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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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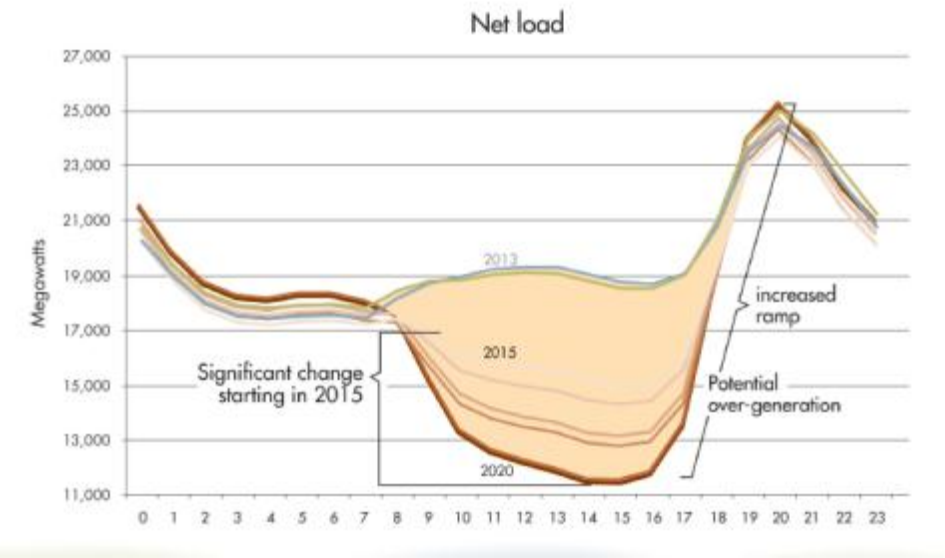
REFLEX METHODOLOGY & ASSUMPTIONS

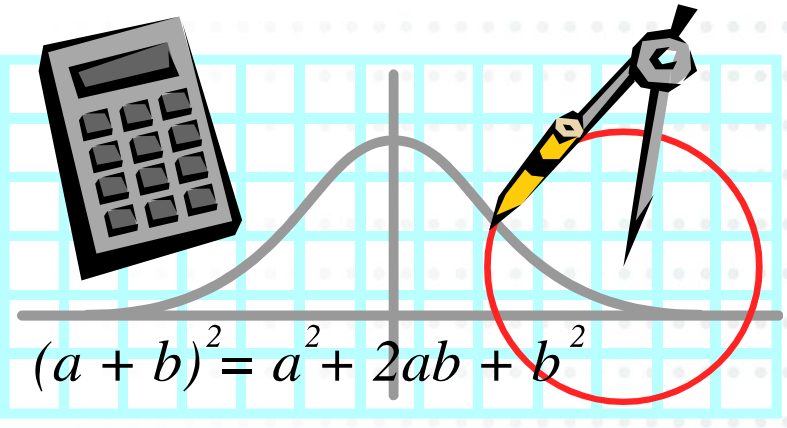
Defining the Problem

- **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?

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

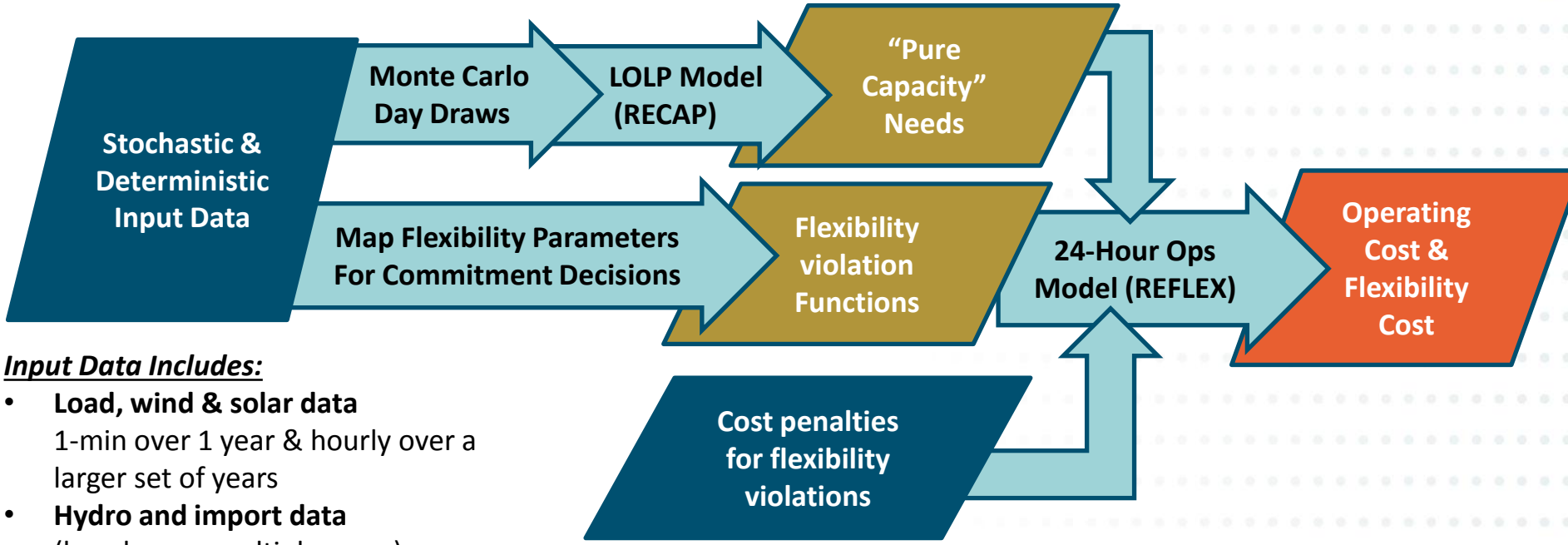
REFLEX is an Extension of Conventional Capacity Planning

- **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



Input Data Includes:

- **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***)

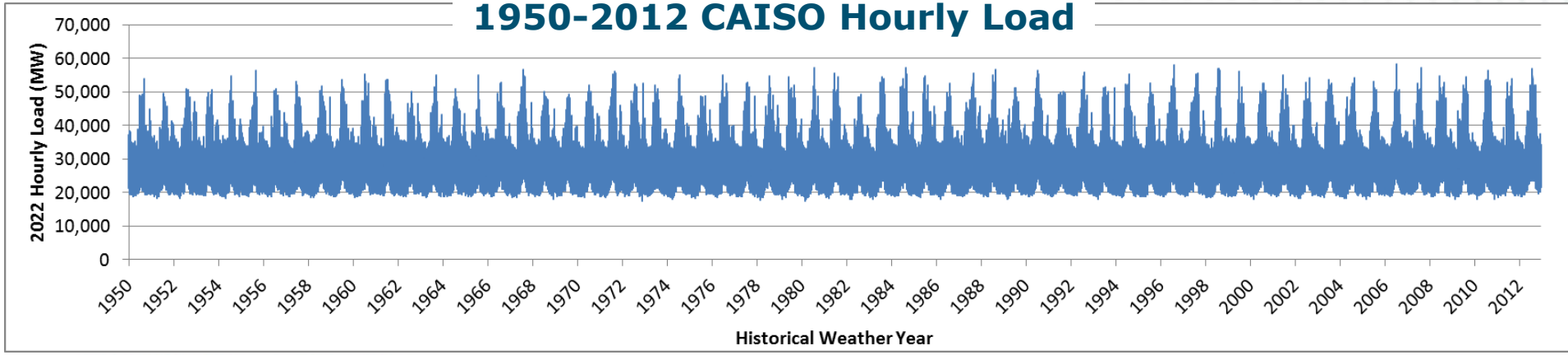
User-defined Cost per MWh for:

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

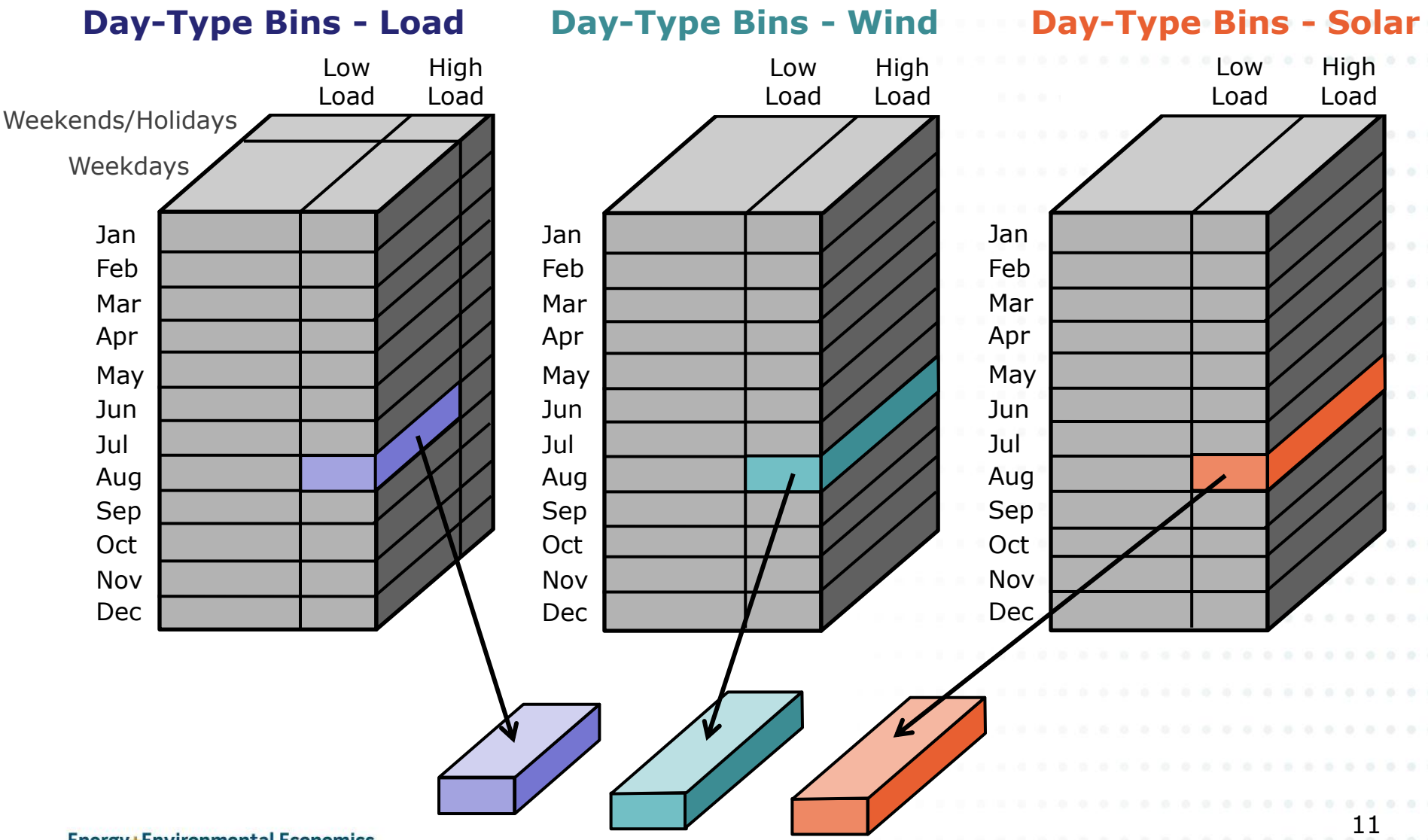
+ Parallel calculation of conventional capacity needs & flexibility impact for use in 24-hour operations model

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"

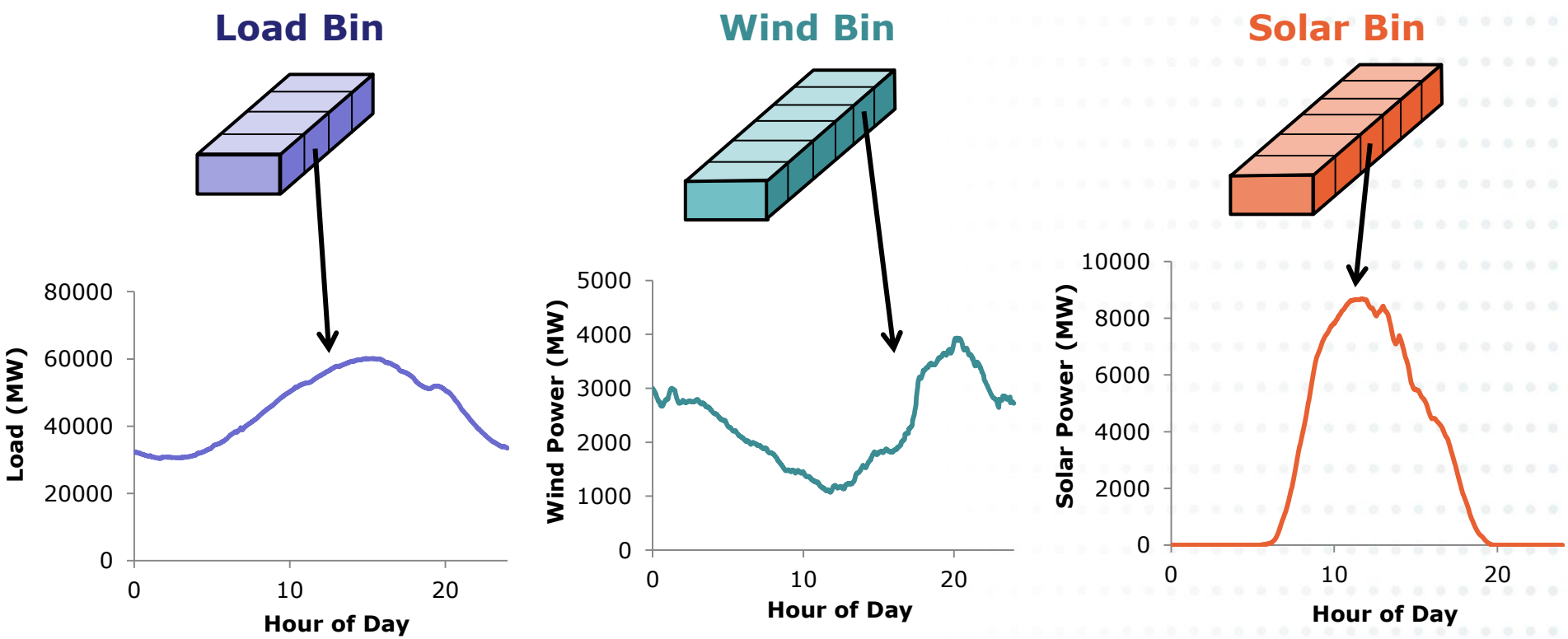


Example Draw: High Load Weekday in August



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.

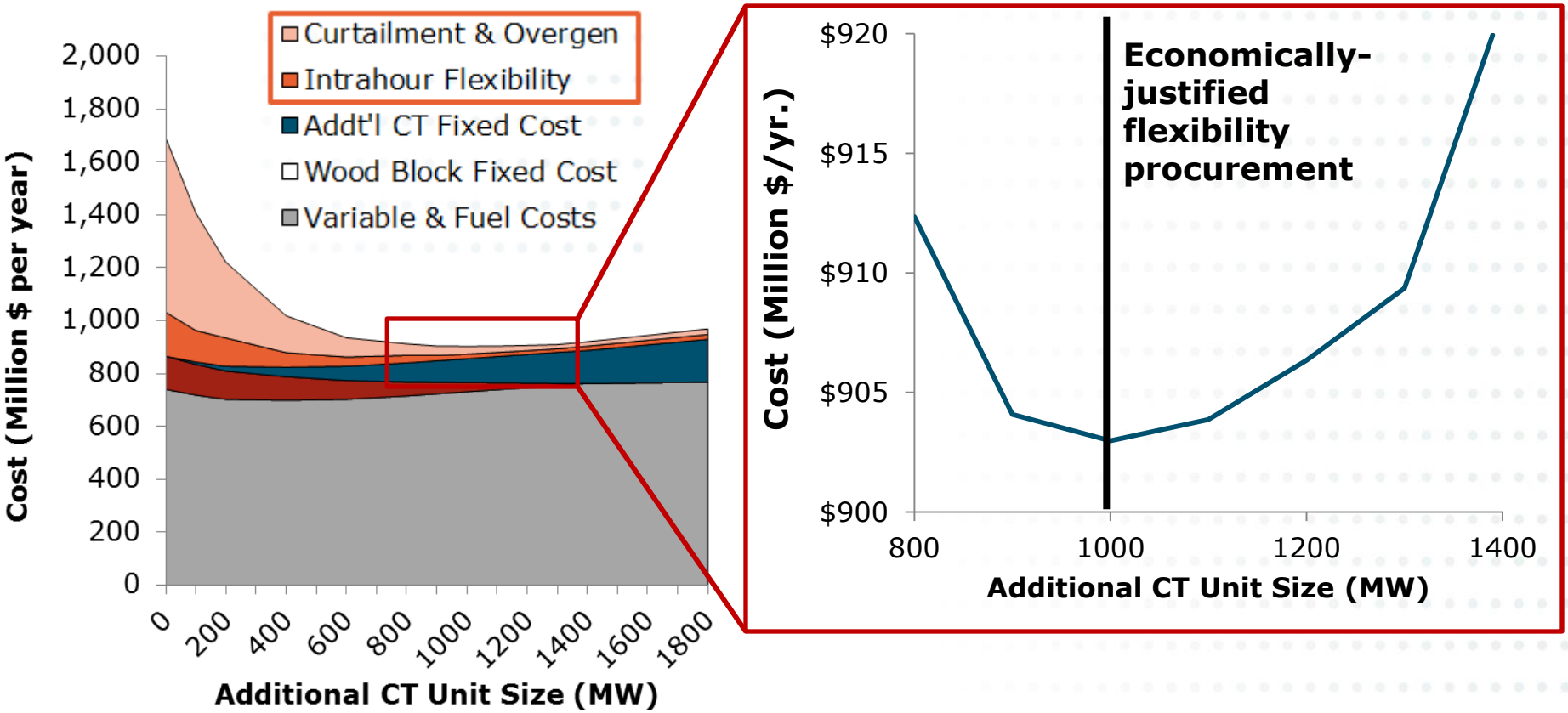


Load Following Needs

- **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: 3 years (wind) 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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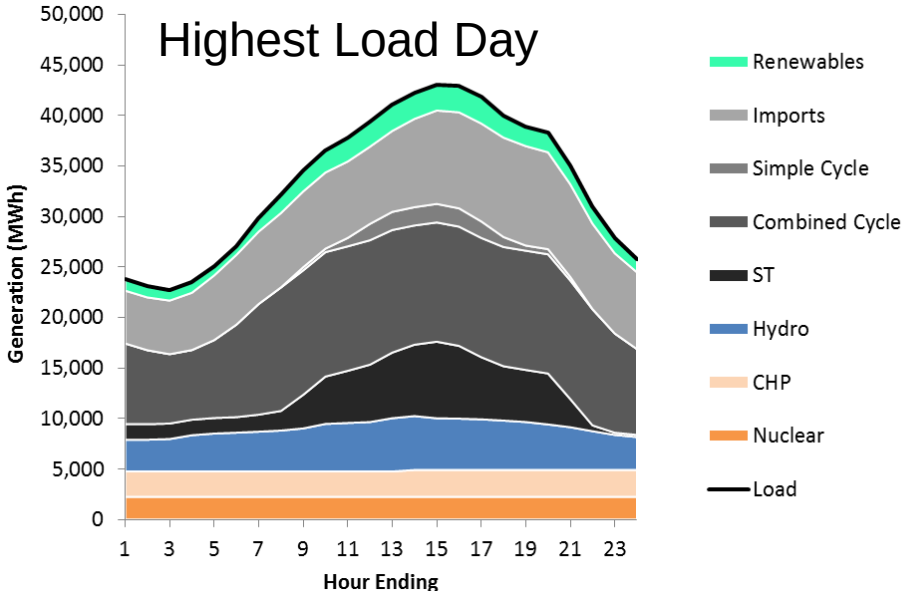
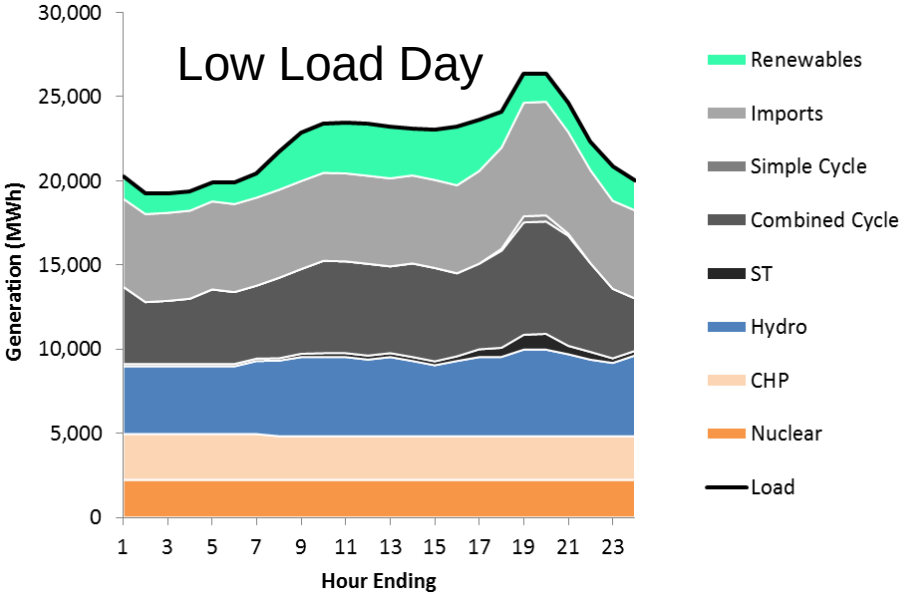
2012 CASE

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**



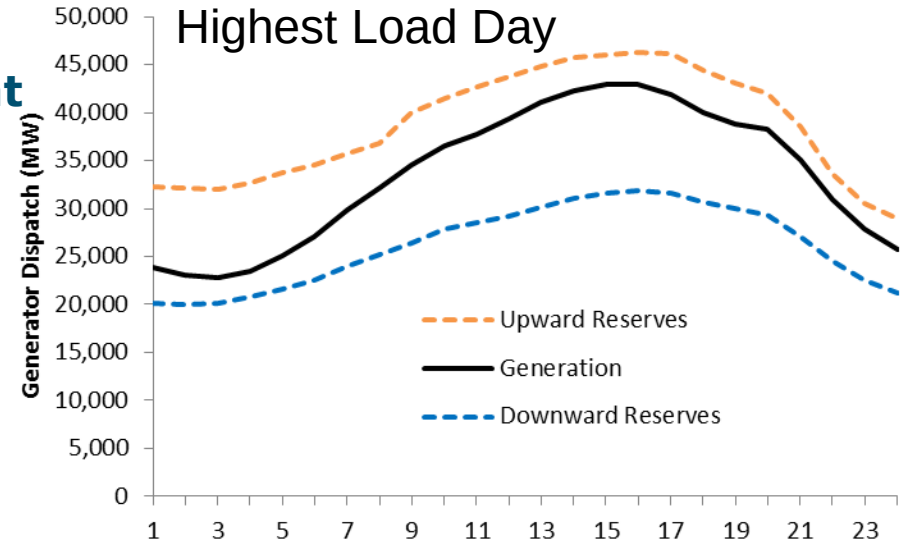


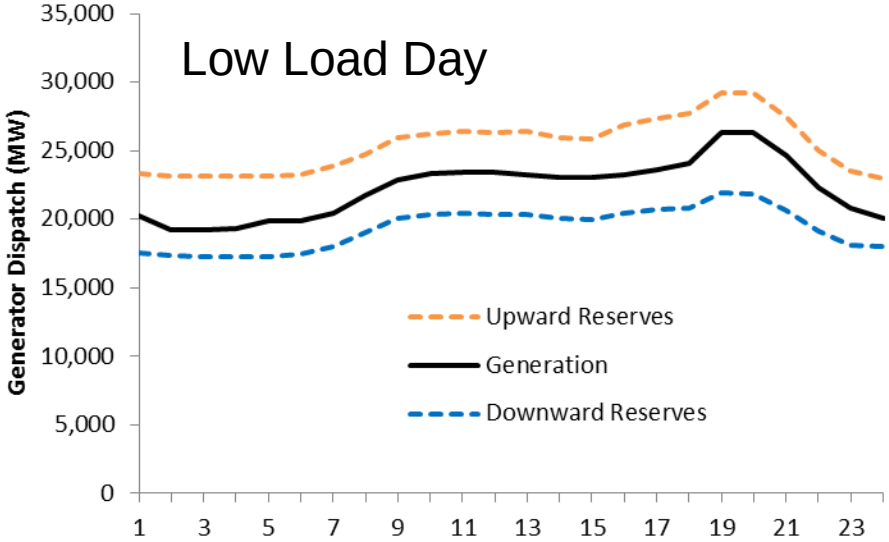
REFLEX Load Following Reserves response surface

- **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

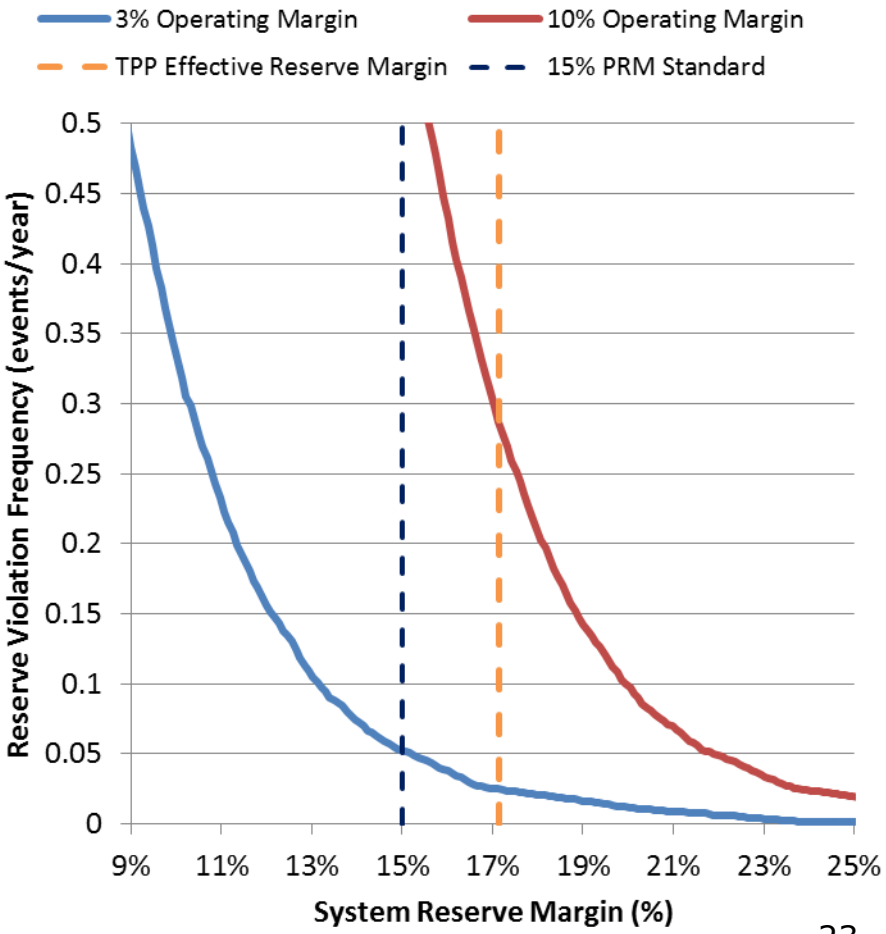
- E3 replicating TPP case does not include SONGS
- PRM is calculated as total ELCC divided by 1-in-2 peak load, minus 1
- CPUC scenario tool analysis of the case shows a 15.1% PRM
- There may be a discrepancy with generator stack modeled in PLEXOS

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

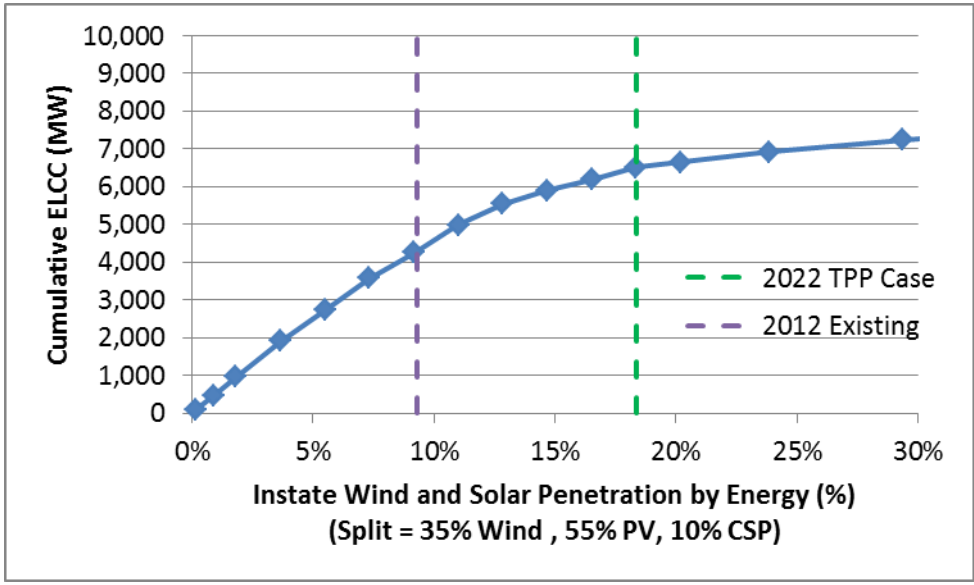
3% spinning reserves + 3% non-spinning reserves + 3% load-following + 1% regulation = 10% operating margin

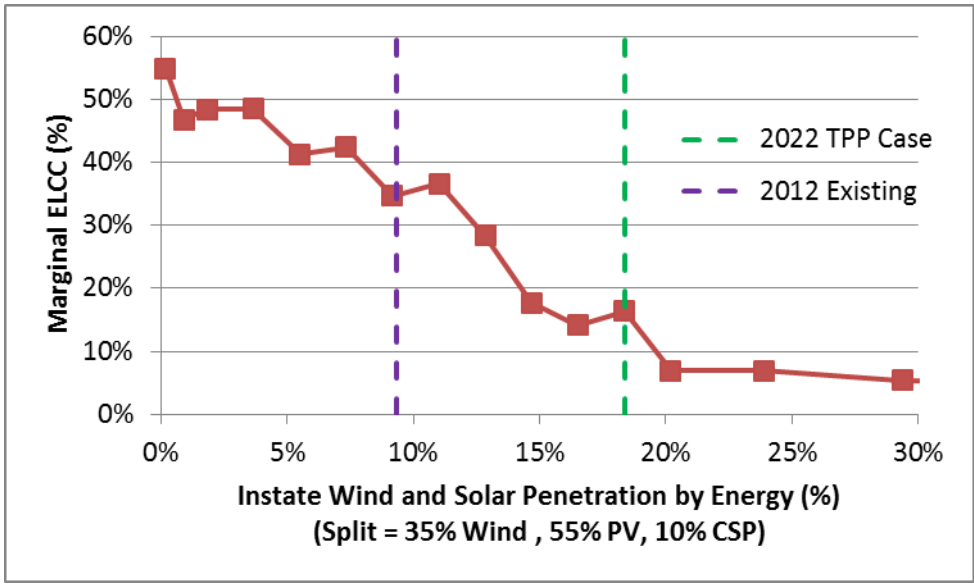


Renewable ELCC

- **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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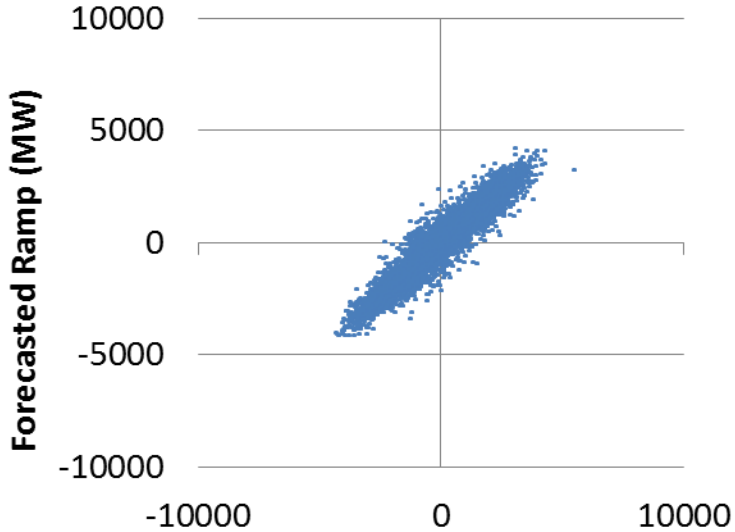
NATURE OF FLEXIBILITY NEEDS

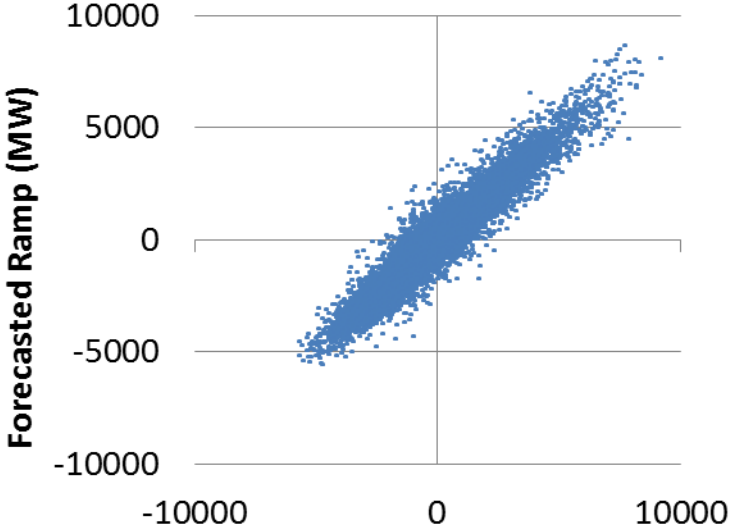
Net Load Ramps Increase Between 2012 and 2022

2012 Case

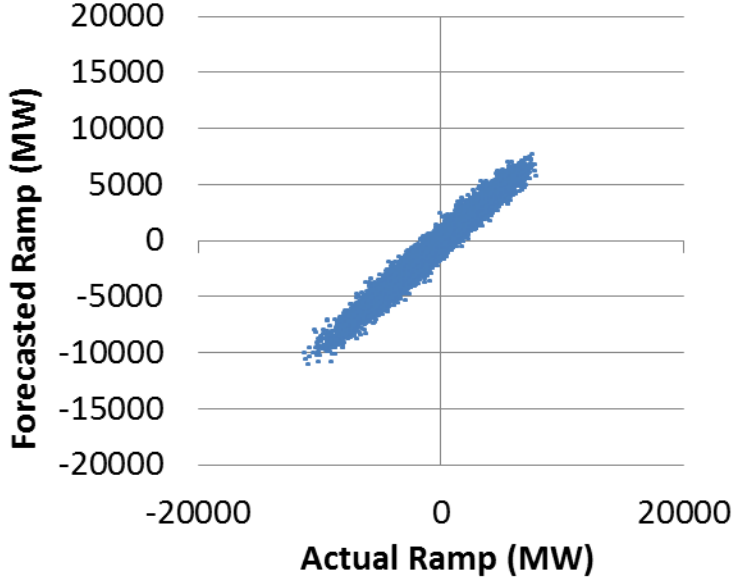
2022 Replicating TPP Case

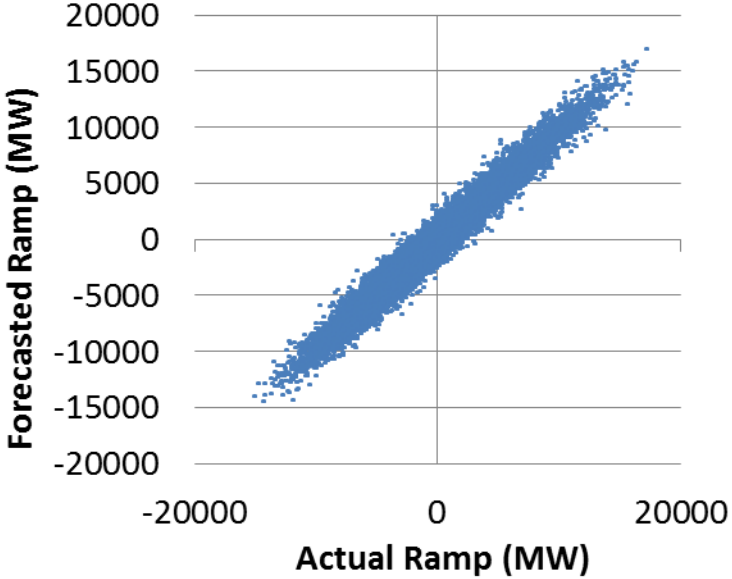
1 Hour Ramp





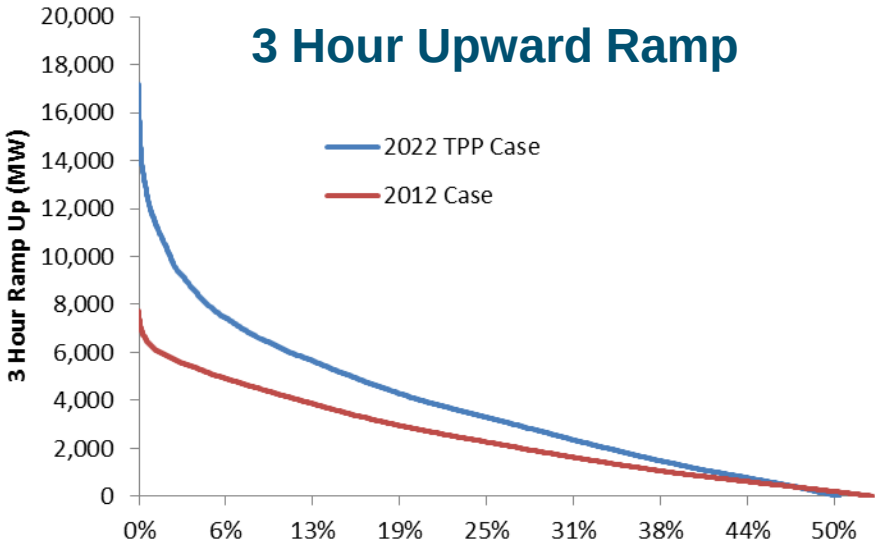
3 Hour Ramp

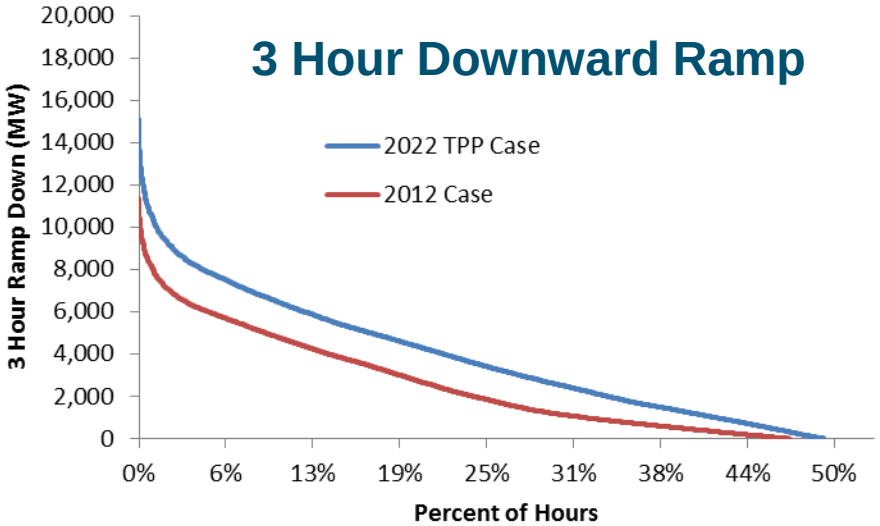




Ramp duration curves

- **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; 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)~~ ~~SDG&E: 25% local~~
Fuel & AB32 Permit Prices for 2022 Scenario	$4.3/MMBtu $24/metric ton CO2 (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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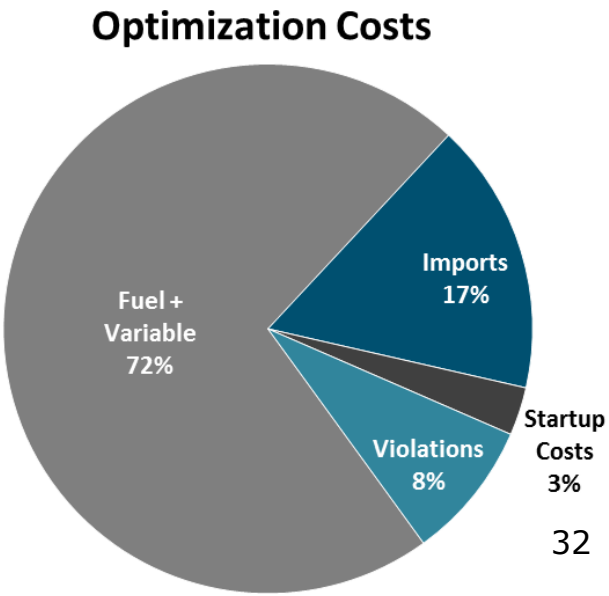
Base Case Results
High cost over-generation

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**

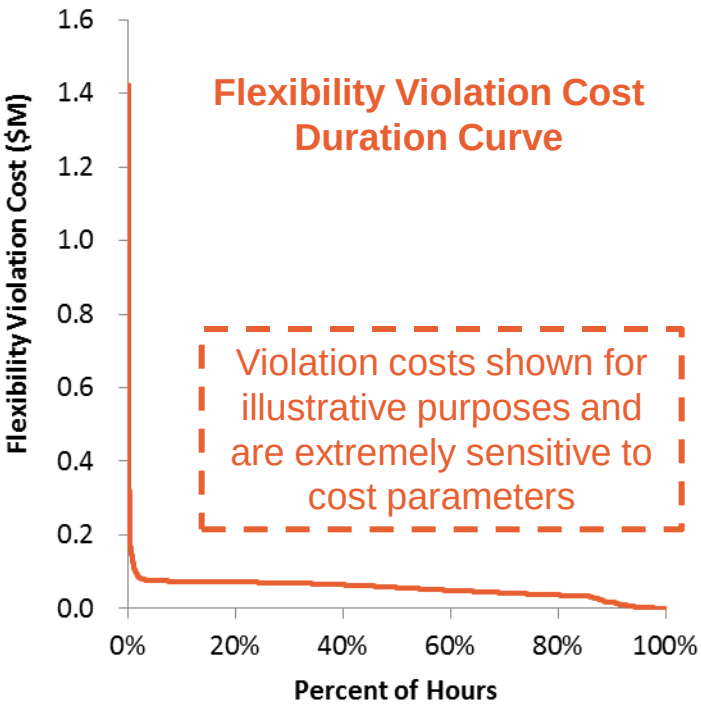
Violation costs shown for illustrative purposes and are extremely sensitive to cost parameters

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



Interpreting flexibility violation costs

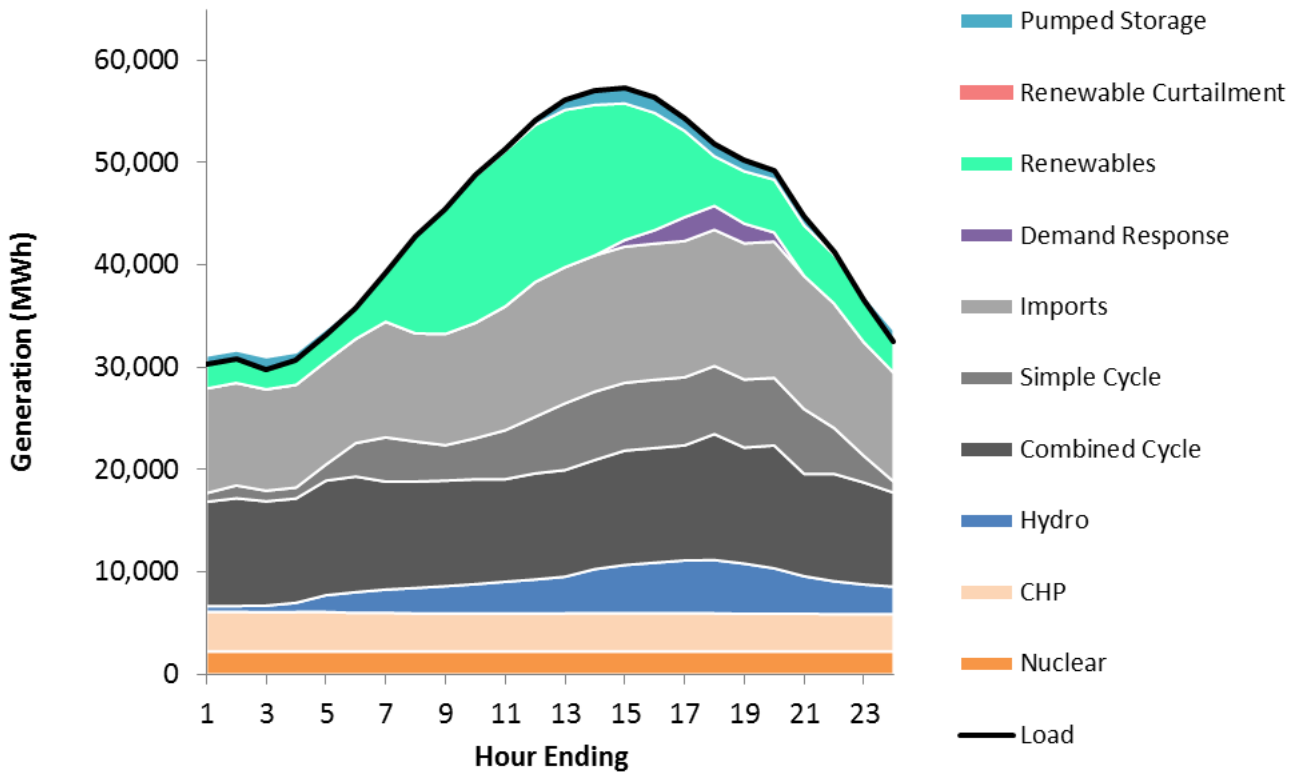
- **Expected flexibility violations of $475 MM/year are a significant cost**
  - May be possible to reduce total costs by procuring new resources
- **As noted, significant additional work is needed to determine appropriate penalties to translate violations into costs**
  - What is the impact of a violation?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



Highest net load day

+ September, weekday, high-load draw

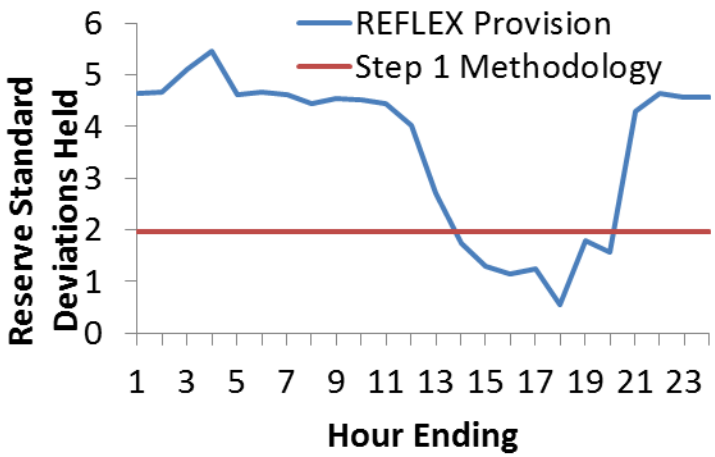
- All units and DR dispatched
- Highest net load occurring in September is due to the limited set of random draws, nothing fundamental

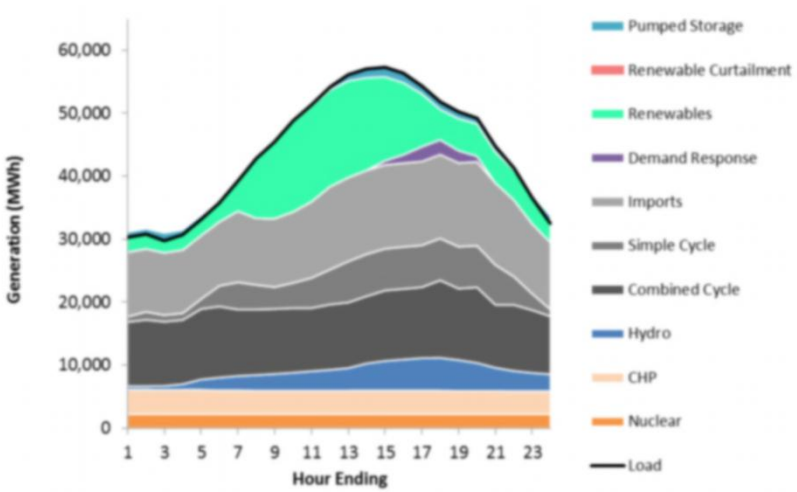


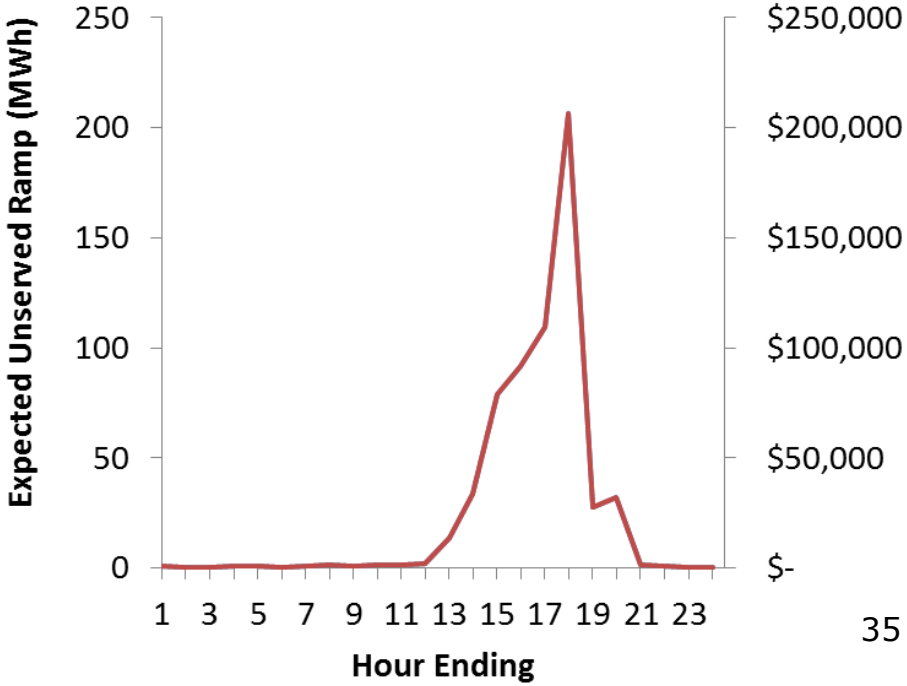
Draw 185

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

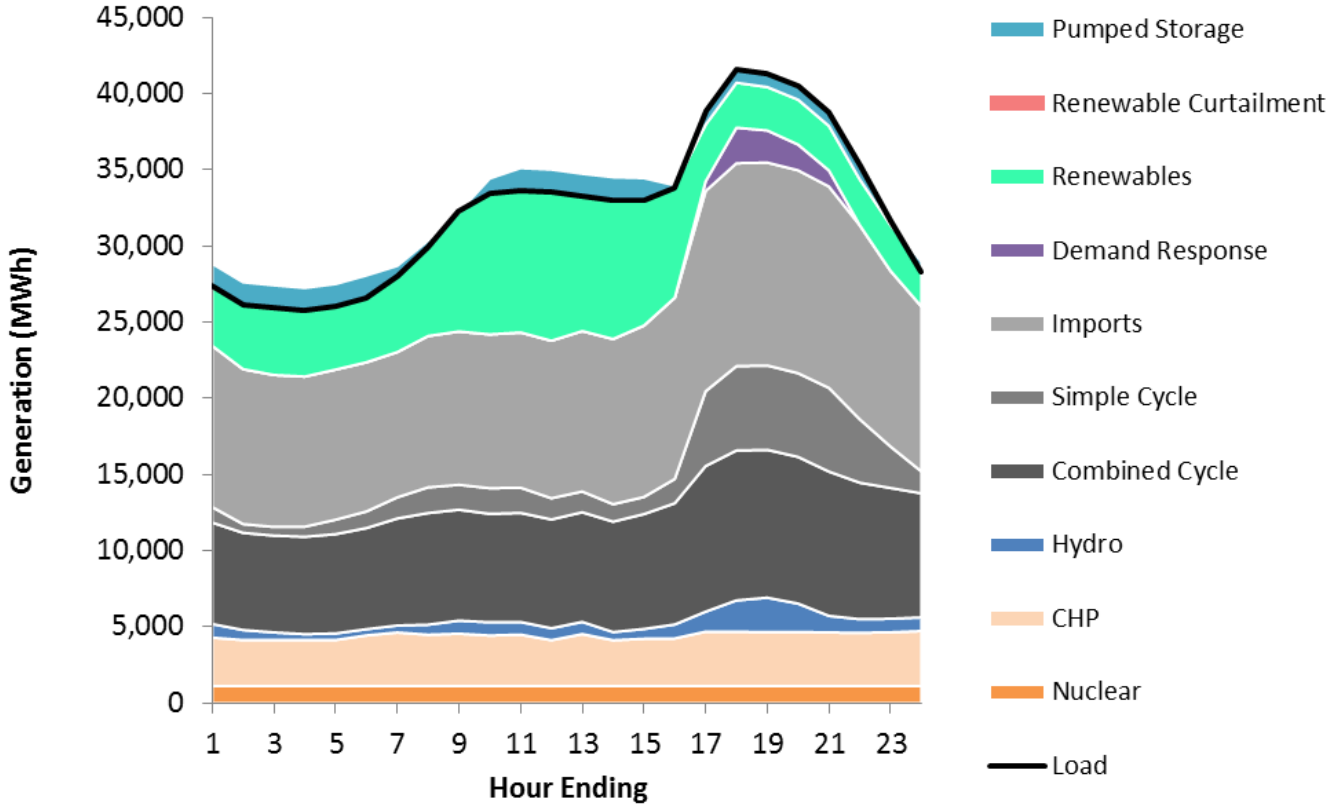






Day with the largest net load ramp

- **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



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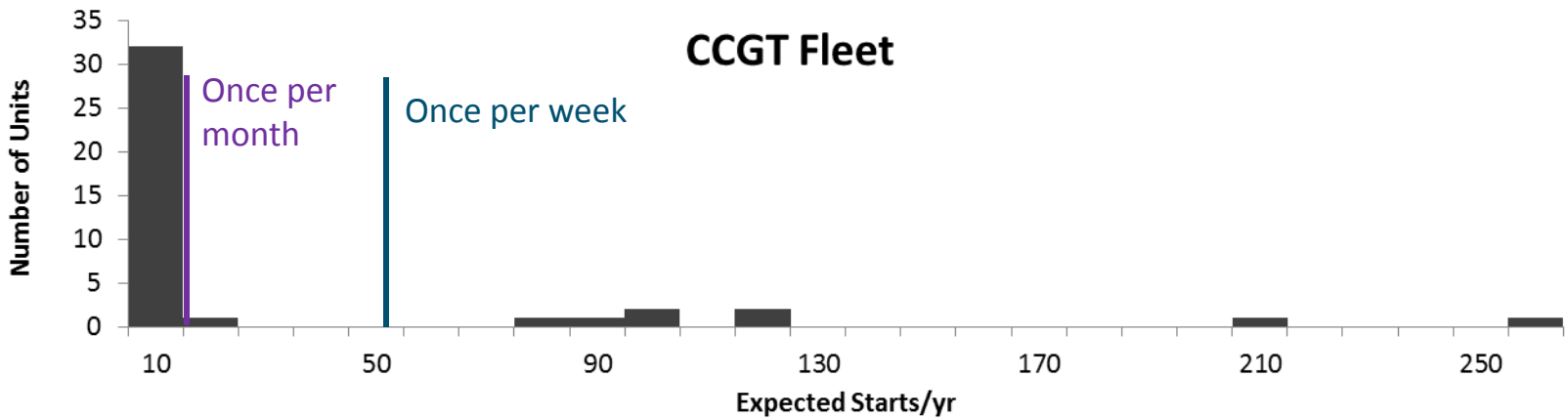
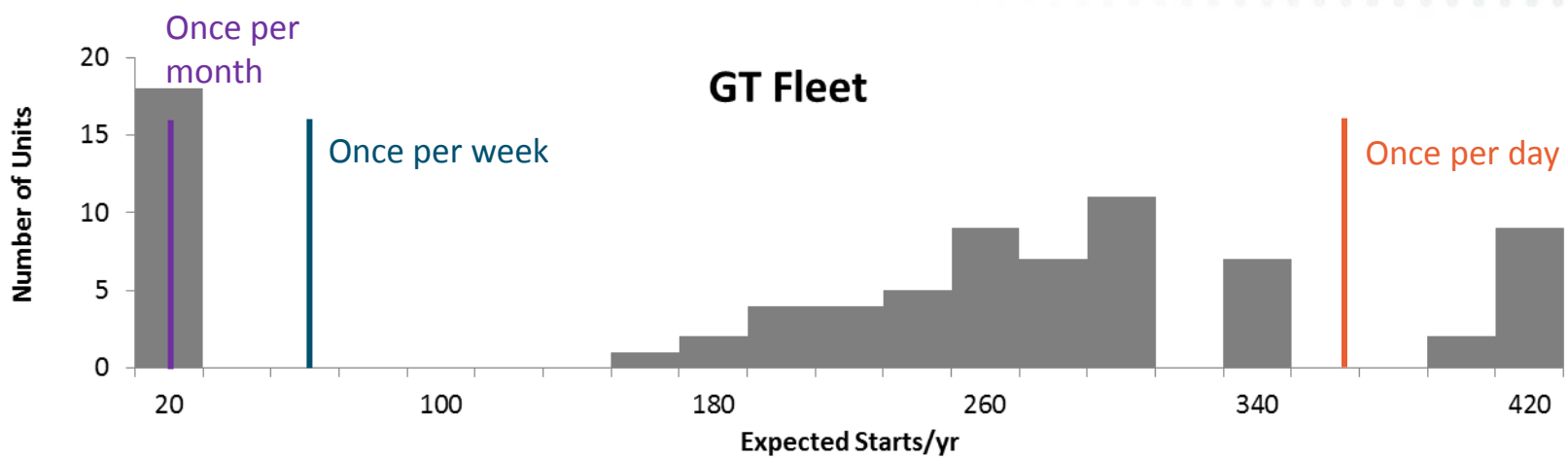
Draw 359

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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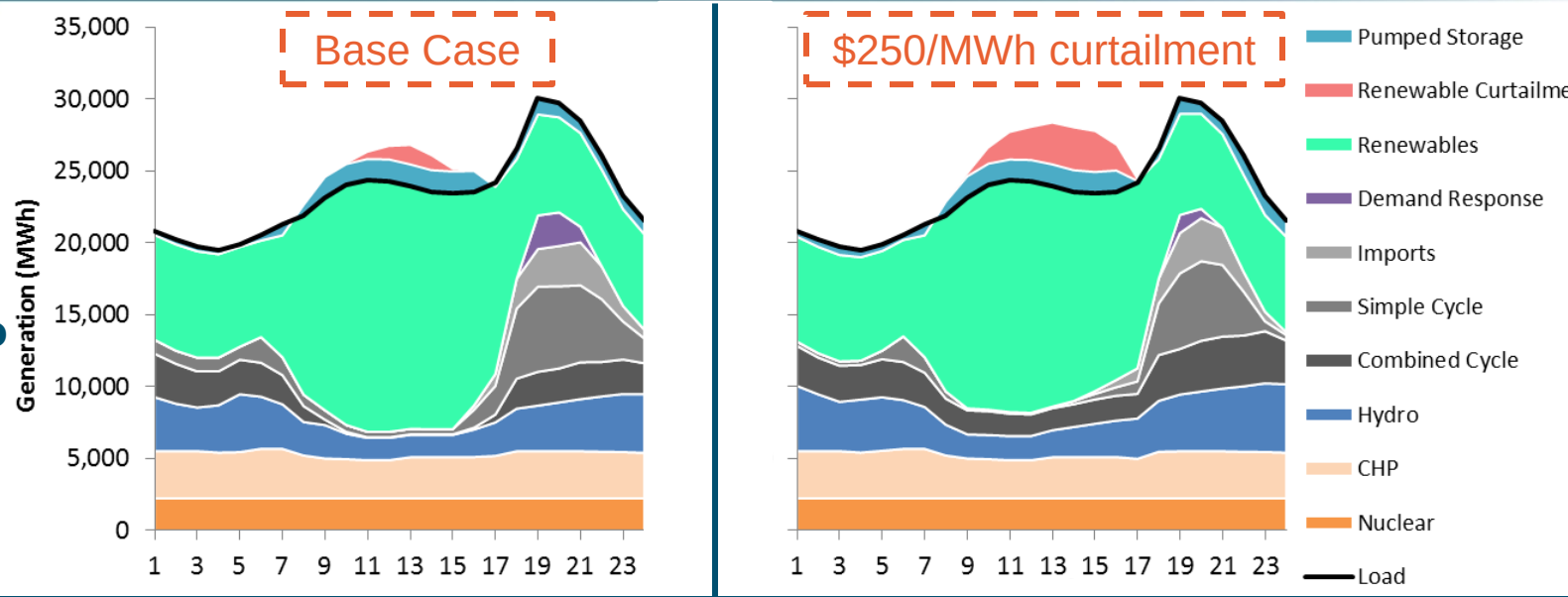
Base Case Results $250/MWh Curtailment Sensitivity

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

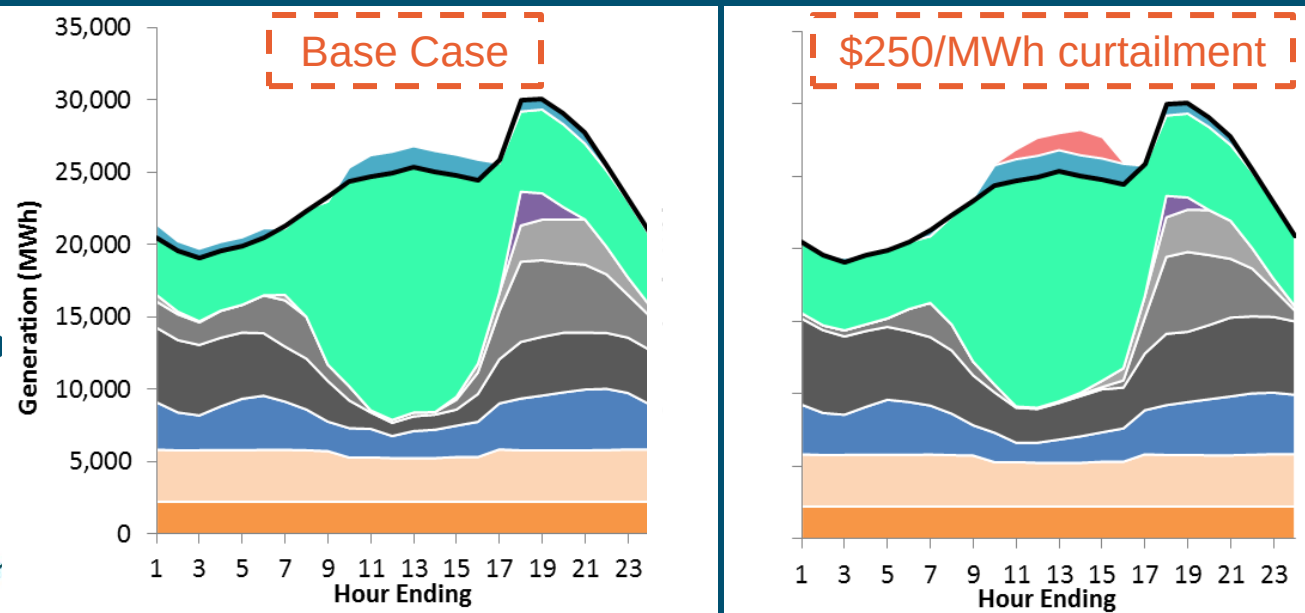
Low-load, high hydro, high solar draws

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



Draw 279

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



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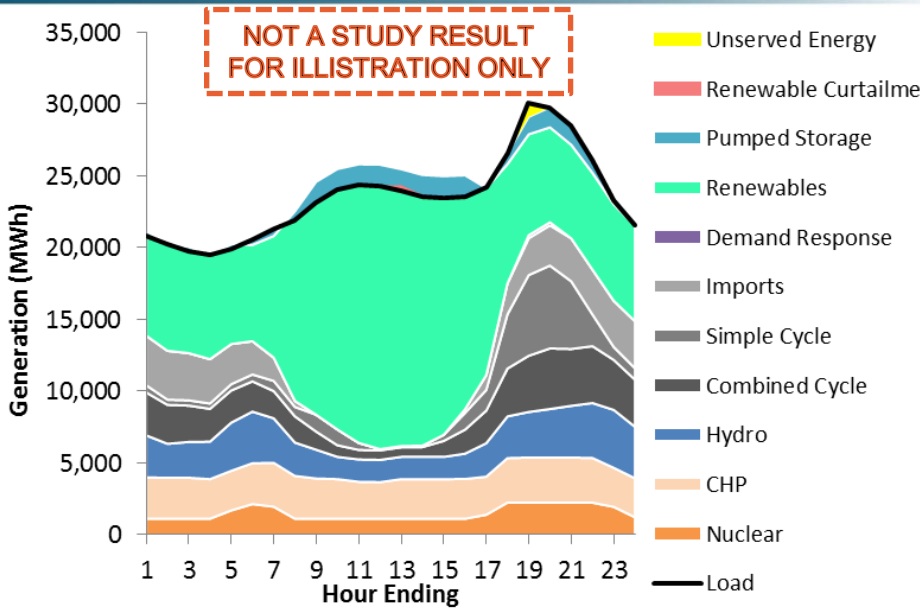
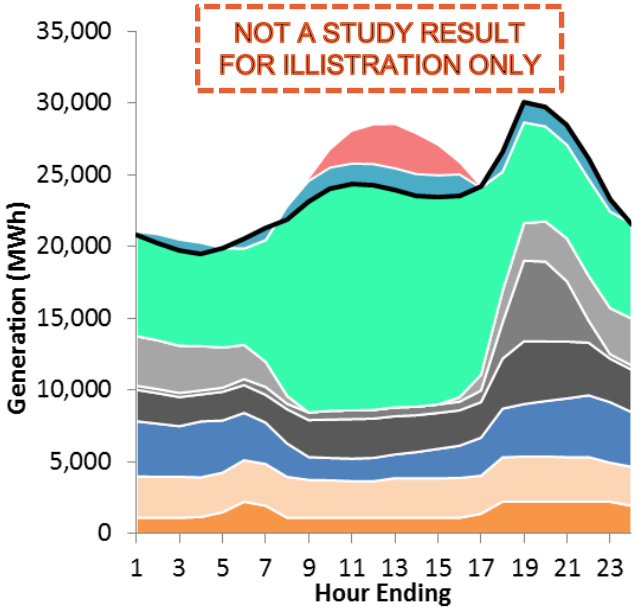
Draw 262

Using over-generation to preserve ramping capability

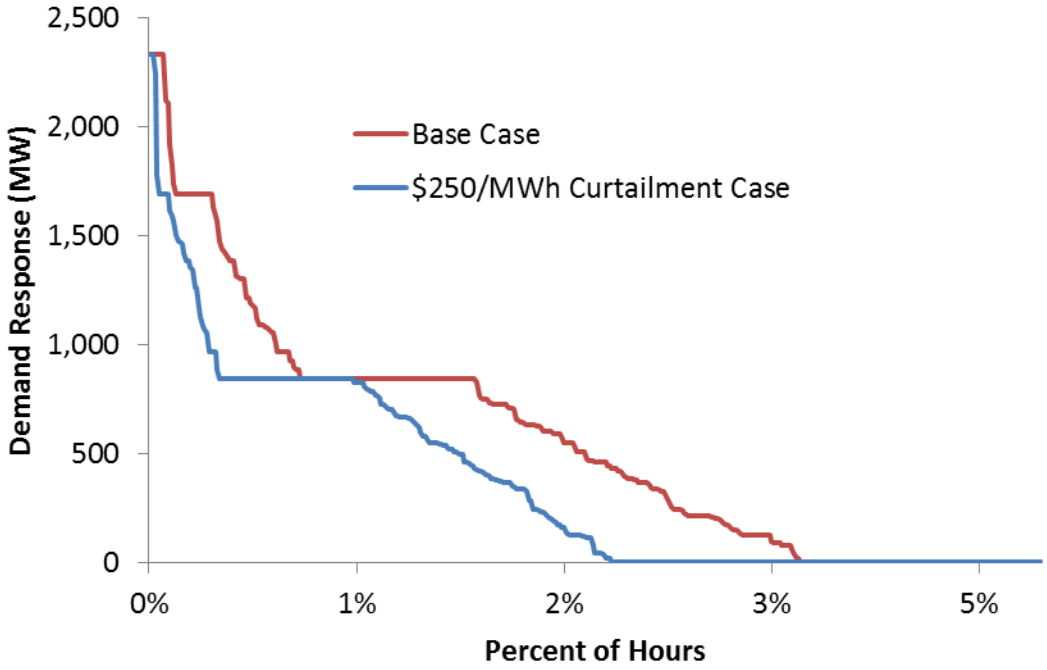
- **Turning thermal resources off to make space for renewables can create upward ramping challenges when renewables production drops**
  - Unserved energy shown in example day
- **Over-generation allows slow-start thermal resources to remain online to meet subsequent ramps**
- **Operational strategy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





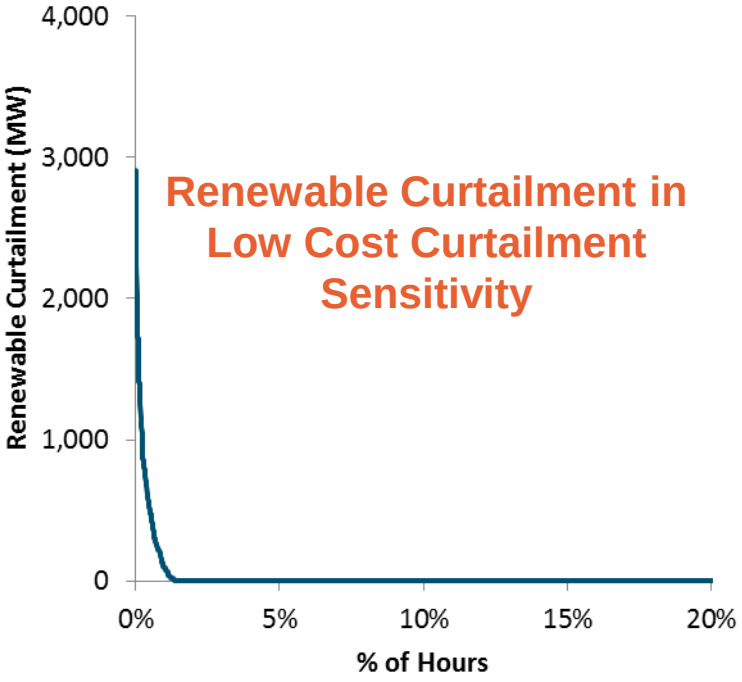
Demand response

- 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



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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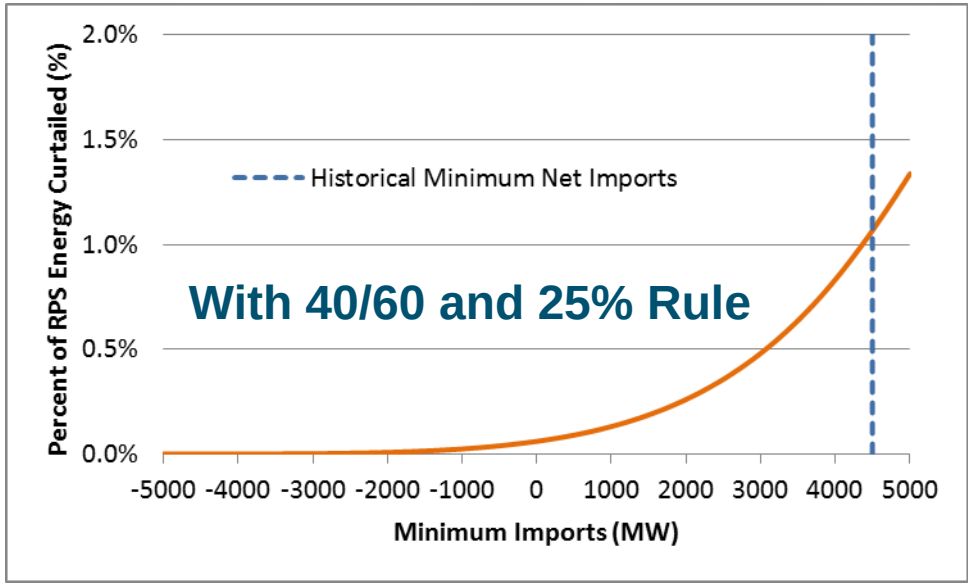
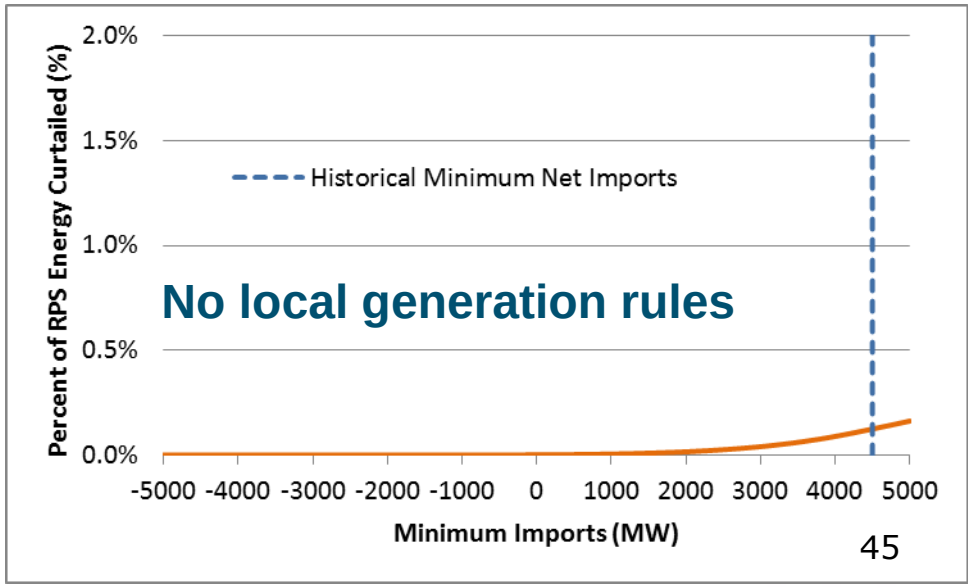
Looking Ahead

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**

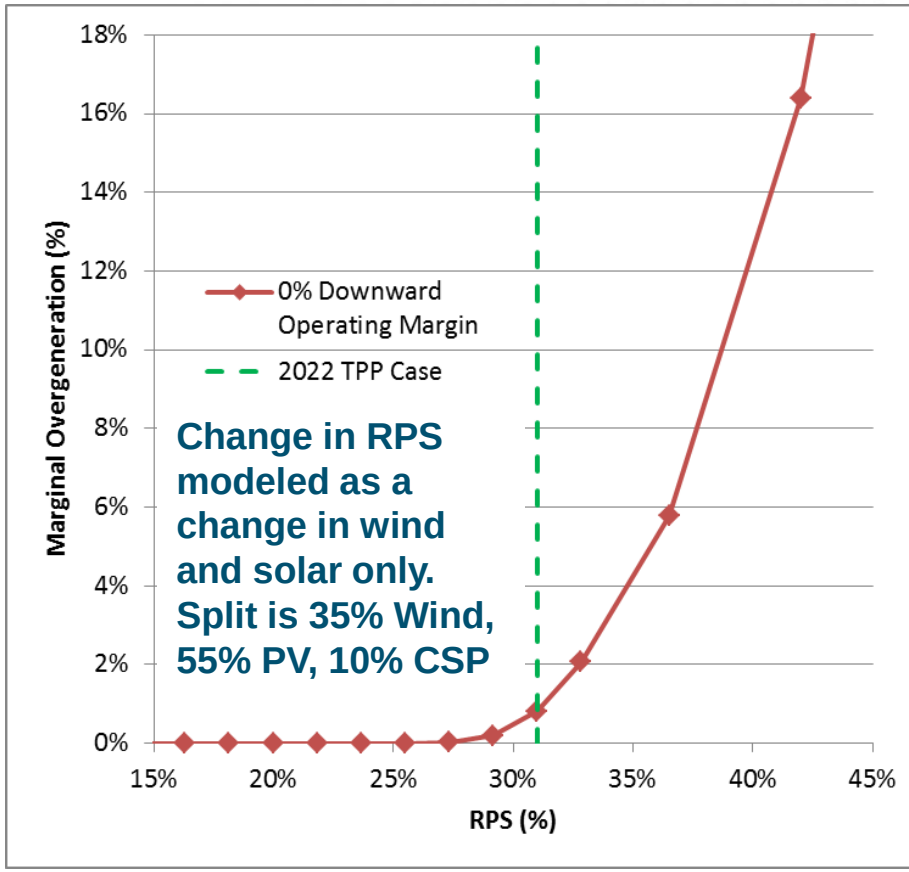
Additional over-generation to provide system flexibility not shown, nor is the mitigating impact of storage





Marginal over-generation

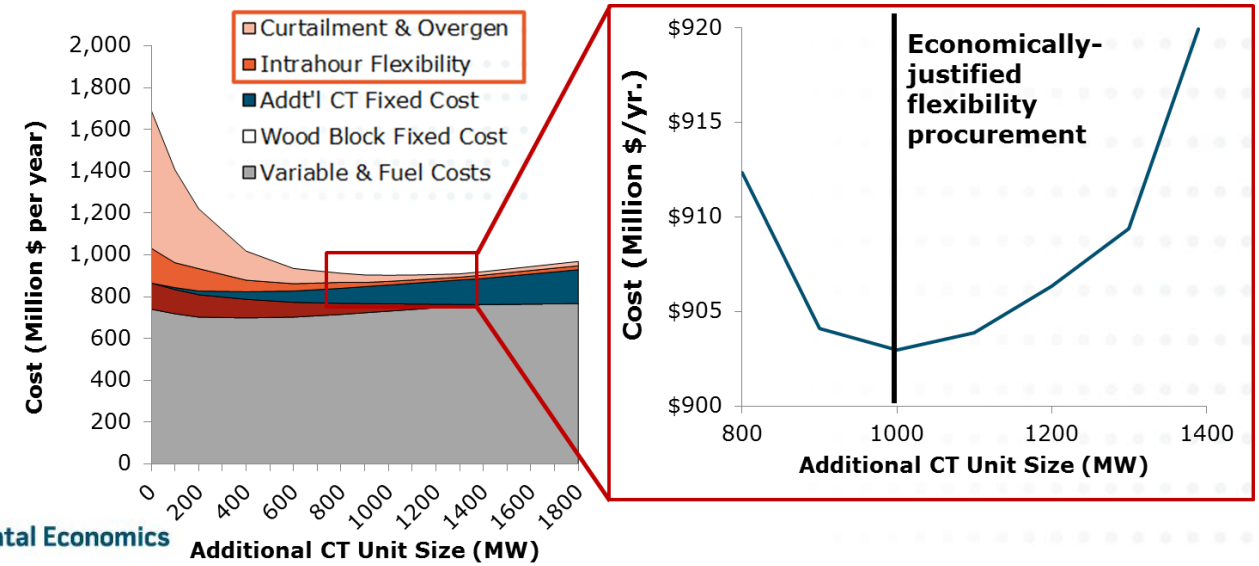
- **Curtailment looks like it becomes an issue starting at around 33% RPS**
- **REFLEX can model the economic effect of renewable integration solutions:**
  - Exports
  - Responsive load
  - Storage
  - Increasing conventional fleet flexibility
  - Increasing renewable portfolio diversity



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



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Thank You!

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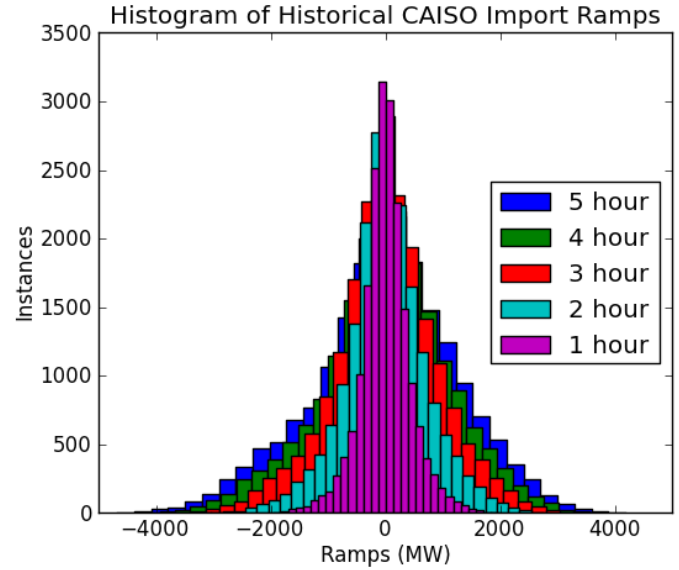
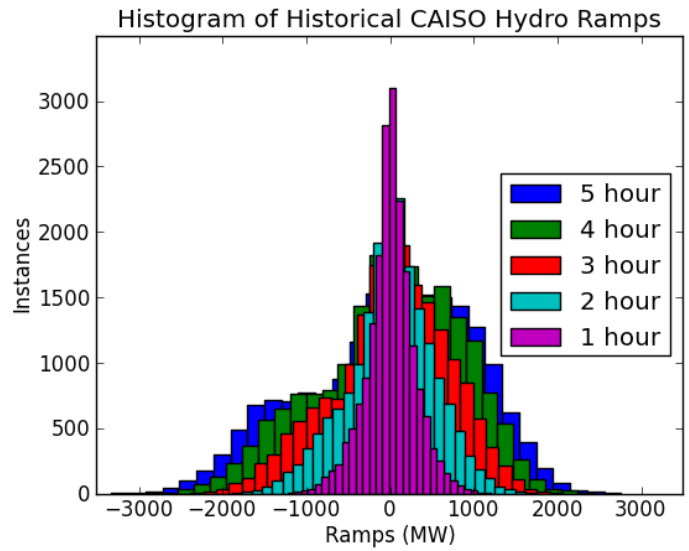
Stochastic Treatment of Hydro and Imports

- 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



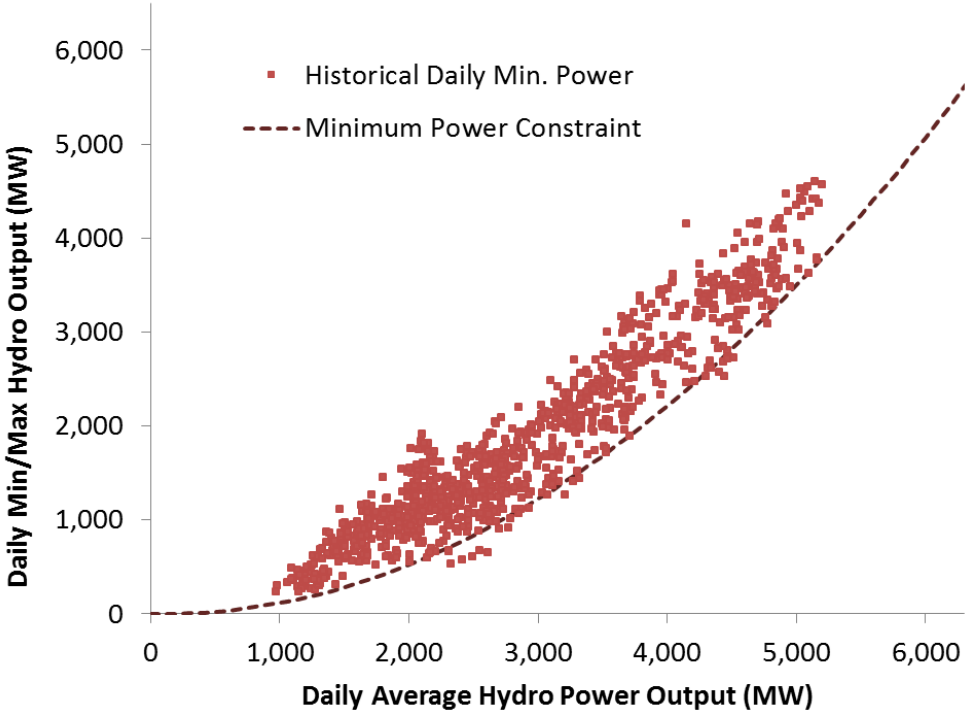


Stochastic Treatment of Hydro and Imports

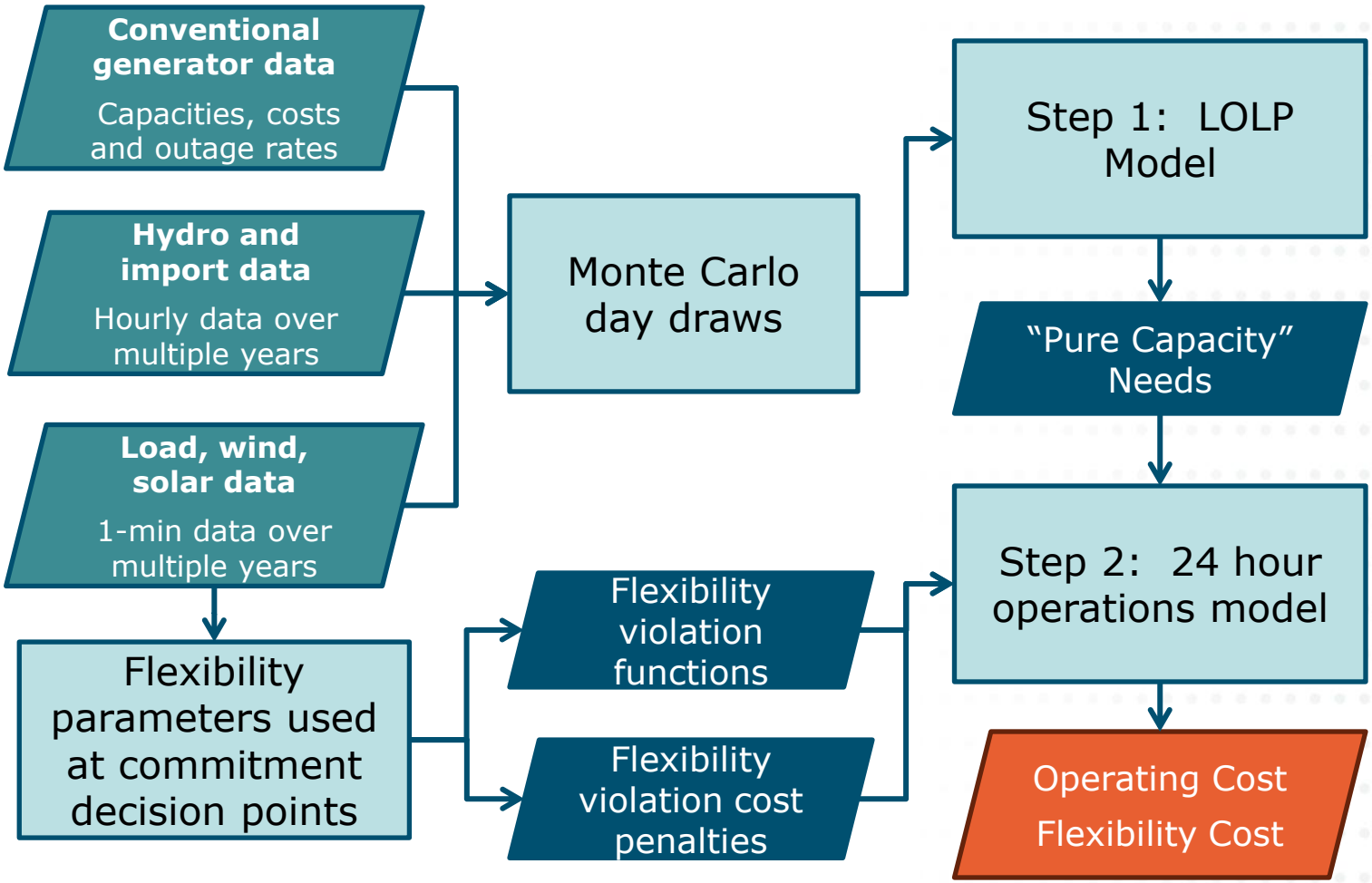
+ Hydro and imports informed by historical record

- 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



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

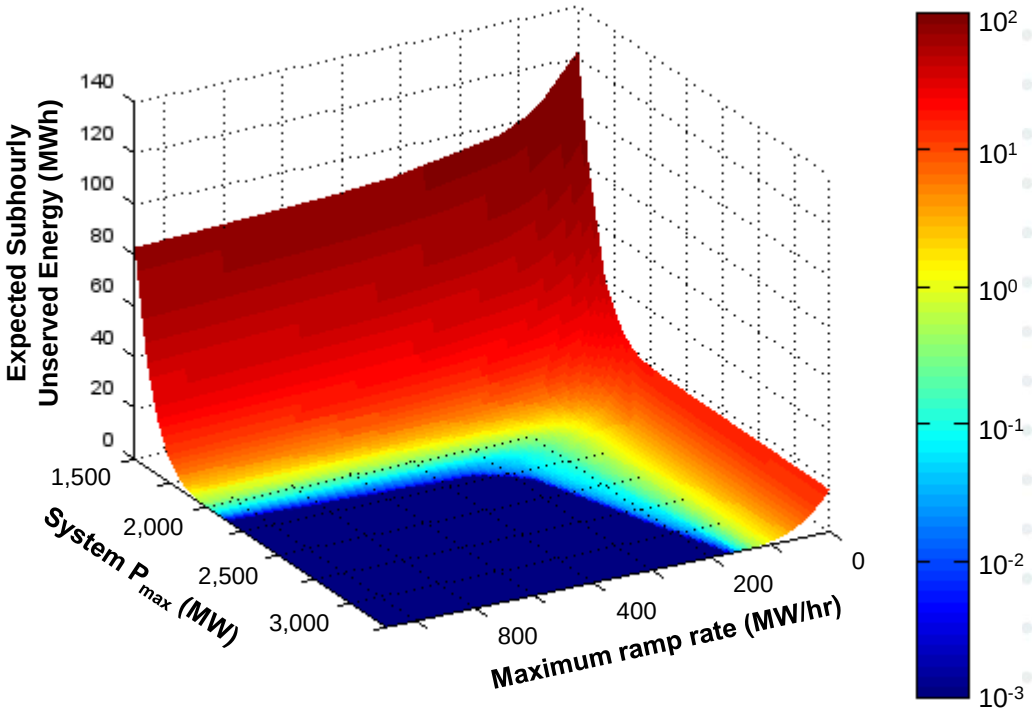
- **REFLEX makes unit commitment decisions at specified intervals**
  - Day-ahead, 4 hour-ahead, 1 hour-ahead
  - Ramping policy functions incorporated into commitment decisions
- **Ramping policy functions account for both forecast error and net load variability**
  - Forecast error incorporated through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

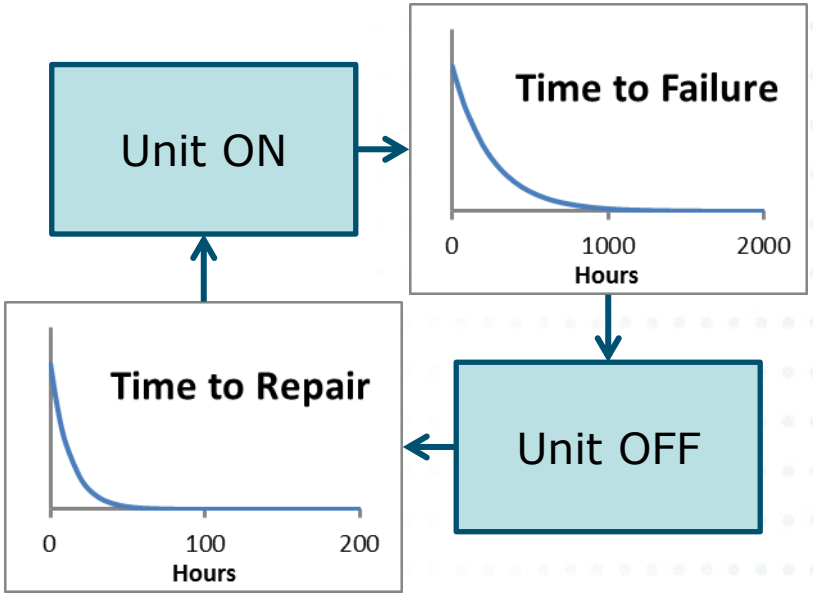
Demand = 2,000 MW
Renewables = 500 MW



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