The State of Energy Storage and its Future Role in the Commonwealth

Stakeholder Session #1: Study Overview, Approach and Early Insights

June 7, 2023

Tom Ferguson, PhD, Energy Storage Programs Manager, DOER

Kush Patel, Senior Partner
Liz Mettetal, PhD, Associate Director
Andrew DeBenedictis, PhD, Director
Nate Grady, Sr. Managing Consultant

Agenda

- Study Goals, Context & Logistics | 10 min, State Team
- Introduction & Study Overview | 5 min, E3
- Study Task 1: Energy Storage Today | 20 min, E3
- Study Task 2: Long Duration Energy Storage | 10 min, E3
- Study Task 3: Reliability Modeling | 15 min, E3
- Next Steps | 5 min, State Team
- Breakout Room Q&A | 20 min, all

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Session Goals

- Introduce new energy storage study
- Explain drivers behind study
- Share initial findings
- Share key assumptions and inputs that will go into modeling
- Spur stakeholder involvement and feedback

About DOER and MassCEC

DOER

The Massachusetts Department of Energy Resources (“DOER”) is an agency of the Executive Office of Energy and Environmental Affairs (“EEA”). DOER’s mission is to create a clean, affordable, equitable and resilient energy future for all residents, including low-income and Environmental Justice populations, businesses, communities, and institutions in the Commonwealth.

MassCEC

The Massachusetts Clean Energy Center (“MassCEC”) is a state economic development agency dedicated to accelerating the growth of the clean energy sector across the Commonwealth to spur job creation, deliver statewide environmental benefits and to secure long-term economic growth for the people of Massachusetts. MassCEC’s mission is to accelerate the clean energy and climate solution innovation that is critical to meeting the Commonwealth’s climate goals, advancing Massachusetts’ position as an international climate leader while growing the state’s clean energy economy.

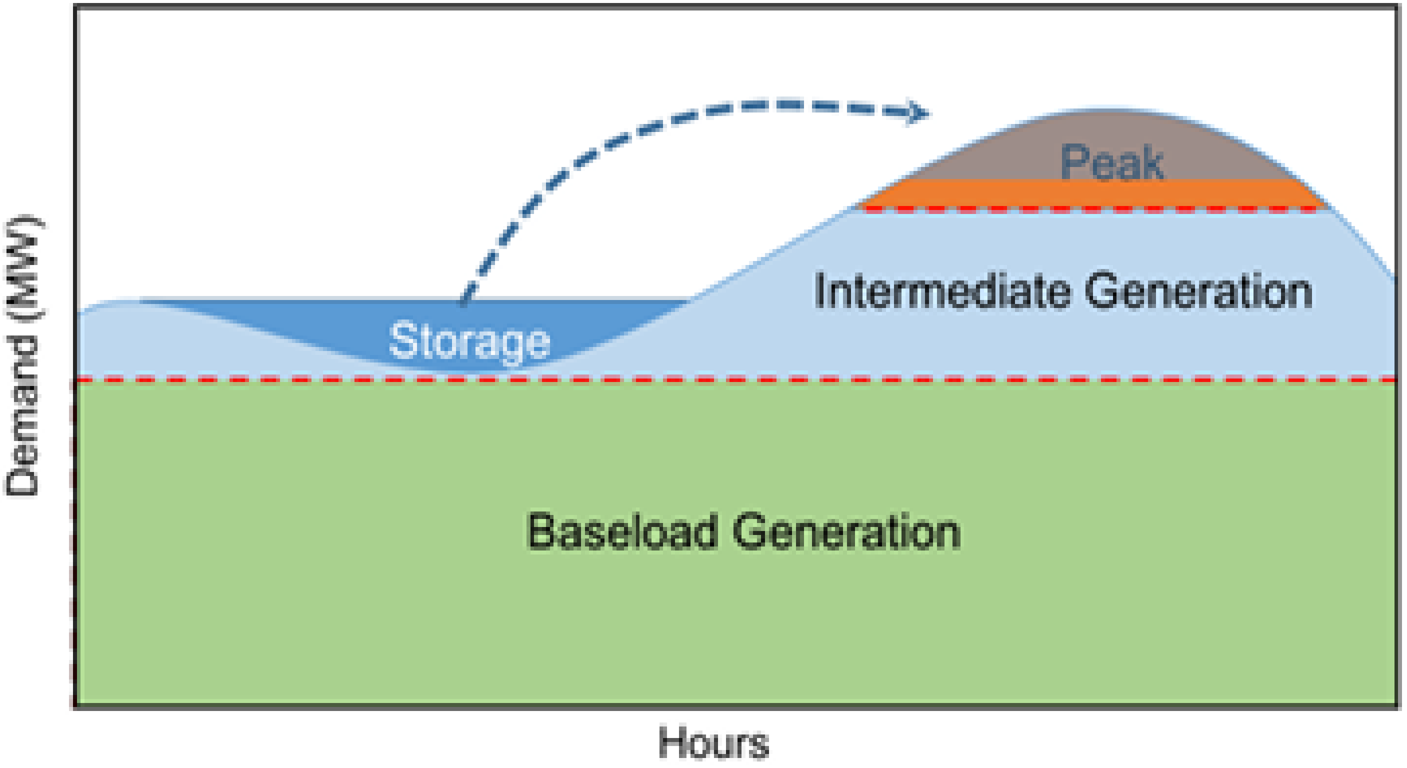
Goals and Background

Energy Storage Study Goals

1) **Review energy storage deployment in the Commonwealth since State of Charge Report**
2) **Study the role of storage in a 2050 Net Zero Commonwealth, particularly mid- and long-duration storage technologies**

State of Charge Report

- Published in 2016, groundbreaking report examined potential value and uses of storage in Commonwealth
- **Key Finding**: Energy storage deployment can provide substantial ratepayer, environmental, and system owner benefits that outweigh costs



2022: Climate Bill, CECP, and Storage

Legislative Requirement – Approved August 11, 2022

- Section 80 of Chapter 179 of the Acts of 2022 (“An Act Driving Clean Energy and Offshore Wind”) requires DOER, in consultation with MassCEC, to conduct a study on the current status of energy storage and the potential role of mid- to long-duration energy storage.

Clean Energy and Climate Plan for 2050 (CECP) – Released December 2022

- Lays out Commonwealth’s Plan to achieve Net Zero in 2050 in an equitable and just manner
- Calls for collective GHG emission reductions of 85% relative to 1990 levels
  - Electric sector reduction of 93%
  - Requires 2.5x increase in electric sector load relative to 2020 and over 50 GW of solar and wind
- Storage to play a critical role in renewables integration and in meeting CECP’s Net Zero goal

What specific roles will storage play? What kinds of storage will we need? How do we incentivize its deployment?

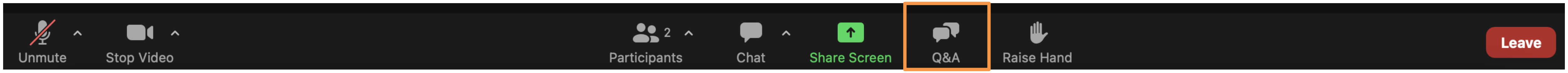
Session Outline and Format

Outline

- DOER introduction
- E3 presentation
  - ➢ Hired by MassCEC and DOER to conduct study
  - ➢ Present initial findings and key assumptions and inputs for their modeling
- DOER next steps
- Breakout rooms to begin to receive stakeholder input and feedback
  - ➢ Please answer the poll now to be put in the right breakout room

Format

- Please put your questions and comments in Zoom's Q&A feature during the presentation



  - ➢ We'll answer those we can in the chatbox , and others we'll defer to breakouts or follow on meetings with you.
  - ➢ We also encourage you to submit your comments to DOER at thomas.ferguson@mass.gov
- Presentation and recording to be made available at study website.

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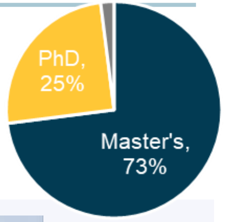
About E3

100+ full-time consultants

30 years of deep expertise

Engineering, Economics, Mathematics, Public Policy…




San Francisco


New York


Boston


Calgary

E3 Clients

300+ projects per year across our diverse client base

Example Recent Related Projects

- Maine Renewable Energy Goals Market Assessment (2021)
- Net Zero New England: Electric Reliability under Deep Decarbonization (2020)
- New York Energy Storage Roadmap – NYSERDA (2022, 2018)
- New York Peaker Repowering/Replacement Study – NYSERDA (2019)
- Minnesota Dept. of Commerce, Minnesota Energy Storage Cost-Benefit Analysis (2019)
- California Energy Commission, EPC-19-056, Assessing the Value of Long Duration Storage (2020-present)
- Confidential work for a number energy storage owners, developers and investors with a focus on revenue forecasting and market analysis

Project Team

State of Massachusetts Team

Rees Sweeney-Taylor
Program Manager, MassCEC

Corrin Moss
Program Administrator, MassCEC

Tom Ferguson
Energy Storage Programs Manager, DOER

Joanna Troy
Director of Policy and Planning, DOER

E3 Project Leadership

Kushal Patel
Lead Partner
Senior Partner

Liz Mettetal
Project Lead
Associate Director

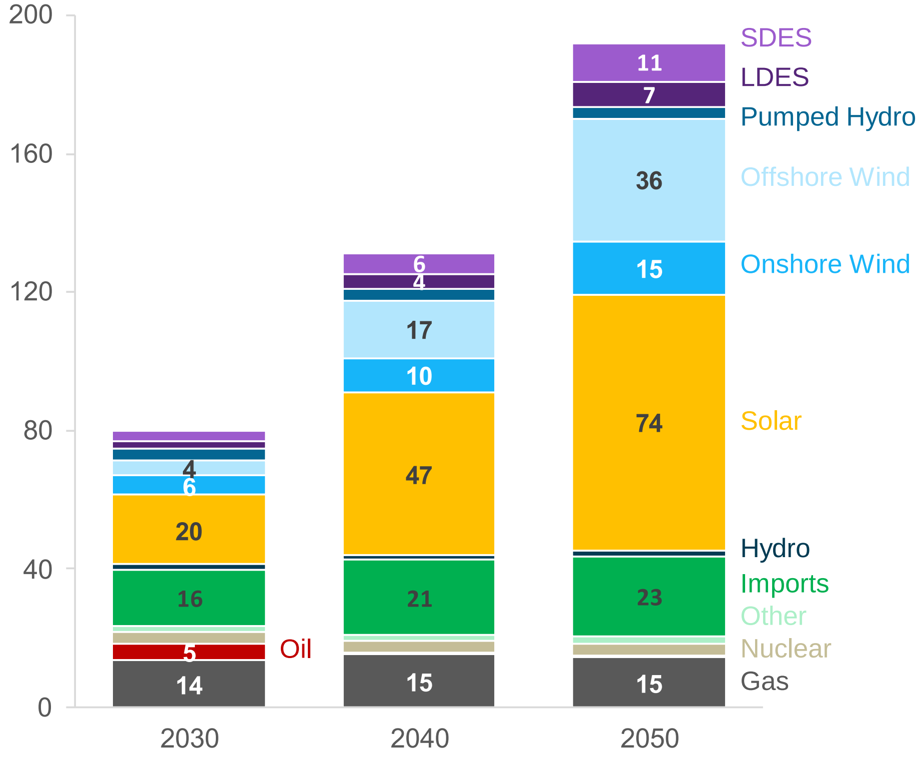
Andrew DeBenedictis
Project Manager
Director

Nathan Grady
Markets & Financial Modeling Lead
Senior Managing Consultant

Storage serves key electric system needs in the Massachusetts 2050 Clean Energy and Climate Plan

- **Renewable resources (solar, onshore wind, offshore wind) and storage are key in the state's 2050 CECP**
  - Also includes electrification aligned with economy-wide Net Zero
  - ISO-NE achieves 97% zero-carbon consumption by 2050
  - Across all CECP scenarios, New England utilizes between 22 GW and 28 GW of energy storage by 2050
- **Storage can support key electric grid balancing**
  - **Hourly and Sub-Hourly Ramping**: providing fast-ramping capability to manage output volatility
  - **Intraday Shifting**: shifting renewable output across several hours to times of high customer demand, e.g. charging during early afternoon solar hours and discharging during evening peaks
  - **Interday Shifting**: seasonal shifting of renewable output to provide dispatchable capacity during prolonged periods of low renewable output

Installed Electric Capacity in New England CECP 2050, Phased Scenario
(GW)



Overview of Key Study Questions & Tasks

- **This study addresses three broad questions:**

  1. ***What is the current state of energy storage in the Commonwealth?***
     How much storage is deployed? What programs exist to encourage deployment? What are the costs/benefits of current use cases for short-duration energy storage (SDES)?

  2. ***What is the market outlook for emerging mid- and long-duration storage (LDES) technologies?***
     What is the level of maturity for various emerging LDES technologies? How are costs projected to evolve for LDES technologies?

  3. ***What are potential applications of mid- and long-duration storage?***
     How can LDES contribute to reliability in a decarbonized system? What benefits will LDES be able to provide at the distribution level?

- **The study output will include public report, inclusive of analysis, summary of stakeholder feedback, key findings and policy recommendations**

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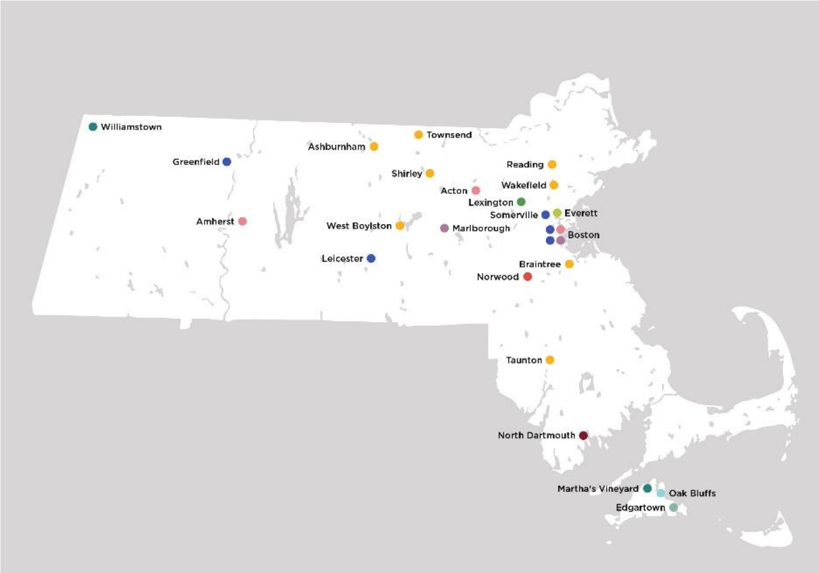
Existing state programs promote deployment towards the Commonwealth's targets

- **The Energy Storage Initiative (ESI) established a target of 1,000 MWh of energy storage by December 31, 2025**
  - ESI created the Advancing Commonwealth Energy Storage (ACES) program to fund pilot and demonstration projects for a range of energy storage use cases
- **ConnectedSolutions:** A demand response program offering incentives based on performance during calls
- **Clean Peak:** Incentivizes renewable generation dispatch during peak hours each season; storage that charges primarily from renewable energy qualifies
- **SMART:** Primarily a solar incentive program, includes an adder for energy storage paired with solar

ACES Installations

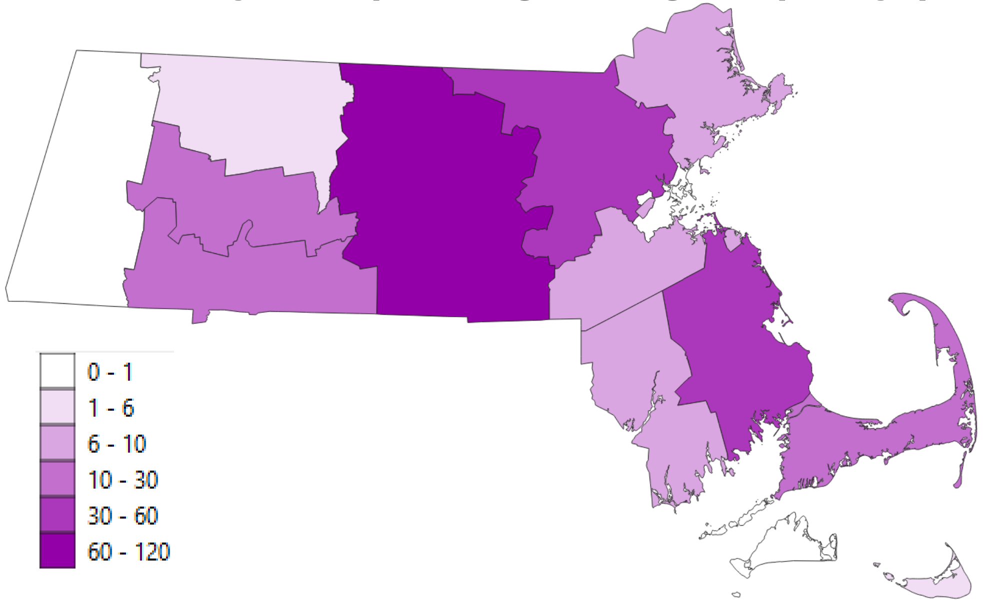


Stakeholder question: What are the biggest barriers that remain unaddressed by current programs? What are the best opportunities?

The state is making meaningful progress toward its 2025 target

- The majority of existing storage in the state comes from two pumped hydro facilities built in the 1970s, which have a combined capacity of nearly 1800 MW, and average duration of 7 hrs
- The remaining ~300 MW of existing storage are mostly small (<5 MW), front-of-meter Li-Ion installations, clustered in Worcester, Middlesex, and Plymouth counties
  - Many of these are co-located with solar, and have been developed since the launch of the SMART incentive program
- Interconnection queue (not shown) indicates a similar geographic development focus, with many larger storage projects proposed

Total Non-Hydro Operating Storage Capacity (MW)



Resource Connection Type	Capacity (MW)	Energy (MWh)	Avg. Duration (Hrs)
Front of Meter	2,028	13,488	7
Behind the Meter	50	45	1
Total	**2,078**	**13,533**	**n/a**
Additional Resources (<0.5 MW)	37	24	1

Technology	Capacity (MW)	Energy (MWh)	Avg. Duration (Hrs)
Hydroelectric Pumped Storage	1,768	12,944	7
Lithium-Ion Battery	282	565	2
Sodium-Ion Battery	18	15	1
Thermal Storage	3	1	0
Vanadium Redox Flow Battery	1	3	6
Zinc Iron Flow Battery	-	-	-
Latent Heat Storage	-	-	-
Flywheel	-	-	-
Battery (Unspecified)	2	5	2
Total (Pumped Hydro Excluded)	**307**	**588**	**n/a**
Additional Resources (<0.5 MW)	37	24	n/a

Energy storage can access a variety of value streams

Retail Level Value Streams	T&D Level Value Streams	Wholesale Level Value Streams
Power Quality	Congestion	Blackstart
State/Utility Programs	Reliability/Loading	Voltage Support
Backup Power/Resiliency	Local Capacity	Energy & Ancillary Services
Retail Demand & Energy Charges	T&D Deferral	Capacity

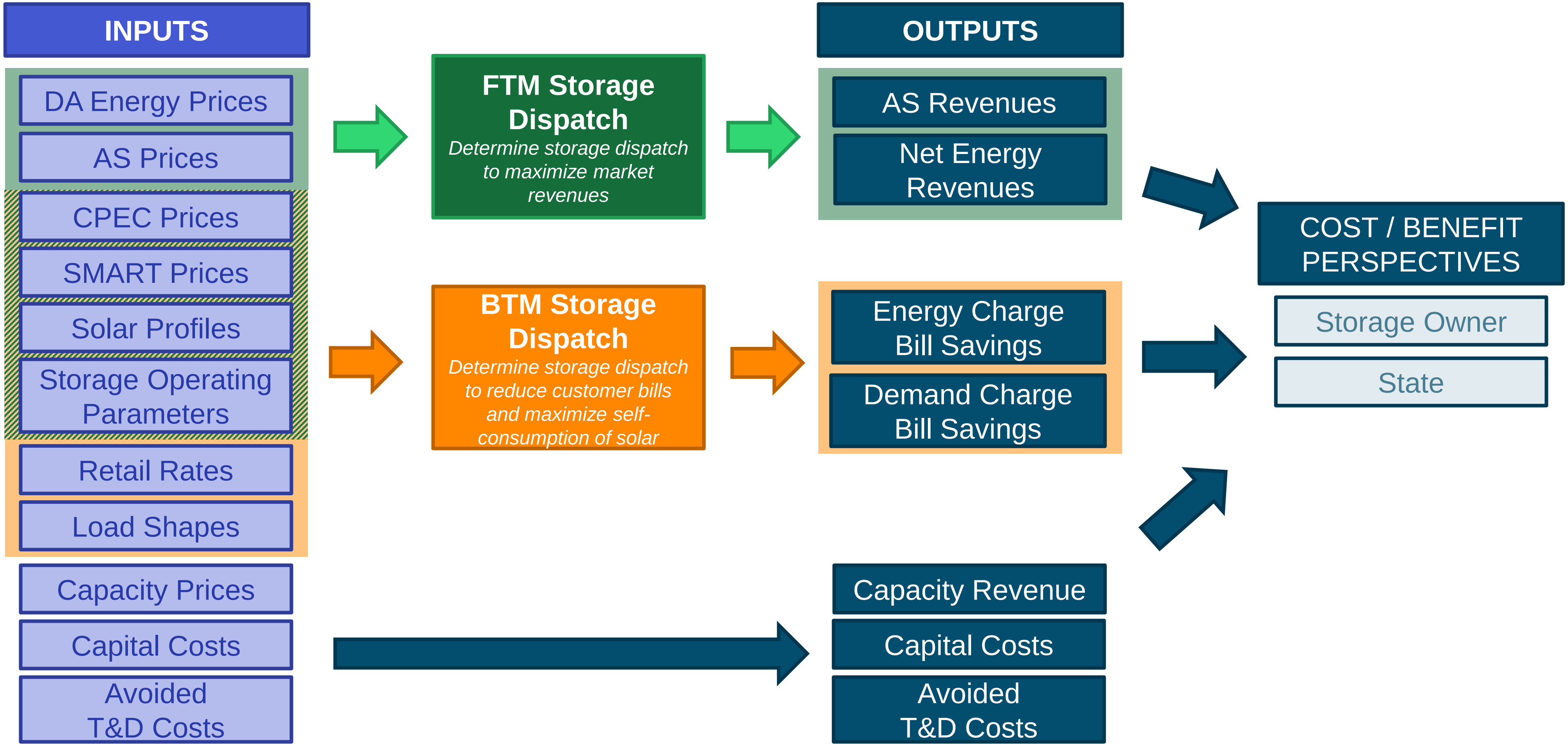
Non-quantified benefits will be qualitatively discussed

Values in blue will be estimated quantitatively

+ **Use cases vary across market segment and can be dependent on co-location with renewables**
+ **Challenges include monetizing these value streams, and forecasting their potential future value**

Stakeholder question: Which value streams are most attractive to developers? Are there other value streams we should be considering? Data/opportunities to measure other value streams?

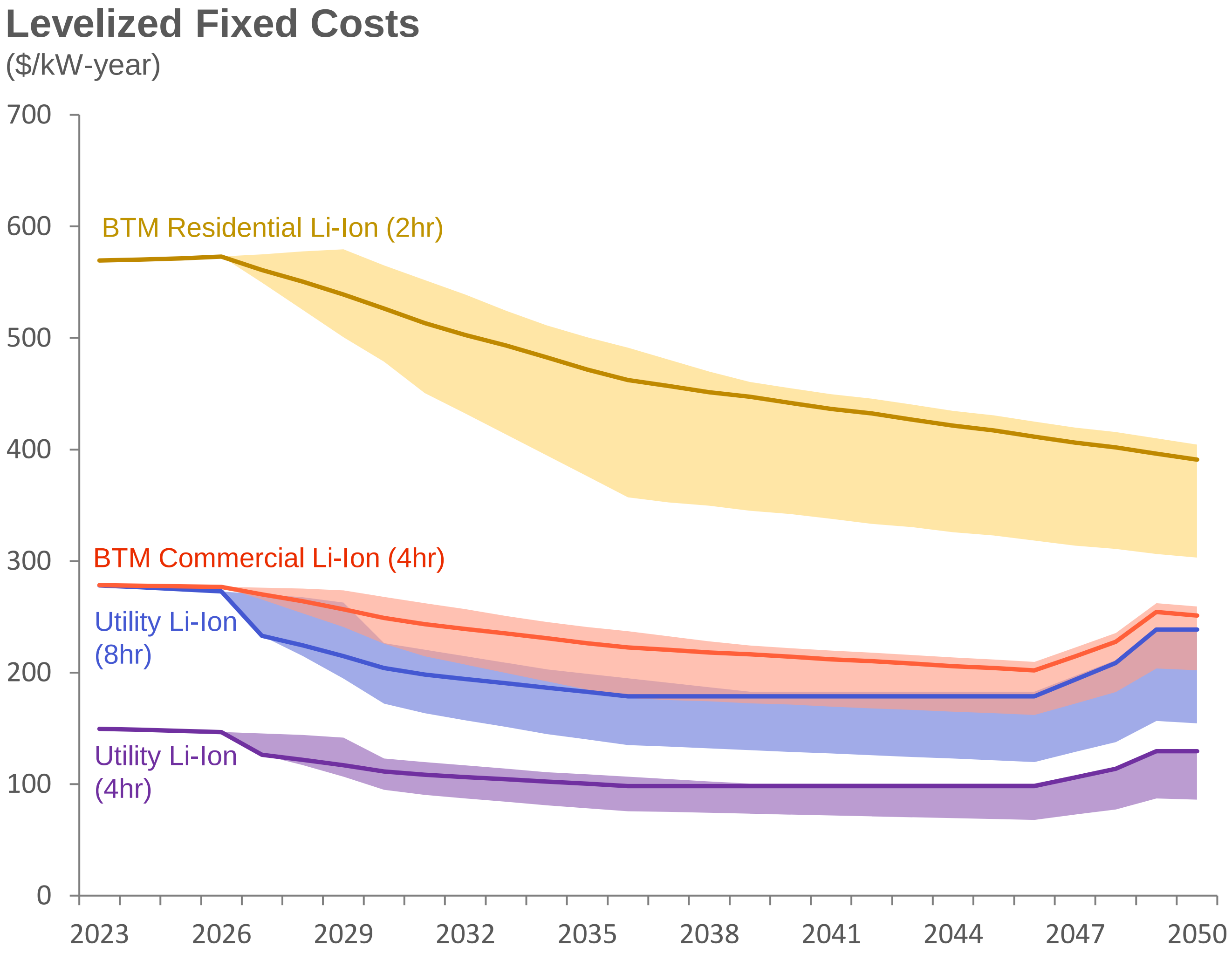
Storage business case modeling compares costs to an applicable stack of benefits



Storage costs will benefit under the IRA

- **Lithium-ion batteries remain the most cost-effective existing commercial technology for short-duration applications**
- **Present day costs derived from Lazard LCOS 8.0**
  - Our modeling prevents cost declines through 2026, while global supply chains catch up with demand
  - Capital cost declines starting in 2026 are based on NREL ATB 2022 trajectories
- **Utility and commercial batteries and pumped hydro are modeled as eligible for IRA tax credits**
  - Tax credits modeled at 30% through 2045, at which point they phase down over 3 years
  - 30% assumes prevailing wage but no additional bonus credits

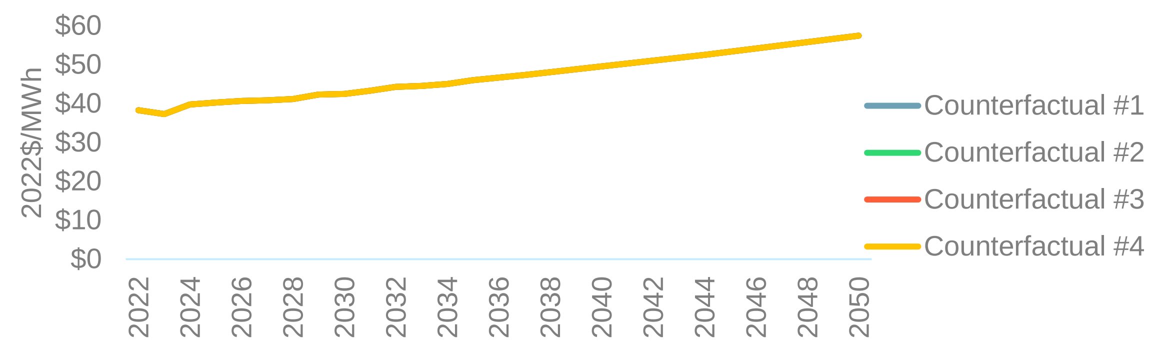
Stakeholder question: Are these consistent with your experience/expectations?



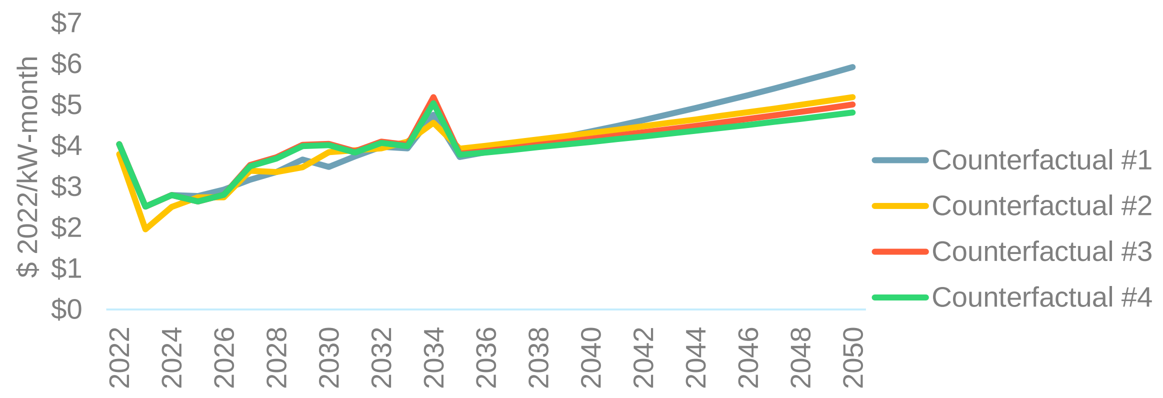
Other key inputs rely on public data sources

Key Data Items	Sources
Storage costs and operating characteristics	Lazard, NREL, E3's Pro Forma
Historical data (unit operations, prices)	EIA, EPA, ISO-NE
Retail rates	National Grid, Eversource, Unitil
Energy prices	Avoided Energy Supply Components in New England (AESC), with adjustments based on E3's professional judgement
Capacity prices	
Marginal emission rates	
T&D deferral	
Ancillary services	E3 estimate based on historical
Value of Lost Load	LBNL

AESC Energy Prices – 2022 $/MWh



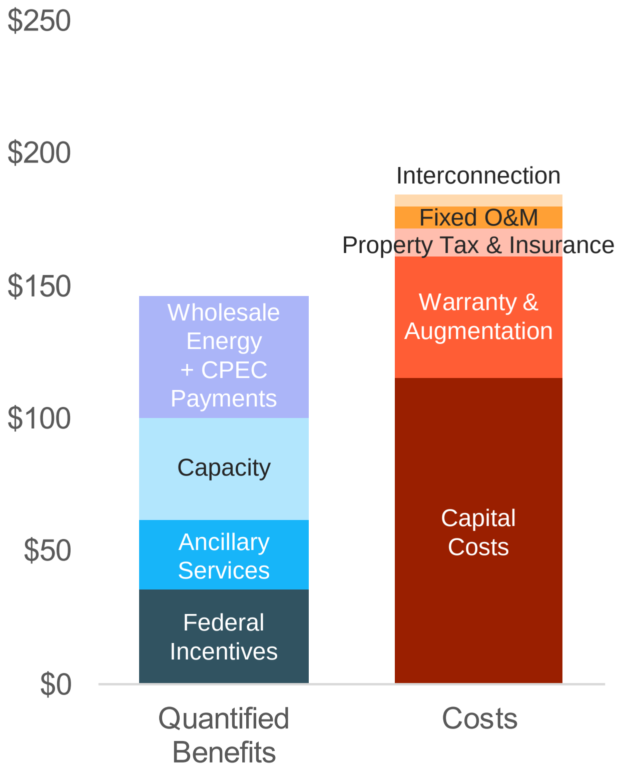
AESC Capacity Prices – 2022 $/kW-month



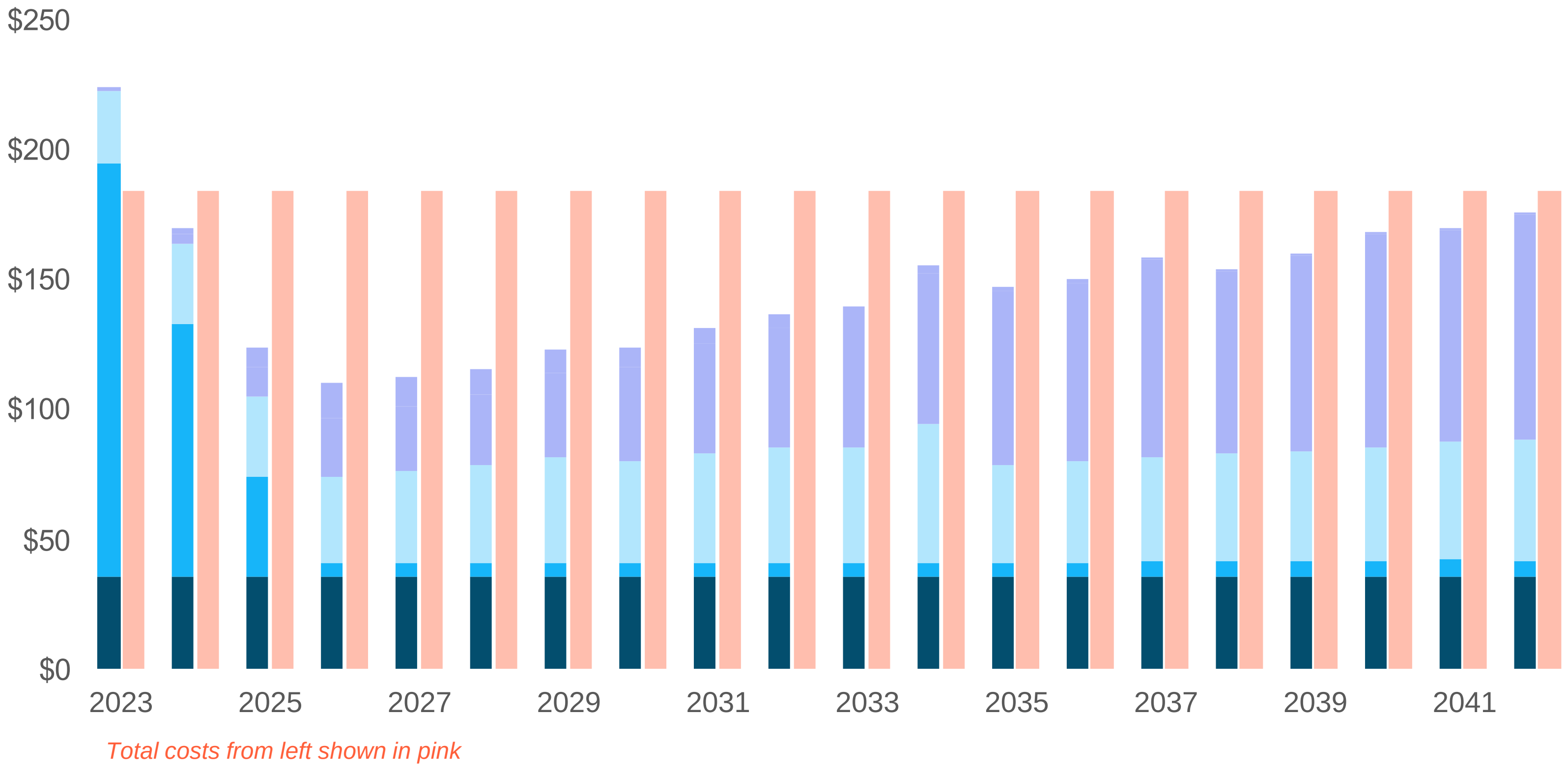
Stakeholder question: Are there other data sources the E3 team should consider?

Draft model output: Front-of-the-meter standalone batteries projected to struggle to recover costs in 2023

Participant Cost Test (Developer Perspective)
(Levelized $2022/kW-year)

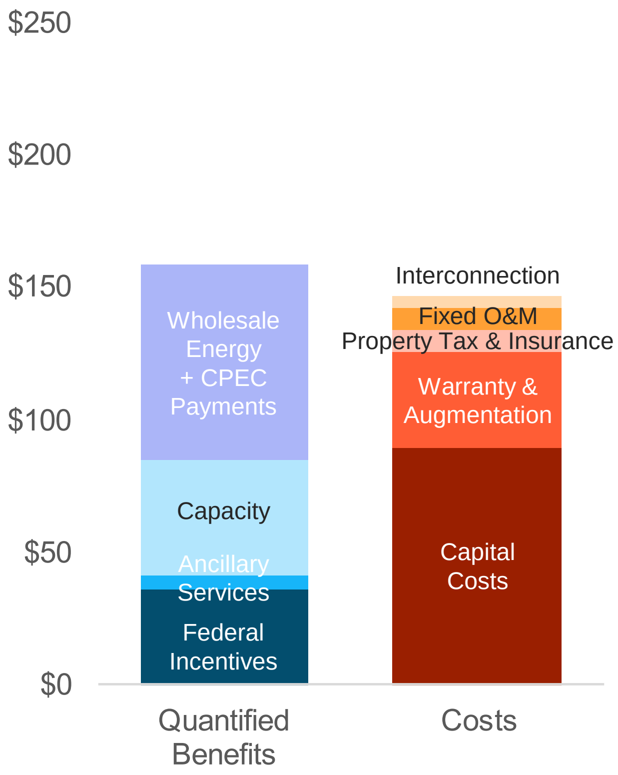


Participant Cost Test – Annual Results (Developer Perspective)
($2022/kW)

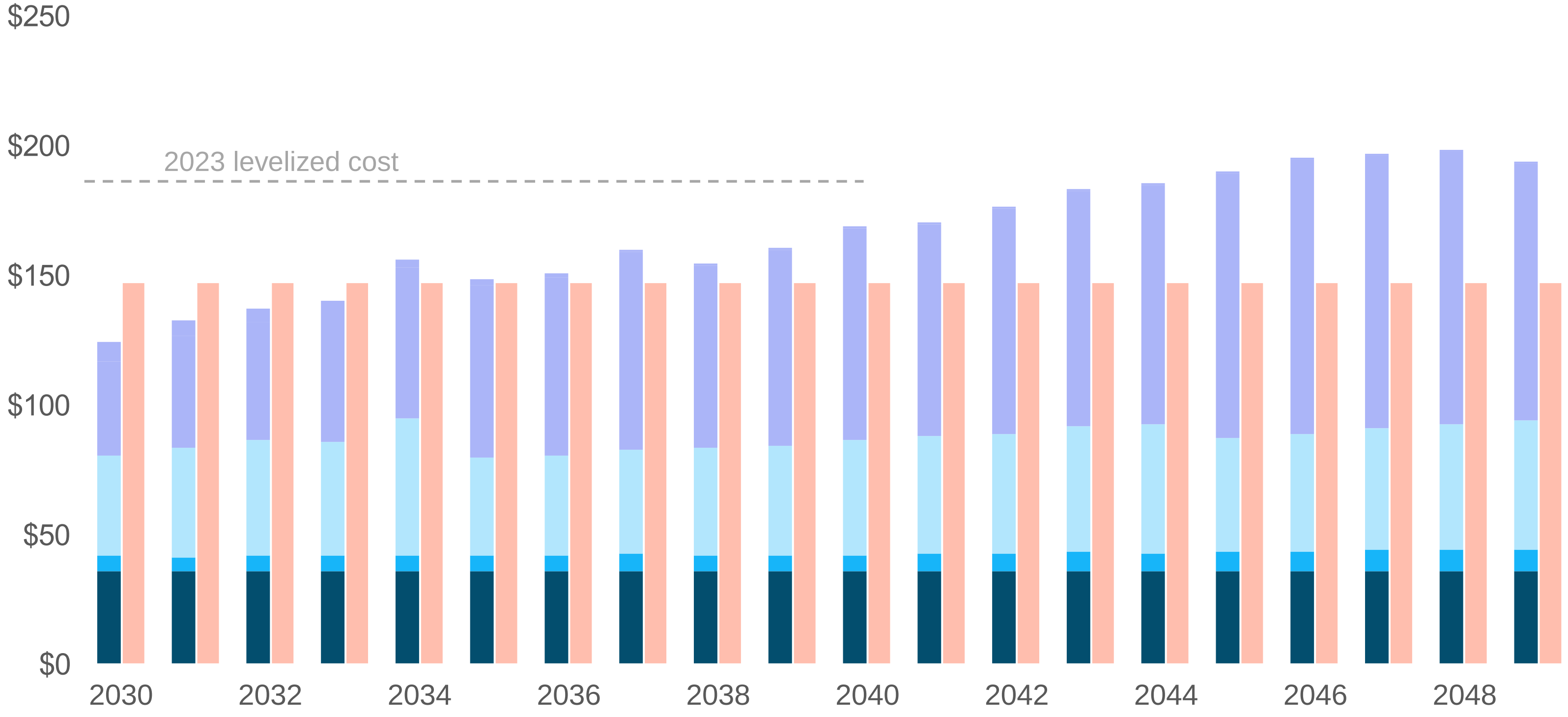


Draft model output: Front-of-the-meter standalone batteries begin to recover costs in 2030

Participant Cost Test (Developer Perspective)
(Levelized $2022/kW-year)



Participant Cost Test – Annual Results (Developer Perspective)
($2022/kW)



Total costs from left shown in pink

1 MW, 4-hr Li-Ion Battery at C&I customer site, Distribution connected

The current state of energy storage in MA

- **The Commonwealth has over 300 MW and nearly 600 MWh energy storage (excluding pumped hydro) installed and operational today**
  - 85% of these projects are front-of–the-meter resources
  - 144 MW and 223 MWh energy storage are co-located with solar
  - The interconnection queue has more than enough MW to surpass the Commonwealth's goal, but these projects are highly uncertain
- **Standalone FTM storage projects may struggle to recover costs today**
  - High capital costs and potentially short-lived ancillary service revenues create a challenging economic landscape
  - By 2030, lower capital costs (in part due to the 30% IRA tax credit) and higher energy and capacity revenues are expected to make projects profitable
  - Uncertainty of revenue streams, siting difficulties, safety concerns, and other challenges deter investment and deployment today

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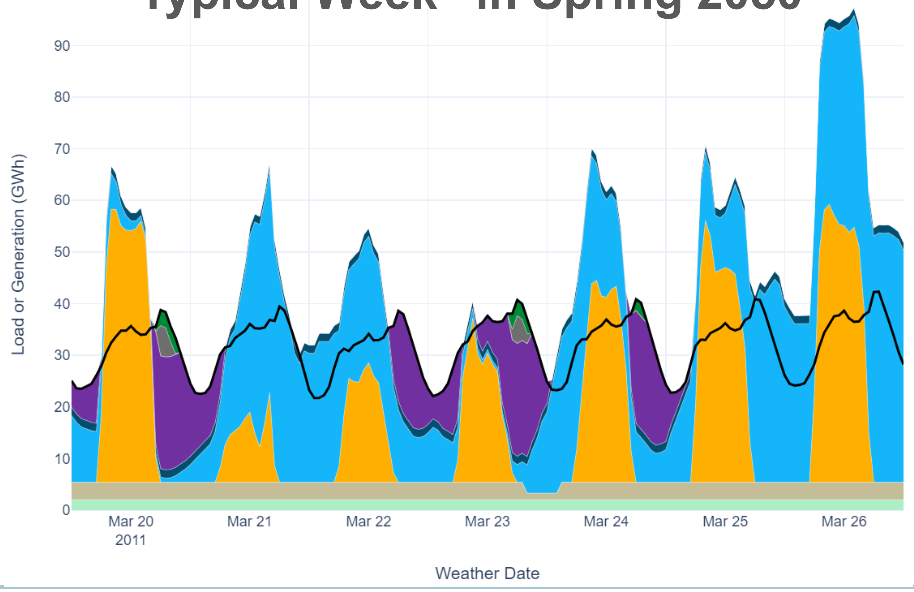
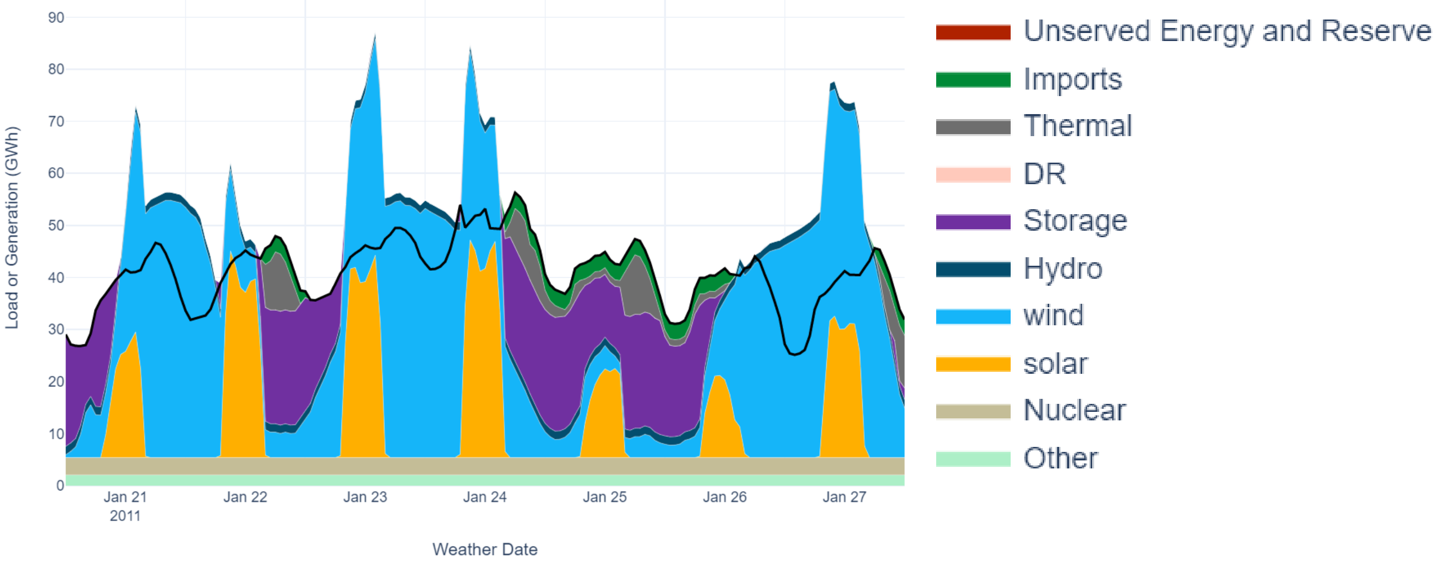
LDES has the potential to support long-term electric grid

- **In the state's portfolios, short-duration storage helps minimize curtailment and shift excess renewable energy to hours with high load/low renewable energy**
- **During critical weeks, short-duration is insufficient to support multi-day stretches of high load and low renewable output**
  - This is the key reliability challenge as Massachusetts electrifies & transitions to winter peaking
  - A zero-carbon firm resource, such as long duration storage, could help serve that role

"Typical Week" in Spring 2050



"Critical Week" in January 2050



Scenarios from Phased scenario, 2011 weather conditions

Candidate long-duration technologies span a range of characteristics and maturities

Category	Technology	Technology Readiness	Market Readiness	Land Use / Footprint	Siting Considerations	Max. Duration (hrs)	Avg. Round trip Efficiency (%)	Cost	Lifetime (yrs)
Mechanical	Novel Pumped Hydro	Commercial	Commercial	High	Geologic formations, potential water well	0-15	70-85%	TBD	30-60
	Gravity-based energy storage	Experimental	Pilot	Medium	N/A	0-15	70-90%	TBD	30-50
	Adiabatic Compressed Air Energy Storage (A-CAES)	Emerging	Pilot	Medium	Geologic formations, underground caverns	6-24	50-70%	TBD	30-50
	Liquid Air Energy Storage	Emerging	Pilot	Low	N/A	10-25	40-70%	TBD	30-50
Thermal	Sensible Heat	Experimental	Pilot	Low	Access to water	200	55-60%	TBD	30-50
	Latent Heat	Commercial	Commercial	Low	Access to water	25-100	40-50%	TBD	20-40
	Thermochemical Heat	Experimental	R&D	Medium	Access to water	N/A	N/A	TBD	TBD
Chemical / Electrochemical	Aqueous Flow Battery	Experimental	R&D	Medium	N/A	25-100	50-70%	TBD	5-20
	Hybrid Flow Battery	Emerging	Pilot	High	N/A	25-50	55-75%	TBD	5-20
	Metal Anode Battery	Experimental	Pilot	High	N/A	50-200	40-55%	TBD	15-30

Stakeholder question: Are there other technologies and is our technology readiness assessment accurate?

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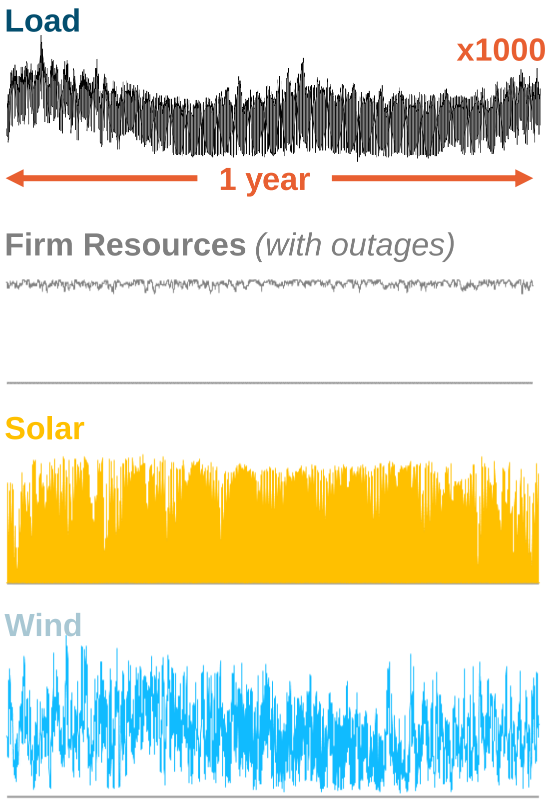
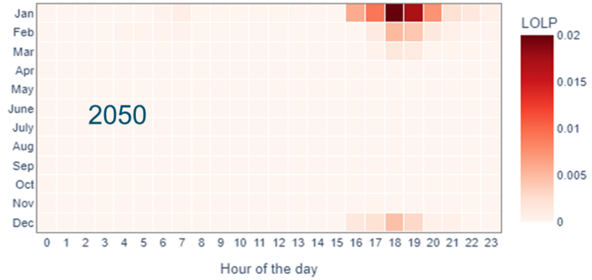
E3 will leverage loss-of-load probability modeling to assess MDES/LDES capacity contributions

+ **E3 will utilize it’s Monte Carlo-based optimization model, RECAP, to evaluate the potential for MDES/LDES to support electric grid reliability**
  - RECAP uses historical weather, load, solar, and wind correlations as the foundation for time-sequential simulation of the system over many potential conditions
  - Time-sequential modeling allows for tracking storage state-of-charge
+ **E3 developed load and renewable output profiles for ISO-NE for 39 weather years**
+ **In this study, we’ll characterize the reliability challenge and the role of MDES/LDES to contribute to reliability**

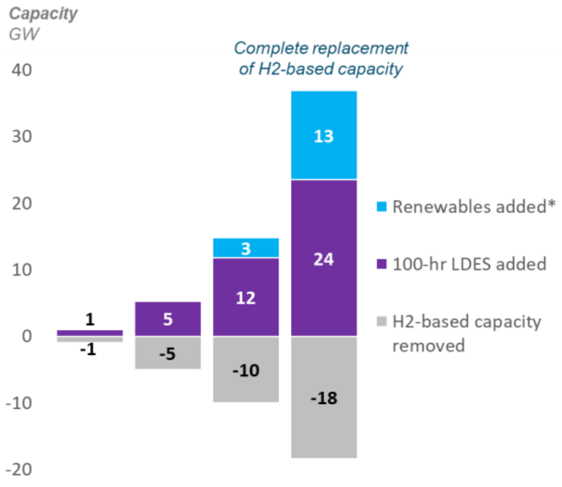
Monte Carlo Simulation of loads, renewable profiles, and generator outages used to simulate 1,000 years of plausible system conditions



Characterize the Reliability Challenge illustrate periods of high loss of load probability in 2030, 2040 and 2050 based on state’s planning portfolios



Characterize Effective Capacity Contributions for generic mid and long duration storage resources

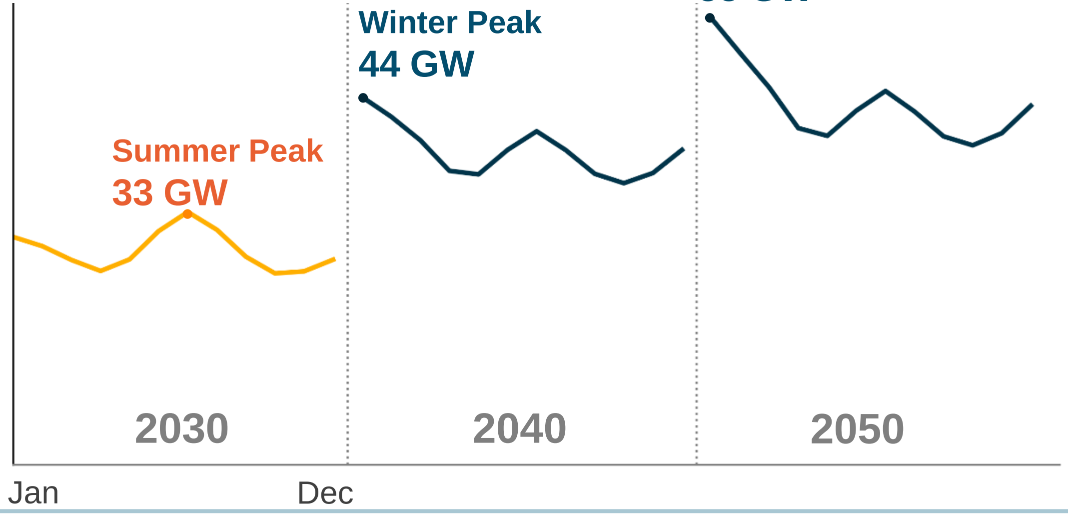


Example RECAP result from New York

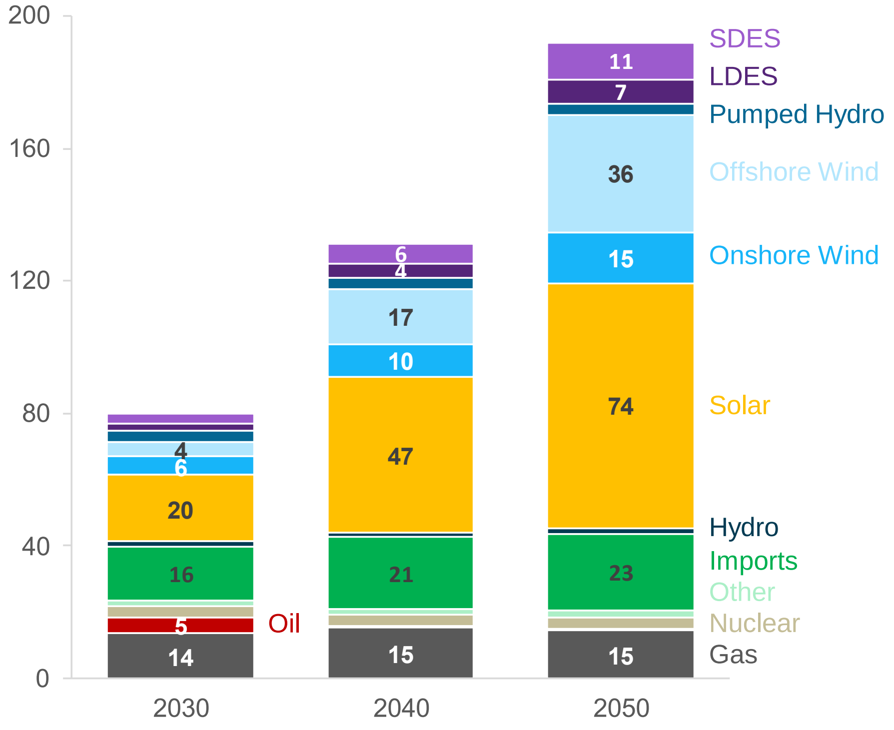
Study leverages the state's CECP 2050 portfolio to evaluate the potential for LDES to provide reliability

+ **E3's reliability modeling is based on New England's projected loads and installed electric capacity from the Phased Scenario**
  - System transitions to winter peaking by 2040, with a peak of 55 GW by 2050
  - Renewable and storage resources (including 7 GW of LDES) are the major resource additions to meet load growth
  - System retains 20 GW of firm capacity, including 15 GW of gas-fired generation, 3 GW of nuclear generation, and 2 GW of biomass generation to support system reliability

Peak Loads
(GW)

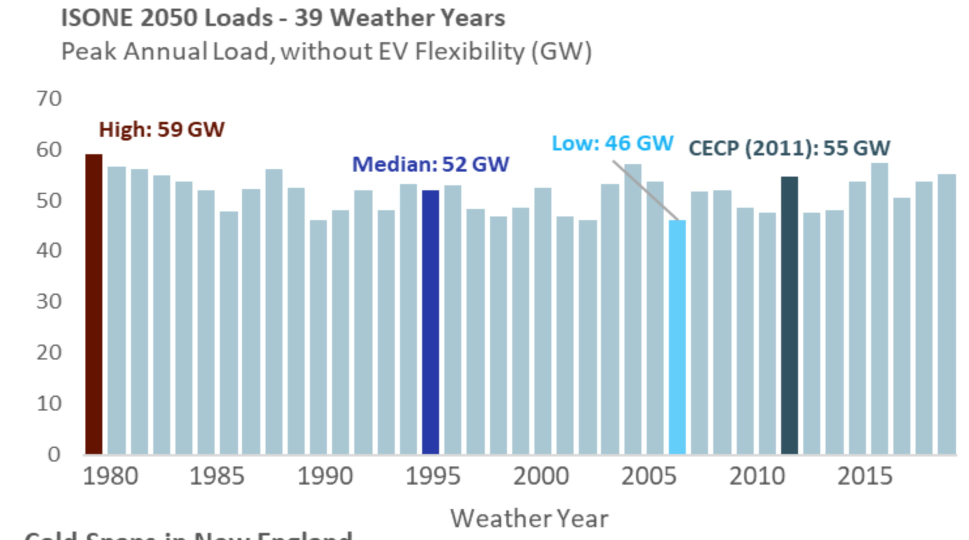


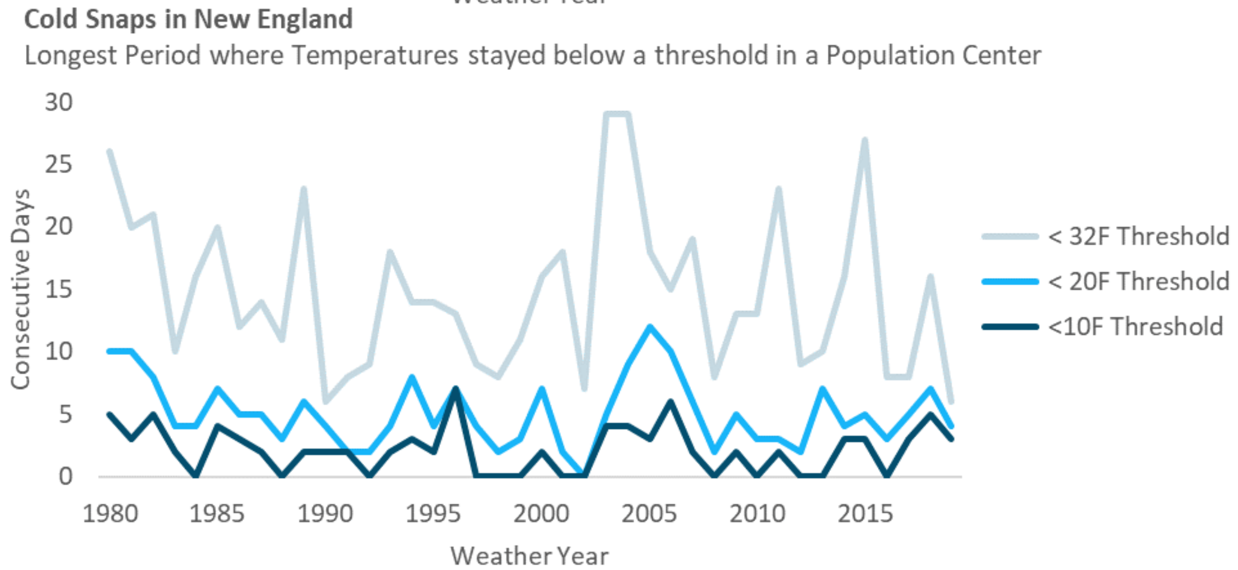
Installed Electric Capacity in New England CECP 2050, Phased Scenario
(GW)



Why is simulating the system over many years of weather data important?

- **Highest risk days for loss of load in winter peaking systems are periods with low renewable generation and increased load from heating electrification**
  - A sufficient number of such events must appear in the simulation input data to correctly evaluate low probability events present in “1-in-10” conditions
- **For example, 2011 weather compared to other years had:**
  - Slightly higher peak (55 GW) relative to median (52 GW) but much lower than coldest year (59 GW)
  - Temperatures below 20F for as long as 3 consecutive days, relative to average of 5 and a maximum of 12 across all years





Ongoing work: The future of MDES/LDES supporting resource adequacy in MA

- **Mid- and long-duration energy storage has potential to provide reliability in future high-renewables systems through intra- and inter-day load shifting**
  - Many candidate long-duration energy storage technologies exist in various stages of maturity today – no clear "winner" has emerged
- **Work is ongoing to assess reliability contributions of MDES/LDES**
  - Our team is finalizing a characterization of the winter reliability challenge in 2030, 2040 and 2050 under the state's planned 2050 CECP Phased scenario
    - Includes a characterization of at least two key contingencies: loss of transmission to offshore wind, one other based on stakeholder input
  - Ongoing reliability modeling to evaluate the ability of MDES/LDES to provide effective capacity to the system
    - Will inform assessment of its ability to replace other firm dispatchable generation (e.g., gas) on the system
    - Will include assessment of diversity benefits with offshore wind

Stakeholder question: What are the contingencies/scenario assumptions of greatest interest?

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Study Timeline

Task	Date
Study Kickoff	March 29, 2023
Stakeholder Session #1	June 9, 2023, 9:30-11am (EDT)
Stakeholder Interviews	Ongoing until September 1, 2023
Stakeholder Modeling Feedback	June 21, 2023
Stakeholder Session #2	August 16, 2023, 9:30-11am (EDT)
Stakeholder Final Feedback Due	September 1, 2023
E3 Results to MassCEC and DOER	October 1, 2023
DOER Report, including final study results, to Legislature	By December 31, 2023
Public comment due on DOER Report	Early 2024

Next Steps

Now

- Go to breakout rooms for initial reactions and discussion (20 min.)

Going Forward

- Seeking continued stakeholder engagement – critical to study outcomes and potential policy recommendations
  - Session 2: 8/16 @ 9:30am EDT - Registration Link
  - Interviews
  - Written comments – Please submit to: thomas.ferguson@mass.gov
- Webpage for the study: here
- Recording of today's session will be made available and posted on the study website.

Breakout Rooms

- We'll have four breakout rooms, each comprising at least one E3 and one DOER/CEC representative
- Half of the breakout rooms will focus on the current state of storage deployment, the other half will focus on the potential role of mid- and long-duration technologies in a Net Zero Commonwealth
- Representatives will moderate and put up a slide with questions to guide discussion
- Given there may be a large number of participants in each breakout room, please raise your hand and a moderator will call on you to speak
- Discussion will last 20 min., after which session will end. We will not reconvene to the main room

THANK YOU!

Breakout Room Q&A

- **Room(s) 1 & 2: Energy Storage Today**
  - What are the biggest barriers that remain unaddressed by current programs? What are the best opportunities?
  - Which value streams are most attractive to developers? Are there other value streams we should be considering? Data/opportunities to measure other value streams?
  - Are IRA-adjusted cost projections for SDES consistent with your experience/project/expectation?
  - Are there other data sources the E3 team should consider for business case analysis?
- **Room(s) 3 & 4: Long Duration Energy Storage and Reliability Modeling**
  - Are there other LDES technologies the E3 team should consider?
  - What value streams/use cases should the team consider in evaluating the benefits of LDES?
  - Do attendees have any info they would like to share related to capital cost outlook for different LDES technologies, to inform E3 benchmarking?
  - What are the contingencies/scenario assumptions of greatest interest?
  - What distribution-level use cases are of interest for LDES?

Appendix / Not Currently Used

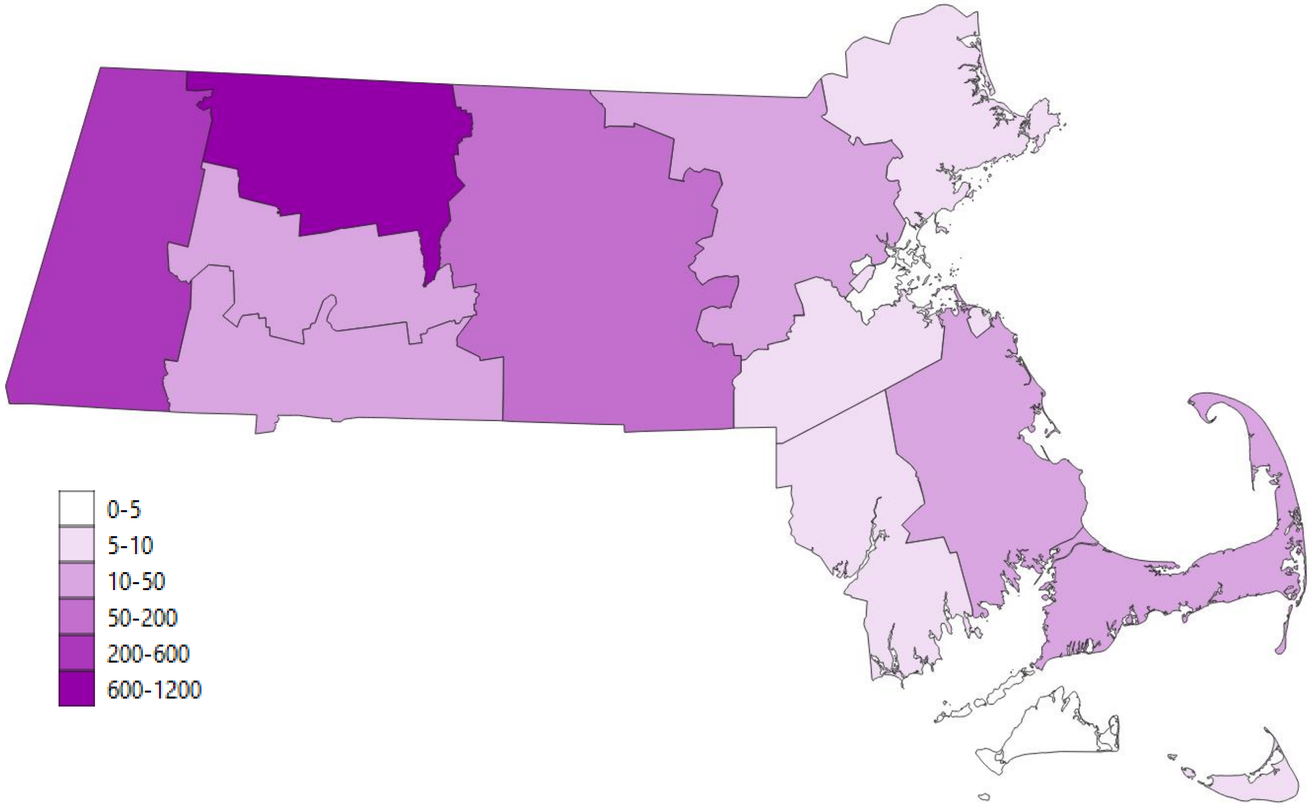
Energy+Environmental Economics

Existing Energy Storage in MA

Technology	Capacity (MW)	Energy (MWh)	Avg. Duration (Hrs)	Count
Hydroelectric Pumped Storage	1,768	12,944	7	5
Lithium-Ion Battery	287	581	2	103
Sodium-Ion Battery	18	15	1	3
Thermal Storage	3	1	0	3
Vanadium Redox Flow Battery	1	3	6	1
Zinc Iron Flow Battery	-	-	-	-
Latent Heat Storage	-	-	-	-
Flywheel	-	-	-	-
Battery (Unspecified)	2	5	2	1
Total	**2,079**	**13,549**	**n/a**	**116**
Additional Resources (<0.5 MW)	37	24	n/a	2,554

Resource Connection Type	Capacity (MW)	Energy (MWh)	Avg. Duration (Hrs)	Count
Front of Meter	2,038	13,505	7	96
Behind the Meter	46	49	1	22
Total	**2,084**	**13,554**	**n/a**	**118**
Additional Resources (<0.5 MW)	37	24	1	2,554

Total Operating Storage Capacity (MW) – All Technologies



E3-simulated Renewable Generation Profiles

Profile	Primary Source(s)	Weather Conditions Captured	Notes
Loads	**ISO-NE** Public Hourly Load Data **NOAA** Historical Weather Data	1979 – 2020	• Neural network regression used to back-cast hourly load patterns under broad range of weather conditions using recent historical load data (2014-2019) and long-term weather data (1979-2019) • Historical shape scaled to match future forecasts of regional energy demand • Shapes for load modifiers (e.g. transportation electrification) layered on top of neural network results
Wind	**NREL** WIND Toolkit	2007 – 2012	• Profiles for **Onshore and offshore wind resources** simulated based on generic plant location and characteristic assumptions (e.g. hub height & power curve)
Solar	**NREL** System Advisor Model	1998 – 2019	• Profiles for **utility-scale solar resources** simulated based on generic locations and technology characteristics chosen by E3 (tracking vs. tilt, inverter loading ratio)

RECAP Inputs and Outputs

+ RECAP evaluates resource adequacy through simulations over hundreds of years

Inputs

Load
- *Hourly load for 1979-2019*

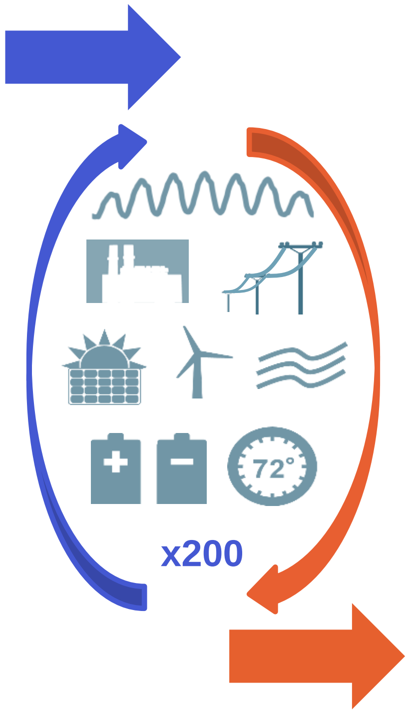
Dispatchable Generation
- *Capacity*
- *FOR by resource category*

Renewables
- *Capacity*
- *E3-simulated generation profiles for many weather years*

Hydro
- *Hydro availability for many hydro years*
- *Max/min power constraints*

Storage
- *Capacity*
- *Duration*
- *Roundtrip efficiency*

Imports
- *Firm capacity*



Outputs

LOLH
- *Loss of load hours*
- *Hrs/yr of total expected lost load per year*

LOLE
- *Loss of load expectation*
- *Days/yr of total expected lost load per year*

ALOLP
- *Annual loss of load probability*
- *% probability of having a single loss of load in any given year*

EUE
- *Expected unserved energy*
- *MWh/yr of energy that cannot be served*

ELCC
- *Effective load carrying capability*
- *Equivalent quantity of 'perfect capacity' for a variable or energy-limited resource*

TPRM
- *Target planning reserve margin*
- *PRM required to achieve a specified reliability threshold (i.e. LOLH, LOLE, ALOLP, or EUE)*

Storage Use & Value Streams Cases

Potential Measurable & Monetizable Value Streams →

Potential Modeling Use Cases	Wholesale			Transmission and Distribution	BTM	
	Energy arbitrage	Avoided generation capacity	Ancillary services	T&D deferral	Bill savings	Backup power/ Resiliency
Wholesale standard	√	√	√			
Distribution deferral	√	√	√	√		
Wholesale solar + storage	√	√	√			
BTM storage only					√	√
BTM solar + storage (res)					√	√
BTM solar + storage (C&I)					√	√