduces the cost of integrating distributed renewable generation through reductions to reverse power flow costs and avoiding feeder upgrades	$219 million to ratepayers (over 10 years starting in 2020, for 1,776 MW of storage)

Wholesale market price effects

Battery storage reduces customer demand and peak load, shifting the marginal generating unit (that is, eliminating the need for the most expensive generating unit being run on the system) thereby lowering electric rates paid by all consumers on the system.[92] (Economists call this effect "elasticity;" many energy planners call it Demand Reduction Induced Price Effect, or DRIPE.) Multiplying this small drop in price by consumers' total electricity purchases produces substantial savings in total power expenditures and an effective transfer of value from generators to consumers.[93] While reduced capacity costs produce benefits in the year after the new battery system is deployed, a reduction in energy prices will be felt immediately by consumers.[94]

AEC's review of the literature found one estimate for wholesale market price effects (see Table 20).

Table 20. Estimate of wholesale market prices effects

Source	Justification for benefit inclusion	Value
MA PAs 2021	- Battery storage results in the Demand Reduction Induced Price Effect (DRIPE)	From $78.14/kW in 2023 to $27.47/kW in 2027 (2021$)

Environmental Benefits

Battery storage programs can yield important benefits to the natural environment and the human communities that rely on natural resources by avoiding some of the worst impacts of business-as-usual energy infrastructure investments. Among the environmental benefits of battery energy storage systems are reductions in energy infrastructure land footprint, greenhouse gas emissions, and air pollution. Other additional environmental benefits may exist but have not yet been quantified in public proceedings, for example, savings from reduced water use or avoidance of additional air and water pollutants.

Smaller land footprint than generation facilities

Compared to power plants, battery storage systems require comparatively little space and infrastructure, yielding cost savings and additional benefits if the "extra" land is used for other

[92] NYDPS 2015. Page 19.
[93] Ibid.
[94] NYSEG and RG&E 2020. Page 48.

purposes.[95] On average, gas plants, pipelines, and gas storage require 12.4 acres per MW of capacity; in comparison, large-scale centralized battery storage systems require between 0.004 and 0.04 acres per MW, and distributed battery storage systems are installed behind-the-meter and require no additional land space per MW of capacity.[96] The U.S. Bureau of Economic Analysis estimates the average value of non-developed land in the United States as $6,500 per acre.[97] At this (highly generalized) land price, installing a large-scale battery storage system instead of a 60 MW gas peaker plant would yield cost savings of approximately $80,450 per MW.[98]

Reducing greenhouse gas emissions and air pollution

Batteries may be charged from emission and pollution-free renewable energy generation sources like wind and solar, making the energy discharged from the batteries a zero-emitting resource. When paired with renewables, batteries lower greenhouse gas emissions and air pollution,[99] including CO_2, NO_x, sulfur oxides (SO_x), and particulate matter (PM)[100], to the degree that the marginal fossil fuel generation is displaced. Battery storage paired with renewables reduces greenhouse gas emissions and air pollution by:

- Supplying additional energy during peak demand, especially in areas where population density is high or the transmission system is constrained, reducing the need to burn fossil fuels to supply energy.[101]
- Powering electric vehicles and electric heating systems in residential and commercial buildings without combusting additional fossil fuel.[102]
- Replacing gas "peaker" power plants.[103]
- Replacing energy (and avoiding emissions) from backup diesel generators.[104]

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[95] MA DOER 2016. Pages vii, 9.

[96] (1) Strata. 2017. *The Footprint of Energy: Land Use of U.S. Electricity Generation*. Available online: https://docs.wind-watch.org/US-footprints-Strata-2017.pdf. Page 1. (2) International Renewable Energy Agency (IRENA), 2015. Case Studies: Battery Storage. Available online: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_Battery_Storage_case_studies_2015.pdf. (3) Leslie, P. 2014. Battery Storage Projects. Puget Sound Energy Presentation. UW Energy and Environment Seminar. Available online: https://class.ece.uw.edu/500/2014aut-e/11-13-14%20Pres%20(PSE%20Storage).pdf. (4) U.S. Department of Energy. 2020. "Potential Benefits of High-Power, High-Capacity Batteries." Available online: https://www.energy.gov/sites/prod/files/2020/02/f71/Potential_Benefits_of_High_Powered_Batteries_Report.pdf. Pages 9-11.

[97] Larson, 2015. "New Estimates of Value of Land of the United States." Bureau of Economic Analysis. Available online: https://www.bea.gov/systel%20m/files/papers/WP2015-3.pdf.

[98] Note that this estimate of land savings value may be low, because peaker plants are commonly sited close to load, i.e. in more densely populated areas, where land values tend to be higher. For more information on energy storage for peaker replacement, see Clean Energy Group's Phase Out Peakers project pages at: https://www.cleanegroup.org/ceg-projects/phase-out-peakers/#:~:text=It%20lays%20out%20a%20community,mix%20of%20resources%20by%202030.

[99] US RAP 2019. Page 26.

[100] US ESA 2017. Page 26.

[101] (1) MA DOER 2016. Page 41 and vii ; (2) US ESA 2017. Page 12 and 13; (3) MA AEC 2019a. Page 7.

[102] (1) DC Pepco 2021. Page ii; (2) US NESP 2020. Page 4-21.

[103] CA CPUC 2020. Page 30.

[104] MN E3 2019. Page 67.

The greater the round-trip efficiency of battery storage, the more greenhouse gas emissions and pollution is avoided,[105] which is of particular benefit for public health in areas with poor air quality.[106] In addition, the ability to enable greater deployment of renewable energy when paired with battery storage may increase potential emission reductions.

AEC's review of the literature finds that battery storage has the potential to substantially reduce greenhouse gas emissions and air pollution, as summarized in Table 21, particularly when installed under strategically structured state incentives.[107] For example, Massachusetts' demand-side measures' BCA (MA PAs 2021) includes a Massachusetts-specific social cost of carbon based on costs specific to the Commonwealth, including both social costs and allowances required under the Regional Greenhouse Gas Initiative (RGGI).[108]

Table 21. Estimates of reduced emissions and pollution benefit

Sources	Justification for benefit inclusion	Value
MA DOER 2016 (pages vii, 41)	- Fossil fuel generators are replaced by battery storage to supply energy during peak loads in heavily populated areas, reducing emissions	1.06 MMT CO_2e (over 10 years starting in 2020, for 1,776 MW of storage)
US ESA 2017 (pages 12,13)	- Battery storage charged with wind and solar energy emits zero emissions and can serve the grid during peak demand	Cumulative 3.7 MMT CO_2e (2017-2025 for 35 GW of storage)
DC Pepco 2021 (page iv)	- Emissions from fossil fuels are reduced when excess energy stored in batteries join the heating electrification network in buildings and supply energy to electric vehicles	95,000 MT (over 5 years from 2021)
US ESA 2017 (page 13)	- Integration of battery stored energy generated from wind and solar technologies reduces emissions and pollution	0.0251 lb SO_x/MWh (average) 0.1946 lb NO_x/ MWh (average) 1,000 MT CO_2e SO_x, NO_x and PM (cumulative by 2025) (2017-2025 for 35 GW of storage)

Note: Carbon dioxide equivalent (CO_2e) uses the global warming potential of greenhouse gases in terms of carbon dioxide units.[109]

Reduced water consumption

By providing extra capacity to energy systems, battery storage systems can replace greenhouse gas-emitting peaker plants that are approximately 40,000 times more water-intensive than batteries, per

105 Western FER 2020. Page 14.
106 MN E3 2019. Page 11.
107 CA SGIP 2021. Page 50.
108 MA PAs 2021.
109 EPA. No date. "CO_2e." Available online: https://www3.epa.gov/carbon-footprint-calculator/tool/definitions/co2e.html#:~:text=Carbon%20dioxide%20equivalent%20or%20CO,in%2040%20CFR%20Part%2098.

kWh: Research from the U.S. EIA demonstrates that, while the average power plant in the United States requires 13 gallons of water per kWh produced, a Lithium-ion battery only requires 0.00034 gallons per kWh.[110] AEC's review of the literature did not reveal any monetary valuations of the benefits of water conservation. While it is difficult to quantify the value of water in a BCA, it is necessary to account for this benefit in the BCA especially given the increasing prevalence of drought conditions in the United States (see the section on *Difficult-to-Monetize Benefits* below for more discussion on how to incorporate benefits such as water conservation into a BCA on battery energy storage).

Grid Reliability

Battery energy storage systems can improve the reliability of the grid, offering benefits not only to customers, but also to electric distributors and utilities. With the ability to store energy for later use, battery systems can reduce the occurrence of power outages and increase the emergency preparedness of the grid, lower peak demand and resulting congestion along transmission and distribution lines and enhance the grid's black start capabilities.

Fewer power outages

Fewer power outages mean avoided power outage costs, and this benefits customers and the energy system itself. The system benefit of avoided power outages is distinct and separate from the avoided costs of power outages to consumers. (This latter consumer benefit is estimated as the VoLL—see discussion in the *Resilient power during outages and the value of lost load* (VoLL) section above.) Battery storage can reduce the frequency and duration of power outages[111] and benefit the energy system by providing a reliable source of stored energy in the event of service interruptions.[112]

Some confusion between the benefits to customers, utilities, and the electric system may, nonetheless, arise due to the common practice of using the VoLL (a measure of consumer benefits from avoided outages) as a proxy to represent the savings from avoided outages to utilities or the system as a whole. VoLL does not measure system benefits, but it is used as a proxy to represent those benefits. Valuing the benefit of fewer power outages is difficult because there is no market for energy interruptions, but—according to economic theory—avoided outages for the electric system can be assumed to have a value equal to the costs to customers in the event of power outages. (Power suppliers would pay up to, but not beyond, the VoLL in order to avoid losses.[113]) For a summary of AEC's review of the literature on VoLL values and the value of avoided outages, see Table 9 above. For a detailed discussion of VoLL and the system benefits of avoided power outages, see MA AEC 2019a and MA AEC 2019b.

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[110] (1) U.S. EIA. November 9, 2018. "Water withdrawals by U.S. power plants have been declining." Available online: https://www.eia.gov/todayinenergy/detail.php?id=37453#. (2) Rostami, F., et al. *Energy Storage Materials, 48*: 2022. "Comparative sustainability study of energy storage technologies using data envelopment analysis." Available online: https://www.sciencedirect.com/science/article/pii/S2405829722001635

[111] Ibid.

[112] US ESA 2017. Page 11.

[113] "In the optimum cases, the level of supply security should be defined in such a way that the marginal damage costs, expressed by VoLL, are equal to the marginal costs for ensuring uninterrupted electricity supply. Accordingly, the calculation of the economic indicator VoLL represents, on the one hand, an opportunity to determine the level of damage caused by a power interruption, the results of which, on the other hand, describes the value of power supply security." Schröder and Kuckshinrichs, 2015. Page 4.

Avoided emergency calls

Battery storage can reduce the frequency and duration of power outages[114] by providing a source of emergency power in the event of service interruptions.[115] Fewer outages is a benefit to customers and the energy system (as discussed in the section above), but avoiding blackouts also provides benefits to the utility by lowering their costs of outage response. For example:

- Utilities may save time and money from avoiding dispatching restoration crews.[116]
- Utilities avoid fines and legal fees related to power outages.[117]
- Customers avoid making some safety-related emergency calls and utilities avoid the expenses associated with responding to those calls[118]—estimated by AEC in a previous paper at $11.43 per year per customer (see Table 22).

Table 22. Estimate of avoided safety-related emergency call benefit

Source	Justification for benefit inclusion	Value
MA AEC 2019b (pages 21-22) MA NEI Evaluation 2011 (page D-8)	- Fewer power outages as a result of battery storage results in fewer safety-related phone calls	$11.43/year/customer (2010$)
MA AEC 2019 (page 19)	- Fines collected from utility companies for violating storm preparedness policies	$24.8 million in total fines

Peak shaving and shifting

Battery storage systems lower and shift peak demand by charging at times of low electric demand and low generation costs and discharging their stored energy at times of peak demand when generation costs are the highest. Shaving and shifting peak demand not only saves customers and utilities money, but it also enhances grid reliability[119] by:

- Drawing on stored energy to reduce the need for quick ramp-ups of power generation during times of peak demand.[120]
- Reducing uncertainty in forecasts of future loads and associated capital investment needs.[121]

[114] MA AEC 2019a. Page 21.
[115] US ESA 2017. Page 11.
[116] NYSEG and RG&E 2020. Page 54.
[117] MA AEC 2019b. Pages 18-21.
[118] Ibid. Page 21.
[119] US ESA 2017. Page 6.
[120] CT Green Bank 2020. Page 227.
[121] US NESP 2020. Page 4-9.

- Reducing congestion along transmission and distribution lines during peak times.[122]
- Producing a greater buffer for system capacity to handle peak demand, in turn reducing the likelihood of power outages and the associated costs.[123]

AEC's review of the literature found one estimate for peak reductions from battery storage, as summarized in Table 23.

Table 23. Estimate of reduced ancillary services cost benefit

Source	Justification for benefit inclusion	Value
CT Green Bank 2020 (pages 76, 227)	- Peak load reductions create more buffer for system capacity to handle peak demand, which reduces the likelihood of an outage	$104.90/kW peak load reduction, with $10 million in additional benefits from 100 MW of energy storage capacity, from 2021 to 2025

Black start capability

Black start refers to the process of bringing a generator back online after a blackout or other shut down: most generators need external power to restart, and battery storage can be used as a black start resource,[124] increasing the resilience and reliability of the entire grid.[125]

Batteries providing black start capability enhance overall resilience and reliability by:

- Achieving full-rated power output in seconds.[126]
- Dispatching power to get a generator back online and, once back online, absorbing any excess power to balance load and generation.[127]
- Being flexible for use in conjunction with most generators.[128]
- Providing additional grid balancing services in addition to black start, such as spinning reserves.[129]

[122] US RAP 2019. Page 53.
[123] CT Green Bank 2020. Page 76.
[124] Department of Energy. 2020. *Potential Benefits of High-Power, High-Capacity Batteries.* Available online: https://www.energy.gov/sites/prod/files/2020/02/f71/Potential_Benefits_of_High_Powered_Batteries_Report.pdf. Page 4.
[125] US NESP 2020. Pages 4-10.
[126] M. Düsel. 2020. "Benefits of Battery-Storage Based Black-Start Capability." *Power*. Available online: https://www.powermag.com/benefits-of-battery-storage-based-black-start-capability/.
[127] Department of Energy. 2020. *Potential Benefits of High-Power, High-Capacity Batteries.* Available online: https://www.energy.gov/sites/prod/files/2020/02/f71/Potential_Benefits_of_High_Powered_Batteries_Report.pdf. Page 12.
[128] T. Fohrmann. 2021. "Battery energy storage systems for black start capability." Energy Central. Available online: https://energycentral.com/o/siemens-energy/battery-energy-storage-systems-black-start-capability.
[129] Ibid.

Reduced grid congestion

By capturing and storing energy at times of low demand for use at times of peak demand, battery storage systems can reduce transmission congestion on the grid[130] (as discussed in the *Avoided transmission and distribution costs* section above), particularly in electrically constrained locations.[131] The reduction in congestion can improve the reliability of electric service and prevent unplanned outages or unpredictable losses of service, while also reducing transmission costs.[132]

Difficult-to-Monetize Benefits

When identifying and valuing the various benefits associated with battery storage programs, some benefits are especially difficult to quantify or may require new or novel measurement techniques. To leave these benefits unmeasured, however, is equivalent to assigning them a value of zero in a BCA, which results in lower BCA ratios and reduces the likelihood that storage measures and programs are found to be cost-effective.

NESP's 2020 *National Standard Practice Manual* describes various approaches that can be used to account for benefits that are difficult to monetize, including proxies, jurisdiction-specific studies, alternative thresholds, and qualitative accounting:[133]

- A proxy is a value that can be substituted when a monetized impact is not available; types of proxies include percentage adders, electricity, gas, and fuel savings multipliers, and customer adders.
- Jurisdiction-specific studies use results from studies conducted within the jurisdiction in question, or in nearby jurisdictions, to estimate a benefit's value and can be used to estimate hard-to-quantify benefits.
- Alternative thresholds typically reduce the cost-effectiveness threshold of a benefit-cost ratio, for example, from 1.0 to 0.9; the use of alternative thresholds has an identical effect as using a percentage adder, a technique that approximates non-monetized impacts by scaling up impacts that are monetized.[134]
- Qualitative accounting can be used when no quantifiable results are available and entails gathering qualitative information about a benefit; this approach, however, typically assigns a zero-dollar value to the benefit in the BCA.

AEC's review of recent literature identified the following benefit categories as difficult to monetize.

Participant non-energy benefits

Through the deployment of battery storage technology, several non-energy benefits may accrue to participants in the program. These benefits include, for instance, customer comfort and enhanced power quality. As discussed above in the *Consumer Benefits* section, improved grid resiliency during

[130] US NESP 2020. Page 4-6.
[131] MN E3 2019. Page 10.
[132] Ibid.
[133] US NESP 2020.
[134] Ibid. Page C-4.

power outages is another difficult-to-quantify participant benefit of battery storage programs. Some BCAs, such as CA Brattle 2017 and Pepco DC 2021, omit these benefits from their analyses. CT PURA 2021 includes difficult-to-monetize participant non-energy benefits as a separate, non-quantified category in its BCA. US NESP 2020 notes that proxy values are frequently used to account for participant non-energy benefits.

Societal non-energy benefits

Battery storage technology can also benefit society at large in difficult-to-monetize ways. These benefits include reductions in air pollution, changes in water use, reduced societal impacts from power outages and disruptions, and more efficient land use.[135] (Power outages effect all of society, and not just utility customers, because they impact essential services used by utility customers and non-utility customers alike, such as hospitals and other essential services.) Similar to participant non-energy benefits, difficult-to-monetize societal benefits can often be factored into BCAs using proxies; in addition, as with participant non-energy benefits, societal non-energy benefits can be included in a BCA if they are clearly attributable to a project or measure and if some method of quantification can be justified.[136]

Societal non-energy benefits of battery storage system implementation programs include the following:

- **Public health benefits from the closure of peaker plants:** Battery energy storage can provide energy system reliability in lieu of peaker plants, allowing for the closure of peaker plants and the curtailment of their emissions. The reduction in emissions can yield substantial public health benefits by way of reduced morbidity and mortality as well as reduced health expenditures due to pollution-related health conditions including asthma, respiratory illnesses, and cancers, especially in the urban areas where peaker plants are typically sited.[137]
- **Environmental Justice (EJ) benefits:** Across the United States, systemically inequitable energy planning has led to disproportionate burdens of pollution and pollution-related health conditions in black, indigenous and people of color (BIPOC) communities, low-income, and EJ communities.[138] Increasingly, states and municipalities are taking steps to address these inequities. For example, in 2020, New Jersey's Governor signed Senate Bill S232, requiring the New Jersey Department of Environmental Protection (DEP) to "evaluate environmental and public health stressors of certain facilities on overburdened communities when reviewing certain permit applications."[139] In order to help address EJ issues, a battery-related BCA should

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[135] (1) AEC 2019b; (2) Pepco DC 2021.
[136] (1) US NESP 2020; (2) CT Green Bank 2020.
[137] (1) Casey, J.A., et al. 2020. "Coal-fired power plant closures and retrofits reduce asthma morbidity in the local population." *Nature Energy, 5*, 365-366. Available online: https://www.nature.com/articles/s41560-020-0622-9. (2) Lin, C., et al. 2019. "A global perspective on coal-fired power plants and burden of lung cancer." *Environmental Health, 18*. Available online: https://ehjournal.biomedcentral.com/articles/10.1186/s12940-019-0448-8, (3) Robbins, S. H., and Mango, M. *The Peaker Problem.* Prepared for Clean Energy Group. Available online: https://www.cleanegroup.org/wp-content/uploads/The-Peaker-Problem.pdf. Page 9.
[138] Maninder, P.S., et al. 2019. "Fine Particulate Air Pollution from Electricity Generation in the US: Health Impacts by Race, Income, and Geography." *Environmental Science and Technology, 53 (23)*, 14010-14019. Available online: https://pubs.acs.org/doi/abs/10.1021/acs.est.9b02527.
[139] NJ Senate No. 232 (2020). Available online: https://pub.njleg.gov/bills/2020/S0500/232_R1.HTM.

account for EJ-related benefits—benefits specific to the reduction in systemic inequalities in environmental and health outcomes in overburdened communities—that result from battery storage implementation and the resulting impacts on energy system emissions.

AEC Recommendation

Incorporate difficult-to-monetize benefits, including participant non-energy benefits and societal non-energy benefits such as public health and environmental justice benefits, into a battery BCA using any one of the methods suggested above: proxies, jurisdiction-specific studies, and alternative thresholds.

Costs

Battery storage programs entail administrative, capital, labor, and operational costs for program administrators and, depending on the program design, capital and labor costs for customers that host battery storage resources.

- **Program administration** costs include the costs to administer a battery storage project or program, including customer incentives and rebates[140] and acquiring the necessary permits, licenses, and agreements related to the integration of battery storage to the grid, such as power purchase agreements, siting licenses, and/or grid interconnection agreements.[141]
- **Capital and labor** costs include the labor and equipment necessary for a battery storage project or program.[142] Battery installation requires specialized equipment and labor, such as the batteries themselves, interconnection cables, and associated HVAC or switchgears.[143] It is important to note that—depending on the structure of the program—the costs of the batteries and their installation may fall on either the program administrator or the host customer.[144] However, even when a battery program comprises customer-owned behind-the-meter batteries, there may still be capital costs for the program administrator for any additional infrastructure necessary to integrate, regulate, and monitor those resources.[145]
- **Program operation** costs include fixed and variable maintenance, round-trip efficiency losses, warranty fees, and insurance fees. Fixed and variable operations and maintenance costs include site visits, customer service, monitoring, reporting, and waste management.[146] Round-trip efficiency losses refer to the energy lost between charging a battery from the grid and

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[140] NYSEG and RG&E 2020. Page 63.
[141] US DOE 2020. Page 150.
[142] NYSEG and RG&E 2020. Page 64.
[143] US DOE 2020. Pages 149-150.
[144] NYSEG and RG&E 2020. Page 64.
[145] Mongird, K., Viswanathan, V., Alam, J., Vartanian, C., Sprenkle, V., & Pacific Northwest National Laboratory. 2020. *Grid Energy Storage Technology Cost and Performance Assessment.* Prepared for U.S. Department of Energy. Available online: https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf. Page 8.
[146] MA DOER 2016.

discharging to the grid from a battery, and there are costs associated with efficiency losses such as those due to thermal management, power conversion, energy conversion, and/or leakages.[147] The equipment provider is responsible for battery warranty fees, and the utility pays for insurance fees that cover risk management, such as potential battery combustion.[148]

Useful resources include: 1) the U.S. Department of Energy's 2020 *Grid Energy Storage Technology Cost and Performance Assessment* report,[149] which provides a description of all anticipated costs of grid energy storage technology, and 2) the New York State Electric and Gas Corporation's 2020 *Benefit Cost Analysis (BCA) Handbook / Version 3.0* report, which provides a foundational methodology for calculating the benefits and costs of utility projects.

AEC Recommendation

Use up-to-date battery-specific engineering references to establish correct program costs.

Sensitivity Analyses

As with any modeling exercise, the results of BCAs are influenced by their input assumptions. Given the uncertainty inherent to many of these assumptions, an important component of a BCA is the use of sensitivity analyses, which assess the robustness of BCA results to changes in given input assumptions. Sensitivity analyses can be used to calibrate and/or refine a BCA model in its development, or to determine a range of values for a final BCA result. Within the context of battery storage, several input assumptions in particular are subject to important uncertainties that might significantly influence BCA results and, thus, merit sensitivity analysis.

AEC Recommendation

A battery-related BCA should include several sensitivity analyses, falling into two categories. Sensitivities recommended for model calibration are analyses that can be used to fine-tune model results based on adjustments to input assumptions; and sensitivities for full results presentation are analyses that capture the uncertainty inherent to particular assumptions to arrive at a range of benefit-cost ratio values.

1. **Conduct the following sensitivities for calibration of models:**

    - **Fuel prices:** The cost of fuels, which are used as inputs in the energy system, can vary considerably and be difficult to predict. Variations in fuel prices can lead to variation in calculated values of the net present value (NPV) and benefit-cost ratio for a battery storage-related BCA.

[147] Mongird, K., Viswanathan, V., Alam, J., Vartanian, C., Sprenkle, V., & Pacific Northwest National Laboratory. 2020. *Grid Energy Storage Technology Cost and Performance Assessment.* Prepared for U.S. Department of Energy. Page 5.
[148] Ibid.
[149] Ibid.

- For example, Pepco (an electric utility providing service in areas of Maryland and the District of Columbia) has published a five-year Climate Action Plan including a BCA which estimates that a 20 percent change in the price of gasoline could change the estimated NPV of the plan by over 14 percent, or $22 million.[150]

- **Capacity prices:** Avoided capacity is a major benefit of battery energy storage systems. Capacity prices (set in regional auctions such as PJM's Reliability Pricing Model) factor into BCA cost calculations. As such, variations in capacity price can impact BCA results.
  - For example, in the Brattle Group's California-focused 2017 BCA, reducing the estimated generation capacity cost from $113 per kW-year to $33 per kW-year results in a drop in the estimated value of battery storage from $283 per kW-year down to $132 per kW-year.[151]

- **Power prices:** A change in the expected power price can affect calculations of the actual and avoided costs on energy bills and, therefore, impact battery storage BCA estimates of the benefit of lower energy bills.
  - For example, in Pepco's 2022 BCA, a 20 percent change in electricity price modifies the estimated NPV of its Climate Action Plan by a margin of $2 million, relative to a base NPV of $154 million.[152]

- **Resource adequacy event notification:** Events of limited resource adequacy (that is, not enough generation to supply customer demand) can lead to service interruptions or outages for customers and therefore present a potential cost to customers; advance notice from a utility can alleviate some of this cost by allowing customers time to prepare for a potential service interruption. Therefore, increasing or decreasing the amount of advance notice given to customers concerning resource adequacy events can also bear an impact on the BCA results.
  - For example, by reducing the notification time for resource adequacy events from 24 hours to 1 hour, the Brattle Group's 2017 BCA in California found that the value of battery storage declined from $283 per kW-year to $174 per kW-year.[153] Conversely, increasing the notification time for resource adequacy events raises the value of batteries.

- **Frequency regulation:** The extent to which battery owners can participate in the frequency regulation market and thereby earn revenue from their battery.
  - For example, restricting the opportunity for frequency regulation can reduce the value of a battery storage initiative from $283 per kW-year down to $223 per kW-year,

[150] DC Pepco 2021.
[151] CA Brattle 2017.
[152] DC Pepco 2021.
[153] CA Brattle 2017.

according to the BCA conducted by the Brattle Group.[154] Whereas enhancing opportunities for frequency regulation raises the value of batteries.

- **Battery efficiency:** Allowing for variability in the estimated round-trip efficiency of energy storage can introduce variation in the duration and maximum total benefit of energy storage.

    - For example, according to the BCA published by Frontiers in 2020 investigating long duration storage resources in 2050 on the Western interconnection, while 80 percent efficiency yields a maximum total benefit of $109.1 million and a storage duration of 32 days, 40 percent efficiency provides only $56.3 million in maximum total benefit and 9 days of energy storage.[155]

- **Renewable penetration:** The degree of penetration of renewable resources (as well as the extent of renewables investments anticipated or required from state energy regulations) in the energy market can substantially affect the value of batteries and the results of the battery-focused BCA.

    - For example, as found in GE's 2017 BCA of battery storage in Hawaii, reducing wind and solar penetration from 50 percent to 20 percent can reduce annual net benefits of a battery storage program from $10 to 30 million per year down to $0 to 5 million per year.[156]

2. Conduct the following sensitivities for full results presentation:

- **Social Cost of Carbon:** The Social Cost of Carbon (SCC) is a valuation of the future costs imposed on society by present-day emissions of CO_2. SCC (and other avoided greenhouse gas emission) values are strongly dependent on the choice of social discount rate, and both or either can be varied in sensitivity analysis. The U.S. Government Interagency Working Group estimates of the SCC from 2021 use discount rates of 5 percent, 3 percent, and 2.5 percent, with resulting estimates of the SCC ranging from $14 per ton of CO_2-e emissions to $76 per ton (for emissions released in 2020).[157] The U.S. Government Interagency Working Group (IWG) has received feedback that the SCC should be raised (by lowering the social discount rate).[158] The

154 Ibid.

155 Western FER 2020.

156 HI GE Energy 2017.

157 U.S. Government Interagency Working Group on Social Cost of Greenhouse Gases. 2021. *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide*. United States White House. Available online: https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf. Page 5.

158 (1) Stanton, E.A., C. Lala, and T. Stasio. 2021. Comments on 2021 Guidance Towards Updating the U.S. Social Cost of Greenhouse Gases. Applied Economics Clinic. Prepared for Friends of the Earth. Available online: https://aeclinic.org/publicationpages/2021/6/22/comments-on-2021-guidance-towards-updating-the-us-social-cost-of-greenhouse-gases; (2) Interagency Working Group on Social cost of Greenhouse Gases, United States Government. February 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990. Available online: https://www.whitehouse.gov/wpcontent/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

IWG's Technical Support Document acknowledges that 3 percent, which is the IWG's default rate, "is likely an over-estimate and warrants reconsideration in future updates of the SC-GHG."[159] AEC recommends presenting final BCA results from a range of SCC values with discount rates and values from 0.1 to 2.5 percent.

  - For example, Pepco's 5-Year Climate Action Plan BCA includes a default assumption of a 2 percent SCC discount rate in its calculations of benefits and costs, resulting in a Net Present Value of the 5-Year Program of roughly $154 million. Pepco's sensitivity analysis of the SCC provides a wider range of program values, from $36 million at a 3 percent SCC discount rate up to $638 million at a 1 percent SCC discount rate.[160]

  - MA PAs 2021 BCA model spreadsheets include a carbon price sensitivity analysis and provide final results with and without a carbon price.[161]

- **Financial discount rate:** The financial discount rate, or the rate at which near-term future financial costs are discounted to present-day terms, can greatly affect the valuation of the benefit-cost ratio of a battery storage program.

  - For example, the nation-wide BCA conducted by RAP in 2019 uses a base discount rate of 10 percent and arrives at a benefit-cost ratio in the range of 0.9 to 2.5. RAP also presents the results of reducing the discount rate to 6 percent, which raises the benefit-cost ratio to 1.2 to 3.5, and 14 percent, which reduces the benefit-cost ratio to a range of 0.7 to 2.[162] While AEC recommends using both a 0.1 to 2.5 percent social discount rate and a utility's own weighted average cost of capital (WACC), it is important to ensure that BCA results are robust to alterations of the financial discount rate by conducting sensitivity analysis.

Stakeholder Process

If utilities conduct their BCAs in a "black box," with minimal public input, they may arrive at analytic conclusions that lack confidence (or "buy in") from the general public, environmental or consumer advocates, state agencies, utility commissions, and other stakeholders. In order to ensure unbiased and informed results from a BCA on battery storage**, it is critical that the BCA be conducted 1) by the regulator rather than the regulated utilities, and 2) in a transparent and thoughtful way that builds the confidence of all stakeholders in the end result.**

Conducting a robust battery storage BCA requires consistent, inclusive, and equitable engagement with stakeholders. Stakeholders should include representatives from: state agencies, utilities, consumer and

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[159] Interagency Working Group on Social cost of Greenhouse Gases, United States Government. February 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990. Pg. 17. Available online: https://www.whitehouse.gov/wpcontent/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

[160] DC Pepco 2021

[161] MA PAs 2021.

[162] US RAP 2019.

environmental advocates, low-income communities, ratepayers, regulators, environmental justice communities, non-governmental organizations, government, renewable energy developers and battery companies.[163] Stakeholder processes are an opportunity for information sharing as well as essential for soliciting input to be used in developing, refining, and finalizing a BCA and developing recommendations based on BCA conclusions.

In the literature reviewed by AEC, stakeholder engagement was successfully utilized to:

- Identify battery performance information/data[164]
- Identify key market drivers[165]
- Identify battery deployment barriers[166]
- Develop appropriate peak load forecasts, costs and benefits[167]
- Develop recommendations for program performance metrics and reporting,[168]
- Select appropriate discount rates[169]
- Provide additional information and materials related to BCA analyses.[170]

Stakeholder processes can include various kinds of engagement, such as workshops, surveys, and/or interviews.[171] It is important that stakeholder engagement run parallel to BCA processes: that is, that stakeholders are engaged from the beginning of a BCA process and are providing input throughout the entirety of a BCA process from start to finish. Facilitating stakeholder engagement from the beginning of a BCA process—and at every stage of a BCA process—ensures that there are adequate opportunities for stakeholders to provide input on proposed BCA framework and BCA methods and assumptions—thereby developing broad acceptance of BCA results.[172] It is also important that BCA assumptions, methods, data inputs and outputs are made available to stakeholders for the purposes of independent, third-party review, quality control, and feedback. Assessments by a wider group of experts than those involved in the BCA development process can help to improve accuracy and method design and is essential in establishing legitimacy of battery storage BCA results.

AEC Recommendation

Conduct an inclusive, diverse, and equitable stakeholder process from start-to-finish of a BCA assessment and include representatives from state agencies, utilities, consumer and environmental advocates, low-income representatives, ratepayers, regulators, environmental justice communities, non-governmental organizations, government, renewable energy developers and battery companies.

[163] (1) NYDPS 2015. PDF page 4; (2) MN E3 2019. Page 70; (3) US NESP 2020. Page 49; (4) RI SEPA 2020. Page 5.
[164] US DOE 2020. Page iv.
[165] MA DOER 2016. Page 57-8.
[166] NYDPS 2015. PDF page 7.
[167] NE AESC 2021. Page 248.
[168] DC CEAIWG 2021. Page 13.
[169] US NESP 2020. PDF page 114.
[170] US RAP 2019. Page 72.
[171] MA DOER 2016. Page 57-8.
[172] RI SEPA 2020. Page 18.

Appendix A: Annotated bibliography

CA Brattle 2017: Hledik R., et al. September 2017. *Stacked Benefits: Comprehensively Valuing Battery Storage in California*. The Brattle Group. Available online: https://www.brattle.com/wp-content/uploads/2017/10/7208_stacked_benefits_-_final_report.pdf

- This report assesses the economics of battery storage initiatives, including their economic benefits, in California. It assesses battery storage values between 2013 and 2016, models two battery discharge cases, analyzes the incremental value of a single storage project on the California power system, and focuses on quantifying avoided system costs.
- This study includes a BCA with dollar values for several benefit categories including: energy price arbitrage, ancillary services, generation capacity or resource adequacy, transmission and distribution capacity, reduced carbon dioxide (CO_2) emissions, reduced transmission congestion, extension of transmission and distribution equipment life, additional ancillary services (ramping, voltage support, black start, and inertia), flexible resource adequacy value, avoided startup costs of other generators on the system, bill reductions for end-use customers (e.g., avoided demand charge, time-of-use rate), improved reliability for end-use customers (i.e., as backup generation), and enhanced power quality.

CA CPUC 2020: California Public Utilities Commission (CA CPUC). April 16, 2020. *2020 Policy Updates to the Avoided Cost Calculator.* Rulemaking 14-10-003. Available online: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M334/K786/334786698.pdf

- The Avoided Cost Calculator for California was first developed after California's energy crisis in 2003 and 2004. Before the update provided by this document, the calculator did not reflect the value of distributed energy resources, the operational regime of a highly intermittent renewable system, nor the goal of greenhouse gas emissions reductions. As such, the avoided supply-side resource cost calculations needed changes to no longer be based solely on the fixed and fuel costs of gas-fired power. In 2020, Energy Division Staff used this document to propose a new approach to calculating avoided-supply side resource costs and linking them to the integrated resource planning process of selecting the least-cost renewable portfolio. One of the changes proposed was accounting for batteries as replacement technologies for gas-fired generators. This document does not include a BCA. But it does include sections on greenhouse gas emissions and avoided cost values, distribution avoided cost, and transmission avoided costs.

CT PURA 2021: Connecticut Public Utilities Regulatory Authority Docket No. 17-12-03RE03. July 2021. *PURA Investigation into Distribution System Planning of the Electric Distribution Companies – Electric Storage.* Submitted By Marissa P. Gillett, John W. Betkoski III, & Michael A. Caron. Available online: https://portal.ct.gov/-/media/PURA/electric/Final-Decision-17-12-03RE03.pdf

- Connecticut's electric storage program implemented through PURA aims to accelerate the deployment of both front-of-the-meter and behind-the-meter residential and commercial/industrial energy storage through a series of programs and financing. It aims to deploy a total of 580 MW of battery storage by 2030. The program design elements used in its construction include market research surveys, cost-effectiveness testing, community-based social marketing strategies, and innovative financing mechanisms.

- This program includes a BCA at both the residential level and the commercial and industrial level from the Connecticut Green Bank's "Solarize Storage" program, which was a proposal that was later adopted in the CT PURA order, in which the benefit and cost categories include: (1) avoided energy, (2) avoided generation capacity benefits, (3) avoided transmission and distribution benefits, (4) reliability, (5) DRIPE energy benefits, (6) DRIPE capacity benefits, (7) Cross-DRIPE Benefits, (8) lost utility revenue, (9) upfront incentives, (10) performance incentives, (11) upfront incentive program costs, (12) performance incentive program costs, and (13) avoided non-embedded emissions.

CA SGIP 2021: California Center for Sustainable Energy. 2021. *Self-Generation Incentive Program Handbook.* Available online: https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/self-generation-incentive-program/2021-sgip-handbook-v4.pdf

- This report outlines California's procedures and policies associated with applying for incentives for on-site distributed energy resources, with the objective of reducing greenhouse gas emissions, electricity demand, and customer electricity purchases.
- This report is not a BCA, but instead describes how incentives can be paired with distributed energy storage to effectively reduce air pollution.

DC CEAIWG 2021: District of Columbia Clean Energy Act Implementation Working Group. November 16, 2021. *Framework for Compliance with the Clean Energy Omnibus Amendment Act of 2018 (the CEDC Act) of the District of Columbia*. Case No. GD-2019-04-M. Available online: https://edocket.dcpsc.org/apis/api/Filing/download?attachId=143219&guidFileName=9a60d7a2-b795-47e2-b65f-639ce2fa4c96.pdf

- DC's CEAIWG presents comments and recommendations from stakeholders on metrics, a BCA framework, and reporting requirements that the Public Service Commission should use when analyzing proposed utility programs and projects to meet the District's climate goals. Storage resources are one of several categories of projects addressed in this report.
- This working group report does not include a BCA but does broadly review and recommend best practices for BCA methods that are relevant to DC stakeholders.

DC Pepco 2021: Hledik, R., S. Sergici, J. M. Hagerty, M. Witkin, J. Olszewski, S. Ganjam. January 31, 2021. *Pepco's Climate Solutions 5-Year Action Plan: Benefits and Costs*. Case No. 1167. Available online: https://edocket.dcpsc.org/apis/api/Filing/download?attachId=145484&guidFileName=8d93b10e-ace7-4401-bae1-205ecc837ef0.pdf

- Pepco's *Climate Solutions 5-Year Action Plan* summarizes the utility's near-term initiatives and programs to align itself with the District of Columbia's climate goals.
- This Action Plan includes a utility-authored BCA in which the benefit categories are reduced electricity generation costs, reduced renewable energy credit costs, reduced generation capacity costs, reduced electricity distribution costs, reduced electricity line losses, reduced transportation fuel costs, reduced building fuel costs, reduced greenhouse gas costs, reduced criteria air pollutant costs. The cost categories include equipment costs, equipment installation costs, utility incentive payment to customers, ongoing maintenance costs, program administration costs, and supporting software costs

HI GE Energy 2017: GE Energy Consulting. December 2017. *Oahu Grid Stability Study Phase 4: Battery Energy Storage Analysis*. Available online: https://www.hnei.hawaii.edu/wp-content/uploads/Oahu-DPV-Grid-Stability-Battery-Energy-Storage.pdf

- This report quantifies the net benefit of energy storage systems and determines the best size and power-to-energy ratio for the Oahu, Hawaii system. The report quantifies the benefits of such as energy shifting and ancillary benefits.
- This study includes a BCA with benefit categories that include frequency regulation, capacity resource, spinning and non-spinning reserves, replacement reserves, energy arbitrage, avoided curtailment, wind/solar smoothing, black start, transmission and distribution (T&D) upgrade deferral, reduced transmission congestion, improved reliability, reduced outage rates, integration of distributed energy resources, uninterruptible power supply, demand charge management, and energy bill management.

NJ AEC 2022: Castigliego, J.R., Alisalad, S., Peddada, S., and Stanton, E.A. 2022. *Economics Impacts of a Clean Energy Transition in New Jersey*. Applied Economics Clinic. Available online: https://aeclinic.org/publicationpages/2022/06/07/economic-impacts-of-a-clean-energy-transition-in-new-jersey

- This report evaluates the economic outcomes of a transition to clean energy in New Jersey in comparison to a business-as-usual scenario, in which all existing energy policies remain the same. The economic impacts assessed in this report include the development of clean energy jobs, the loss of jobs in the fossil fuel industry, changes in economic activity, and changes in tax revenue.
- This report is not itself a BCA, but instead it elaborates on the benefits of job creation, a benefit often included in BCAs.

MA AEC 2019a: Stanton, E.A. Updated April 2019. *Massachusetts Battery Storage Measures: Benefits and Costs*. Applied Economics Clinic. Prepared for: Clean Energy Group. [AEC-2019-04-WP-02]. Available online: https://aeclinic.org/publicationpages/2019/3/15/updated-massachusetts-battery-storage-measures-benefits-and-costs

- This AEC white paper discusses the cost-effectiveness of battery storage using Massachusetts' efficiency program evaluation methodology.
- This white paper does not include a BCA (although it is based on an earlier AEC white paper that does include a benefit-cost ratio[173])but does provide detailed information on Massachusetts energy efficiency and demand-side measure (including battery storage) BCAs, including battery benefit categories that may not be captured in all BCAs. These categories include peak shifting, and summer versus winter values (capacity and reliability).

MA AEC 2019b: Woods, B. and Stanton, E.A. April 2019. *Massachusetts Non-Energy Benefits of Battery*

[173] Stanton, E. A. July 2018. *Massachusetts Battery Storage Measures: Benefits and Costs*. Applied Economics Clinic. Prepared for: Clean Energy Group. [AEC-2018-07-WP-02]. Available online: https://aeclinic.org/publicationpages/2018/7/30/massachusetts-battery-storage-measures-benefits-and-costs, p. 22

Storage. Applied Economics Clinic. [AEC-2019-04-WP-01]. Available online: https://aeclinic.org/publicationpages/2019/3/15/massachusetts-non-energy-benefits-of-battery-storage

- This AEC white paper conducts preliminary valuations of seven non-energy benefits of battery storage.
- This white paper does not include a BCA but does present a selection of non-energy benefits of batteries that are not often captured in BCAs including: avoided power outages, higher property values, avoided fines, avoided collections and terminations, avoided safety-related emergency calls, job creation, less land used for power plants.

MA DOER 2016: Massachusetts Department of Energy Resources, Massachusetts Clean Energy Center, Customized Energy Solutions, Ltd., Alevo Analytics, Sustainable Energy Advantage, LLC, Daymark Energy Advisors, and Strategen. 2016. *State of Charge: Massachusetts Energy Storage Initiative Study*. Available online: https://www.mass.gov/doc/state-of-charge-report/download

- The *State of Charge* study analyzes the economic benefits and market opportunities for energy storage in Massachusetts, as well as potential policies and programs that could support energy storage deployment and grow the storage industry in Massachusetts. The study concludes that up to 1,766 MW of energy storage (over a ten-year timespan starting in 2020) would maximize Massachusetts' ratepayer benefits and would result in up to $2.3 billion in positive impacts in the Commonwealth.
- This source is not itself a BCA but provides useful background information specific to energy storage resources including categories of costs and benefits as well as their values.

MA PAs 2021: Massachusetts Energy Efficiency Program Administrators. 2021. "BCR Model" spreadsheets. "Massachusetts Joint Statewide Electric and Gas Three-Year Energy Efficiency Plan: 2022-2024." Available online: https://ma-eeac.org/wp-content/uploads/Exhibit-1-Three-Year-Plan-2022-2024-11-1-21-w-App-1.pdf.

- This source—created by Massachusetts' gas and electric local distribution companies' energy efficiency program administrators—contains benefit-cost ratio model spreadsheets used to calculate the values in the "Massachusetts Joint Statewide Electric and Gas Three-Year Energy Efficiency Plan: 2022-2024" approved by the Massachusetts Department of Public Utilities in February 2022 (DPU Dockets 21-120 through 21-129). Battery storage has been part of Massachusetts' energy efficiency plans since 2019 and has been evaluated by this BCR Model. A July 2018 AEC white paper presents a BCA for battery storage using the program administrators BCR Model spreadsheets and a set of adjusted assumptions.[174]

MA NEI 2011: Massachusetts Program Administrators. August 15, 2011. *Massachusetts Special and Cross-Sector Studies Area, Residential and Low-Income Non-Energy Impacts (NEI) Evaluation*. Prepared by NMR. Available online: https://ma-eeac.org/wp-content/uploads/Residential-and-Low-Income-Non-Energy-Impacts-Evaluation-1.pdf

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[174] Stanton, E. A. July 2018. *Massachusetts Battery Storage Measures: Benefits and Costs*. Applied Economics Clinic. Prepared for: Clean Energy Group. [AEC-2018-07-WP-02]. Available online: https://aeclinic.org/publicationpages/2018/7/30/massachusetts-battery-storage-measures-benefits-and-costs, p. 22

- This report sought to quantify non-energy impacts (NEI'S) from utility programs. It also assesses the reliability of NEI values found in the literature and the extent to which they apply to program administrator's low-income programs and quantifies NEIs that apply to program administrator's residential and low-income programs.
- This report does not include a BCA but includes literature reviews on a variety of NEI's from the perspective of utilities, participants, and society. It also focuses on non-resource benefits, occupant perspectives, and the perspectives of low-income rental housing to assess NEI benefits.

MN E3 2019: Ouyang J., et al. December 31, 2019. *Minnesota Energy Storage Cost-Benefit Analysis*. Energy + Environmental Economics. Available online: https://mn.gov/commerce-stat/pdfs/energy-storage-cost-benefit-study-2020.pdf

- This report analyzes the costs and benefits of deploying energy storage systems in Minnesota. The report recommends that utilities pursue energy storage projects over the next 5-10 years to gain operational experience, consider including storage in distribution and capacity plans, and structure bidding processes so that storage can demonstrate benefits that are higher than costs.
- This analysis includes a BCA with background information from multiple states with a variety of sources for cost assumptions. Benefit categories include energy value, capacity value, regulation, spinning, and supplemental reserve value, real-time potential value, congestion reduction value, and distribution upgrade deferral.

NE AESC 2021: Synapse Energy Economics. May 14, 2021. *Avoided Energy Supply Components in New England: 2021 Report.* Prepared for AESC 2021 Study Group. Available online: https://www.synapse-energy.com/project/avoided-energy-supply-costs-new-england-aesc

- The *Avoided Energy Supply Components in New England: 2021 Report* develops projections of electric and gas sector costs that would be avoided by improvements in energy efficiency in New England. The temporal timeframe of the study is 2021-2035, with values extrapolated through the mid-2050s. The report also estimates demand reduction induced price effects of efficiency programs on market prices for electric energy, electric capacity, and gas.
- This report is not itself a BCA but instead reviews various methods and assumptions related to several BCA categories including: avoided fuel and fuel costs, reducing greenhouse gas emissions, avoided capacity costs, avoided energy costs, avoided costs of compliance, non-embedded environmental costs, DRIPE benefits, avoided T&D, improved reliability.

NJBPU 2020: New Jersey Board of Public Utilities Docket Nos. QO19010040 and QO20060389. August 24, 2020. *Order Adopting the New Jersey Cost Test*. Available online: https://www.state.nj.us/bpu/pdf/boardorders/2020/20200824/8A%20-%20ORDER%20New%20Jersey%20Cost%20Test.pdf

- This NJBPU order explains the adoption of the interim New Jersey Cost Test, a modified Total Resource Cost test, for use in assessing the cost-effectiveness of energy efficiency and peak demand reduction programs. Included in New Jersey's cost-effectiveness test framework are the benefits and costs typically associated with energy efficiency and peak demand reduction programs, as well as discount rates.

- The order is not itself a BCA, but instead explains the NJBPU's preferred method for calculating a benefit-cost ratio, which according to the New Jersey Clean Energy Act,[175] must be greater than or equal to 1.0 at the portfolio level. It is not required for a program to have this benefit-cost ratio, but it is recommended for programs with scores of 1.0 or higher to be adopted into portfolios of energy efficiency and peak demand reduction programs if implementation of the program is in the public interest, due to their minimizing effect on overall net benefits.

NYDPS 2015: New York Department of Public Service. July 1, 2015. *Staff White Paper on Benefit-Cost Analysis in the Reforming Energy Vision Proceeding*. New York State of Opportunity. 14-M-0101. Available online: https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/c12c0a18f55877e785257e6f005d533e/$FILE/Staff_BCA_Whitepaper_Final.pdf

- This white paper proposes a BCA framework within New York's Reforming Energy Vision (REV) proceedings and offers guidance on key parameters in that framework.
- This report offers a review of BCA methods. The benefits included in this study were avoided generation capacity costs, including reserve margin, avoided energy, avoided transmission capacity infrastructure and operations and maintenance (O&M), avoided transmission losses, avoided ancillary services, wholesale market price impacts, avoided distribution capacity infrastructure, avoided O&M costs, avoided distribution losses, net avoided restoration costs, net avoided outage costs, externalities, net non-energy benefits. Cost categories include program administration costs, added ancillary services costs, incremental T&D and distributed system platform costs, participant distributed energy resource costs, "lost" utility revenues, utility shareholder incentives, and net non-energy costs.

NYS Roadmap 2018: New York Department of Public Service (NYDPS) and New York State Energy Research and Development Authority (NYSERDA). 2018. *New York State Energy Storage Roadmap and Department of Public Service / New York State Energy Research and Development Authority Staff Recommendations*. Prepared by E3. Available online: https://www.ethree.com/wp-content/uploads/2018/06/NYS-Energy-Storage-Roadmap-6.21.2018.pdf

- This report provides a strategic roadmap for New York State to achieve its 1,500 MW energy storage target by 2025, optimizing for efficiency of the overall system, costs and revenues associated with energy storage, and removing impediments to installing storage.
- The framework is not a BCA but instead examines the relationship between costs of energy storage technologies and potential future value streams through identifying specific use cases and business models. Key analytical takeaways are segmented by market: all markets, customer-sited, distribution system, and bulk system. It also analyzes seven recommended courses of action, including: retail rate actions and utility programs, utility roles, direct procurement, market acceleration incentives, soft costs, "clean peak" actions, and wholesale market actions.

NYSEG and RG&E 2020: New York State Electric and Gas Corporation (NYSEG) and Rochester Gas and

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[175] New Jersey Department of Environmental Protection. 2018. "Clean Energy Act P.L.2018, Ch. 17." Available online: https://pub.njleg.gov/bills/2018/PL18/17_.HTM

Electric Corporation (RG&E). June 30, 2020. *Benefit Cost Analysis (BCA) Handbook*. Version 3.0. Available online: https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={C6575ECA-9A6F-4D13-A1F5-7E71FE3DF9CF}

- The *Benefit Cost Analysis (BCA) Handbook* describes the BCA framework used in New York's program evaluation of four categories of utility expenditures: investments in distributed system platform capabilities, procurement of distributed energy resources through competitive selections, procurement of DER through tariffs, and energy efficiency programs. The Handbook details the methodology for calculating benefits and costs of proposed programs and details the various assumptions that can be used.
- This Handbook provides a BCA methodology in which the bulk system benefits include avoided generation capacity cost, avoided energy purchased at the locational based marginal price, avoided transmission capacity infrastructure and related O&M, avoided transmission losses, avoided ancillary services, and wholesale market price impacts. Distribution system benefits include avoided distribution capacity infrastructure, avoided O&M, and avoided distribution losses. Reliability and resiliency benefits include net avoided restoration costs and net avoided outage costs. External benefits include net avoided CO_2, net avoided sulfur dioxide (SO_2) and nitrogen oxides (NO_X), avoided water impacts, and avoided land impacts, and net non-energy benefits related to utility and grid operations. Cost categories include program administration costs, added ancillary service costs, incremental T&D and distributed system platform costs, participant distributed energy resource cost, lost utility revenue, shareholder incentives, and net non-energy costs.

RI DPUC 2021: Synapse Energy Economics Inc. on behalf of the Rhode Island Division of Public Utilities and Carriers (DPUC). 2021. *Benefit-Cost analysis of the Rhode Island Community Remote Net Metering Program.* Available online: http://www.ripuc.ri.gov/generalinfo/Synapse-CRNM-BCA-2021-Redacted.pdf

- This report estimates the cost and benefits of the Community Remote Net Metering program, using Rhode Island's benefit-cost test. The test is conducted over a 25-year period. The costs and benefits of expanding the current program by 30 MW are assessed.
- This report includes a BCA. Its costs include utility administration costs, utility measure costs, utility shareholder incentives, increased transmission costs, increased distribution costs, participant measure costs, participant non-energy costs, and third-party developer costs. The power sector benefits include reduced energy costs, reduced generation capacity costs, reduced transmission costs, reduced distribution costs, reduced ancillary service costs, wholesale market price suppression, reduced costs of renewable energy standard compliance, renewable energy credits, reduced greenhouse compliance costs, improved reliability, net risk benefits, utility non-energy benefits, and innovation and market transformation. Customer benefits include participant water and other fuel impacts, participant non-energy benefits, low-income participant non-energy benefits, and customer empowerment. Societal benefits include reduced greenhouse gas emissions, reduced environmental impacts, economic development impacts, societal low-income benefits, public health benefits, and energy security benefits.

RI SEPA 2020: Smart Electric Power Alliance. June 2020. *Developing a Comprehensive Benefit-Cost Analysis Framework the Rhode Island Experience*. Available online:

https://sepapower.org/resource/developing-a-comprehensive-benefit-cost-analysis-framework-the-rhode-island-experience/

- This report examines the Rhode Island BCA framework, how it is being used to assess utility investments, lessons for other states, and recommendations for improving it. The report focuses on the need for better understanding of benefits and costs of new technologies, and how a comprehensive BCA framework can help regulators and utilities manage risk associated with investment in new technologies.
- This report does not include a BCA but provides a general framework for BCAs that do not directly relate to batteries or storage. This source provides information on BCA stakeholder processes.

US DOE 2020: Baxter R., et al. December 2020. *Energy Storage Grand Challenge Cost and Performance Assessment 2020. U.S. Department of Energy*. Technical Report Publication No. DOE/PA-0204. Available online: https://www.energy.gov/sites/default/files/2020/12/f81/Energy%20Storage%20Grand%20Challenge%20Roadmap.pdf

- This report documents the Department of Energy's roadmap for accelerating the development, commercialization, and utilization of energy-storage technologies in the United States. In particular, the Department outlines a goal to develop and domestically manufacture technologies to meet all U.S. demand of storage technology in 2030.
- This assessment does not include a BCA but does provide background on energy storage costs (not benefits) across many different types of storage including: different types of batteries as well as pumped hydro, compression air, and hydrogen.

US EIA 2021: U.S. Energy Information Administration. August 2021. *Battery Storage in the United States: An Update on Market Trends*. Available online: https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage_2021.pdf

- This report analyzes survey responses to document trends in battery storage capacity installations in the United States through 2019.
- This update does not include a BCA but does include background on battery storage costs (but not benefits). These costs include a breakdown of total installed costs of batteries in the United States

US ESA 2017: Energy Storage Association. 2017. *35x25 A Vision for Energy Storage*. Available online: https://energystorage.org/wp/wp-content/uploads/2019/06/esa_vision_2025_final.pdf

- The *35x25 Vision for Energy Storage* study describes opportunities to deploy more than 35 GW of new energy storage systems by 2025 in the United States. It also highlights the benefits to consumers, utilities, and grid operators: operational cost savings, customer engagement, reliability and resilience improvements, reduced emissions, and 167,000 new jobs.
- This source does not include a BCA but provides several storage-specific benefit categories to use in a BCA, along with reporting data points of estimated benefits from other BCA studies.

These benefit categories include market contributions to grid services; enhanced grid reliability and resiliency; jobs growth; and emissions reductions.

US NESP 2020: National Energy Screening Project (NESP). August 2020. *National Standard Practice Manual for Benefit-Cost Analysis of Distributed Energy Resources*. Available online: https://www.nationalenergyscreeningproject.org/national-standard-practice-manual/

- This manual provides a nation-wide framework for cost-effectiveness tests: energy efficiency, demand response, distributed generation, distributed storage, and electrification.
- This manual includes the national standard BCA with a wide variety of benefits for distributed storage and demand response; it does not address utility-scale storage.

US NESP 2022: National energy Screening Project. March 2022. *Methods, Tools and Resources: A Handbook for Quantifying Distributed Energy Resource Impacts for Benefit-Cost Analysis.* Available online: *https://www.nationalenergyscreeningproject.org/wp-content/uploads/2022/03/NSPM_Methods-Tools-Resources.pdf*

- This handbook acts as a companion resource to the US NESP 2020 manual; it provides definitions of frequently used terminology in BCAs, steps to follow when conducting a BCA, important metrics to identify, formulas for calculating the values of benefits and costs, and resources for accessing modeling tools and useful information.
- This handbook is not itself a BCA but instead an informative tool to be used in combination with the US NESP 2020 handbook for conducting a BCA.

US NRECA 2019: National Rural Electric Cooperative Association (NRECA). April 2019. *Battery Energy Storage Overview*. Available online: https://www.cooperative.com/programs-services/bts/documents/reports/battery-energy-storage-overview-report-update-april-2019.pdf

- NRECA's *Battery Energy Storage* overview reviews stationary electrochemical battery energy storage system technology and applications. The report specifically focuses on lithium-ion and flow batteries by presenting recent cost trends, examining adoption drivers, and examining growth forecasts in the United States.
- This overview does not include a BCA but provides insight on cost trends relating to battery energy storage. Lithium-ion batteries have seen rapid declines in production costs thanks in large part to the growing market for electric vehicles, which require lithium-ion batteries.

US RAP 2019: Littell D., et al. October 2019. *The Economics of Distributed Energy Resources*. RAP. Available online: https://www.raponline.org/knowledge-center/economics-distributed-energy-resources/

- This paper considers changes to traditional regulatory models in light of developments in advanced energy technologies. It also examines potential uses, valuation studies, and methodologies for certain advanced distributed energy resource technologies. The paper suggests new benefit-cost approaches.
- This study does not include a BCA, but provides methods to measure the benefits of distributed energy resources (DERs) which include: production energy value, production capacity, production environmental compliance value/avoided costs, reduced reserves and ancillary

service costs, reduced risk, reduced renewable obligation or Renewable Portfolio Standard (RPS) cost, demand-response-induced price effect, reduced O&M, avoided transmission capacity costs, avoided line losses, enhanced bulk system reliability, reduced transmission O&M, avoided distribution system capacity costs, avoided distribution line losses, reduced or increased credit and collection costs and avoidance of uncollectible bills for utilities, reduced distribution O&M, enhanced distribution reliability, customer choice and control, reduced energy usage of grid electricity, reduced energy usage from other fuels (fuel oil, gas, propane, wood), reduced bills, reduced overall energy usage, employee productivity, resilience benefits, property values, customer comfort, health impacts and air quality improvements, resilient infrastructure, benefits for low-income customers, water quality and aquatic species improvement, employment and local economic impacts.

Western FER 2020: Zhang J., et al. December 16, 2020. *Benefit Analysis of Long-Duration Energy Storage in Power Systems with High Renewable Energy Shares*. Frontiers in Energy Research. Available online: https://www.nrel.gov/docs/fy21osti/75429.pdf

- This study investigates the system level services and associated benefits of long duration storage on the 2050 Western Interconnection.
- This analysis does not include a BCA but does provide background on benefit categories, including energy arbitrage, generator efficiency improvements, startup and shutdown cost reduction, ancillary services, congestion management, transmission and distribution deferral, capacity value of energy storage, and resiliency support.

Energy Storage Benefit-Cost Analysis

A Framework for State Energy Programs

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

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