

Application of the Critical Periods Reliability Framework in Long-term Capacity Expansion Modeling

Energy Systems Integration Group
Spring Technical Workshop

Tucson, Arizona

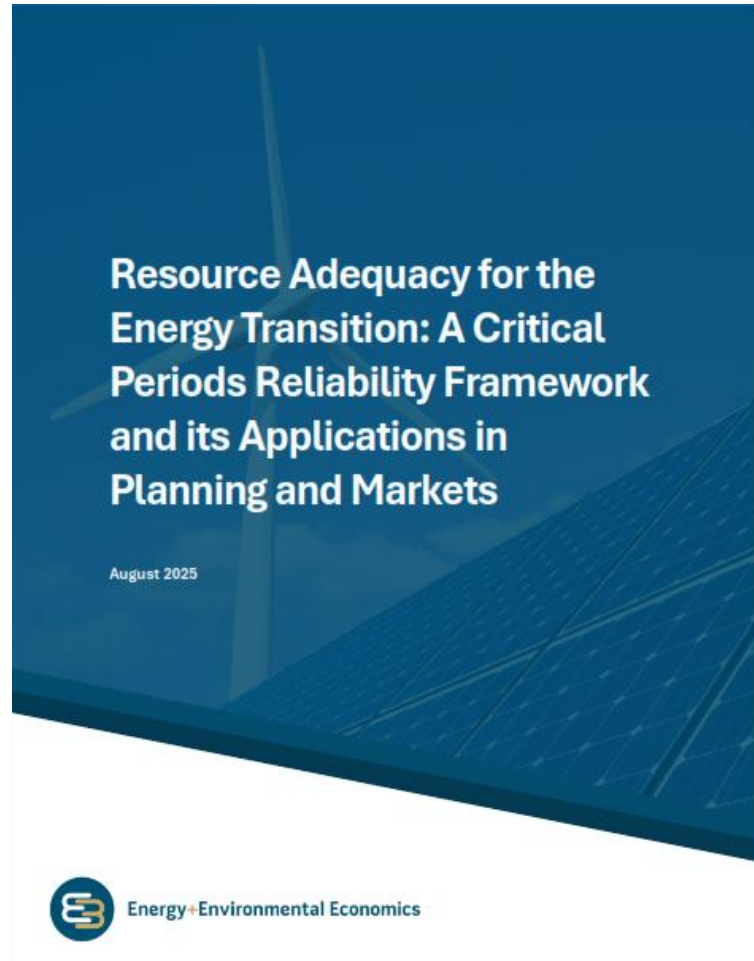
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Energy+Environmental Economics

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E3's new whitepaper describes the emerging consensus around measuring power system resource adequacy



<https://www.ethree.com/new-framework-resource-adequacy/>

- + The paper addresses the two major problems in resource adequacy:
 - Physical problem of ensuring reliability
 - Economic problem of ensuring efficient investment
- + Solving both problems requires robust loss-of-load probability modeling that accurately characterizes:
 - The conditions under which power supply may be inadequate to serve load
 - The incremental impacts to reliability of changes to the resource portfolio
- + The paper provides a holistic mathematical framework with applications in both system planning and markets

Why we need a scientific approach to resource adequacy need determination and accreditation

- + Resource adequacy is an externality that must be remedied with actions outside the electricity spot market because of structural barriers that prevent the market from clearing at a societally optimal reliability level
- + Determination of resource adequacy need is both critical for electric reliability and a large driver of electricity costs
- + Accurate resource accreditation is a primary signal for the value of new resources and is necessary for economically efficient investment
- + Effective hedging of capacity costs requires a well-formulated, fundamentals-based capacity spot market against which the forward contract can settle, enabling both the buyer and the seller to be able to reasonably anticipate potential price movements

Recent developments have made clear the need for changes in the traditional accreditation methods

1. The hours that are critical for reliability are increasingly diverging from the hours with highest peak load

2. Saturation and interactive effects among variable and energy-limited resources are becoming increasingly important as penetration grows

3. Traditional methods of accrediting conventional resources have been revealed as insufficiently accurate by widespread underperformance during major winter storm events

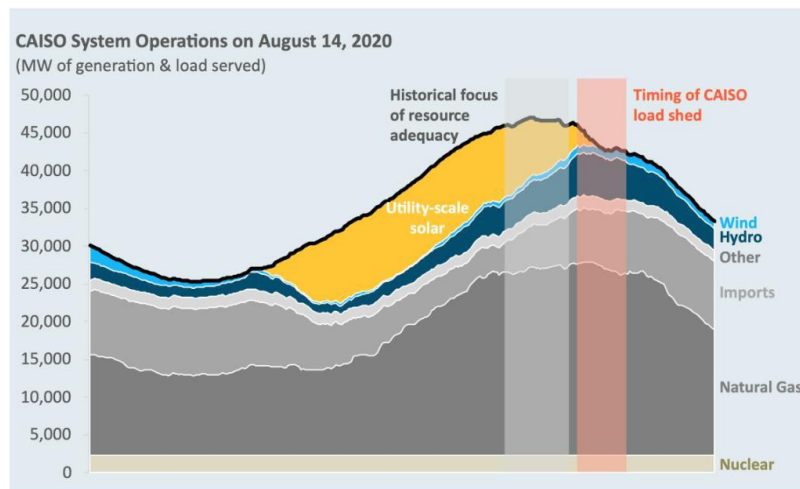


Figure 3: California's rotating blackouts on August 13-14 of 2020 occurred not during peak demand hours, but after sundown when solar generation fell to zero

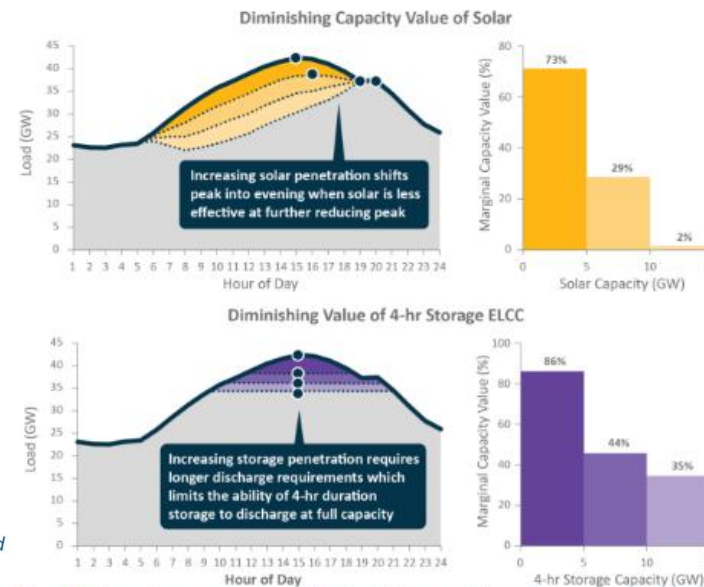


Figure 4: Solar and storage resources exhibit diminishing marginal contributions to reliability as penetration increases

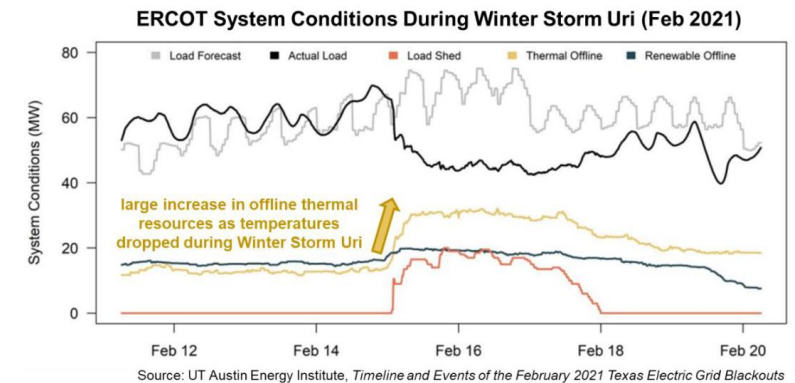


Figure 6: Significant outages of natural gas generation were a key contributor to the rotating outages on the ERCOT system during Winter Storm Uri

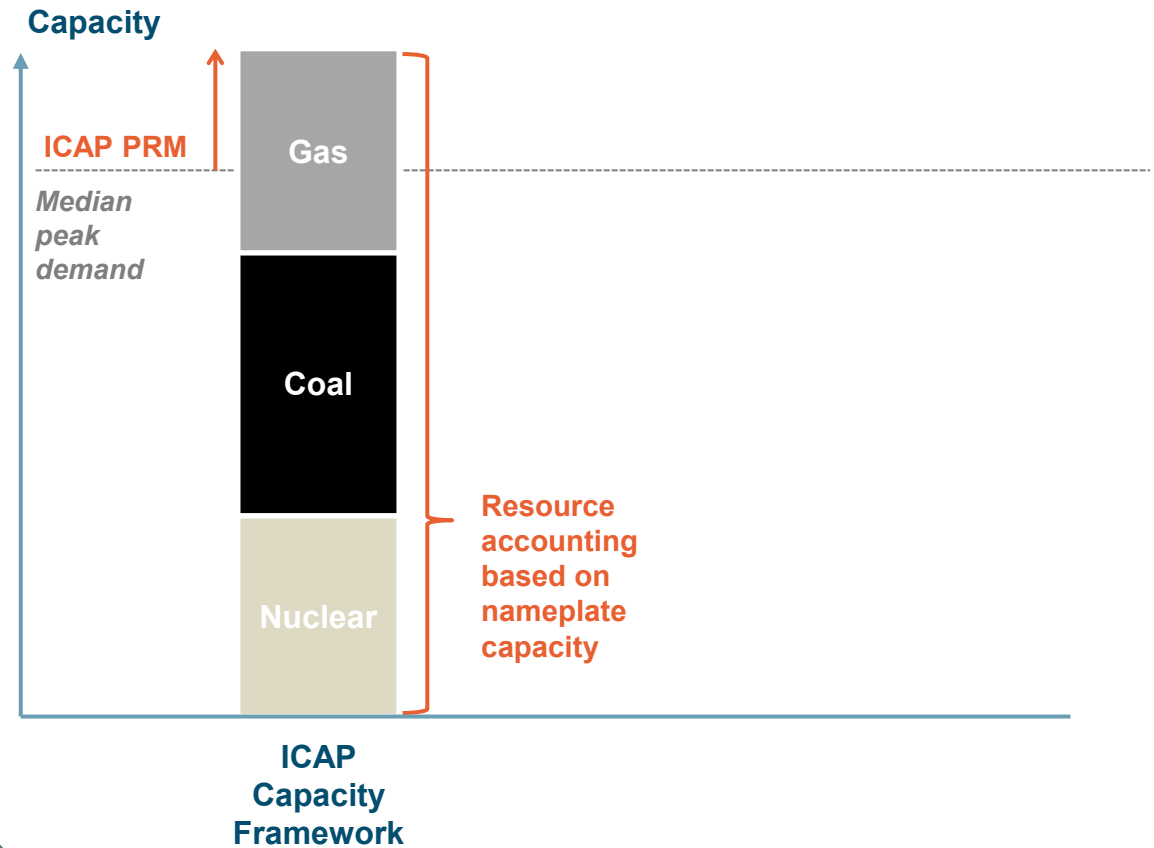
The conventional accreditation framework rests on simplifying assumptions that are increasingly inaccurate

+ PRM defined based on Installed Capacity method (ICAP)

- ❑ Covers annual peak load variation, operating reserve requirements, and thermal resource forced outages

+ Individual resources accredited based on nameplate capacity

- ❑ Small differences in forced outage rates
- ❑ No interactions among resources
- ❑ Forced outages also incorporated through performance penalties



$$\text{Installed Capacity} = \sum_{i=1}^n G_i$$

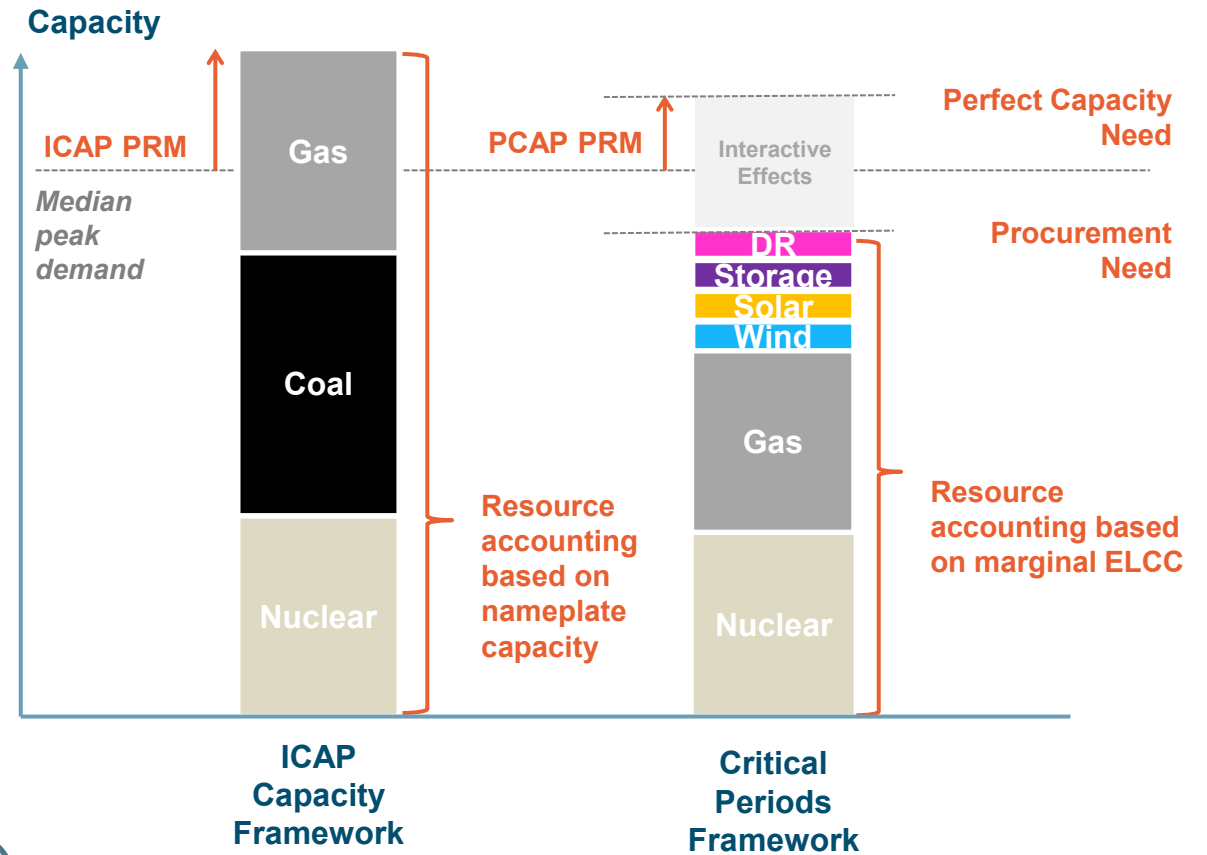
The Critical Periods framework is more accurate and more adaptable for a diverse resource mix

+ PRM defined based on need for Equivalent Perfect Capacity (PCAP)

- ❑ Covers annual peak load variation and operating reserves only; forced outages addressed in resource accreditation

+ Individual resources accredited based on Marginal ELCC

- ❑ Large differences in availability during key hours
- ❑ Significant interactions among resources
- ❑ ELCC values are dynamic based on resource portfolio



$$Portfolio\ ELCC = f(G_1, G_2, \dots, G_n)$$

Measuring ELCC of a portfolio and individual resources

+ ELCC is a function of the portfolio of resources

- ❑ The function is a surface in multiple dimensions
- ❑ The Portfolio ELCC is the height of the surface at the point representing the total portfolio

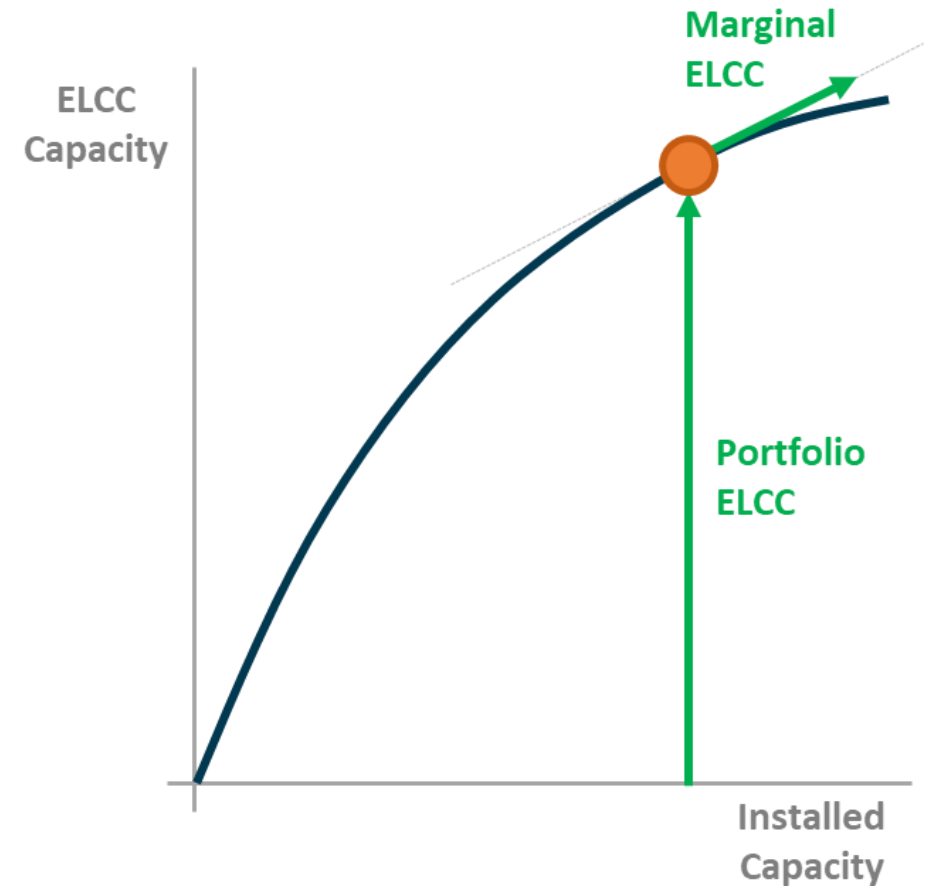
$$\text{Portfolio ELCC} = f(G_1, G_2, \dots, G_n) \text{ (MW)}$$

- ❑ The Marginal ELCC of any individual resource is the gradient (or slope) of the surface along a single dimension – mathematically, the partial derivative of the surface with respect to that resource

$$\text{Marginal ELCC}_{G_1} = \frac{\partial f}{\partial G_1} (G_1, G_2, \dots, G_n) \text{ (\%)}$$

+ The functional form of the surface is unknowable

- ❑ Marginal ELCC calculations give us measurements of the contours of the surface at specific points
- ❑ It is impractical to map out the entire surface

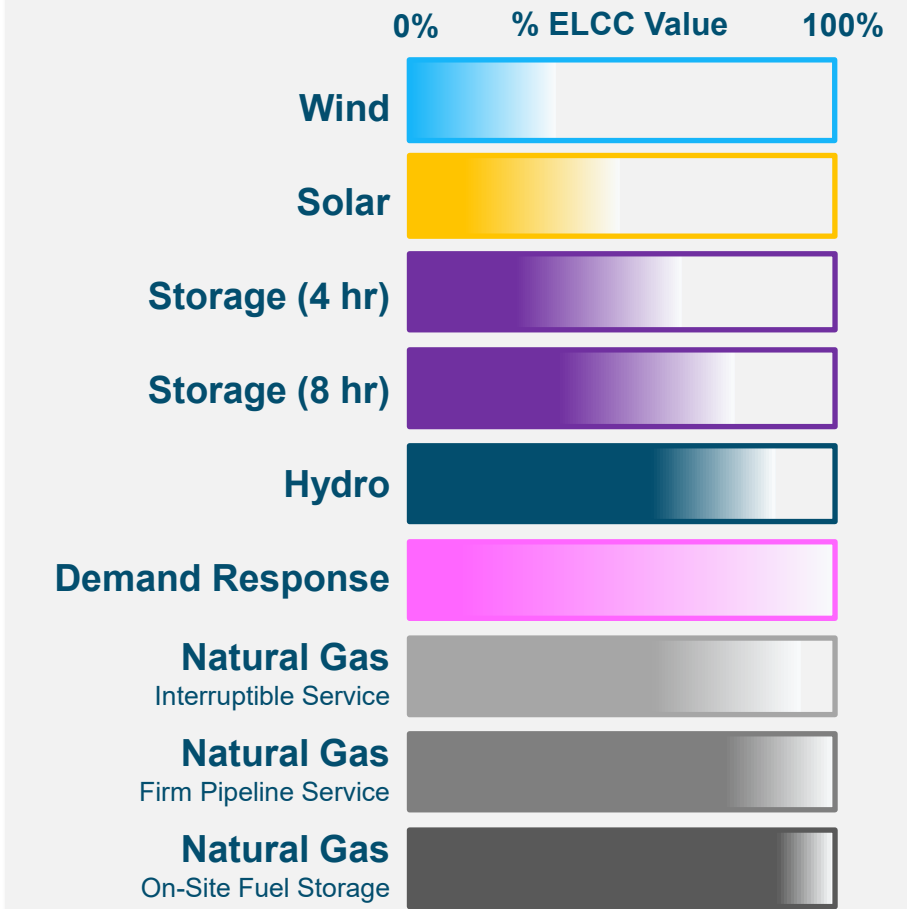


No resource is “perfect” – Marginal ELCC is applied to all resources in the Critical Periods framework

- + Marginal ELCC creates level playing field by measuring all resources against perfect capacity
- + Accounts for all factors that can limit availability:
 - Energy availability
 - Hourly variability in output
 - Duration and/or use limitations
 - Temperature-related de-rates and outage rates
 - Correlated outage risk
- + Interactive effects in the portfolio cannot be uniquely attributed to individual resources

$$Portfolio\ ELCC = \sum_{i=1}^n MELCC_i + Interactive\ Effects$$

Illustrative ELCC Values Across Technologies



The industry is moving toward a “Critical Periods” framework for need determination, need allocation, and resource accreditation

FERC approved MISO’s Direct Loss-of-Load (DLOL) framework in 2024

4

ISO-NE currently proposing marginal ELCC approach

3

1

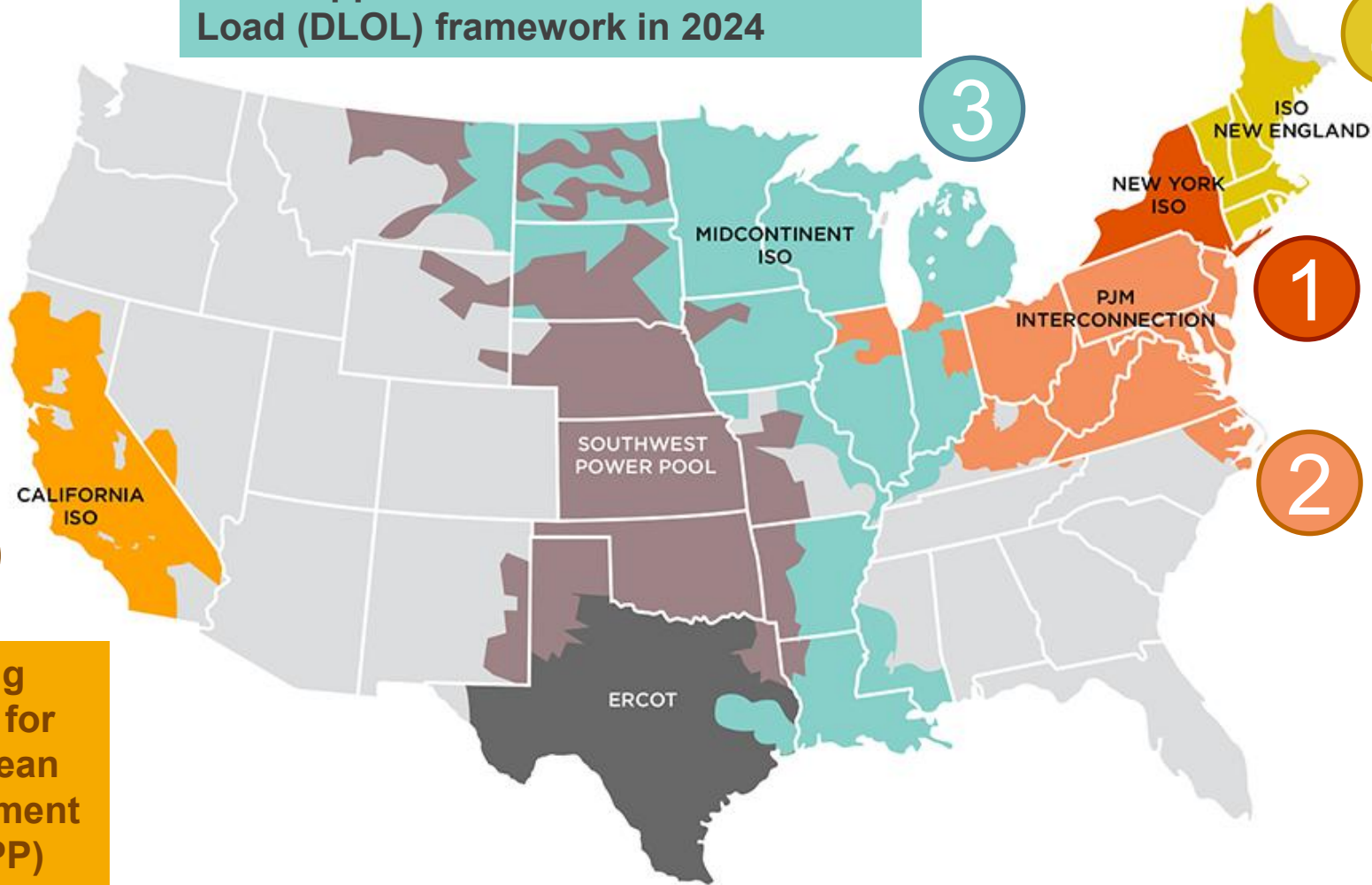
FERC approved NYISO move to marginal capacity accreditation in late 2022

2

PJM filed to FERC for marginal capacity accreditation Oct 2023 and received approval in 2024

5

CPUC proposing marginal ELCC for Reliable and Clean Power Procurement Program (RCPPP)



There are two primary methods of incorporating RA requirements into LTCE modeling

Parameterization

- + Parameterize RA need and ELCCs through custom constraints to ensure the optimal solution is approximately resource adequate
- + Pros: Surfaces can provide fairly precise RA information to minimize the need for iteration
- + Cons: Requires significant upfront investment through multiple LOLP model runs

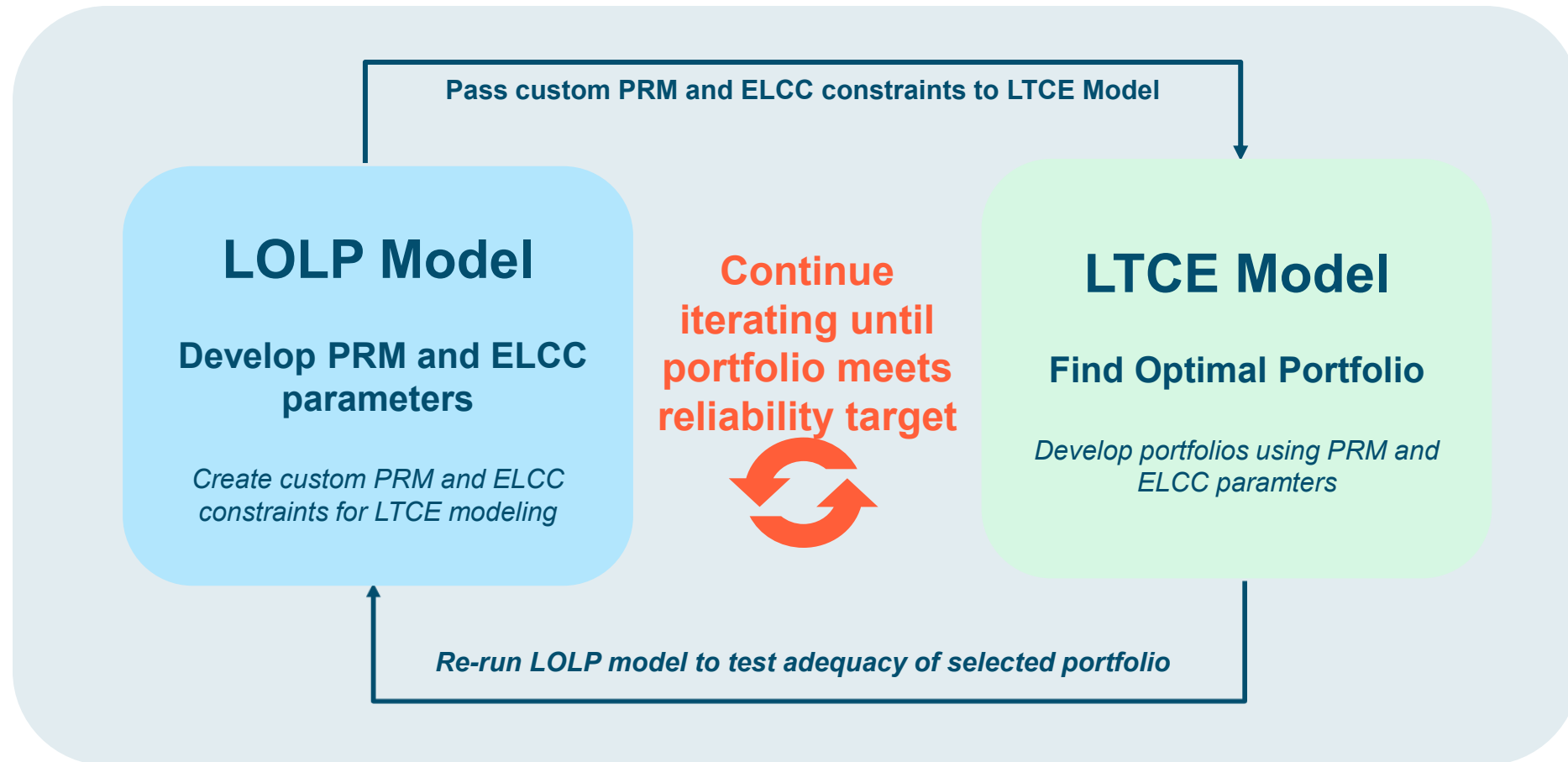
Endogenization

- + Co-optimize costs and resource adequacy by directly considering a very wide range of load and resource conditions in LTCE model
- + Pros: Does not require upfront LOLP model runs
- + Cons: May require more back-end iteration if computational constraints do not allow consideration of a broad enough range of conditions

Choice of a method for incorporating resource adequacy into LTCE is largely a *practical* one: which method converges on an optimal portfolio most quickly and with the most tractable problem size

Portfolios developed in LTCE model should be tested in a detailed LOLP model to ensure adequacy is achieved

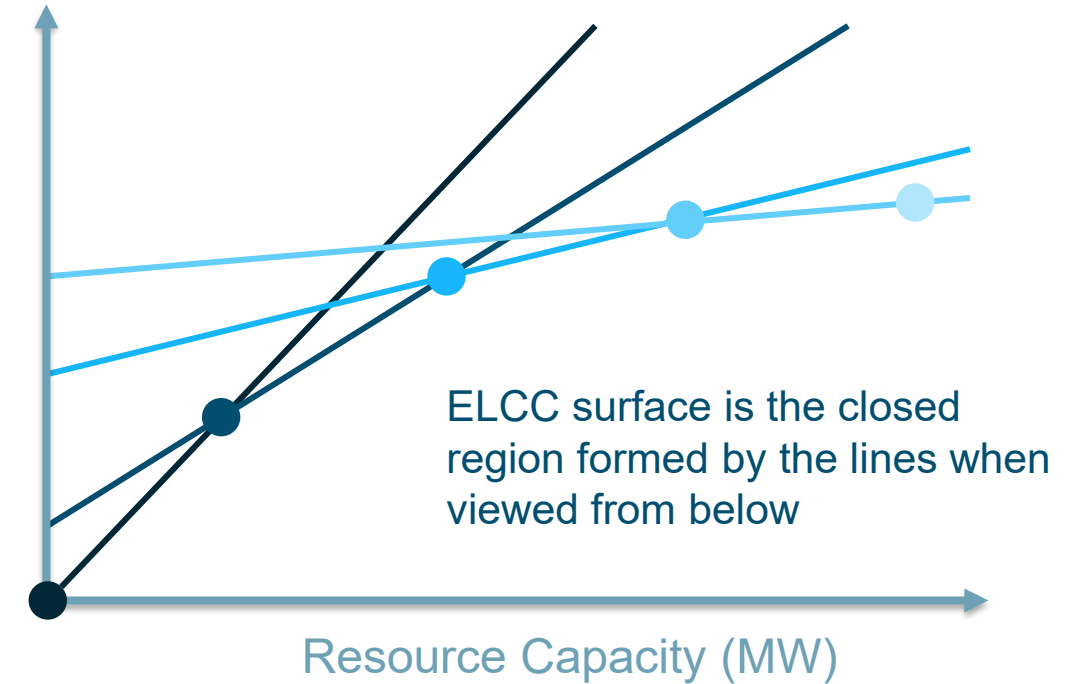
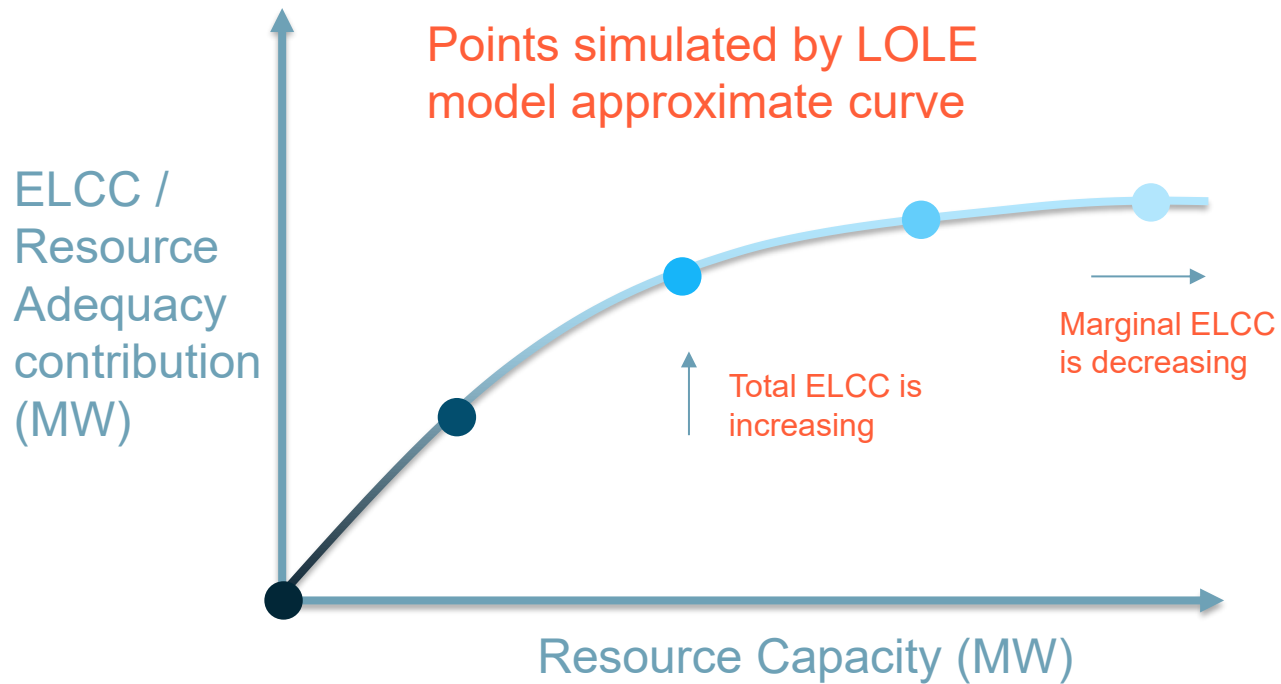
Portfolio calibration process for each RA framework to ensure each portfolio meets 0.1 LOLE



“Surface” approach to parameterization: piecewise-linear ELCC function captures changing marginal values

Calculate Portfolio and Marginal ELCC at different levels of penetration through repeated LOLP model runs

Linear equations to approximate ELCC curve and used to constrain optimal capacity expansion modeling



Implementing in capacity expansion model

All equations implemented in capacity expansion linear optimization simultaneously

>> Only one will be binding each year

$$ELCC \leq 1 * ResCap + 0$$

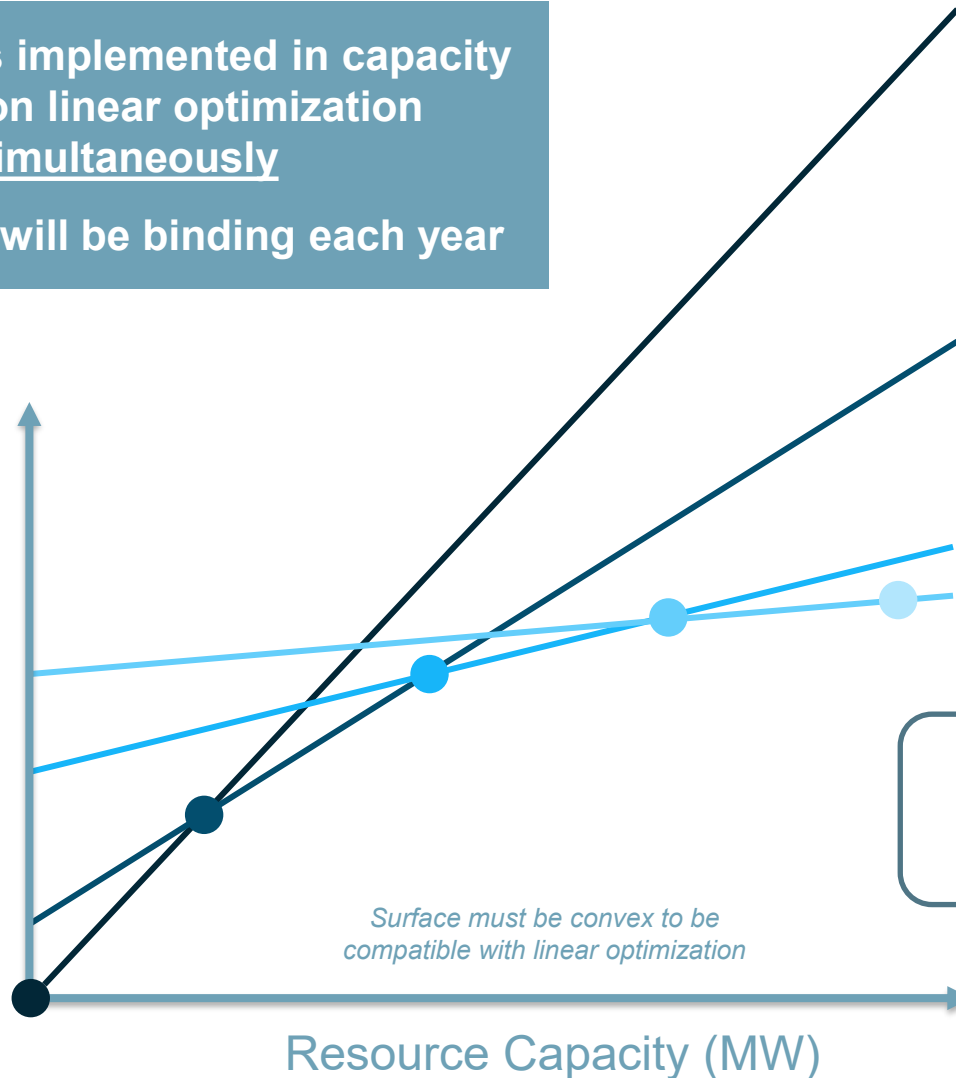
Example values

$$ELCC \leq 0.7 * ResCap + 80$$

$$ELCC \leq 0.3 * ResCap + 200$$

$$ELCC \leq 0.1 * ResCap + 300$$

ELCC / Resource Adequacy contribution (MW)



Surface must be convex to be compatible with linear optimization

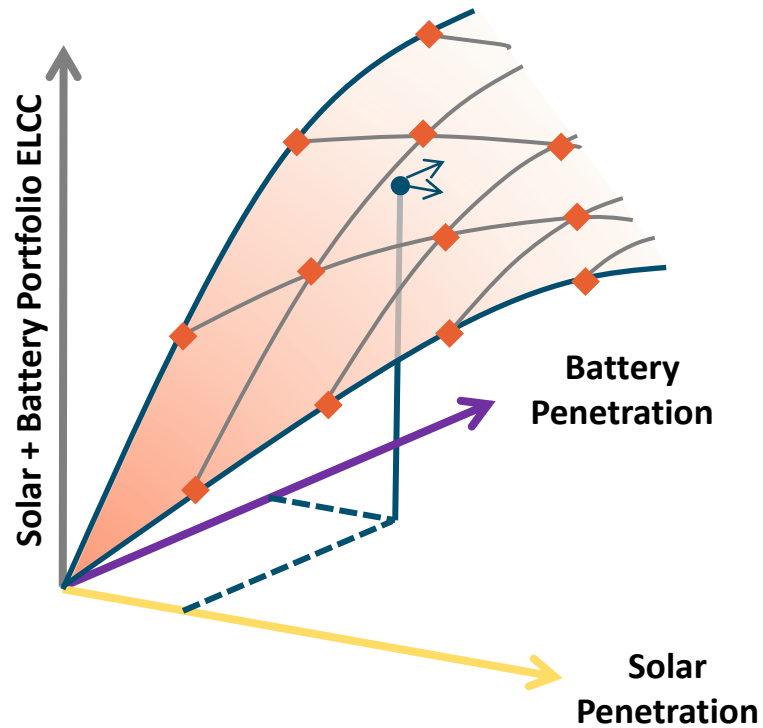
$$\text{Portfolio ELCC} \leq \text{Incremental Capacity Value} * \text{Resource Capacity} + \text{Line Intercept}$$

General form of equation

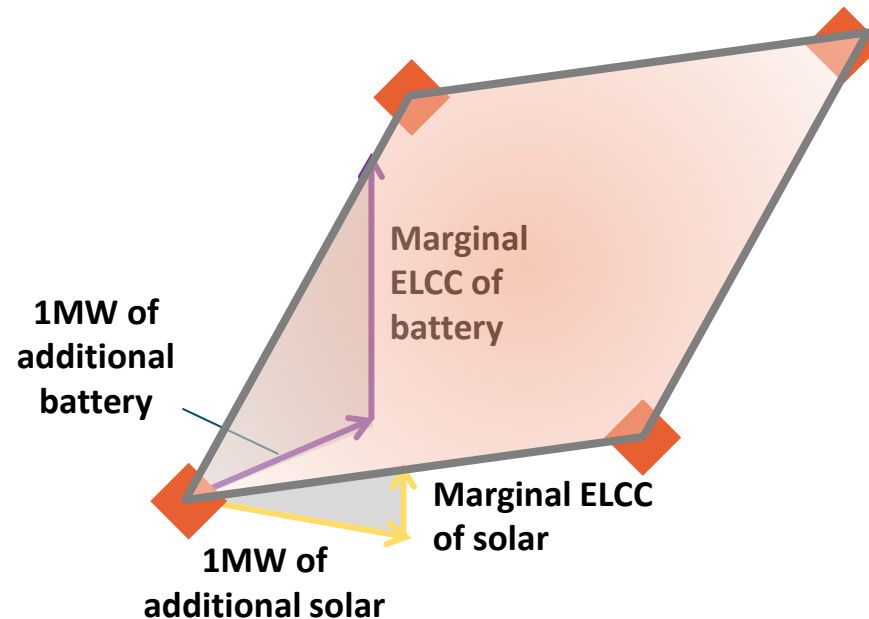
Piecewise-planar surface in multiple dimensions can capture both saturation and diversity effects

◆ The height of the orange dots gives the total solar + storage portfolio ELCC

↕ The slope between each point gives the marginal capacity value of solar and storage at a given capacity



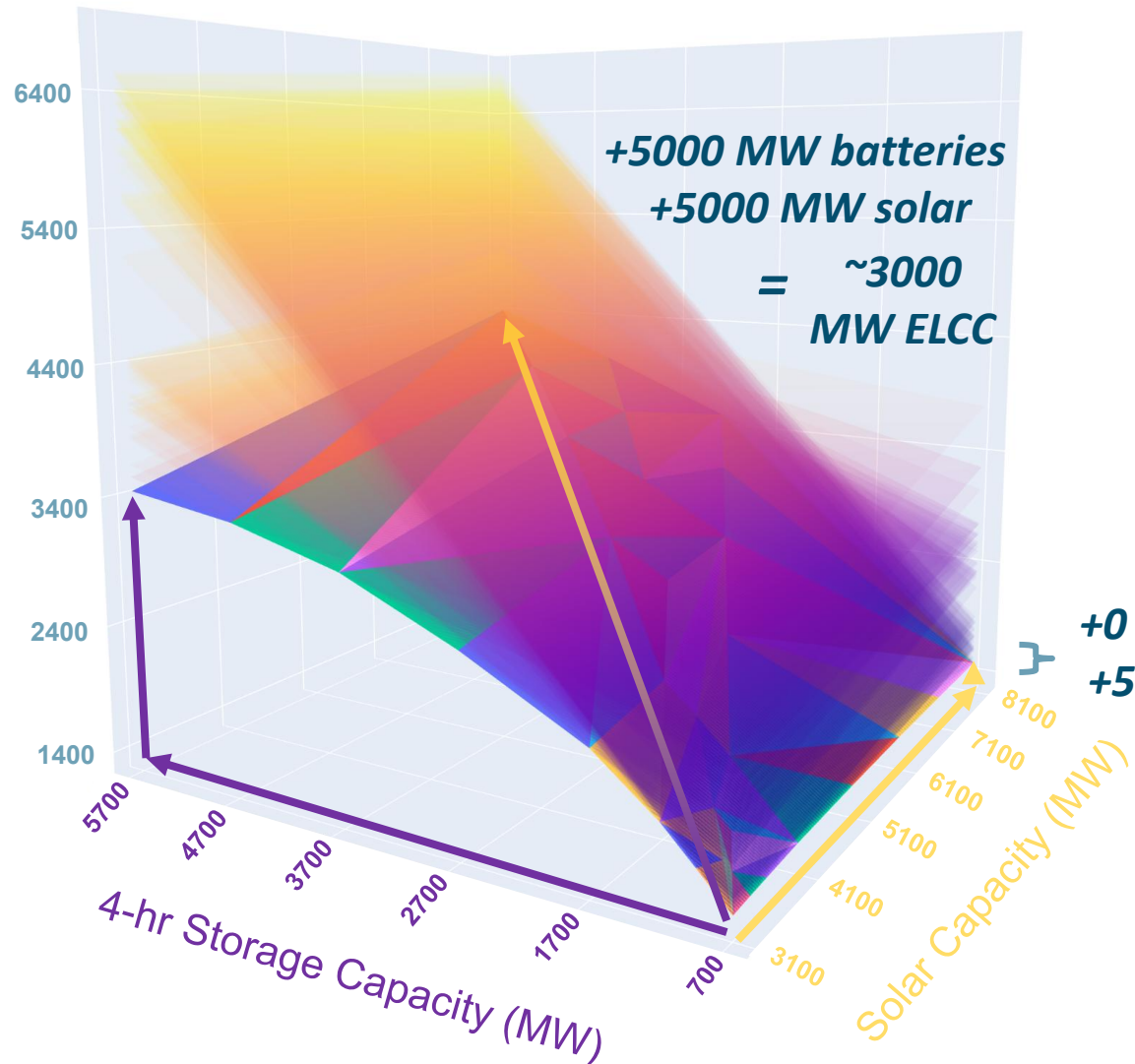
For any plane on the surface:



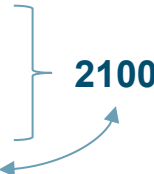
Surface shows interactive effects of solar and storage



Solar +
Storage
Portfolio
ELCC
(MW)



Solar (MW)	Storage (MW)	ELCC (MW)
5000	0	100
0	5000	2000
5000	5000	3000



900 MW ELCC from diversity

E3 use cases to date

Platforms

- **E3's RESOLVE capacity expansion model**
 - Python + pyomo code for linear equations
- **PLEXOS LT**
 - Custom constraints and decision variables

Configurations

- **1 Dimension**
 - Wind
 - Solar
 - Batteries
- **2 Dimensions**
 - Solar + battery
 - Solar + wind
- **3 Dimensions**
 - Solar + battery capacity + battery duration
- **Complex**
 - 2D Solar + battery & 1D wind

Cases

- California PUC
- Florida Power & Light
- Xcel Energy
- NV Energy
- Puget Sound Energy
- NorthWestern Energy
- El Paso Electric
- Sacramento Municipal Utility District
- Omaha Public Power District
- Nova Scotia Power
- New Brunswick Power
- + more

Endogenous RA modeling is only needed for whole power systems

- + The RA modeling techniques described here are needed for power systems in which selection of a given resource changes the value of other resources
- + For these systems, it is important for ELCC parameters to be dynamic as a function of the portfolio
- + For participants in markets or RA programs, RA need and resource accreditation is a function of the entire portfolio
- + These entities can be modeled as “ELCC takers” against forecasts of future need allocation and resource accreditation from E3 or another vendor



Thank you!

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