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# Renewable Energy Flexibility (REFLEX) Results

CPUC Workshop

August 26, 2013

# Scope of E3 Work

- **Investigate flexibility and capacity needs using REFLEX for PLEXOS and other tools**
- **2012 Historical Case**
  - 2012 Loads and Renewables
  - Test and refine REFLEX model
  - Develop model for imports and test internal transmission constraints
- **TPP/Commercial Interest Case**
  - Develop multi-year datasets with the same build assumptions as the deterministic case
  - Define probabilistic context for CAISO deterministic case
  - Test the need for flexible capacity and determine the value of operational solutions like economic pre-curtailment

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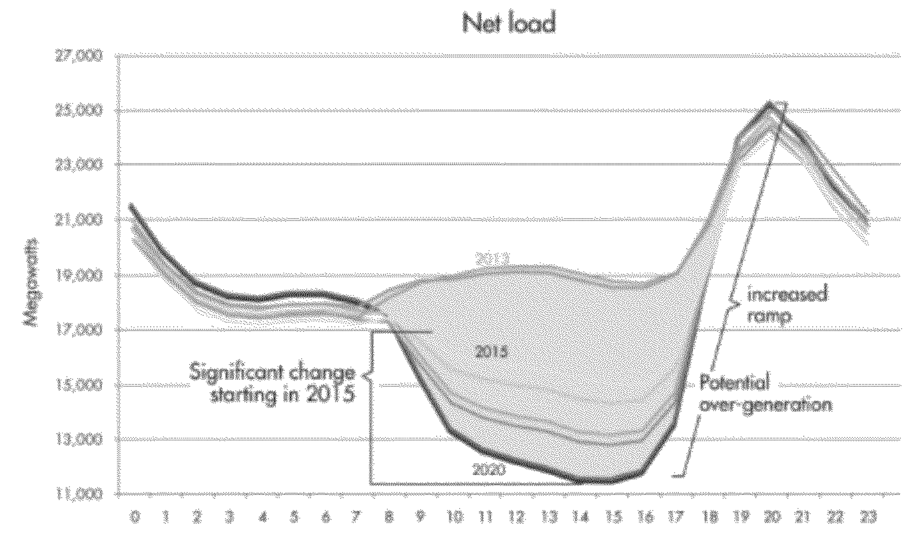
# REFLEX METHODOLOGY & ASSUMPTIONS

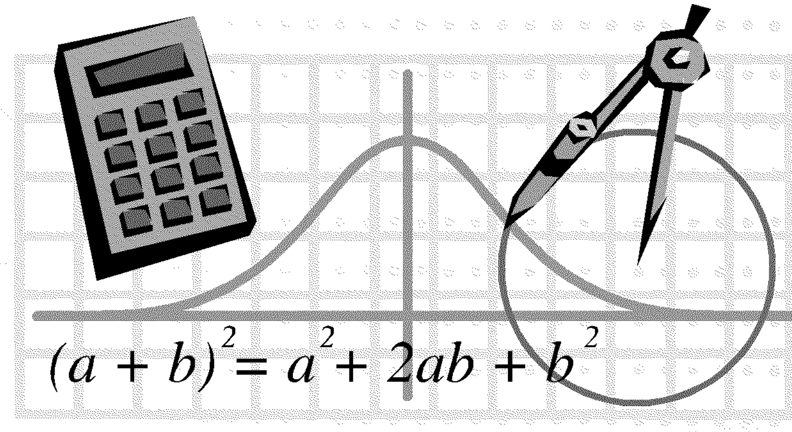
# Defining the Problem

- **Introduction of variable renewables has shifted the capacity planning paradigm**
- **The new planning problem consists of two related questions:**




1. How many MW of dispatchable resources are needed to (a) meet load, and (b) meet flexibility requirements on various time scales?
2. What is the optimal mix of new resources, given the characteristics of the existing fleet of conventional and renewable resources?

# Problem is Stochastic in Nature

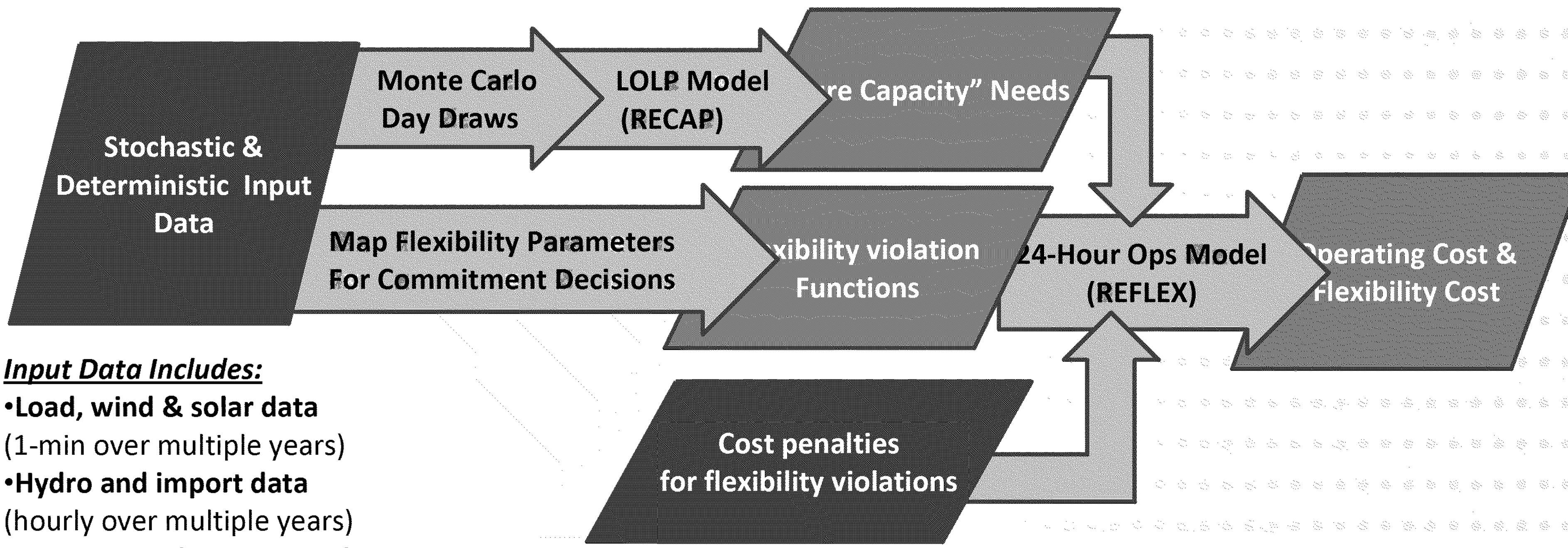



- **Load is variable and uncertain**
  - Often characterized as "1-in-5" or "1-in-10"
  - Subject to forecast error
- **Renewable output is also variable and uncertain**
- **Supplies can also be stochastic**
  - Hydro endowment varies from year to year
  - Generator forced outages are random
- **Need robust stochastic modeling to know size, probability and duration of any shortfalls**

# Modeling Approach

- **REFLEX performs stochastic production simulation modeling**
- **Complementary to ISO's deterministic simulation case**
  - Utilizes matching base assumptions as ISO case for resource build, average load, fuel costs & import limits to promote comparability
  - Includes large sample of alternative draws of load, wind, solar and hydro shapes to capture wider distribution of operating conditions the system is likely to encounter
  - Enables calculation of likelihood, magnitude, duration & cost of flexibility violations to provide more detail on operational challenges
  - Creates economic framework for user to adjust penalty costs to guide model's choices of tradeoffs between types of violations (e.g., lost load vs. curtailment vs. overgeneration & ramp shortages) vs. additional operating costs

# REFLEX Modeling Process




***Input Data Includes:***

- **Load, wind & solar data** (1-min over multiple years)
- **Hydro and import data** (hourly over multiple years)
- **Conventional generator data** (Capacities, costs & outage schedules ***from deterministic case***)

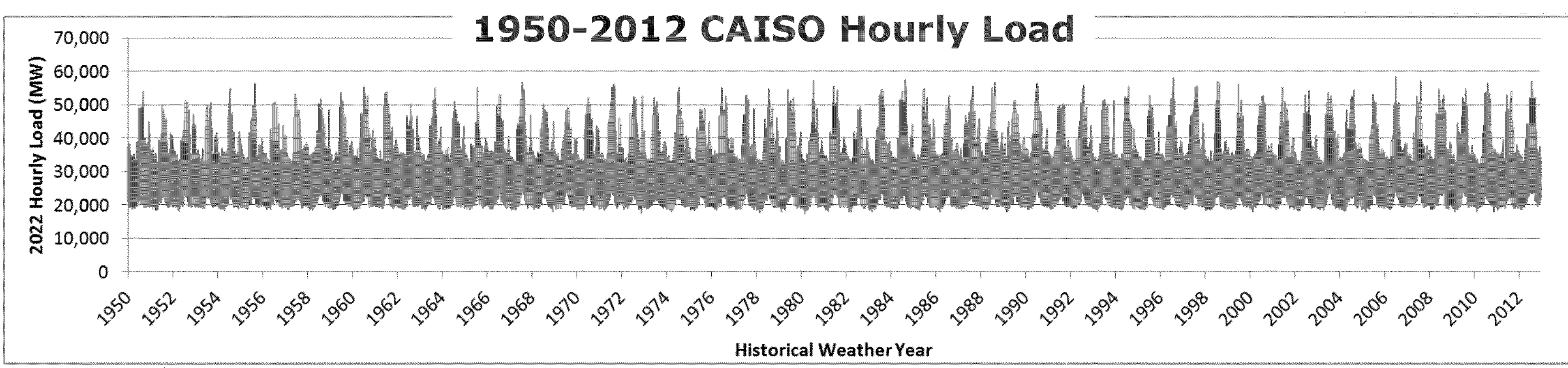
***User-defined Cost per MWh for:***

- Unserved Energy (USE)
- Reserve shortage
- Overgeneration
- Renewable Curtailment
- Upward Ramping shortage
- Downward Ramping shortage

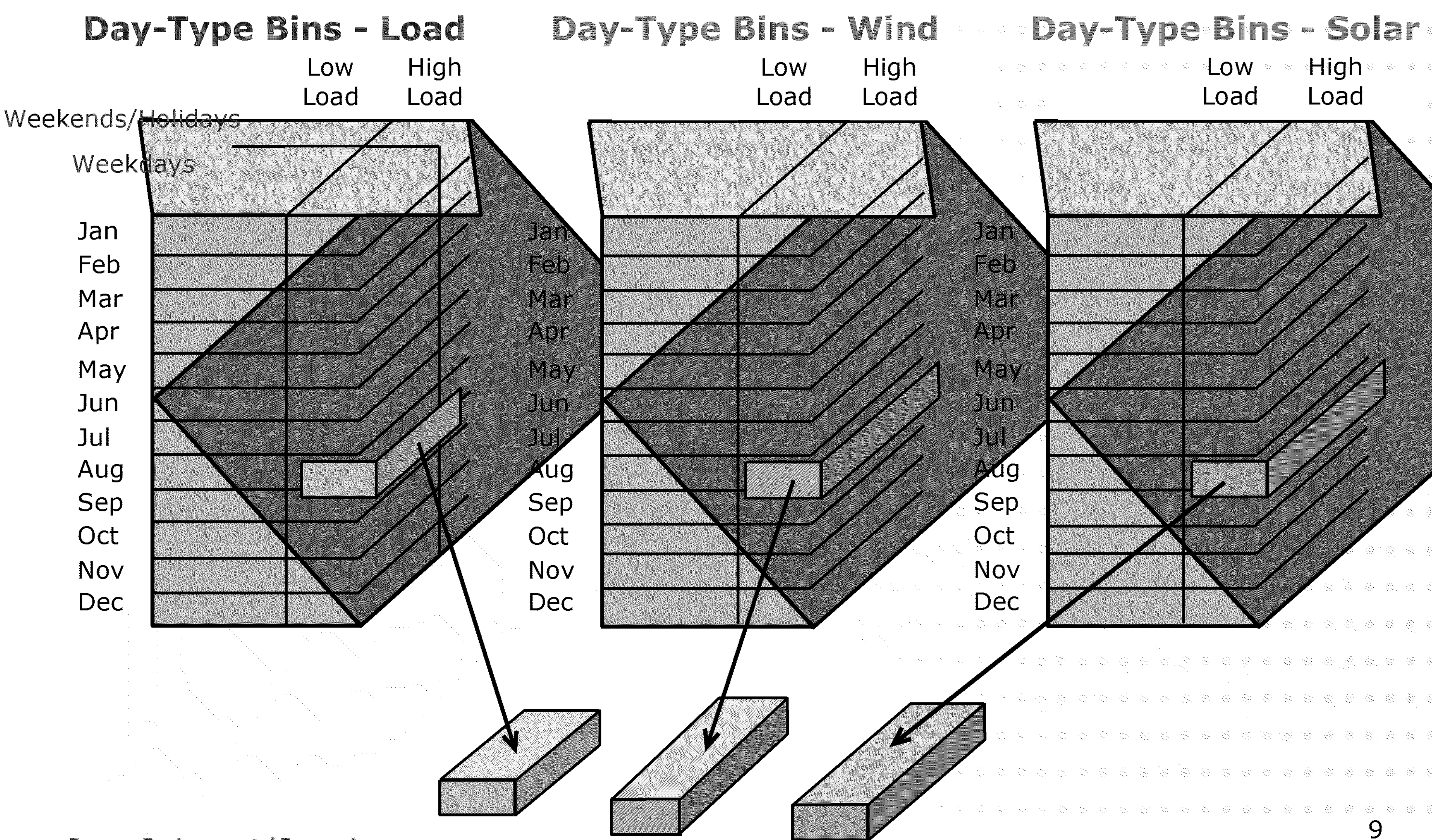
- **Parallel calculation of conventional capacity needs & flexibility impact for use in 24-hour operations model**

# Stochastic Data & Monte Carlo Draws

- **Correlated draws of load, wind, solar and hydro shapes**
- **Load:**
  - Use neural network based approach to predict daily CAISO load under historical weather conditions (from 1950-2012 daily time horizon),
  - Scaled to 2022 energy and 1-2 peak load, adjusted for embedded distributed Solar PV
  - Split into weekday/weekend day types & high load, low load, average "bins" for each month
- **Wind & Solar**
  - Selected from weather conditions & predicted output on days in same load "bin"



# Example Draw: High Load Weekday in August



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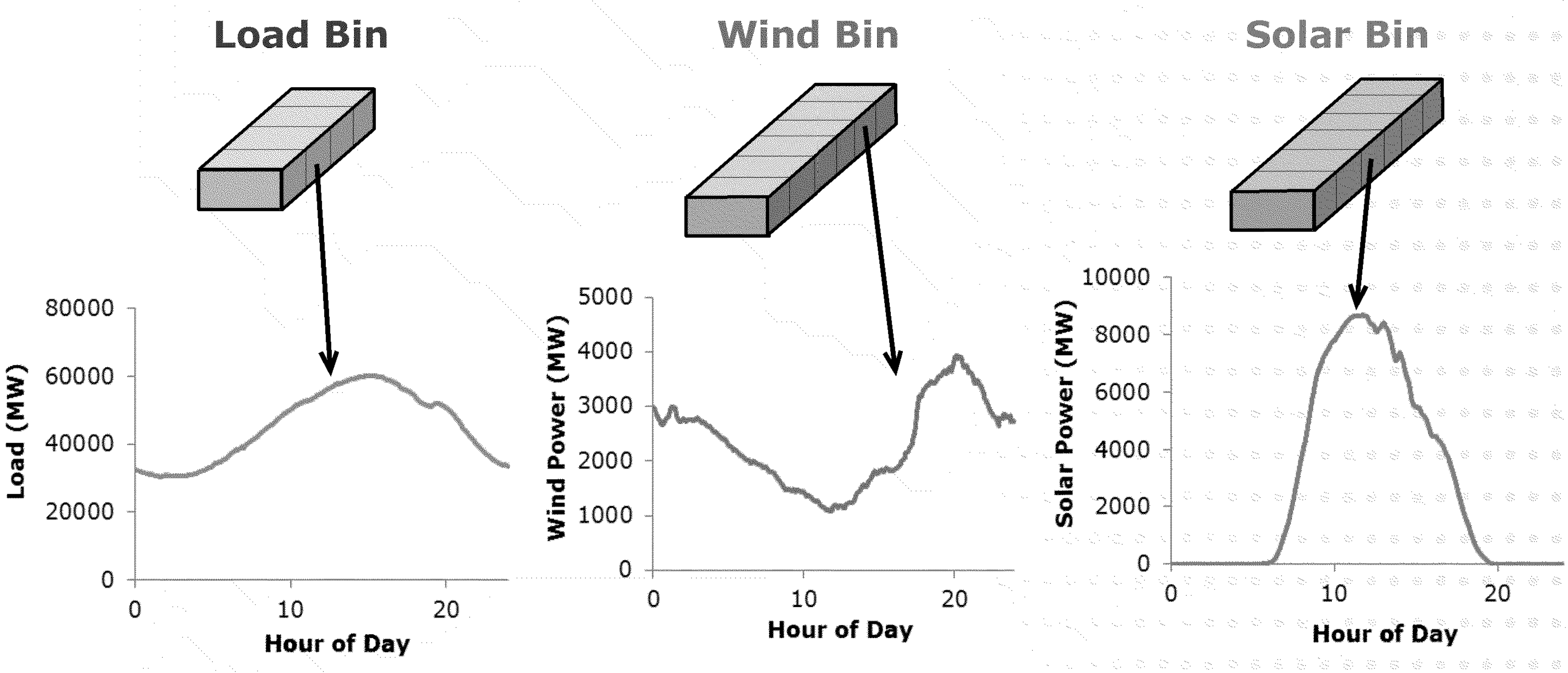
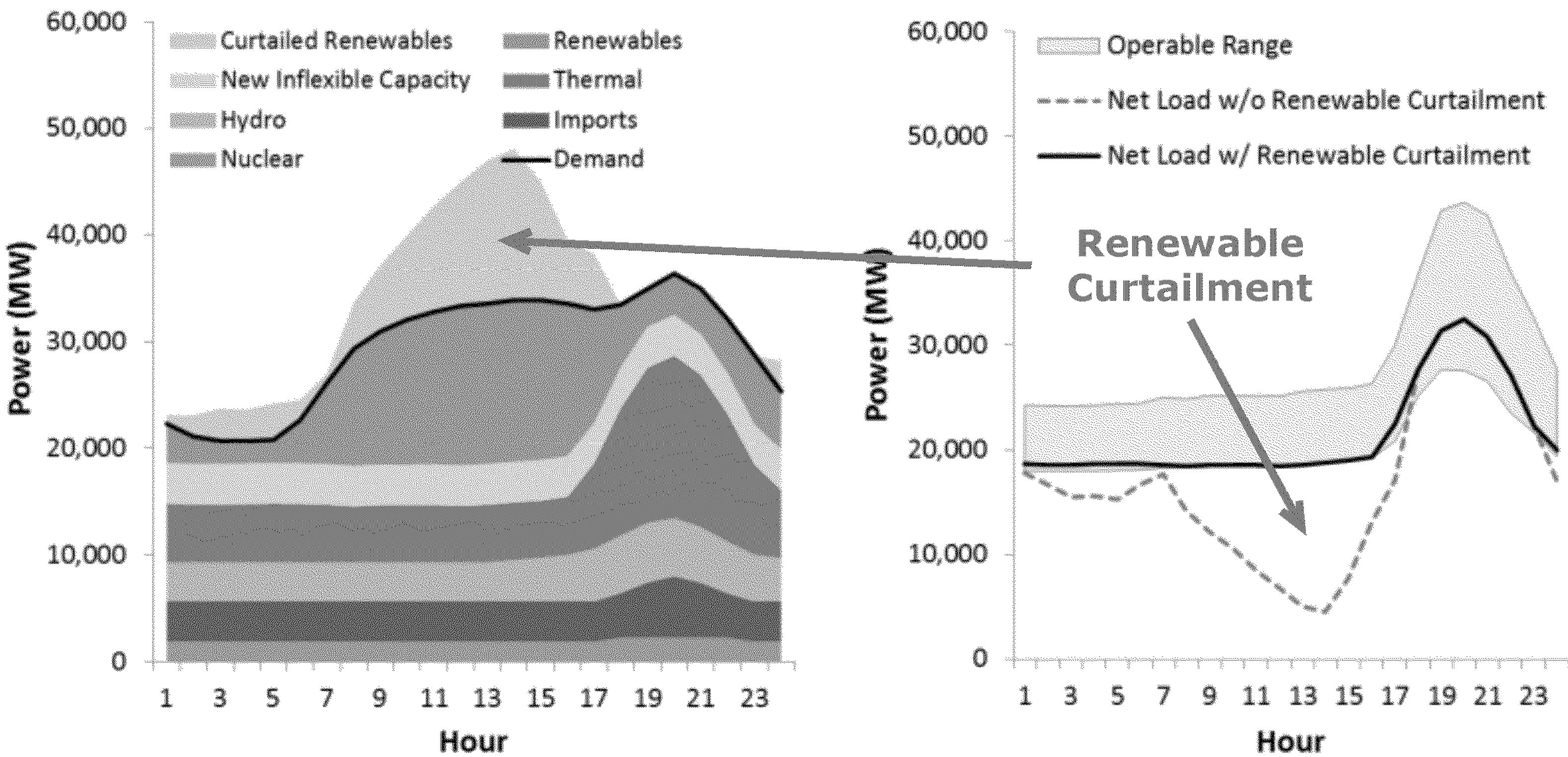
# Example Draw: High Load Weekday in August

- **Within each bin, choose each (load, wind, and solar) daily profile randomly, and independent of other daily profiles.**



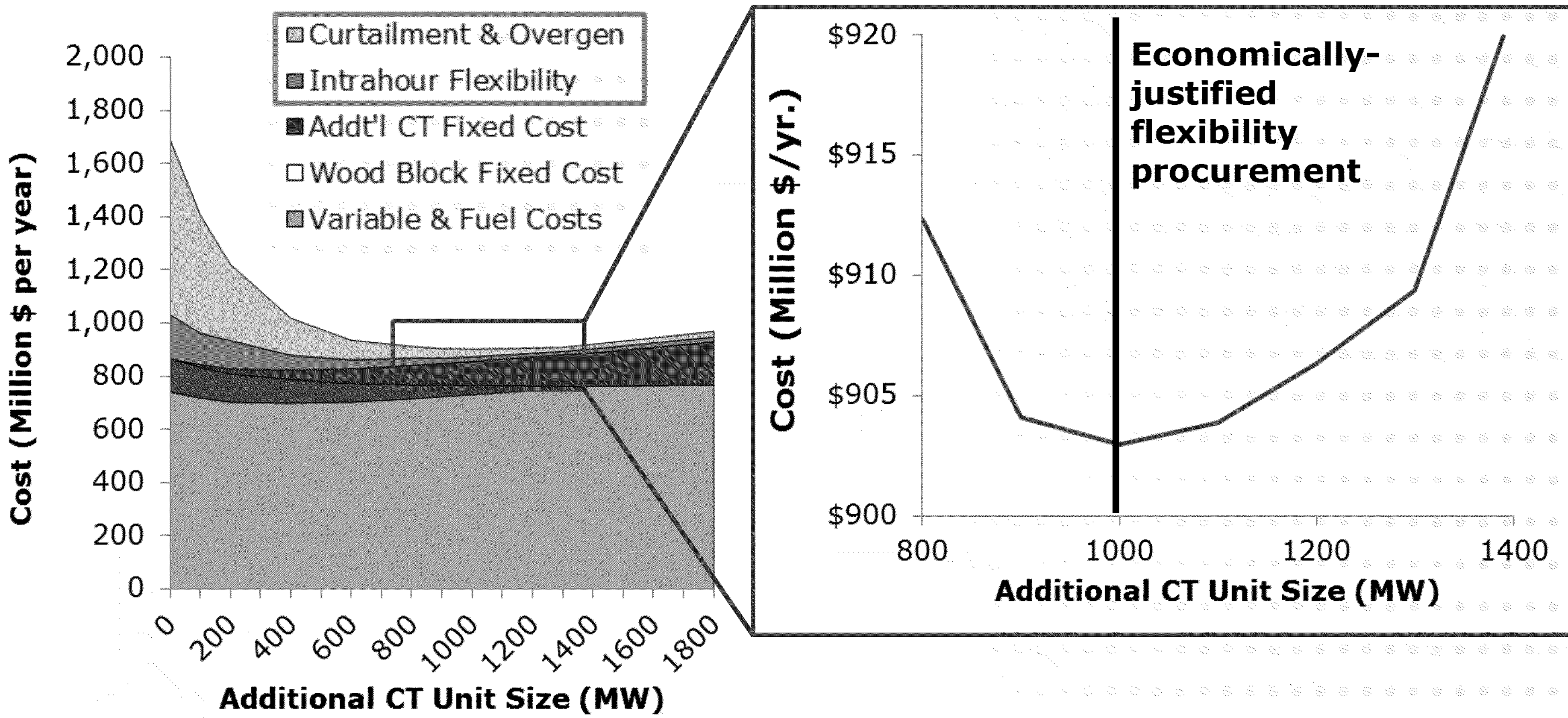
# Tradeoff May be Necessary Between Overgeneration and Loss of Load




- Scheduled curtailment of renewables can help position conventional resources to meet ramping requirements
- How does the cost of curtailment compare to the cost of procuring new flexible resources?

# Optimal Flexibility Investment

- **REFLEX provides an economic framework for determining optimal flexible capacity investments by trading off the cost of new resources against the value of avoided flexibility violations**



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# Base Cost Penalties Assumed for Flexibility Violations

- **Relative cost penalties impose flexibility mitigation strategy "loading order**

### Hourly Violation Penalties

| Type of Violation | Input | Notes |
|---|---|---|
| Unserved Energy | $40,000/MWh | Based on literature search |
| Overgeneration | $300/MWh | Little difference btw. overgen & curtailment |
| Curtailment Cost | $250/MWh | Cost of replacement energy to meet RPS |
| Spinning reserves | $1.5 MM/MWh | Spinning reserves are always maintained |

### Intra-hourly Violation Penalties

| Type of violation | Input | Notes |
|---|---|---|
| Upward Ramping Violation | $1,000/MWh | Results in CPS violation |
| Downward Ramping Violation | $200/MWh | May lead to curtailment |
| Insufficient Regulation | $1,000/MW | CAISO Market Process |

# Comparison between LTPP approaches

| Item | Deterministic Modeling in PLEXOS | REFLEX |
|---|---|---|
| Load Peak and Shape | 1 Draw | Draws from 63 years |
| Intermittent Generation | 1 Draw | Draws from:<br>3 years (wind)<br>12 years (solar) |
| Maintenance and Forced Outage | 1 Draw | Monte Carlo Draws |
| Dispatch Granularity | Hourly | Hourly |
| Dispatch Horizon | 8760 Hours | 3 day unit commitment |
| Economic Dispatch | Yes | Yes |
| Reliability Measure | Reserve Shortfall | LOLP, LOLF, EUE, $EUR_U$, $EUR_D$, EOG |

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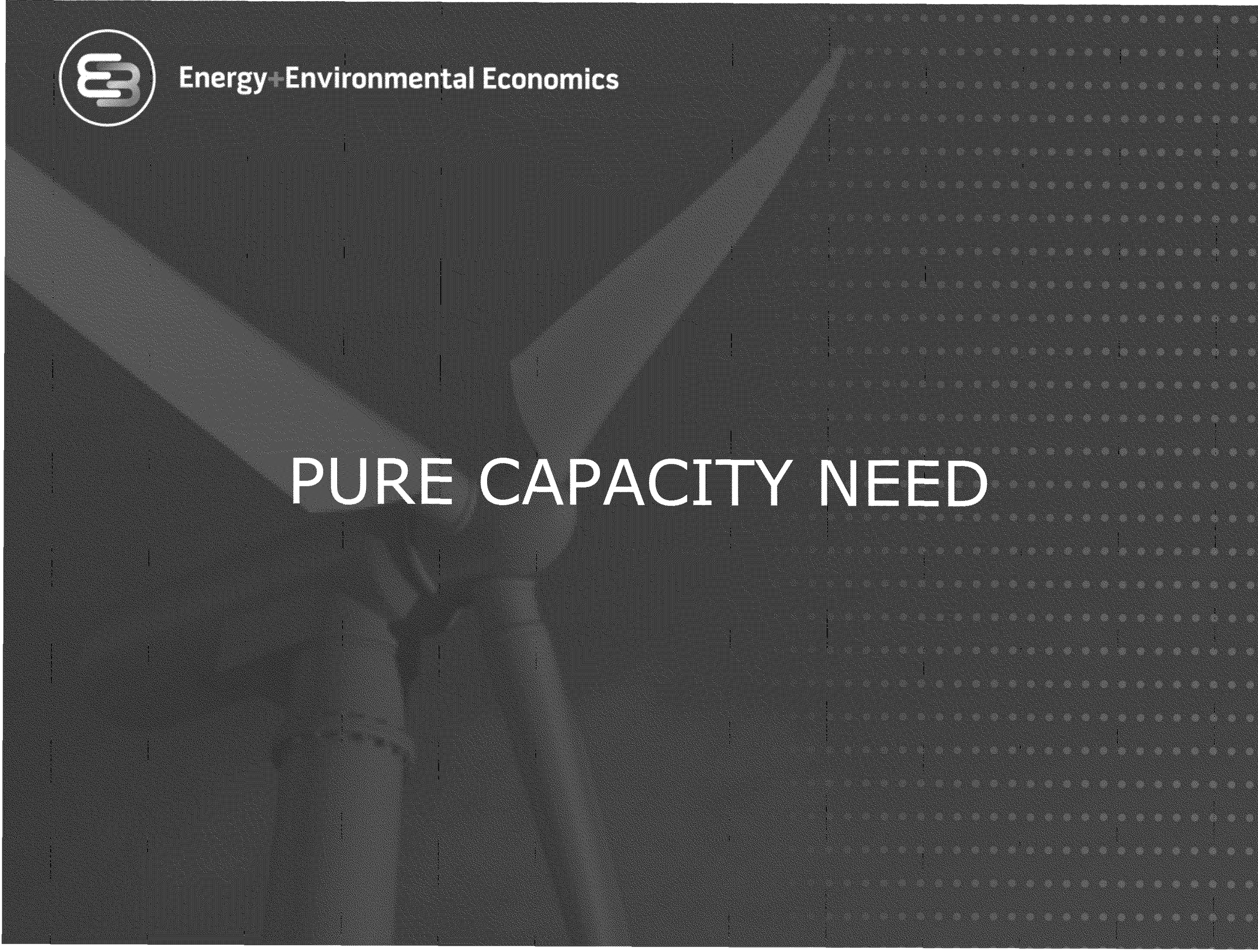
# 2022 REPLICATING TPP CASE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PURE CAPACITY NEED

# Analysis Steps

- **Step 1: PRM check**
  - Add capacity (if needed) to achieve a 15% PRM
- **Step 2: LOLF check**
  - Calculate Loss-of-Load Frequency to ensure that system achieves 1-event-in-10 year standard
  - Necessary to ensure that REFLEX violations are related to flexibility, not pure capacity shortages
  - Uses E3's Renewable Capacity Planning (RECAP) Model developed for the CAISO
- **RECAP also allows for comparison of NQC with effective load carrying capability (ELCC)**

# Step 1: PRM Check

- **E3 replicating TPP case does not include SONGS**
- **PRM is calculated as total ELCC divided by 1-in-2 peak load, minus 1**
- **CPUC scenario tool analysis of the case shows a 15.1% PRM**
- **There may be a discrepancy with generator stack modeled in PLEXOS**

| 2022 | 1A Early SONGS | 2A Replic. TPP DR | E3 Replic. TPP |
|---|---|---|---|
| **Demand (MW) *** | | | |
| Counterfactual Load | 58,178 | 60,755 | 58,178 |
| IEPR Self Gen PV | 1,364 | 1,364 | 1,364 |
| IEPR Self Gen Non PV | 1,850 | 1,850 | 1,850 |
| IEPR Non Event Based DR | 93 | 93 | 93 |
| IEPR Net Load | 54,871 | 57,448 | 54,871 |
| Inc. EE | 3,103 | 1,926 | 1,926 |
| Inc. Small PV | 710 | 0 | 0 |
| Inc. D-CHP | 0 | 0 | 0 |
| Managed Demand Net Load | 51,058 | 55,522 | 52,945 |
| **Supply (MW)** | | | |
| Existing Resources | 50,442 | 50,442 | 50,442 |
| Resource Additions | 10,360 | 10,259 | 10,259 |
| Non-RPS | 4,867 | 4,867 | 4,867 |
| RPS | 5,492 | 5,391 | 5,391 |
| Authorized Procurement | 0 | 0 | 0 |
| Imports | 13,308 | 13,308 | 13,308 |
| Inc. S-CHP | 0 | 0 | 0 |
| Event Based DR | 2,595 | 2,336 | 2,336 |
| Resource Retirements | 17,263 | 13,146 | 15,392 |
| OTC | 13,146 | 13,146 | 13,146 |
| Nuclear | 2,246 | 0 | 2,246 |
| Other Non Renewables | 1,871 | 0 | 0 |
| Net Supply | 59,442 | 63,199 | 60,953 |
| Net System Balance | 8,384 | 7,677 | 8,008 |
| | 116.4% | 113.8% | 115.1% |



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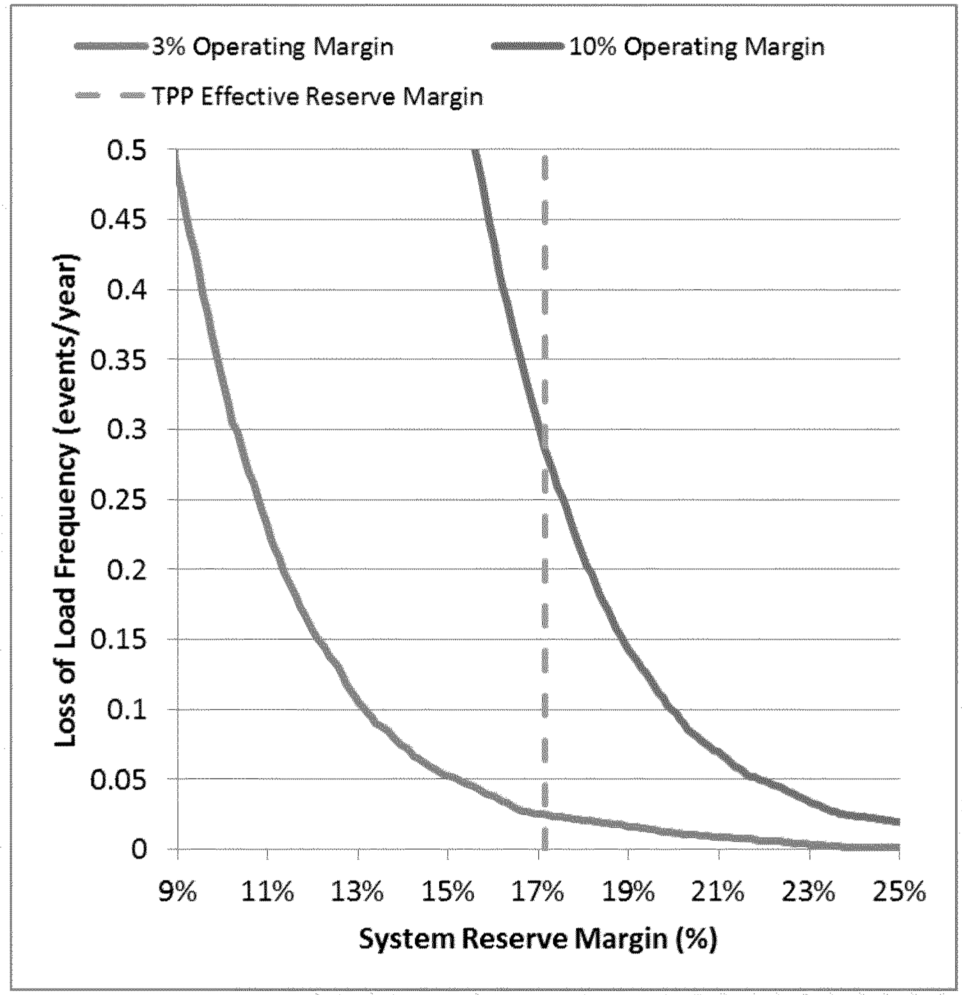
# Step 2: LOLE Check

- **Replicating TPP case meets 1-in-10 standard, including 3% spinning reserves**
  - LOLF = 0.025 events/year
  - LOLE = 0.052 hours/year
  - EUE = 84 MWh/year
- **LOLF is much higher under deterministic case assumptions**
  - 10% operating margin to account for Reg., Spin, Non-Spin and Load Following
  - 1-in-5 peak load
  - LOLF of 0.3

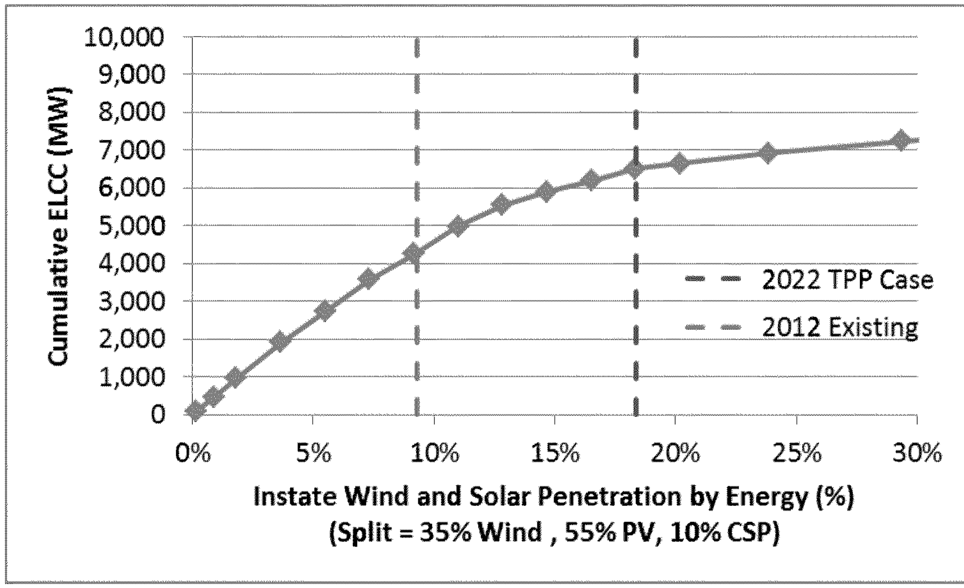
3% spinning reserves + 3% non-spinning reserves + 3% load-following + 1% regulation = 10% operating margin

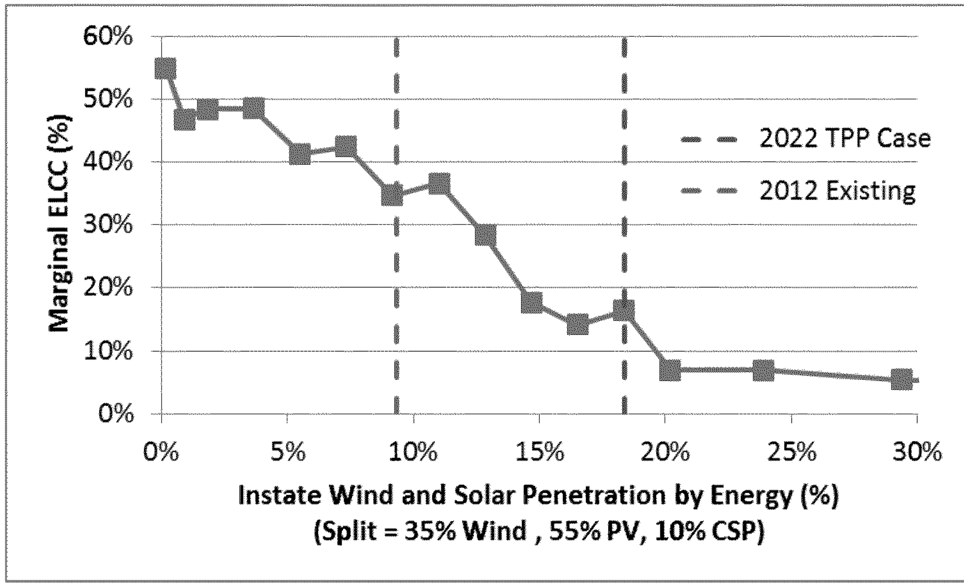


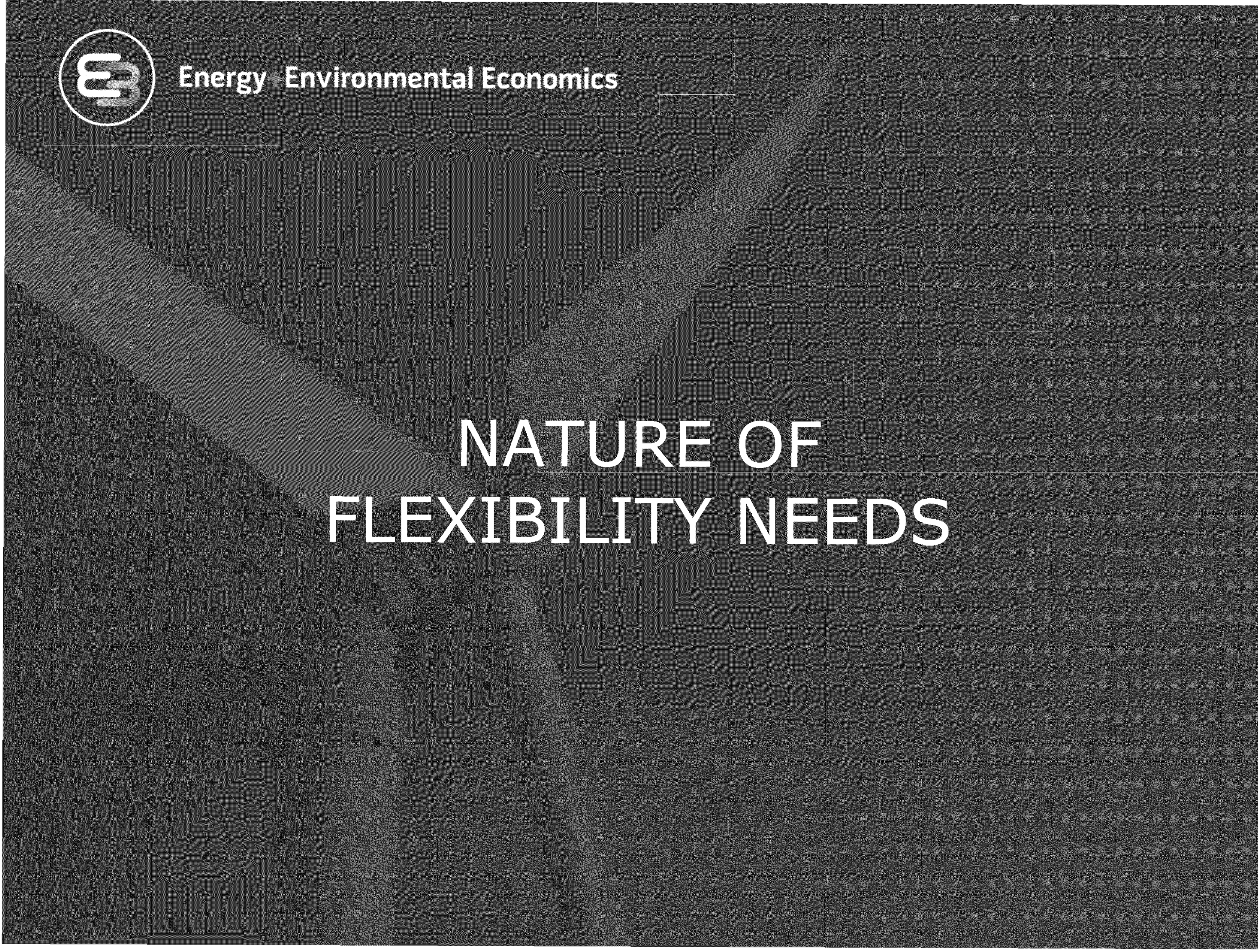
# Renewable ELCC

- **Initial Accumulation of renewable capacity value is fairly well approximated by linear trend (e.g., NQC methodology)**
- **By 33% penetration the, marginal ELCC of variable renewables has decreased substantially**

Figures use a fixed ratio of wind to solar. Storage, load growth, and responsive load is ignored

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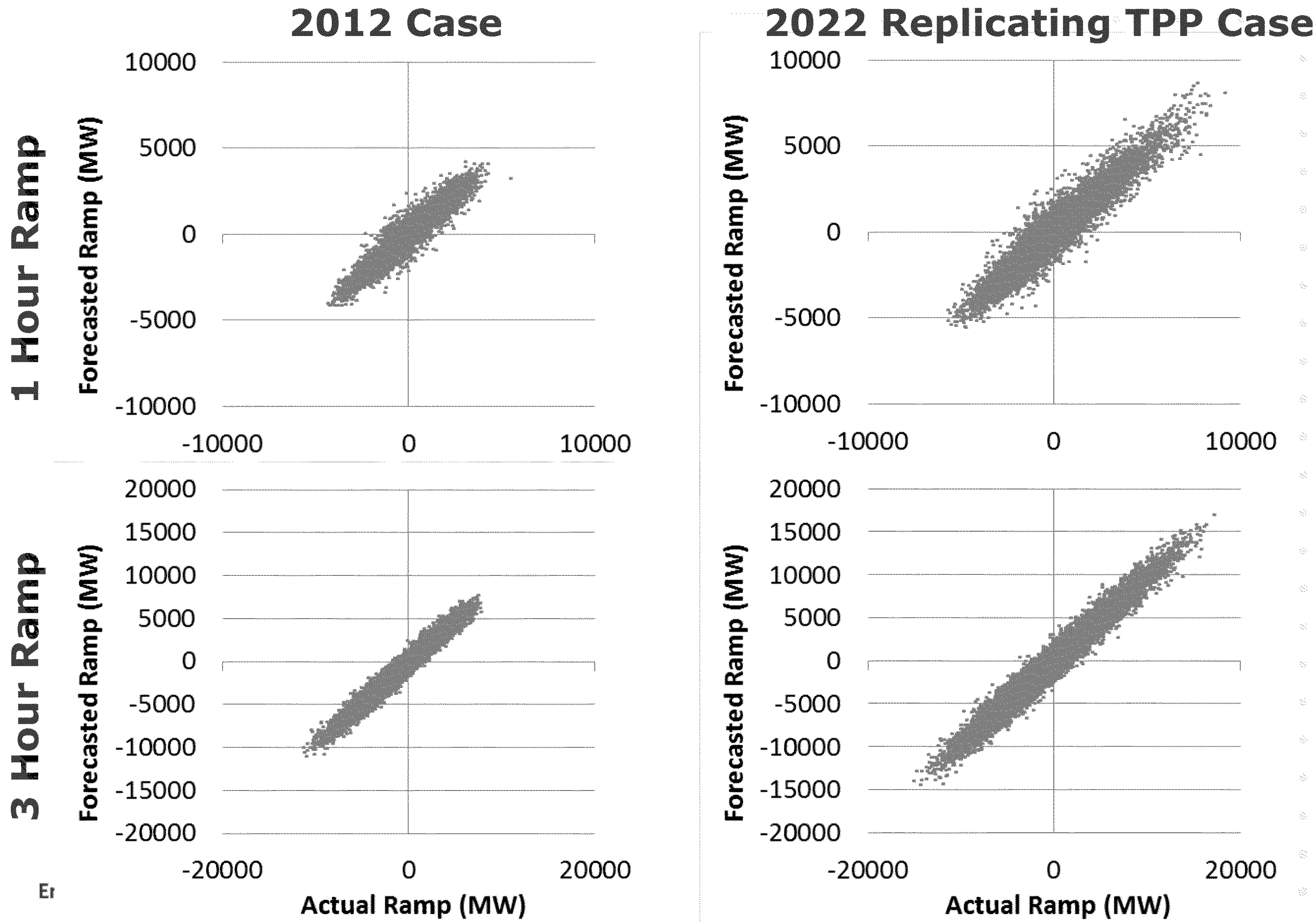
NATURE OF
FLEXIBILITY NEEDS

# Net Load Ramps Increase Between 2012 and 2022

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REFLEX RESULTS

# Input Data Assumptions for 2022 33% RPS REFLEX Case

| Assumptions | Input & notes |
|---|---|
| **CA Conventional Generators** | ISO deterministic case parameters & outage schedules |
| **Nuclear** | SONGS retired;<br>Diablo as must-run |
| **Conventional Hydro** | Modeled as single statewide aggregate resource; max based on NQC; energy, min & ramp modeled stochastically based on historical data |
| **Existing Pumped Hydro** | Helms (3 units), Eastwood, & Hodges-Olivenhain dispatched by model with same parameters as deterministic |
| **Imports/Exports (ramping, minimum & maximum)** | Ramping capability based on CAISO daily renewables Watch (Min = 0, Max = 13,308) |
| **Imports (heat rate)** | Specified by month & hour based on ISO deterministic run (default = 10,000 Btu/kWh) |
| **Local reliability (LCR) requirements** | LA basin: 40% local (40/60 Rule)<br>SDG&E: 25% local |
| **Fuel & AB32 Permit Prices for 2022 Scenario** | $4.5/MMBtu<br>$24/metric ton CO2<br>(From ISO Case parameters) |



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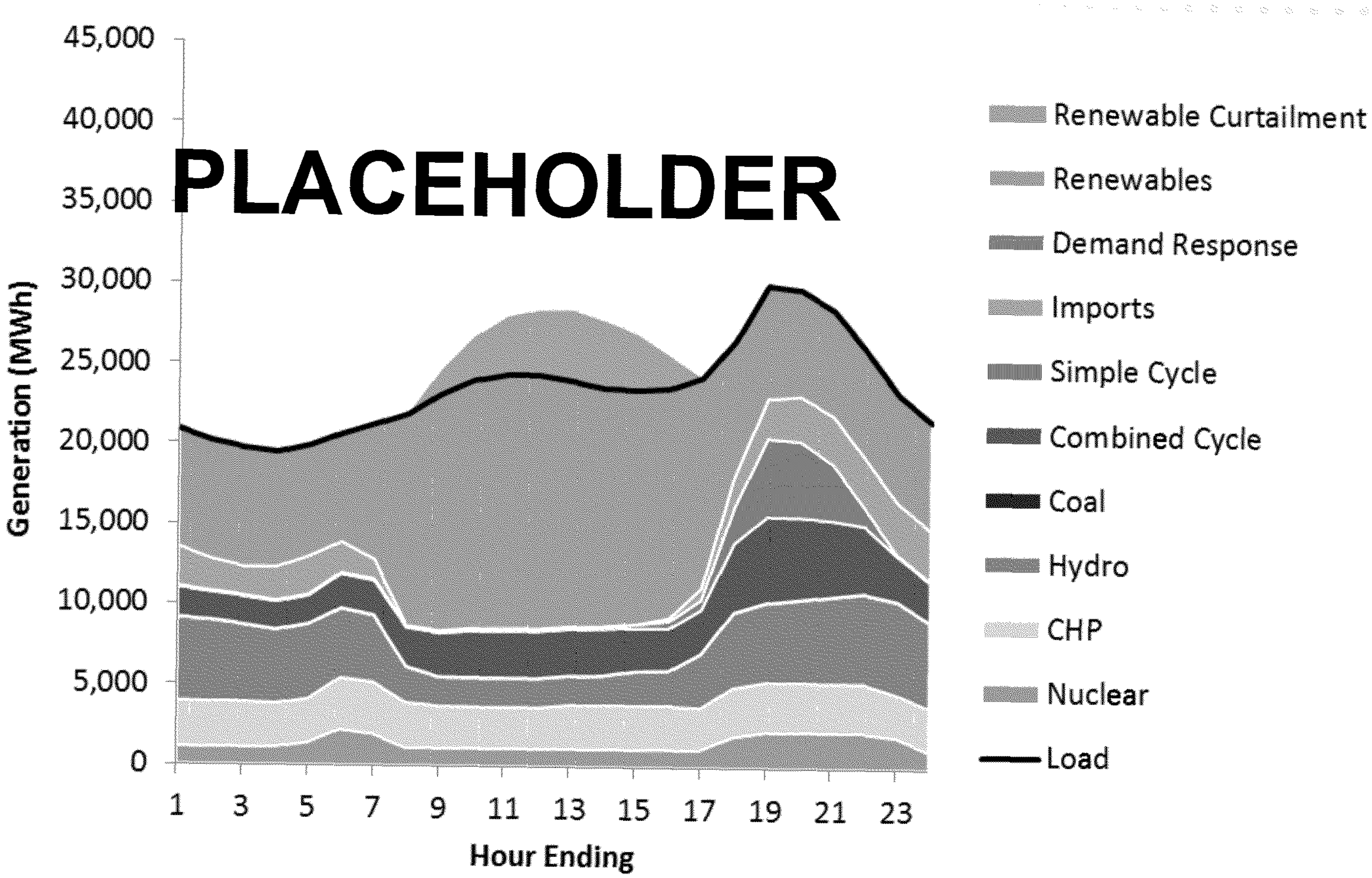
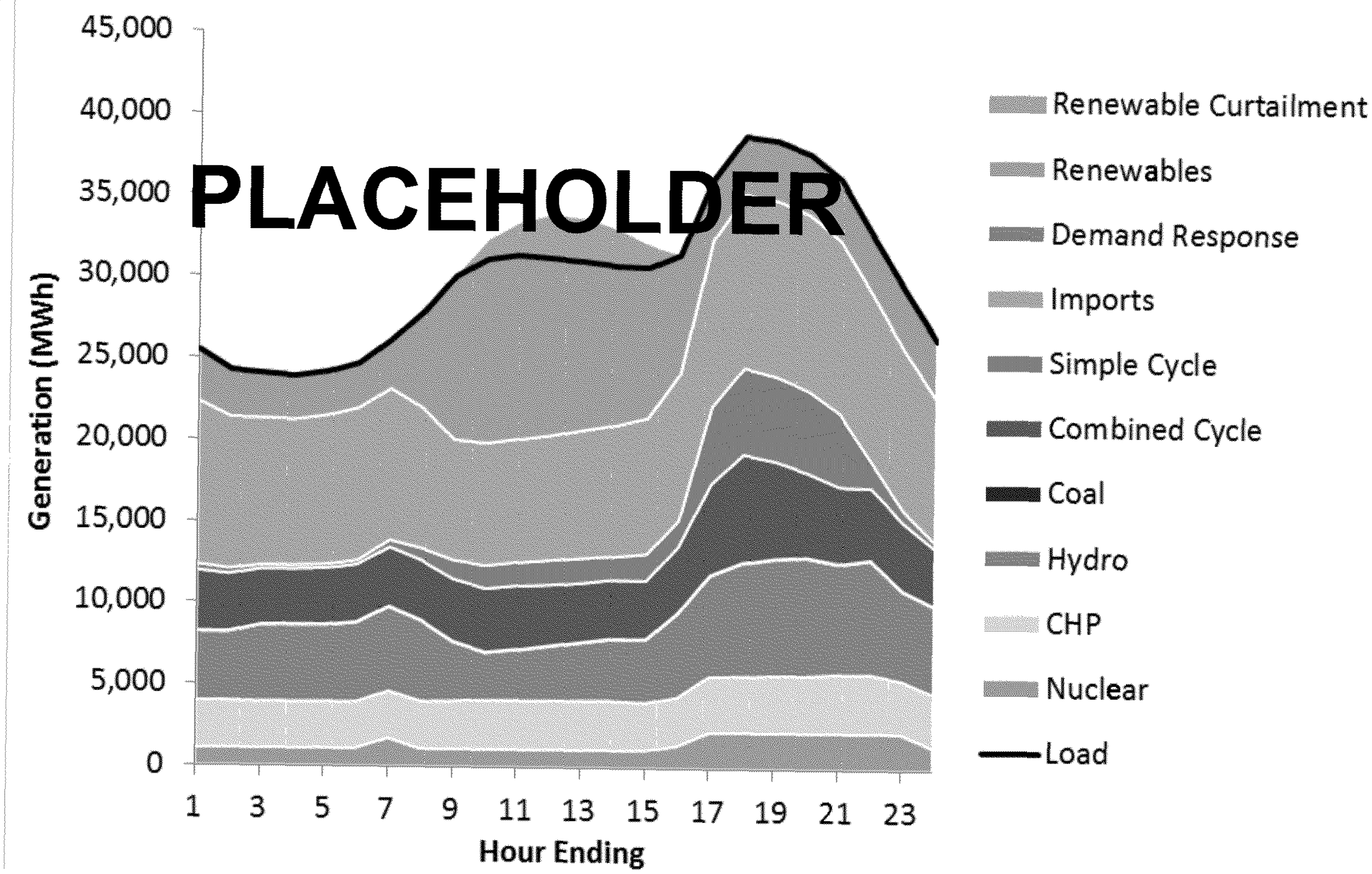
# Daily snapshots

- **Day with maximum curtailment**



# Daily snapshots

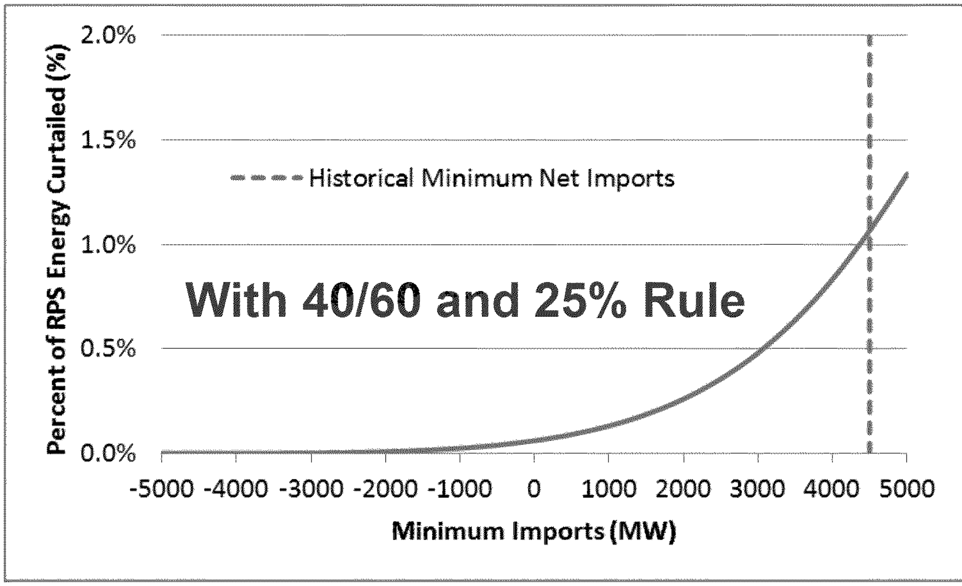
- **Day with maximum net load ramp**

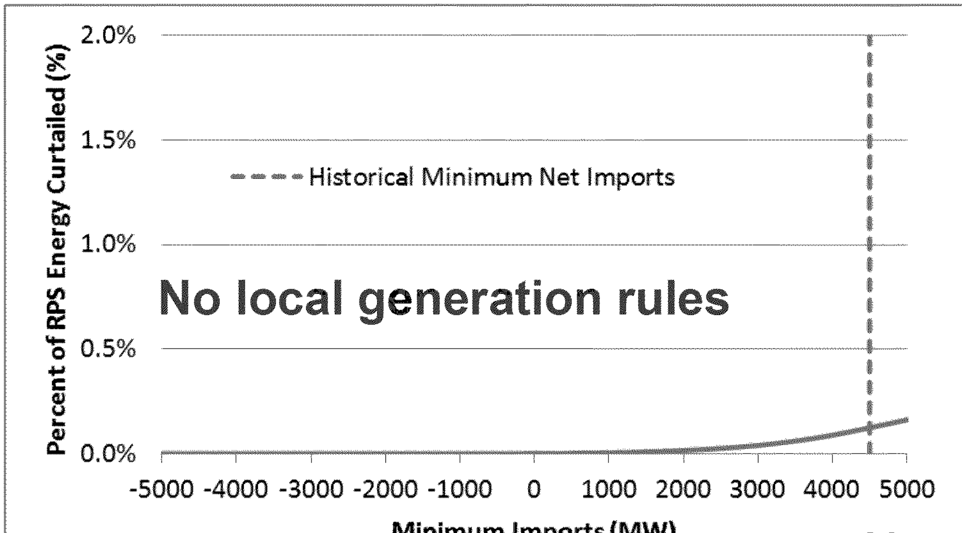


# Placeholder for additional results

# Curtailment as a function of export capability

- **33% scenarios result in over-generation on a bulk system level in all scenarios**
  - 6,200 MW of export capability needed before no over-generation was seen (0% downward operating margin)
- **No LCR sensitivity shown to limit problems, but 1.5 hours of over-generation/year still seen without export capability**




Additional over-generation to provide system flexibility not shown, nor is the mitigating impact of storage



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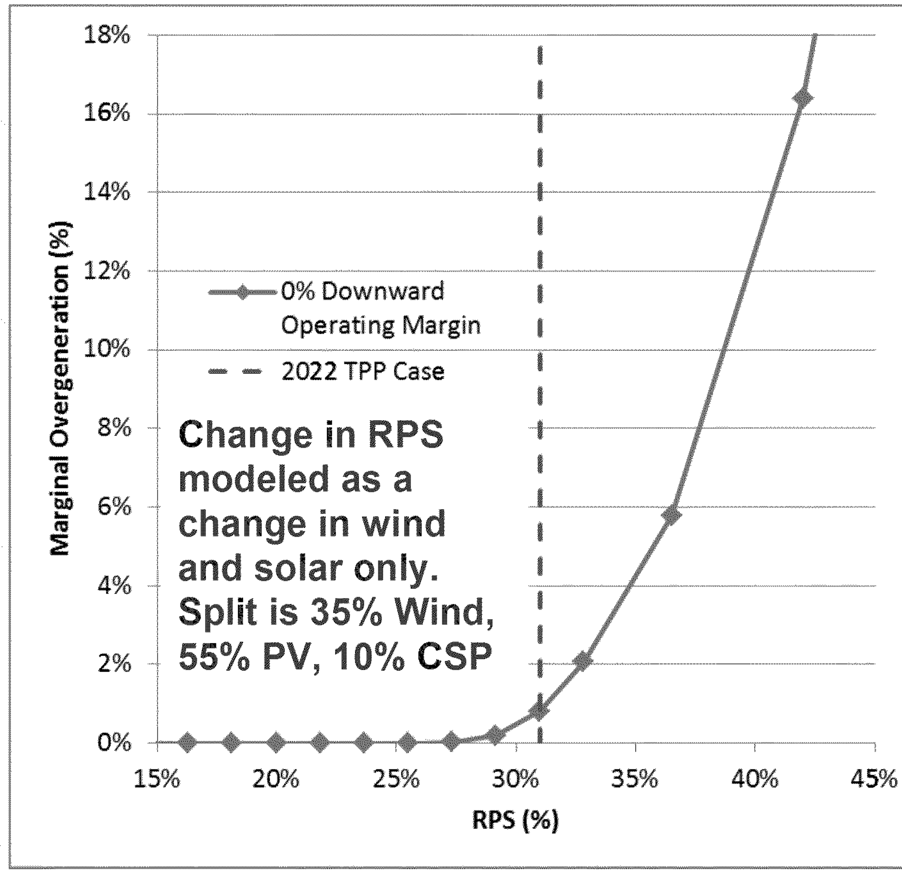
# Marginal over-generation

- **Additional renewables after 33% RPS will lead to higher levels of marginal curtailment without implementing solutions:**
  - Exports
  - Responsive load
  - Storage
  - Increasing conventional fleet flexibility
  - Finding ways to allow renewable contributions to local capacity
  - Focus on dispatchable renewables




Additional over-generation to provide system flexibility not shown, nor is the mitigating impact of storage or exports

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# Thank You!


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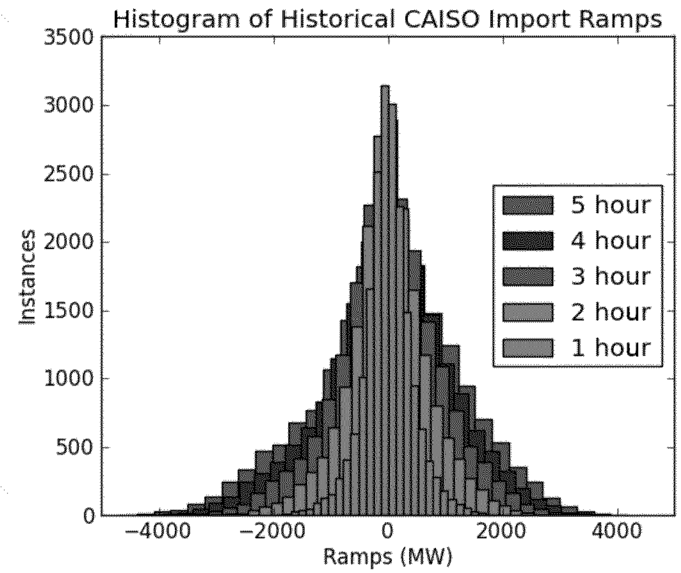
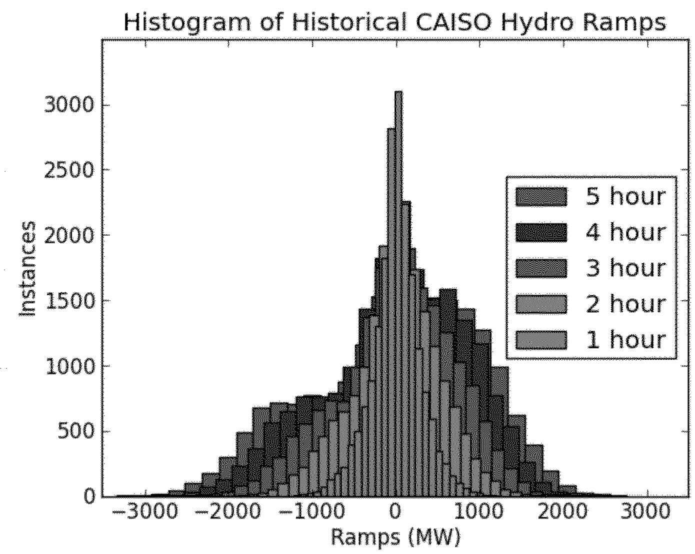
# Stochastic Treatment of Hydro and Imports

- **Hydro and imports are adjusted by unit commitment and dispatch engine**
- **Subject to multi-hour ramping constraints developed from historical record (e.g., 99th percentile)**
- **Min and max values to further bound the range of values**

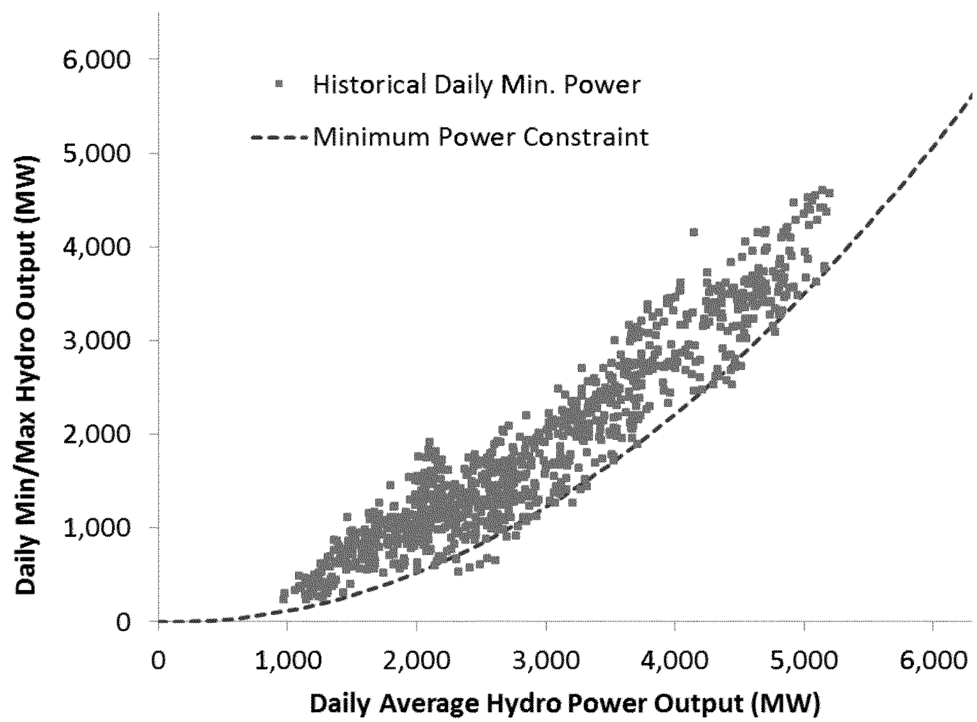


# Stochastic Treatment of Hydro and Imports

- **Hydro and imports informed by historical record**
  - Daily average hydro energy selected from stochastic bin for same month
  - Hydro and imports subject to multi-hour ramping constraints developed from historical record (99th percentile)
  - Max values based on NQC and SCIT tool
  - Min hydro based on historical record
  - Min imports set at 0 MW due to uncertain export capability in 2022

**Daily hydro minimum capacity as a function of daily average hydro**

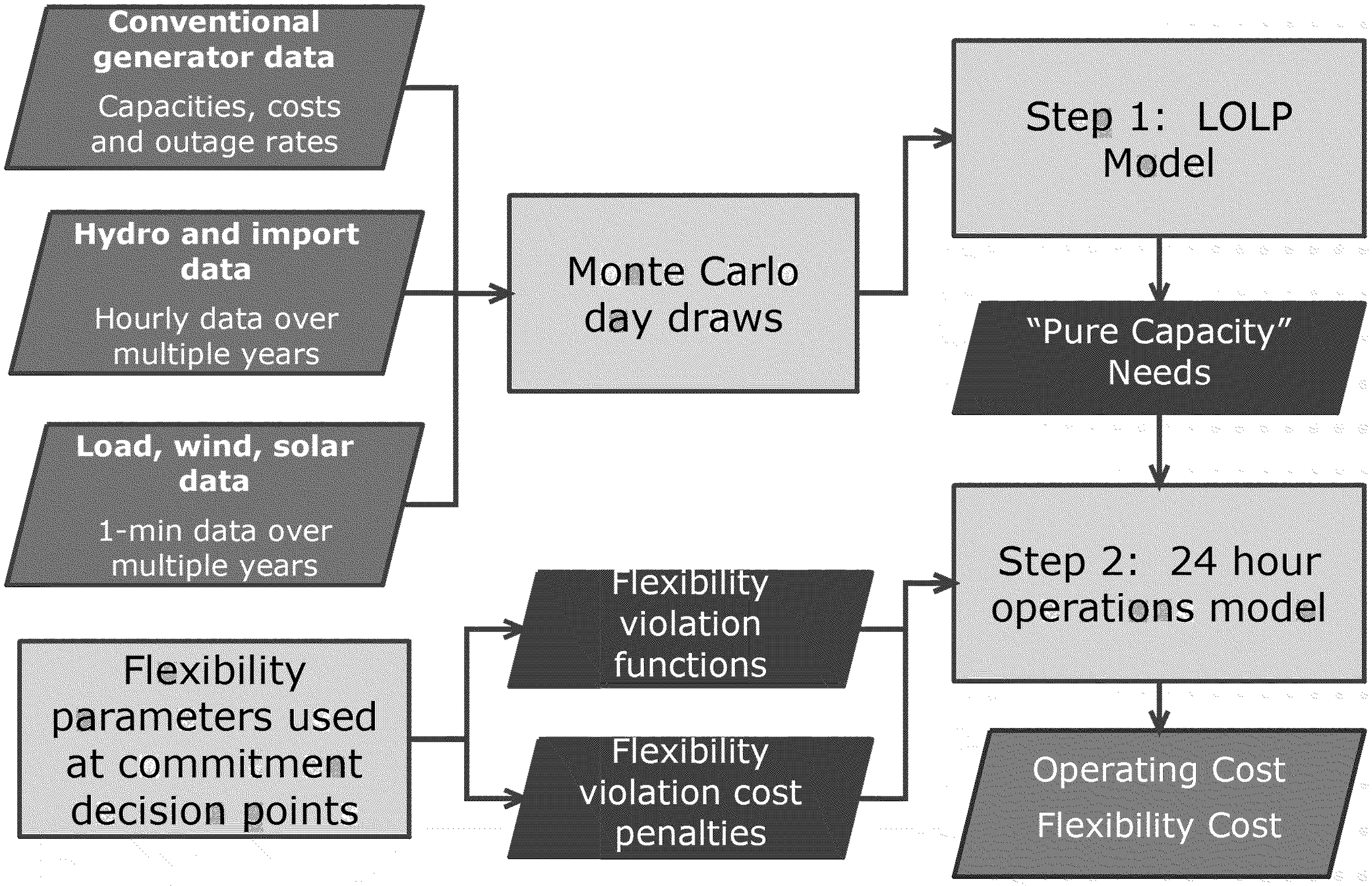


# REFLEX is an Extension of Conventional Capacity Planning

- **REFLEX utilizes a framework similar to conventional reliability planning based on Loss of Load Probability (LOLP) or Expected Unserved Energy (EUE)**
  - Similar metrics are calculated for Expected Unserved Ramp (EUR), in both the upward and downward direction, and Expected Overgeneration (EOG)
  - Flexibility costs are calculated as the product of the expected flexibility violations and a penalty value

| | Quantity of Generation | Speed of Generation |
|---|---|---|
| Upward Direction | EUE | $EUR_U$ |
| Downward Direction | EOG | $EUR_D$ |

# High-level Model Organization



# Load Following Needs

- **Load Following needs can be parameterized through stochastic analysis of potential flexibility violations given a set of operating choices**
  - Used at each defined commitment interval (e.g., day-ahead, hour-ahead, 15 minutes)
- **Unit Commitment model selects optimal Load Following reserve levels from a set of pre-defined "ramping policies"**
  - Model minimizes total cost, including costs of sub-interval flexibility deficiencies (unserved energy or overgeneration)
  - Carrying more Load Following reserves reduces sub-interval ramp deficiencies, but increases operating costs

# Incorporating Forecast Error

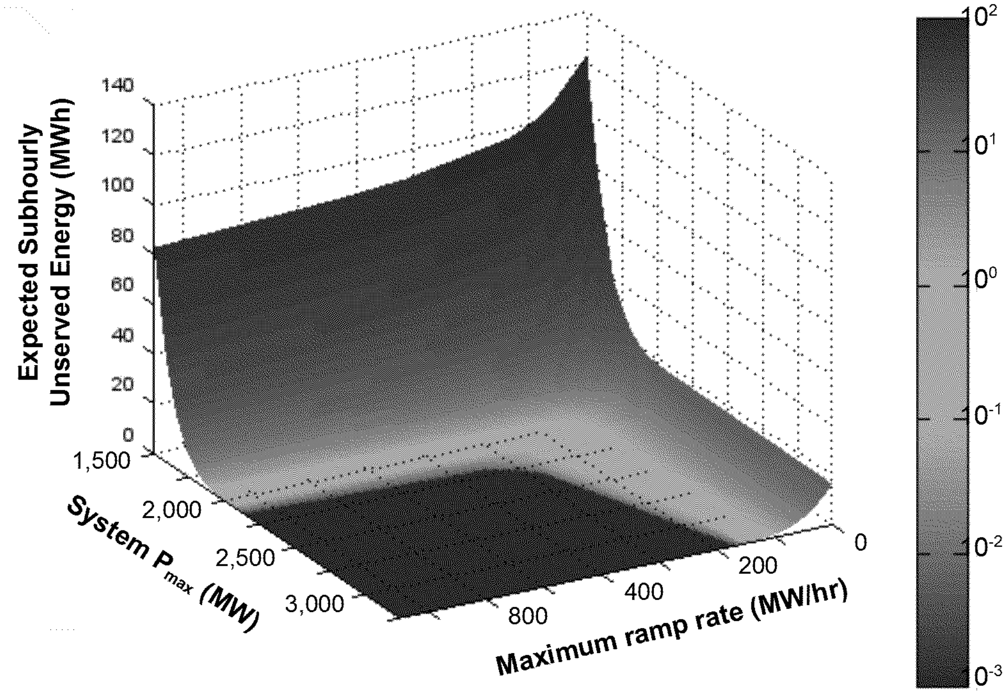
- **REFLEX makes unit commitment decisions at specified intervals**
  - Day-ahead, 4 hour-ahead, 1 hour-ahead
  - Ramping policy functions incorporated into commitment decisions
- **Ramping policy functions account for both forecast error and net load variability**
  - Forecast error incorporated through choice on capacity (MW) axis
  - Sub-interval variability incorporated through choice on ramp rate (MW/min.) axis
- **If forecast error is reduced, ramping policy function will show smaller probability of flexibility violations under a given policy**

# Example Ramping Policy Function

- **Approximate expected sub-interval flexibility violations using 1-min data**
- **Flexibility violations depend on the following variables:**
  - **Demand**
  - **Renewables**
  - **Generic properties of dispatch decision:**
    **Committed capacity (MW)**
    **Max. ramp rate (MW/min.)**
- **Simulate these violations over wide range of each of these variables**
- **Ramping policy functions serve as input to dispatch model to trade off operating cost against flexibility violations**

**Example subhourly unserved energy function for hour with:**

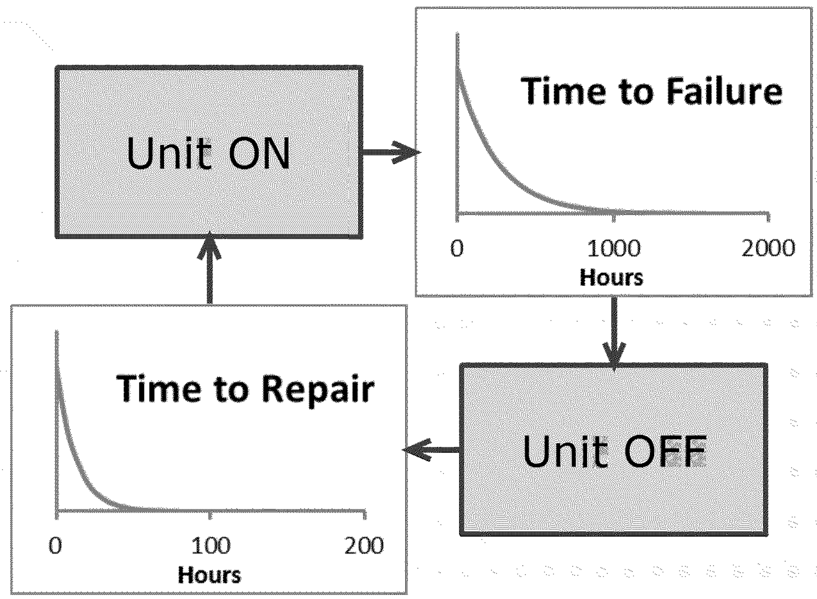
Demand = 2,000 MW
Renewables = 500 MW



# Forced outage and Maintenance

- **Forced outages are modeled using mean time to failure and mean time to repair and assuming exponential distributions**
- **Maintenance is allocated after an initial model runs identify unconstrained months**

Markov Chain
Forced Outage Model



# Stochastic Input Data

| Data Type | Stochastic | Time Slice | Source |
|---|---|---|---|
| **Loads** | Variable & Uncertain | Hourly 2004-2012 | 2004-2012 CAISO OASIS web portal |
| **Wind Profiles** | Variable & Uncertain | Hourly 2004-2006 | NREL Western Wind Dataset |
| **Solar PV Profiles** | Variable & Uncertain | Hourly 1998-2009 | NREL Solar Anywhere and SAM |
| **Solar Thermal Profiles** | Variable & Uncertain | Hourly 1998-2005 | NREL Solar Anywhere and SAM |
| **Hydro Energy** | Variable | Monthly 1970-2011 | EIA hydro production datasets |
| **Hydro minimum capacity** | Variable | Monthly 1970-2011 | CAISO & EIA hydro production data |