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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
- **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

# Status of REFLEX Modeling

- **Currently showing preliminary results from test runs**
  - Model and database are largely complete
  - Results are based on 359 stochastic draws of 3 days each
    - Working on ways to improve run time to model more days
  - Very high overgeneration penalty assumed for first run
    - Models case where renewable curtailment is unavailable or to be avoided at (nearly) all cost
- **Today's results illustrate the stochastic method for need determination using REFLEX and provide interesting insights for discussion**

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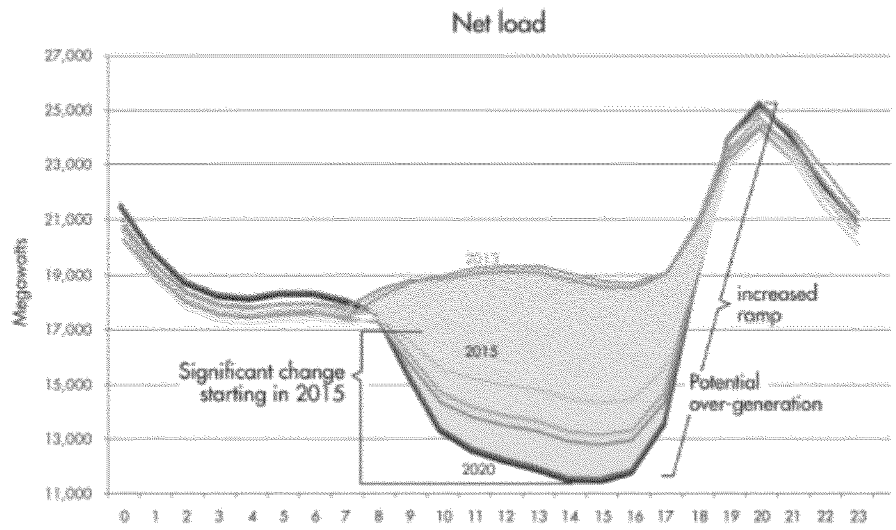
# REFLEX METHODOLOGY & ASSUMPTIONS

# 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?



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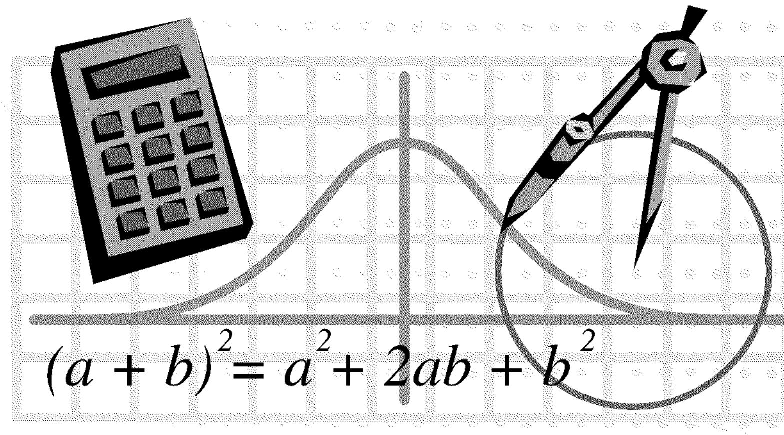
# Problem is Stochastic in Nature




- **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

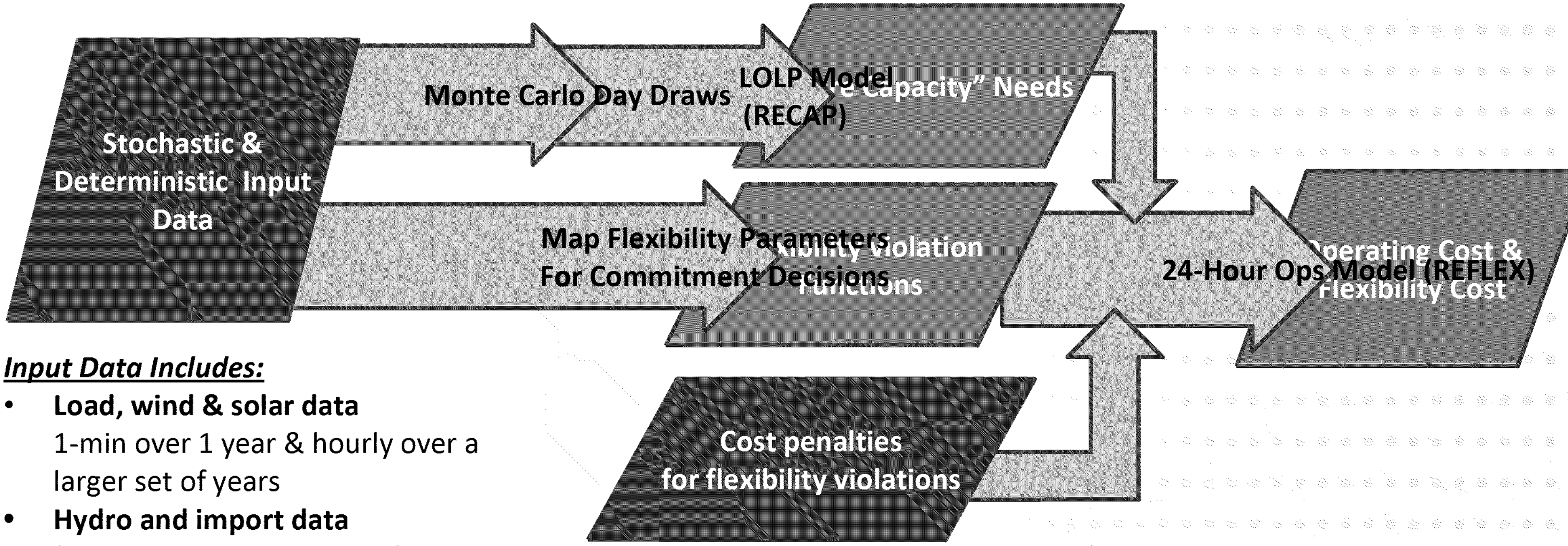
# REFLEX is an Extension of Conventional Capacity Planning

- **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)

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

- Cost penalties provide a flexibility violation "loading order"
- Flexibility costs are calculated as the product of the expected flexibility violations and the penalty value

# REFLEX Modeling Process




***<u>Input Data Includes:</u>***

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

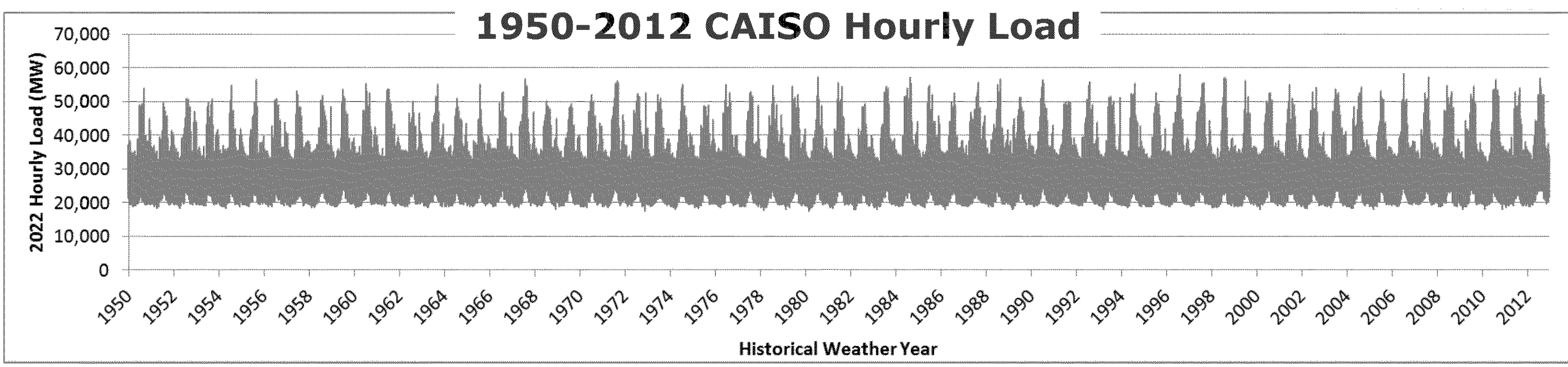
***<u>User-defined Cost per MWh for:</u>***

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

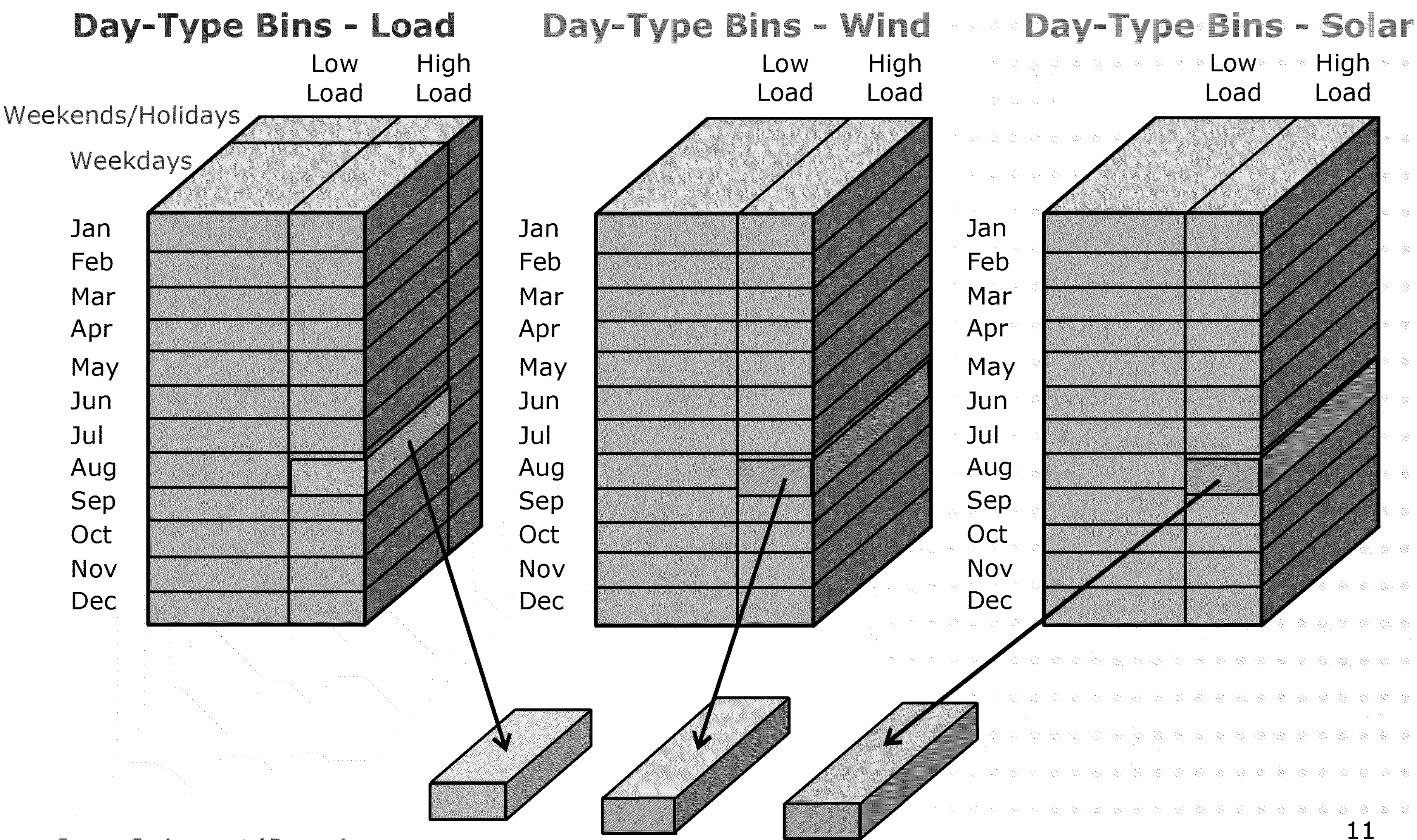
- **Parallel calculation of conventional capacity needs & flexibility impact for use in 24-hour operations model**

# 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"

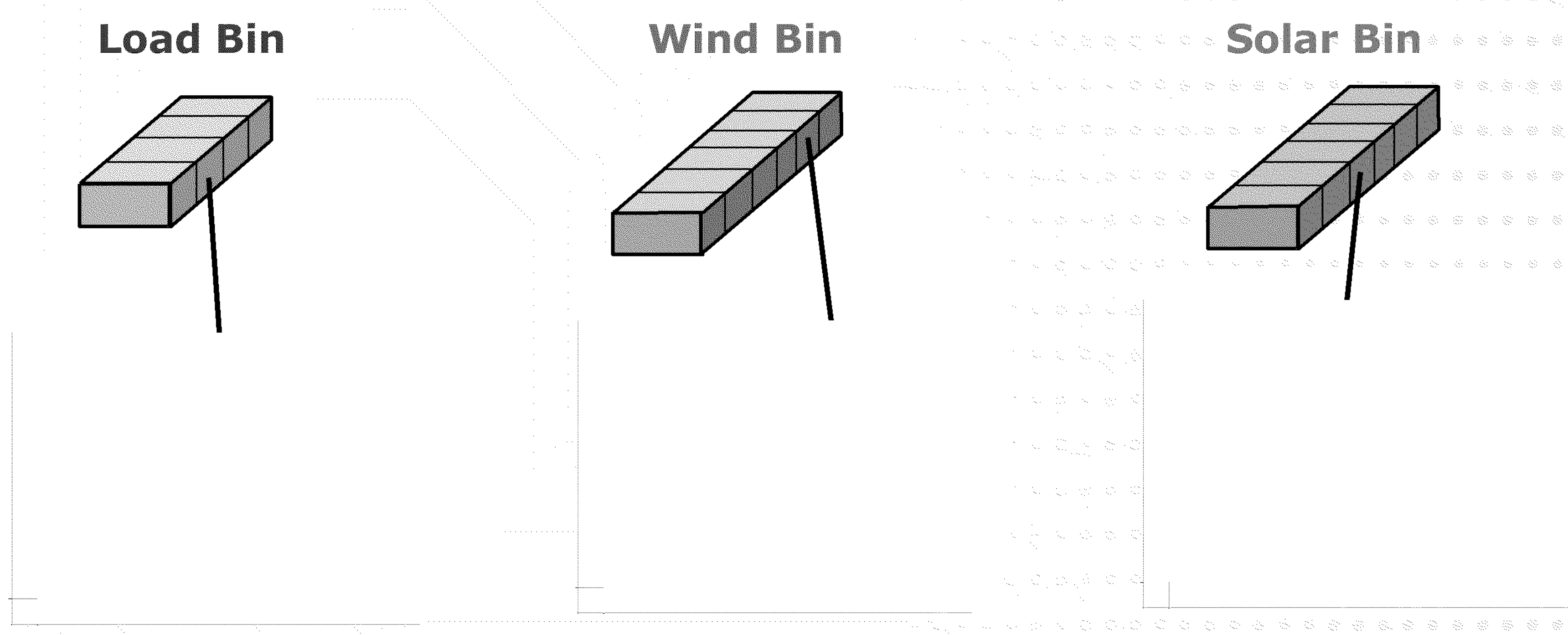


# Example Draw: High Load Weekday in August



# 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.**

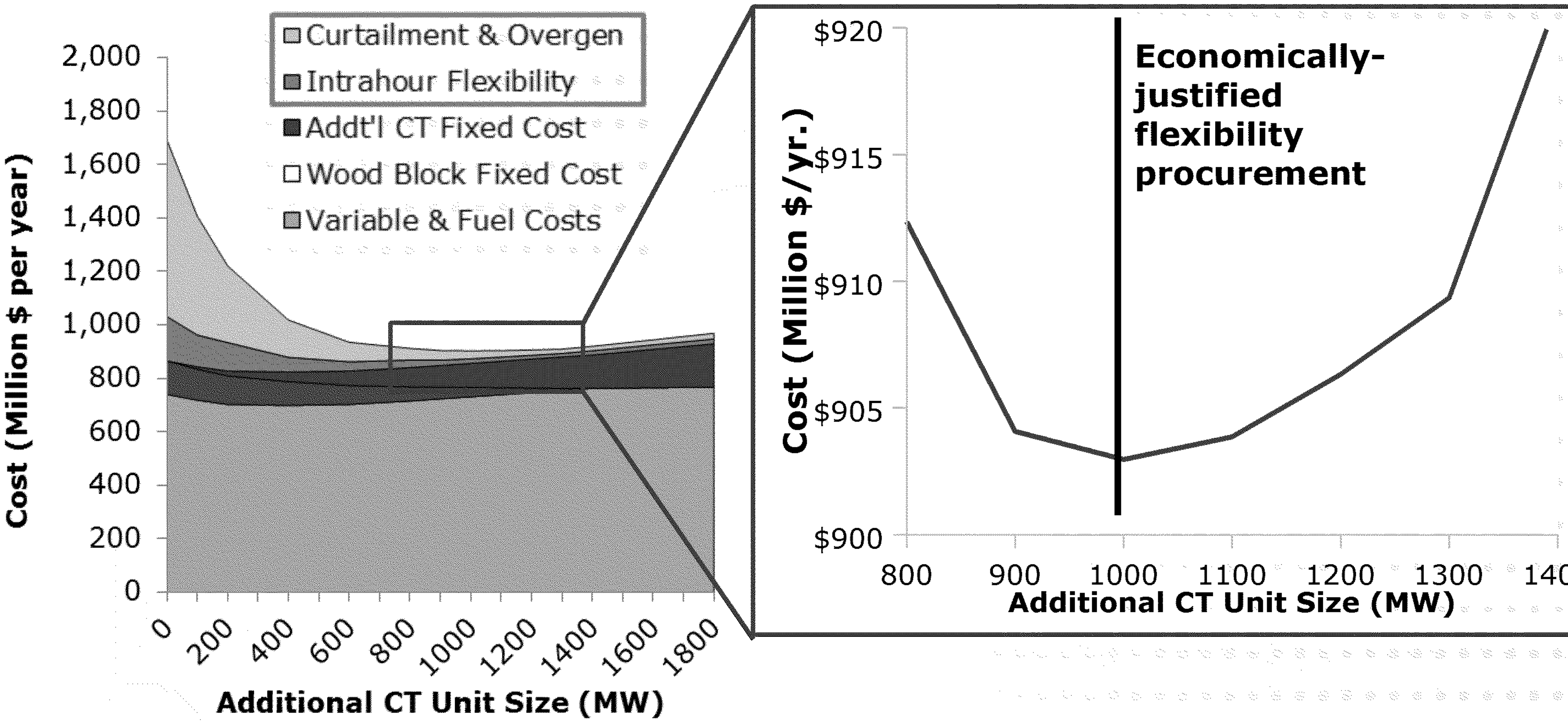


# Load Following Needs

- **Load Following needs are parameterized through stochastic analysis of potential flexibility violations given a set of operating choices**
- **Quantity of Load Following Reserve is a variable that is chosen endogenously**
  - 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 ($EUR_U$ and $EUR_D$) but increases operating costs and the likelihood of overgeneration (EOG)

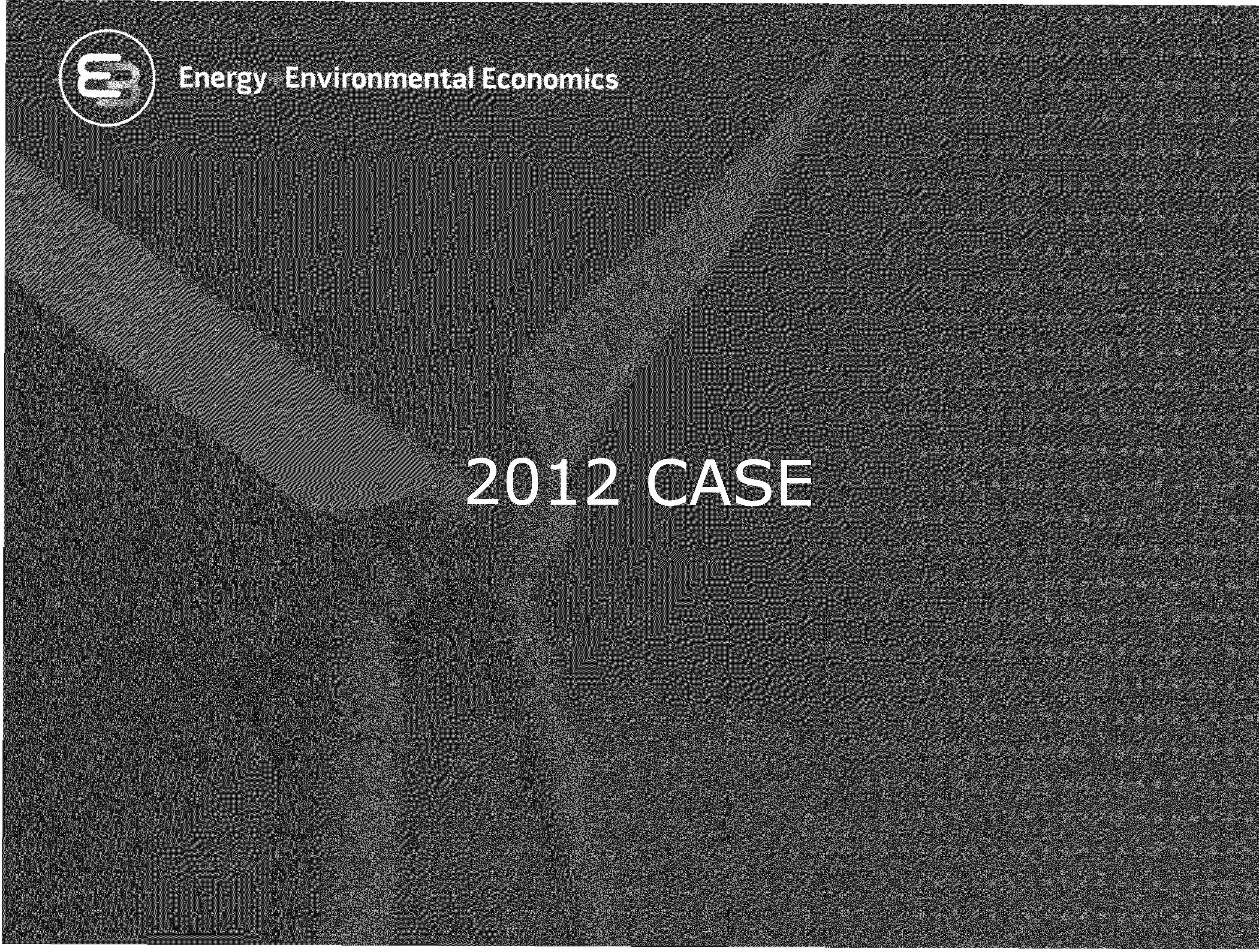
# Optimal Flexibility Investment

- **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**



# 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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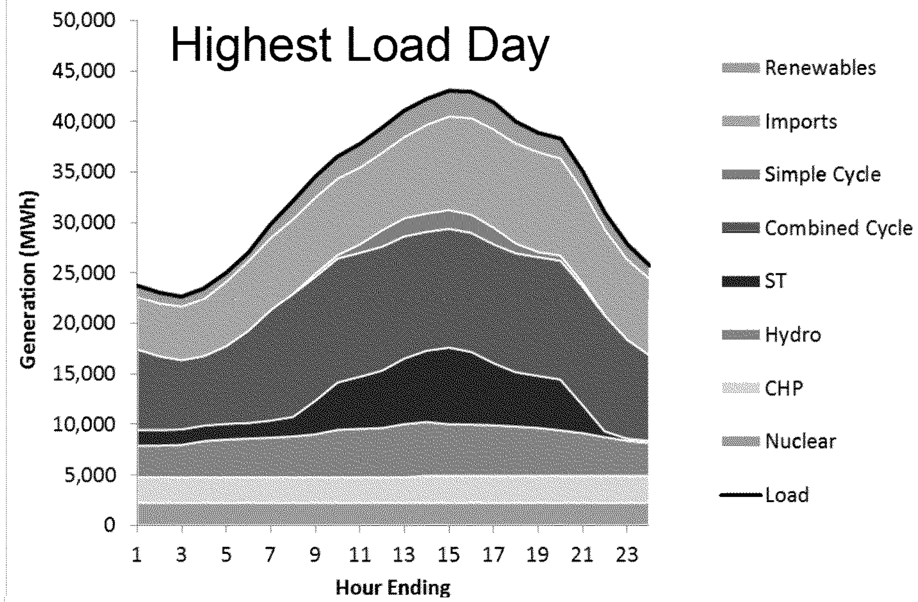
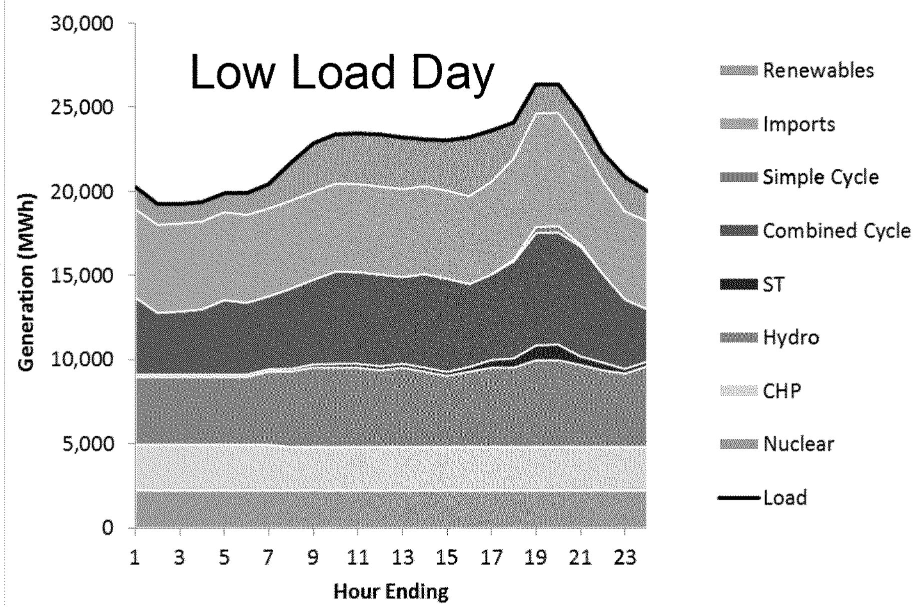
2012 CASE

# Ran 2012 Test Case

- **RECAP model showed no capacity shortages or system level over-generation after 5,000 years of draws**
- **REFLEX runs had no capacity, flexibility, or over-generation violations over 1 year of draws**



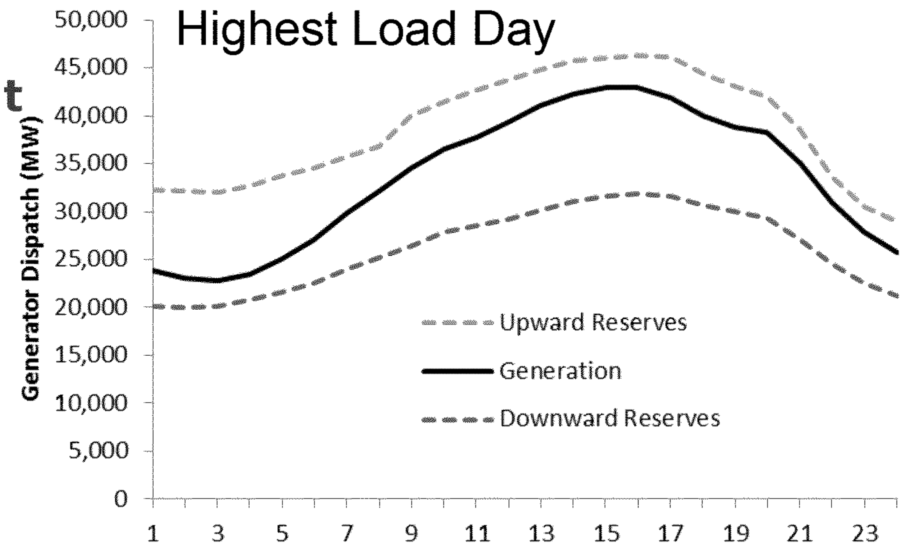



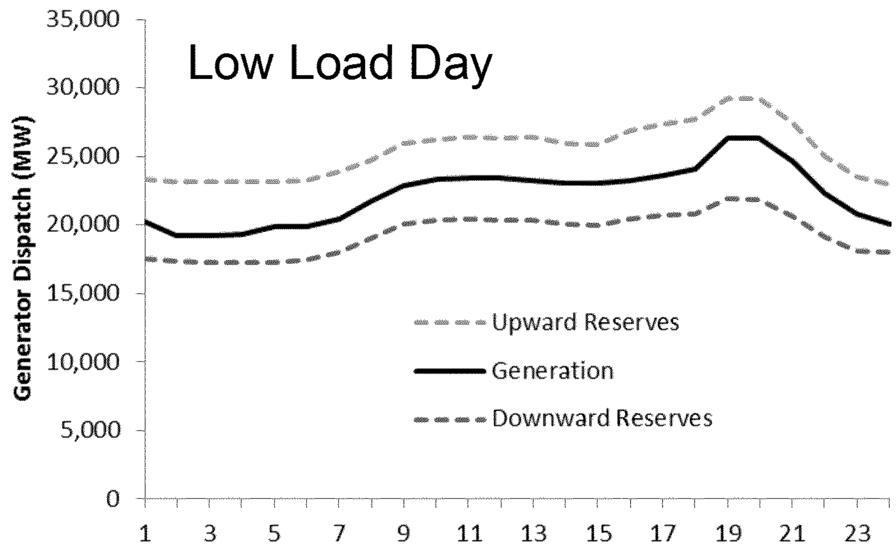
# REFLEX Load Following Reserves response surface

- **REFLEX reserve provision results are reasonable compared to current practice**

| | Upward | | Downward | |
|---|---|---|---|---|
| | % of Load | MW | % of Load | MW |
| minimum | 7% | 1,150 | 6% | 1,972 |
| average | 20% | 5,231 | 15% | 3,660 |

- **After confirming the model logic was working as expected, we moved our attention to the 2022 case**



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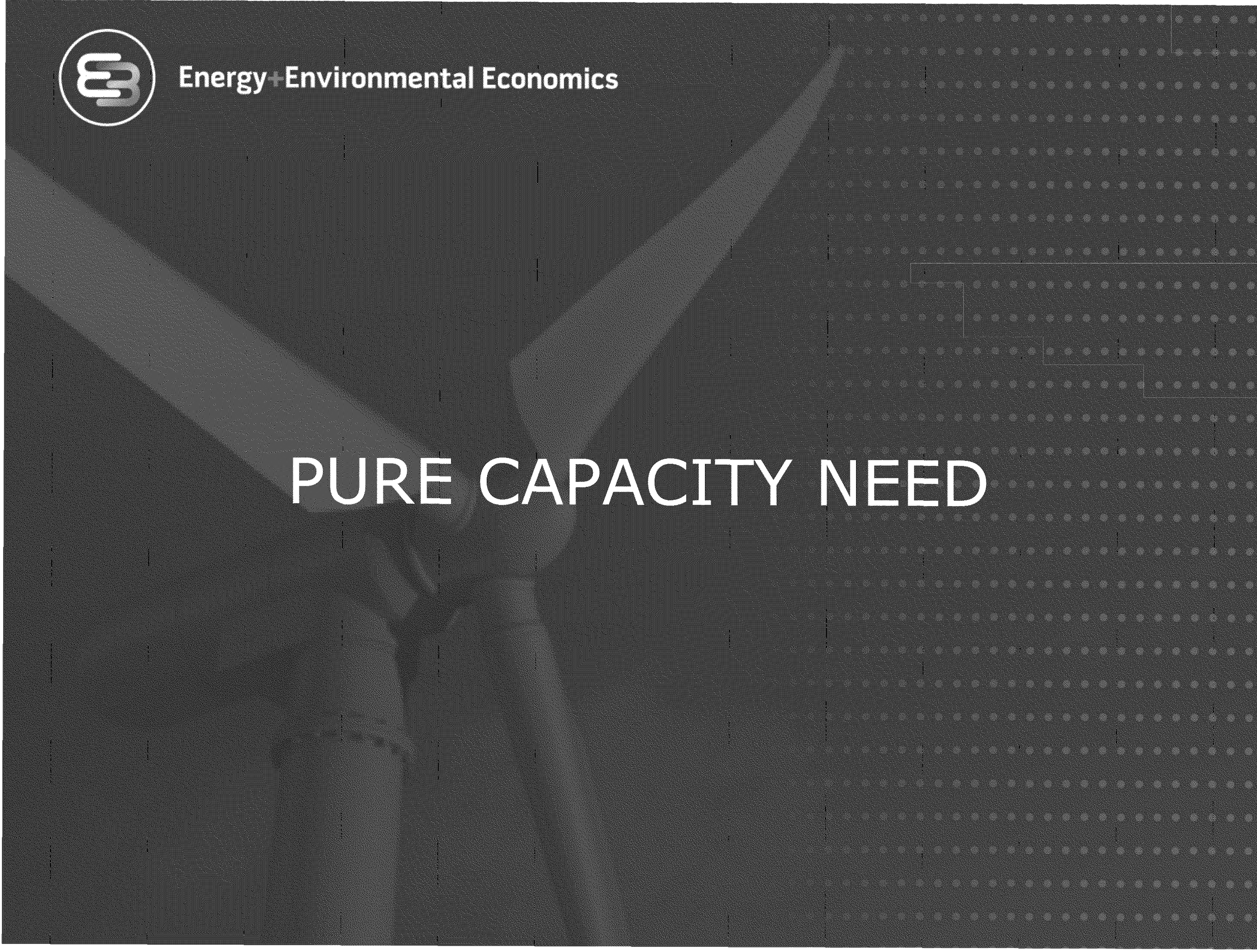
# 2022 REPLICATING TPP CASE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PURE CAPACITY NEED

# 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

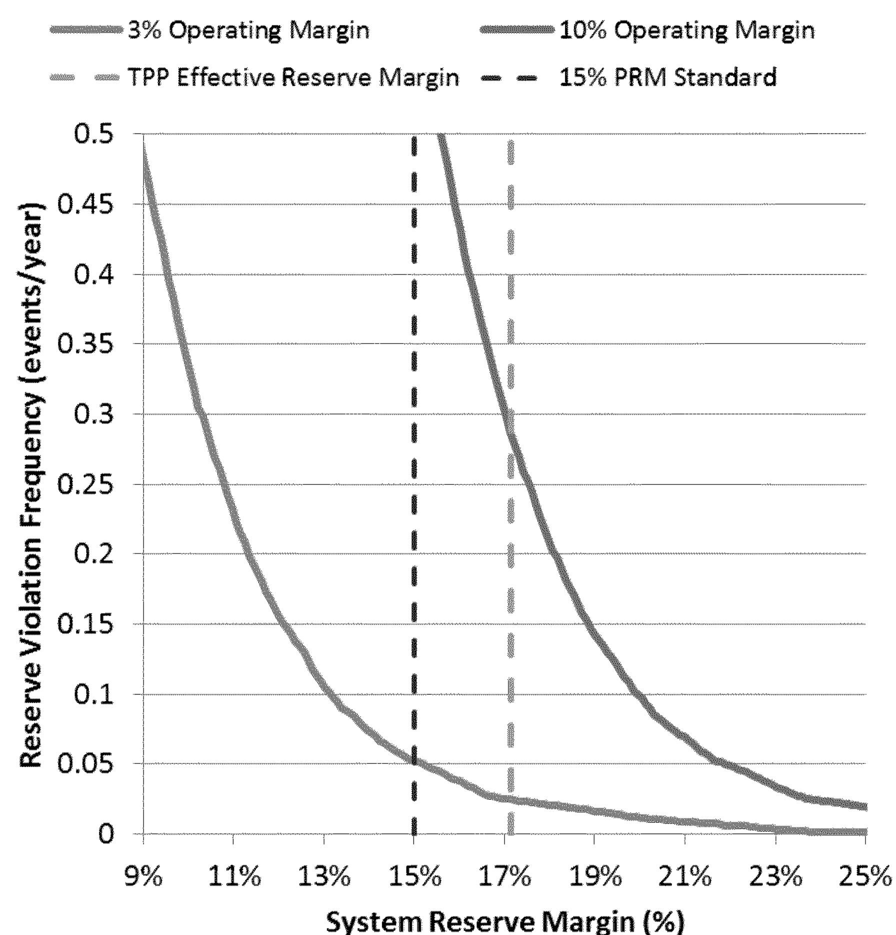
- **E3 replicating TPP case does not include SONGS**
- **PRM is calculated as total ELCC divided by 1-in-2 peak load, minus 1**
- **CPUC scenario tool analysis of the case shows a 15.1% PRM**
- **There may be a discrepancy with generator stack modeled in PLEXOS**

| 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% |

# Step 2: LOLE Check

- **Replicating TPP case meets 1-in-10 standard, including 3% spinning reserves**
  - Violations of:
    - 0.025 events/year
    - 0.052 hours/year
    - 84 MWh/year
- **Violations are not surprising under deterministic case assumptions**
  - 10% operating margin to account for Reg., Spin, Non-Spin and Load Following
  - 1-in-5 peak load
  - 30% chance of violation across all years

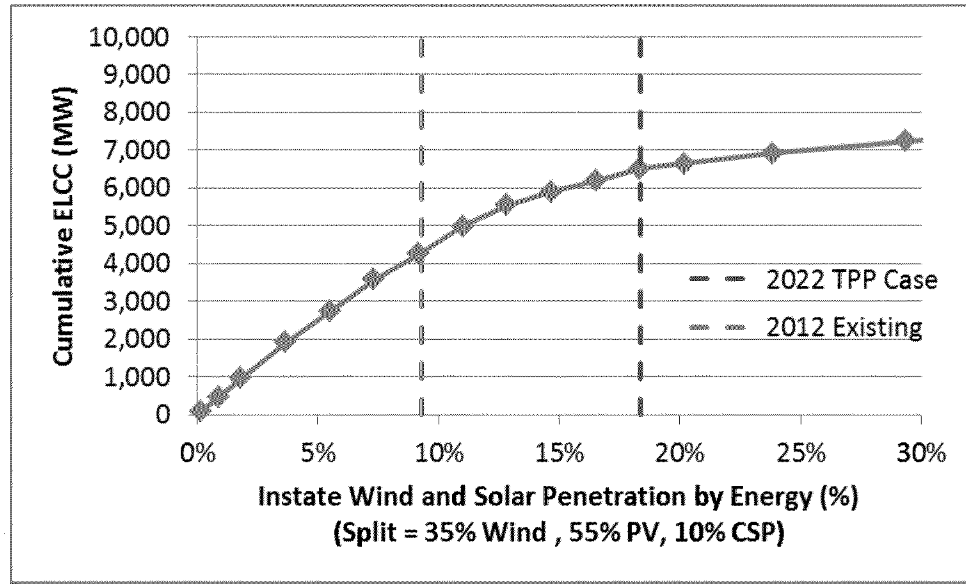
3% spinning reserves + 3% non-spinning reserves + 3% load-following + 1% regulation = 10% operating margin

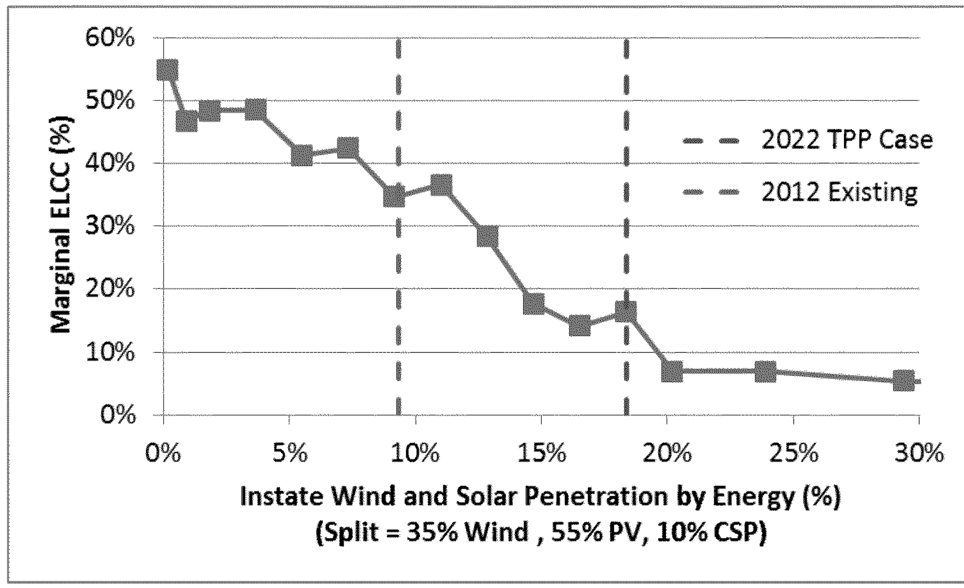


# Renewable ELCC

- **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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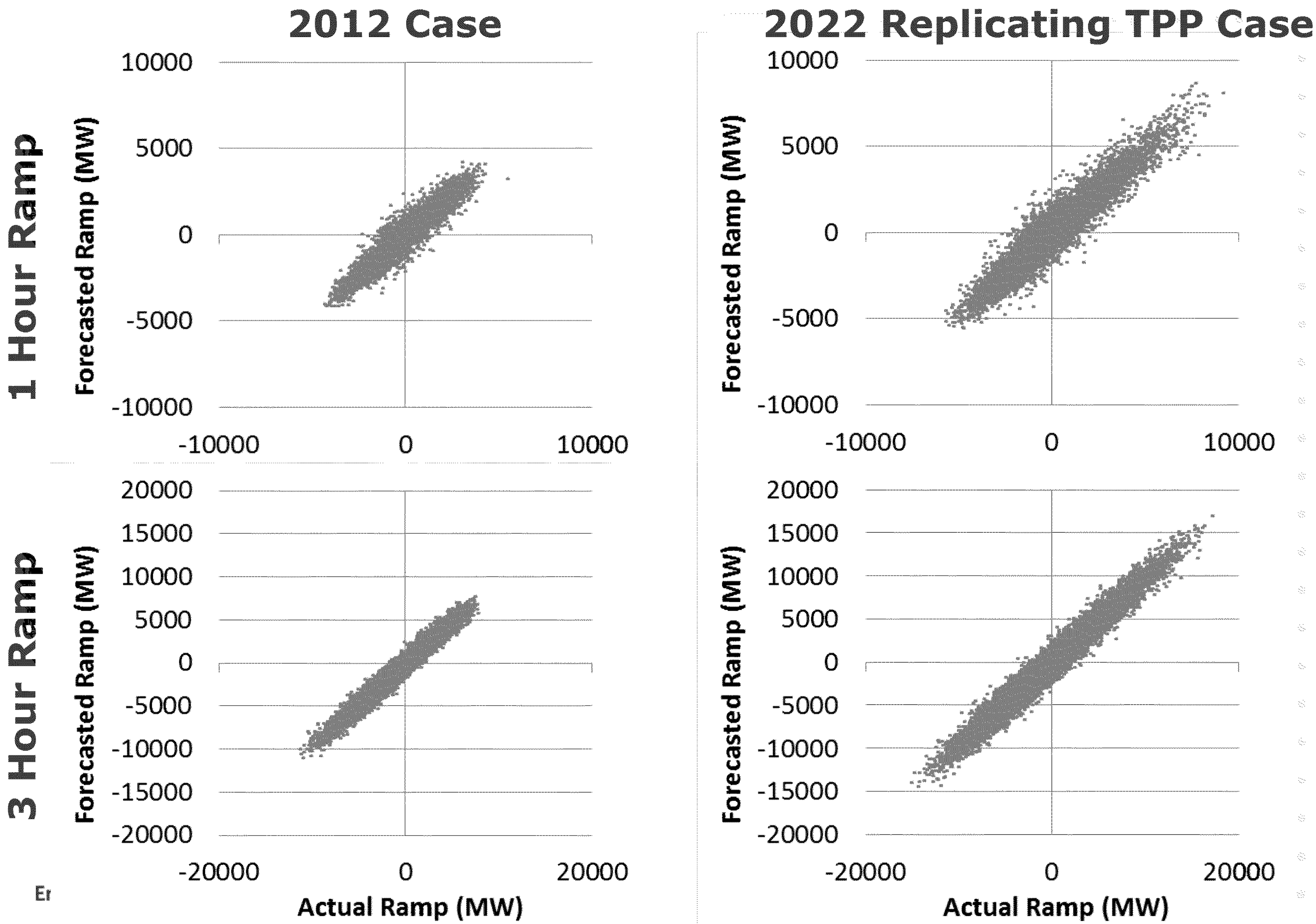
# NATURE OF FLEXIBILITY NEEDS

# Net Load Ramps Increase Between 2012 and 2022



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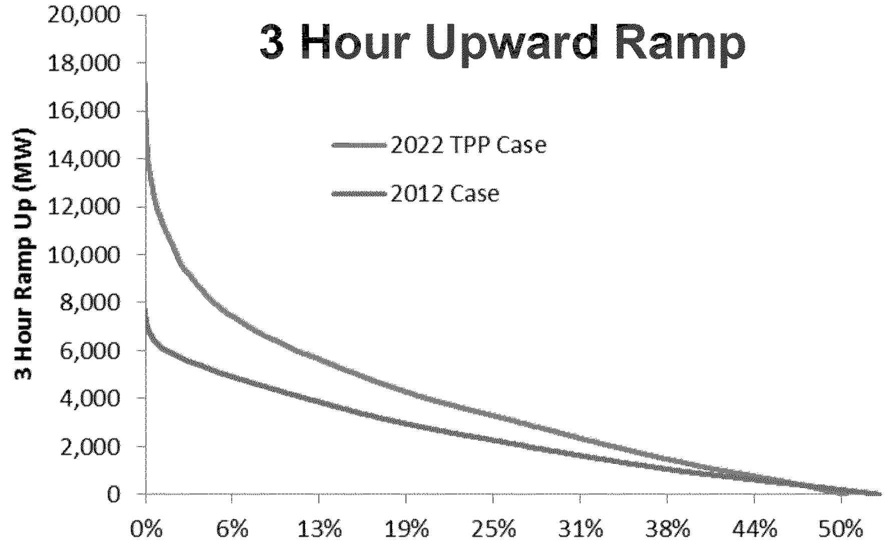
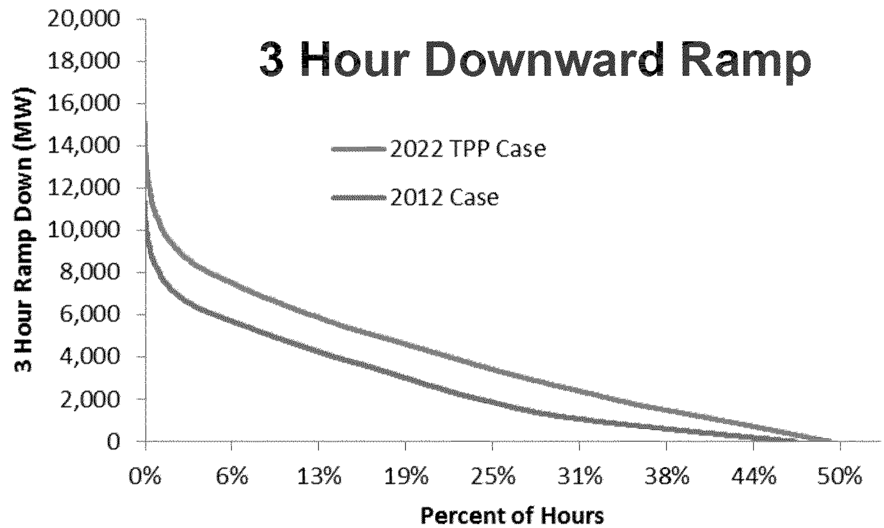
# Ramp duration curves

- **Significant increases multi-hour ramping needs due to renewable penetration and load growth**
  - Maximum upward 3 hour ramp expected to double



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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; Monte Carlo outage draws |
| **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 case |
| **Imports/Exports (ramping, minimum & maximum)** | Ramping capability based on historical path flows (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** | $4.3/MMBtu<br>$24/metric ton CO2<br>(From ISO Case parameters) |

**The LCR constraints were removed due to REFLEX convergence problems caused by 40/60 violations. Additional LCR capacity may be needed to avoid violations in LA Basin.**

# Cost Penalties Assumed for Flexibility Violations

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

### Hourly Violation Penalties

| Type of Violation | Test Run Value | Best estimate of final value |
|---|---|---|
| Unserved Energy | $100,000/MWh | $40,000/MWh |
| Overgeneration | $2,000,000/MWh | Linked closely to curtailment cost |
| Curtailment Cost | Hard constraint | **$250/MWh**; Replace lost revenues |
| Spinning reserves | Hard constraint | Hard constraint |

### Intra-hourly Violation Penalties

| Type of violation | Test Run Value | Best estimate of final value |
|---|---|---|
| Upward Ramping Violation | $10,000/MWh | $1,000/MWh; highly dependent on the degree of shortage experienced |
| Downward Ramping Violation | $10,000/MWh | **$200/MWh**; Could result in need for curtailment |
| Insufficient Regulation | $10,000/MW | $1,000/MW; insufficient regulation likely results in CPS violations |

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# Base Case Results
# High cost over-generation

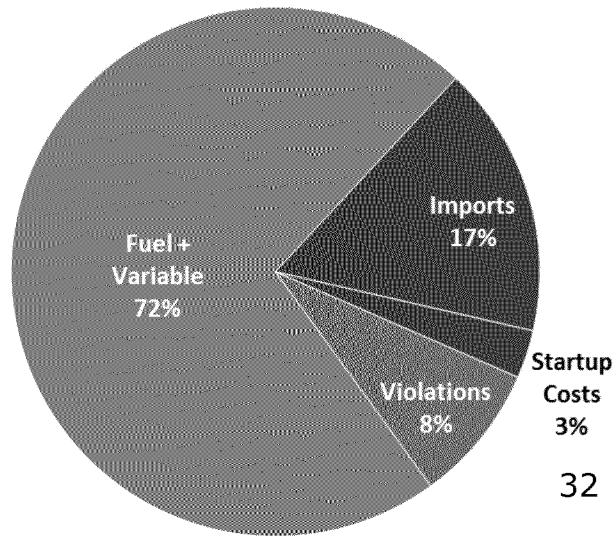
# Violations and production cost summary statistics

- **No unserved energy; one day with unavoidable over-generation**
- **Annual production cost of $5,100 MM/year**
- **Annual flexibility violation costs of $475 MM/year**

Violation costs shown for illustrative purposes and are extremely sensitive to cost parameters

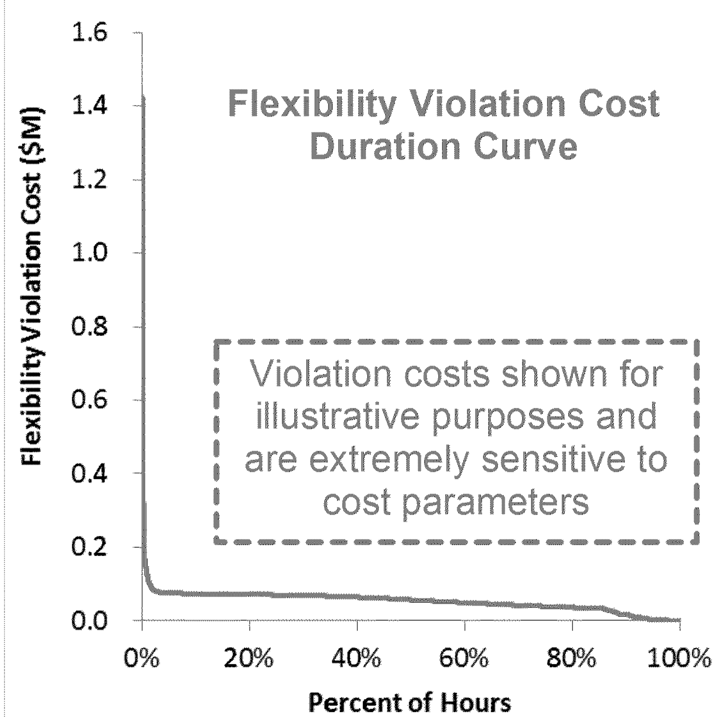
| Violation Type | Expected Violations (MWh/yr) |
| --- | --- |
| Regulation Up | 2,255 |
| Regulation Down | 4,767 |
| Spinning Reserves | 0 |
| Load following up | 420,100 |
| Load following down | 228,780 |
| Curtailment | 4,906 |
| Total | 660,807 |

**Optimization Costs**



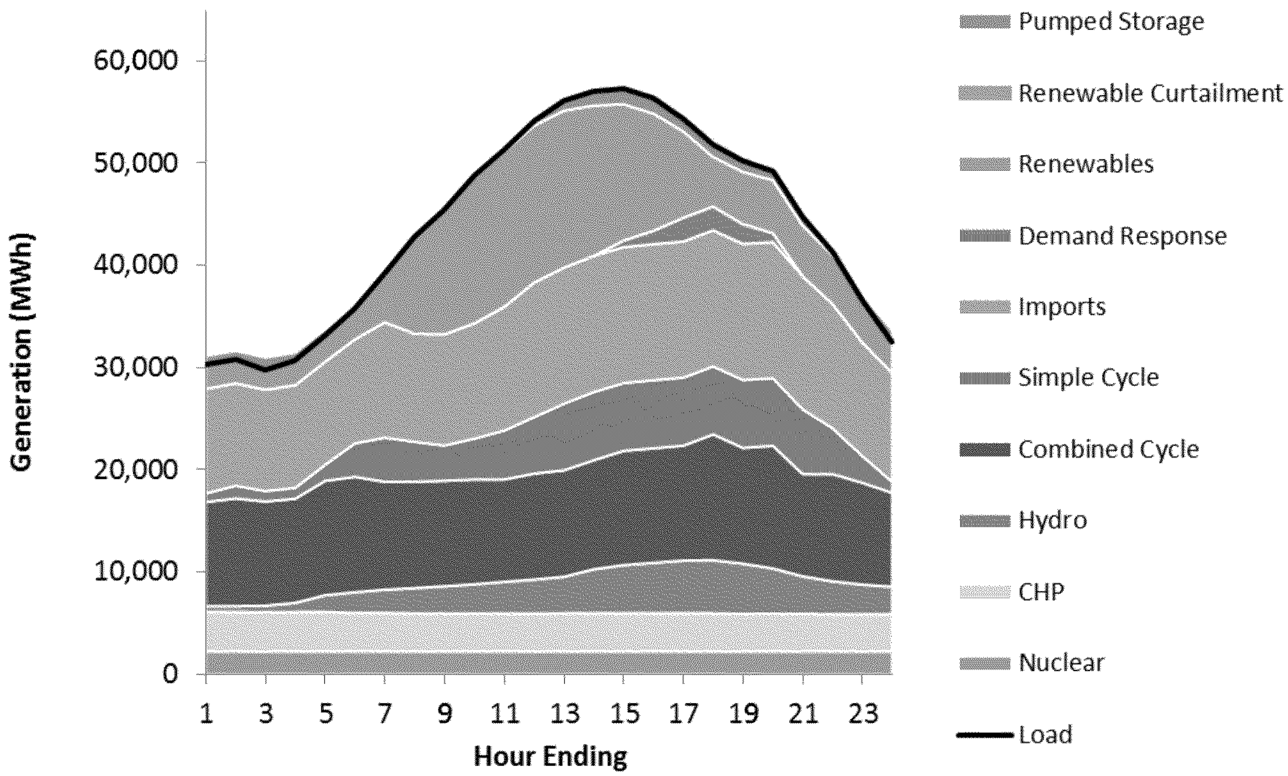
# Interpreting flexibility violation costs

- **Expected flexibility violations of $475 MM/year are a significant cost**
  - May be possible to reduce total costs by procuring new resources
- **As noted, significant additional work is needed to determine appropriate penalties to translate violations into costs**
  - What is the impact of a violation?
  - 5 minute simulation may be necessary
    - Not a focus due to time constraints



# Highest net load day

- **September, weekday, high-load draw**
  - All units and DR dispatched
  - Highest net load occurring in September is due to the limited set of random draws, nothing fundamental



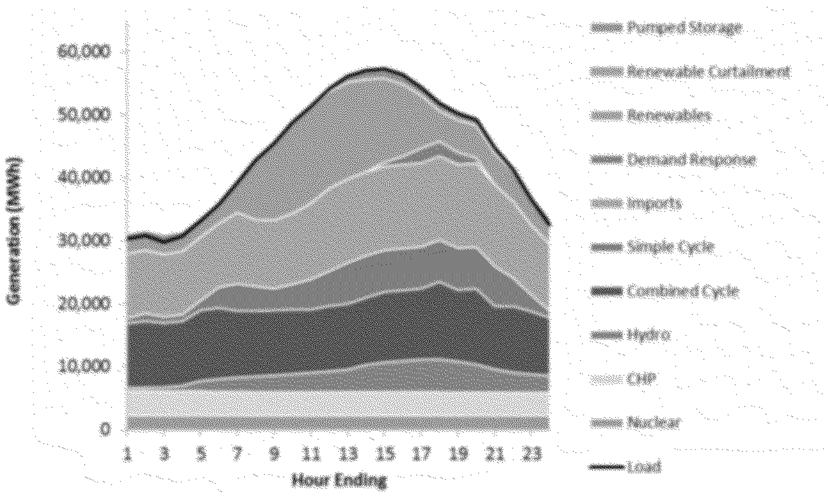


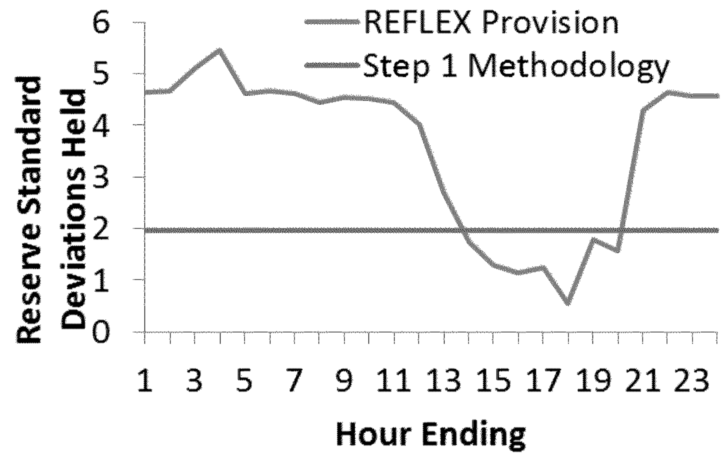


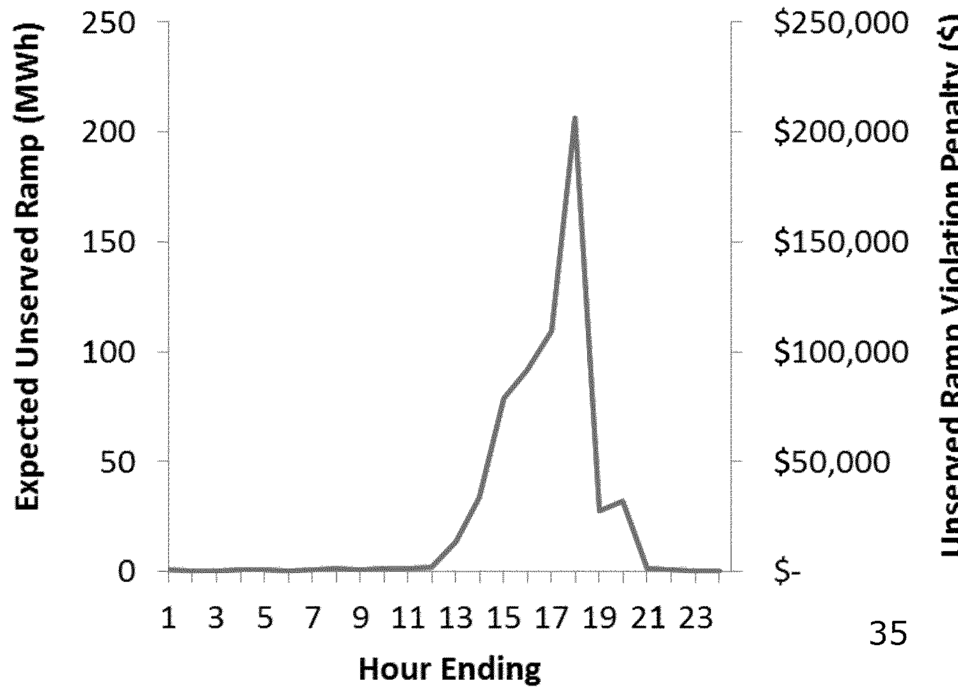

Draw 185

# Highest net load day

- **This day would have resulted in a load following shortage in the deterministic run**
- **In REFLEX this is expressed as 608 MWh of expected ramping shortage ($EUR_U$), penalized at $608,000**

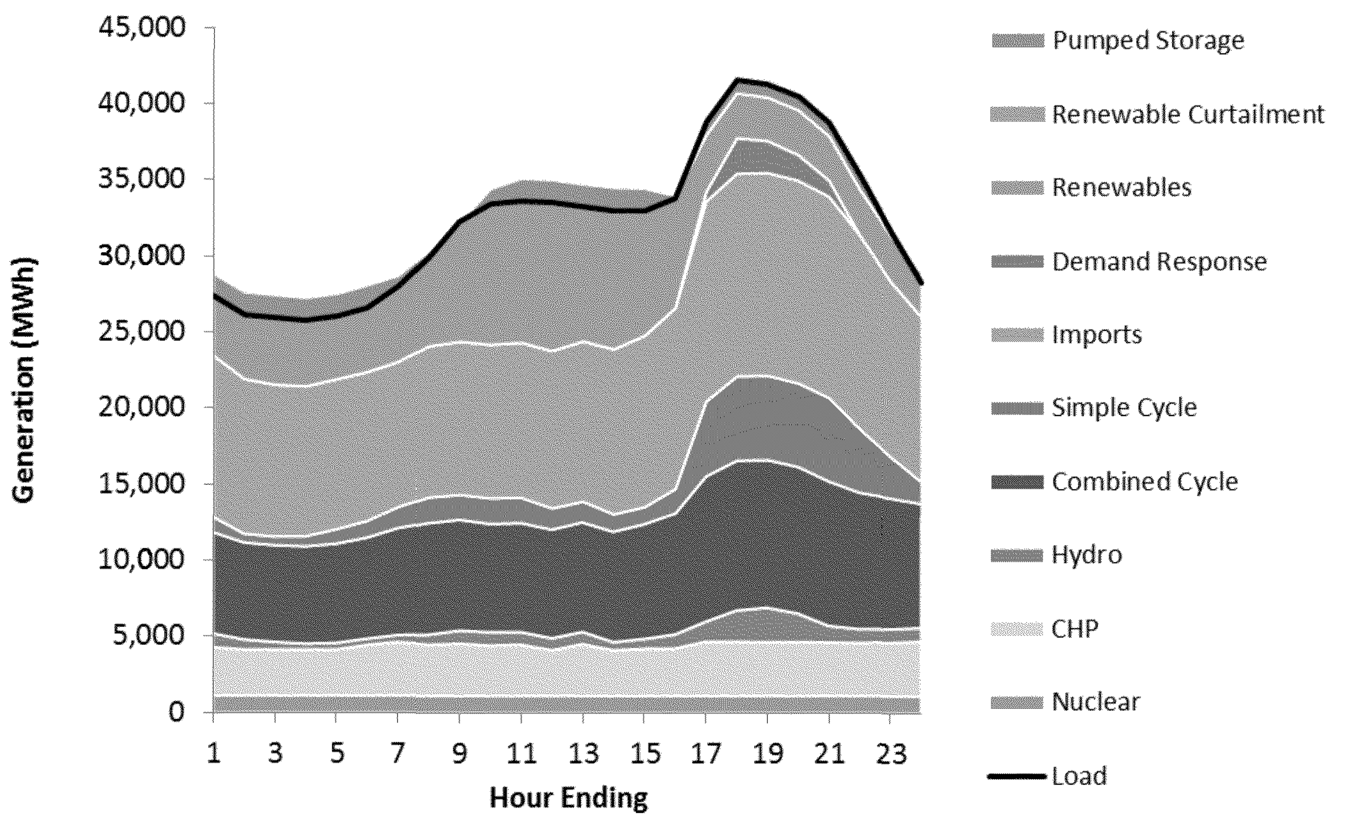


# Day with the largest net load ramp

- **December, weekend, high-load and solar draw**
  - Single largest 1 hour net load ramp of the year
  - Step 1 load following violations recorded at HE 18-20



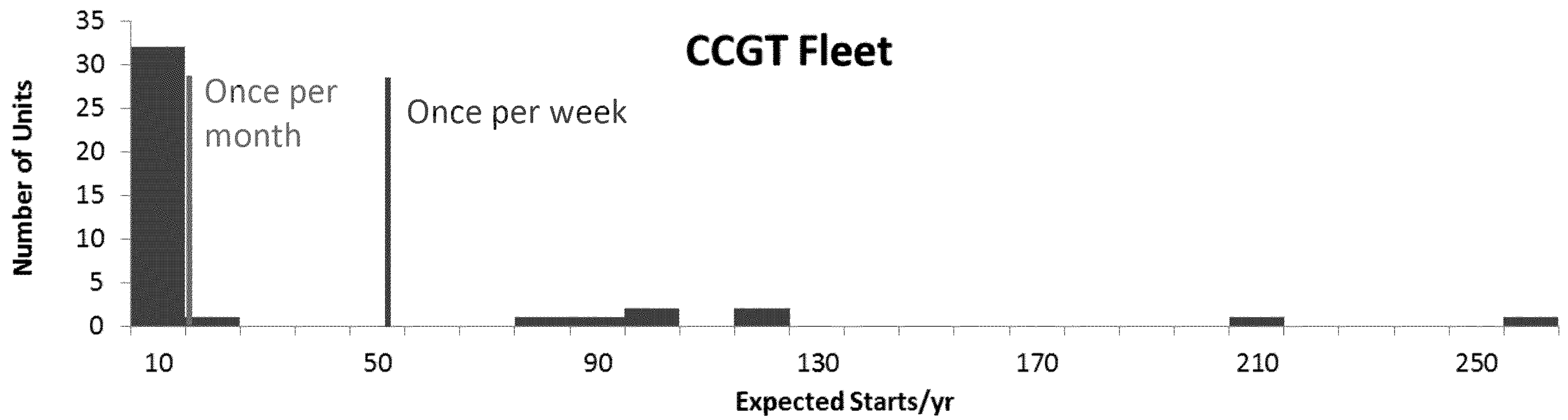


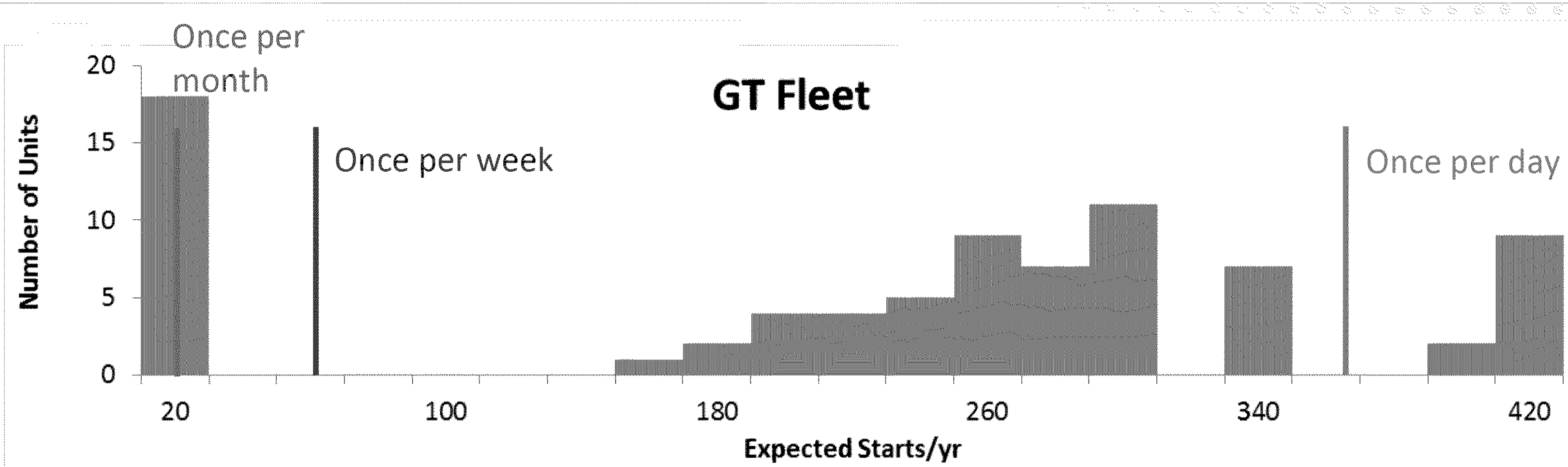



Draw 359

# Startup behavior

- **Start-up costs not included in optimization, inclusion should reduce number of starts, but at the expense of additional flexibility violations**





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# Base Case Results $250/MWh Curtailment Sensitivity

# Test Case With Low Overgen. Penalty Not Yet Complete

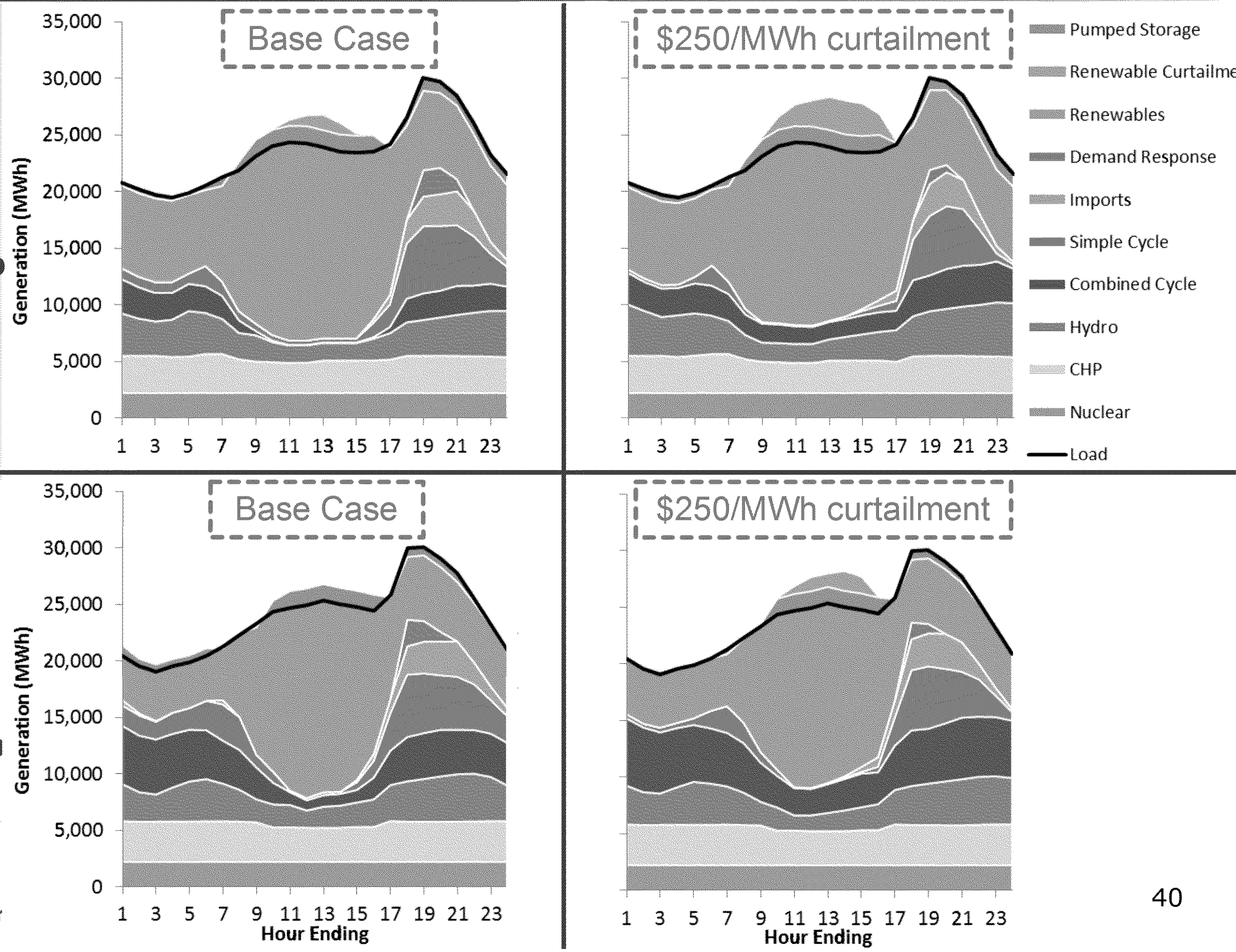
- **This section shows how the operations change on a few selected days**
- **The model begins to make an economic tradeoff between overgeneration and $EUR_U$**
  - The following days have non-negligible $EUR_U$ during evening hours
  - REFLEX engages in "prospective" curtailment of renewables in order to smooth upward ramps
  - This is the tradeoff REFLEX is designed to assess

# Low-load, high hydro, high solar draws

- **April**
- **Weekend**
- **Low-load**
- **High hydro**
- **High solar**

Draw 279

- **February**
- **Weekend**
- **Low-load**
- **High hydro**
- **High solar**

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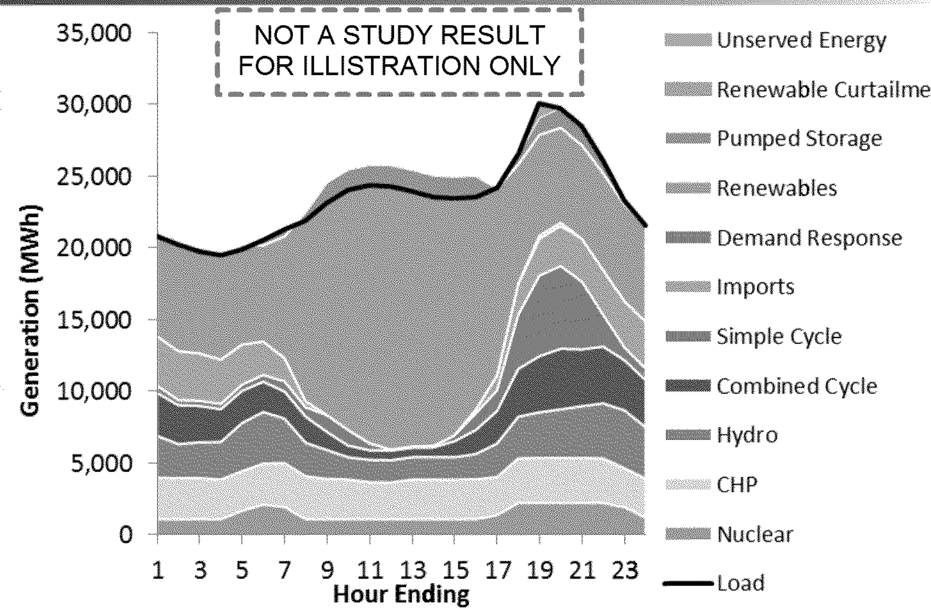
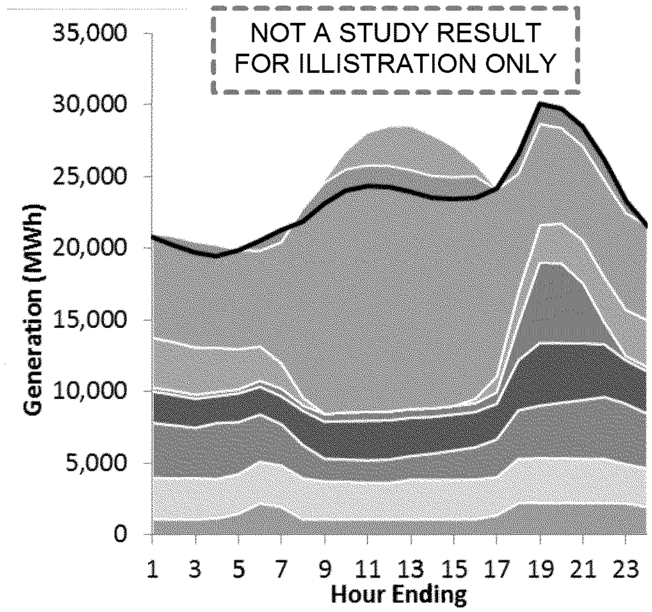
Draw 262

# Using over-generation to preserve ramping capability

- **Turning thermal resources off to make space for renewables can create upward ramping challenges when renewables production drops**
  - Unserved energy shown in example day
- **Over-generation allows slow-start thermal resources to remain online to meet subsequent ramps**
- **Operational strategy must be informed by explicit cost penalties**








Draw 279

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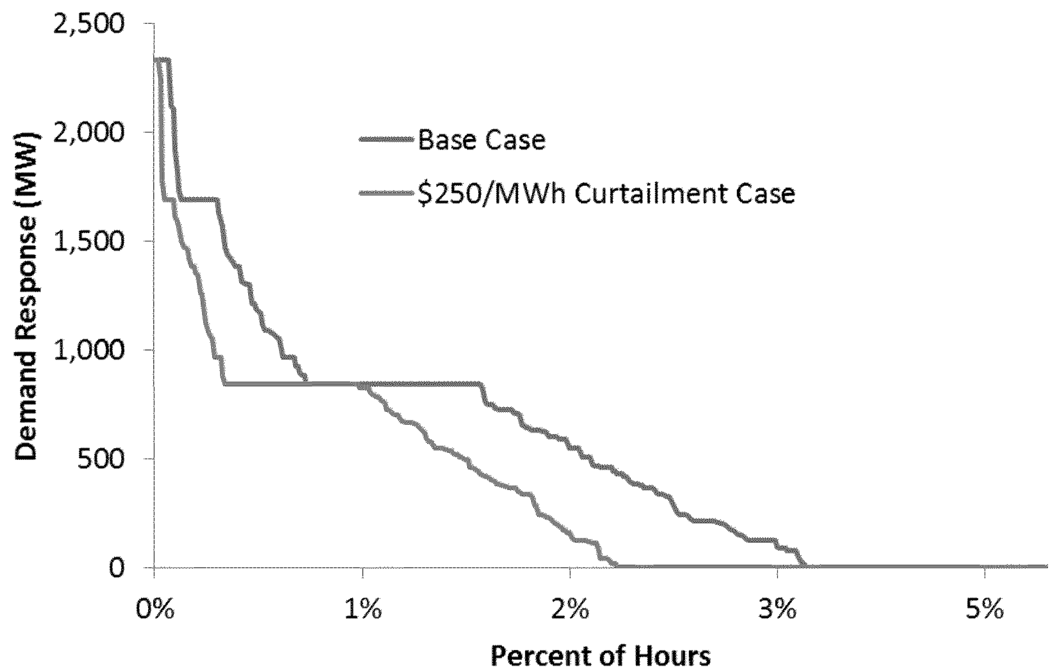
# Demand response

- **Economic curtailment reduced demand response calls by 35%**
- **Modeling next steps include ensuring DR programs are accurately characterized by season, and hour of day, and price**



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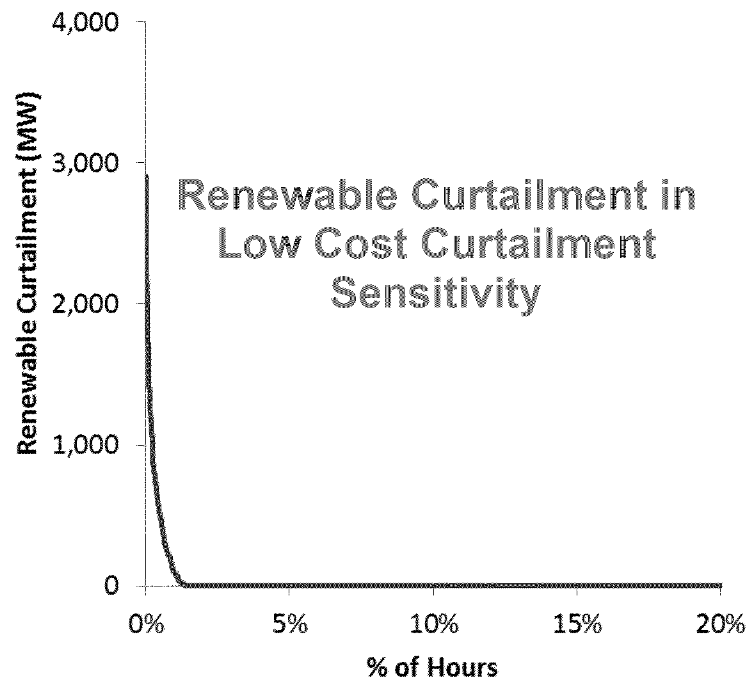
# Economic renewable curtailment

- **Model chose to curtail in 1.5% of the hours when given the option at $250/MWh**
  - 0.1% of RPS energy
- **Additional economic benefits are likely when using startup costs in the unit commitment process**
- **Due to the benefits of allowing curtailment to address flexibility violations, additional focus will be given to this case in the final results**
  - Appropriate societal cost for undelivered RPS needs to be considered



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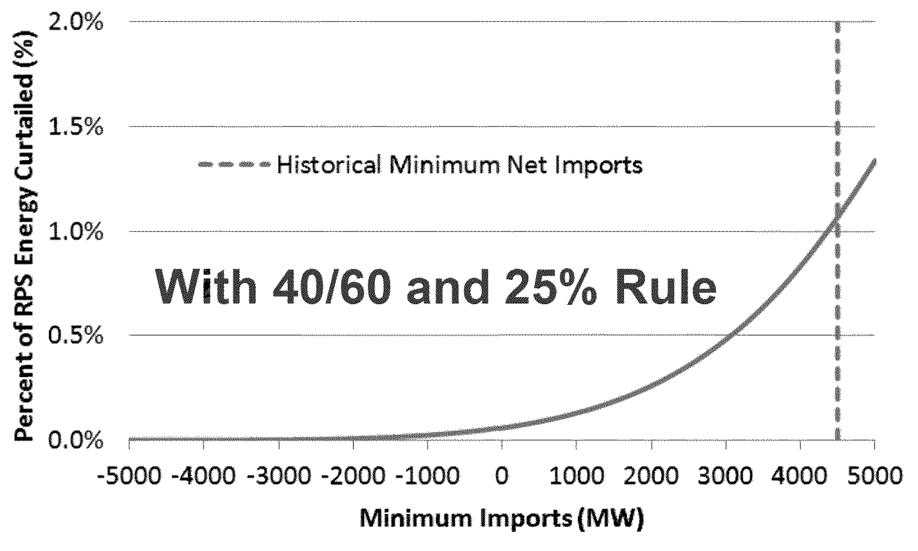
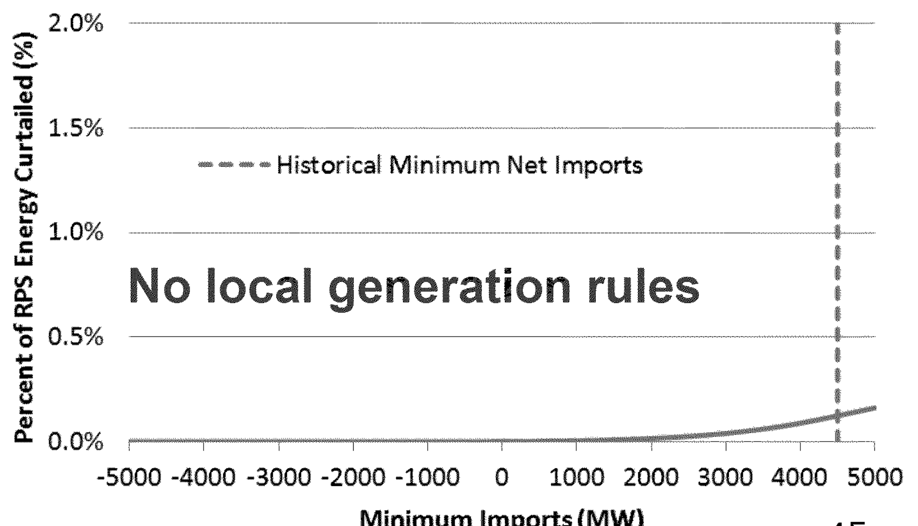
Looking Ahead

# 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**

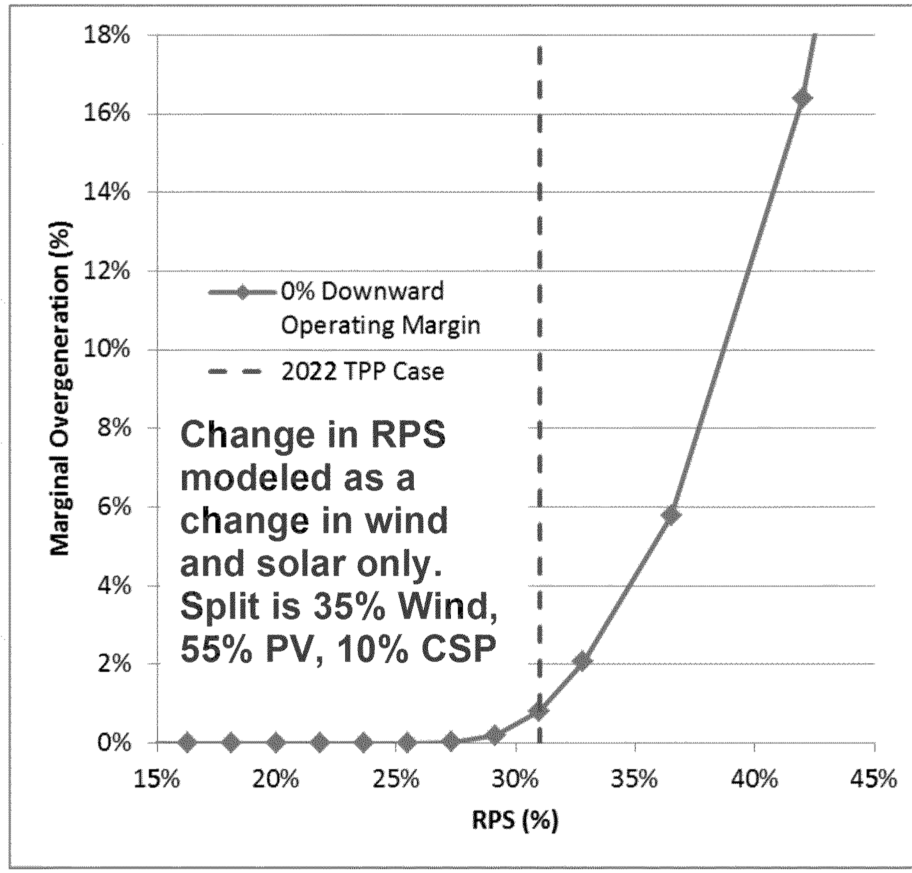
Additional over-generation to provide system flexibility not shown, nor is the mitigating impact of storage



# Marginal over-generation

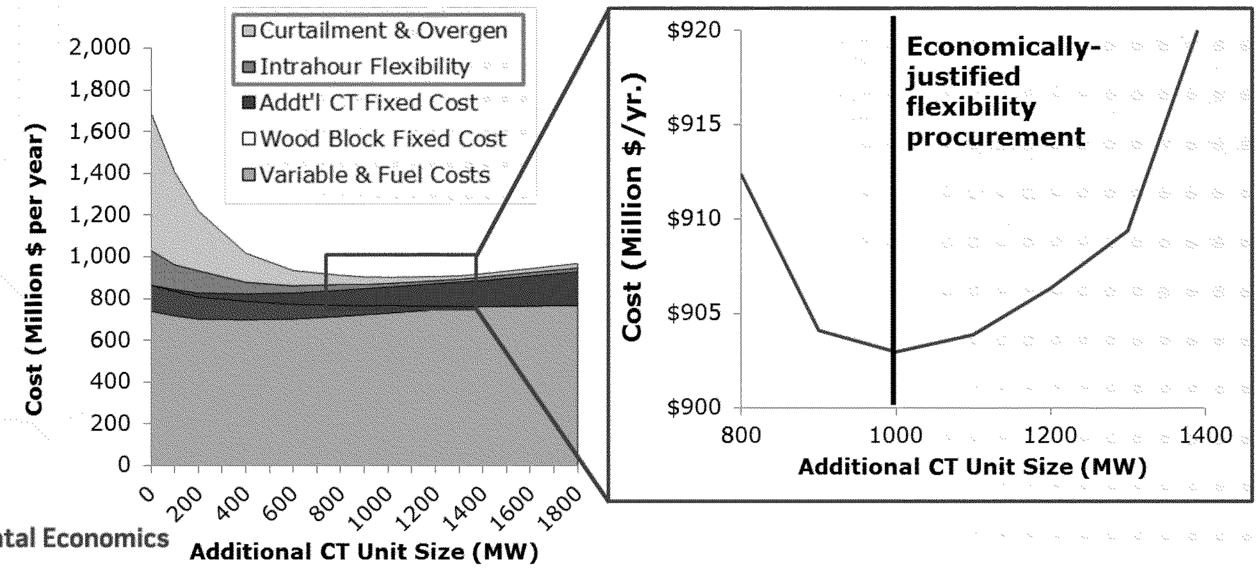
- **Curtailment looks like it becomes an issue starting at around 33% RPS**
- **REFLEX can model the economic effect of renewable integration solutions:**
  - Exports
  - Responsive load
  - Storage
  - Increasing conventional fleet flexibility
  - Increasing renewable portfolio diversity




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

# Conclusions and next steps

- **Preliminary results show significant operational challenges but no unserved energy due to flexibility shortages**
- **Flexible capacity may be justifiable to avoid flexibility related costs (curtailment, unit start-up, CPS violations, etc.)**
- **Next step will be to refine modeling assumptions and cost penalties with additional focus on the economic curtailment sensitivity**



Energy+Environmental Economics

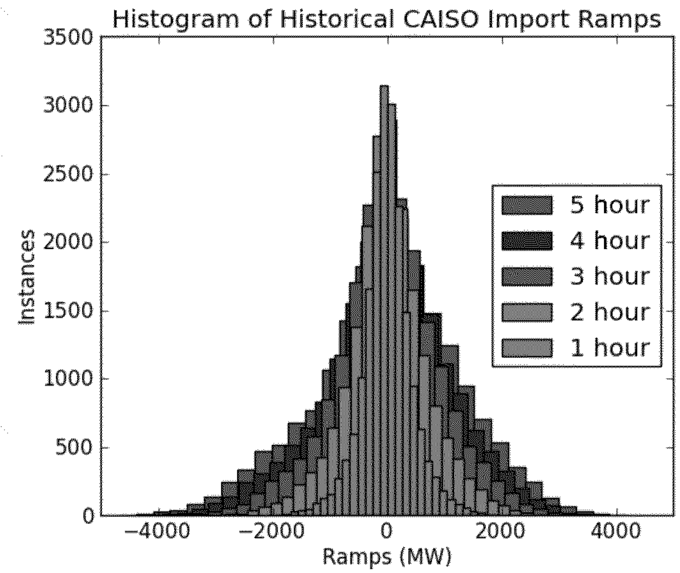
# Thank You!

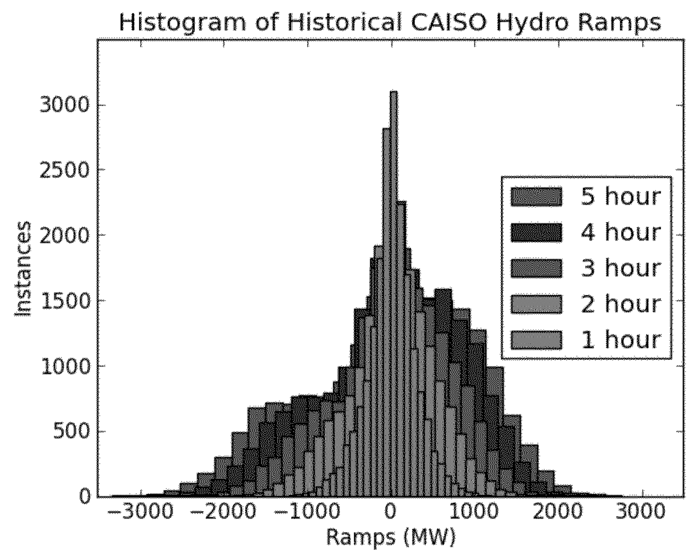
Energy and Environmental Economics, Inc. (E3)
101 Montgomery Street, Suite 1600
San Francisco, CA 94104
Tel 415-391-5100
Web http://www.ethree.com

Arne Olson, Partner (arne@ethree.com)
Ryan Jones, Senior Associate (ryan.jones@ethree.com)
Dr. Elaine Hart, Consultant (elaine.hart@ethree.com)
Jack Moore, Senior Consultant (jack@ethree.com)
Dr. Ren Orans, Managing Partner (ren@ethree.com)

# Stochastic Treatment of Hydro and Imports

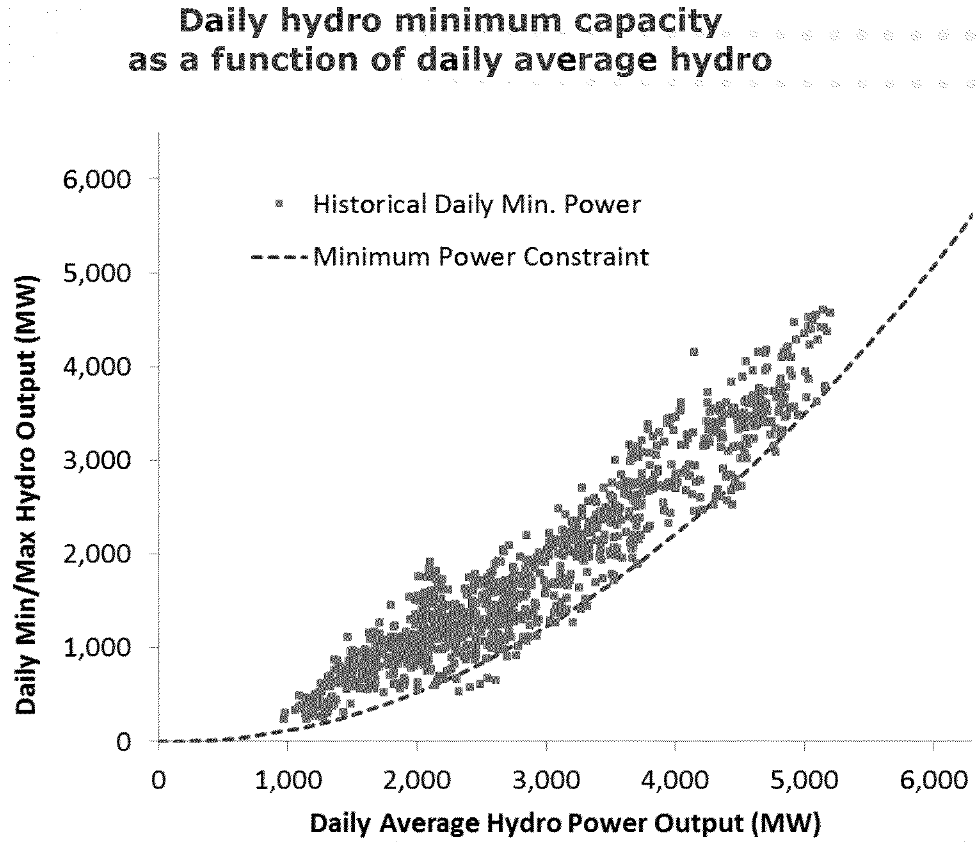
- **Hydro and imports are adjusted by unit commitment and dispatch engine**
- **Subject to multi-hour ramping constraints developed from historical record (e.g., 99$^{th}$ percentile)**
- **Min and max values to further bound the range of values**



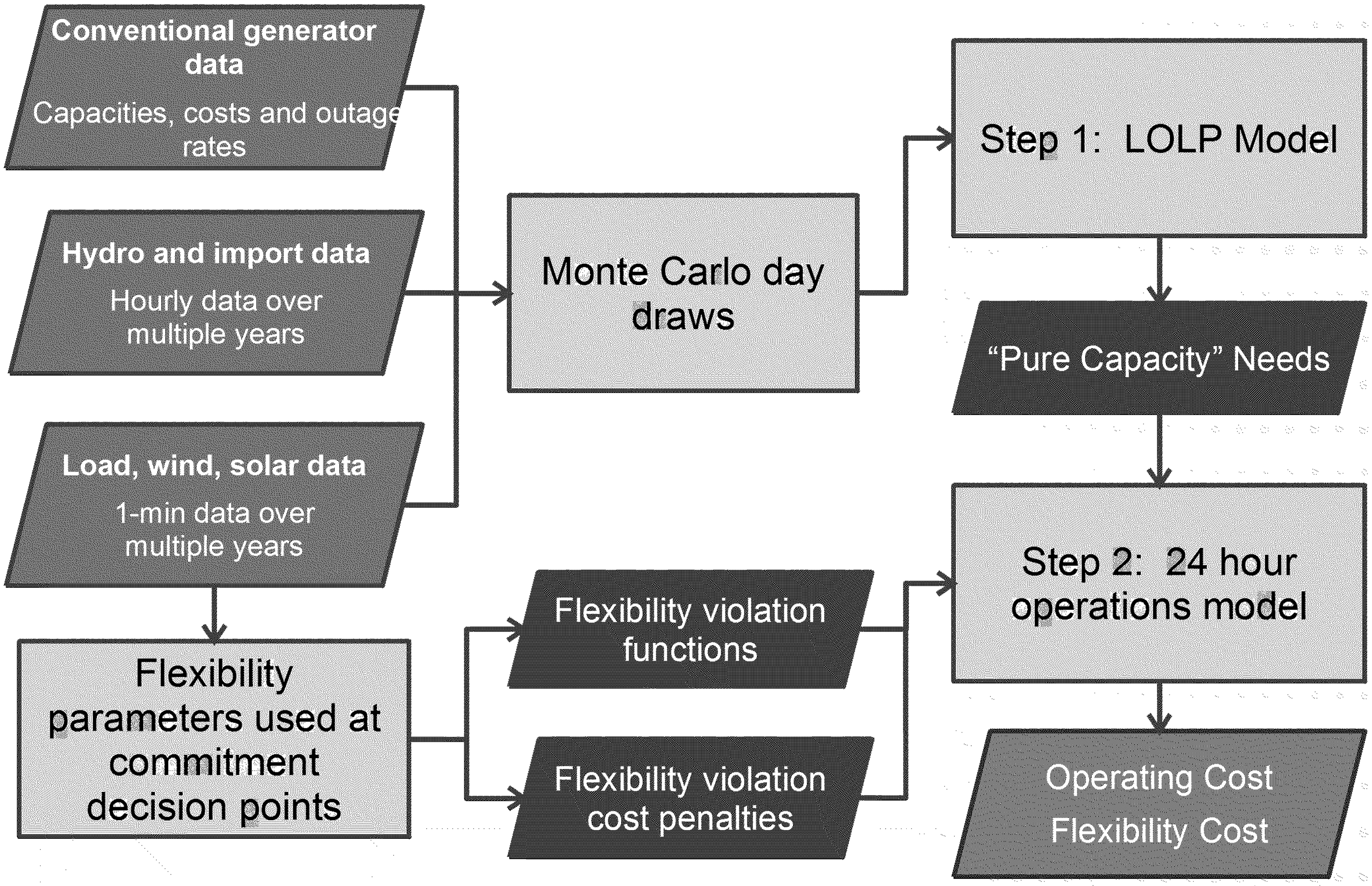



# Stochastic Treatment of Hydro and Imports

- **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



# High-level Model Organization



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# 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

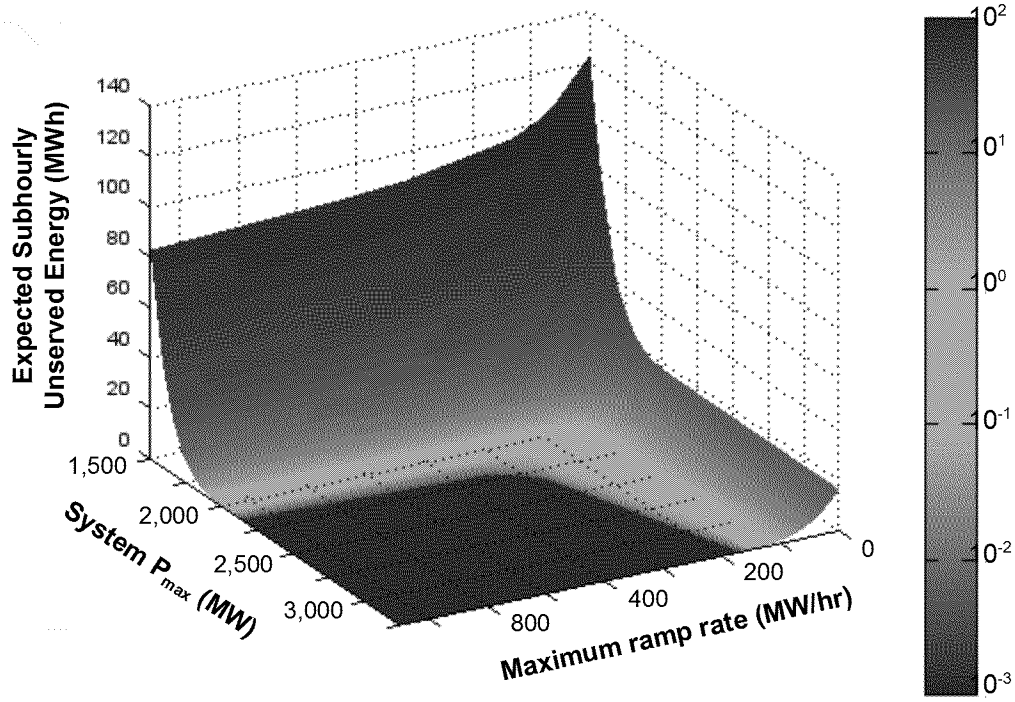
- **REFLEX makes unit commitment decisions at specified intervals**
  - Day-ahead, 4 hour-ahead, 1 hour-ahead
  - Ramping policy functions incorporated into commitment decisions
- **Ramping policy functions account for both forecast error and net load variability**
  - Forecast error incorporated through 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



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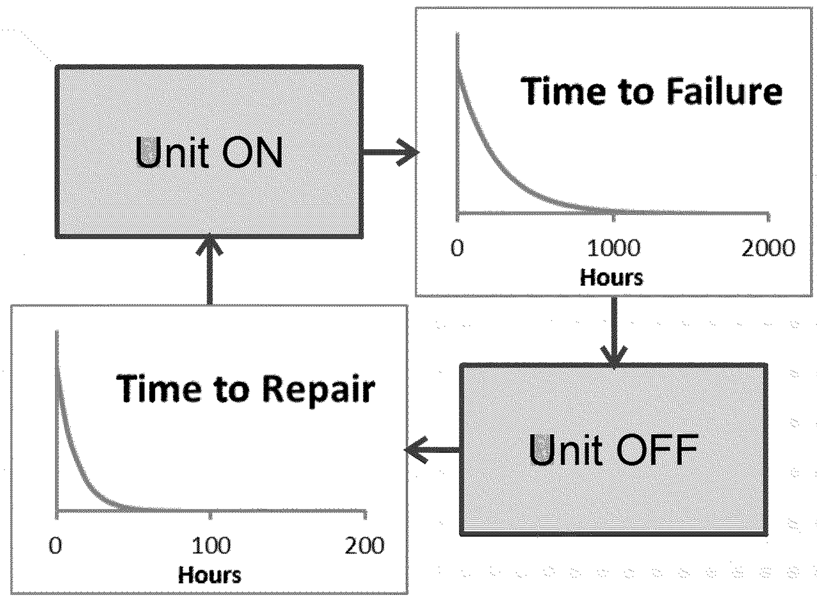
# Forced outage and Maintenance

- **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 |