New England Energy Storage Duration Study

PREPARED BY

J. Michael Hagerty

Ragini Sreenath

Kate Peters

Andrew Levitt

PREPARED FOR

CYPRESS CREEK RENEWABLES

DECEMBER 18, 2023

Brattle

Disclaimer

PLEASE NOTE

- This report was prepared for Cypress Creek Renewables, in accordance with The Brattle Group's engagement terms, and is intended to be read and used as a whole and not in parts.
- The report reflects the analyses and opinions of the authors and does not necessarily reflect those of The Brattle Group's clients or other consultants.
- The projections provided in this presentation are necessarily based on assumptions with respect to conditions or events which may or may not arise or occur in the future. While we believe these assumptions to be reasonable for purposes of preparing our analysis, they are dependent upon future events that are not within our control or the control of any other person. Actual future outcomes can and will differ, perhaps materially, from those evaluated in these projections. No one can give any assurance that the assumptions and methodologies used will prove to be correct or that the projections will match actual results of operations. We do not make any representation with respect to the likelihood of any specific future outcome, and cannot and do not accept liability for losses suffered.
- While the analyses presented may assist Cypress Creek Renewables in rendering informed decisions, it is not meant to be a substitute for the exercise of Cypress Creek Renewables's own business judgment. Neither we nor Brattle will accept any liability under any theory for losses suffered, whether direct or consequential, arising from the reliance on the analyses presented, and cannot be held responsible if any conclusions drawn from this presentation should prove to be inaccurate.
- There are no third party beneficiaries with respect to this report, and The Brattle Group does not accept any liability to any third party in respect of the contents of this report or any actions taken or decisions made as a consequence of the information set forth herein.

Executive Summary

Projected New England Energy Storage Duration Needs

As New England electrifies and decarbonizes over the coming decades additional clean generation and energy storage resources are needed to satisfy clean energy goals and resource adequacy needs

	Storage Duration	Study Findings on New England Storage needs
Through 2032	**Short to Mid Duration Storage (1 to 4 hrs)**	• New England needs **2 GW of short-duration (1-2 hr) storage and 4 GW of mid-duration (4 hr) storage** through 2032 • Rising electrification demand (+4 GW by 2032) coinciding with fossil retirements (-6 GW by 2032) create a need for new resources to meet resource adequacy targets • System needs short- to mid-duration storage at lower (<50%) renewable energy penetration that can provide fast-responding ancillary services and shift solar to meet summer evening peak demand
Mid-2030s	**Mid Duration Storage (4 to 8 hrs)**	• **Additional 12 GW of mid-duration storage (4 GW of 4 hr, 8 GW of 8 hr)** needed through the mid-2030s • Accelerated pace of electrification and renewable energy deployments shifts New England's reliability risks from summer peak demand hours to winter days with high heating demand and low OSW output • System increasingly reliant on renewable energy (50 – 60%) requires mid-duration storage that can balance hourly generation with demand throughout the year and can meet sustained tight market conditions
2040s	**Long Duration Storage (10+ hrs) or Clean Firm Generation**	• **10-12 GW of long-duration (10+ hrs) storage or clean firm generation** needed to achieve deep decarbonization in 2040s • New England will rely primarily on clean resources to serve demand while achieving 80%+ reductions in GHG emissions and meet state economy wide carbon goals • Clean resources that can serve 20-100 consecutive hours of demand (e.g. clean firm imports, long-duration storage with renewable energy, hydrogen, or energy efficiency) required to decarbonize system

Storage needs will be higher if market conditions differ from our assumptions, such as: (1) demand growth accelerates due to electrification, data centers, etc., (2) fossil resources retire faster than recent past, (3) storage costs decrease more than projected, and (4) transmission constraints increase value in certain pockets on the system.

Study Objectives and Projected Results

Study Motivation and Objective

New England states are pursuing significant reduction in electric power sector greenhouse gas (GHG) emissions to meet state policy goals in 2030 to 2050 through a transition of its generation fleet towards renewable energy and other clean energy resources

To support the clean energy transition, Massachusetts passed HB5060 in 2022 that requires the Department of Energy Resources (DOER) and Clean Energy Center (CEC) to:

- Conduct a study how to optimize the cost-effective deployment and utilization of both new and existing mid-duration (4 – 10 hours) energy storage and long-duration (10+ hours) energy storage (LDES)
- Investigate the necessity, costs and benefits of requiring distribution companies to conduct solicitations and procurements of up to 4,800 GWh of stored energy from renewable generation delivered to periods of high demand each year

Our report is intended to supplement the DOER/MassCEC energy storage study by demonstrating the scale and timing of mid- to long-duration storage needed in New England and Massachusetts through 2032 and longer-duration resources by 2050

Analytical Approach and Power System Models

We simulated in Brattle's gridSIM model the New England power system through 2050 to identify the least-cost resources to meet future demand and reliability requirements in a decarbonized system

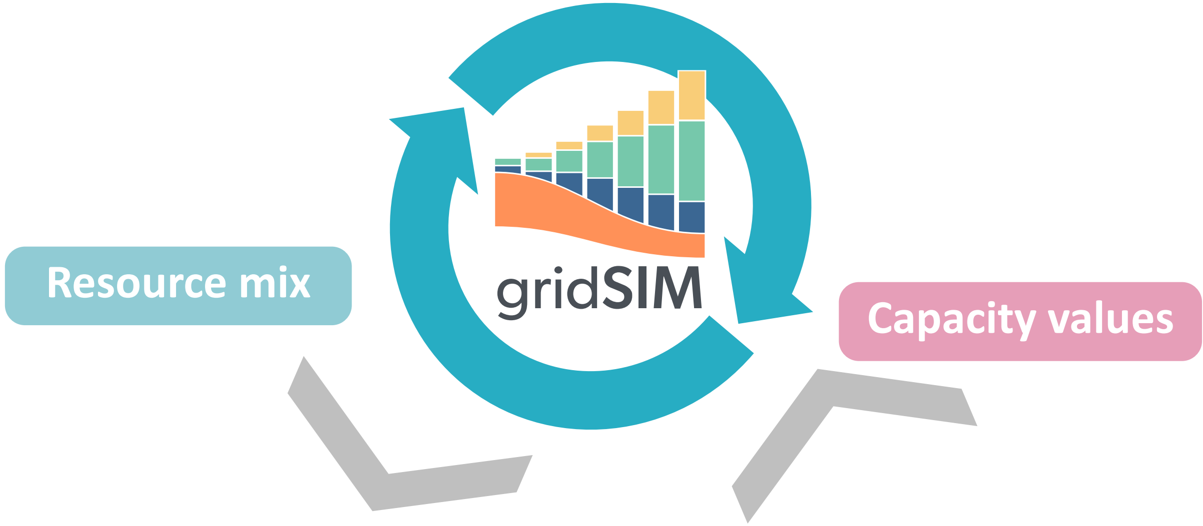
To accurately capture the evolving power system needs and synergies between renewable energy and storage, we integrated the capacity values estimated by Brattle's Capacity Capability Model (CCM) into gridSIM

- gridSIM captures hourly dispatch over multi-day periods and identifies least cost resource additions & retirements to meet resource adequacy demand based on CCM capacity accreditation
- CCM captures contributions of wind, solar and storage simultaneously to meeting tightest market conditions across 20 weather years accounting for the existing resource mix and each resource's incremental contributions to achieving reliability targets relative to "perfect" capacity. ELCC results are reported to gridSIM

GridSIM and CCM solve iteratively to account for the year-to-year changes in generation resource mix that impact ELCCs

gridSIM

- Capacity expansion optimization engine
- Minimize NPV of investment & operational costs



Capacity Capability Model (CCM)

- 20-years of hourly load, wind, and solar profiles
- Derives hourly output of storage through dispatch algorithm
- Provides capacity values of renewable energy and storage to gridSIM based on peak-normalized expected unserved energy (EUE), see appendix for more details

Note: gridSIM and CCM are Brattle proprietary models

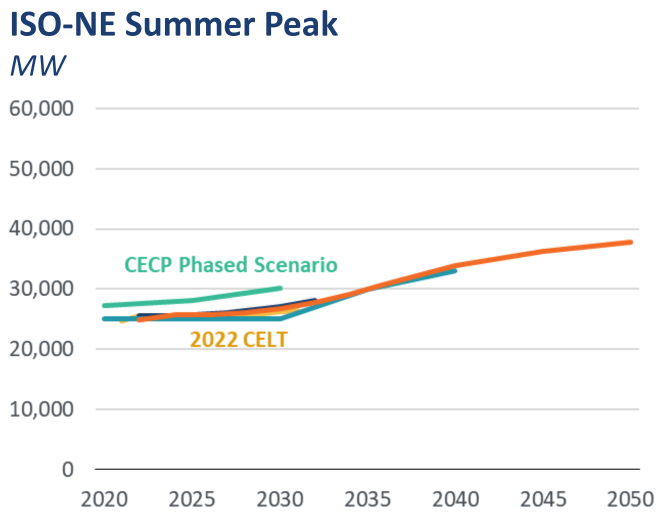
Projected Electricity Demand and Resource Adequacy Needs

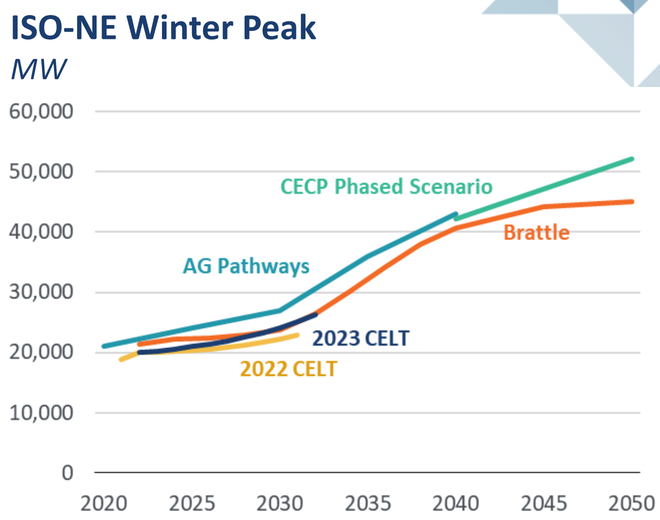
We developed long-term demand forecasts that align with the ISO-NE 2023 CELT and Pathways study

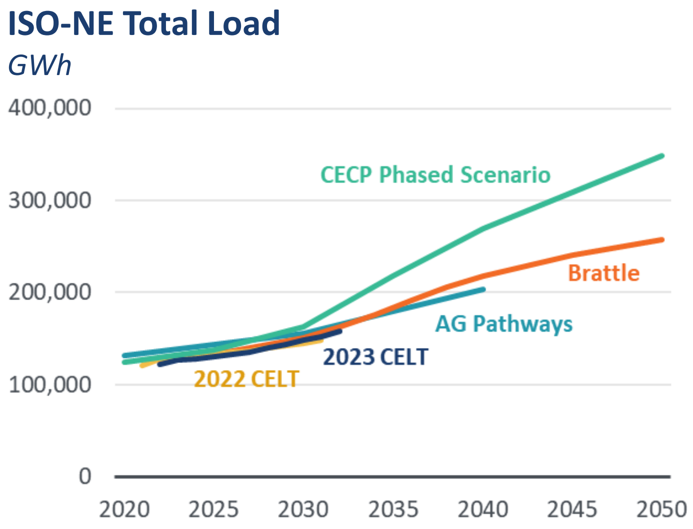
- We assumed similar electrification adoption through 2031 as projected in the transportation load forecast and heating load forecast
- Total load is consistent with ISO-NE Pathways modeling through late 2030s and is slightly more aggressive in 2040
- CECP load forecasts are higher due to 60 TWh of electrolysis demand that we do not include

Hourly demand based on 2019 ISO-NE load shapes plus additional hourly demand from electrification

Annual reserve margin is consistent with ISO-NE net ICR forecasts (11%-16%) through 2031. After 2031, we assume the net ICR increases to 18% due to higher demand uncertainty in a winter peaking system





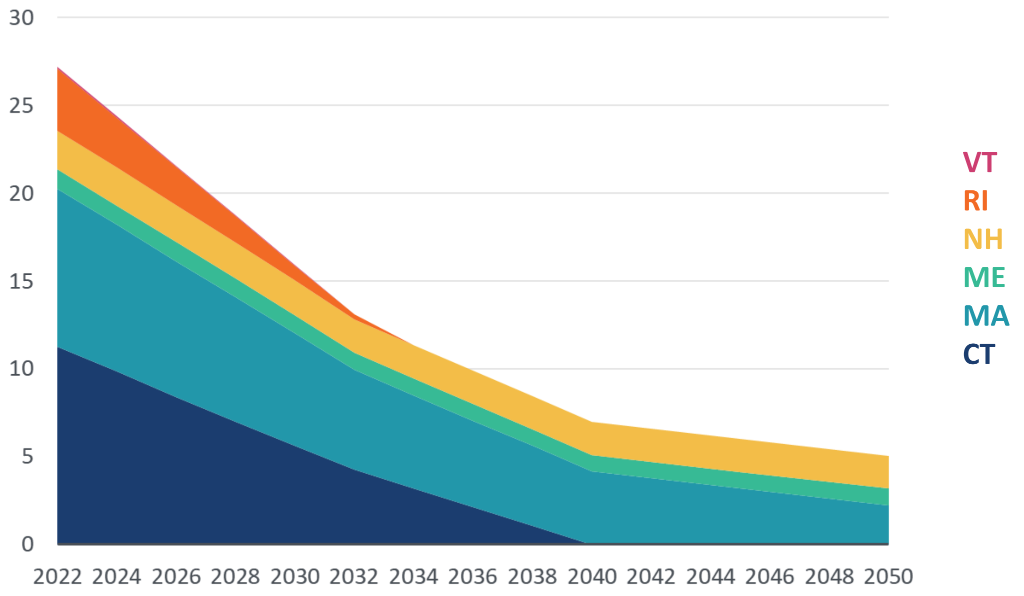


State-by-State Renewable Energy and Carbon Goals

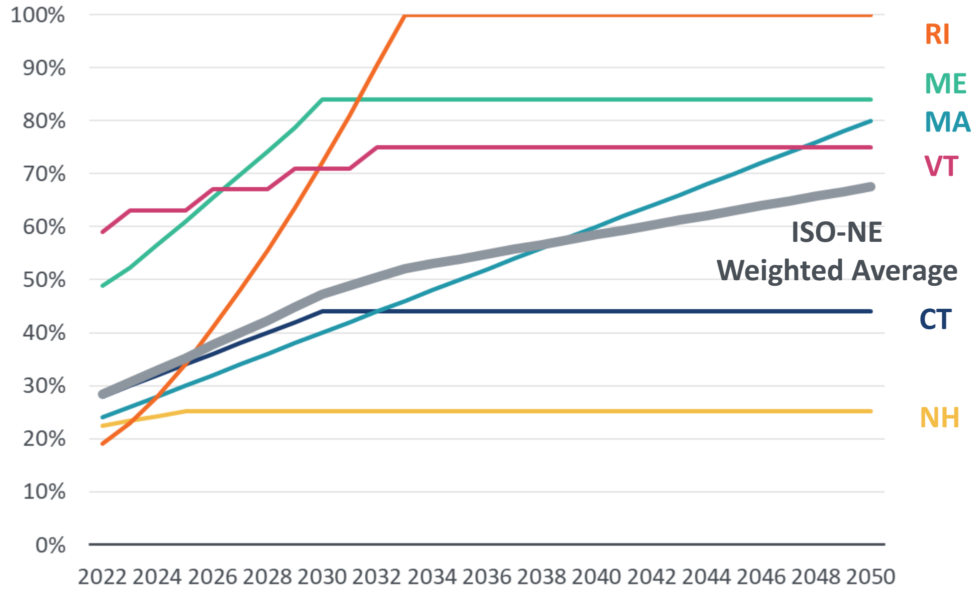
State-level Renewable Portfolio Standards (RPS), renewable & storage procurements, and GHG policies are modeled in gridSIM at an ISO-NE level to achieve:

- About 90% electric sector GHG reduction by 2050 (from 2005 levels)
- 70% renewable energy by 2050

GHG Electric Sector Emission Targets
$MMTCO_2e$



State RPS Targets
%



Note: MA target for the electric sector does not count CO_2 emissions from biogenic combustion.
Source: Massachusetts 2050 Clean Energy and Climate Plan.

Supply-Side Assumptions

Data Element	Source
Existing generation & storage resources	**Velocity Suite** for capacity, heat rate, and storage duration; capacity benchmarked against CELT and S&P **NREL Annual Technology Baseline 2022** for fixed and variable operations & maintenance costs (FOM, VOM)
Existing generation retirements	**Velocity Suite, ABB Inc.** for announced retirements plus an additional 500 MW/year of fossil retirements based on recent historical averages; nuclear remains online through 2050
New generation & storage resources	**NREL Annual Technology Baseline 2022:** Moderate cost case (capital, FOM, VOM) accounting for IRA impacts **ISO-NE Pathways Study** and **Second Maine Resource Integration Study** for transmission costs, *see Appendix for more detail*
State clean energy procurements	**State procurement targets** for offshore wind (8.4 GW by 2030) and battery storage (1.4 GW by 2030, not including HB5060, see next slide for details) **NECEC** line comes online in 2026 and provides 1.2 GW capacity at 90% capacity factor
Renewable generation shapes (hourly)	**ISO-NE** for offshore wind and onshore wind and **NREL SAM** for solar based on 2019 weather for gridSIM **ISO-NE** offshore wind, onshore wind and solar historical 2001 – 2021 profiles for CCM
Fuel prices	**Forwards and AEO 2022 Ref. Case** for natural gas **AEO 2022 Ref. Case**, Tables 3 and 54 for nuclear, coal, oil

Notes: FOM – fixed operations and maintenance costs; VOM – variable operations and maintenance costs; NECEC – New England Clean Energy Connect; SAM – System Advisor Model; AEO – Annual Energy Outlook

Energy Storage Resource Assumptions

Our simulations account for the option to add several durations (1 hour, 2 hour, 4 hour, and 8 hour) of lithium-ion battery storage to identify near-term and long-term storage needs

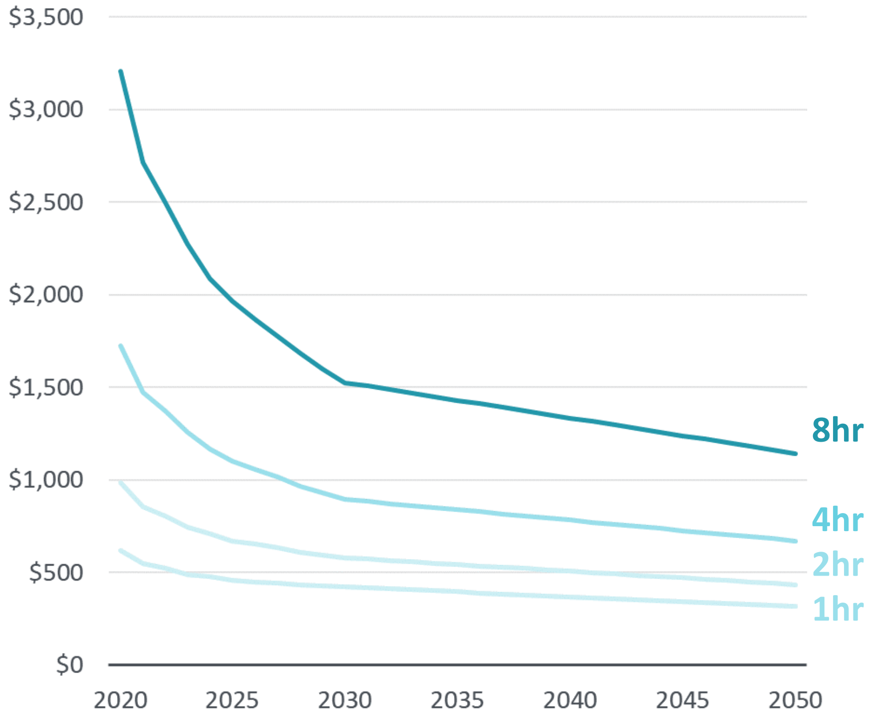
We run two cases to analyze the impact of MA policy on storage:

- Base Case: Massachusetts procures 13.2 GWh of mid- to long-duration energy storage capacity to achieve HB5060 by 2030
- Sensitivity Case: No HB5060-related storage procurements; storage enters based on future market conditions

Clean firm resources may enter starting in 2040 as a proxy for emerging technologies (e.g., H2, LDES, clean imports, etc.) that operate over longer durations without GHG emissions

- Due to uncertainty in costs, characteristics, and availability, we do not model several potential clean firm resources that could emerge
- Entry may occur earlier than 2040 if the economics of the developing clean firm resources become more attractive than 8-hr Li-ion storage

New Storage Resource Capital Costs
$2020/kW



Note: We assume one cycle per day such that 13.2 GWh of energy storage capacity can provide 4,800 GWh of stored energy to periods of high demand per year

Projected Renewable Energy and Storage Additions through 2032

New England needs 24 GW of renewables and 5 GW of storage to meet its policy goals and maintain reliability in 2032 both with and without HB5060

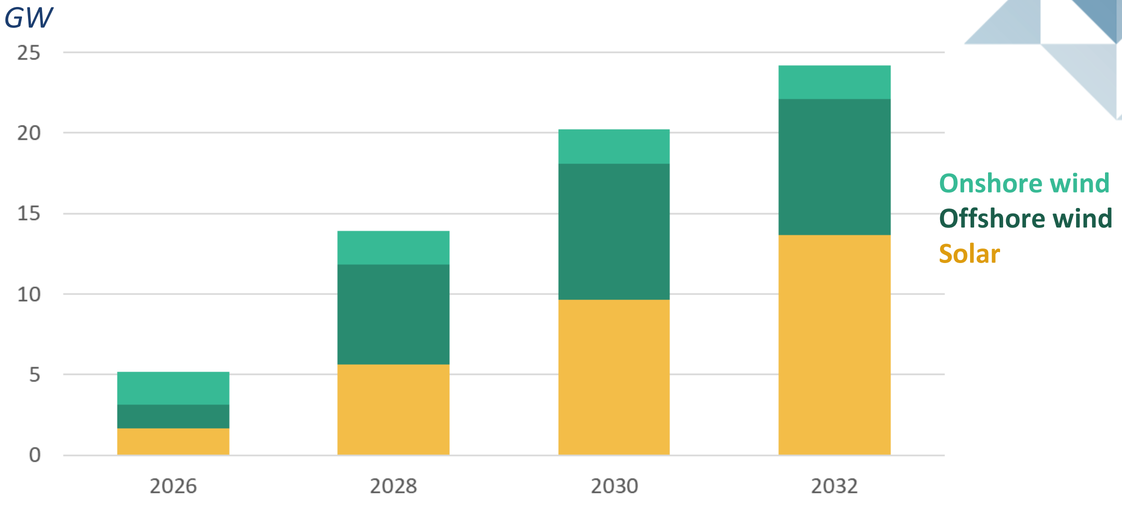
Renewable Energy Additions:

- Renewable energy additions are split between solar (14 GW), offshore wind (9 GW), and onshore wind (2 GW)

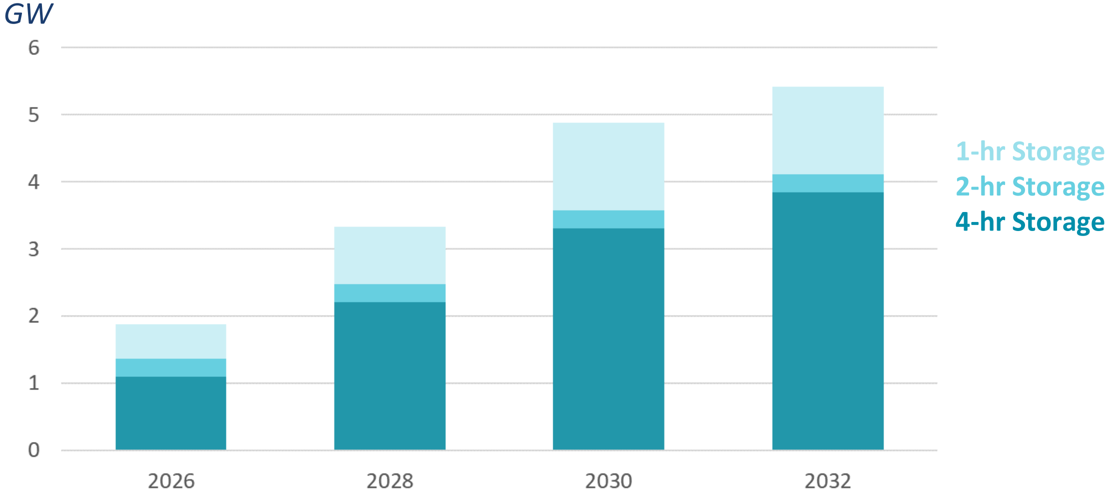
Storage Additions:

- Existing procurements (CT, ME, and MA) for 1.8 GW of storage by 2030 are met by 1-hr and 2-hr storage*
- 3.8 GW of 4-hr storage built by 2032:
  - 3.3 GW is added to meet HB5060 through 2030
  - An additional 0.5 GW built economically in 2032
- *Sensitivity Case*: 3.9 GW of 4-hr storage enters in 2032, demonstrating its cost effectiveness without HB5060; HB5060 procurements will accelerate development of storage to 2026 and spread it out over several years

Cumulative Renewable Energy Additions through 2032



Cumulative Storage Additions through 2032



Note: Results show cumulative resource additions since 2022, with HB5060

* In order to satisfy near-term storage procurement targets in CT, ME, and MA, 1-hr and 2-hr duration storage is built by 2026 due to its lower per-kW costs.

Cost Effectiveness of 4-hr and 8-hr Storage through 2032

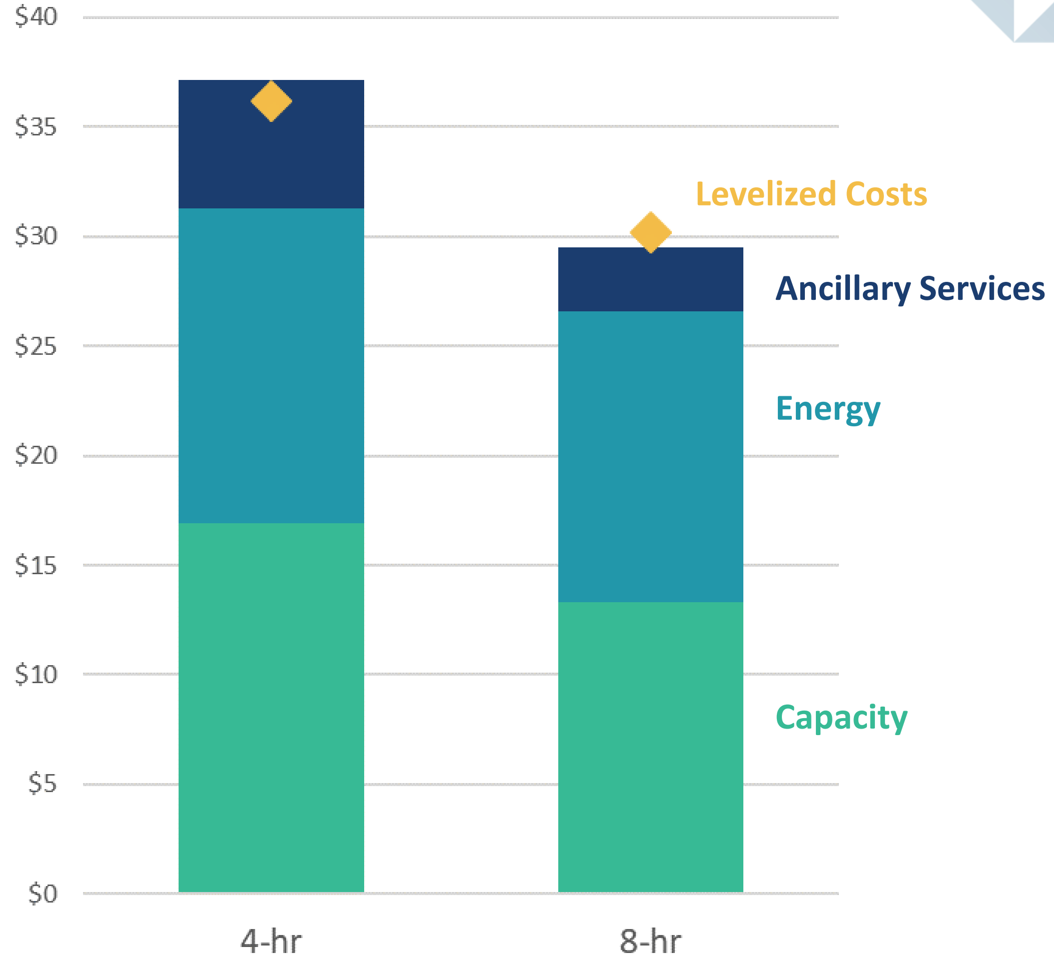
Through 2032, 4-hr storage is more cost-effective than 8-hr storage (i.e., levelized revenues exceed levelized costs) to meet near-term system needs

- 4-hr levelized costs are higher than 8-hr on a per-GWh basis as the costs of the inverter are spread over less storage capacity
- However, 4-hr storage provides more energy, ancillary service, and capacity value per GWh that overcomes the higher cost
- Capacity value of 4-hr storage in the early to mid-2030s of 60 – 70% is similar to 8-hr (about 90%) due to a shorter-term peak compared to later years

ELCCs of both durations decrease in the late 2030s following 12 GW of storage entry, with 4-hr ELCCs decreasing faster than 8-hr (see details on slide 15)

2032 Levelized Revenues vs Costs

$/kWh-year



Projected Renewable Energy and Storage Additions through 2038

Through 2038, New England needs an additional 4 GW of 4-hr and 9 GW of 8-hr storage to balance hourly generation and demand in the winter peaking and renewable-heavy system

Renewable Energy Additions:

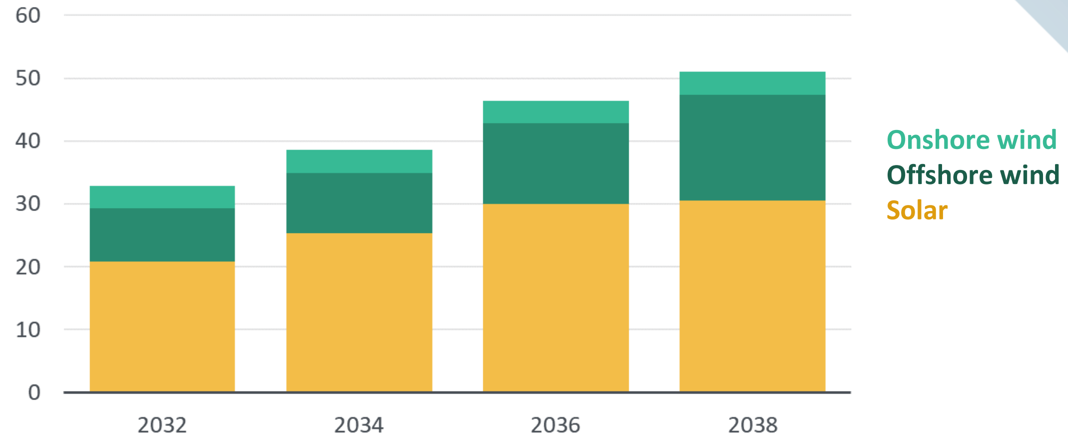
- Renewable energy additions in the mid-2030s are evenly split between solar (+9 GW) and offshore wind (+8 GW)

Storage Additions:

- Through the mid-2030s, longer duration storage is needed to maintain reliability in an increasingly clean and winter peaking system
- An additional 4 GW of 4-hr storage added by 2036
- 8-hr storage first enters in 2036 followed by a significant increase by 2038
- The Base Case and Sensitivity Case result in similar levels of storage capacity through 2038

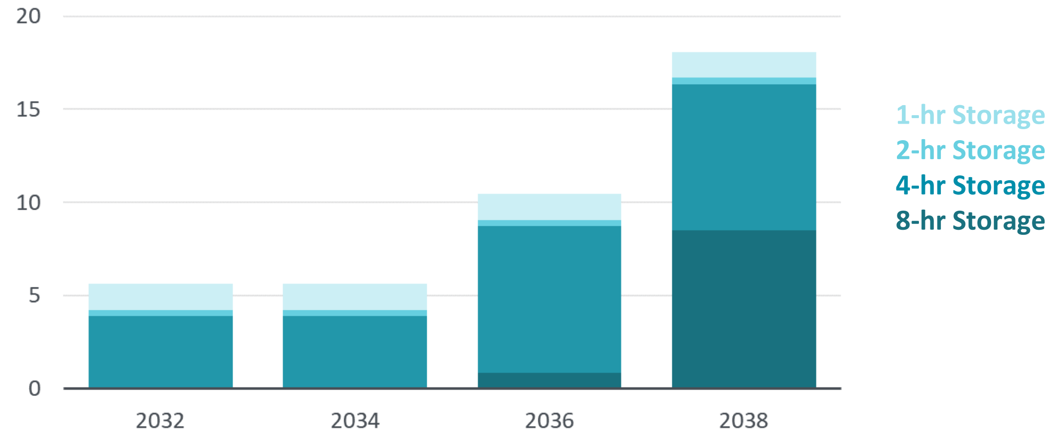
Cumulative Renewable Energy Additions through 2038

GW



Cumulative Storage Additions through 2038

GW



Note: results show cumulative resource additions since 2022, with HB5060. The two cases are similar after 2032, see additional details in the appendix

Capacity Value of Renewables and Storage

Accurately capturing renewable and storage capacity value (and the synergies between them) is critical for maintaining reliability and projecting the resource mix

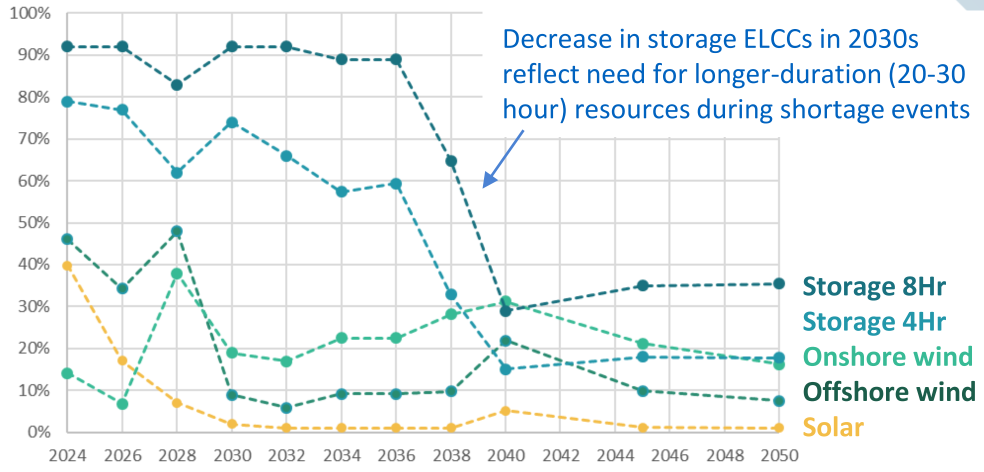
4-hr storage ELCCs initially are about 14-26% lower than 8-hr through the mid-2030s, but then drop to 50% lower in later years following the significant storage additions

- 4-hr storage is preferred through 2036 when its capacity value is 64-86% of 8-hr storage
- From 2036 to 2040, ELCC of both decreases significantly due to 12 GW of storage additions and 4-hr drops to about 50% of 8-hr storage
- This shift in ELCC results in significantly more 8-hr storage in the late-2030s than 4-hr storage, as shown on the next slide

Projected 2045 and 2050 ELCCs for storage imply a need for 20 – 25 hour duration resources to achieve ISO-NE reliability targets in a highly decarbonized system

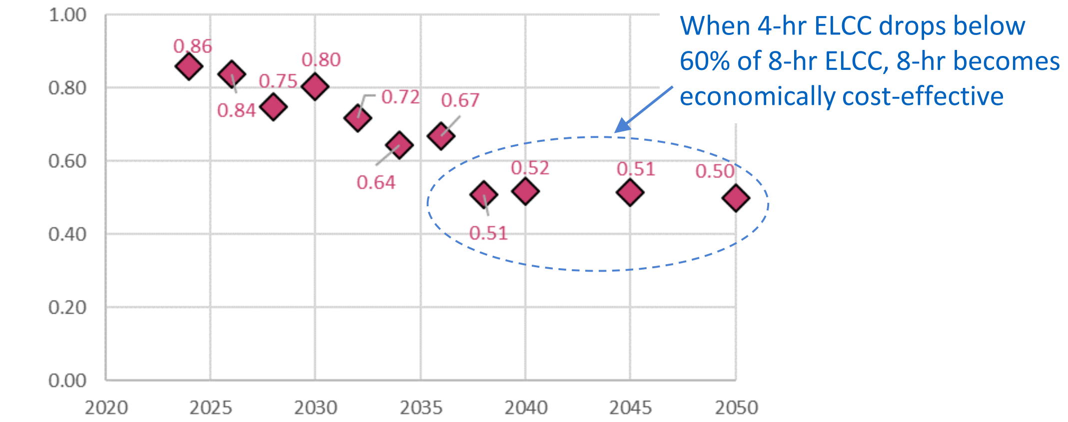
Marginal Capacity Value of Renewables and Storage

UCAP %



Relative Capacity Value of 4-hr Storage to 8-hr Storage

% of 8-hr ELCC



Note: UCAP % reflects each resource's contributions to achieving reliability targets relative to "perfect" capacity. Results shown for with HB5060 case.

Projected Renewable Energy and Storage Additions through 2050

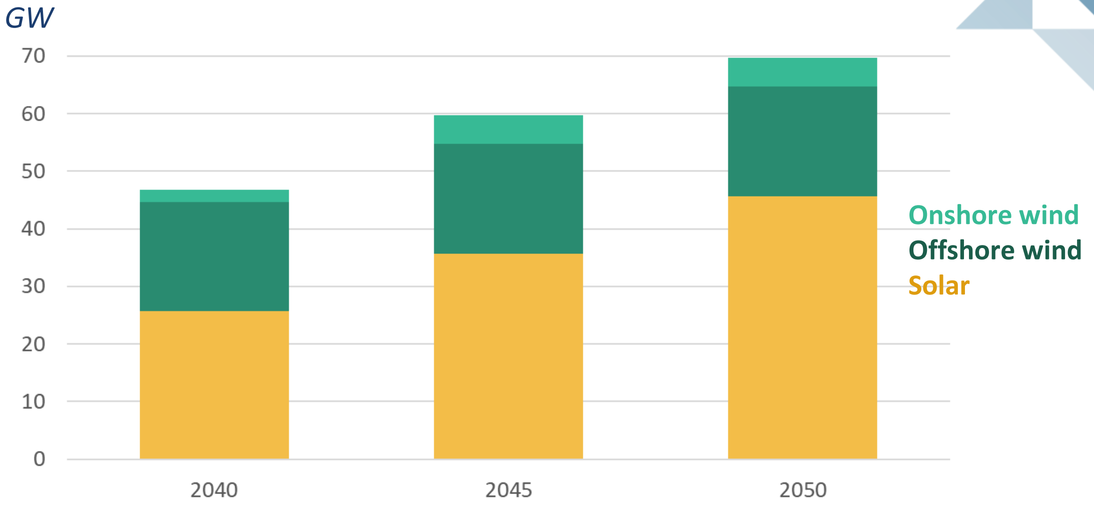
Renewable energy needs accelerate through 2050 as electricity demand increases due to electrification and GHG emissions limits tighten to achieve policy goals of 90% GHG reductions relative to 2005

To achieve long-term resource adequacy needs and balance renewable energy generation demand, additional storage will be needed from 2033 – 2040

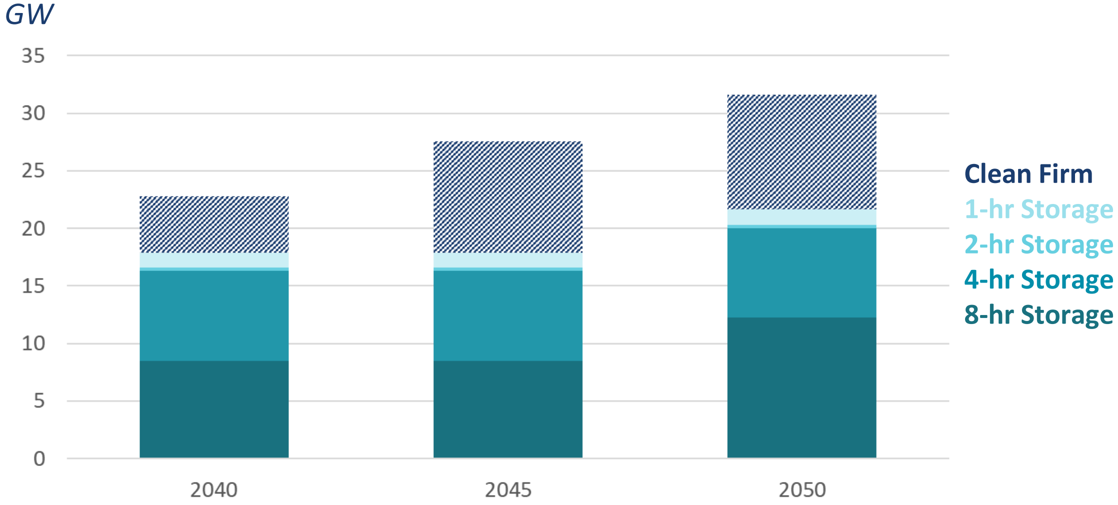
- +4 GW of 4-hr storage (8 GW total)
- +9 GW of 8-hr storage

By 2050, about 10 GW of additional "clean firm" resources will be needed to provide continuous output over longer periods to meet hourly demand during the tightest market conditions

Cumulative Renewable Energy Additions through 2050



Cumulative Storage & Clean Firm Additions through 2050



Note: results show cumulative resource additions since 2022, with HB5060. The two cases are similar after 2032, see additional details in the appendix

Clean Firm Capacity Operations

Several technologies could contribute to meeting the clean firm capacity needs:

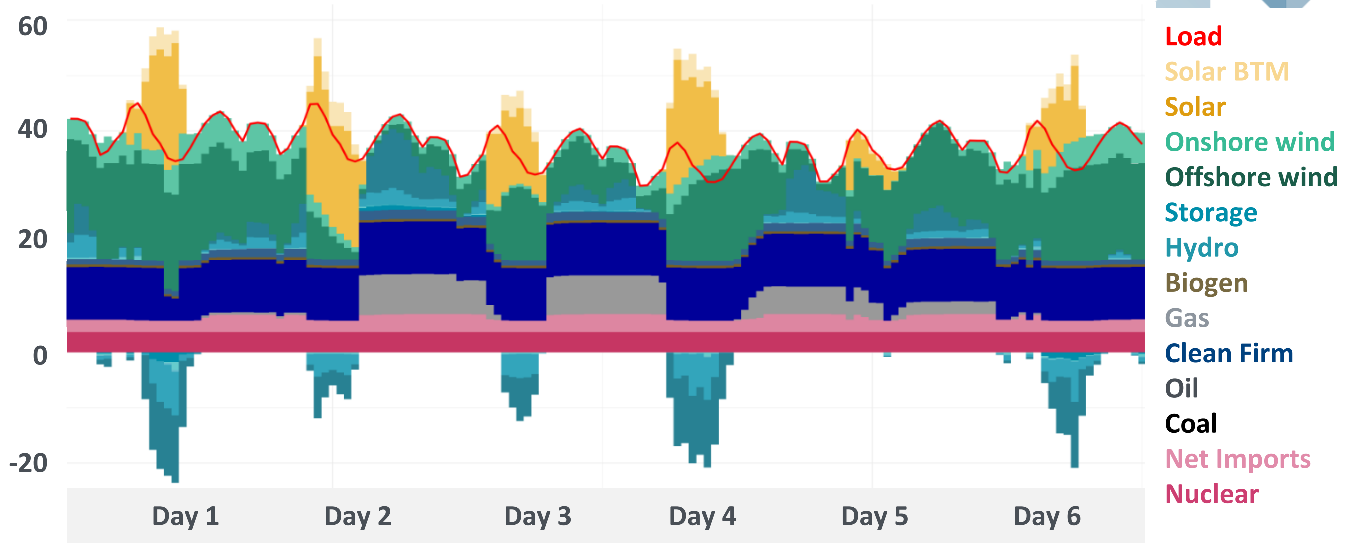
- Renewables with longer-duration storage
- Clean firm imports
- H_2 or biomass-fueled turbines
- Energy efficiency

Clean firm capacity enters in 2040 primarily to meet resource adequacy requirements and is increasingly needed to operate to meet hourly demand by 2050

- Generation occurs in the winter to serve high load, low renewable periods
- Capacity factor increases from 5% in 2040 to 11% in 2050
- Initially runs for 20 – 40 consecutive hours in 2040 but increases to 130 – 150 hours in 2050

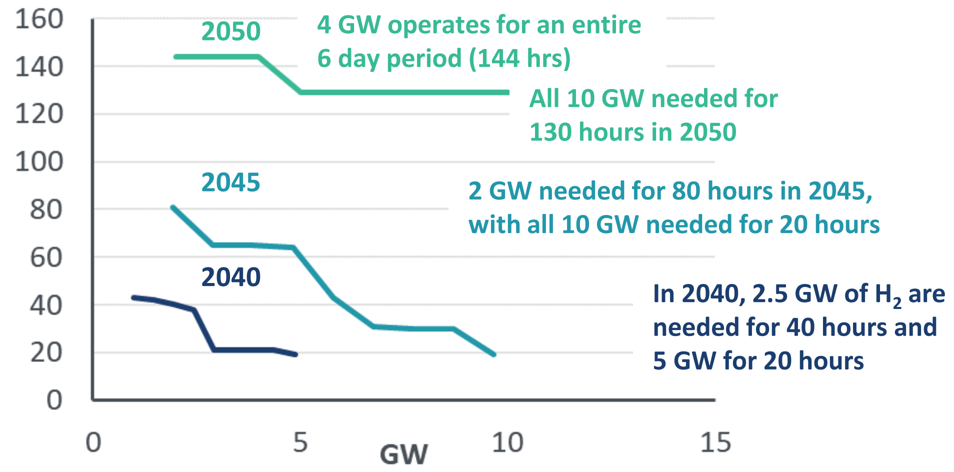
Winter 2050 Six Day Period

GW



Clean Firm Maximum Dispatch Event Duration

consecutive hours of operation

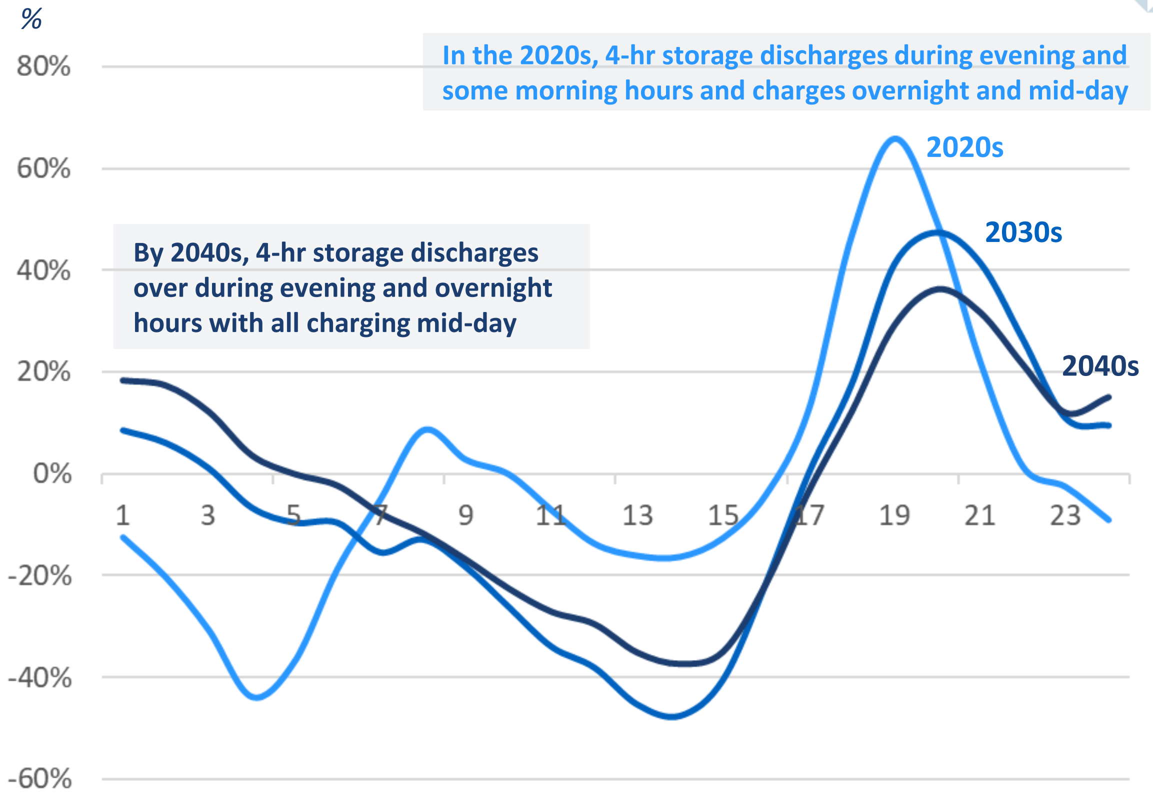


Role of Shorter and Longer Duration Storage

The role of storage will shift as the New England system increasingly decarbonizes and relies on clean resources to balance renewable energy with hourly electricity demand

- **Near-term (2020s):** Storage provides fast-responding ancillary services and meets evening peak demand; best met by shorter-duration (1-4 hr) storage
- **Mid-term (2030s):** Storage balances hourly generation throughout the year and meets longer evening peak hours; requires mid-duration (4-8 hr) storage
- **Long-term (2040s):** Storage and other clean firm generation resources need to generate daily for 10+ hours to balance generation with demand and for 20-100 consecutive hours to maintain reliability in highly decarbonized system

4-hr Storage Hourly Average Charge and Discharge Profile



Detailed Assumptions

gridSIM Modeling Overview

INPUTS

Supply

- Existing resources
- Planned builds and retirements
- Fuel prices
- Investment/fixed costs
- Variable costs

Demand

- Representative day hourly demand
- Forecasts of annual and peak demand
- Planning reserve margins

Regulations and Policies

- State energy policies and procurement mandates

gridSIM OPTIMIZATION ENGINE

Objective Function

- Minimize NPV of Investment & Operational Costs

Constraints

- Planning Reserve Margin
- Hourly Energy Balance
- Regulatory & Policy Constraints
- Resource Operational Constraints

OUTPUTS

Annual Capacity Additions

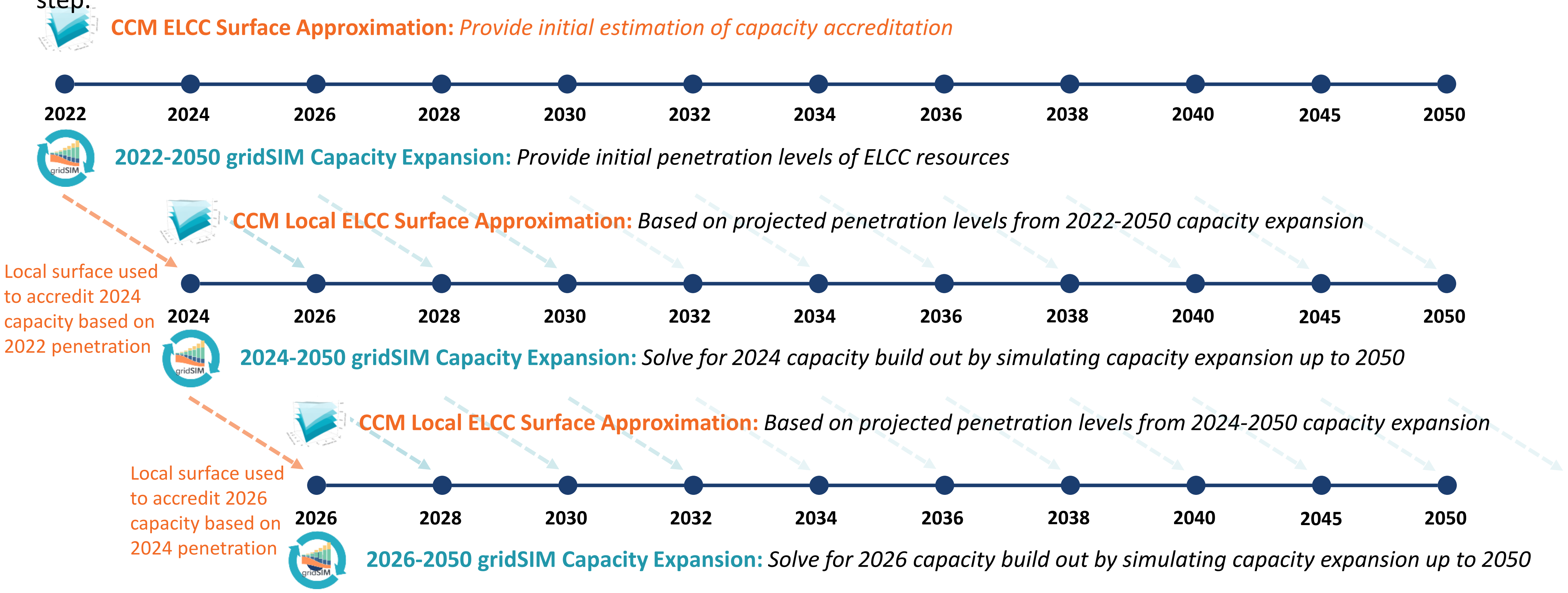
Annual Economic Retirements

Marginal System Costs

System Emissions

Internal Capacity Accreditation Through Sequential Optimization

GridSIM optimizes capacity year-by-year by using a local capacity value surface approximated around the previous year's penetration of studied resources. To account for intertemporal decision making, we simulate capacity expansion for entire time horizon in each step.



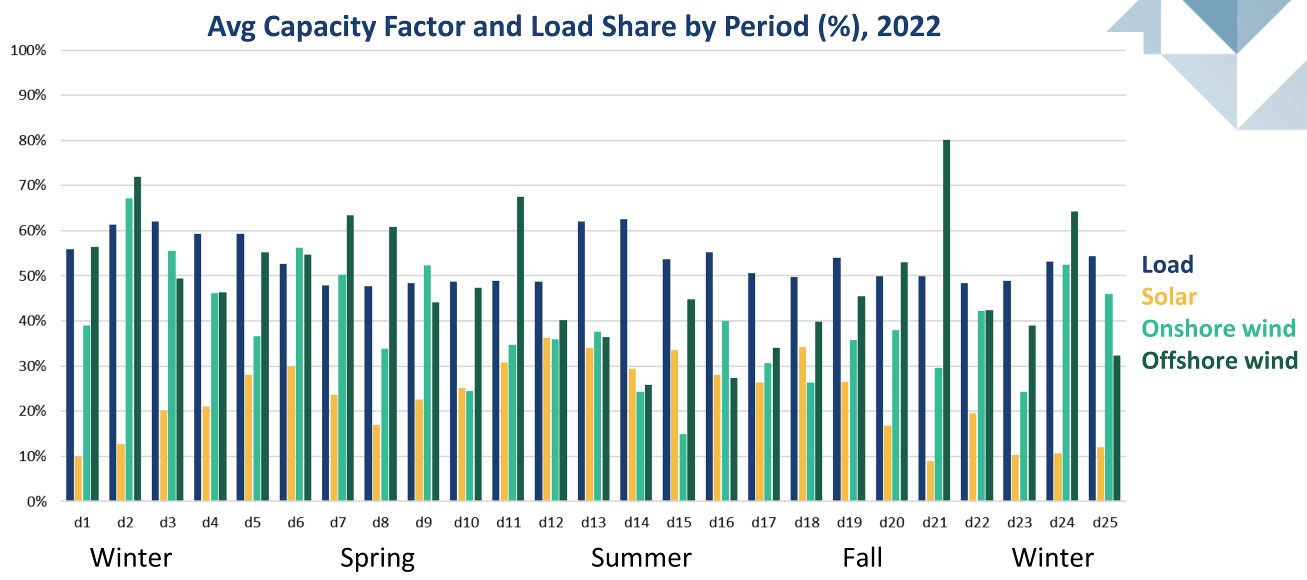
… Sequentially solve until 2050 capacity is optimized

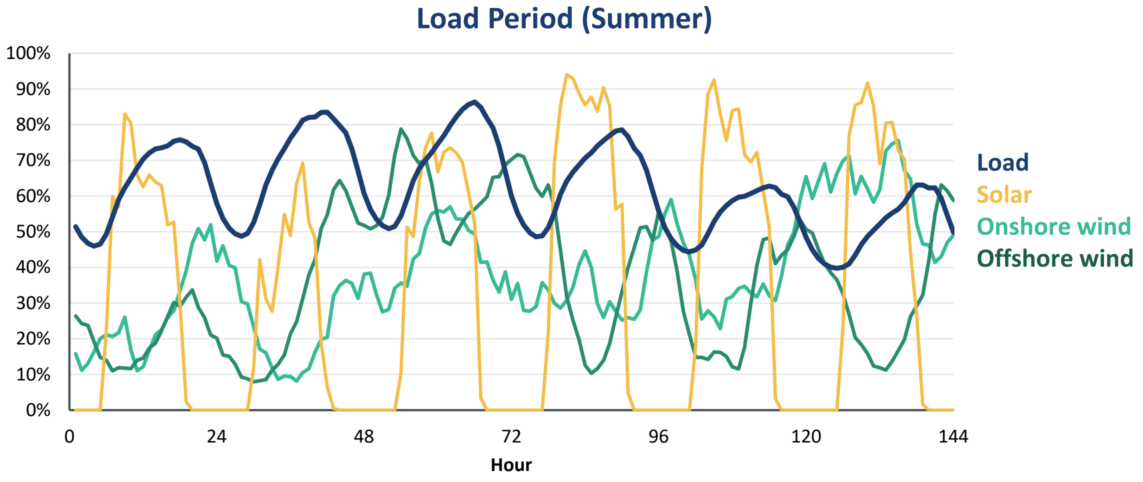
Representative Period Selection

GridSIM models representative periods instead of 8760 observations in each year

- Periods are 6 days (144 hrs) long
- 25 periods per year (4 per season plus peak)
- Each rep period is assigned a weight to create a representative 8760
- Periods selected based on k-means clustering of load and renewable profile data
- Intra- and inter-period variation in profiles determines storage value
- Models every two years from 2022 to 2040, and 2045 and 2050

ISO-NE Representative Periods





ISO-NE State Power Sector Climate Goals

- All state level green-house gas (GHG) emissions, renewable portfolio standards (RPS), clean energy standards (CES), and MW procurement policies are modeled in gridSIM
- RPS and CES goals are aggregated to ISO-NE wide goals, incorporating all state targets
- GHG goals are modeled as-is for states with electricity sector reduction targets. States without specific goals are assumed to maintain current emissions levels (i.e. no increase).
- RGGI applies to all states: 30x30 reduction (2020 levels), but is not more aggressive than other state driven goals
- ISO-NE state targets for the electric sector do not count CO_2 emissions from biogenic combustion

State	GHG Goal	RPS/CES Goal	Procurement
CT	100x40	44% by 2030 RPS	300 MW storage by 2024, 650 MW by 2027, 1,000 MW by 2030. 2 GW OSW by 2030.
ME	No electric sector specific targets, no increase in emissions through 2050	84% by 2030, including 30% met by existing resources	300 MW storage by 2025, 400 MW by 2030
MA	93x50 (1990 levels) Equivalent limit of 2 MMTCO2e in 2050	80% by 2050 total RPS/CES	355 MW storage by 2026, 5.6 GW OSW by 2027
NH	No electric sector specific targets, no increase in emissions through 2050	25.2% by 2025 RPS, including existing biogen and hydro and solar carve out	
RI	100x33	100% by 2033 RPS	884 MW OSW by 2030 (only one response to RI RFP)
VT	100x32	75% by 2032 RPS	
ISO-NE	Approximately 90x2050 from 2005 levels	Weighted average of state goals: 50% by 2032 and 68% by 2050	Total of state goals

Sources: EPA Historic Emissions; AG Pathways Study; National Berkeley Labs; CESA; Massachusetts 2050 Clean Energy and Climate Plan.

Renewable Build Limits

We model annual and cumulative renewable build limits to reflect supply chain and developmental constraints

- Solar capacity additions are limited to 2 GW per year
  - Solar limits are 5x historical 10-yr additions
  - Technical potential exceeds current buildout, but does not account for all limitations
- Onshore wind capacity is limited to 5 GW additional to today's existing and planned capacity
  - 5 GW limit informed by ISO-NE modeling, [Maine 2021 Renewable Potential Study]

ISONE Rural & Urban Solar Technical Potential (GW)

	Rural Potential	Urban Potential	**Total Potential**
Connecticut	12	5	17
Maine	659	2	661
Massachusetts	52	11	63
New Hampshire	36	2	38
Rhode Island	9	1	10
Vermont	35	1	36
Total	**803**	**22**	**825**

Source: [U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis]

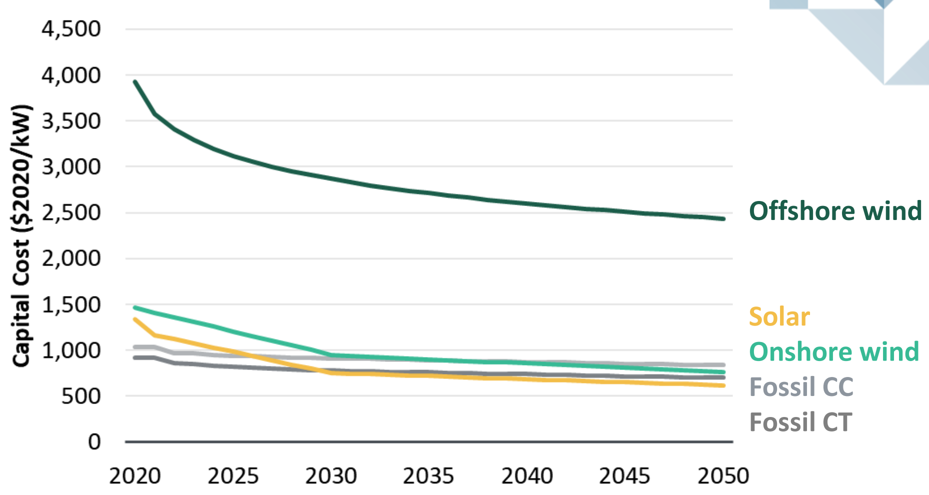
New Generation & Storage Capital Costs

GridSIM can choose to build new assets to provide energy, capacity, or satisfy clean energy policy goals

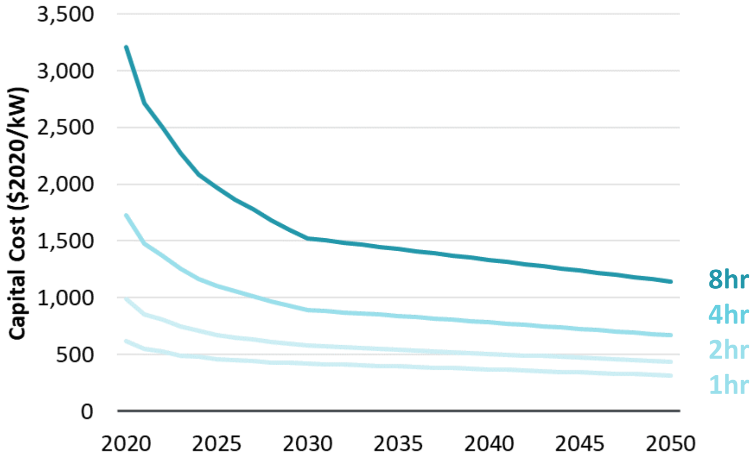
- New asset capital costs are shown to the right
- Cost assumptions are based on NREL ATB 2022 Moderate case
- Hydro, biogen, and nuclear exist in ISO-NE today but are not considered as potential new resources
- Recent Brattle work found that a portion of supply chain cost increases are incorporated into latest ATB estimates and costs are starting to recover
- Cost reductions of $15/kW-yr, adjusted with inflation, are modeled for storage assets to reflect Ancillary Service revenues

Additional costs will account for fixed operating costs and interconnection costs for renewable resources from ISO-NE studies and Pathways modeling, see next slide for details

New Generation Capital Costs ($2020/kW)



New Storage Resource Capital Costs ($2020/kW)

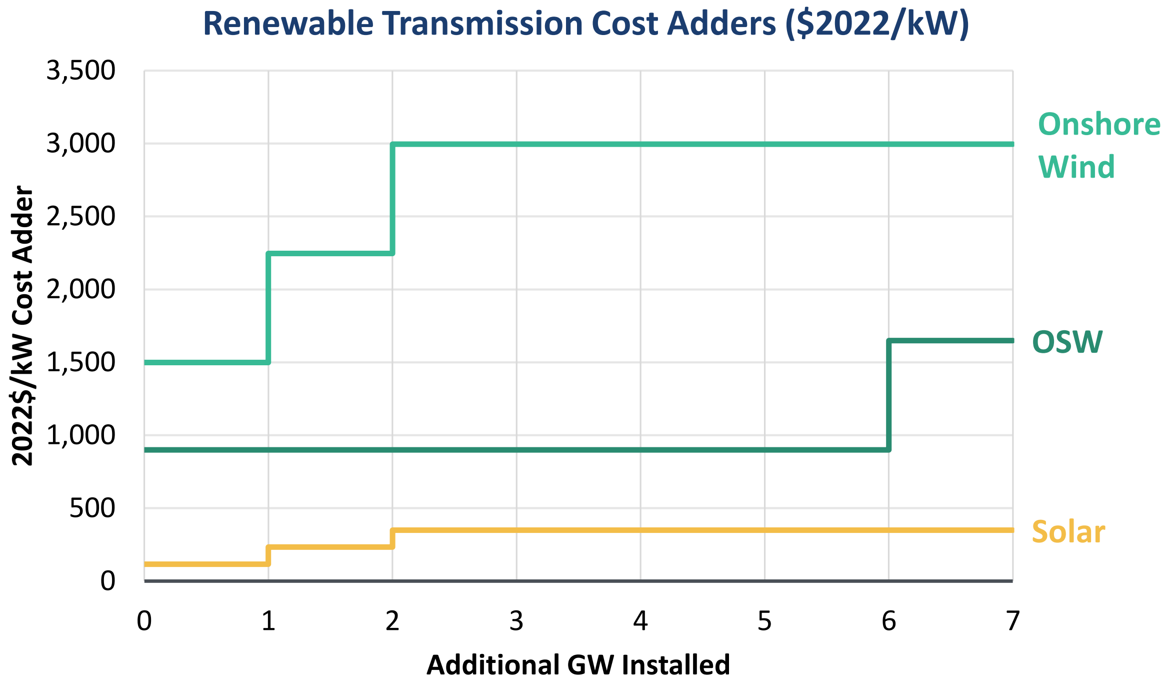


Note: Costs do not reflect IRA related tax credits, additional interconnection costs or storage A/S revenues

Renewable Transmission Interconnection Costs

Renewable resources have additional construction costs associated with land siting and interconnection constraints

- Sites with the best solar and wind conditions located close to transmission lines will be the cheapest to develop
- Those sites are limited in New England and additional capacity will incur increased development costs
- Upward sloping transmission cost curves reflect limits on cheap resource availability
- Transmission cost assumptions are based on recently published ISO-NE studies (Pathways modeling and Second Maine Resource Integration Study)



Note: Costs adders are incremental to base capital costs from NREL ATB shown on previous slide

Federal Tax Credits

Qualifying assets will earn ITC and PTC subsidies from the IRA

Tax credits are assumed to be extended through the study horizon (2050)

- Onshore wind: $26/MWh PTC for 10 years
- Solar: $26/MWh PTC for 10 years. Solar is assumed to earn the PTC (more lucrative than ITC)
  - Declining capital costs and capacity factors around 20% make the PTC more attractive than the ITC
- Offshore wind: 30% ITC
- Storage: 30% ITC

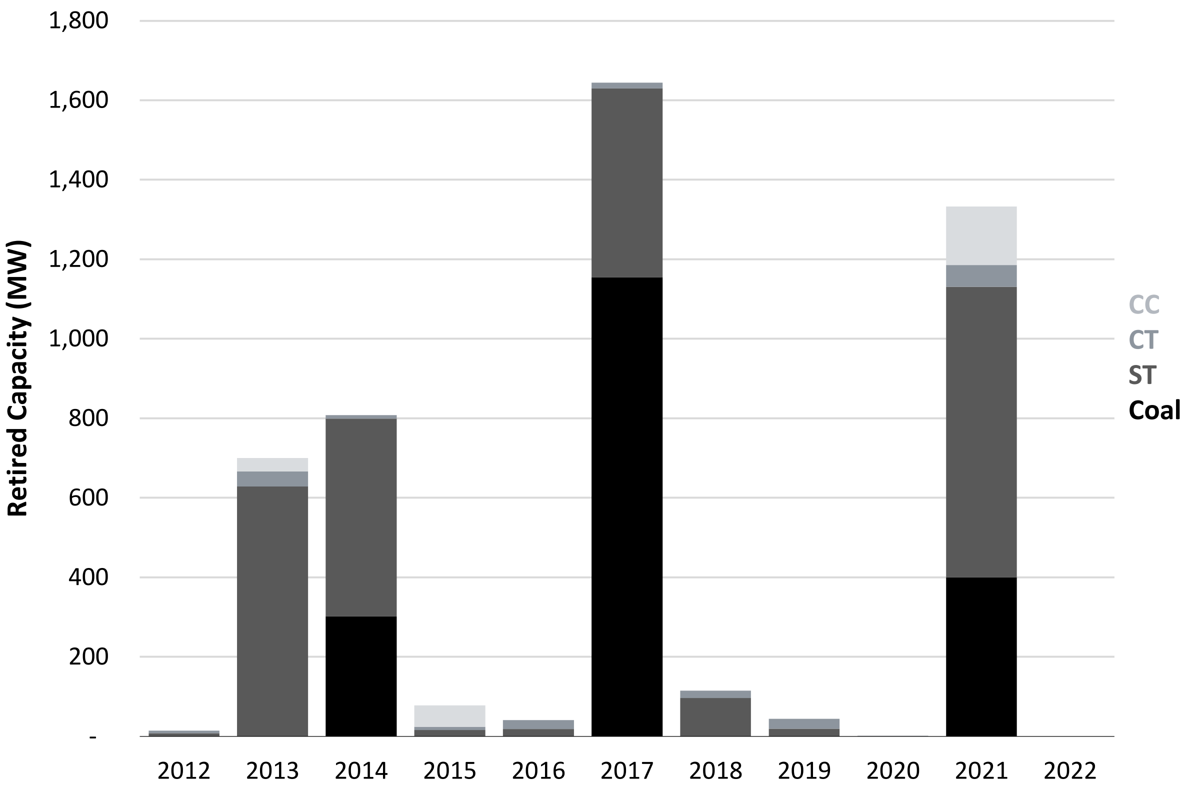
Fossil Capacity Retirements

ISO-NE fossil fleet has declined in recent years and will continue to decline as the system decarbonizes

- Expensive, inefficient, carbon-intensive generators are the first to retire, such as coal plants and larger steam turbines
- Some fossil plants will continue to serve peaking capacity need in future years by only operating in a few hours each year

We model at least 500 MW of annual fossil retirements based on historical trends

Fossil Fuel Retirement Capacity by Fuel Type (MW), 2012-2022



Modeling Resource Adequacy

The reliability requirement and accreditation metric calculated in the Capacity Capability Model is based on peak-normalized expected unserved energy (EUE)

- "Normalized" means the EUE target is proportionate to the peak gross load
- The EUE target is initially calibrated to approximate 1-in-10 LOLE, following PJM's proposal

The total capacity value of the clean fleet compares a "clean portfolio" to a "perfect supply" scenario to measure the equivalent perfect capacity that meets the same EUE target in both scenarios

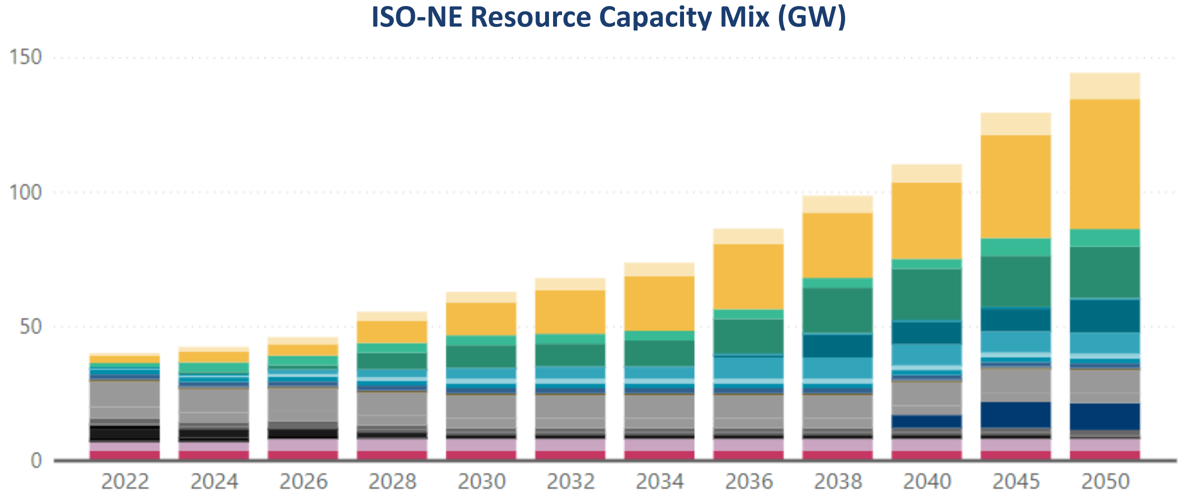
- Resource-specific marginal values represent change in capacity value with an incremental addition of that resource
- Puts greater weighting on the superpeak net load hours and less on the shoulder hours

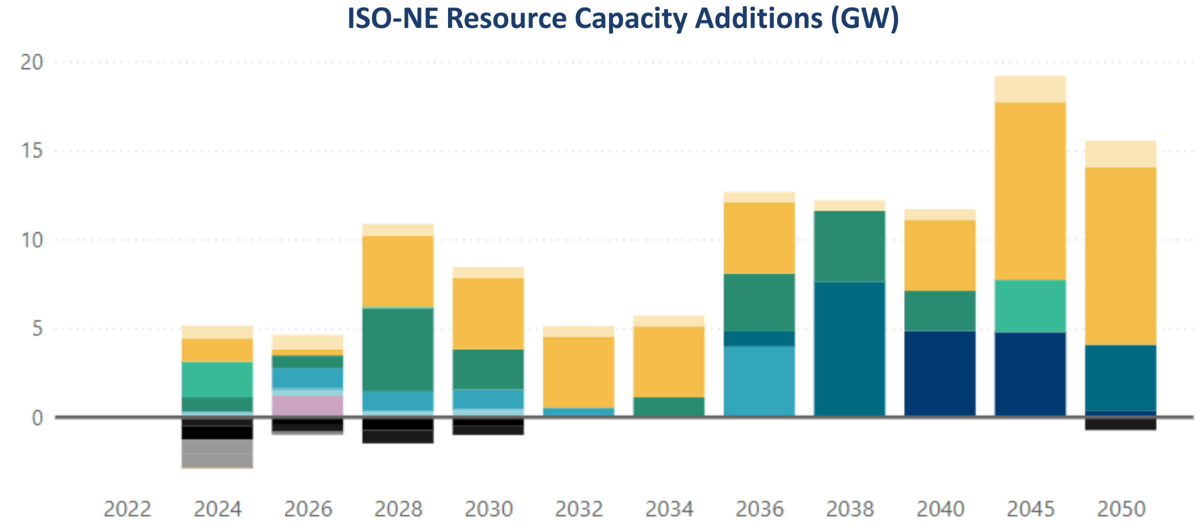
EUE is expected to be the primary reliability metric in the future market:

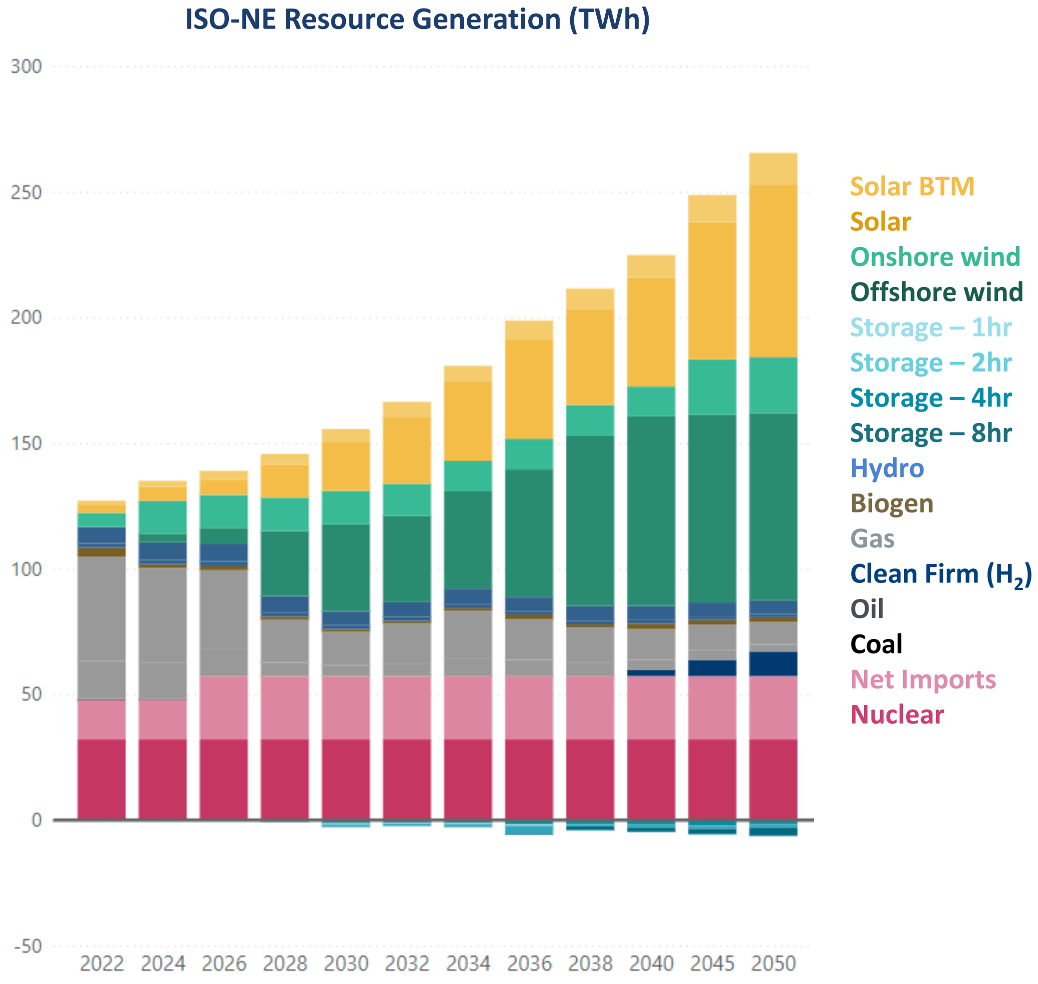
- EUE matches the direction several RTOs are headed (PJM, MISO, and ISO New England in particular)
- EUE is well behaved under evolving resource mixes and load shapes because it is inherently sensitive to multiple different severe events in the weather-year record, which the RTOs have cited as desirable for maintaining reliability in a clean energy future

Detailed Results

Generation and Capacity Results with HB5060



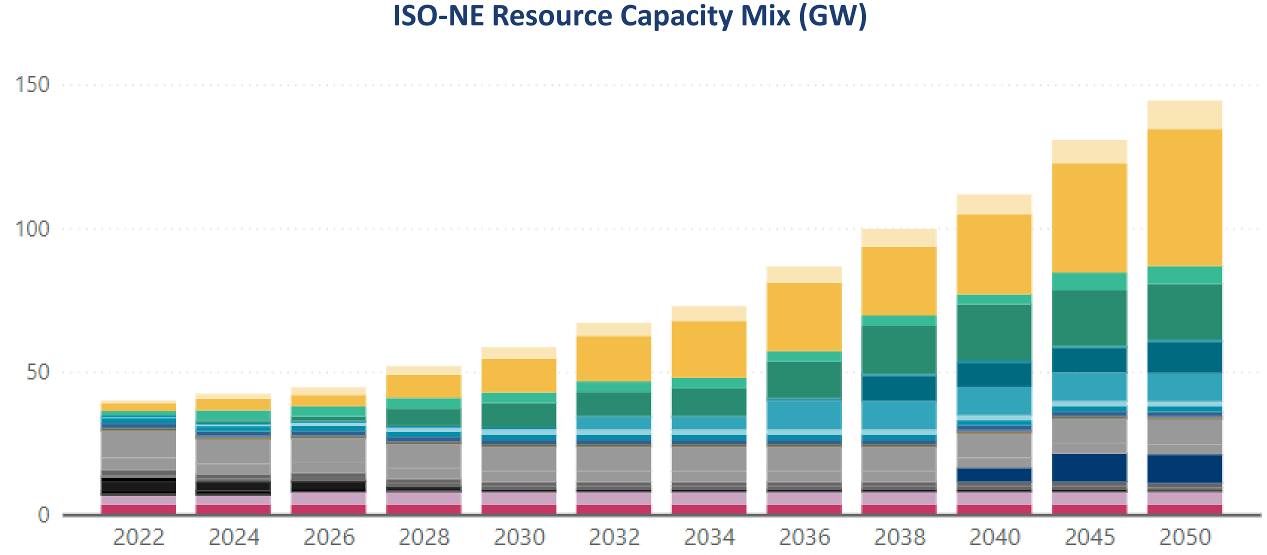


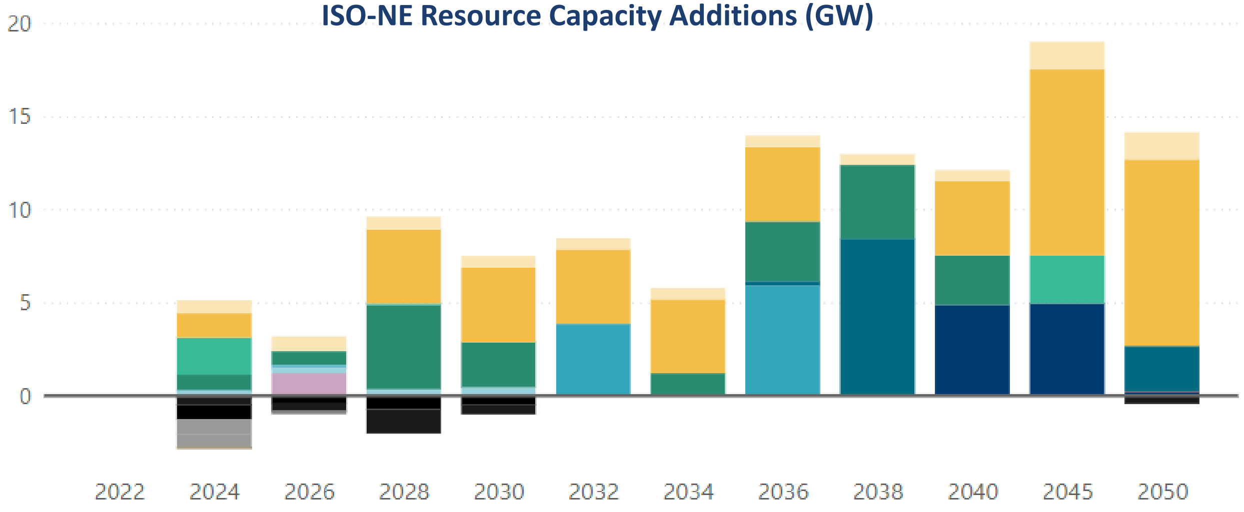


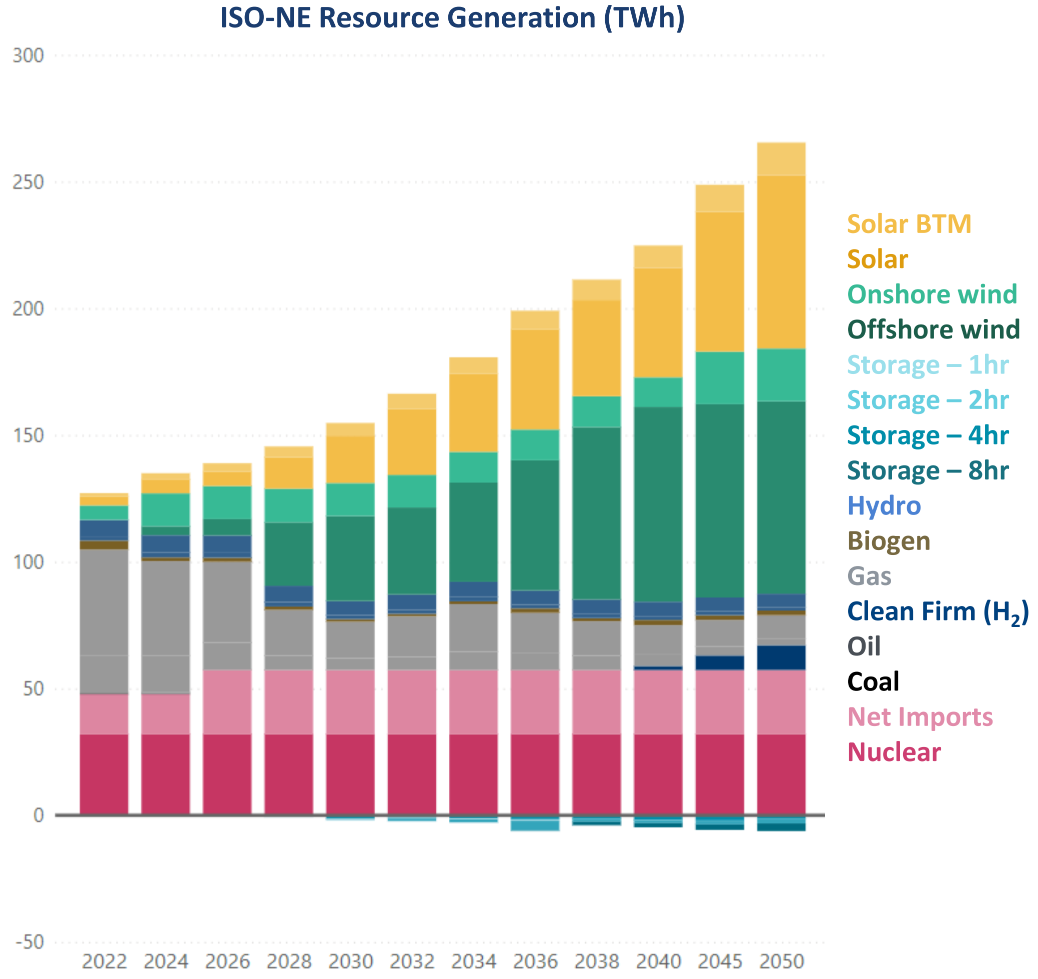
Note: Models every two years from 2022 to 2040, and 2045 and 2050

DETAILED RESULTS

Generation and Capacity Results without HB5060







Note: Models every two years from 2022 to 2040, and 2045 and 2050

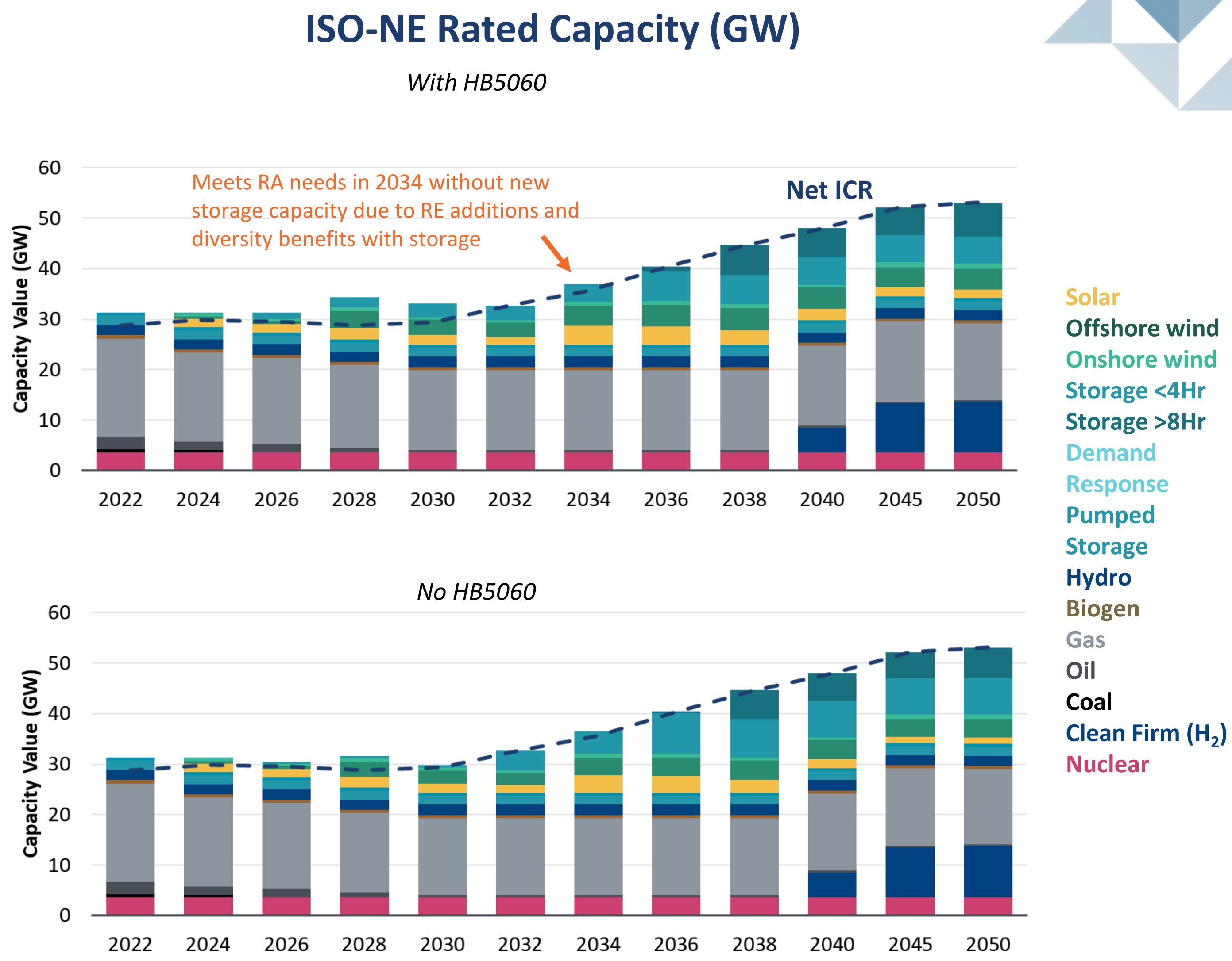
Capacity Value of Modeled Resources

ISO-NE primarily meets its current reliability needs with fossil units

Peak demand projected to remain flat through 2030, before rising due to electrification starting in the early 2030s

By 2050, most resource adequacy needs are met by renewables, storage, and clean CTs

- Fossil units retire throughout the study horizon as carbon constraints limit generation and energy revenue potential
- Storage assets comprise a significant amount of capacity needs through the 2030s, with clean firm playing a larger role beginning in 2040

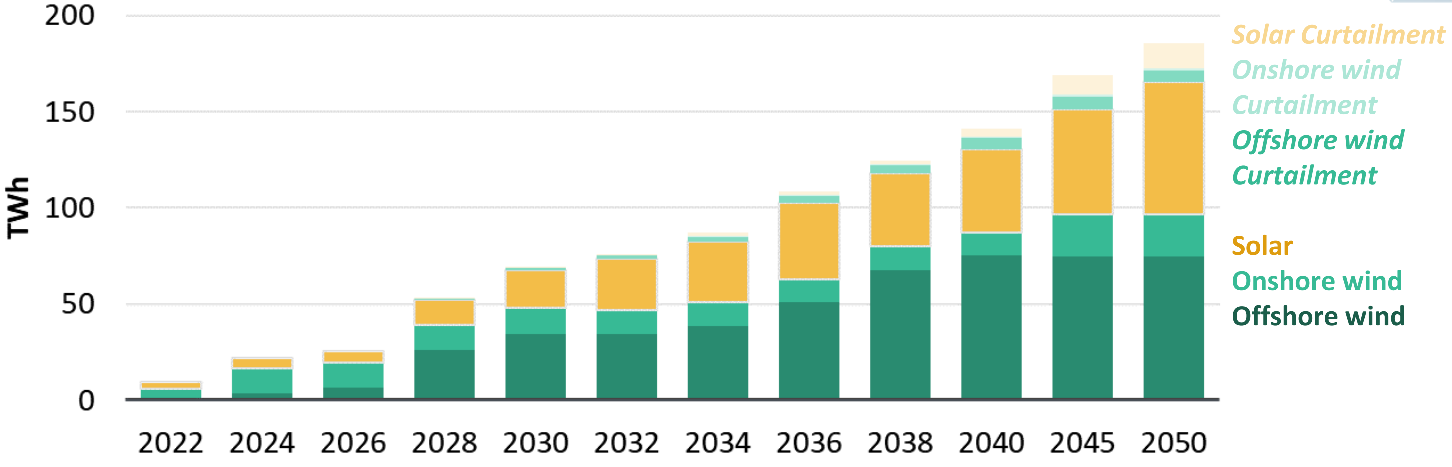


Renewable Curtailments

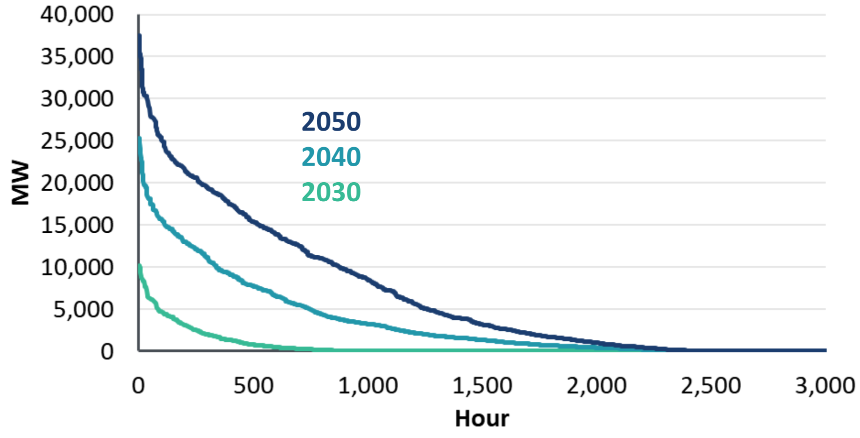
Renewable energy curtailments become more frequent in later years at high penetration levels

- Solar curtailments remain below 5% through 2038 and then increase to around 15% in 2045 and 2050
- Wind curtailments fluctuate from 5% to 9% starting in the mid-2030s

ISO-NE Renewable Generation and Curtailments (TWh)



Curtailment Duration Curve



	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040	2045	2050
Solar												
Generation (TWh)	3.4	5.6	6.2	13.1	19.6	26.6	31.4	39.7	38.3	43.4	54.7	68.4
Curtailment (TWh)	0.0	0.0	0.0	0.1	0.4	0.6	1.3	1.5	1.9	3.8	9.6	13.1
% of Total Curtailed	0%	0%	0%	1%	2%	2%	4%	4%	5%	8%	15%	16%
Onshore Wind												
Generation (TWh)	5.6	13.0	13.1	13.3	13.3	12.8	12.1	12.1	12.3	11.9	22.0	22.2
Curtailment (TWh)	0.0	0.0	0.0	0.0	0.2	0.3	1.1	1.1	0.8	1.1	1.6	1.5
% of Total Curtailed	0%	0%	0%	0%	1%	3%	8%	8%	6%	9%	7%	6%
Offshore Wind												
Generation (TWh)	0.1	3.5	6.5	25.9	34.5	34.3	38.7	50.8	67.7	75.3	74.6	74.6
Curtailment (TWh)	0.0	0.0	0.0	0.2	1.1	1.3	2.3	3.4	3.7	5.5	6.3	5.9
% of Total Curtailed	0%	0%	0%	1%	3%	4%	6%	6%	5%	7%	8%	7%

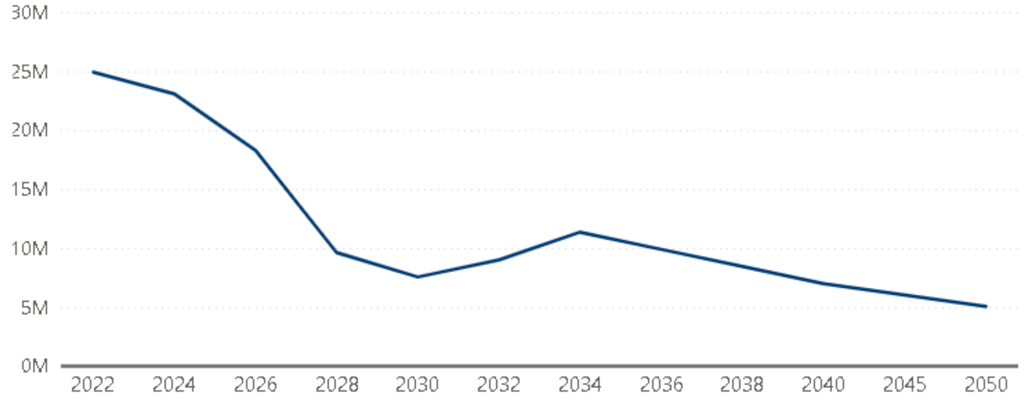
Note: results show operations in system with HB5060 policy

Carbon Emissions

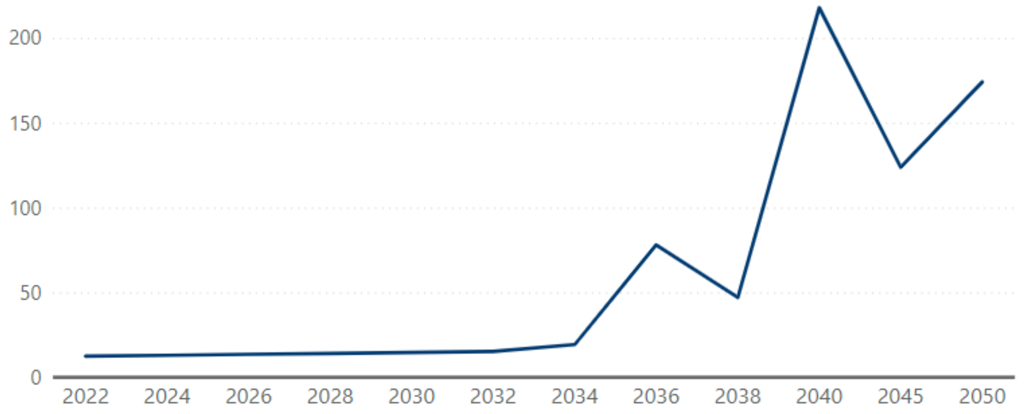
ISO-NE's electric grid will increasingly decarbonize their generation fleet over next two decades to meet clean energy and emissions goals

- Through the early 2030s renewable generation is primarily added to meet state RPS goals and RE procurements, limiting the impact on GHG prices
- Beginning in the late-2030s, the declining RGGI GHG cap and available carbon allowance drives further renewable development and higher carbon prices of $50-70/ton
- After 2040, carbon prices increase up to $200/ton in nominal terms to attract sufficient resources to reduce emissions

ISO-NE Annual Carbon Emissions (short tons)



ISO-NE Annual Carbon Price ($Nom/short ton)



Note: results show operations in system with HB5060 policy

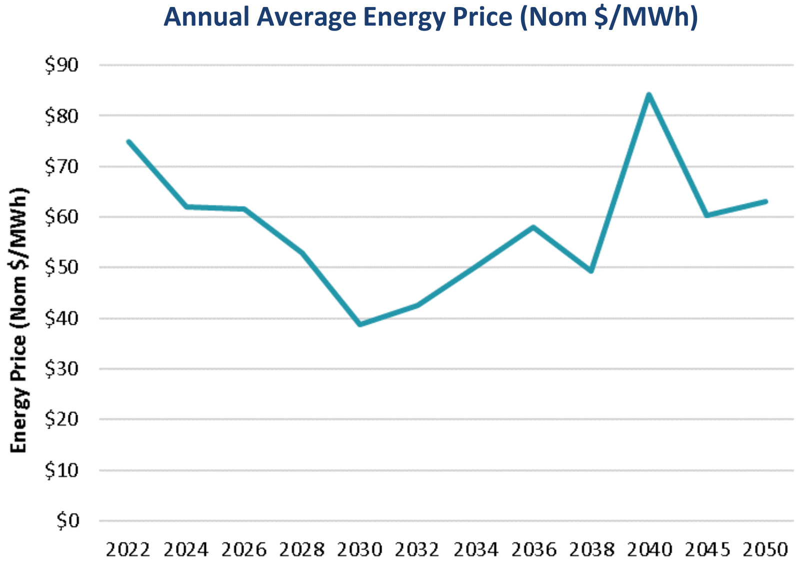
Market Prices (with HB5060)

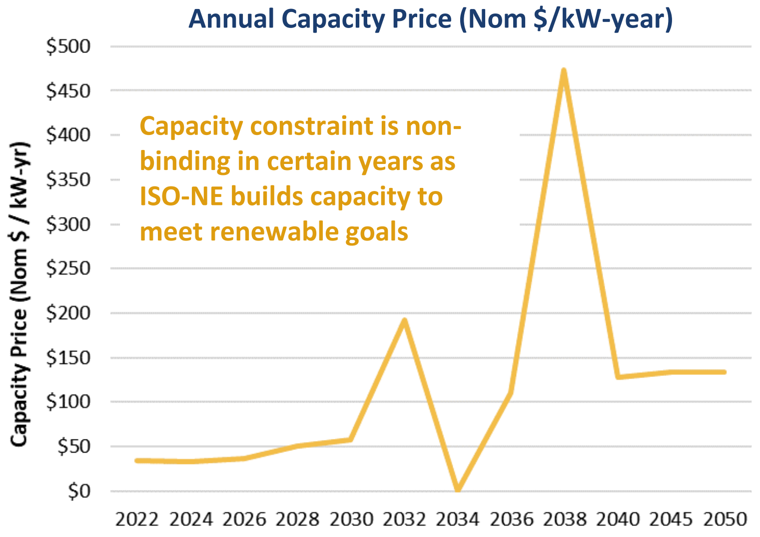
Energy price trends:

- Prices decline through 2030 with increasing renewable entry and low GHG prices
- Prices start to rise in the mid-2030s before spiking in 2040 due to GHG prices increasing to over $200/ton

Capacity price trends:

- GridSIM capacity constraint is non-binding in early years due to current excess RA supply, clean energy goals and limited load growth, resulting in capacity prices at the projected floor price
- Capacity prices increase in 2032 and then 2036 to 2050 due to rising demand and retiring fossil resources
- Capacity prices reach $450/kW-year in 2038 due to the declining ELCC of 8-hr storage, thus higher market prices are required for entry





Note: results show prices in system with HB5060 policy

Prepared By

J. Michael Hagerty

PRINCIPAL
WASHINGTON

Michael.Hagerty@brattle.com

Andrew Levitt

SENIOR CONSULTANT
WASHINGTON

Andrew.Levitt@brattle.com

Ragini Sreenath

ENERGY ASSOCIATE
BOSTON

Ragini.Sreenath@brattle.com

Kate Peters

ENERGY RESEARCH ASSOCIATE
NEW YORK

Kate.Peters@brattle.com

Our Offices


BOSTON

BRUSSELS

CHICAGO

LONDON

MADRID

NEW YORK

ROME

SAN FRANCISCO

SYDNEY

TORONTO

WASHINGTON, DC

Clarity in the face of complexity

Brattle