Modeling Storage and Resource Adequacy in Capacity Expansion Models

PRESENTED BY

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PRESENTED TO

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Contents

Challenges to Modeling Storage in Capacity Expansion Models

- Storage resources add complexities to capacity expansion models since their resource adequacy value is highly dependent on the resource mix, especially their interaction with other storage and renewable resources
- Modeling Long Duration Energy Storage (LDES) technologies additionally requires computationally expensive temporal models to capture multi-day and multi-month charging dynamics
- Currently substantial uncertainty exists for new storage technologies regarding capital cost trajectories, storage capabilities, and operations
- Adequately capturing operating conditions of highly decarbonized and electrified systems that present opportunity for LDES (e.g. renewable droughts, weather volatility) will be increasingly important

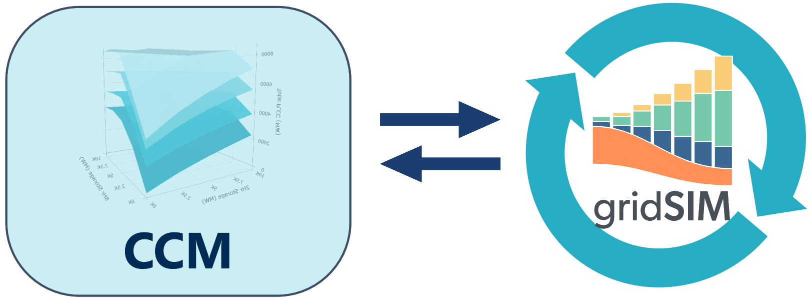
This presentation explores two approaches to modeling the resource adequacy value of energy storage within decarbonized systems

Case Study #1: Modeling Endogenous ELCCs in ISO-NE

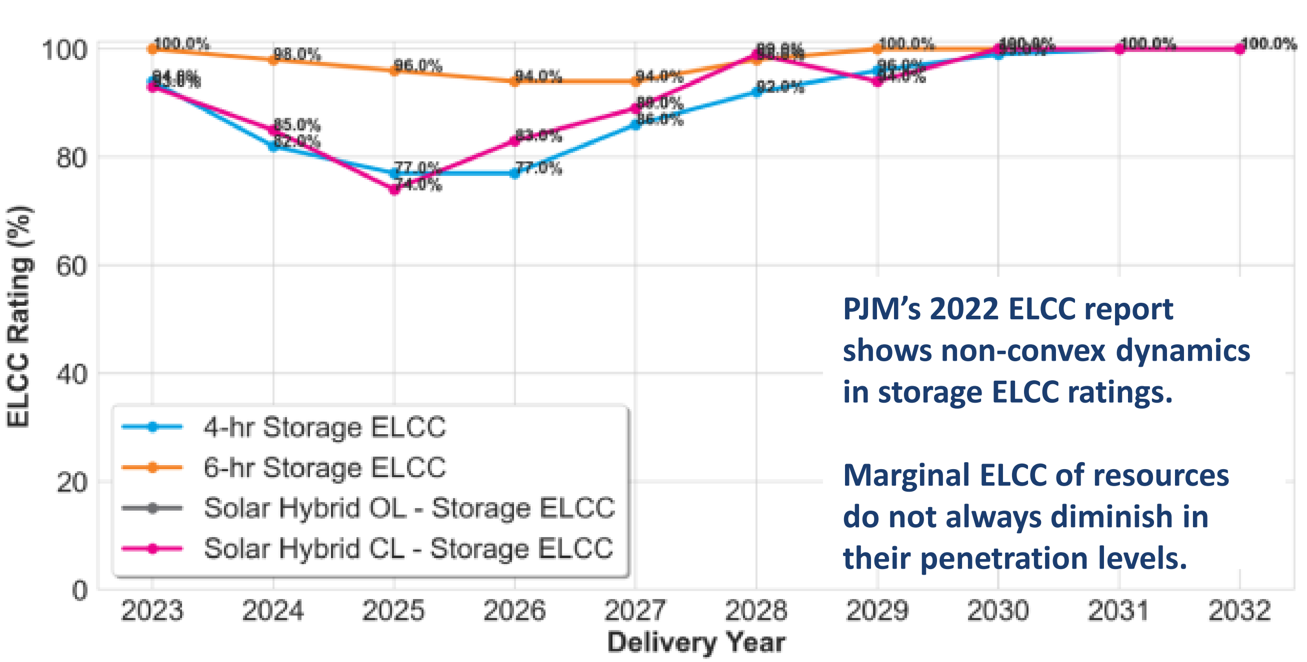
Problem: Interaction of storage ELCC is inherently divergent and path dependent based on other storage, wind, and solar ELCC's. Further, decades of weather data are needed to capture adequacy risks

Solution: Modeling ELCC values endogenously within capacity expansion models better captures the complementary and antagonistic relationships in resource marginal value as capacity mix changes overtime.

We utilize a sequential solve approach to model a non-convex problem: marginal ELCC values do not always diminish with increasing penetration levels.



PJM ELCC Ratings for Storage and Hybrid Resources



PJM's 2022 ELCC report shows non-convex dynamics in storage ELCC ratings.

Marginal ELCC of resources do not always diminish in their penetration levels.

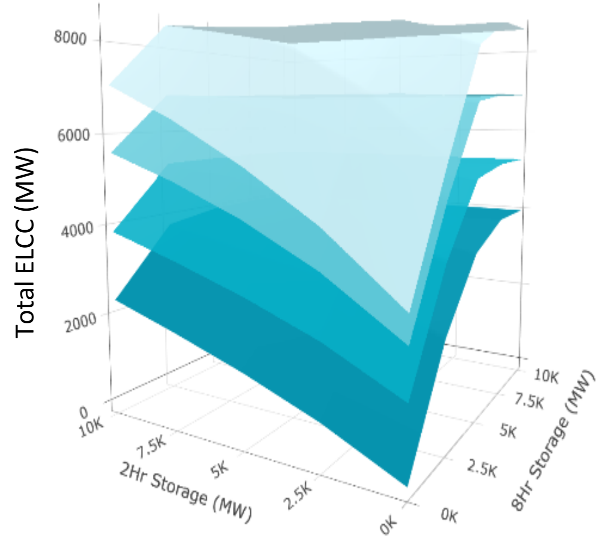
Source: PJM, December 2022 Effective Load Carrying Capability (ELCC) Report, January 6th, 2023.

Modeling Approach

We employed Brattle's gridSIM™ capacity expansion model to identify the least-cost portfolio of resources to meet future demand and reliability requirements in New England out to 2050.

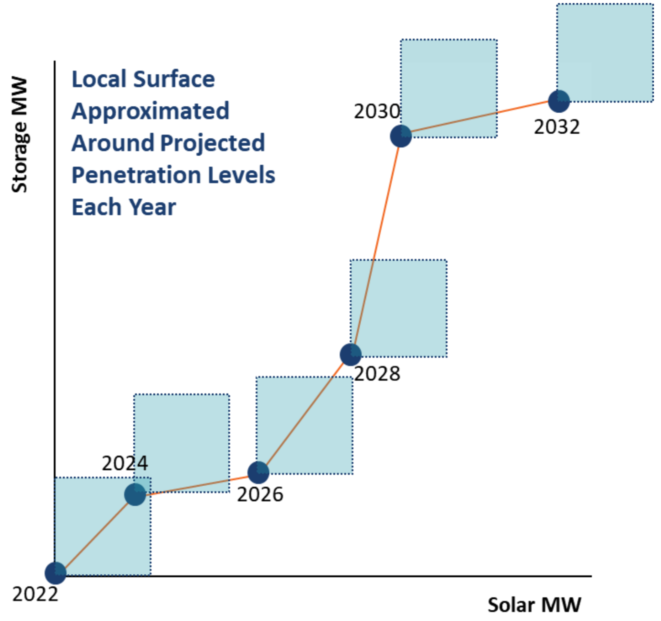
- **gridSIM™** simulates hourly market operations, investment and retirement of resources, and endogenously accounts for co-varying solar, wind and storage accreditations using a local multidimensional ELCC surface.
- For ISO-NE, the **Capacity Capability Model (CCM)** uses 20-years of hourly load, wind, and solar profiles, derives hourly output of storage through a dispatch algorithm, and develops a global ELCC surface which reflects the complementary and antagonistic relationships in resources' marginal value (based on its marginal reduction in net peak load, as a proxy) for any given fleet composition.
- To incorporate the global ELCC surface into gridSIM, a linear program, the non-linear surface is translated into many linear surfaces (facets), which combines the convenient mathematical properties of a diminishing marginal ELCC (and the benefits to run-time) with a sequential solve approach to accurately capture non-diminishing resource interactions.

Illustrative ELCC Surface



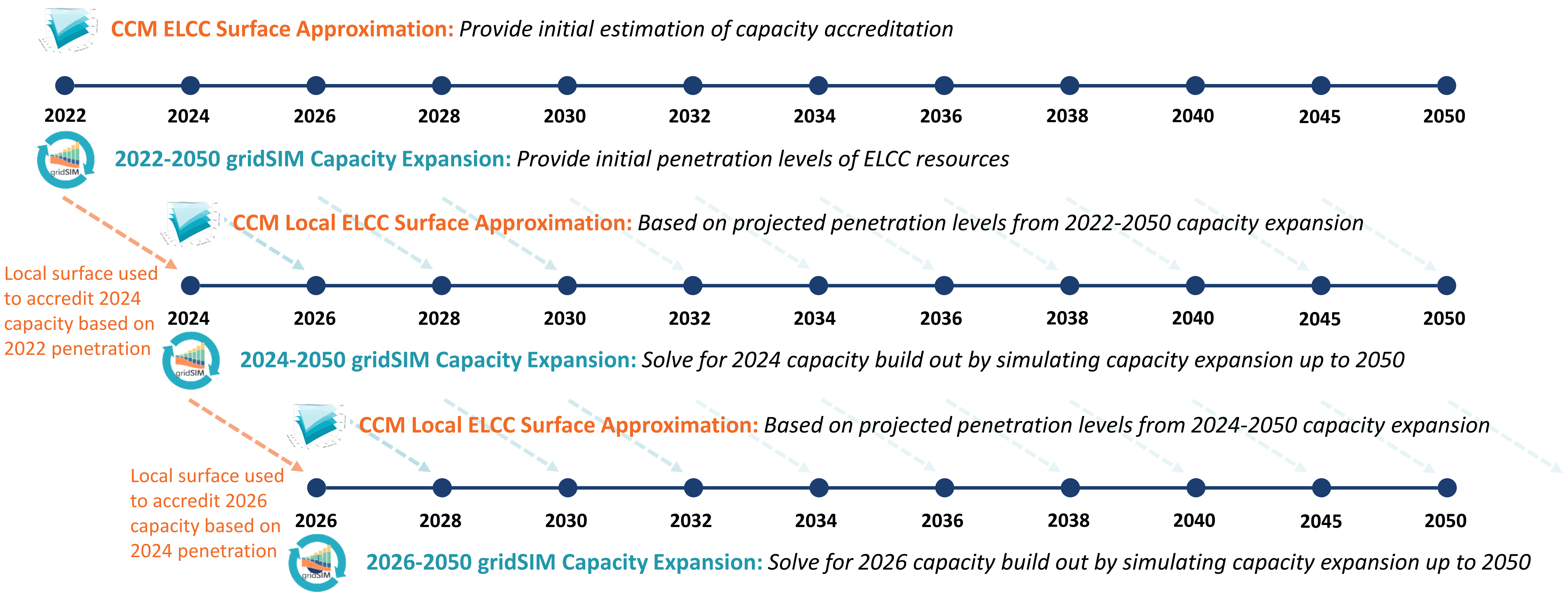
Note: Different surfaces for varying solar penetration levels

Illustrative Local ELCC Surface



Internal Capacity Accreditation Through Sequential Optimization

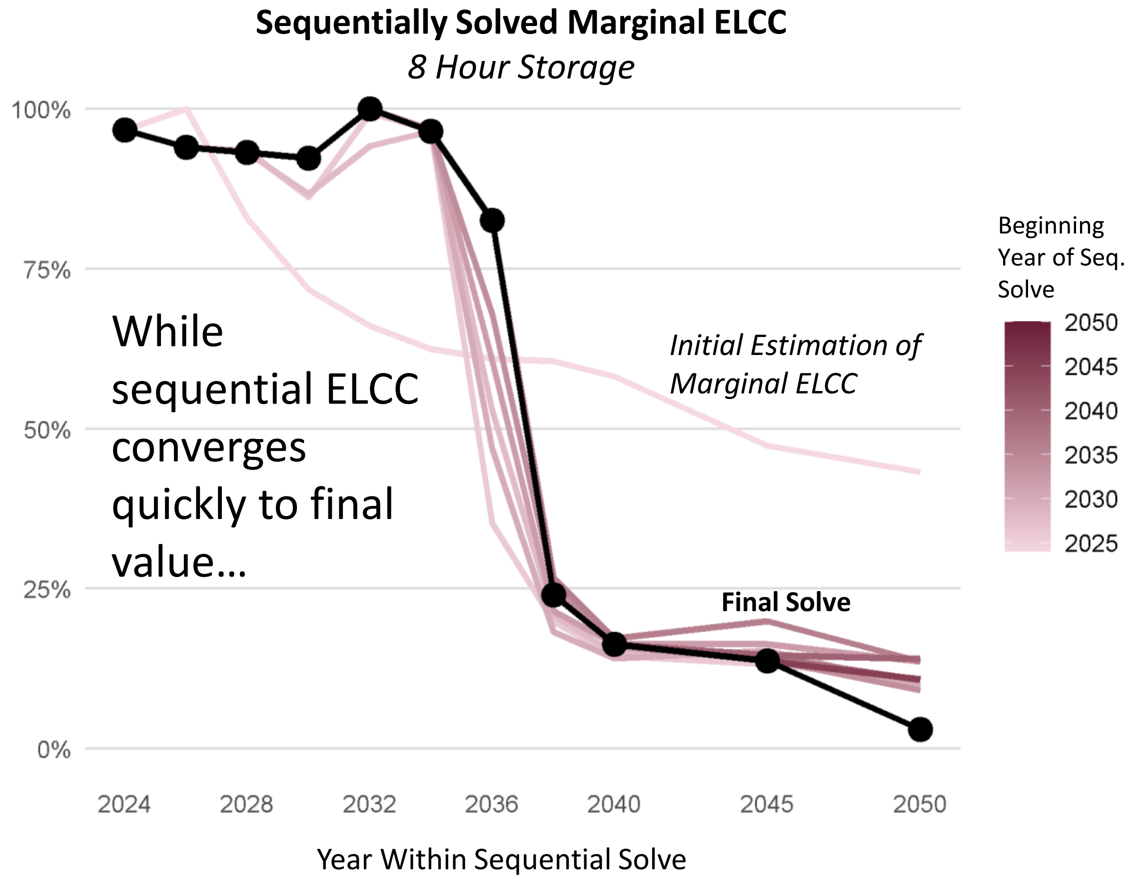
gridSIM™ optimizes capacity each year by using a local capacity value surface approximated around the prior year's penetration of studied resources. To account for intertemporal decision making, we simulate capacity expansion for the entire time horizon in each step.

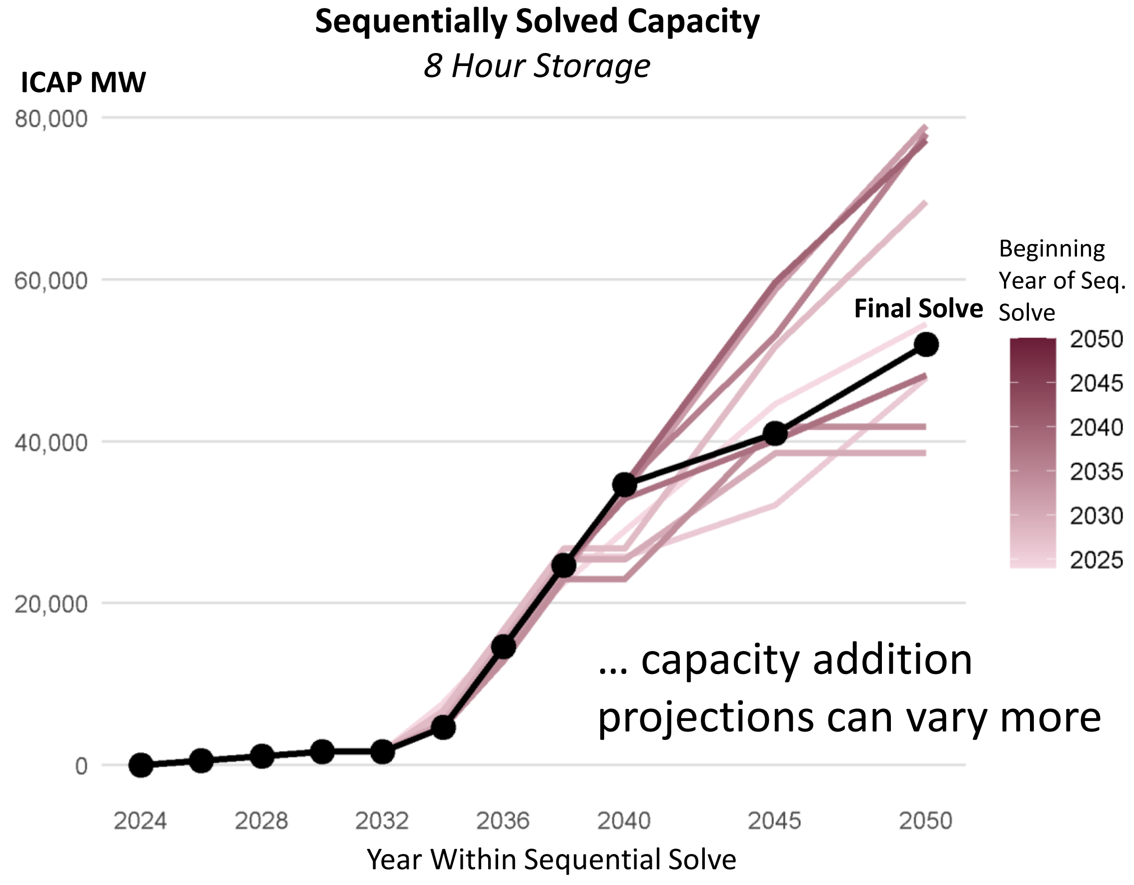


… Sequentially solve until 2050 capacity is optimized

Internal Capacity Accreditation Through Sequential Optimization

Graphs below describe how capacity of 8-hour storage is sequentially added over time. In each sequential solve, storage build decisions account for both the current and future marginal value of storage, where future marginal values are based on previously projected penetration levels of the ELCC resource fleet.





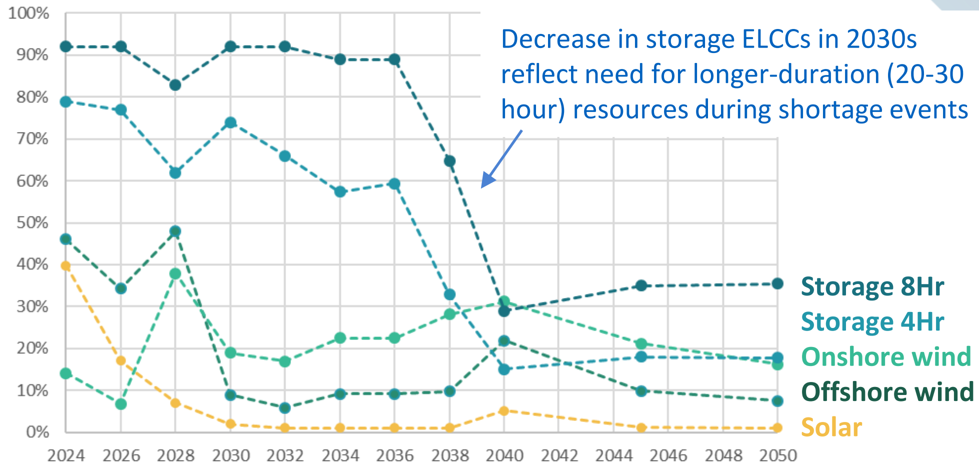
Capacity Value of Renewables and Storage

Accurately capturing renewable and storage adequacy value (and the synergies between them) is important for maintaining reliability, projecting the resource mix, and correctly valuing assets for their true attributes within an evolving system.

- 4-hr storage ELCCs initially are about 20% lower than 8-hr through the mid-2030s, but then drop to 50% lower in later years following significant storage additions.
- Projected 2045 and 2050 ELCCs for storage imply a need for 20–25hr resources to maintain ISO-NE reliability in a highly decarbonized system.

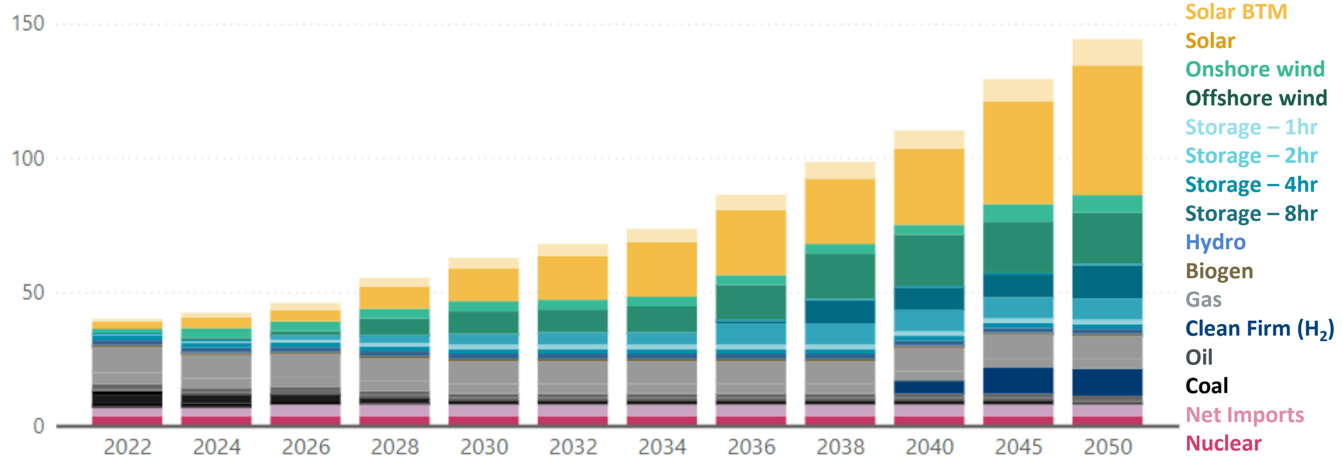
Marginal Capacity Value of Renewables and Storage

UCAP %



ISO-NE Capacity Expansion Modeling Results

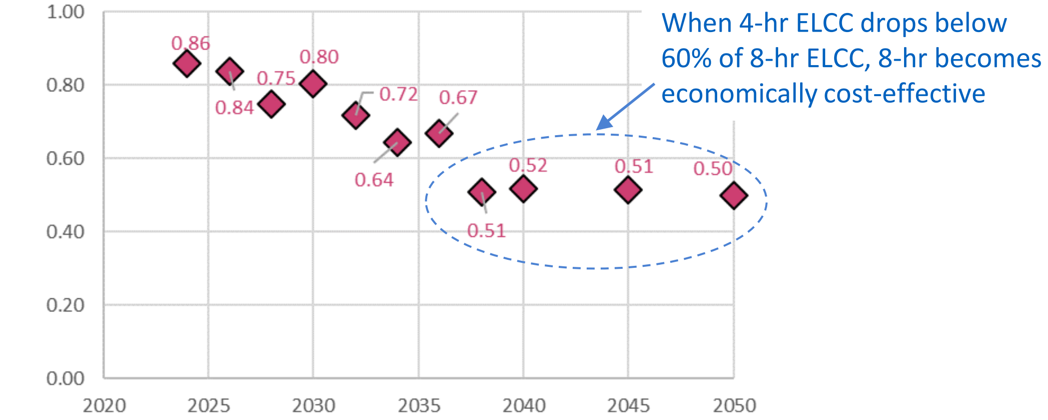
GW



See Brattle's New England Energy Storage Duration Study. Note 8hr storage is the maximum duration modeled.

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

% of 8-hr ELCC



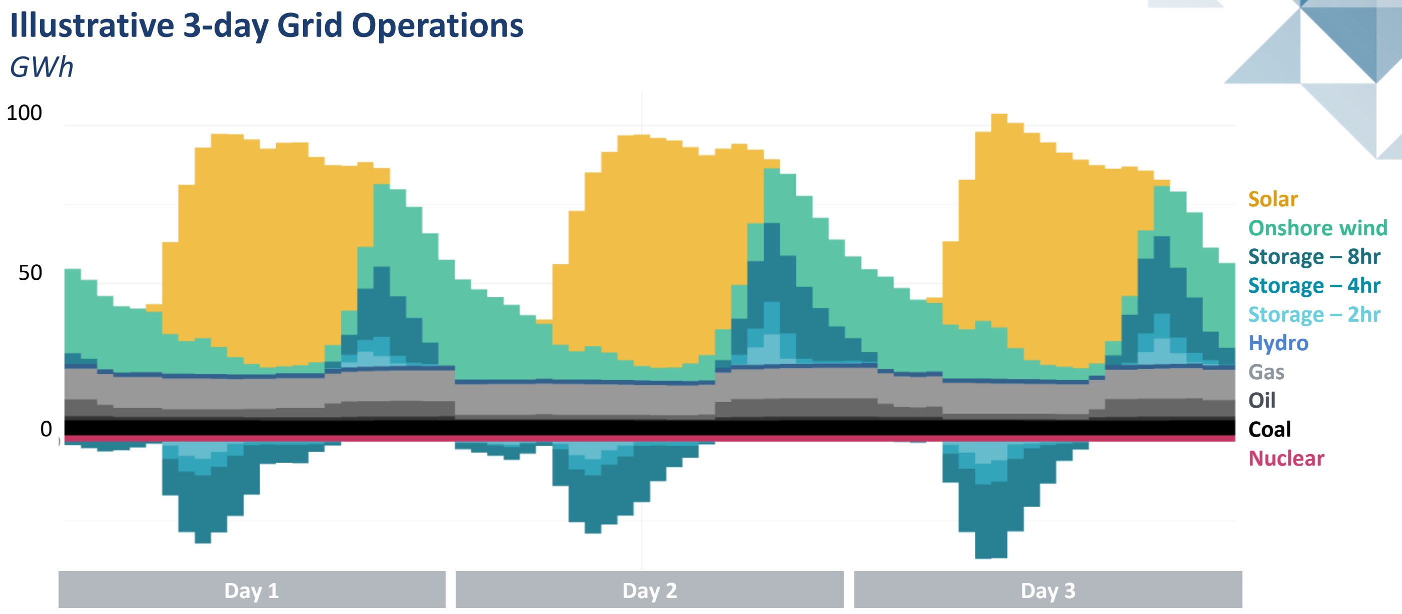
Note: UCAP % reflects each resource's contributions to achieving reliability targets relative to "perfect" capacity.

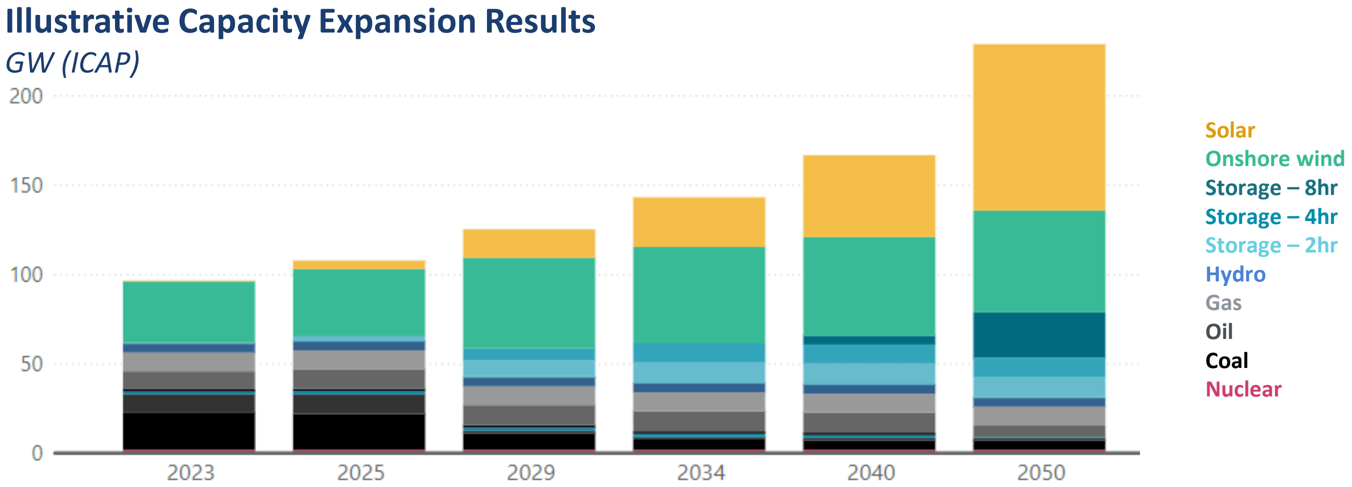
Case Study #2: Hourly Capacity Accreditation in SPP

An alternative to estimating ELCC values with a surface, is to endogenously model capacity value using an **hourly operating reserve** approach and **weather and resource adequacy sampling**:

- The simulation will balance supply and demand in every hour including operating reserves, which eliminates the need to estimate ELCC values exogenously *(replaces traditional peak load + reserve margin planning targets)*
- Captures 15+ years of weather conditions
- Longer duration storage is built only in later years when load conditions and high renewable generation shares create unique resource adequacy challenges

Brattle is conducting SPP's Future Energy and Resource Needs Study (FERNS) to examine optimal generation and transmission expansion and resource adequacy risk under a range of renewable and electrification scenarios.





Draft Results.

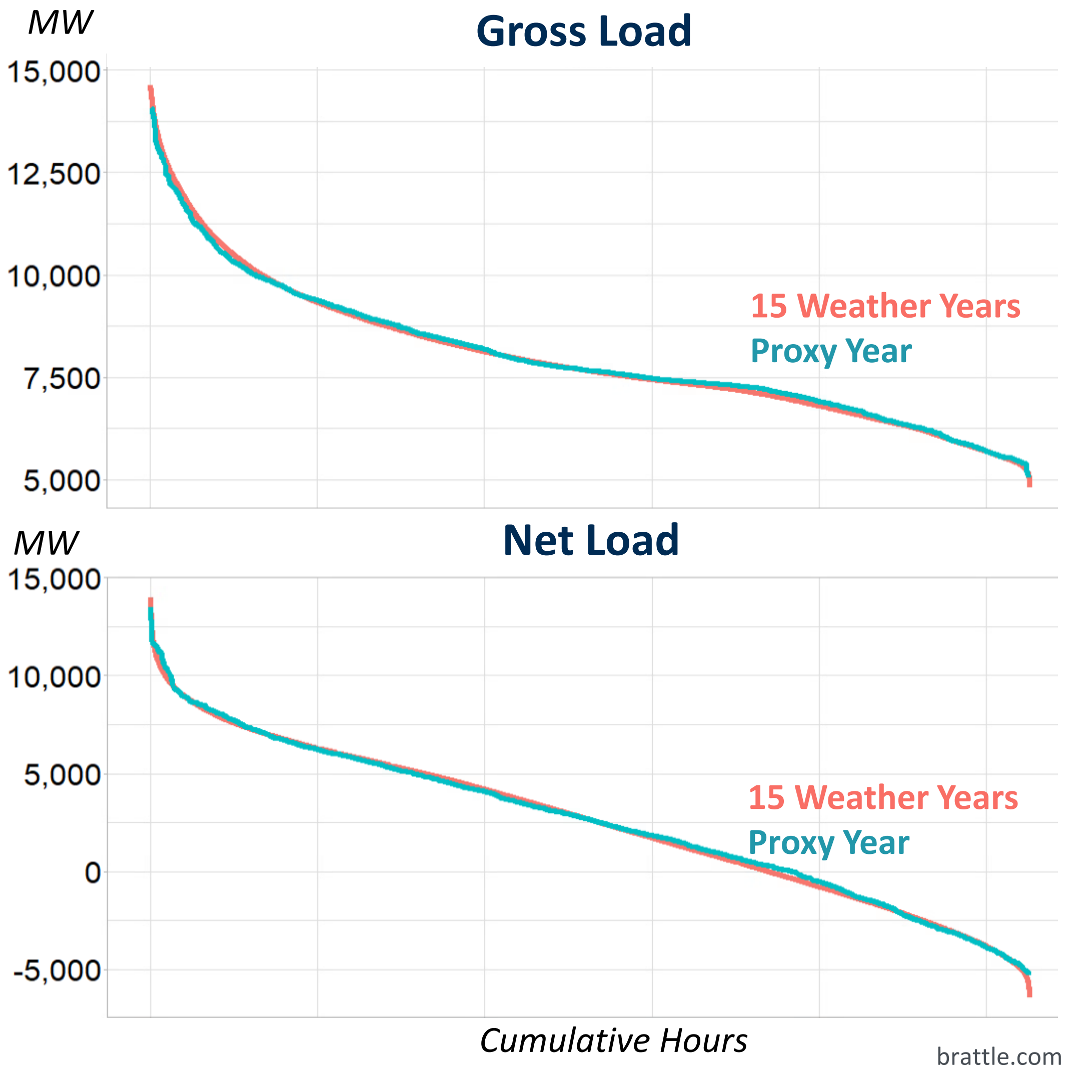
Weather-Reflective Proxy Year

The FERNS Study relies on Brattle's **Weather and Resource Adequacy Sampling (WRAS) Tool** to create a single proxy year from 15 weather years of data:

- The proxy year is comprised of 25 three-day periods. Each 3-day period is weighted based on the frequency of periods with similar conditions during the entire 15-year sample to capture multi-day events
- The tool selects probability-weighted proxy year periods based on multi-variable "k-means clustering" algorithm for gross load, net load (adjusted for weather-correlated forced fossil outages), and solar/wind profiles
- Weather representative proxy year eliminates the need for planning reserve margin and allows for hourly approach + operating reserve margin

Approach is computationally efficient, while representing the spread of renewable and load conditions that unveil the value of storage

SPP Central-East Zone, 2029, Medium Electrification



Note: Vertical axis scales differ across figures.

Draft Results.

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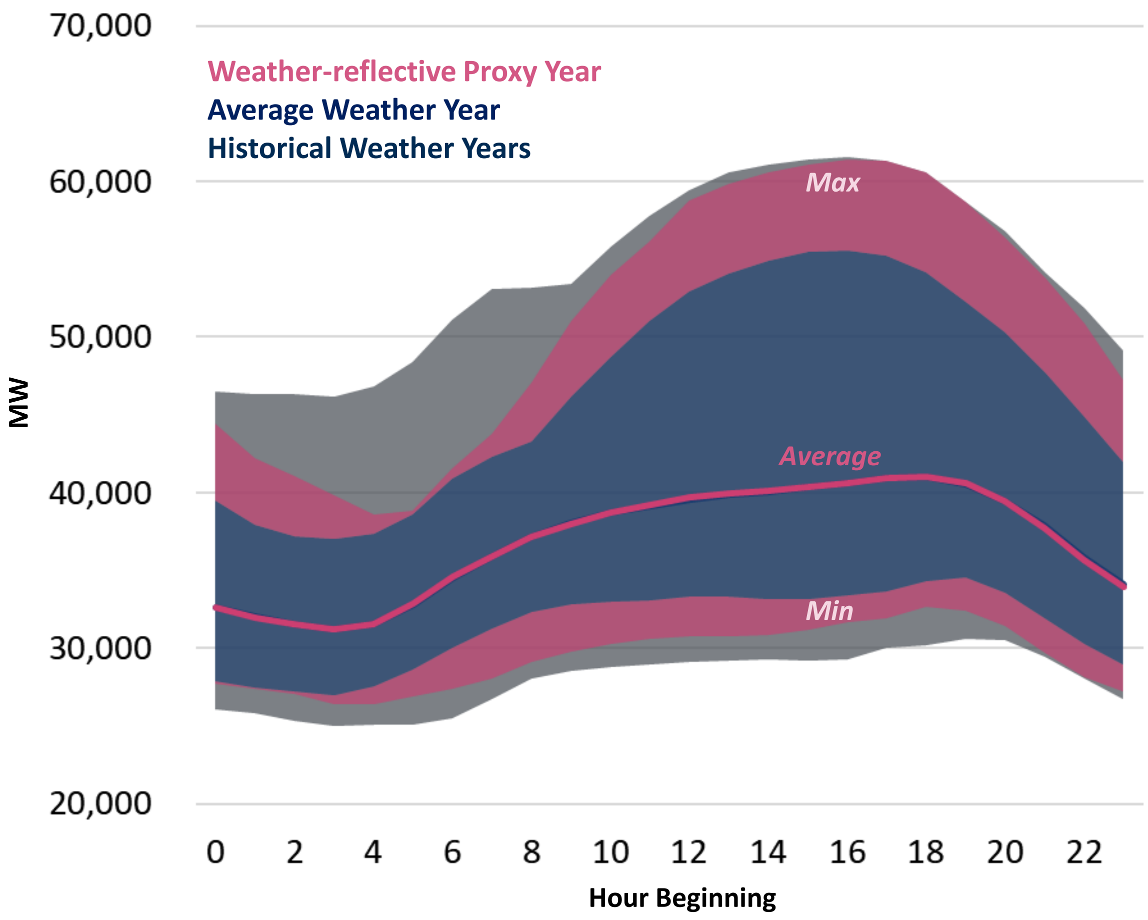
Modeling Multiple Weather Years

The FERNS Study uses a **weather-reflective** proxy year, based on load and renewable data for 15 weather years

- Includes heat waves, cold snaps, renewable droughts, inter-zonal correlations, weather-related forced outage rates
- Realistic seasonal, daily, hourly variations
- Same average, but full set of weather-related challenges
- Captures geographic diversity in load and resource availability within SPP and surrounding regions

The weather-reflective proxy year (**pink**) captures the full range of challenging actual weather conditions over the past 15 years (**gray**) better than a weather-normalized hourly profile (**blue**)

SPP-Wide 24-Hour Load Shape (2029, Medium Scenario)



Draft Results.

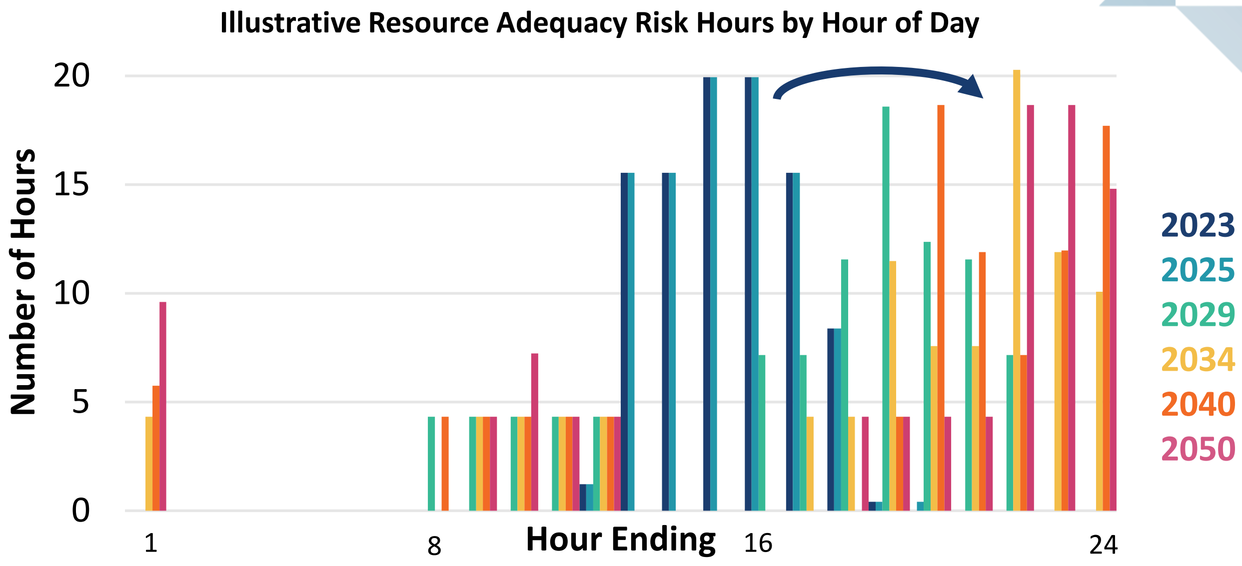
Future System Resource Adequacy Risks

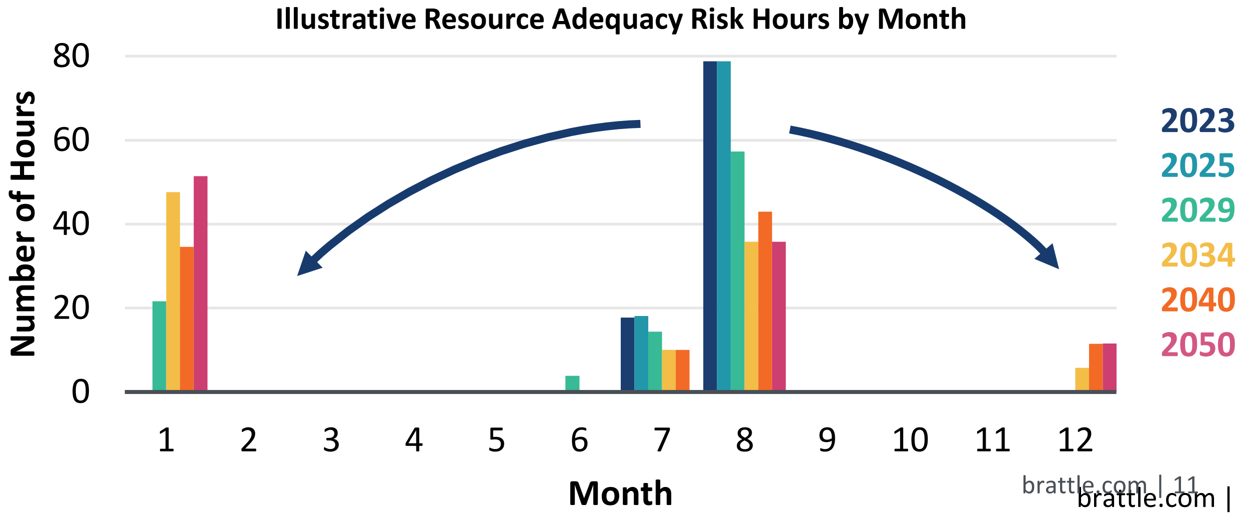
Evolving net load conditions means resource adequacy risks change over time

Charts show the top 100 hours with highest resource adequacy risk in each year (defined as hours with the lowest "supply cushion"):

- Today, RA challenges occur mostly in the mid-afternoon during July and August
- By 2030, tight resource adequacy hours shift to evening hours (compared to afternoon hours in earlier years) or morning winter hours
- By 2040 and 2050 these effects are very pronounced, when 8+hr storage becomes cost effective in SPP system

The hourly capacity accreditation approach endogenously values storage and renewable resources during tight resource adequacy hours – all within a single optimized solution





Draft Results.

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Questions for Technology Developers

- What are the fixed and variable costs and technical parameters of LDES technologies (cycling efficiencies, degradation impacts, cycling limits, etc)?
  - Given cycling impacts on operational efficiency and lifetime impacts, should models attribute full rated power and SOC capability to assets? What augmentation costs are needed to maintain full rated asset functionality?
- How do developers anticipate LDES to be used in future markets? Do they anticipate A/S and real-time energy revenues (daily DA+RT energy arbitrage) to be negligible value opportunities? Will the primary LDES use case to contributing resource adequacy (and therefore earn lucrative capacity revenues)?
- How are developers thinking about the reliability value of LDES in the context of accreditation methodologies?

About the Authors

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Kate Peters specializes in strategic planning and regulatory matters related to an increasingly decarbonized electric power system. She has expertise in capacity expansion modeling, electrification grid-impact studies, and the emerging role of virtual power plants (VPPs) in decarbonized markets. She has supported utilities, renewable developers, research organizations, and other private sector clients in regulatory and strategy engagements.

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Dr. Andrew W. Thompson is an energy economist with a background in electrical engineering and expertise in wholesale electricity market design, regulatory economics, and policy analysis of network industries, particularly in the energy sector. He helps clients understand the market implications of integrating emerging resources particularly focused on short and long-duration storage.

Additional Reading

Case Study #1

- Hagerty, J. Michael, Ragini Sreenath, Kate Peters, Andrew Levitt, "New England Energy Storage Duration Study" Brattle report, December 2023.

Case Study #2

- Pfeifenberger, Johannes, Kai Van Horn, Kate Peters, "SPP Future Energy and Resource Needs Study (FERNS): Capacity Expansion Modeling Approach" Brattle presentation prepared for SPP CPPTF, REAL, SAWG, FGSAG, ESWG, February 2024.
- Additional presentations will be made available in the meeting materials for upcoming SPP stakeholder meetings: Consolidated Planning Process Task Force (CPPTF), Resource and Energy Adequacy Leadership Team (REAL), Supply Adequacy Working Group (SAWG), Future Grid Strategy Advisory Group (FGSAG), Economic Studies Working Group (ESWG), Strategic Planning Committee (SPC).

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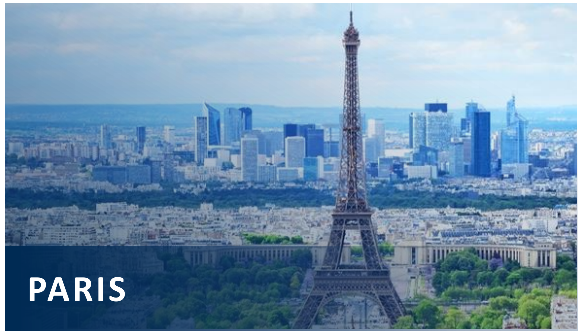
- Transportation
- Water

A Global Firm



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Additional Slides

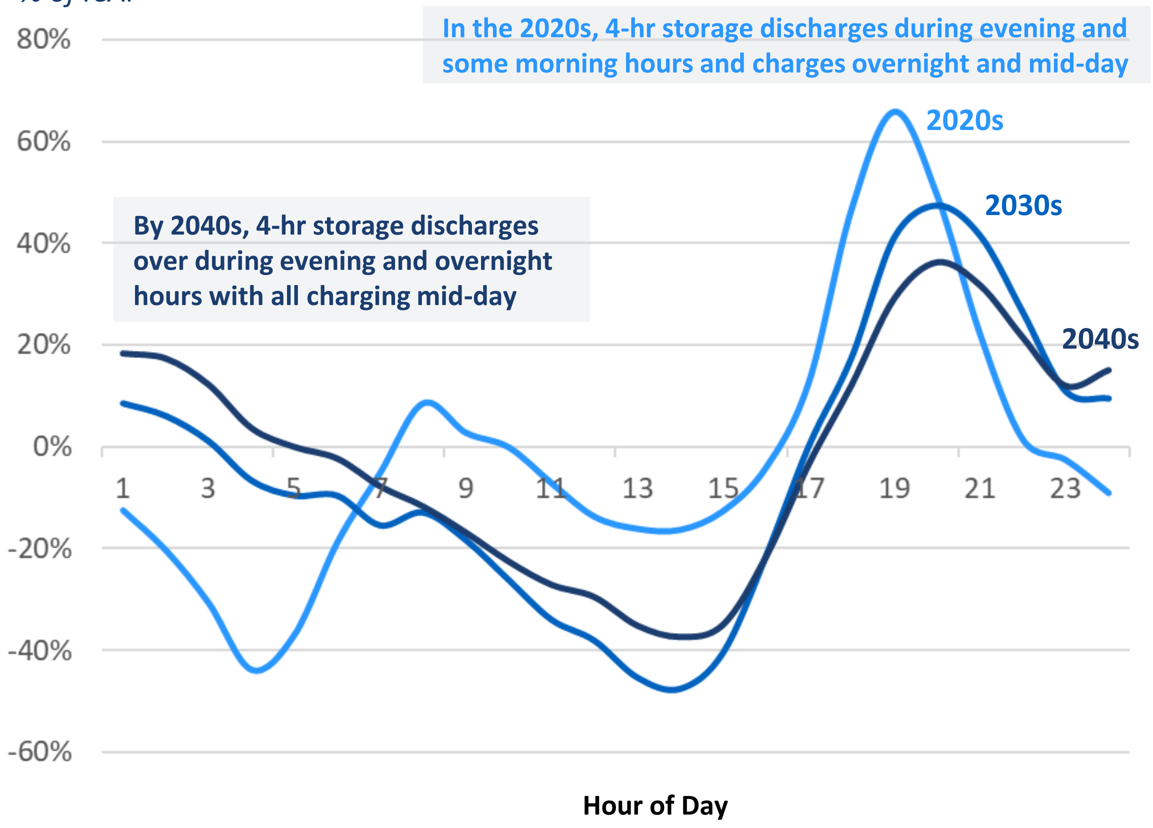
Role of Shorter and Longer Duration Storage

Although we did not model LDES in this case study, we examined the changing role of 4hr storage to illustrate the evolving system need for longer storage durations:

- **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

% of ICAP



Zonal Topology

- In addition to the internal SPP zones, we model the interties for up to 8 external zones with variable hourly transmission flows to/from SPP to capture the economic and resilience benefit interregional diversity
- External zones create geographic diversity benefits to meet energy supply and resource adequacy conditions in SPP

SPP Zones and Interties to Neighboring Systems