Maine Energy Storage Market Assessment

Sponsored by the State of Maine Governor's Energy Office

March 2022

Energy+Environmental Economics

Project Team

This report was produced by Energy and Environmental Economics, Inc. (E3) and sponsored by the Maine Governor's Energy Office (GEO). While the GEO and other Maine stakeholders provided input and perspectives regarding the study scope and analysis, all decisions regarding the analysis were made by E3. Thus, this report solely reflects the research, analysis, and conclusions of the E3 study authors.

E3 is a leading economic consultancy focused on the clean energy transition. E3's analysis of clean energy issues and the electric power sector is utilized extensively by utilities, regulators, developers, and government agencies in leading-edge jurisdictions such as California, New York, and Hawaii. E3 has offices in Boston, New York, San Francisco, and Calgary.

E3 Primary Authors: Tristan Wallace, Liz Mettetal, PhD; Tara Katamay-Smith and Lakshmi Alagappan.

Acknowledgment

The report authors greatly benefited from the advice and feedback provided by a diverse group of Maine stakeholders and experts for this project. Feedback was provided through public comments and follow-up meetings as needed.

Table of Contents

List of Figures

List of Tables

Acronyms

Acronym	Description
A-CAES	Adiabatic Compressed Air Energy Storage
ACP	Alternative Compliance Payment
AESC	Avoided Energy Supply Cost
AS	Ancillary Services
ATB	NREL Annual Technology Baseline
BTM	Behind-the-Meter
C&I	Commercial and Industrial
CAES	Compressed Air Energy Storage
CMP	Central Maine Power
COD	Commercial Online Date
CPES	Clean Peak Energy Standard
CT	Combustion Turbine
DA	Day-Ahead
DER	Distributed Energy Resource
DOE	Department of Energy
E3	Energy and Environmental Economics, Inc.
EIA	Energy Information Agency
ELCC	Effective Load Carrying Capacity
EMT	Efficiency Maine Trust
EPA	U.S. Environmental Protection Agency
EV	Electric Vehicle
FCA	ISO-NE Forward Capacity Auction
FERC	Federal Energy Regulatory Commission
FTM	Front-of-the-Meter
GEO	Governor's Energy Office
GHG	Greenhouse Gas
GW	Gigawatts
ICE	Interruption Cost Estimate Calculator
IOU	Investor-Owned Utility
IRP	Integrated Resource Plan
ISO	Independent System Operator
ISO-NE	Independent System Operator New England
ITC	Investment Tax Credit
kW	Kilowatts
LCOS	Levelized Cost of Storage
Li-ion	Lithium-ion
LNG	Liquified Natural Gas
LSE	Load Serving Entity
MW	Megawatts
NEB	Net Energy Billing
NEM	Net Energy Metering
NEPOOL	New England Power Pool

NPV	Net Present Value
NREL	National Renewable Energy Lab
NWA	Non-Wires Alternatives
O&M	Operation and Maintenance
PCT	Participant Cost Test
PG&E	Pacific Gas & Electric
PUC	Maine Public Utilities Commission
PV	Photovoltaic
REC	Renewable Energy Certificate
RGGI	Regional Greenhouse Gas Initiative
RIM	Ratepayer Impact Measure
RPS	Renewable Portfolio Standard
RSP	Regional System Plan
RT	Realtime
RTO	Regional Transmission Organization
SAIDI	System Average Interruption Duration Index
SAM	NREL's System Advisor Model
SCT	Societal Cost Test
SMART	Solar Massachusetts Renewable Target
T&D	Transmission and Distribution
TOU	Time of Use
VDER	Value of Distributed Energy Resources
VOLL	Value of Lost Load

Executive Summary

Energy storage has the potential to provide many benefits to Maine's electric grid and customers. The term is broadly defined in Maine law as any technology that can help absorb energy and store it for use at a later time. The ability to shift electric power generation to when customers need it most is increasingly valuable as Maine adds intermittent renewable generation to its power grid and electrifies transportation and buildings to support economy-wide decarbonization goals. Under the right conditions, energy storage's many benefits may include helping the state integrate more renewable energy and reducing carbon emissions, lowering customer bills, and supporting electric grid reliability and resilience.

To support its energy transition and accelerate storage deployment, Maine Governor Janet Mills signed bipartisan legislation, **L.D. 528**, ***An Act to Advance Energy Storage in Maine,*** in June 2021. The legislation established Maine as the ninth state with codified energy storage targets: **300 megawatts (MW)** of installed capacity within the state by 2025 and **400 MW** by 2030. These targets, some of the most ambitious in the country given the state's electric load, help make Maine's broader clean energy goals possible, including 80% renewable energy by 2030 and 100% renewable energy by 2050. Today, Maine has installed nearly 50 MW of energy storage, with hundreds of MW of planned projects and potential projects in the interconnection queue.

This study, commissioned by the Maine Governor's Energy Office (GEO) and conducted by Energy and Environmental Economics (E3) as required by the legislation, has three primary aims: to evaluate storage technologies and use cases, to assess the market and policy landscape and hurdles to storage deployment, and to perform cost-benefit analysis for a select set of scenarios. The cost-benefit analysis relies on well-established economic practices and uses publicly available data. The analysis and input assumptions were also reviewed by stakeholders through public meetings, with feedback incorporated into the final study analysis.

The scenarios modeled as part of this study demonstrate opportunities to deploy storage in the state to serve different customer and electric grid needs over the next decade. We note that the scenarios reflect only a subset of the many storage technologies and use cases and are not meant to be prescriptive. The scenarios instead highlight key potential value streams which could be accessible by a broad range of potential technologies and projects. The scenarios inform ongoing policy discussions and actions related to helping Maine achieve its storage target.

The study also identifies economic and policy hurdles that the state must overcome to ensure its storage goals are achieved. The study concludes with policy considerations to ensure the state's storage goals are met, and briefly notes possible additional analysis to further inform how storage is deployed to maximize benefits to Mainers.

Key Takeaways

The study identified key findings related to energy storage in Maine, including the following:

- **Several promising energy storage technologies may help Maine achieve its target, though batteries will likely comprise most of the storage deployed in Maine in the next five years.** Energy storage includes a diverse set of technologies, with distinct physical and economic characteristics, and the technology landscape is evolving quickly. While technologies like pumped hydro storage have been deployed for a century, there are many new and emerging energy storage technologies with the potential to create benefits to Mainers by lowering electric grid costs, integrating renewables, and providing other benefits. Lithium-ion (Li-ion) batteries are expected to be the most common storage technology deployed in the near-term, given continued declining costs, high round trip efficiency, siting flexibility, and the ability to provide the fast-response needed to integrate and balance renewables. That said, other technologies may prove to have better economics in the coming years, or provide a range of other advantages (e.g., longer duration, other grid services, etc.).
- **Energy storage may provide many distinct benefits to Mainers, with potential value streams evolving as the needs of the electric grid and customers change.** If storage can continue to fall in cost and overcome deployment hurdles, it can help lower wholesale electricity generation costs (benefiting consumers), lower utility infrastructure costs (benefiting ratepayers), and lower electricity bills and increase resiliency (benefiting customers). As greater solar penetration drives down mid-day prices, storage can charge during the day and help serve peak demand in the early evening hours. In Maine, some of the highest value services for certain projects in the near-term may be avoided transmission and distribution (T&D) infrastructure costs. However, realizing these avoided costs by specific storage projects will depend on the ability to site storage in the most valuable locations and on potential business model and/or regulatory changes to help these benefits to be monetized. Similarly, behind-the-meter storage, located at the customer site, may provide significant value to customers such as avoided outages. However, the size of this value stream depends on the customer's specific economics including the value of lost load (VOLL).
- **Cost-benefit analysis results show cost-effectiveness for wholesale ("grid-connected") storage but continued cost declines and the ability to monetize multiple value streams will be important.** The commercial viability of storage projects will depend both on realizing cost declines and on the ability to monetize multiple revenue streams. Value "stacking" is particularly important to projects given uncertainty around future wholesale prices and potential changes in market rules and design. Currently, wholesale (also referred to as front-of-the-meter or FTM) storage projects can pursue multiple wholesale market revenue sources. While ancillary services (AS) revenue is likely to supply most revenue in the near term, energy arbitrage opportunities will continue to grow, supplying most of the revenue in the longer term. Capacity revenue will remain an important revenue stream and could supply at least a quarter of expected revenue in each year over the next decade. That said, policy goals, technological advancements, and other drivers may influence changes in market design, making the evolution of revenue streams less certain.
- **Customer-sited storage can reduce customer bills and increase resiliency by protecting against outages (loss-of-load).** Building on-site energy storage can reduce electric bills for residential, commercial or industrial customers. In addition, customers benefit from avoided outages,

though quantifying the value of lost load is highly uncertain and can vary depending on customer type, outage duration and location. Recent policy and market changes in ISO New England, the region's independent system operator, are allowing customer-sited (also referred to as behind-the-meter or BTM) storage to participate in wholesale markets through aggregation, i.e. grouping together smaller projects that individually may lack scale and coordination necessary for proper market participation. This provides alternative revenue streams for customer-sited storage. While these revenue streams are lower today than customer bill savings, they provide customer-sited storage investments optionality and alternative revenue streams that increase their overall attractiveness.

+ **Long-duration energy storage technologies may support New England's need for clean, firm energy in a deeply decarbonized future.** New England's reliability challenge as it decarbonizes will increasingly be ensuring sufficient energy availability during high load, low renewable production periods in winter months. Long-duration energy storage, which often refers to technologies designed to shift generation on scales longer than a day, can help move power from times of year with more abundant renewable generation to periods of prolonged low wind and solar production (e.g., cold winter snaps). A range of potential long-duration energy storage technologies (e.g., iron-air batteries, hydrogen generation) could provide Maine with low- or zero-carbon dispatchable generation or long-duration energy storage, particularly beyond 2030 as regional carbon targets become stricter and emerging technology costs fall. While today no long-duration storage technology is widely and commercially available, there are an increasing number of promising demonstration-scale projects across the U.S.

+ **Notable hurdles remain related to near-term storage deployment in the state**. While the commercial viability and costs of energy storage have declined precipitously over the last several years, energy storage remains too costly to scale for some potential use cases today, and challenges with interconnection limit the pace of its deployment. In addition, the ability to access and monetize certain revenue streams remains limited, given the lag in wholesale market reforms, rates designs, and other barriers. Other revenue streams associated with integration of renewables will not materialize until greater penetrations of renewables are present on the system. Policy considerations, discussed in the study conclusions, can help alleviate the economic and other barriers to accelerated storage deployment.

1 Introduction

1.1 Study Motivation

An energy storage system, as defined by Maine law,[1] is a commercially available technology that uses mechanical, chemical or thermal processes for absorbing energy and storing it for a period of time for use at a later time. It has often been called the "Swiss Army knife" of the electricity system in recognition of the many services it can perform including: the ability to take advantage of power price differentials across time, provide contingency reserves and flexibility to the grid, avoid the construction of peaking generators, relieve transmission congestion and renewable curtailment, defer transmission and distribution (T&D) wire investments, increase resiliency, and help to integrate intermittent renewable resources.

Maine is among the nation's leaders in enacting policies to facilitate a clean energy transition, including targets of economy-wide carbon neutrality by 2045 and 100% renewable electricity by 2050. Energy storage is a key enabler of renewable energy and has the potential to provide significant benefits to the State of Maine. In June 2021, Governor Janet Mills signed L.D. 528, which set energy storage targets for the State of Maine as follows:

+ **300 megawatts of installed capacity within the state by the end of 2025**
+ **400 megawatts of installed capacity within the state by the end of 2030**

Maine has already seen storage deployment across the state but achieving these ambitious targets and optimizing storage usage to provide all potential benefits to Maine will require supportive economics, markets, and policy, and this study is designed to inform the State of Maine's policy and decision-making over the next decade as it seeks to accelerate deployment. The study evaluates the market and policy landscape, and constructs cost-benefit analyses for a selected set of scenarios, which reflect storage deployment under selected use cases. The study also identifies existing barriers to storage deployment today. Based on these findings, the study identifies potential policy considerations for the State of Maine to ensure that its storage targets are realized.

1.2 Role of the Governor's Energy Office and Stakeholders in Process

The Governor's Energy Office (GEO) is the sponsor of this study, and supported Energy and Environmental Economics, Inc. (E3) in designing and guiding the study, conducting public comment processes, and preparing this report. As part of this study, the GEO and E3 conducted a public comment

[1] "An Act To Reform Maine's Renewable Portfolio Standard," 129th Maine Legislature, accessed on February 25, 2022, https://www.mainelegislature.org/legis/bills/bills_129th/chapters/PUBLIC477.asp

process in which stakeholders were invited to participate in two webinars. In the first webinar, conducted on January 10th, 2022, E3 presented the initial study design and the modeling framework, and solicited feedback from stakeholders. This feedback was then used to modify the scenarios that were investigated in the study, as well as the modeling for the cost-benefit analyses.

The second webinar was conducted on February 14th, 2022 and presented the draft results of the cost-benefit analyses, as well as preliminary policy considerations considering those results. Stakeholders were invited to provide comments on these preliminary results and policy considerations following the webinar to be considered in the final report. A final webinar will be held following the publication of this report.

1.3 Objectives

The goal of this study is to assess opportunities and potential challenges in achieving Maine's energy storage goals. Specifically, this study:

+ Evaluates the policy and market context (Section 2).
+ Assesses the range of potential storage technologies, along with value streams and use cases (Section 3).
+ Evaluates the costs and benefits of different storage deployment options (methods in Section 4 and results in Section 5).

2 Policy and Market Context

2.1 Maine's Renewable Energy and Storage Goals

The State of Maine has some of the most ambitious decarbonization policies in the country, aimed at mitigating the worst impacts of climate change on the state, catalyzing the development of Maine's clean energy economy, and reducing and stabilizing energy costs. In 2019, Governor Janet Mills signed **L.D. 1494** and **L.D. 1679**, which set the course for addressing climate change in Maine. L.D. 1494 increased the state's renewable portfolio standard (RPS) – i.e., the share of the state's electricity coming from renewable resources – to a total of 80% by 2030 and a goal of 100% by 2050. To complement this, L.D. 1679 established the Maine Climate Council, tasked with advising on strategies for Maine to meet economy-wide emission reductions of at least 45% below 1990 levels by 2030 and 80% below by 2050.

These policies pave the path for significant renewable growth over the next decade. To support this renewable generation, in 2019 Maine established the bipartisan **Commission to Study the Economic, Environmental and Energy Benefits of Energy Storage to the Maine Electricity Industry**, which released its report of the same name in December 2019 (referred to as the 'Commission Report' in this document). This report found reliability and cost benefits from energy storage resources, generating four key findings:

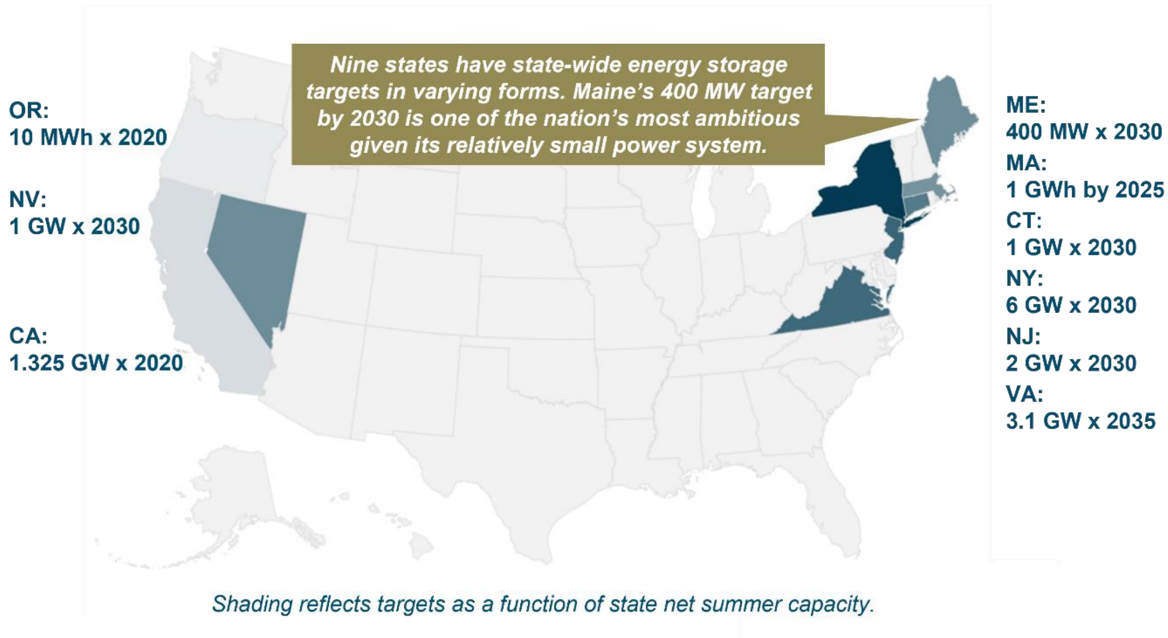
- Energy storage has the potential to reduce costs and improve reliability;
- Energy storage complements and supports renewable energy;
- Energy storage technology is dynamic and evolving and presents cost-effective options; and
- Energy storage development may be inhibited by market barriers or a lack of clear regulatory signals.

Based on these findings, the Commission Report made the following recommendations:

- Establish **state targets** for energy storage development;
- Encourage **energy storage paired with renewable and distributed generation** resources;
- Advance energy storage **as an energy efficiency resource**;
- Address **electricity rate design issues** relating to time variation in costs;
- **Clarify utility ownership** of energy storage;
- **Advocate** for energy storage consideration **in regional wholesale markets**; and
- Conduct an in-depth Maine-specific analysis of energy storage costs, benefits, and opportunities.

In response to this Commission Report, Maine's legislature passed **L.D. 528** in June 2021, ***An Act To Advance Energy Storage in Maine***. In addition to requiring the energy storage market assessment study that this report satisfies, L.D. 528 set state goals for energy storage of 300 MW of installed capacity within the state by the end of 2025 and 400 MW by the end of 2030, becoming the ninth state to set energy storage goals. **The 400 MW goal represents roughly 17% of Maine's peak electricity demand in 2021, a relatively higher share of local peak demand compared to other New England states with energy storage goals.**[2] Maine's targets, along with other existing targets across the U.S., are shown in Figure 1.

Figure 1. U.S State Energy Storage Targets



Note: Figure as of January 2022.

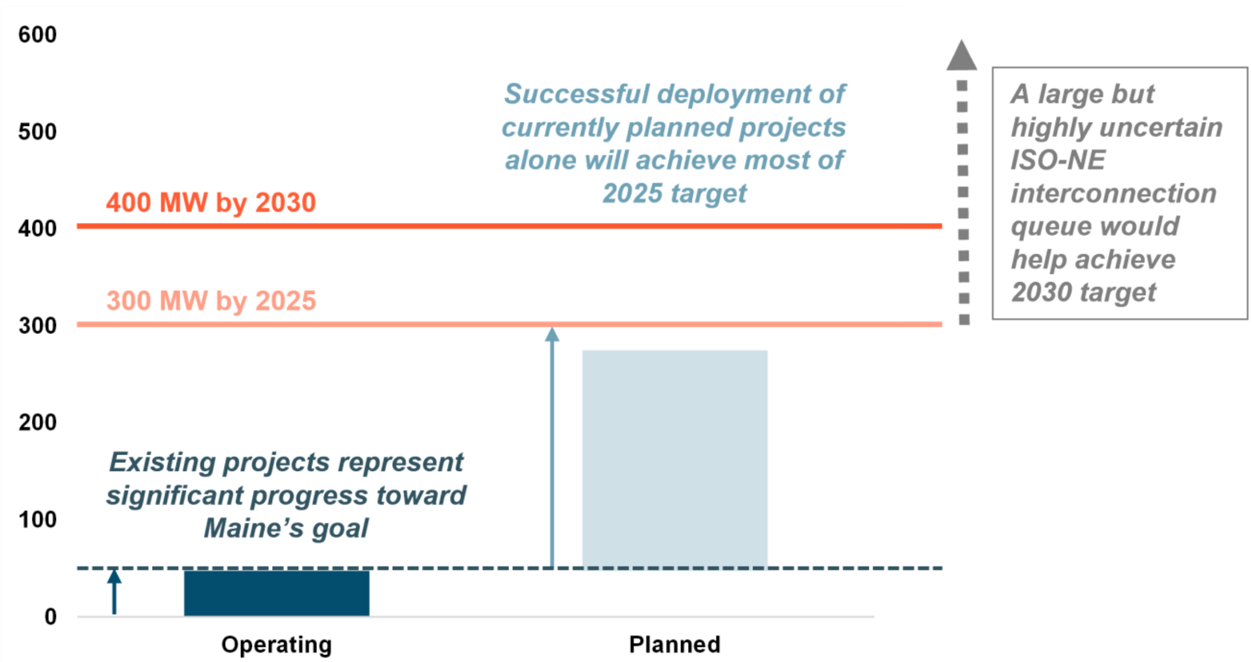
L.D. 528 also directs the state to explore options to expand existing opportunities and develop new ones to support energy storage that reduces peak demand through its electric efficiency and conservation programs. As advocated by the GEO and ultimately included in the legislation, L.D. 528 specifically includes the design of a pilot program starting in 2022 for up to 15 MW of energy storage at critical care facilities. Lastly, L.D. 528 directs the Maine Public Utilities Commission (PUC) to open a docket to consider time of use rate design in conjunction with energy storage, which began in October 2021. Maine's T&D utilities (investor-owned and consumer-owned utilities) were required to submit targeted optional rates for energy storage by December 1, 2021. The docket (2021-00325) is currently ongoing at the Maine PUC.

[2] Connecticut has a goal of 1,000 MW of energy storage by 2030. This is estimated as roughly 15 percent of local peak demand in 2021. Massachusetts has an energy storage goal of 1,000 MWh by 2025, assuming 2-hour duration on average, this represents roughly 4 percent of local peak demand in 2021.

2.2 Maine's Actions and Progress to Date

Maine has already begun to make progress toward its storage targets, with total storage capacity in Maine of nearly 50 MW at the end of 2021, as shown in Figure 2. More details about existing and planned storage projects are provided in Table 1, which demonstrates that grid-scale storage has been in operation in Maine since 2015, and there are over 200 MW of planned energy storage capacity, with additional projects in the ISO-NE interconnection queue. While the planned projects and those in the interconnection queue are enough to exceed the 2030 target, historically a small share of projects are ultimately constructed. This means the state is making progress towards its target, but effort will be required to ensure the state remains on track to meet its target.

Figure 2. Operating and Planned Energy Storage in Maine Relative to Maine's Targets[3]



[3] "ISO New England - Forecast Report of Capacity, Energy, Loads, and Transmission," ISO-NE, accessed January 5, 2022, https://www.iso-ne.com/system-planning/system-plans-studies/celt/; Hitachi Energy Velocity Suite, accessed January 5, 2022; "Interconnection Request Queue," ISO-NE accessed on February 28, 2022, https://www.iso-ne.com/system-planning/interconnection-service/interconnection-request-queue/

Table 1. Planned and Operating Storage Projects in Maine[4]

Plant Name	County	Unit Status	Expected Online Date	Grid Connected (Y/N)	Capacity (MW)
Boothbay Storage Project	Lincoln	Operating	5/5/2015	Y	0.5
William F Wyman	Cumberland	Operating	12/31/2016	Y	16.7
Madison BESS	Somerset	Operating	5/30/2019	Y	4.7
Madison BTM	Somerset	Operating	3/31/2020	Y	1.5
Great Lakes Millinocket Battery	Penobscot	Operating	12/31/2020	Y	20.9
Industrial Drive Rumford BESS Project	Oxford	Operating	7/1/2021	Y	4.9
Middlesex Road Topsham Solar	Sagadahoc	Planned	3/1/2022	Y	4.99
CED Denmark Solar Hybrid	Oxford	Planned	11/1/2022	Y	2.3
Manchester BESS	Kennebec	Planned	1/1/2023	Y	14
Sanford ESS	York	Planned	1/31/2023	Y	5
South Portland ESS LLC	Cumberland	Planned	1/31/2023	Y	10
Cross Town Energy Battery Energy Storage	Cumberland	Planned	4/1/2023	Y	175
Bonny Eagle Renewable BES	Cumberland	Planned	1/1/2025	Y	7.8
Rumford Renewable BES	Oxford	Planned	1/1/2025	Y	6.9
Total					**275**

2.3 Maine and Regional Policy and Market Context

The majority of Maine's electric transmission grid[5] is operated by ISO New England (ISO-NE), an independent, non-profit Regional Transmission Organization (RTO) that manages the wholesale power market. In 2020, Maine's share of ISO-NE's annual load,[6] as well as generation,[7] was about 10 percent. Through ISO-NE, generators in Maine can participate in the wholesale energy markets (day ahead and real-time) for energy arbitrage[8] opportunities, ancillary services[9] (forward reserve, 10-minute spinning reserves, 10-minute non-spinning reserves, 30-minute non-spinning reserves and regulation capacity and regulation service), as well as the 3-year auction-based forward capacity market. Most recently, this capacity market saw over 700 MW of energy storage resources clear in the 2022 (FCA 16) auction, including over 200 MW in Maine. Maine's participation in this market provides opportunities for coordinated decarbonization activities across the region that could lower costs and provide benefits to Maine ratepayers.

---

4 "ISO New England - Forecast Report of Capacity, Energy, Loads, and Transmission," ISO-NE, accessed January 5, 2022, https://www.iso-ne.com/system-planning/system-plans-studies/celt/; Hitachi Energy Velocity Suite, accessed January 5, 2022; independent research.

5 About 5% of Maine's load is in the Northern Maine Independent System Administrator (NMISA). NMISA is connected to the rest of Maine indirectly through Canada.

6 "ISO New England - Energy, Load, and Demand Reports," ISO-NE, accessed January 19, 2022, https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/zone-info.

7 Hitachi Energy Velocity Suite, accessed February 17, 2022

8 Energy arbitrage takes advantage of power price differentials in different time periods by charging when prices are low and discharging when prices are high.

9 Ancillary services are defined as a service, other than electric power, provided to the electric power system, including load, regulation, reserve, and voltage support. "Glossary and Acronyms," ISO-NE, accessed March 10, 2022, https://www.iso-ne.com/participate/support/glossary-acronyms/.

Access to ISO-NE's wholesale markets provides a breadth of revenue opportunities for storage, and ISO-NE's rules regarding storage participation are evolving. Federal Energy Regulatory Commission (FERC) Order 841, which was approved in 2018, required ISO-NE to open access to wholesale markets for energy storage resources. The Order stipulated that storage resources be allowed to provide all the market services that they are physically capable of providing, and the markets must account for physical and operational storage characteristics in their bidding parameters and other rules. For example, they can be dispatched (and set market clearing prices) as both a buyer and a seller.

Each Independent System Operator (ISO) and RTO was required to submit a compliance filing either demonstrating how their current market rules and tariffs account for storage or include market rule revisions to meet FERC mandates. ISO-NE submitted their initial compliance filing in December 2018, largely relying on their preexisting tariff provisions. However, ISO-NE did modify their participation model for standalone storage facilities, as well as lowered the minimum size of an eligible storage facility from 1 megawatt to 0.1 megawatts. Most revisions were accepted but subsequent revisions were made over the next few years and the third and final compliance filing was accepted in February 2021.

FERC Order 2222, which builds off FERC Order 841, was approved by FERC in September 2020 and requires ISO/RTOs to allow distributed energy resource (DER)[10] participation, including behind-the-meter (BTM) storage, in wholesale markets (energy, ancillary services, forward capacity market) via aggregators.[11] It states that DERs can participate in both wholesale markets and retail services if they do not double count the services. The order requires tariff revisions to allow for wholesale market participation by DERs through aggregators but leaves many key decisions for ISO/RTOs to address including: the minimum size of DER aggregation, sharing data on physical parameters of the assets, deciding how to restrict the double-counting of services and setting their own metering and telemetry requirements.

Each ISO/RTO must submit its compliance filing outlining how the market will allow for such participation and include any necessary tariff revisions (size, location, interconnection, bidding parameters, data and metering requirements). ISO-NE's compliance filing was due in February 2022 and they created two new participation models for these distributed (but aggregated) resources, including one with dispatch and

[10] Distributed energy resources are defined by ISO-NE as "any asset located on the distribution system, any associated subsystem or behind a customer meter, which may include, but is not limited to, electric storage resources, distributed generation, demand response, energy efficiency, thermal storage, and electric vehicles and their supply equipment. "Glossary and Acronyms," ISO-NE, accessed February 25, 2022, https://www.iso-ne.com/participate/support/glossary-acronyms.

[11] As outlined by FERC, "Order No. 2222 requires each RTO/ISO to revise its tariff to establish distributed energy resource aggregators as a type of market participant that can register distributed energy resource aggregations under one or more participation models in the RTO/ISO tariff that accommodate the physical and operational characteristics of each distributed energy resource aggregation." "Participation of Distributed Energy Resource Aggregations in Markets Operated by Regional Transmission Organizations and Independent System Operators," FERC, accessed on February 25, 2022, https://www.federalregister.gov/documents/2021/06/28/2021-13442/participation-of-distributed-energy-resource-aggregations-in-markets-operated-by-regional#citation-7-p33854

one with settlement only.[12] The current timeline for ISO-NE is to have capacity market changes effective by Q4 2022, as well as energy and ancillary service market changes by Q4 2026.

The impact of these market design changes in terms of market participation and storage revenues remains to be seen. This will certainly give more optionality to DERs for how they choose to participate, but a decision to participate will hinge on the rules around the potential double-counting of services, as well as the tradeoffs and potential revenue (or bill savings) with other competing services. Given the uncertainty around how storage projects will choose to participate in these markets, the modeling in this study considers a range of value streams. These wholesale market opportunities are also discussed in further detail below in Section 3, which details the potential use cases and value streams for storage in Maine.

2.4 Regional Storage Policies

States across the region have adopted a variety of policies to encourage both wholesale and customer-sited energy storage including tax credits, upfront rebate programs, performance-based incentives, and programs that often focus on demand response[13] activities. Below are examples of some of the leading policies in the region to encourage energy storage deployment.

2.4.1 ConnectedSolutions and Other Regional Incentive Programs

Originally created as part of Massachusetts' three-year energy efficiency program, ConnectedSolutions is now available to customers of Eversource, National Grid or Cape Light Compact in Connecticut, Massachusetts, and Rhode Island. It is a pay-for-performance demand response program for customer-owned distributed energy resources, including battery storage, and seeks to reduce utility peak demand expenses, including higher power prices and potentially avoid the need for new peaking generating capacity. It includes performance-based incentive payments that are locked in for five years and specifies the months that discharge events can occur and the limit for the amount of discharge events in a year.[14] This additional revenue stream helps support storage adoption for customers that are seeking access to backup power. A 2019 survey found that most participants experienced high satisfaction with the

[12] Dispatchable resources can be given instructions by the ISO regarding their operations including starting up, shutting down, raising or lowering generation, changing interchange schedules, or changing the status of a dispatchable load in accordance with applicable contracts or demand bid parameters. Settlement only resources produce less than 5 MW and are entitled to receive capacity credit but are not centrally dispatched by the ISO control room and are not monitored in real time. "Glossary and Acronyms," ISO-NE, accessed February 14, 2022, https://www.iso-ne.com/participate/support/glossary-acronyms.

[13] Demand response programs pay electricity consumers to reduce their electricity usage at key times, typically either when marginal wholesale prices are high, or the reliability of the grid is threatened. They are seen as a key tools to reduce peak demand on the grid and avoid high prices, as well as future investments in peaking generators.

[14] Upfront incentive payments for C&I customers are available for Eversource customers only to help pay for required metering. "Program Materials for Connected Solutions for Commercial / Industrial Customers," Mass Save, accessed on February, 16, 2022, https://www.nationalgridus.com/media/pdfs/bus-ways-to-save/connectedsolutions-ciprogrammaterials.pdf

program.[15] While the program details can vary by state, utility, and customer class, Table 2 below shows details of the battery program for residential customers in Massachusetts.

Table 2. ConnectedSolutions Battery Program – National Grid Massachusetts for Residential Customers[16]

Performance Incentive	$275/kW
Discharge Events per Season	60
Months Discharge Events Can Occur	June through September
Time Discharge Events Can Occur	2 p.m. to 7 p.m.
5-year incentive lock	Yes

Other states also have similar incentive programs. Connecticut's recently adopted Energy Storage Solutions[17] policy is based on and adapted from the ConnectedSolutions program, but also includes upfront incentive payments which help lower installation costs, in addition to performance-based incentives. In Vermont, Green Mountain Power offers two programs to incentivize storage, including reduced lease payments for customer-sited storage through its Powerwall program,[18] and an upfront incentive for storage ownership through its Bring Your Own Device Program.[19] By mid-2021, Green Mountain Power noted that roughly 3,000 Powerwall systems had been installed in customers' homes, which helped save over $3 million in customer costs in 2020.[20]

2.4.2 New York Value of Distributed Energy Resources (VDER)

New York's Value of Distributed Energy Resources (e.g. The Value Stack) was a successor to the state's net energy metering program and was approved in 2017. It creates utility tariffs that compensate distributed resources, including energy storage, based on when and where they provide electricity to the grid in the form of bill credits. It seeks to align the benefits of distributed resources with their compensation to the

---

[15] The study found that over 95% of the participants would recommend the program to other customers and are likely or very likely to continue with the program. "2019 Residential Energy Storage Demand Response Demonstration Evaluation – Summer Season," Navigant, a Guidehouse Company, accessed on December 22, 2021, https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/12189610

[16] "Battery Program," National Grid, accessed on February 16, 2022, https://www.nationalgridus.com/MA-Home/Connected-Solutions/BatteryProgram

[17] "Energy Storage Solutions," Connecticut Public Utilities Regulatory Authority, accessed on February 16, 2022, https://portal.ct.gov/pura/electric/office-of-utility-programs-and-initiatives/clean-energy-programs/energy-storage-solutions-program

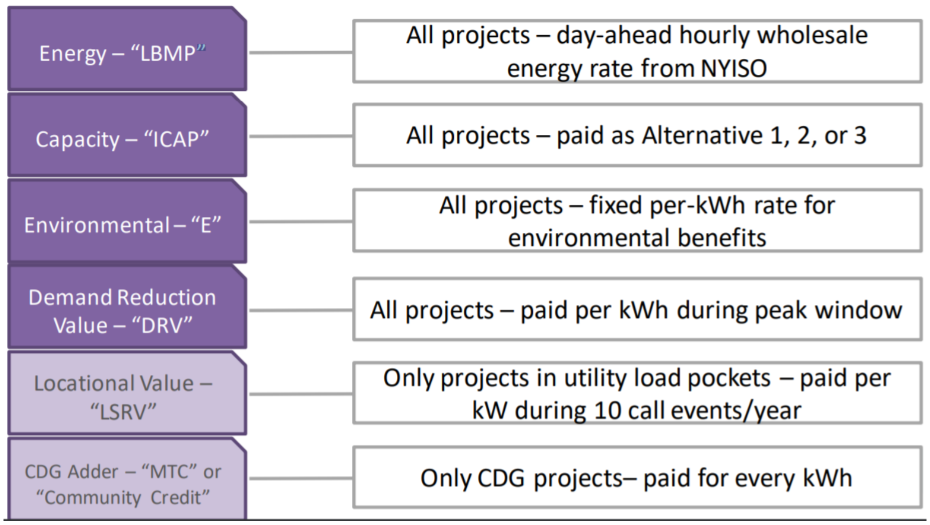
[18] "Energy Storage Solutions," Connecticut Public Utilities Regulatory Authority, accessed on February 16, 2022, https://portal.ct.gov/pura/electric/office-of-utility-programs-and-initiatives/clean-energy-programs/energy-storage-solutions-program

[19] "Tesla Powerwall," Green Mountain Power, accessed on February 16, 2022, https://greenmountainpower.com/rebates-programs/home-energy-storage/powerwall/

[20] "GMP's Pioneering Network of Powerwall Batteries Delivers First-in-New-England Benefit for Customers & Grid, Cutting Carbon and Costs," Green Mountain Power, accessed on February 28, 2022, https://greenmountainpower.com/network-of-powerwall-batteries-delivers-first-in-new-england-benefit-for-customers/

resource owner based on the value they provide to the grid and to the environment. Figure 3. below lists the details of the components of The Value Stack.

Figure 3. New York Value Stack Components[21]



2.4.3 Massachusetts Clean Peak Energy Standard

Massachusetts' Clean Peak Standard,[22] which was created in 2020, is a program designed to provide incentives for meeting electricity needs, or reducing demand, during peak demand periods with clean resources. Load Serving Entities (LSEs) in the state are required to meet a certain share of their retail sales with clean peak energy in the form of clean peak credits. The requirement starts at 1.5% in 2020, rising by 1.5% annually thereafter. Eligible technologies include battery storage, all renewables and demand response. Storage is required to be co-located with renewables or charge during wind-based and solar-based charging periods and must be connected to the grid in Massachusetts. As of December 2021, there were over 60 MW of qualified storage projects under the program.[23]

Clean peak credits can be generated by storage resources for discharging in certain time periods (see Table 3 below for time periods). The program includes various credit multipliers which vary by season and resource type (see Table 4 below for the credit multipliers).

---

[21] "Summary of Updated Value Stack Order," NYSERDA, accessed on February 16, 2022, https://www.nyserda.ny.gov/-/media/Migrated/NYSun/files/2019-04-25-Updated-VS-Order-Overview-Slides.ashx

[22] "Clean Peak Energy Standard," Massachusetts Department of Energy Resources, accessed on February 16, 2022, https://www.mass.gov/clean-peak-energy-standard

[23] "CPS Qualified Units List," Massachusetts Department of Energy Resources, accessed on February 28, 2022, https://www.mass.gov/doc/cps-qualified-units-list

Table 3. Clean Peak Standard Peak Discharge Periods

Season	Peak Season	Discharge Period
Winter	12/1 to 2/28	4pm - 8pm
Spring	3/1 to 5/14	5pm - 9pm
Summer	5/15 to 9/14	3pm - 7pm
Fall	9/15 to 11/30	4pm – 8pm

Table 4. Clean Peak Standard Peak Multipliers

Multiplier Category	Multiplier Value	Applicable Resources
Summer/ Winter multiplier	4	All
Fall/Spring multiplier	1	5pm - 9pm
Monthly peak hour multiplier	25	3pm - 7pm
SMART ES Resource Multiplier	0.3	SMART Solar + Storage
Resilience	1.5	BTM Storage
Existing Resource	0.1	Existing CDG & Demand Response
Contracted Resource	0.01	Offshore Wind

Alternative compliance payments (ACPs) are penalties assessed to LSEs if they fail to meet their requirements and serves as the functional "maximum" that a clean peak credit (on a MWh basis) could be worth. The regulation includes declining ACPs over time, which starts at 45 $/MWh in 2020 and declines to under 5 $/MWh in 2050. There are also stipulations that the pace of ACP decline can change based on the supply of credits in any given year relative to demand.

2.4.4 Solar Massachusetts Renewable Target (SMART) Program

The Solar Massachusetts Renewable Target (SMART) program is a tariff-based declining block incentive program to support solar development in the state (projects less than 5 MW) and replaced the state's SREC-II program in November 2018. In July 2020, the program doubled to 3.2 GW and required energy storage on solar projects greater than 500 kW in capacity. The program includes a storage incentive for storage paired with solar. The Storage Adder ranges from $0.0247 to $0.0763 per kWh of electricity and is based on the battery size and how much electricity can be provided at a given time. The storage capacity must be at least a quarter of the capacity of the solar, must have a duration of two to six hours, have at least 65% roundtrip efficiency, and discharge at least 52 cycles per year.[24] As of January 2022, there were over 190 MW of approved solar projects that were utilizing the storage adder.[25]

[24] "Solar Massachusetts Renewable Target (SMART) Program Summary," Massachusetts Department of Energy Resources, accessed on February 16, 2022, https://www.mass.gov/doc/smart-launch-and-program-overview/download?_ga=2.264790863.1181886720.1541775161-483334923.1493903549

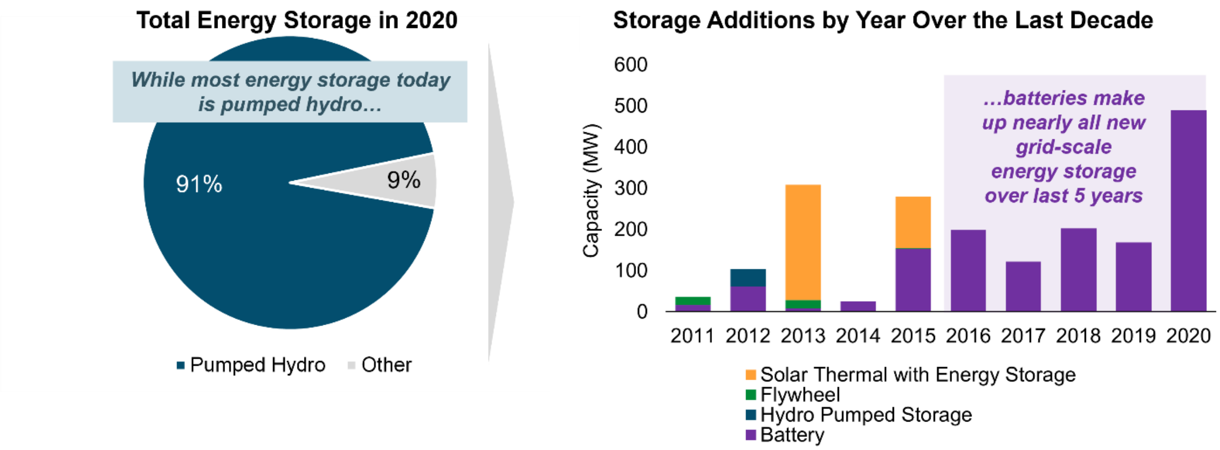
[25] "SMART Solar Tariff Generation Units," Massachusetts Department of Energy Resources, accessed on February 28, 2022, https://www.mass.gov/doc/smart-solar-tariff-generation-units

3 Storage Technology Overview

3.1 Storage Technologies Landscape

Shifting electric generation across hours, days, weeks or seasons is made possible through a range of energy storage technologies with different characteristics, capabilities and costs. Given the many services it can provide the electric grid, energy storage is expected to play an increasingly important role in the power sector in coming decades, especially as electrification and renewable penetration increases. Today, most existing energy storage across the U.S. is pumped hydro (Figure 4). That said, most high value pumped hydro sites have been exhausted, and new developments over the last decade have primarily been thermal storage and batteries.

Figure 4. Existing Grid-Connected Energy Storage Capacity in the United States and Annual U.S. Storage Additions Since 2010 [26]



3.2 Technology Comparison

This study evaluated a range of potential energy storage technologies that could be relevant to the State of Maine. Storage technologies typically fall into four types: electrochemical, electrical, thermal, and mechanical. This list was then screened into a smaller list of technologies that were potentially deployable in Maine in the near term.

[26] "2020 Form EIA-860 Data - Schedule 3, 'Generator Data' (Operable Units Only)," U.S. Energy Information Administration, accessed on February 25, 2022, https://www.eia.gov/electricity/data/eia860/

Table 5. Storage Types

Type	Examples
Electro-chemical	Batteries, flow batteries
Electrical	Capacitor, super capacitor
Thermal	Hot water storage, solar thermal
Mechanical	Pumped storage, compressed air, flywheel energy storage
Chemical/fuel-based	Hydrogen, synthetic fuels

A range of storage technologies were reviewed for potential deployment in Maine. Brief commentary on each technology is provided below.

+ **Pumped hydro** is the largest share of U.S. grid-connected storage capacity and is a mature, commercially ready technology that can provide bulk power. As a form of mechanical storage, it operates by pumping water from a downhill reservoir using lower-priced off-peak energy to an uphill reservoir to store energy. Energy is then released during on-peak times, or as needed, by allowing the water to flow downhill through a turbine. Concerns over water and land use have limited recent pumped hydro development. Further, siting flexibility is a major concern for future development of pumped hydro storage and the study team is not aware of any pumped hydro projects under development in Maine.
+ **Compressed air energy storage (CAES)** is similar to pumped hydro but stores compressed air instead of water. Energy is created during discharge by heating and expanding the compressed air and driving it through a turbine-generator. Like pumped hydro, siting is a concern as it requires large underground caverns or more expensive above-ground storage reservoirs to store the compressed air. Adiabatic CAES (A-CAES) is similar to traditional CAES but instead stores the heat released by compression to later reheat the compressed air during discharge, which can eliminate emissions and increase efficiency.
+ **Lithium-ion (Li-ion) batteries** are viewed as the most likely near-term deployable storage technology in Maine today, given its current competitive costs, expectations for continued declining costs, and the potential high-value services it provides to the grid. This chemical storage is known for its high energy density, which allows a large amount of storage in a small amount of space. This technology is also modular, mobile and provides the fast-response needed to integrate and balance renewables. Remaining challenges include battery degradation, shorter lifespan, and potential supply chain risks with lithium supply and cathode manufacturing, as well as potential safety issues given their inherent flammability. However, the deployment of more batteries and continued refinement of standards and regulations for manufacturing, testing, and operations and maintenance are expected to largely mitigate these safety risks, similar to other

technologies.[27] Durations for li-ion batteries typically only go up to four hours, which is driven by the higher cost of longer duration batteries, as well as the current needs of the system to shave peak hours and shift energy to different times of the day that do not always warrant a longer duration battery. However, as the technology continues to advance and costs continue to fall, along with further decarbonization, longer duration li-ion batteries will play an important role.

+ **Flow batteries** are an alternative battery technology to Li-ion. Energy is stored in two tanks of liquid electrolytes, and during discharge the liquid is pumped through electrodes and electrons are extracted. While this form of battery is more expensive for shorter durations, it has longer life cycles, given that there is no capacity degradation over time, and may make sense for longer durations. Flow batteries are also non-flammable, unlike Li-ion but are lower density and thus require more space.
+ **Iron-air batteries** are another emerging alternative to Li-ion batteries that involves interacting iron with oxygen to generate power. This technology, which uses cheap and abundant raw materials, is still in the development phase but is quickly gaining traction as a potential source of long-duration storage, with the first demonstration project expected in 2025.
+ **Solar thermal storage systems** leverage heat to store energy that is not directly converted into power at the solar field. The energy can be stored as hot fluids (water, molten salts, or other working fluids) for later use. This technology is a significant portion of the storage that has been deployed over the last decade, but one of the key limitations is siting given the large amount of land needed for the solar panels.

These technologies differ in their level of commercial maturity, as well as their flexibility for siting, duration, and efficiency. The list of technologies considered in this study and their key characteristics are provided in Table 6.[28]

[27] "New developments in battery safety for large-scale systems," Joshua Lamb and Judith Jeevarajan, 2021, https://link.springer.com/article/10.1557/s43577-021-00098-0

[28] Other potential future energy storage options are not considered in detail as part of this report but may become important in the future. For example, electric vehicles could serve as energy storage in Maine's future grid, once significant deployment of EVs occurs. Vs, which charge off their Li-ion battery off the electric grid, could be managed in the future through vehicle-to-grid integration. Management programs may, for example, control and shift when a vehicle charges to shift charging to off-peak hours (V1G). In more advanced integration scenarios, vehicles can store electricity during times of excess generation and discharge back to the grid during peak hours (referred to as vehicle-to-grid or V2G).

Table 6. Overview of Key Energy Storage Technologies Screened for Maine

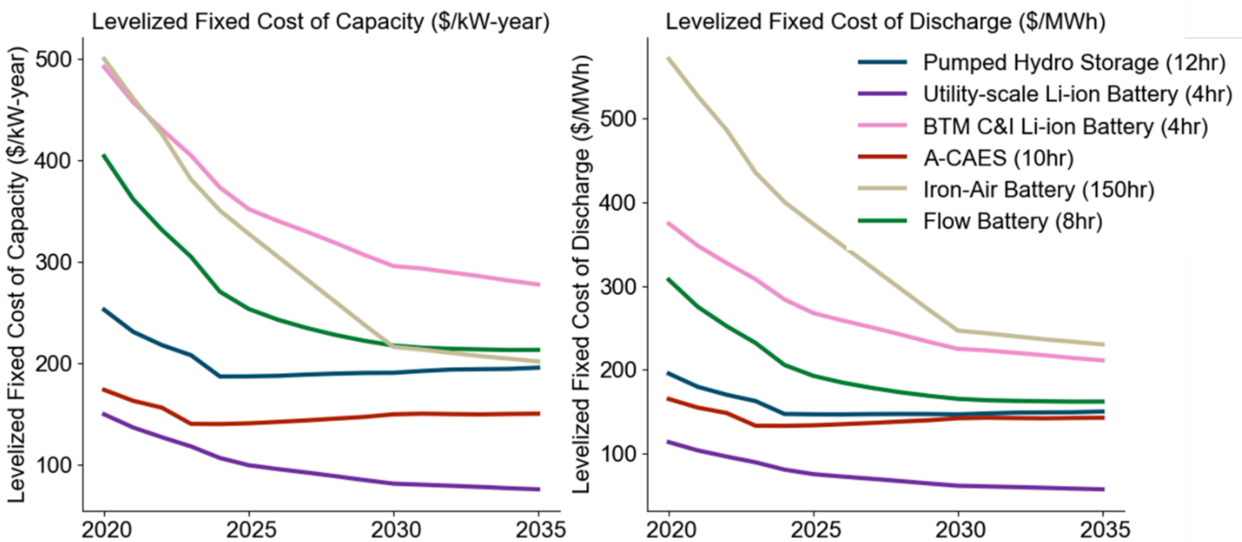
	Pumped hydro	Li-ion Battery	CAES/A-CAES	Iron-Air Battery	Flow Battery	Solar Thermal Storage
Commercial readiness	High	High	Medium	Medium	Medium	High
Siting flexibility	Low	High	Low	High	High	Low
Scalability (size, location requirements, manufacturing capability)	Low	High	Low	Medium-High	Medium-High	High
Duration	Long (6-10 hrs)	Flexible (1-6 hrs)	Long (8-48 hrs)	Long (100+ hrs)	Flexible (6+ hrs)	Long (6-10 hrs)
Roundtrip efficiency[29]	65-85%	85-95%	40-80%	>45%	70-85%	40%
Response time (to provide full power)	Minutes	Seconds	Minutes	Seconds	Seconds	Varies

An overview of mid-range cost estimates for these technologies is provided in Figure 5. This figure shows fixed costs, including capital costs, fixed operations and maintenance (O&M), augmentation, warranty, and interconnection costs. Cost estimates are shown on a levelized basis in terms of both per kW of installed capacity and per MWh of discharge energy.

E3 utilized resource cost information for this study from its in-house pro forma model, which is based on benchmarking to a wide range of public sources including industry analyst reports, national lab studies, and utility integrated resource plans (IRPs). For Li-ion battery costs in particular, Lazard and the National Renewable Energy Laboratory (NREL) are primary sources of information. For emerging technologies, primary research is performed and estimates from vendors are considered, along with learning curves for future cost reductions.

[29] Roundtrip efficiency is defined as the "percentage of electricity put into storage that is later retrieved" and is an indication of efficiency losses. "Utility-scale batteries and pumped storage return about 80% of the electricity they store," U.S. Energy Information Administration, https://www.eia.gov/todayinenergy/detail.php?id=46756#:~:text=Round%2Dtrip%20efficiency%20is%20the,lost%20in%20the%20storage%20process

Figure 5. Levelized fixed cost of capacity (left, in \$/kW-yr) and of discharge energy (right, in \$/MWh).[30]



3.3 Storage Potential Value Streams

Energy storage can provide a range of high-value services to the grid. These services result in various value (revenue or cost-saving) streams depending upon siting, sizing, market products and prices. Value streams can also differ by market segment and co-location with renewables. Challenges can include both monetizing these value streams and forecasting their potential future value. The cost-benefit analysis for this study focuses on several key value streams (which are described in more detail in Section 3.3.2) including ancillary services, arbitrage in the energy market and shifting renewable generation, peaking capacity and generating capacity deferral, local capacity and distribution deferral, retail bill savings, and resiliency benefits.

Each of these value streams are driven by fundamental market dynamics that are evolving as more intermittent renewables are brought online, given both improving economics and renewable energy targets. Storage can help to balance intermittent renewables nearly instantaneously as well as smooth renewable power output throughout the day to better align with customer demand patterns. Further, it can provide peaking capacity that is becoming increasingly cost-competitive with gas-fired resources, service constrained areas on the grid and provide increased reliability and cost savings for customers.

Reporting from the Energy Information Agency (EIA), as shown in Table 7 below, reveals that ancillary services (primarily frequency regulation and spinning reserves) lead the way in terms of applications for battery storage today, followed by excess wind and solar generation and energy arbitrage.

[30] Costs do not include charging costs. Costs per kWh of discharge energy assume a 10% - 15% capacity factor, depending on technology; actual capacity factors will depend on use case and market dynamics.

Table 7. Battery Storage Applications Reported by Owners in the U.S., 2019 vs 2020

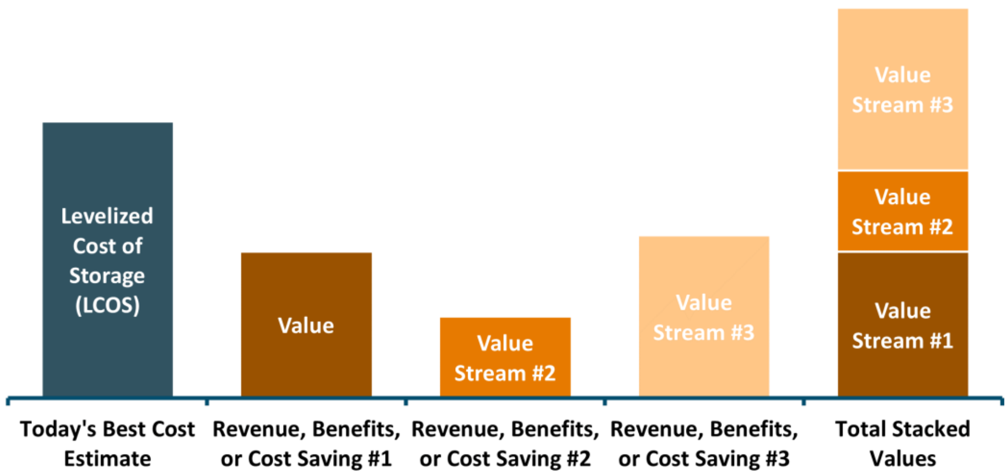
Application	2019 Total Capacity (MW)	2019 Percent of Reporting Capacity	2020 Total Capacity (MW)	2020 Percent of Reporting Capacity
Frequency Regulation	742	73%	759	42%
Ramping / Spinning Reserve	199	20%	594	33%
Excess Wind and Solar Generation	163	16%	546	30%
Arbitrage	165	16%	537	29%
Load Following	112	11%	409	22%
Load Management	97	10%	390	21%
System Peak Shaving	193	19%	229	13%
Voltage or Reactive Power Support	144	14%	170	9%
Backup Power	58	6%	1,091	6%
Co-Located Renewable Firming	77	8%	88	5%
Transmission and Distribution Deferral (e.g. nonwire alternatives)	35	3%	51	3%

3.3.1 Value Stacking

Some of these services (and value streams) are mutually exclusive; others can be "stacked" and performed either at the same time or with the same resource at different times but optimized for maximum value. This flexibility is especially important as the electric system evolves to become more decarbonized, decentralized and complex.[31] For example, energy storage might not be able to provide system and local distribution capacity at the same time if two peaks are close and there is not enough time for energy storage to charge between them, nor can they operate simultaneously in the energy market for arbitrage and the ancillary services market for regulation or spinning reserves. Ultimately, the type, number and value of services that storage can provide are likely to change as the needs of the system change and storage technology advances. Optimizing among these various services will be important and an individual storage project's value proposition hinges on multiple potential value streams, therefore value stacking is essential.

[31] This complexity will likely take the form of a system with two-way power flow characterized by more renewable, intermittent energy; increasing diversity of end-uses and customer preferences; and increased beneficial electrification of the heating and transportation sector.

Figure 6. Example of Stacking Value Streams in the Wholesale Energy and Ancillary Services Markets



3.3.2 Key Value Stream Types

Ancillary services are needed for short-timescale grid balancing and storage is well-suited to provide these services due to its near-instant response time and is expected to outcompete most gas-fired resources. Further, storage resources can be optimized between operation in the wholesale energy market and providing ancillary services. This study includes two ancillary services market products, 10-minute spinning reserves and regulation capacity.[32]

Peaking capacity can be another value stream for storage resources. Load growth and legacy plant retirements are driving needs for new generating capacity. Declining costs are resulting in storage becoming increasingly cost competitive with fossil-fired peakers and ISO-NE's forward capacity market provides a means to monetize storage's capacity capability. However, Maine is currently in a discount region for capacity given export constraints to the rest of the New England system given its current transfer limits to other regions relative to its current and expected generating resources. And lastly, the evolution of capacity crediting for storage is something that should be monitored and will have a key bearing on how storage can realize its capacity value stream. As past analysis[33] performed by E3 has shown, given its energy-limited status, storage shows a diminishing value to provide peak capacity as its

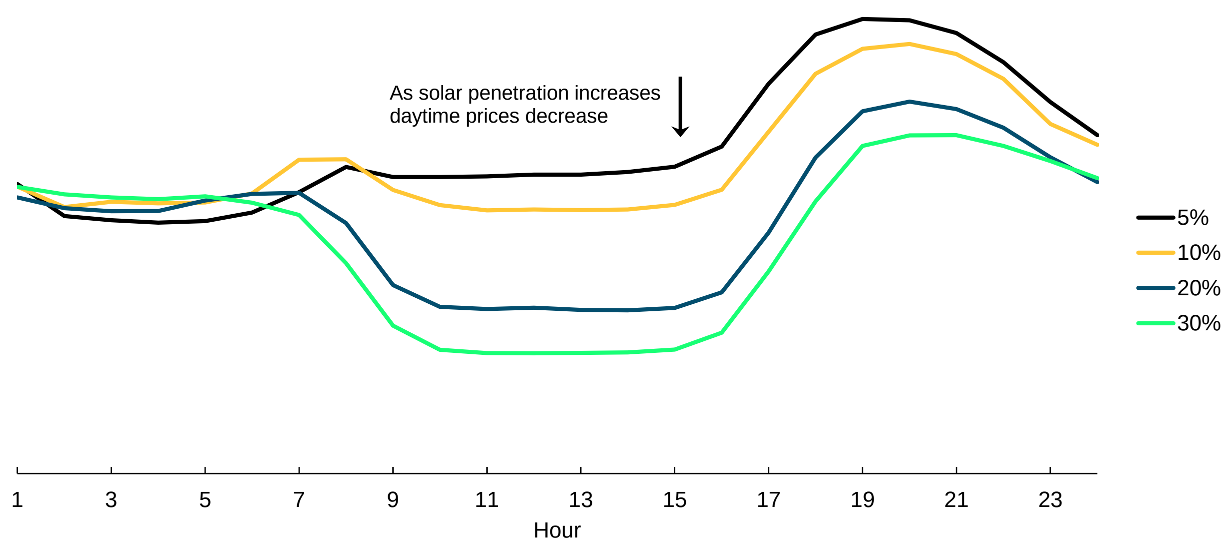
[32] Spinning reserves are online and synchronized to the grid and can start generating within a specified amount of time (e.g. 10 minutes, 30 minutes). Regulation capacity requires units to regulate power system frequency by adjusting their generation/consumption output level after receiving the automatic generation control signal. "Glossary and Acronyms," ISO-NE, accessed February 14, 2022, https://www.iso-ne.com/participate/support/glossary-acronyms.

[33] "Capacity and Reliability Planning in the Era of Decarbonization," Energy and Environmental Economics, Inc., accessed on February 26, 2022, https://www.ethree.com/wp-content/uploads/2020/08/E3-Practical-Application-of-ELCC.pdf

penetration increases. ISO-NE is currently undergoing a key project where it is exploring how to modify its rules for resource capacity accreditation in the forward capacity market.

Energy arbitrage, which is charging during low-priced hours and discharging during high priced hours, is expected to become increasingly important as intermittent renewable generation (especially solar) increases in penetration and drives down the energy price in hours with the higher renewable generation. In the case of solar, increased penetration will impact power price shapes and will lead to more storage charging in the daytime and more discharge in shoulder and nighttime hours. Responding to price signals that align with renewable output will also allow renewable resources to be more optimally used and will reduce curtailment.

Figure 7. Illustrative Example: Hypothetical Pattern of Daily Energy Prices as a Function of Solar's Share of Total Generation[34]



T&D deferral can be an important application for storage deployments. In Maine, there is a requirement for a Non-Wires Alternative (NWA) Coordinator to review transmission projects and evaluate whether NWAs would be cost-effective to pursue in lieu of the grid investment. Although E3 sees opportunities for T&D deferral to be more limited in contributing to Maine's storage goals given it is highly site-specific and the need to be handled as a one-off procurement, it is an important tool to limit new and potentially expensive line investments and upgrades, and will become increasingly important with greater electrification.

Retail bill savings are an important value stream for BTM storage customers, and depending on rate structures can manifest itself through demand charge savings or energy charge savings. Demand charge savings are designed to capture costs required to maintain system capacity and are allocated based on a

[34] The left-hand axis is purposely excluded/not labeled given the illustrative nature of this graphic.

customer's peak demand. Therefore, they vary by customer load profile, the length of the peak period window in the rate structure and the duration of the storage asset. Energy charge savings vary by rate structure and are largely independent of a customer's load shape.

Emission reductions can be an important value stream if price signals are aligned properly. Emission reductions can be achieved through storage operations by charging when marginal emissions of the charging generation are lower than when discharging. And in the longer term, storage can indirectly lead to more emission reductions by allowing more renewables on the system, further lowering emissions.

Resiliency can be an important value stream for customer-sited storage as storage can provide uninterrupted power during system outages. In this study, resiliency is quantified by using historical outage rates and a value of lost load (VOLL). The value of lost load attempts to capture economic losses associated with power outages, but there can be quite a range given this can vary based on customer type, the duration of outage and its location.

3.4 Use Cases

Value streams can be "stacked" to create different use cases, which often vary by market segment and whether storage is paired with a renewable resource (often solar). Below are three such use cases.

- **Wholesale storage**: Storage that participates in wholesale markets is also referred to as front-of-the-meter (FTM) storage. These storage resources can generate revenues through energy arbitrage (charging during low-priced hours and discharging during high-priced hours), as well as by participating in frequency regulation and spinning reserve markets. These resources can also participate in the ISO-NE forward capacity market.
- **Customer-sited storage for commercial and industrial (C&I) customers:** C&I customers often turn to storage to take advantage of bill savings, in addition to providing backup power. Customer-sited storage is also referred to as behind-the-meter (BTM) storage. C&I rates often include a demand charge, which is a charge applied to the highest power demand during any given month, which may vary by time-of-use (TOU) period. Storage can be used to offset high customer demand during peak TOU hours thereby reducing the customer's electricity bill.[35]
- **Customer-sited storage for residential customer:** This use case is similar to customer-sited C&I storage, except that storage is sited with a residential customer who faces a different rate structure. Residential rates are generally energy rates and may vary by TOU period. Charging storage in off-peak TOU hours and discharging in peak hours can provide bill savings to a residential customer.

Each of these use cases can be configured as a standalone system or can be paired with a solar system. Pairing with solar allows storage to take advantage of the federal investment tax credit (ITC), as well as construction cost savings. However, the requirement for the ITC that a storage unit must be charged by solar generation may lead to less optimal operation to generate energy arbitrage revenue (for wholesale

[35] As a result of tariff changes in response to FERC Order 2222, distributed energy resources (including energy storage) will be able to participate in wholesale markets through aggregation, which could also be a consideration for use cases for customer-sited storage later in the decade.

applications) or bill savings (for customer-sited applications). It may also be more difficult for a paired resource to participate in ancillary services markets.

These uses cases, as well as with and without solar, are the basis of the scenarios assessed in the cost-benefit analysis.

3.5 Other Considerations for Storage Deployment

3.5.1 Permitting & Interconnection

Permitting for energy storage systems is site- and project-specific and may involve local, state, and federal agencies. Additional permitting will usually be required if storage is also co-located with renewables. Permitting for larger storage projects often includes requirements for interconnection, electrical design, signage, lighting, vegetation management, noise, and decommissioning.

Interconnection is often a barrier to storage development. In ISO-NE's 2021 Regional System Plan (RSP), the ISO's Interconnection Request Queue included 5.35 GW of battery storage requests across New England, but the ISO reports that it is "unlikely that all resources seeking interconnection will be built"; among other reasons, projects will often submit multiple interconnection requests for a single project and ultimately withdraw all but one.[36] Conversations with developers suggest that multiple interconnection requests are often submitted to increase chances of one of the requests going through in a timely manner.

3.5.2 Decommissioning, Disposal, and Recycling

At the end of the storage system life, equipment must be dismantled, with the location returned to a brownfield or greenfield state. Specific decommissioning plans and/or funds may be required at the time of permitting, particularly for mechanical systems such as compressed air or pumped hydro energy storage which may impact the natural environment in which they are sited. Other technologies, such as batteries, are more contained and therefore easier to dismantle and remove with fewer impacts to the natural environment.

Proper disposal and recycling of energy storage equipment, particularly batteries, at end-of-life needs to also be considered. The U.S. Environmental Protection Agency (EPA) highlights the need for proper disposal and recycling of Li-ion batteries both because they can be hazardous if not properly disposed, and because of the economic and strategic importance of the critical minerals that they contain.[37] Only about half of Li-ion batteries were recycled world-wide in 2019, though interest in battery recycling has grown as battery use, particularly as the use of EVs and stationary energy storage continues to increase.[38] While the majority of battery recycling (as well as production) occurs overseas today, in early 2022 the

---

[36] "2021 Regional system plan," ISO New England, 2021, https://www.iso-ne.com/system-planning/system-plans-studies/rsp/

[37] "Used lithium-ion batteries," US EPA, 2021, https://www.epa.gov/recycle/used-lithium-ion-batteries

[38] "Lithium-ion battery recycling finally takes off in North America and Europe," IEEE Spectrum, 2021, https://spectrum.ieee.org/lithiumion-battery-recycling-finally-takes-off-in-north-america-and-europe

U.S. Department of Energy issued two notices of intent to provide $2.91 billion for domestic battery production, including for recycling facilities.[39]

3.5.3 Safety

Codes, standards, and regulations continue to evolve to ensure the safety of energy storage systems.[40] Equipment installation and operations and maintenance must follow all regulations as well as manufacturers' instructions. For batteries, although rare, there is a risk of fire which can be prevented through proper detection methods, testing, fuses and inverter projection, and proper coordination with equipment suppliers. Other hazards include high heat release, flammable gases, toxicity, and stranded energy.[41] A safety emphasis should be placed on incident preparedness and employee training, and like all energy infrastructure, cyber security should also be addressed.

3.5.4 Land Use

Land-use considerations for energy storage systems depend largely on the energy density of the storage technology, as well as specific geographic and geologic requirements for some types of storage. Pumped hydro and compressed air energy storage are at the lower end of energy density, in the single-digit watt-hour (Wh)/kg figures, while lithium-ion batteries may be 100 – 200 Wh/kg. Other battery technologies such as flow batteries are somewhere in between. High energy density generally improves siting flexibility and reduces land-use.

Pumped hydro and compressed air energy storage also require specific geographies and geological formations, significantly limiting the number of viable sites. Environmental considerations can make siting and permitting challenging. These projects are very site-specific and require significant long-term investments which allow for long permitting and construction timelines.

3.6 Barriers to Storage Deployment Today

Several barriers exist to storage deployment today. This project has identified and assessed the following barriers today to storage deployment in Maine:

+ **Rate designs:** Rate designs are not always structured to recognize the variation in the cost of electricity generation to incentivize Maine storage to charge when electricity is low cost and discharge during higher cost/peak periods. Similarly, high demand charges associated with current storage classification also make projects less attractive. Further, rate designs are not

---

[39] "Biden Administration, DOE to Invest $3 Billion to Strengthen U.S. Supply Chain for Advanced Batteries for Vehicles and Energy Storage," US Department of Energy, 2022, https://www.energy.gov/articles/biden-administration-doe-invest-3-billion-strengthen-us-supply-chain-advanced-batteries

[40] "Draft Storage/Stationary Batteries Standards List," UL, https://www.sandia.gov/ess-ssl/docs/Stationary_Batteries_Standards_List_UL_4-1-14.pdf

[41] "Fire Safety," NYSERDA, 2021, https://www.nyserda.ny.gov/-/media/Files/Programs/Energy-Storage/BESS-Fire-Safety-Webinar-presentation.ashx

always structured to align with societal avoided costs, including emissions, as well as locational values, diluting the benefits that storage can provide. Lastly, as mentioned by several stakeholders throughout the study process, storage resources that are located on the distribution system but participating in the wholesale market are often assessed the retail rate for their charging energy, as opposed to the wholesale rate, which is a key barrier to their deployment.[42]

+ **Storage costs:** While the costs of energy storage have declined about 10 to 15 percent per year, building batteries is still too expensive today to allow scale in many use cases today, especially when not factoring in local policy programs and requirements. This is coupled with high soft costs, including permitting, siting, interconnection, and financing. These economics are evident in the modeling results provided later in the report.
+ **Inability and uncertainty to access certain market revenue streams**: Today, wholesale market rules and tariffs are not designed to provide storage with compensation for all potential services and benefits that storage may provide the system. With the implementation of FERC Order 841 and Order 2222, this barrier is being addressed through ongoing market reforms. That said, until those changes are implemented and developers have greater certainty about the revenue streams available to them, this will remain a barrier to projects.
+ **Transmission constraints:** Today, multiple zones exist in Maine with transmission constraints,[43] limiting the ability to develop additional renewable resources, adequately serve load outside the state, and obtain capacity revenue. Increased access to broader markets through additional transmission, which perhaps would remove the ability for storage to help alleviate local congestion, would allow storage to increase its revenue potential across different zones in the state and increase benefits to the broader regional system.
+ **Market revenue uncertainty**: Today, much of the value for wholesale level storage stems from the ancillary services markets. However, those markets are often viewed as thin and can saturate in the coming years. This, along with challenges for capacity revenue, may place a higher emphasis on revenue from energy arbitrage which is subject to uncertain market factors (fuel prices, future electrification and demand, renewable penetration).
+ **Difficulty identifying the best sites for locating storage:** Lack of good data surrounding the distribution and local system constraints, as well as proper customer class load data, hinders the ability for developers to identify the best locations to site storage to maximize system benefits, as well as identify customers who would most benefit from energy storage.

3.7 Additional Storage Use Cases

This section discusses other potential use cases for energy storage, which were not the focus of this study.

[42] As mentioned in the previous section, wholesale storage modeled in the cost-benefit analysis is assumed to be located on the transmission system and therefore does not address this specific barrier identified by stakeholders.

[43] "Resolve, To Study Transmission Solutions To Enable Renewable Energy Investment in the State," State of Maine Governor's Energy Office, accessed on February 25, 2022, https://www.maine.gov/energy/sites/maine.gov.energy/files/inline-files/LD1401_Transmission_Renewable_Energy%20Study_Stakeholder%20Report.pdf

3.7.1 Microgrids

An emerging solution to the challenge of ensuring resilient power systems under deep decarbonization is microgrids. The Department of Energy defines microgrids as a combination of loads and distributed energy resources with clearly defined boundaries, which can act as a single controllable entity and can connect and disconnect from the grid to operate as either grid-connected or islanded.[44] Microgrids can improve energy system resilience by enabling independent operation from the grid. Storage is typically a critical component in microgrid projects.

For islands in Maine in particular, microgrids with energy storage may successfully contribute to Maine's storage goals while helping to reduce outage events during weather events. In Maine, pilot projects such as the ongoing research at Isle au Haut demonstrate the value of this type of solution in certain locations in Maine.

3.7.2 Long-Duration Energy Storage

Long-duration energy storage technologies may support New England's need for clean, firm power generation in a deeply decarbonized future. Firm capacity is capacity that can provide electricity on demand and operate as long as needed. In New England today, natural gas and nuclear are key sources of firm capacity. In the future, new emerging long-duration energy storage technologies could also support the region's firm capacity needs. While there isn't a single definition for long-duration energy storage, it often refers to technologies designed to shift generation on scales longer than ten hours. This technology can help move power from times with more abundant renewable generation to periods of prolonged low wind and solar production (e.g., cold winter snaps). This could help support some of the firm capacity required within the region as it achieves high levels of decarbonization.

A range of potential long-duration energy storage technologies, including several from Section 3.2 (e.g., pumped hydro, flow batteries, CAES, iron-air batteries, or combustion-based hydrogen generation discussed below), have the potential to provide longer-duration energy storage, particularly beyond 2030 as regional carbon targets become stricter and projects move beyond demonstration and pilot phase. While today no long-duration storage technology is widely and commercially available that has significant new resource potential, there are an increasing number of promising demonstration-scale projects across the U.S.[45]

3.7.3 Hydrogen as Long-Duration Energy Storage

Hydrogen has the potential to provide New England with zero- or low-carbon dispatchable generation or long-duration energy storage, particularly beyond 2030 as regional carbon targets ratchet down and the

[44] "The U.S. Department of Energy Microgrid Initiative," The U.S Department of Energy, access on February 16, 2022, https://www.energy.gov/sites/prod/files/2016/06/f32/The%20US%20Department%20of%20Energy's%20Microgrid%20Initiative.pdf

[45] We note that pumped hydro and CAES are considered long-duration by some definitions but are not likely deployable solutions in Maine.

costs of hydrogen production technologies fall. The use case for hydrogen in the power sector involves its ability to be produced from low or zero-carbon pathways, stored in pipes, tanks or underground storage, and then combusted in gas turbines to balance renewable generation on a multi-day or seasonal scale. Hydrogen could in particular provide zero- or low-carbon energy during periods of sustained low renewable output. The ability to rely on hydrogen or another form of zero- or low-carbon dispatchable generation or long duration energy storage could enable the power sector to avoid costly investments in large amounts of renewables and batteries, and it may lower the costs of achieving a deeply decarbonized grid, as numerous studies across North America, including in New England, have demonstrated.[46]

That said, the future role of hydrogen in North America, including Maine, is highly uncertain today, and depends on several factors, including falling hydrogen production costs and the development of a hydrogen market and supply chain. It also relies on the U.S., and Maine in particular, committing to near-complete power sector decarbonization, as hydrogen is unlikely to be required until the U.S. reaches very high decarbonization levels.

Another opportunity for zero- or low-carbon fuel is renewable natural gas (RNG). This is the focus of a recent DOE-funded pilot project in Maine which uses RNG produced from organic waste from dairy farms, combined with green hydrogen produced from renewables (primarily wind). This zero- or low-carbon natural gas can be used directly in the natural gas distribution system.[47]

3.7.3.1 Potential Hydrogen Production Pathways and Costs in Maine

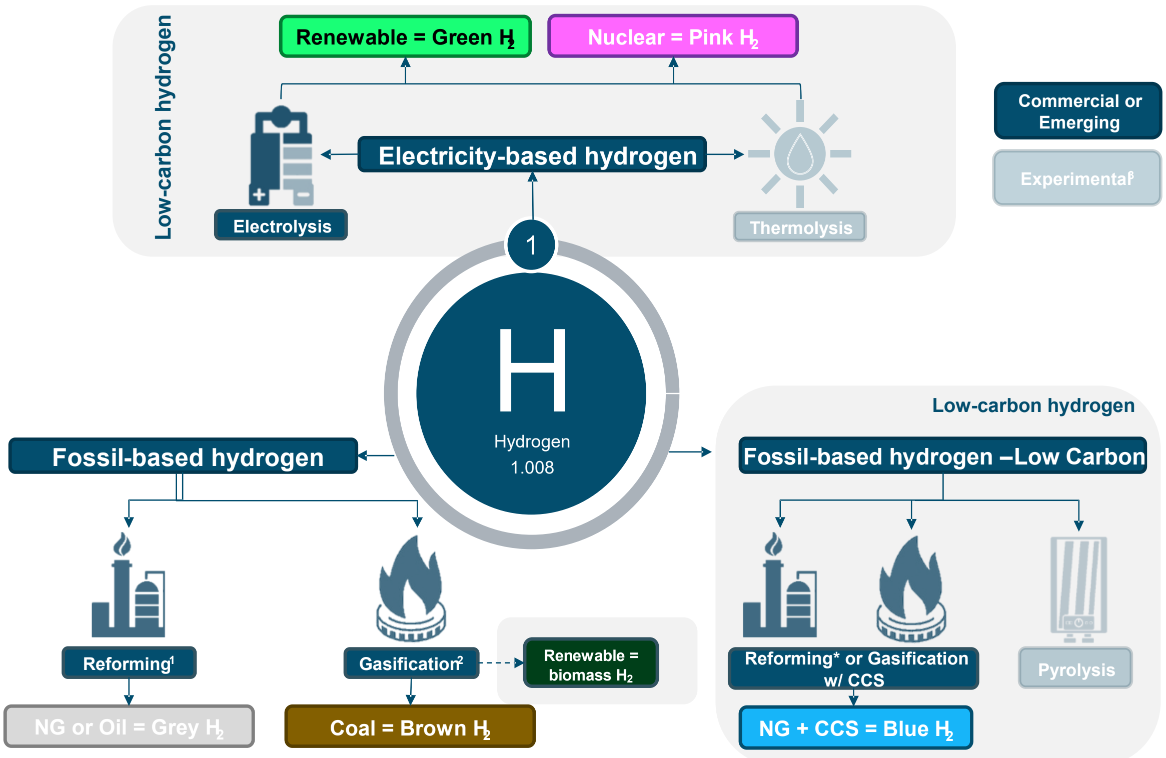
Hydrogen can be produced through several different pathways. The vast majority of hydrogen made in the U.S. today is via steam-methane reforming, which uses natural gas ("grey hydrogen" in Figure 8 below). However, most of the policy focus is on hydrogen created with zero-carbon resources: pink (produced from water via electrolysis using nuclear energy) and green (produced from water via electrolysis using renewable energy). These various production pathways are provided in Figure 8 below.

---

[46] Example studies include: (a) Sepulveda, N. A., Jenkins, J. D., de Sisternes, F. J., & Lester, R. K. (2018). The role of firm low-carbon electricity resources in deep decarbonization of power generation. Joule, 2(11), 2403-2420. (b) E3. Resource Adequacy in the Pacific Northwest. 2019. https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf. (c) Dowling, J. A., Rinaldi, K. Z., Ruggles, T. H., Davis, S. J., Yuan, M., Tong, F., Lewis, N. S. & Caldeira, K. (2020). Role of long-duration energy storage in variable renewable electricity systems. Joule, 4(9), 1907-1928. (d) E3. Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future. 2020. https://www.ethree.com/wp-content/uploads/2020/11/E3-EFI_Report-New-England-Reliability-Under-Deep-Decarbonization_Full-Report_November_2020.pdf. (e) Long, J. C., Baik, E., Jenkins, J. D., Kolster, C., Chawla, K., Olson, A., Cohen, A., Colvin, M., Benson, S. M., Jackson, R. B., Victor, D. G., & Hamburg, S. P. (2021). Clean Firm Power is the Key to California's Carbon-Free Energy Future. Issues in Science and Technology. https://issues.org/california-decarbonizing-power-wind-solar-nuclear-gas/. (f) Sepulveda, N. A., Jenkins, J. D., Edington, A., Mallapragada, D. S., & Lester, R. K. (2021). The design space for long-duration energy storage in decarbonized power systems. Nature Energy, 6(5), 506-516.

[47] "Renewable Power-to-Gas: A technical feasibility and market demonstration of biomethanation as a means for biogas upgrading and renewable natural gas production," Summit Utilities Inc, 2021, https://www.energy.gov/sites/default/files/2021-09/2396-1505_Summit_Utilities_Inc_Summary.pdf

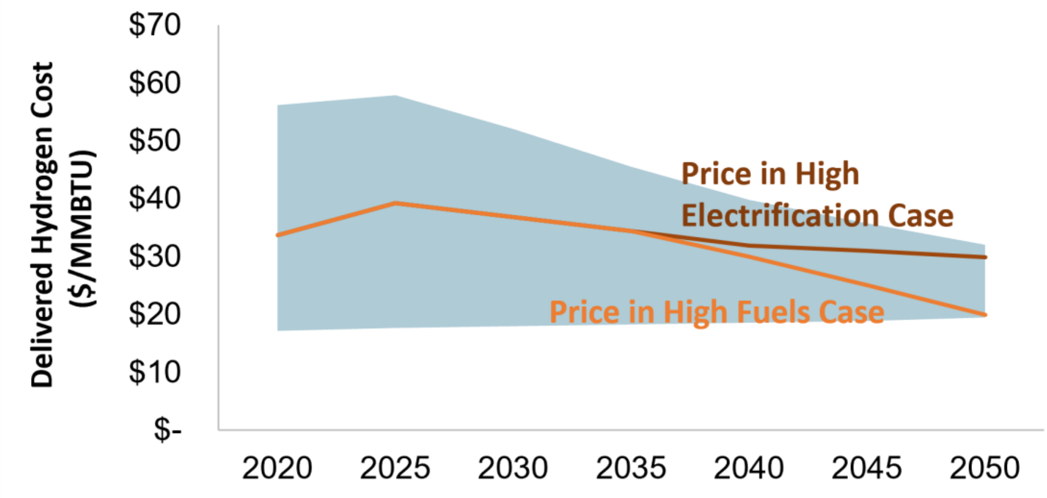
Figure 8. Hydrogen Production Pathways



[1]Includes catalytic reforming, SMR, ATR, and POX
[2]Hydrogen through gasification can be derived from bio feedstocks. This would be considered low-carbon hydrogen.
[3]There are multiple theoretical and experimental ways to break apart hydrogen. This overview includes commonly cited methods

Based on E3's existing work in New England and the current nascent state of hydrogen markets, E3 anticipates that hydrogen to serve the New England market at scale is likely to be produced outside New England and delivered via pipeline, given that New England lacks underground geologic storage and tank-based storage is significantly more expensive. E3 did not develop new hydrogen production costs for this study. Based on an internal analysis of hydrogen production costs that reflect currently available technologies, projected market development for future production pathways, and delivery and storage costs, existing E3 research estimated a range of delivered hydrogen costs for the New England region. This range in costs can be seen in Figure 9 below. At these costs, and given low current carbon pricing, hydrogen is not commercially competitive with alternative fuels (primarily natural gas) today, though it may be valuable to the region as it approaches mid-century.

Figure 9. Estimated Hydrogen Delivery Cost Range Across Potential Possible Production Pathways ($/mmbtu), Based on E3's 2020 Net-Zero New England Study [48]



Note: The figure above, developed as part of E3/EFI's Net Zero New England study, provides a range of potential hydrogen costs based on currently available technologies, projected market development of future production pathways, and delivery and storage costs. The "High Electrification Case" reflects a potential price trajectory for New England under a future in which the region pursues aggressive electrification. The "High Fuels Case" reflects a future in which a more robust economy-wide hydrogen market emerges. We note that these scenarios were not used in this particular study but are shown to indicate how price trajectories may evolve in the region.

[48] The hydrogen costs shown in this figure reflect multiple potential hydrogen production approaches and locations that could be used to produce hydrogen for use in New England: Pennsylvania onshore wind, Canadian hydro, and offshore wind. In all cases we assume a dedicated pipeline would transport hydrogen to New England from its origin. The price may be influenced by the size of the hydrogen market, hence the curves show how the hydrogen price could evolve under a range of futures. "Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future," Energy and Environmental Economics Inc and Energy Futures Initiative, 2020, https://www.ethree.com/wp-content/uploads/2020/11/E3-EFI_Report-New-England-Reliability-Under-Deep-Decarbonization_Full-Report_November_2020.pdf

4 Modeling Approach

This study evaluates the costs and benefits of energy storage deployment in Maine over the next decade for a selected set of scenarios. In this section, we describe the scenarios, modeling approach, key assumptions, and the limitations associated with this analysis.

4.1 Scenario Development

The model analyzes outcomes for storage scenarios that reflect different use cases within the state to help assess the economics of storage in the near-term and inform the state's understanding of how Maine's 2025 and 2030 storage deployment targets may be achieved. The model focuses on the economics of storage built this decade given Maine's 2030 storage target, and focuses on Li-ion batteries as the storage technology given the evaluation criteria noted below. That said, E3 is not endorsing Li-ion batteries as the sole storage technology that should be deployed in Maine. The evaluation criteria includes:

+ Ability to provide high-value services in the near-term
+ Maturity and commercial availability
+ Low costs or cost reduction potential
+ Able to be commercially deployed in Maine within the study period (2022-2031)

Based on the evaluation criteria, E3 modeled Li-ion battery storage under six different use case scenarios[49]:

+ Wholesale standalone storage
+ Wholesale storage + solar
+ Customer-sited standalone storage for C&I customer
+ Customer-sited storage + solar for C&I customer
+ Customer-sited standalone storage for residential customer
+ Customer-sited storage + solar for residential customer

A high-level description of the use cases was provided in Section 3.4, with additional modelling details included in the following sections. For brevity, "customer-sited" systems are sometimes referred to as BTM ("behind-the-meter") systems. A summary of the value streams for each use case from the storage-owner's perspective is shown in Table 8.

[49] While this study scope was limited to the use case scenarios above, other storage technologies could be modeled under a similar cost-benefit analysis framework. For other storage technologies this would mean an update of their costs, operating parameters, and value streams they can access given their flexibility and configuration.

Table 8. Summary of study use cases and associated value streams from the participant perspective

Use Cases	Wholesale Energy	Spinning Reserves	Regulation	Capacity	Energy Bill Savings	Demand Charge Bill Savings	Resiliency
Wholesale Standalone	✓	✓	✓	✓			
Wholesale Storage+Solar	✓			✓			
BTM C&I Standalone						✓	✓
BTM C&I Storage+Solar						✓	✓
BTM Residential Standalone					✓		✓
BTM Residential Storage+Solar					✓		✓

4.2 Cost-Benefit Analysis Perspectives

Storage deployment will generate distinct costs and benefits to participants, ratepayers, and society. This study evaluates these different perspectives for each of the alternative storage deployment scenarios studied. This will enable Maine to not only understand the aggregate impact of storage on the state but will also provide information about how different parties experience costs and benefits, which can inform the design of policy and programs.[50] Specifically, this study focuses on the following economic cost-effectiveness tests:

- **Participant Cost Test (PCT)**: What are the costs and benefits of storage deployment to the asset owner over the lifetime of the investment?
- **Societal Cost Test (SCT):** What are the costs and benefits of storage from the perspective of society? In other words, does storage provide net benefits to Maine? Note that this includes considerations of non-embedded CO_2 emission costs based on an assumed social cost of carbon, and this test assumes the participant is included in society.
- **Ratepayer Impact Test (RIM):** How will the storage investment affect (increase or decrease) average electricity rates?

[50] Given the limited timing and scope of this assessment, a more robust distributional analysis or analysis of the economic impacts of storage deployment was not included.

The approach to evaluating costs and benefits from these different perspectives is based on well-established economic guidance and has been used to evaluate nationwide benefits and costs for DERs.[51] The approach also reflects the standard practice for implementing cost-effectiveness tests in many states, for example the California Standard Practice Manual.[52]

The PCT test is designed to evaluate storage from an asset-owner perspective. Thus, benefits to participants/asset owners may reflect wholesale market revenues, or the retail electricity bill savings and resiliency value from storage providing an uninterruptible power supply (if applicable). Alternately, the SCT represents the impacts from the state of Maine's perspective: the net costs of storage deployment to developers and the effects of environmental externalities, such as the social cost of carbon to reflect the avoided risk of climate damages. Finally, the RIM test evaluates the benefit/costs on non-participating ratepayers by comparing the bill savings of storage owners, a cost which must be borne by all other ratepayers, to the benefits of storage in terms of avoided system costs. Table 9 below details how different cost and benefit streams are reflected within each cost test.

All cost tests look at the costs and benefits over the system lifetime, taking the net present value (NPV) in the installation year of annual revenues using a real discount rate of 5%. Cost test results are reported in levelized terms (dollars per kilowatt-year, $/kW-yr), again over the system lifetime.

The results of the different cost tests will inform the policy discussion related to how the state may encourage storage deployment.

---

[51] "Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy-Makers," Environmental Protection Agency, 2008, https://19january2017snapshot.epa.gov/sites/production/files/2015-08/documents/understanding_cost-effectiveness_of_energy_efficiency_programs_best_practices_technical_methods_and_emerging_issues_for_policy-makers.pdf

[52] "California Standard Practice Manual: Economic analysis of demand-side programs and projects," California's Office of Planning and Research & California Measurement Advisory Council, 2001, https://www.cpuc.ca.gov/-/media/cpuc-website/files/uploadedfiles/cpuc_public_website/content/utilities_and_industries/energy_-_electricity_and_natural_gas/cpuc-standard-practice-manual.pdf

Table 9. Benefits and costs of storage associated with different cost test perspectives[53]

Cost Test:		PCT	RIM[54]	SCT
Revenue Stream / Perspective		*Participant*	*Ratepayer*	*State*
Participant Storage Costs	Capital Costs	Cost		Cost
	Interconnection Costs	Cost		Cost
	Fixed O&M Costs	Cost		Cost
	Warranty & Augmentation Costs	Cost		Cost
Participant Incentives	Federal Incentives	Benefit		Benefit
	State Incentives	Benefit		Cost
	Utility Incentives	Benefit	Cost	
Participant Revenues	Bill Savings - Energy Imports	Benefit	Cost	
	Bill Savings - Demand Charges	Benefit	Cost	
	Resiliency	Benefit		
	Wholesale Energy Revenues	Benefit		
	Spinning Reserve Revenues	Benefit		
	Regulation Revenues	Benefit		
	Capacity Revenues	Benefit		
Electricity System Avoided Costs	Avoided Energy Supply Cost		Benefit	Benefit
	Avoided Capacity Cost		Benefit	Benefit
	Avoided T&D Cost		Benefit	Benefit
	Avoided Local T&D Cost		Benefit	Benefit
	Avoided Emissions Cost			Benefit

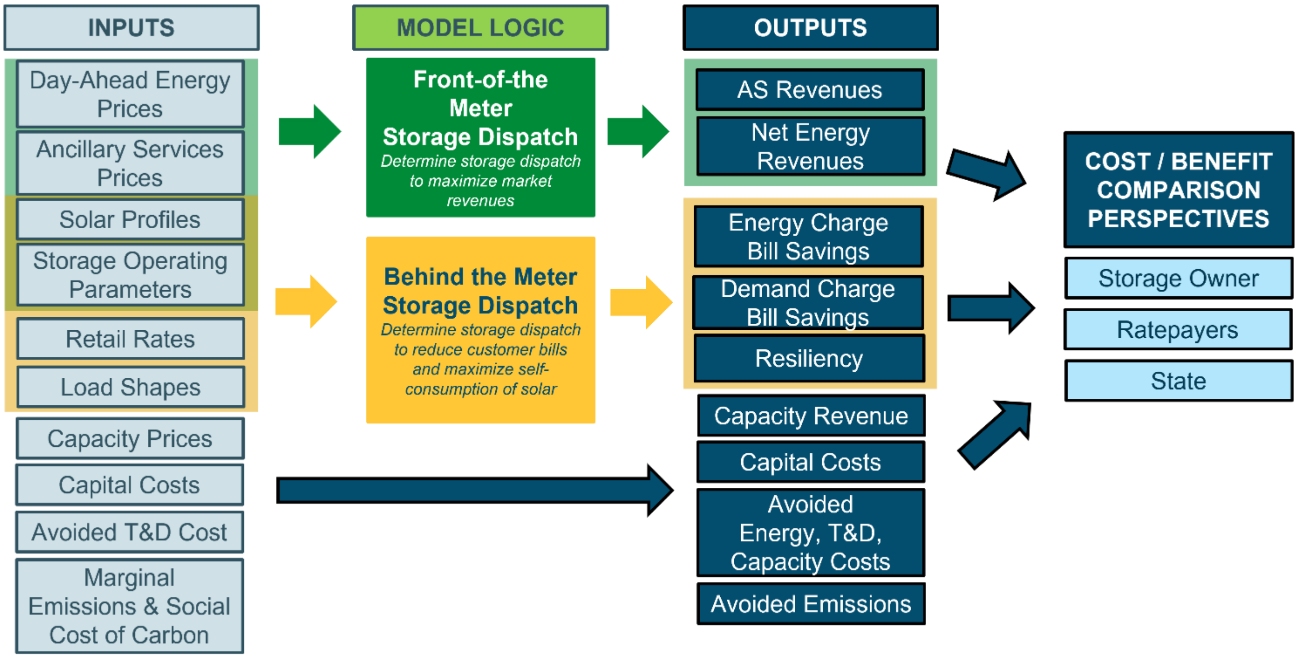
4.3 Cost-Benefit Analysis Model

To evaluate the economics of storage deployment, E3 built a detailed and transparent model to estimate the costs and benefits; an overview of the model is shown in Figure 10. At its core, the model relies on simplified dispatch algorithms to determine the potential revenue streams under different use cases. The total revenues, costs, and system avoided costs are then calculated on an annual and levelized lifetime basis to quantify costs and benefits from the participant, ratepayer, and societal perspective, as discussed in the previous section. The following subsections describe the modeling of each scenario, with further details on each of the inputs provided in Section 4.4.

[53] There are several potential value streams that cannot be quantified given the scope of this project and the availability of data. These are discussed conceptually in Section 3 and qualitatively in the results in Section 5.

[54] For wholesale storage, there are no net impacts to ratepayers (assuming storage remains a price-taker) so this test is excluded in the results that follow.

Figure 10. Modeling schematic



4.3.1 Wholesale Standalone Storage

For wholesale standalone storage applications, dispatch is based on day-ahead energy prices, where storage charges in the cheapest hours and discharges in the most expensive hours. Ancillary services are also included in the revenue stack. The battery is assumed to be available for spinning reserves when the battery is neither charging nor discharging for energy arbitrage. A daily decision is then made between the total revenue from energy arbitrage + spinning reserves and net regulation revenues, with the higher value revenue stack chosen for each day. Storage is also assumed to be eligible for and receive capacity payments.

4.3.2 Wholesale Storage + Solar

When a wholesale storage + solar hybrid system is modeled, the same dispatch assumptions are made as for standalone storage, except that the hybrid system is constrained to only charge from solar. The system has been modeled this way to reflect the requirement for ITC eligibility that storage must charge from solar.[55] Given operating limitations when charging restrictions are in place, it is assumed that wholesale storage + solar will not participate in ancillary services. As with standalone storage, wholesale storage + solar is assumed to be eligible for and receive capacity payments.

---

[55] Although eligibility for the ITC only requires charging with solar during the five-year vesting period, this requirement was assumed over the life of the storage resources for modeling simplicity and results clarity.

4.3.3 Customer-Sited Standalone Storage

Customer-sited standalone storage is charged during off-peak TOU periods and dispatched to offset load during peak TOU periods. It is assumed that customer-sited storage cannot export to the grid. As discussed in the section on Retail Rates, residential customers are assumed to have a volumetric TOU rate, where C&I customers are assumed to have a single volumetric rate with a TOU-period demand charge. To improve dispatch when there is a demand charge, the maximum discharge power in each timestep is limited such that the battery will discharge equally in all peak period hours, a simplified modeling assumption. However, because the C&I customer load is relatively flat, the bill savings that are not captured should be limited.

4.3.4 Customer-sited Storage + Solar

When a customer-sited storage + solar hybrid system is modeled, it is assumed to charge only from solar to be eligible for the ITC. Like customer-sited standalone storage, this analysis assumes that storage cannot export to the grid. Current Net Energy Billing (NEB) tariffs in Maine are a flat rate, and therefore do not provide opportunity for storage to add value to distributed generation. However, it should be noted that the GEO, through a stakeholder group, is evaluating the NEB program and a potential successor program. Further, the Distributed Generation Stakeholder Group[56] has discussed how this potential future program should encourage storage.

4.4 Key Inputs and Assumptions

This section outlines key inputs and assumptions in the benefit-cost analysis model. Where possible, public data sources were used. Data from the Avoided Energy Supply Costs (AESC) for New England 2021 Report was used for many of the inputs, and the AESC Counterfactual 1 in particular.[57]

4.4.1 Market Price Assumptions

4.4.1.1 Day-Ahead Wholesale Energy Prices

Energy prices from the AESC are used to set the average monthly on-peak and off-peak energy price forecast. The forecast energy prices from the AESC have significantly less volatility than historical prices, as well as E3's expectations for future market prices. Therefore, normalized hourly price shapes that align with E3's expectations for the Maine zone of the ISO-NE market were used, and were multiplied by the monthly on- and off-peak average AESC prices.

---

[56] "Distributed Generation Stakeholder Group," State of Maine Governor's Energy Office, accessed on February 28, 2022, https://www.maine.gov/energy/studies-reports-working-groups/current-studies-working-groups/dg-stakeholder-group

[57] "Avoided Energy Supply Costs in New England (AESC)," Synapse Energy Economics Inc, 2021, https://www.synapse-energy.com/project/aesc-2021-materials

4.4.1.2 Ancillary Service Prices

Ancillary services (AS), specifically spinning reserves and regulation (called 10-minute sync and regulation capacity in ISO-NE respectively) are a significant source of revenue for storage in the short-term. While the project team was not aware of a public source for AS price forecasts to use in this report, the AS markets are quite shallow (roughly 200 MW for regulation and under 1 GW for spinning reserves). Although AS markets currently provide a premium to wholesale energy markets in many hours, as more storage is brought into the region, which is very effective at providing these services, we expect these markets to saturate quickly. This saturation will lead to declining prices, as well as the limited ability for any specific storage resource to clear the market and obtain those revenues. However, when saturation occurs and at what price is quite uncertain. For this analysis, assumptions for the saturation price and saturation year were made based on E3's internal analysis, as shown in Table 10.

Table 10. Ancillary service saturation price and year assumptions

	Saturation Price	Saturation Year
Spinning Reserves	$1/MWh	2026
Regulation	$4/MWh	2028

4.4.1.3 Capacity Market Prices

Capacity market prices are based on those included in the AESC 2021 report. An Effective Load Carrying Capacity (ELCC) factor is applied to these prices to reflect that storage resources may not be able to get the full capacity price based on their limited energy capacity. These ELCCs are not currently applied to storage in ISO-NE, but there is an ongoing project to assess the need for resource capacity accreditation for the Forward Capacity Market.[58] Based on the expectation that there will be an ELCC applied to storage in the future, ELCC values from the report *Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future* were used, which start at 95% in 2023 and decline over time to 74% in 2050.[59]

4.4.2 Retail Rates

Two retail rates were examined in the customer-sited analysis in this report: Central Maine Power's (CMP) residential time-of-use (TOU) rate, "A-TOU," was applied to the residential customer and CMP's large general service TOU rate, "LGS-S-TOU," was applied to the C&I customer. These rates are detailed in Table 11. Peak periods include weekdays, excluding holidays, from 7am to 12pm and 4pm to 8pm. Shoulder (part-peak) periods are weekdays from 12pm to 4pm. The remaining weekday hours, and all weekend and holiday hours, are considered off-peak.

[58] "Resource Capacity Accreditation in the Forward Capacity," ISO New England, 2022, https://www.iso-ne.com/committees/key-projects/resource-capacity-accreditation-in-the-fcm/

[59] "Electric Reliability under Deep Decarbonization in New England," Energy and Environmental Economics Inc, 2020, https://www.iso-ne.com/static-assets/documents/2020/08/a2_a_efi_e3_presentation_deep_decarbonization2.pdf

Table 11. Tariff components for modeled retail rates[60]

TOU Period		A-TOU Energy [$/kWh]	A-TOU Demand [$/kW-mo]	LGS-S-TOU Energy [$/kWh]	LGS-S-TOU Demand [$/kW-mo]
Summer	Peak	$0.136562	-	$0.007243	$18.13
Summer	Part-Peak	$0.136562	-	$0.007243	$2.86
Summer	Off-Peak	$0.078349	-	$0.007243	-
Winter	Peak	$0.136562	-	$0.007243	$17.66
Winter	Part-Peak	$0.136562	-	$0.007243	$2.39
Winter	Off-Peak	$0.078349	-	$0.007243	-
Fixed Charge ($/month)		$11.24		$614.11	

4.4.3 Customer Load Shapes

Customer load shapes[61] were provided by Efficiency Maine Trust (EMT). The residential load shape was compiled by EMT from over 250 representative households in 20 randomly selected zip codes within CMP and Versant territories. A known limitation of this analysis is that the load shape is averaged across households and is therefore flatter than the load of an individual household. This load shape is scaled to a total annual consumption of 7500 kWh, which results in peak load of approximately 1.6 kW. The C&I load shape is from a large hospital in Maine with a total annual consumption of approximately 14 GWh and a peak load of 2800 kW.

4.4.4 Solar Generation Profiles

Solar generation profiles are from NREL's System Advisor Model (SAM), version 2017.9.5.[62] Maine specific shapes are based on 2011 historical year, with different shapes for wholesale and customer-sited resources.

4.4.5 Avoided Costs

The model quantifies avoided energy and capacity costs based on the energy and capacity prices discussed in the *Market Price Assumptions* section. In addition, avoided T&D costs and societal emissions costs are considered.

4.4.5.1 Avoided T&D

Avoided T&D costs are evaluated based on estimated avoided pool transmission facilities T&D costs from the AESC of $84/kW-year, applied to the energy storage power capacity. An additional Maine-specific local

---

[60] "Pricing," Central Maine Power, accessed February 28, 2022, https://www.cmpco.com/wps/portal/cmp/account/understandyourbill/pricing/?WCM_GLOBAL_CONTEXT=%2FCMPAGR_Navigation%2FHeader%2FAccount%2FUnderstandYourBill%2FPricing
[61] Load shapes define how load (electricity demand) changes over time and are typically expressed in hours.
[62] "System Advisor Model (SAM)," NREL, 2017, https://sam.nrel.gov/download/version-2017-9-5.html

T&D avoided cost is quantified using the value of $310/kW-yr based on Synapse's analysis for Efficiency Maine Trust.[63] It should be noted that T&D avoided costs are generally location and project-specific and allowing these benefits to be monetized may require potential regulatory changes to the business model.

4.4.5.2 Avoided Emissions Costs

Avoided emissions costs are quantified based on marginal emissions rates and the social cost of carbon estimates included in the AESC 2021 report. Month-hour averages of the hourly marginal emissions rates were used to better reflect uncertainty in the hourly forecasts and reconcile some differences that exist between underlying assumptions in the generation mix for these marginal emissions and those that drive the energy price forecast shape. The AESC provides different estimates of the social cost of carbon; this analysis uses the social cost of carbon which starts at approximately $114/ton in 2021 and increases to $135/ton by 2035, which was created by New York state and uses a 2% discount rate. It should also be noted that this specific social cost of carbon estimate is the recommended estimate in the AESC 2021 Study.[64] Lastly, the Regional Greenhouse Gas Initiative (RGGI) carbon price, which is already embedded in the wholesale energy price, is removed from this social cost of carbon estimate.

4.4.5.3 Avoided Capacity Costs for Customer-Sited Resources

This analysis assumes that customer-sited resources do not bid into the capacity market but can still impact system capacity needs. The avoided capacity cost of customer-sited resources is therefore calculated following the methodology of the AESC for uncleared resources, which assumes a lag in the capacity benefits relative to the system lifetime.

4.4.6 Resiliency

The benefit that storage provides of uninterrupted power during system outages is reflected in a resiliency metric for customer-sited storage configurations. The resiliency benefit is the product of the value of lost load, the outage probability, and the available power in each hour. An estimate of the VOLL for residential and medium to large C&I customers from the DOE-funded Interruption Cost Estimate (ICE) Calculator for Maine of $2.71/kWh and $58.85/kWh of unserved energy is applied to the residential and C&I customers respectively.[65] An average outage probability for each hour of the year is calculated using System Average Interruption Duration Index[66] (SAIDI) metrics for each utility, weighted by the number of customers served by each utility. In each hour, the available power that can be provided by the battery is the lesser of the power capacity and the state of charge in that hour.

---

[63] "Statewide Avoided Transmission and Distribution Costs for Maine," Synapse Energy Economics Inc, 2021, https://www.synapse-energy.com/project/statewide-avoided-transmission-and-distribution-costs-maine

[64] "AESC 2021 Supplemental Study – Update to Social Cost of Carbon Recommendation," Synapse Energy Economics, Access February 11, 2022, https://www.synapse-energy.com/sites/default/files/AESC_2021_Supplemental_Study-Update_to_Social%20Cost_of_Carbon_Recommendation.pdf.

[65] "Interruption Cost Estimate (ICE) Calculator," Lawrence Berkeley National Laboratory and Nexant Inc, retrieved in January 2022, https://icecalculator.com/interruption-cost

[66] SAIDI is a metric used to measure the average amount of time a customer experiences an outage in a given period of time, likely a year.

4.4.7 Storage Costs

Battery costs rely on the mid-point cost estimate from E3's Pro Forma model, which sources primarily from the 2021 NREL Annual Technology Baseline (ATB) and Lazard's Levelized Cost of Storage 7.0 analysis.[67,68,69] Cost assumptions are summarized in Table 12 for 2023 storage installations and Table 13 for 2030 storage installations. High- and low-cost sensitivities are also analyzed in Section 5.2 based on "Conservative" and "Advanced" technology innovation scenarios from NREL's ATB, which takes the highest and lowest costs respectively from 13 projections of cost from a literature review.

For storage + solar hybrid systems, storage is assumed to receive the federal ITC, as shown as a negative cost in Table 12 and Table 13. This analysis includes ITC rates of 30% in 2023, 26% in 2024 to 2025, and 10% for all subsequent years, which account for the U.S. Internal Revenue Service's continuity safe harbor provisions and are applied to 95% of total capital costs.

Table 12. 2023 levelized storage cost assumptions for different wholesale (FTM) and customer-sited (BTM) configurations ($2021/kW-yr).[70]

	FTM Standalone	FTM Storage + Solar	C&I BTM Standalone	C&I BTM Storage + Solar	Residential BTM Standalone	Residential BTM Storage + Solar
Duration	4hr	4hr	4hr	4hr	2hr	2hr
Capital	74.85	68.60	200.25	315.42	255.70	255.70
Interconnection	5.05	4.95	-	-	-	-
Fixed O&M	8.03	8.03	21.99	39.76	-	-
Warranty & Augmentation	28.14	29.46	10.71	20.02	-	-
ITC	-	(23.58)	-	(102.51)	-	(83.10)

Table 13. 2030 levelized storage cost assumptions for different wholesale (FTM) and customer-sited (BTM) configurations ($2021/kW-yr).[71]

	FTM Standalone	FTM Storage + Solar	C&I BTM Standalone	C&I BTM Storage + Solar	Residential BTM Standalone	Residential BTM Storage + Solar
Duration	4hr	4hr	4hr	4hr	2hr	2hr
Capital	43.62	39.65	130.02	204.79	169.14	169.14
Interconnection	4.41	4.29	-	-	-	-
Fixed O&M	8.03	8.03	21.99	39.76	-	-

[67] "Annual Technology Baseline: Electricity 2021," NREL, 2021, https://atb.nrel.gov/electricity/2021/data

[68] "Lazard's Levelized Cost of Storage Analysis - Version 7.0," Lazard, 2021, https://www.lazard.com/media/451882/lazards-levelized-cost-of-storage-version-70-vf.pdf

[69] Lazard's Levelized Cost of Storage 7.0 analysis was released in October 2021, while NREL's Annual Technology Baseline: Electricity 2021 was released in July 2021. Therefore, recent supply chain issues and disruptions to the global economy impacting storage costs were not captured in the analysis. Rather, the price projections included in the analysis represent broad trends and do not include all short-term volatility.

[70] 2023 costs assume 25/75 debt-to-equity ratio, with 4.8% cost of debt and 9.8% cost of equity.

[71] 2030 costs assume 60/40 debt-to-equity ratio, with 5.2% cost of debt and 11.4% cost of equity.

Warranty & Augmentation	18.67	19.53	7.30	13.64	-	-
ITC	-	(5.79)	-	(25.07)	-	(20.71)

4.4.8 Storage Operating Characteristics

The modeled storage operating characteristics are summarized below. The power capacity for customer-sited standalone applications is sized to 75% of the total peak load. For customer-sited configurations with solar, a smaller battery is sized due to limited opportunity for off-peak charging, as discussed in the results section.

Table 14. Summary of storage operating characteristics

	Wholesale	Customer-Sited C&I		Customer-Sited Residential	
Roundtrip Efficiency	85%	85%		85%	
Operating Life	20 yr	10 yr		10 yr	
Duration	4 hr	4 hr		2 hr	
Power Capacity	1000 kW	Standalone: 2100 kW	Solar+Storage: 1000kW	Standalone: 1.2 kW	Solar+Storage: 0.6 kW

4.5 Caveats and Limitations

Energy storage cost-benefit analysis is a broad topic. There are many forms of energy storage and many different use cases, configurations, and site specifications. Analyzing the costs and benefits of a rapidly evolving technology in a fast-changing electricity system is a challenge. This study focuses on providing a high-level valuation while helping to develop an evaluation framework for energy storage in Maine with a focus on use cases in the next decade.

Study limitations are summarized below:

+ **Storage is modeled as a price-taker and not a price-maker.** This means that the spreadsheet model only looks at storage responding to pre-determined price signals but has no ability to impact those prices through its charging and discharging behavior that either adds supply or load to the system. In other words, the amount of storage that is added to the system and is dispatched is assumed to be small enough to not influence the actual prices in the market, nor impact future resource build decisions that would account for the existence of that storage resource.
+ **Storage cost assumptions are based on average costs from publicly available sources.** For any specific project, storage costs will vary given local and project-specific factors, including but not

limited to site acquisition, interconnection upgrade costs, customer acquisition, labor costs for engineering and construction, and financing costs given the creditworthiness of the developer.

+ **Storage + solar modeled systems do not account for potentially less advantageous siting.** Some stakeholders noted that our modeling of storage + solar systems compared to standalone systems do not consider restrictions for siting and land use that occur when the storage resource needs to be co-located with the solar farm, which all else equal can favor standalone systems. However, this advantage for standalone systems can often assume the best possible siting, given land use restrictions, as well as the site to take advantage of the best locational pricing. As stated above, we are assuming average costs for storage, as well as zonal-level price forecasts for energy arbitrage, both of which do not allow this dynamic to be appropriately captured.
+ **Battery degradation is accounted for through augmentation costs, rather than as a function of dispatch.** Degradation occurs over time with the cycling of batteries. Fixed augmentation costs (for batteries with lives longer than 10 years) as shown in Table 13 above, are assumed in response to this degradation to keep the usable capacity constant over time, counteracting the degradation.
+ **VOLL is often subjective.** VOLL is used to determine resiliency benefits for BTM storage and attempts to capture the economic losses associated with power outages, including inconvenience, opportunity costs, property damage and health and safety costs. Notably, VOLL varies significantly depending on customer type, duration, and location, and is often considered highly subjective.
+ **Congestion relief and renewable integration (curtailment reduction and price impacts of shifting generation) benefits are not quantified in the modeling.**
    - In certain locally constrained areas, energy storage can play an important role in alleviating congestion, deferring more costly distribution upgrades, and helping to integrate more renewables by reducing congestion and elevating prices achieved by renewable resources.
    - Specifically, benefits to the storage resource and the broader system from siting storage in a congested node include:
        - Potentially increased energy arbitrage revenue for the storage resource given wider variation in daily energy prices.
        - A reduction in congestion losses at the node, leading to higher energy prices and therefore potentially higher revenue for electric generating units at that node to sell into the broader market, especially intermittent price-taker resources such as wind and solar.
        - Reduced curtailment for any existing wind or solar resources at that congested node, leading to higher revenue and renewable energy certificate (REC) generation for renewable plant owners.
        - Expectations for less curtailment and higher energy prices leading to higher levels of renewable development.
    - Historical nodal prices for specific congested nodes in Maine were tested and minimal impact on energy arbitrage revenue was seen. Further, more detailed market simulation and capacity expansion modeling is needed to capture the change in nodal prices and

renewable curtailment (and thus REC generation), as well as change in expected economic renewable builds, given selectively sited storage near congested price nodes and nodes with renewable curtailment. This more detailed modeling is outside of the bounds of the cost-benefit spreadsheet model used in this analysis.

+ **Emissions-focused dispatch is not modeled.** Some stakeholders recommended optimizing on emissions instead of prices. Although emission reductions are modeled, they are not the objective function, and instead the batteries are modeled as they will be operated which is based on power price signals. Marginal emission rates and any embedded emissions pricing (including RGGI carbon pricing but excluding any social cost of carbon) are already implicit in the energy price forecasts, and any emission reductions that take place with respect to battery dispatch will be based on how marginal emission rates align with prices. However, as decarbonization advances and renewable penetration increases and pushes power prices down in high renewable hours, the charging patterns for batteries will better align with lower emissions-intensive hours and the discharging patterns will better align with higher emissions-intensive hours.

5 Results

This section reports and discusses the results of the cost-benefit modeling. It includes analysis of six core scenarios as well as storage cost sensitivities.

5.1 Cost-Benefit Comparison by Scenario

This section presents results of the six core scenarios:

- Wholesale standalone storage
- Wholesale storage + solar
- Customer-sited standalone storage for C&I customer
- Customer-sited storage + solar for C&I customer
- Customer-sited standalone storage for residential customer
- Customer-sited storage + solar for residential customer

Overall, the cost-benefit analysis shows net benefits for owners of wholesale storage, both standalone and systems paired with solar, by 2025. From the perspective of society, storage benefits outweigh costs already in 2023, largely due to avoided T&D costs. However, those benefits are expected to be project-specific and location-dependent.

For customer-sited storage, higher capital costs and limitations of current rates make directly monetizable benefits (i.e. bill savings) more difficult to realize and these benefits are significantly lower than the total storage costs over the system lifetime. However, C&I customers, who are considered to have a high VOLL, could see significant benefit from the resiliency to electricity system outages that storage provides. From society's perspective, even excluding resiliency benefits, customer-sited storage could have net benefits if T&D deferral costs can be realized, but again those benefits are expected to be project-specific and location-dependent.

Also, it should be noted that the results below are only meant to be relative indications of cost-effectiveness for an average storage project with average costs and are not meant to be a signal for investment. Further, the use cases assume the ability to access their respective assigned value streams, which may be more difficult in practice. Each developer or investor will need to analyze the specific cost-effectiveness for an individual storage project, accounting for their risk appetite and desired level of return.

5.1.1 Wholesale Standalone Storage

Wholesale standalone storage shows cost effectiveness from the owner perspective by the mid-2020s if all wholesale revenue streams can be accessed, while avoided T&D costs contribute largely to cost-effectiveness from the societal perspective.

Wholesale standalone storage generates revenue from energy arbitrage, as well as regulation and spinning reserve ancillary services and capacity markets. A breakdown of annual revenues for a system installed in 2023 is shown in Figure 11. As discussed in the *Market Price Assumptions* section, regulation prices are relatively high in the near term resulting in significant revenues. However, these drop off significantly in the near term. In contrast, the increasing daily price spreads in the wholesale energy market due to increasing penetrations of variable renewables introduces more opportunity for storage to generate revenue from energy arbitrage in later years.[72]

Figure 11. Annual revenues for wholesale standalone storage installed in 2023.

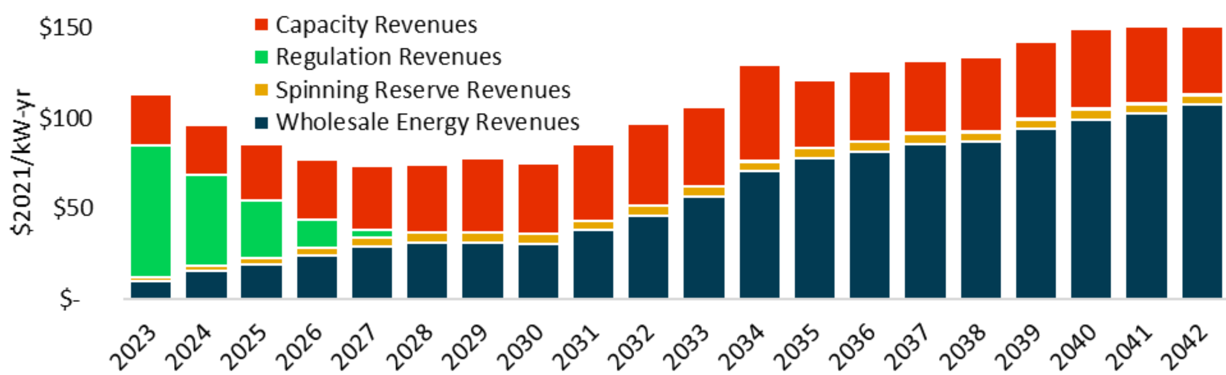
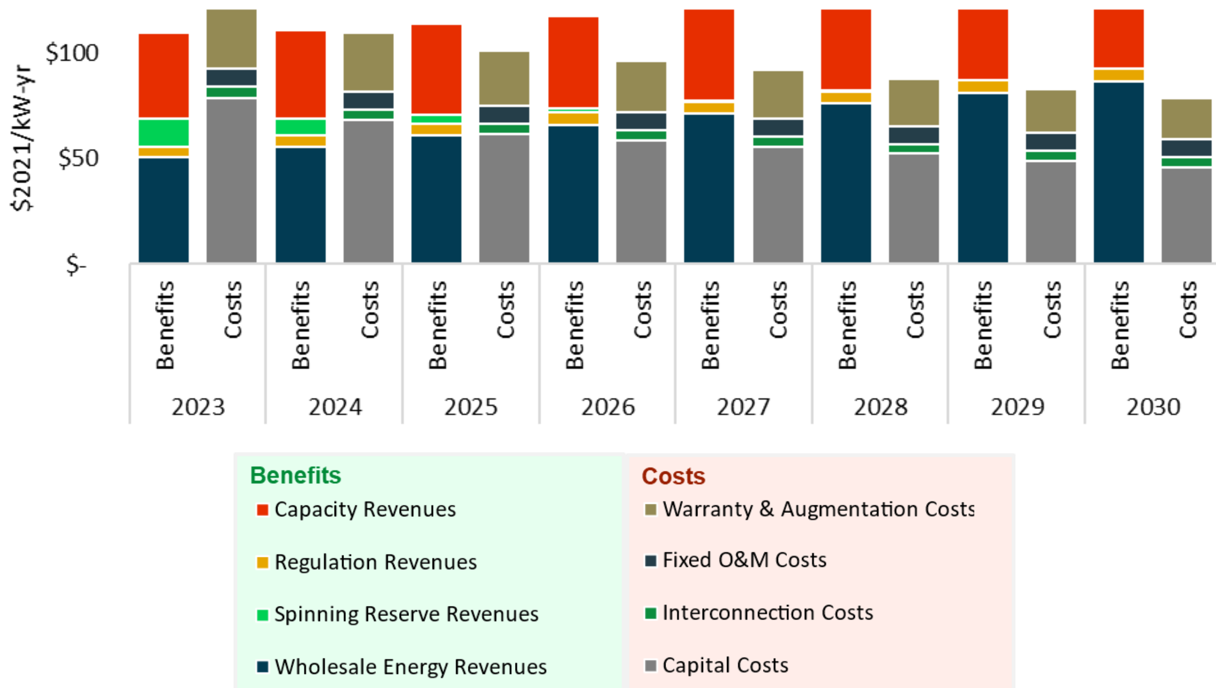


Figure 12 looks at the total benefits and costs to the participant over the system lifetime (the PCT). This chart shows both increasing benefits and decreasing costs, and although a system installed in 2023 has net costs, this analysis shows that by 2024 lifetime benefits could outweigh costs.

[72] Stakeholder feedback was received regarding the need for sensitivity analysis around natural gas prices. Although, this sensitivity was not performed in the study, it should be noted that higher natural gas prices would increase the absolute spread in daily energy prices, therefore increasing the potential for energy arbitrage revenue for storage resources. However, the magnitude of this change would need to be modeled to quantify.

Figure 12. Wholesale standalone storage levelized benefits and costs from participant perspective by storage installation year.

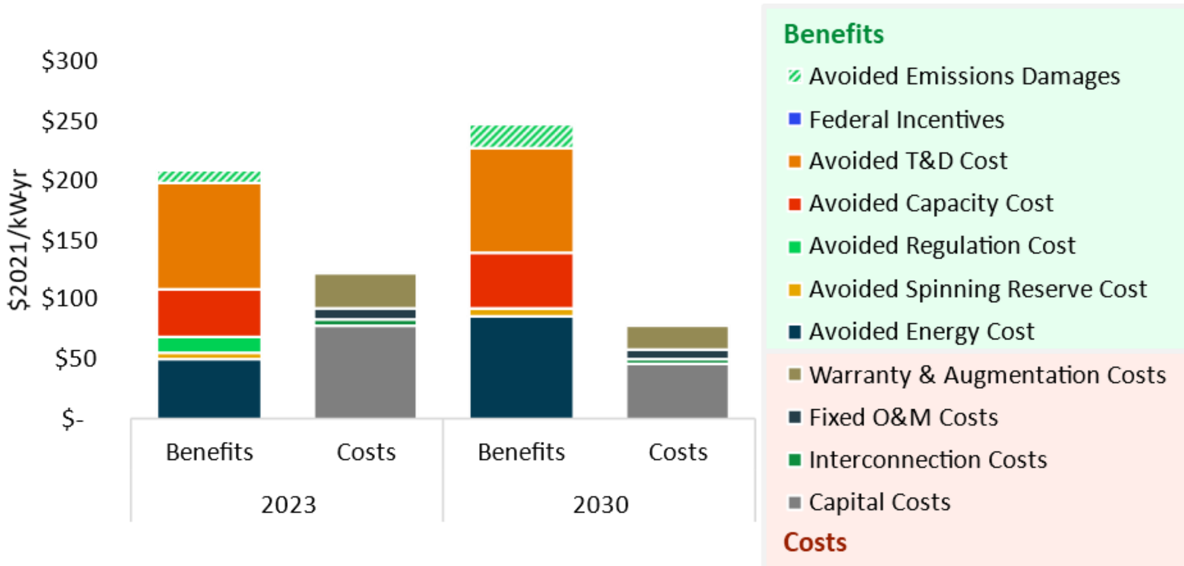


Looking at the State or society's perspective, Figure 13 shows the lifetime benefits and costs for wholesale standalone storage (the SCT). The benefits that can be best quantified and realized by society are the avoided energy, spinning reserve, regulation, capacity, and T&D costs.[73] The avoided societal cost of emissions[74] is also quantified, however it quantifies the avoided risk of climate damages and is not directly monetizable. Even without the avoided emissions costs though, wholesale standalone storage is expected to have net benefits in both 2023 and 2030.

[73] As mentioned in Section 4.4.5.1, avoided T&D costs stem from the AESC 2021 Report estimates for pool transmission facilities T&D costs from the AESC of $84/kW-year, applied to the energy storage power capacity.

[74] As mentioned in Section 4.4.5.2, the avoided societal cost of emissions are from New York state and use a 2% discount rate, and align with the recommended estimate in the AESC 2021 Report.

Figure 13. Wholesale standalone storage levelized benefits and costs from society perspective for 2023 and 2030 installation years.



5.1.2 Wholesale Storage + Solar

Wholesale storage + solar shows cost effectiveness from the owner perspective by the mid-2020s, driven by federal incentives and despite reduced wholesale market participation, while avoided T&D costs contribute largely to cost-effectiveness from the societal perspective.

Wholesale storage in a storage + solar hybrid system is expected to earn revenue from energy arbitrage and capacity markets. In this analysis, storage in a hybrid system is restricted to charging only from solar. There is a requirement that to be eligible for the ITC, the storage must be charged from solar during the vesting period, which is the first 5 years of operation. However, this limitation is modeled over the lifetime of the project in this analysis to better highlight to impact of this limitation. Participation in ancillary services markets may be more difficult for hybrid storage + solar systems and is therefore not included in this analysis. A breakdown of annual revenues for a system installed in 2023 is shown in Figure 14. As was seen for wholesale standalone storage, the increasing daily price spreads in the wholesale energy market due to increasing penetrations of variable renewables allows storage to generate more revenue from energy arbitrage in later years.

Figure 14. Annual revenues for wholesale storage + solar installed in 2023.

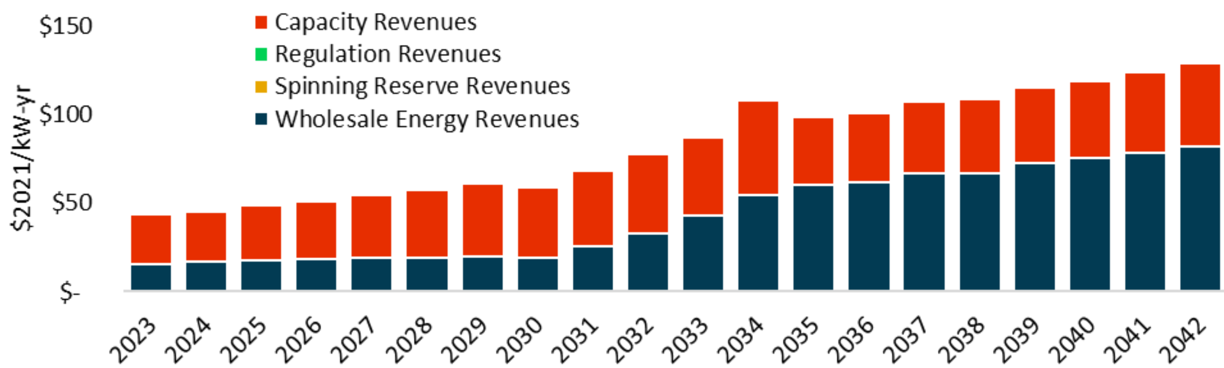
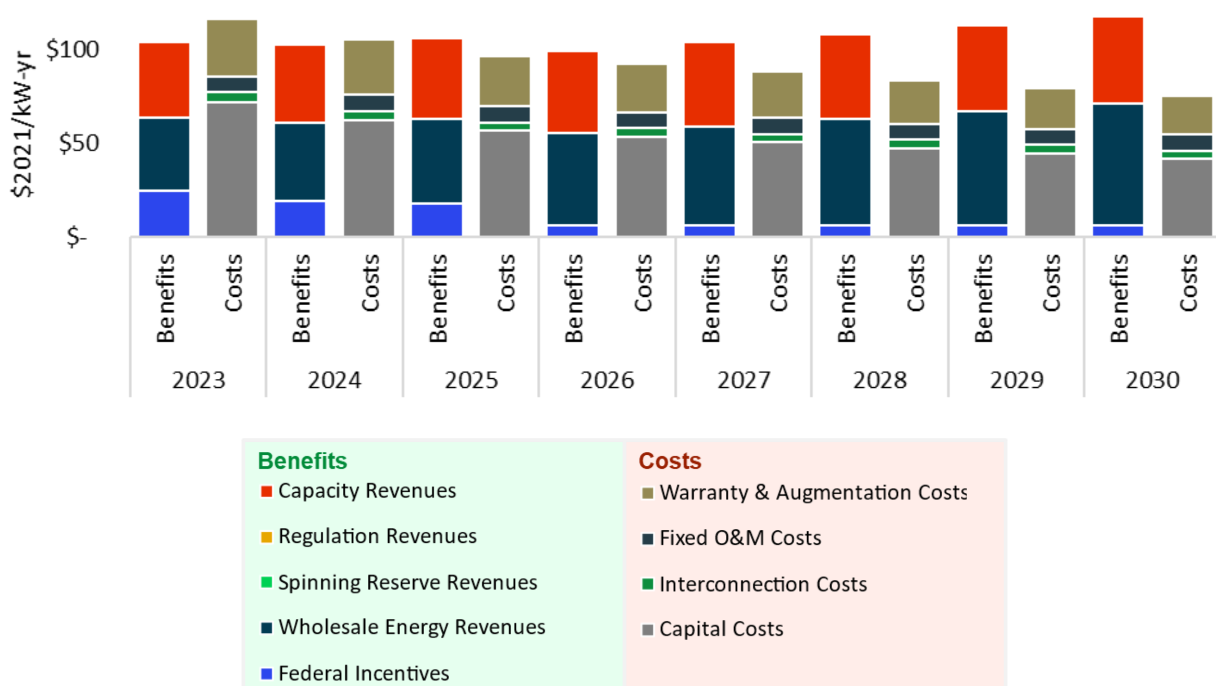


Figure 15 shows the total benefits and costs to the participant over the system lifetime (the PCT) for different installation years. In addition to the revenues, federal incentives (specifically the ITC) are shown as a benefit. This chart shows both increasing benefits and decreasing costs, with benefits outweighing costs from 2025 forwards. Based on this analysis, the ITC is important for storage systems to breakeven over their lifetime in the next 5 years; without the ITC the total benefits do not outweigh the total costs until 2027.

Figure 15. Wholesale storage + solar levelized benefits and costs from participant perspective by storage installation year.



To highlight the impact of ancillary service revenues and of charging only from solar, Figure 16 shows the PCT for a wholesale standalone system with and without AS revenues and a wholesale storage + solar system, all installed in 2025. Overall, ancillary services provide some additional revenue in the short term at the expense of slightly lower energy arbitrage revenues. However, ancillary service prices are already quite low and drop off quickly after 2025. Therefore, this does not have a significant impact on the benefits over the lifetime of the project. Comparing a standalone storage system without AS revenues to storage that charges only from solar, the constraint on charging hours reduces energy arbitrage revenues by about $17/kW-yr (17%) over the lifetime of the project. Figure 16 also highlights the capital cost savings ($5/kW-yr or 8%) for storage in a hybrid system due to synergies between the storage and solar systems, when compared to a standalone system.

Figure 16. Levelized lifetime benefits and costs for wholesale (FTM) storage installed in 2025, comparing FTM standalone with AS revenues, FTM standalone with energy only revenues, and FTM storage + solar.

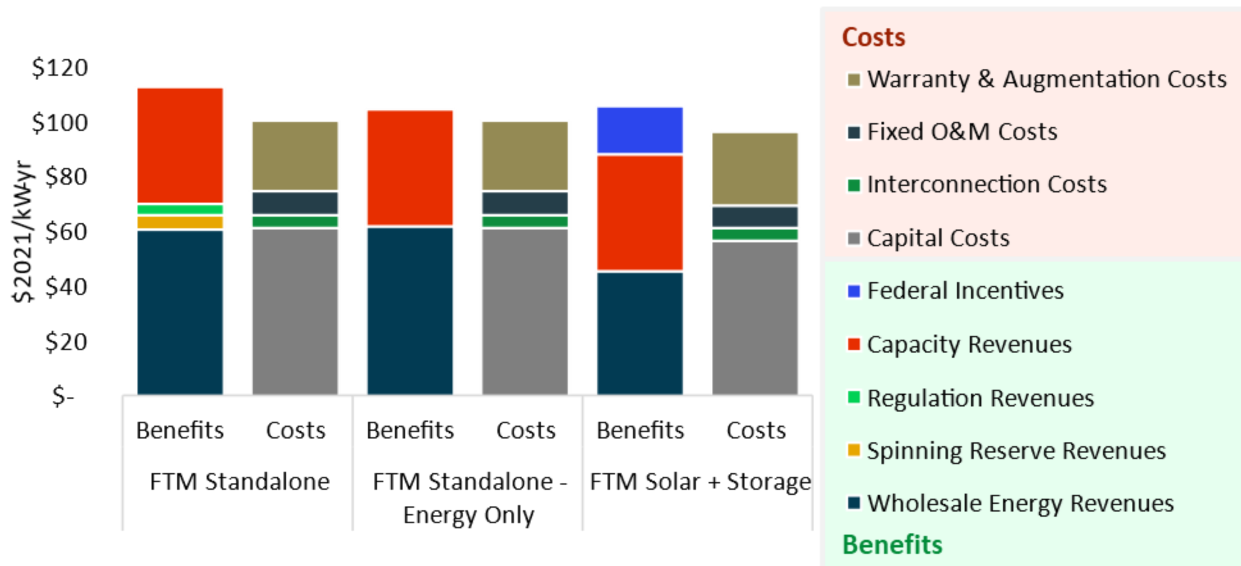
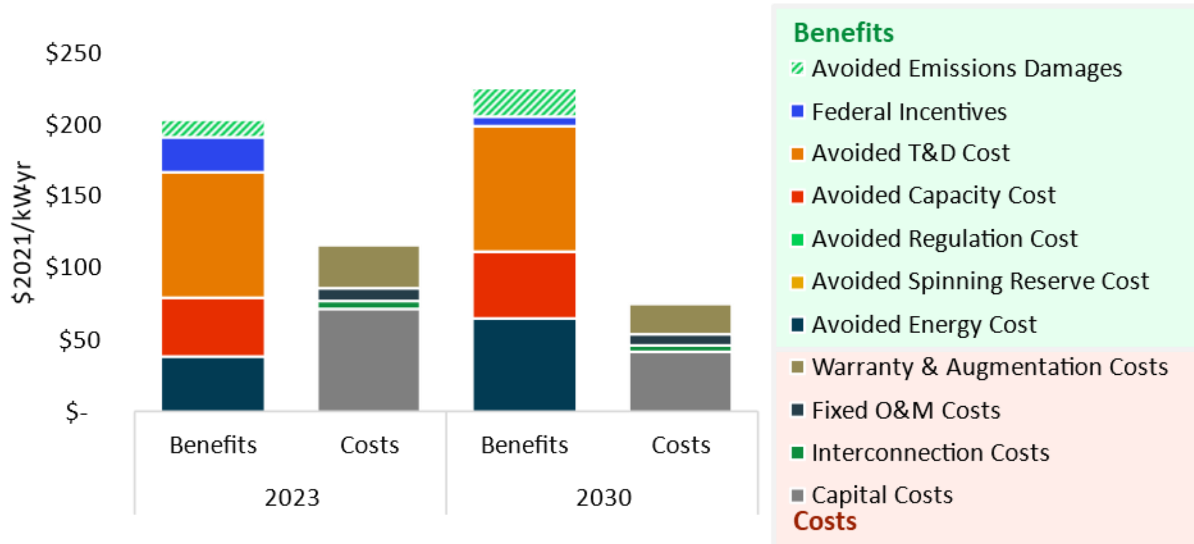


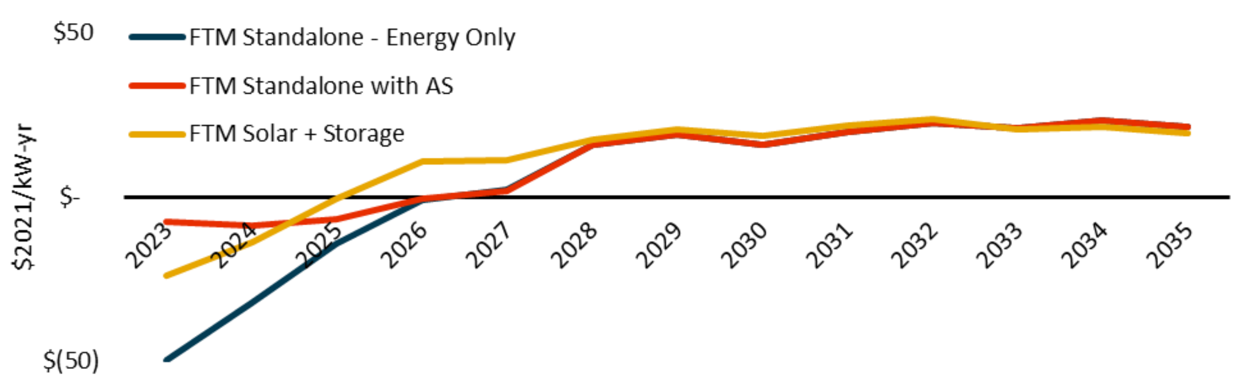
Figure 17 shows the SCT for wholesale storage + solar systems installed in 2023 and 2030. The SCT is similar to that of wholesale standalone storage, but with slightly lower avoided energy costs and no avoided ancillary services costs for the same reason that regulation and spinning reserve revenues are lower for the PCT perspective.

Figure 17. Wholesale storage + solar levelized benefits and costs from society perspective for 2023 and 2030 installation years.



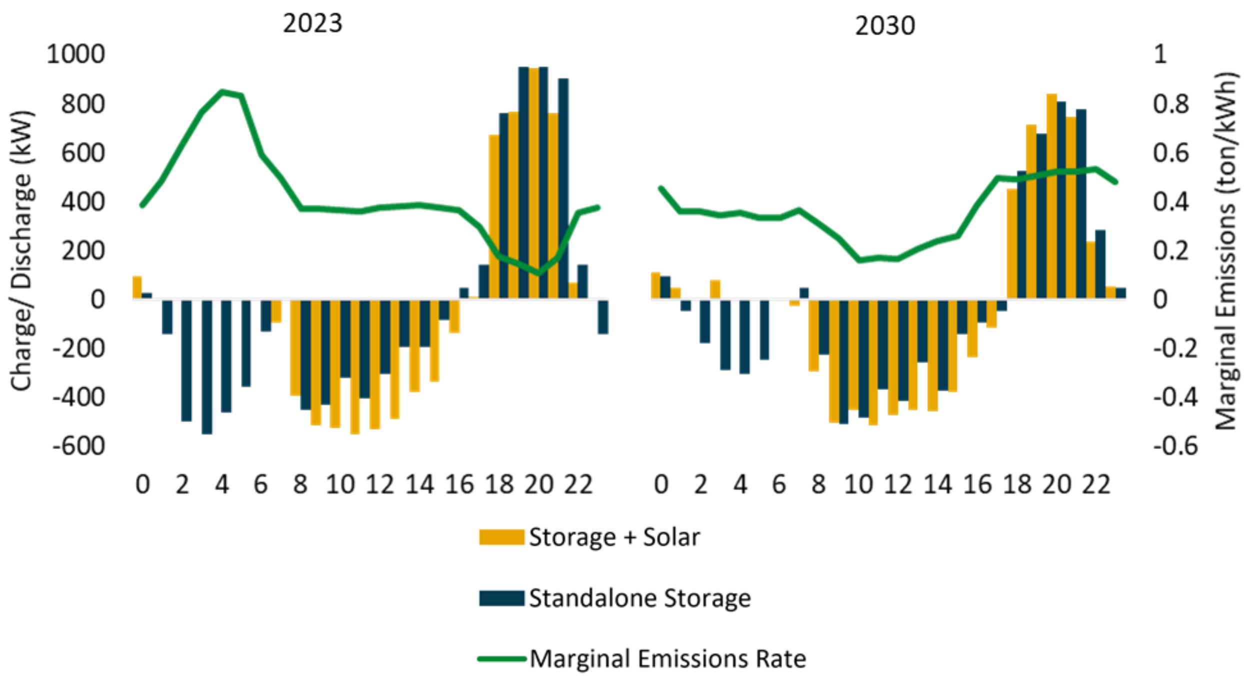
Taking a deeper look at avoided emissions, before 2026 avoided emissions are expected to be low or negative due to poor correlation between energy prices and marginal emissions rates. This is especially true for storage that is only dispatched based on prices, as opposed to storage which is made available for regulation ancillary service and therefore dispatched less often, as well as storage that charges only from solar and therefore has restricted charging hours. This overall trend of increasing annual avoided emissions costs for different system configurations is shown in Figure 18.

Figure 18. Comparison of annual avoided emissions damages by storage configuration and revenue stream for systems installed in 2023.



The dispatch behavior of different system configurations relative to marginal emissions is illustrated in Figure 19 which shows average hourly dispatch for October of 2023 and 2030. Standalone storage dispatch based on energy prices is shown in blue, and storage charging only from solar is shown in yellow. The green line shows the average marginal emissions rate. In 2023, the marginal emissions rates are high when the standalone storage charges in the morning during low price hours, increasing emissions. Both storage configurations discharge in the evening when marginal emissions rates are low, again increasing instead of decreasing emissions. In contrast, by 2030 energy prices and the solar shape are better aligned with marginal emissions rates due to an expected increase in renewable generation. This leads to higher avoided emissions for both standalone and storage + solar configurations.

Figure 19. Average hourly dispatch and marginal emissions rates for October in 2023 and 2030. Charging is negative, discharging is positive.



5.1.3 Commercial and Industrial Customer-Sited Storage

Commercial and Industrial (C&I) customer-sited storage provides bill savings to the owner, as well as large resiliency (back-up power) benefits depending on the owner's willingness to pay for lost load. Benefits to society again depend on resiliency, as well as the ability to realize potentially valuable avoided T&D costs for the system.

Customer-sited commercial and industrial (C&I) storage generates revenues through bill savings. In the scenarios modeled here, the customer is assumed to have a flat energy charge, plus a demand charge that varies by TOU period. Additional rate details are provided in Section 4.4.2. The following subsections present results for C&I standalone and storage + solar systems.

5.1.3.1 Standalone

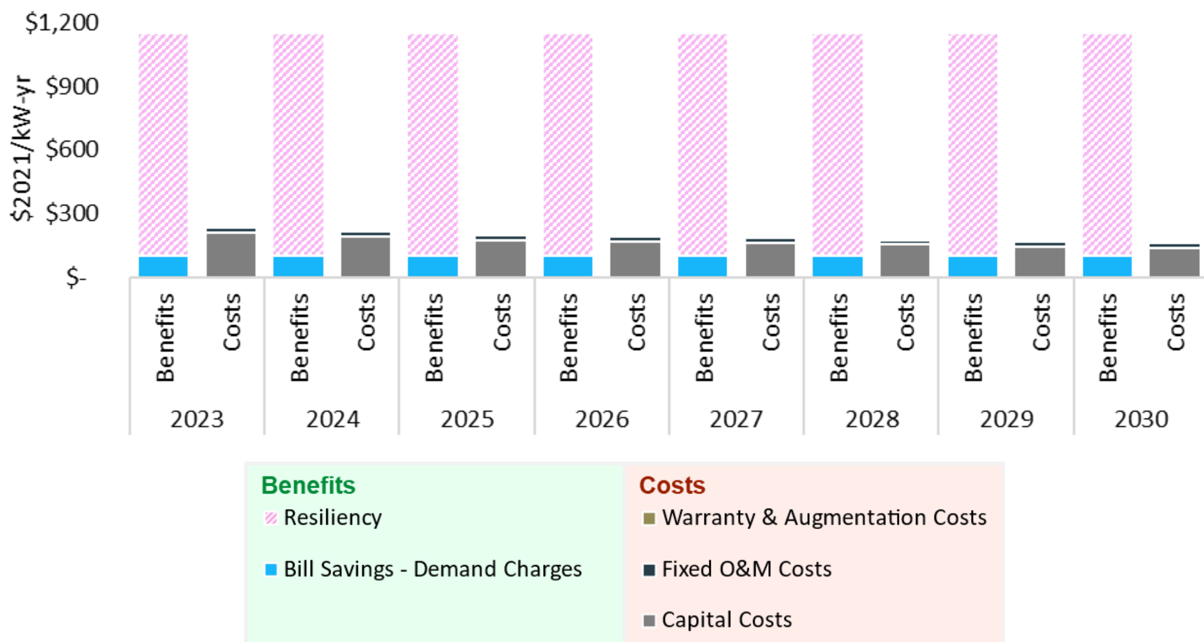
Figure 20 shows the lifetime levelized costs and benefits for customer-sited C&I standalone storage by installation year.[75] Although bill savings from the reduction of demand charges are significant, they do not make up for the storage costs over the lifetime of the system, even with the lower cost of systems installed

[75] The same TOU rate, assumed to increase at the same rate as inflation, is used to model bill savings across all years, therefore a breakdown of annual revenues is not shown.

in 2030. Recall that storage costs for customer-sited applications is significantly higher than for wholesale applications, making the economics much more difficult.

Figure 20 also shows the estimated resiliency benefit of storage, based on the methodology discussed in Section 4.4.6. Including resiliency makes storage look much more beneficial for the customer; however, the value of lost load is difficult to quantify and a customer's willingness to pay for it may be more limited than indicated here.

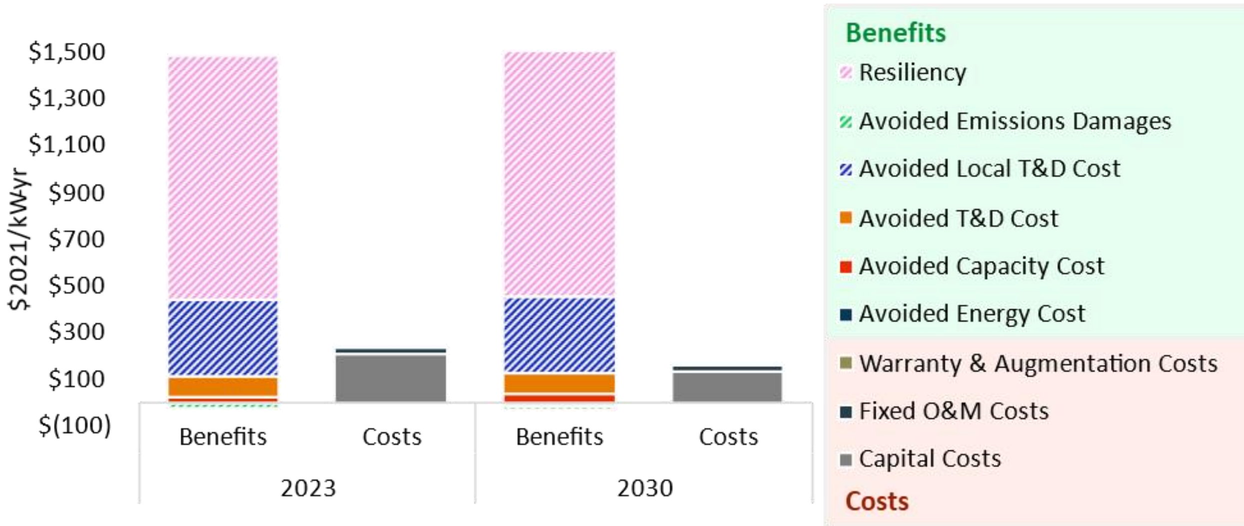
Figure 20. C&I customer-sited standalone storage levelized benefits and costs from participant perspective by storage installation year.



Looking at the State or society's perspective, Figure 21 shows the lifetime benefits and costs for customer-sited C&I standalone storage (the SCT). Avoided local T&D costs add significant benefit, however the magnitude of this benefit is expected to be location-specific and therefore there is uncertainty in how much of this value can be realized. From the perspective of the state or society, the economics of customer-sited C&I standalone storage hinge on the value of the avoided local T&D costs; without local T&D benefits, customer-sited standalone storage could have net costs to the state.

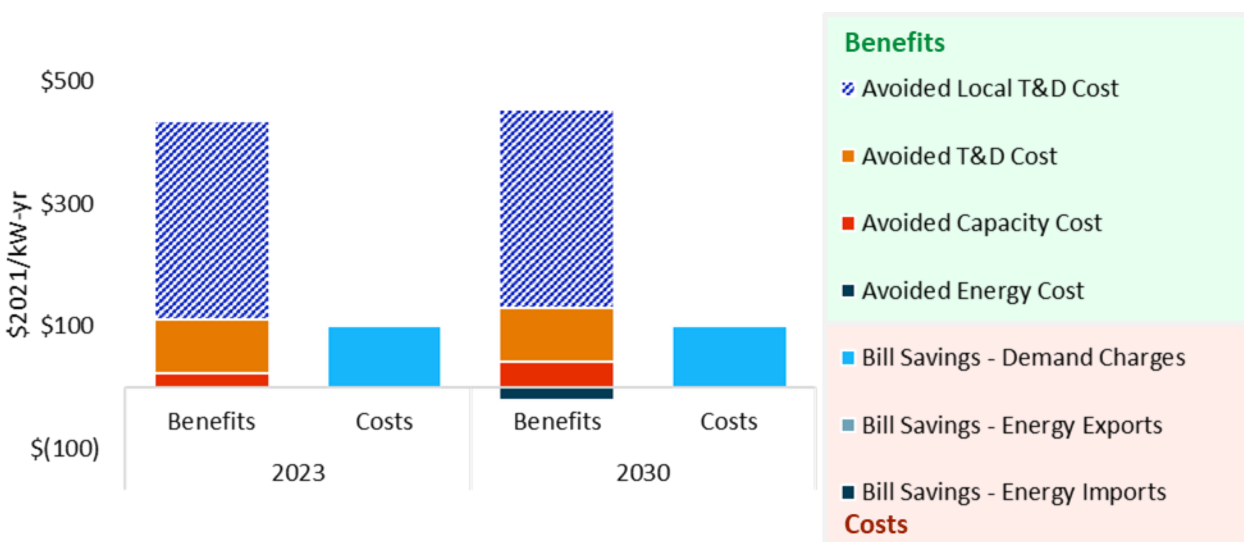
In addition, the avoided emissions cost is negative for customer-sited C&I standalone storage. This is due to TOU periods that are poorly aligned with marginal emissions rates. The impact of this misalignment is exaggerated in the modeling presented here because the TOU periods are held constant over the lifetime of the project. In reality, TOU periods could be updated as energy prices and the timing of system loads change, which would align TOU periods better with avoided emissions costs in the future.

Figure 21. C&I customer-sited standalone storage levelized benefits and costs from society perspective for 2023 and 2030 installation years.



All bill savings for the storage owner are costs that must instead be borne by all other ratepayers. However, ratepayers also benefit from the system avoided costs associated with that storage dispatch. Figure 22 shows customer-sited C&I standalone storage from the perspective of a ratepayer who does not install storage, indicating slightly higher benefits than costs in both 2023 and 2030 if avoided local T&D costs are excluded. If avoided local T&D costs can be realized, benefits would far outweigh costs.

Figure 22. C&I customer-sited standalone storage levelized benefits and costs from ratepayer perspective for 2023 and 2030 installation years.



5.1.3.2 Storage + Solar

Pairing storage with customer-sited solar provides an opportunity to further increase self-consumption. However, current TOU periods currently have peak periods that partially overlap with solar production hours which limits the bill savings that storage can achieve relative to a solar-only system. This is illustrated in Figure 23 which shows an example work week in June 2023. The customer load is shown in blue and solar generation in yellow. The TOU periods, which includes peak, part-peak and off-peak periods are shown beneath in black. Without storage, the imports from the grid of this customer are shown in red. The solar generation alone already does a good job of reducing this customer's load because the solar generation and peak load hours are well aligned. The final imports from the grid after storage is added are shown by the dotted black line. Storage charges during the part-peak TOU hours when there is solar generation, and discharges during the peak TOU hours. This provides some additional bill savings due to demand reduction in the peak hours, but it is limited.

Figure 23. C&I customer-sited storage dispatch in hybrid system for example work week in June 2023.

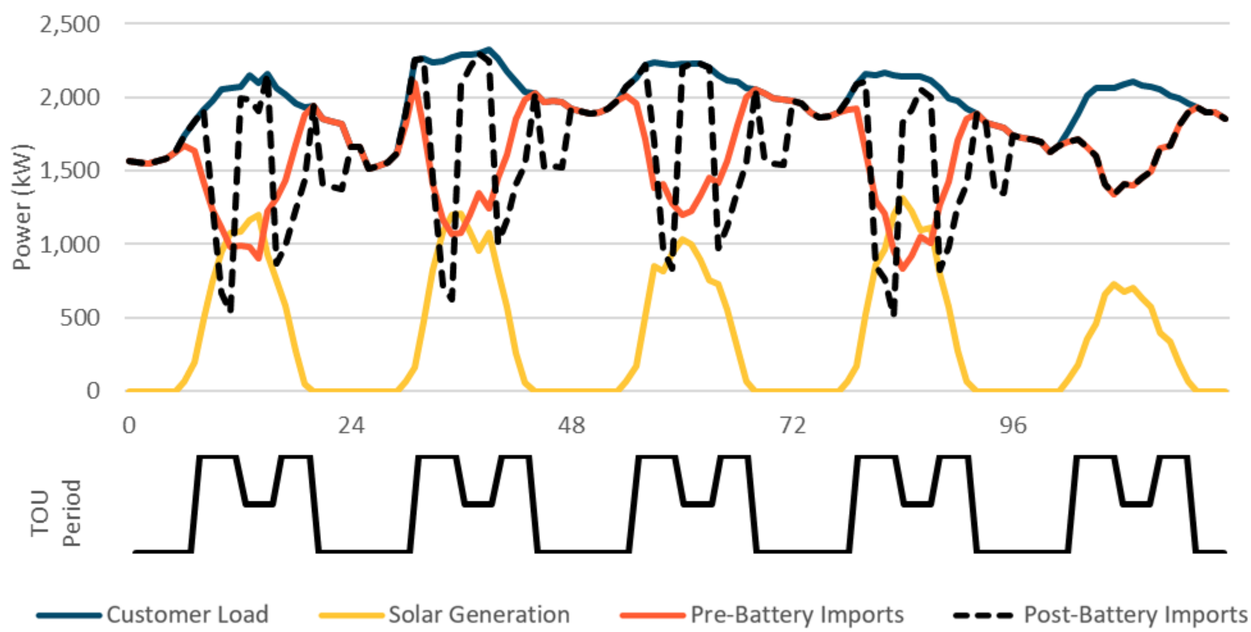


Figure 24 shows the lifetime levelized costs and benefits for customer-sited C&I storage + solar by installation year. Bill savings are relative to a customer with solar, and therefore are quite limited, as discussed above. If TOU periods are adjusted in the future such that peak and shoulder periods do not align with solar generation hours, the opportunity for customer-sited storage + solar would increase. However, based on current TOU periods, this configuration of storage is very unlikely to make economic sense unless the customer is focused on resiliency benefits.

Figure 25 shows similar results for storage paired with solar compared to standalone storage for C&I customer-sited storage from the perspective of society. Ratepayers incur lower costs for solar-paired systems due to the limited bill savings that storage-owners can achieve, as shown in Figure 26.

Figure 24. C&I customer-sited storage + solar levelized benefits and costs relative to a solar-only system from participant perspective by storage installation year.

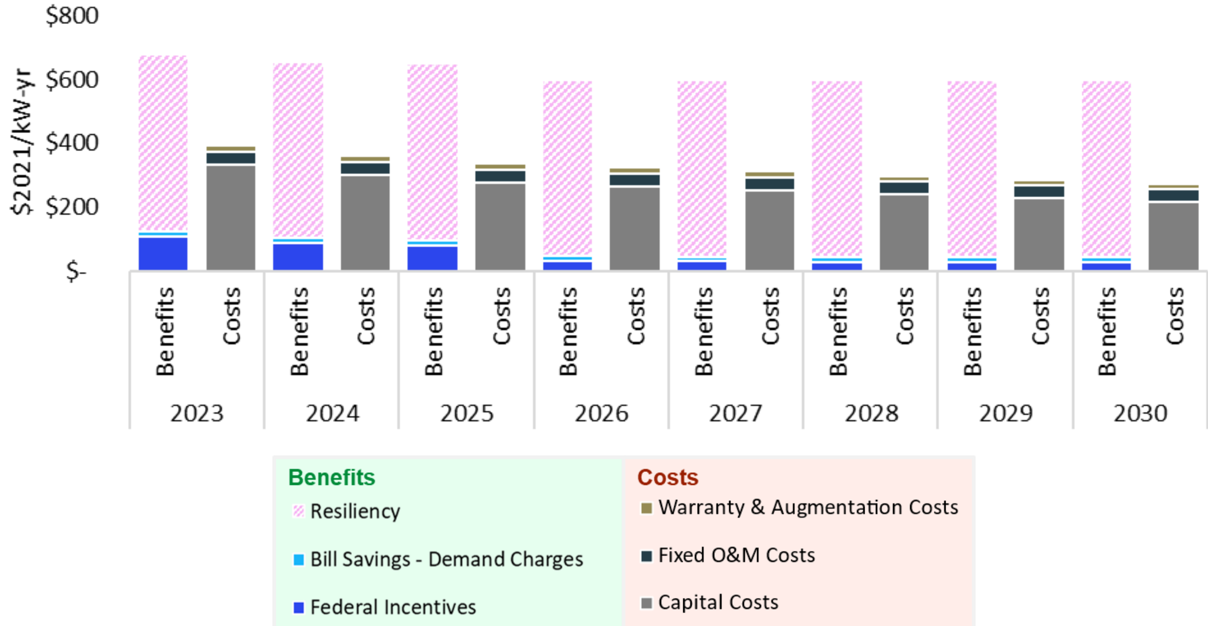


Figure 25. C&I customer-sited storage + solar levelized benefits and costs relative to a solar-only system from society perspective for 2023 and 2030 installation years.

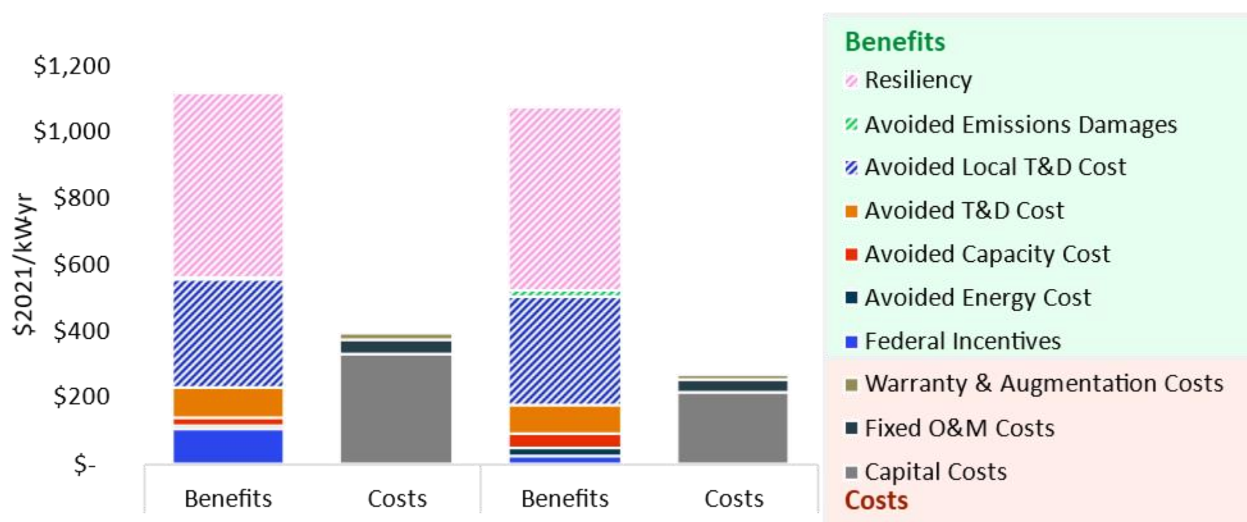
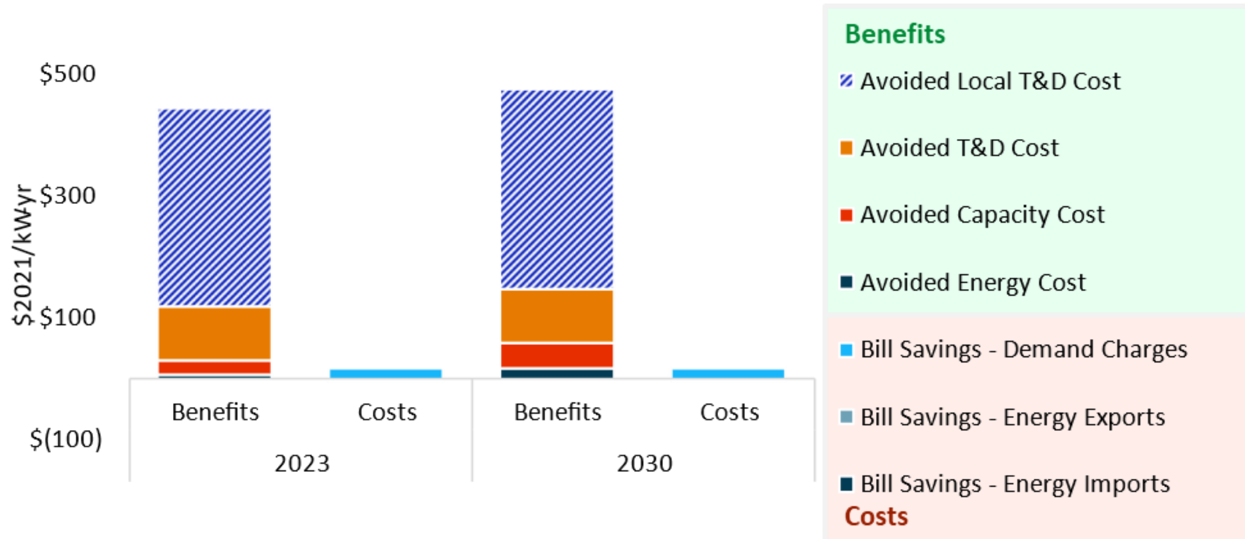


Figure 26. C&I customer-sited storage + solar levelized benefits and costs relative to a solar-only system from ratepayer perspective for 2023 and 2030 installation years.



5.1.4 Residential Customer-Sited Storage

Residential customer-sited storage provides bill savings to the owner as well as resiliency benefits, however both are significantly lower than for C&I customers due to a less favorable rate structure and a lower value of lost load. Therefore, these benefits are not expected to cover storage costs. Society could still see net benefits of residential storage if avoided T&D costs can be realized.

Customer-sited residential storage also generates revenues through bill savings, however residential rates are assumed to have an energy charge that varies by TOU period and no demand charge, in contrast to large C&I rates. Additional rate details are provided in Section 4.4.2. The following subsections present results for residential standalone and storage + solar systems.

5.1.4.1 Standalone

Standalone customer-sited storage can be used effectively to move some residential load from peak to off-peak hours. However, the difference between the modelled peak and off-peak residential rates is only $0.06/kWh which does not result in sufficient bill savings to offset the costs of the storage system (as a point of comparison, Pacific Gas and Electric (PG&E) has an EV rate with a difference of approximately $0.31/kWh, which could provide more opportunity for storage). This is apparent in Figure 27 which shows the lifetime levelized costs and benefits for customer-sited residential standalone storage by installation year. Compared to a C&I customer, resiliency is valued much lower for residential customers. Therefore, even when accounting for resiliency benefits, residential customer-sited standalone storage is not economic.

Figure 28 and Figure 29 provide the perspectives of society and the ratepayer.

Figure 27. Residential customer-sited standalone storage levelized benefits and costs from participant perspective by storage installation year.

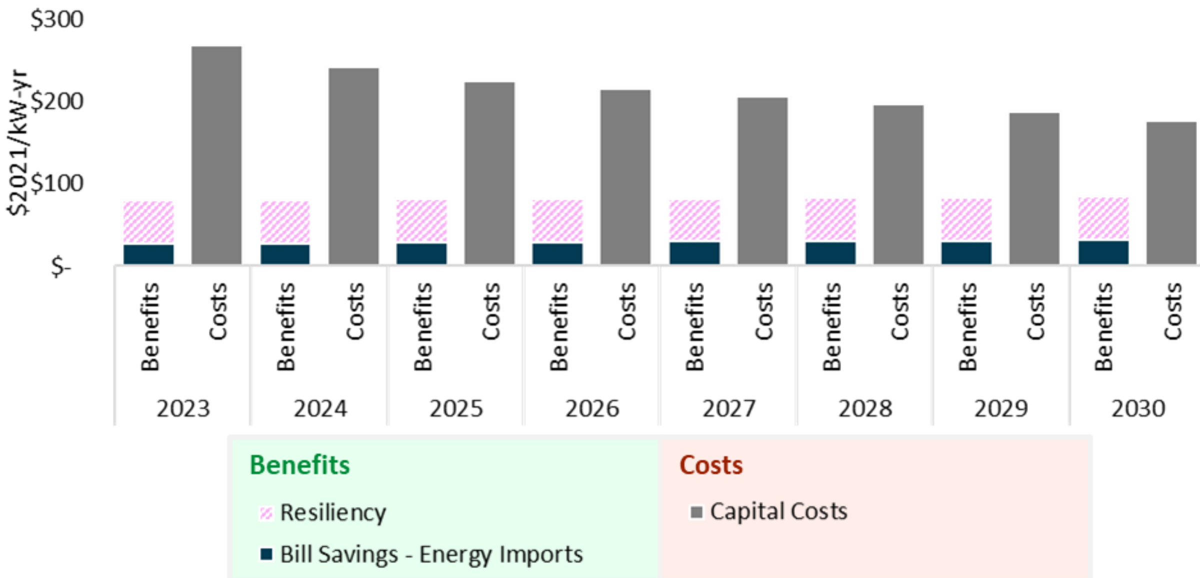


Figure 28. Residential customer-sited standalone storage levelized benefits and costs from societal perspective by storage installation year.

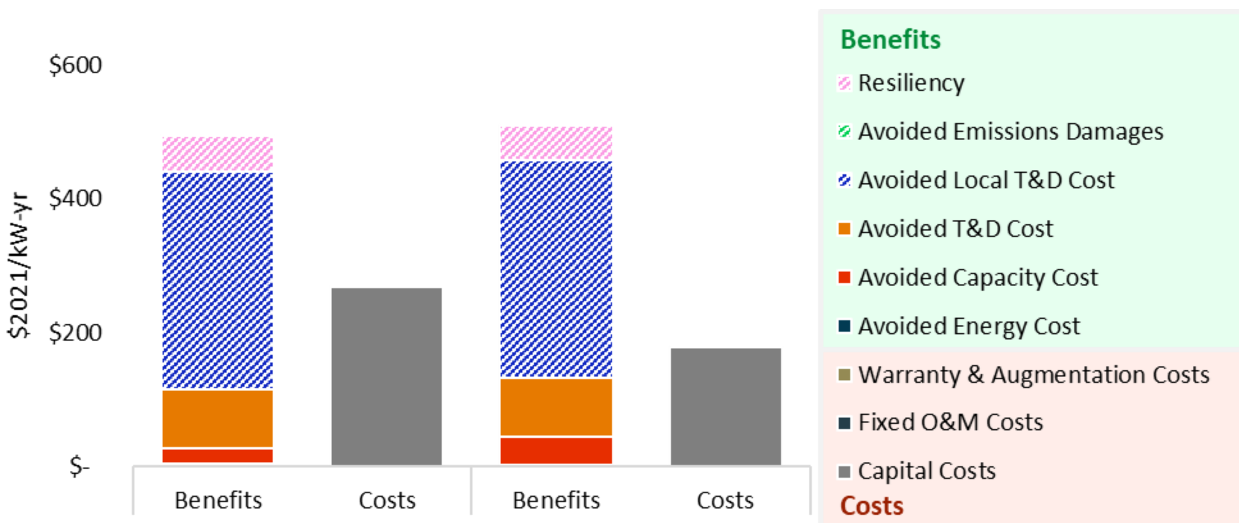
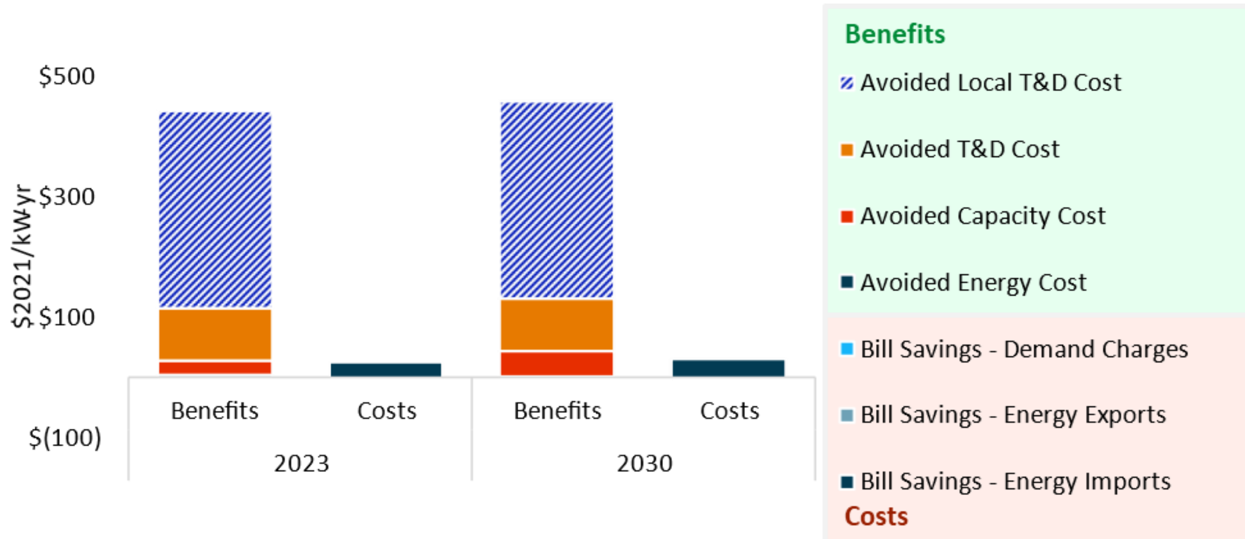


Figure 29. Residential customer-sited standalone storage levelized benefits and costs from ratepayer perspective for 2023 and 2030 installation years.



5.1.4.2 Storage + Solar

Given the requirement to charge with solar, and the timing of the TOU periods that closely align with hours of solar generation, there is very limited opportunity for bill savings for residential storage + solar systems. This results in nearly all the benefit stemming from resiliency and a reduction in loss of load. [76]

5.2 Cost Sensitivities

The cost-benefit results shown in the previous section assume a mid-range cost estimate. This section presents results with low- and high-cost sensitivities to demonstrate the impact of battery storage costs decreasing more or less quickly on the economics of energy storage from the owner's perspective. As was described in Section 4.4.7, high- and low-cost sensitivities are based on "Conservative" and "Advanced" technology innovation scenarios from NREL's ATB, which takes the highest and lowest costs respectively from 13 projections of cost from a literature review (NREL, 2021).

5.2.1 Wholesale Standalone Storage

The timing of cost-effectiveness for wholesale standalone storage could be delayed by a couple years with higher costs.

[76] It should be noted that this finding is specific to the TOU rate structure analyzed here, and with no additional incentives programs (e.g. demand response) that can complement resiliency benefits and help drive residential storage + solar development.

Figure 30 shows a comparison of fixed costs of wholesale standalone storage in 2023, 2025, and 2030. Capital costs are assumed to decline at different rates under the different scenarios. This also impacts the warranty and augmentation costs, which are calculated as a percentage of capital costs. Figure 31 looks at the total benefits and costs to the participant over the system lifetime (the PCT), showing low, mid, and high estimates of total fixed costs. The benefits are assumed to remain the same under all three cost scenarios. This chart shows that using higher cost estimates could delay the timeline on which storage is cost effective until 2026.

Figure 30. Comparison of low-, mid-, and high-cost estimates in 2023, 2025, and 2030 for wholesale standalone storage.

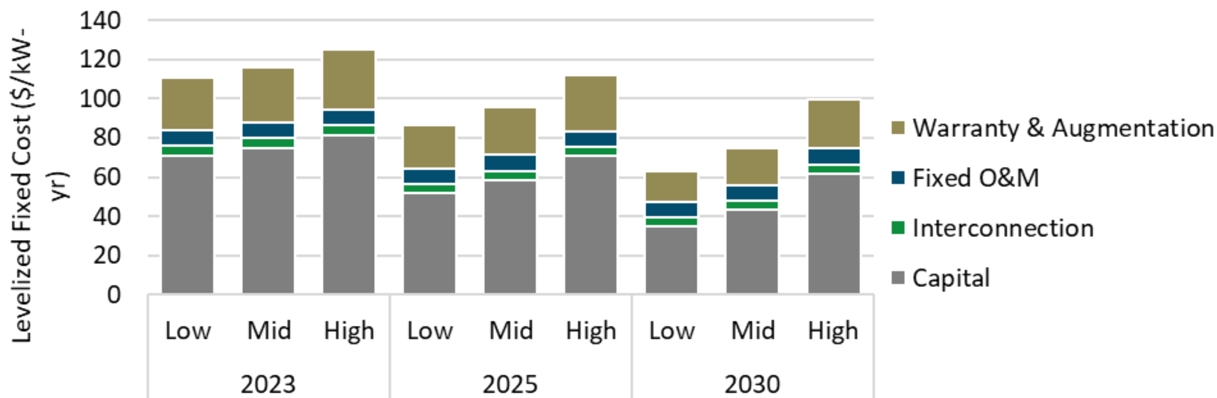
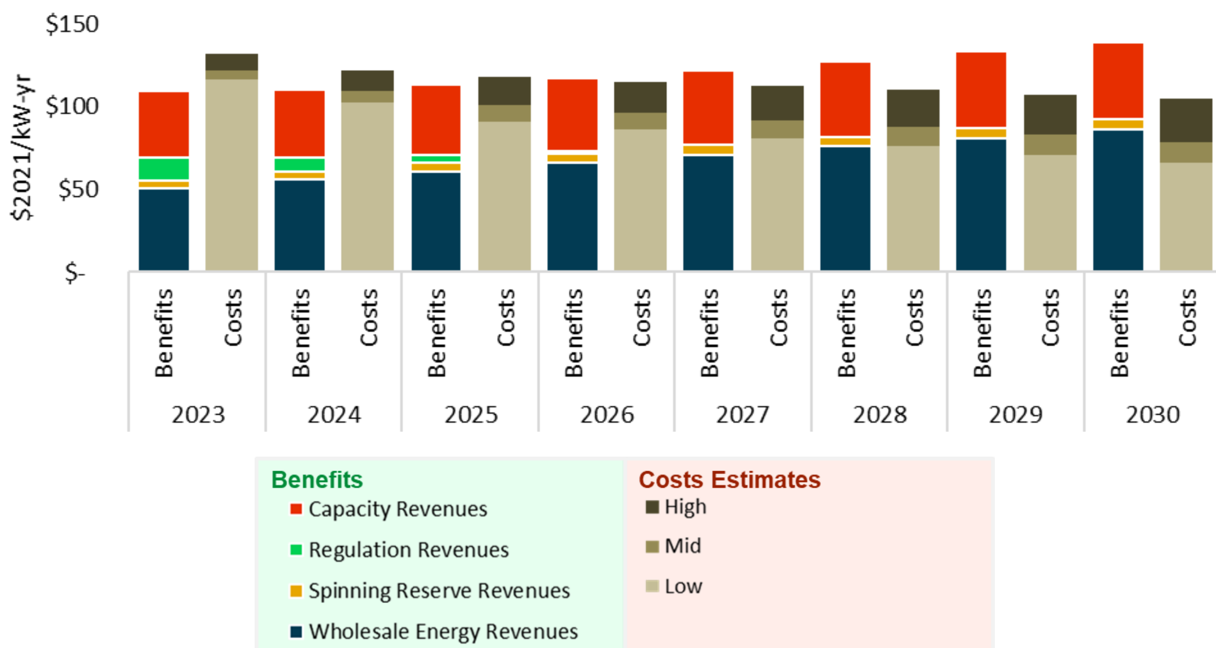


Figure 31. Wholesale standalone storage levelized benefits and costs from participant perspective by storage installation year comparing total low, mid, and high fixed cost to total benefits.



5.2.2 Commercial and Industrial Customer-Sited Standalone Storage

Given high resiliency benefits, higher costs still show cost-effectiveness for C&I standalone storage.

Figure 32 shows a comparison of fixed costs of customer-sited C&I standalone storage in 2023, 2025, and 2030. Like wholesale storage, capital costs are assumed to decline at different rates under the different scenarios. Figure 33 looks at the total benefits and costs to the participant over the system lifetime (the PCT), showing low, mid, and high estimates of total fixed costs. Again, the benefits are assumed to remain the same under all three cost scenarios. Note that resiliency benefits have been cut-off in the chart to zoom-in on cost differences. This chart shows that resiliency adds benefits that are far beyond the costs under any cost estimate. Without resiliency benefits, however, even the low-cost estimate does not have benefits that outweigh costs by 2030.

Figure 32. Comparison of low-, mid-, and high-cost estimates in 2023, 2025, and 2030 for customer-sited C&I standalone storage.

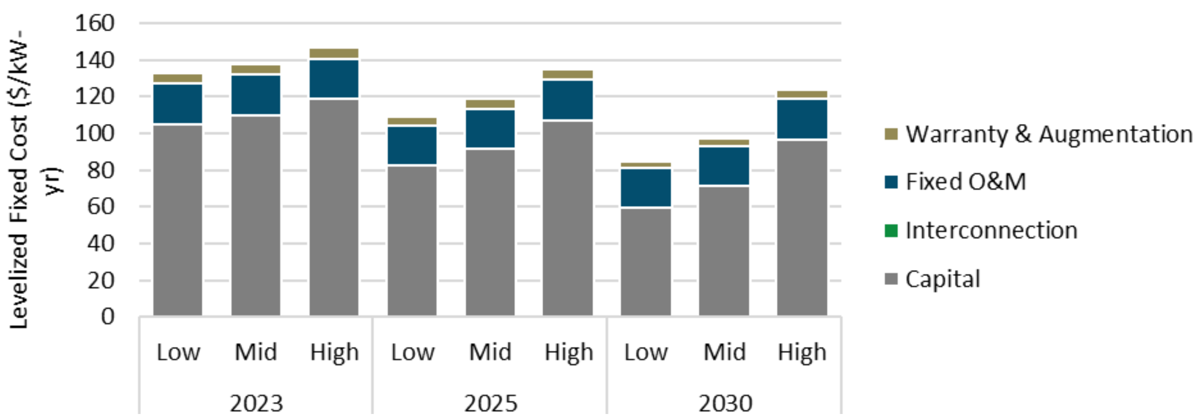
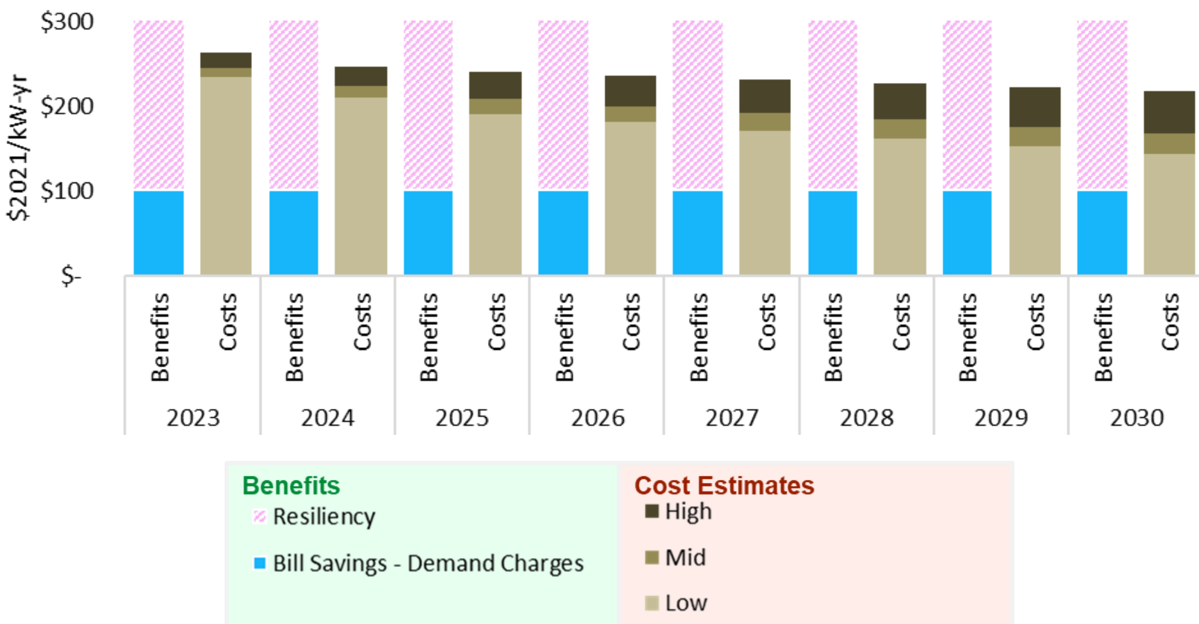


Figure 33. Customer-sited C&I standalone storage levelized benefits and costs from participant perspective by storage installation year comparing total low, mid, and high fixed cost to total benefits.[77]



[77] Resiliency benefits are cut off to highlight difference in costs. Resiliency benefits extend to ~$1000/kW-year.

6 Conclusions & Policy Considerations

Maine is pursuing ambitious storage deployment goals over this decade that will better position the state as it strives for increasing renewable integration and electric sector decarbonization. The 2025 and 2030 storage targets, 300 MW and 400 MW, respectively, provide ambitious yet challenging goal posts for the state. This study assesses the role of storage broadly and the economics of near-term deployment, creating a valuable fact-base to inform state actions and policies.

6.1 Key Takeaways

The study identified key findings related to energy storage in Maine, including the following:

+ **Several promising energy storage technologies may help Maine achieve its target, though batteries will likely comprise most of the storage deployed in Maine in the next five years.** Energy storage includes a diverse set of technologies, with distinct physical and economic characteristics, and the technology landscape is evolving quickly. While technologies like pumped hydro storage have been deployed for a century, there are many new and emerging energy storage technologies with the potential to create benefits to Mainers by lowering electric grid costs, integrating renewables, and providing other benefits. Li-ion batteries are expected to be the most common storage technology deployed in the near-term, given continued declining costs, high round trip efficiency, siting flexibility, and the ability to provide the fast-response needed to integrate and balance renewables. That said, other technologies may prove to have better economics in the coming years, or provide a range of other advantages (e.g., longer duration, other grid services, etc.).
+ **Energy storage may provide many distinct benefits to Mainers, with potential value streams evolving as the needs of the electric grid and customers change.** If storage can continue to fall in cost and overcome deployment hurdles, it can help lower wholesale electricity generation costs (benefiting consumers), lower utility infrastructure costs (benefiting ratepayers), and lower electricity bills and increase resiliency (benefiting customers). As greater solar penetration drives down mid-day prices, storage can charge during the day and help serve peak demand in the early evening hours. In Maine, some of the highest value services for certain projects in the near-term may be avoided T&D infrastructure costs. However, realizing these avoided costs by specific storage projects will depend on the ability to site storage in the most valuable locations and on potential business model and/or regulatory changes to help these benefits to be monetized. Similarly, behind-the-meter storage, located at the customer site, may provide significant value to customers such as avoided outages. However, the size of this value stream depends on the customer's specific economics including the VOLL.
+ **Cost-benefit analysis results show cost-effectiveness for wholesale ("grid-connected") storage but continued cost declines and the ability to monetize multiple value streams will be important.** The commercial viability of storage projects will depend both on realizing cost

declines and on the ability to monetize multiple revenue streams. Value "stacking" is particularly important to projects given uncertainty around future wholesale prices and potential changes in market rules and design. Currently, wholesale (also referred to as FTM) storage projects can pursue multiple wholesale market revenue sources. While AS revenue is likely to supply most revenue in the near term, energy arbitrage opportunities will continue to grow, supplying most of the revenue in the longer term. Capacity revenue will remain an important revenue stream and could supply at least a quarter of expected revenue in each year over the next decade. That said, policy goals, technological advancements, and other drivers may influence changes in market design, making the evolution of revenue streams less certain.

+ **Customer-sited storage can reduce customer bills and increase resiliency by protecting against outages (loss-of-load).** Building on-site energy storage can reduce electric bills for residential, commercial or industrial customers. In addition, customers benefit from avoided outages, though quantifying the value of lost load is highly uncertain and can vary depending on customer type, outage duration and location. Recent policy and market changes in ISO New England, the region's independent system operator, are allowing customer-sited (also referred to as BTM) storage to participate in wholesale markets through aggregation, i.e. grouping together smaller projects that individually may lack scale and coordination necessary for proper market participation. This provides alternative revenue streams for customer-sited storage. While these revenue streams are lower today than customer bill savings, they provide customer-sited storage investments optionality and alternative revenue streams that increase their overall attractiveness.

+ **Long-duration energy storage technologies may support New England's need for clean, firm energy in a deeply decarbonized future.** New England's reliability challenge as it decarbonizes will increasingly be ensuring sufficient energy availability during high load, low renewable production periods in winter months. Long-duration energy storage, which often refers to technologies designed to shift generation on scales longer than a day, can help move power from times of year with more abundant renewable generation to periods of prolonged low wind and solar production (e.g., cold winter snaps). A range of potential long-duration energy storage technologies (e.g., iron-air batteries, hydrogen generation) could provide Maine with low- or zero-carbon dispatchable generation or long-duration energy storage, particularly beyond 2030 as regional carbon targets become stricter and emerging technology costs fall. While today no long-duration storage technology is widely and commercially available, there are an increasing number of promising demonstration-scale projects across the U.S.

+ **Notable hurdles remain related to near-term storage deployment in the state**. While the commercial viability and costs of energy storage have declined precipitously over the last several years, energy storage remains too costly to scale for some potential use cases today, and challenges with interconnection limit the pace of its deployment. In addition, the ability to access and monetize certain revenue streams remains limited, given the lag in wholesale market reforms, rates designs, and other barriers. Other revenue streams associated with integration of renewables will not materialize until greater penetrations of renewables are present on the system. Policy considerations, discussed below, can help alleviate the economic and other barriers to accelerated storage deployment.

6.2 Policy Considerations

Policy support will be critical to lower barriers and encourage storage deployment in Maine leading up to the 2030 storage target, and policies that accelerate near-term deployment will help ensure Maine achieves its mid-century 100% renewable energy target in a cost-effective manner. Suggested near-term actions to promote storage deployment in Maine are detailed below.

+ **Supporting actions that ease the development process for storage resources.** Stakeholders identified roadblocks to permitting, interconnection, siting, and customer identification as hurdles to storage deployment in Maine. Specific strategies to alleviate these hurdles include:
    - Support a standardized statewide permitting process for energy storage resources, lessening the time and resources needed to satisfy permitting requirements across local jurisdictions.
    - Establish policies and guides for storage interconnection that reduce uncertainty for storage developers, as well as support utilities aligning their interconnection processes with ISO-NE to streamline the process for developers and reduce costs.
    - Support updating interconnection procedures to encourage energy storage development, including, as identified by stakeholders, how storage is treated in System Impact Studies as a load during peak events instead of a generator, which can often run contrary to typical battery operations.
    - Collect data to ensure visibility for storage developers and to help enable storage projects are sited where they can provide the most value. This includes data on available sites for development, remaining substation capacity, hourly load data (actual and forecasted) for substations connecting the distribution and bulk systems (i.e., transmission nodes), as well as anonymous customer class load data for targeted retail-level storage.
+ **Supporting technology neutral approaches to policy that seek to grow Maine's energy storage market.** Although Li-ion batteries are currently the most prevalent technology choice for new storage development, that position is subject to change as technologies improve and cost declines are realized. Further, as decarbonization continues, the type of storage needed, and specifically the duration of storage needed, will evolve. Crafting policies that do not favor one storage technology will allow Maine to benefit from and foster innovation among emerging storage technologies, further supporting its decarbonization goals.
+ **Initiating data collection to track storage deployment progress.** Tracking data on storage projects in development and newly commissioned projects will help inform the state on progress towards its goals. In addition to location and configuration, attention should be paid to what use cases and value streams these storage deployments are utilizing so policy emphasis can be appropriately placed.
+ **Emphasizing storage in the continued efforts to invest in energy efficiency and renewable energy at state-managed facilities and property.** This will leverage the state government's purchasing power and could include setting requirements for energy storage to be considered for state-managed facilities and coupling storage with government procurements related to energy efficiency, renewable energy, or resiliency. This will build upon considerations in the

2021 State of Maine Lead by Example report[78] which includes an energy and efficiency plan that considers policies to install energy storage on state property, as well as batteries to improve resiliency when designing critical facilities.

- **Making resources and information available to local municipalities and tribes to accommodate energy storage development given a rapidly developing industry.** This should include the benefits of storage for their community, as well as development hurdles that projects may face and potential solutions. It also could include support for model ordinances for storage development in the local municipalities.
- **Monitoring guidance from the DOE and other federal agencies regarding end-of-life considerations and the decommissioning of storage installations.** Such guidance will touch upon best practices for dismantling the technology, transporting it, disposal, or recycling and whether a decommissioning fund is needed. This is recommended as a practical forward-looking step that should be undertaken as Maine considers the eventual retirement of its storage assets.
- **Leveraging the GEO's role as a convenor by developing and running an ongoing energy storage stakeholder group.** This can bring together storage developers, policymakers, utilities, environmental groups, and other interested parties to facilitate discussion on how to encourage energy storage development in the most fair and efficient ways possible. This could also be a forum for sharing information and coordinating storage policy in Maine, as well as with other New England states.

Other challenges to storage deployment require coordination across various regional and state agencies but will be important to accelerating storage in Maine. These include:

- **Supporting adjustments to customer rate design that align customer price signals with societal avoided costs and locational values.** The benefit-cost analysis results show a misalignment of rates for customer-sited storage + solar. Aligning rates with societal avoided costs and location values will ensure that customer-sited storage is deployed in a way that maximizes its effectiveness for society and allows the owner to maximize its benefits. Further, the impact on GHG emissions should be assessed to ensure that time-varying price signals do not inadvertently encourage higher emissions based on the current and forecasted time-varying marginal emission rates of the grid. It should be noted that currently there are open dockets (2021-00273 and 2021-00325)[79] with the PUC considering revised rate structures for energy storage.
- **Supporting the consideration of the best set of possible value streams from all possible perspectives for energy storage in cost-benefit analysis frameworks.** As seen in the benefit-cost analysis results, the cost-effectiveness of storage resources often depends on multiple,

[78] "State of Maine Lead by Example 2021 Report," Governor's Office Policy Innovation and the Future and the Governor's Energy Office, accessed on February 7, 2022, https://www.maine.gov/future/sites/maine.gov.future/files/inline-files/Lead%20By%20Example_2021.pdf.

[79] "Case Search," Maine Public Utilities Commission, accessed on February 7, 2022, https://mpuc-cms.maine.gov/CQM.Public.WebUI/Common/CaseSearch.aspx.

coordinated, value streams. Including the most optimal set of value streams will provide a more accurate view of the cost-effectiveness of storage to its owner and the broader system.

- Specifically, this applies to the cost-benefit analysis framework used to analyze DERs by Maine's Distributed Generation Stakeholder Group. It also applies to the Maine PUC procurement process, which should not only consider all possible value streams from a range of perspectives, but also define a specific cost-benefit analysis framework that will be used to analyze the storage resources, and possibly compare them to other technologies depending on the nature of the procurement solicitation. Clearly defining this framework in advance of soliciting bids will ensure the storage systems are designed to be as competitive as possible.

+ **Supporting efforts to implement incentive programs for energy storage that have the potential to bring high value benefits to Maine.** As seen in the benefit-cost analysis results, without the inclusion of resiliency benefits, or storage incentive programs that EMT has proposed, customer-sited storage often does not look cost-effective from the participant perspective given its high costs. Incentive programs will be important to counterbalance these higher costs and unlock additional societal benefits.

  - In its Triennial Plan V (2023-2025),[80] EMT has proposed two initiatives through its Demand Response Program with upfront and performance incentives for load management technologies, including battery storage with controls, and will aim to lower energy costs in Maine and enhance grid reliability.
  - As proposed, these initiatives would share features with other programs in the New England region, including ConnectedSolutions and Connecticut's recently adopted Energy Storage Solutions Program. Both programs contain similar performance incentives, which are closely tied to the avoided cost estimates contained in the Avoided Energy Supply Costs in New England (AESC). Also, like New York's value stack approach, they aim to offer an additional revenue stream to storage owners based on the benefits provided to the system.

+ **Supporting the development of fair and transparent charging tariffs for wholesale storage resources that are connected to the distribution system but participating in ISO-NE wholesale markets.** This has been cited by several stakeholders as a key barrier to distribution-connected wholesale storage.

  - The state of Texas has addressed this by stating that wholesale storage is not subject to retail tariffs and if a storage facility is connected to the distribution system (and

[80] "Triennial Plan for Fiscal Years 2023-2025," Efficiency Maine Trust, accessed on February 7, 2022, https://www.efficiencymaine.com/docs/Triennial-Plan-V_FY2023-2025.pdf

separately metered) it shall settle at the nodal price of the nearest electrical bus that connects to the transmission system. [81]

- Another example is in New York, where the New York Department of Public Service and NYSERDA recommended that standalone energy storage be exempt from demand charges.[82] This recommendation cited the critical need for energy storage to meet the state's clean energy goals and the need to remove policies that would hinder the economics of energy storage when little ratepayer impact would occur.

6.3 Recommendations for Future Analysis

This study provides a robust fact-base to inform Maine's storage policy and actions. However, additional analysis can also inform how to pursue storage deployment in a way that maximizes benefits to Mainers. Those recommendations, which also relate to certain caveats and limitations explained in Section 4.5, are detailed below:

+ **Peaker Replacement Analysis:** Energy storage has the potential to replace fossil-fuel peaker plants under certain circumstances. Storage can also act as a peaking resource and replace specific inefficient (and often high polluting) peaking generating plants, leading to local environmental and economic development benefits. Useful future analysis could be performed to determine whether a storage resource (and in what duration) could replace the operations of a peaker plant, as well as quantify the revenue to the storage owner and benefits to society.
+ **Jobs and Economic Impact Assessment:** To support policy decisions, analysis could be performed to evaluate the macroeconomic impacts of deploying storage in Maine. This analysis could focus on job creation, labor income and gross regional product and could be broken down into regions in Maine to better understand where the most economic benefits from storage deployment could be achieved.
+ **Location-specific Nodal Modeling:** Congestion relief and renewable integration (curtailment reduction and price impacts of shifting generation) benefits are not quantified in the modeling, given it was beyond the scope of the modeling tools used for this study. Follow-up analysis, performing nodal-level analysis, can capture some of the impacts of adding storage to strategic locations on the grid and show how the prices at specific congested nodes can change, as well as the prices (and potential curtailment) seen by renewable generators at those nodes, all informing the optimal location for storage deployment at a more granular level.
+ **Equity Analysis:** Energy storage could provide distinct benefits to disadvantaged communities, for example through local emission reductions associated with replacing peaking power plants. Equity analysis should be performed to assess and quantify potential benefits, as well as identify

[81] "ORDER ADOPTING AMENDMENTS TO §25.192 AND §25.501 AS APPROVED AT THE MARCH 7, 2012 OPEN MEETING," The Public Utility Commission of Texas, accessed on February 27, 2022, https://www.puc.texas.gov/agency/rulesnlaws/subrules/electric/25.501/39917adt.pdf

[82] "Re: Case 15-E-0751 – In the Matter of the Value of Distributed Energy Resources." New York Department of Public Service, accessed on February 3, 2022, https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B5A84360D-4093-4F1E-83D2-475143ADD169%7D

which areas of the state could benefit most from storage development given these potential benefits.