California ISO Renewable Integration Study

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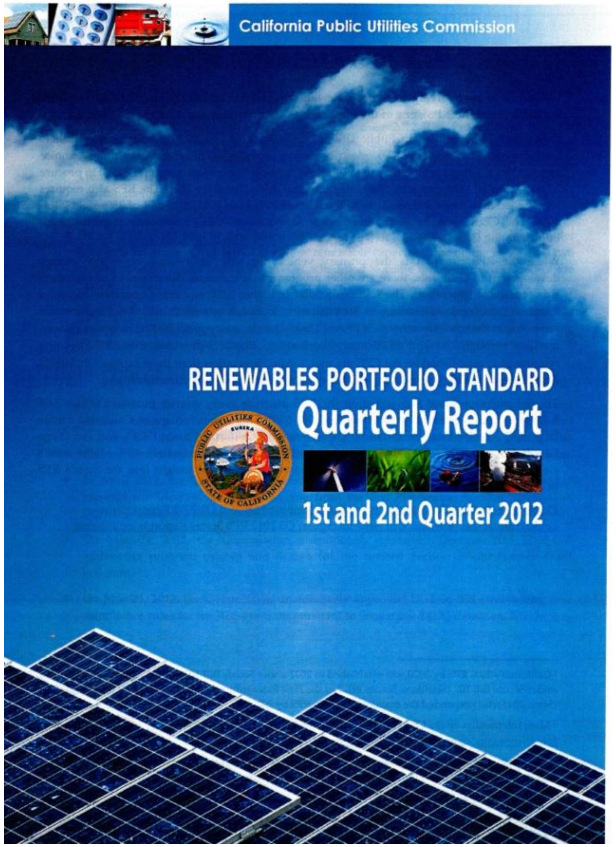
Agenda

- Operational Challenges
- Simulation Studies
  - *Deterministic Production Simulation*
  - *Loss of Load Probability Calculation*
  - *Stochastic Simulations*

Operational Challenges

California has set a high Renewable Portfolio Standard.

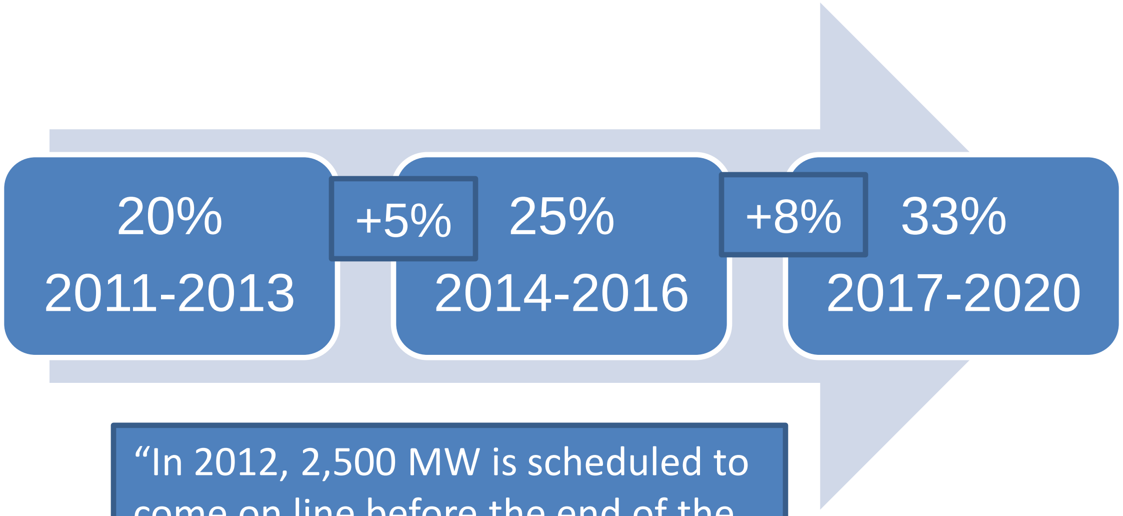


California Public Utilities Commission

RENEWABLES PORTFOLIO STANDARD

Quarterly Report

1st and 2nd Quarter 2012



20%
2011-2013

+5%

25%
2014-2016

+8%

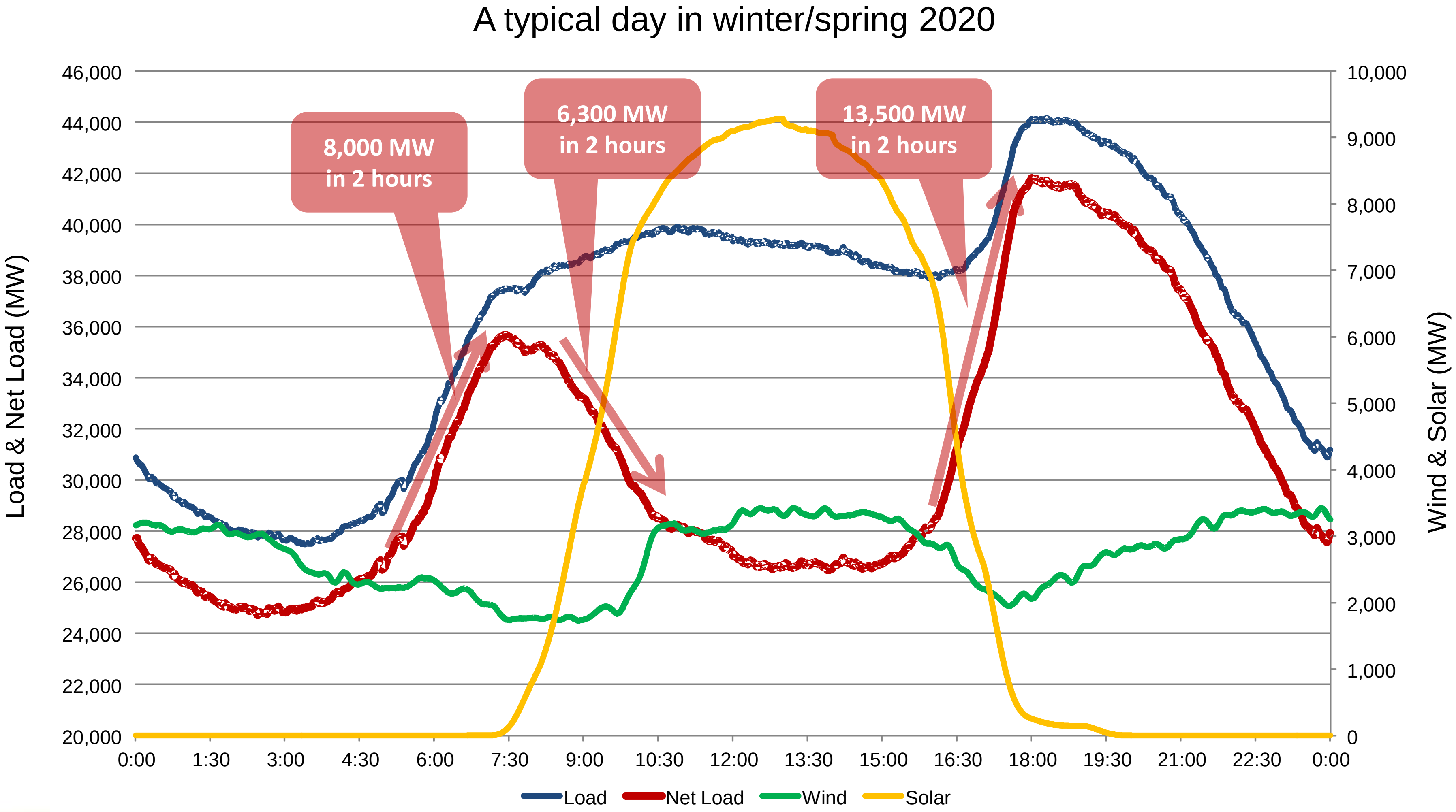
33%
2017-2020

"In 2012, 2,500 MW is scheduled to come on line before the end of the year. That compares with 2,871 MW of new renewables capacity to come on line since the RPS program started in 2003."

The CAISO faces operational challenges over the next 10 years.

- Supply volatility from over 20,000 MW of renewable capacity
- Uncertainty in the 12,000 MW of once-through cooling thermal capacity retirement or repower
- Less predictable load due to distributed generation and plug-in electric vehicles
- Reduced energy revenue to support conventional resources

It requires more flexible capacity to follow the net-load curve.



8,000 MW
in 2 hours

6,300 MW
in 2 hours

13,500 MW
in 2 hours

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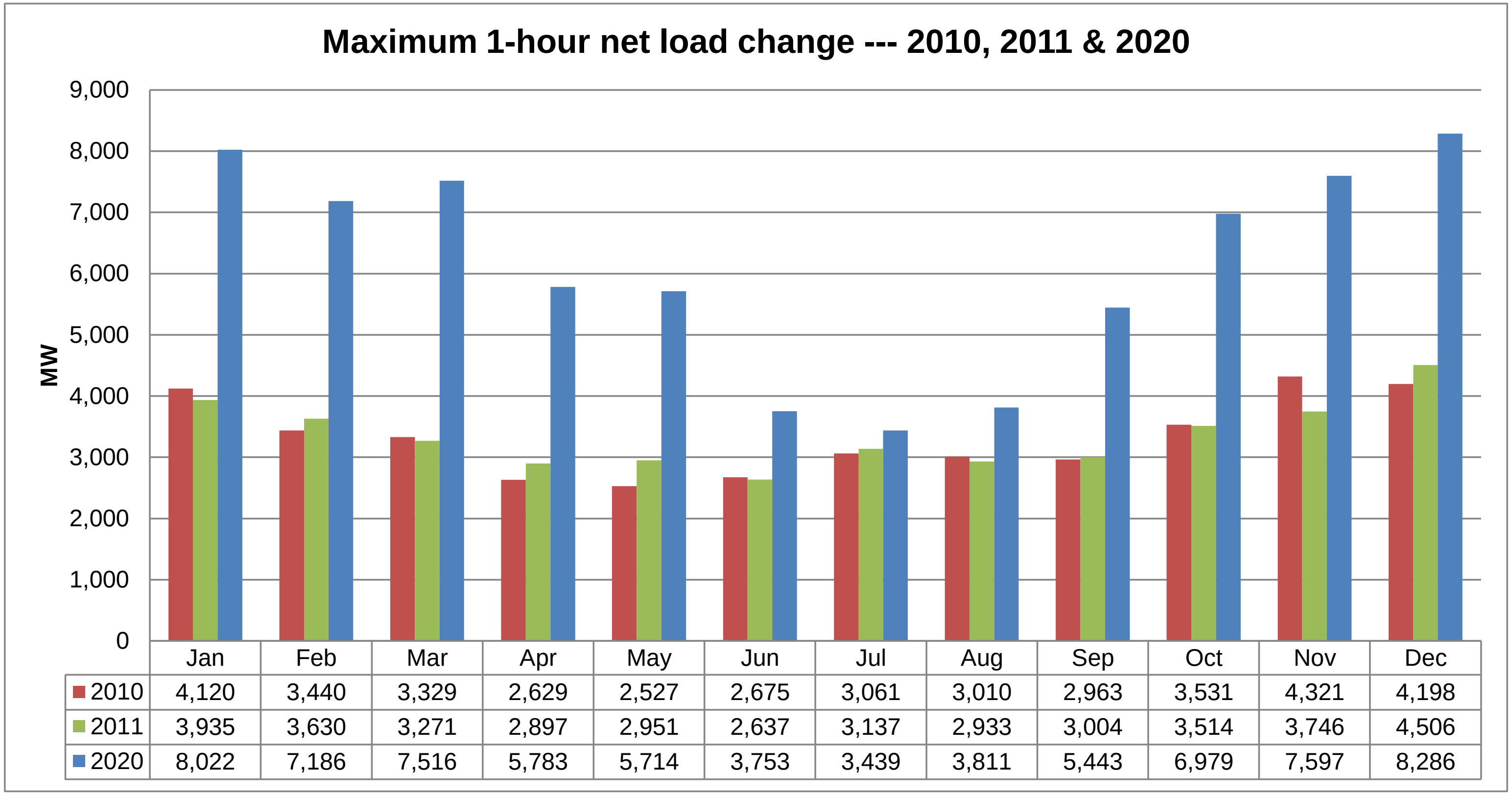
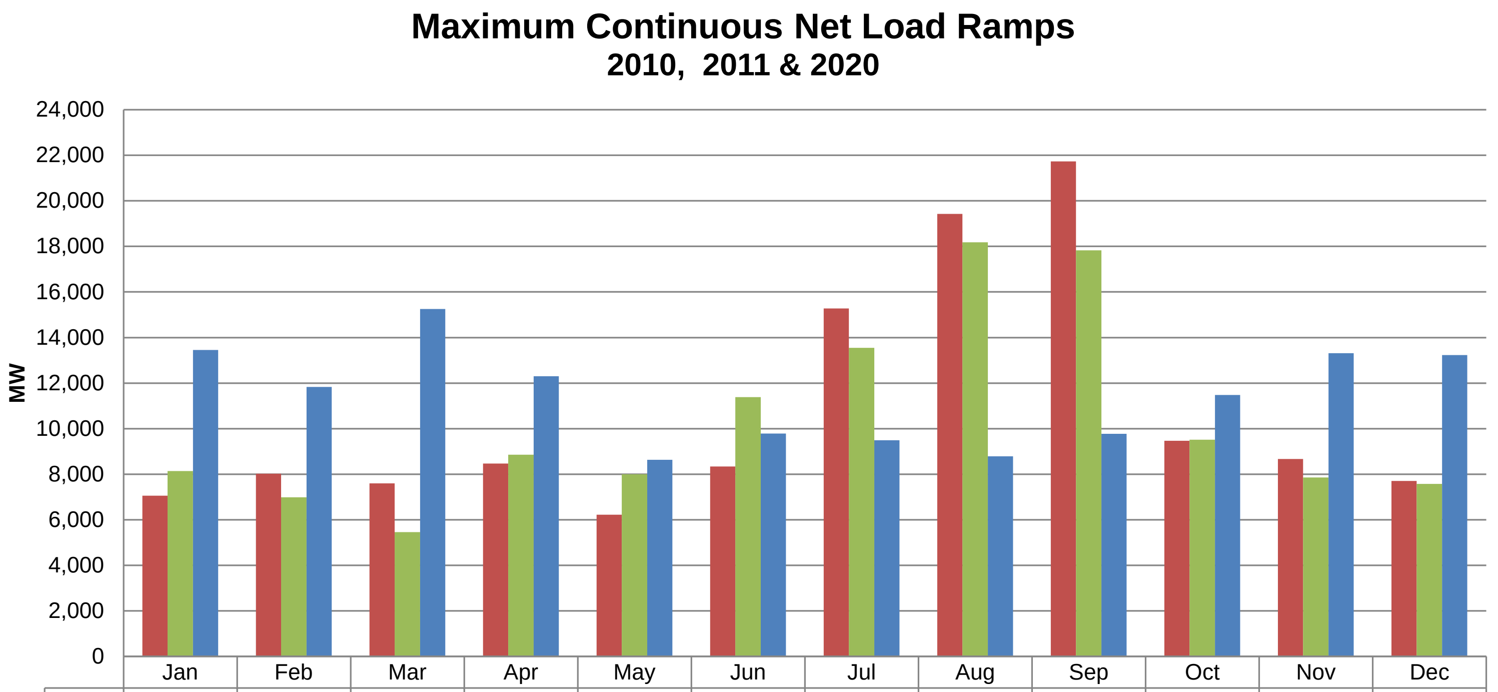
Maximum 1-hour net-load change - 2010 & 2011 actual vs. 2020 estimated



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟥 2010	4,120	3,440	3,329	2,629	2,527	2,675	3,061	3,010	2,963	3,531	4,321	4,198
🟩 2011	3,935	3,630	3,271	2,897	2,951	2,637	3,137	2,933	3,004	3,514	3,746	4,506
🟦 2020	8,022	7,186	7,516	5,783	5,714	3,753	3,439	3,811	5,443	6,979	7,597	8,286

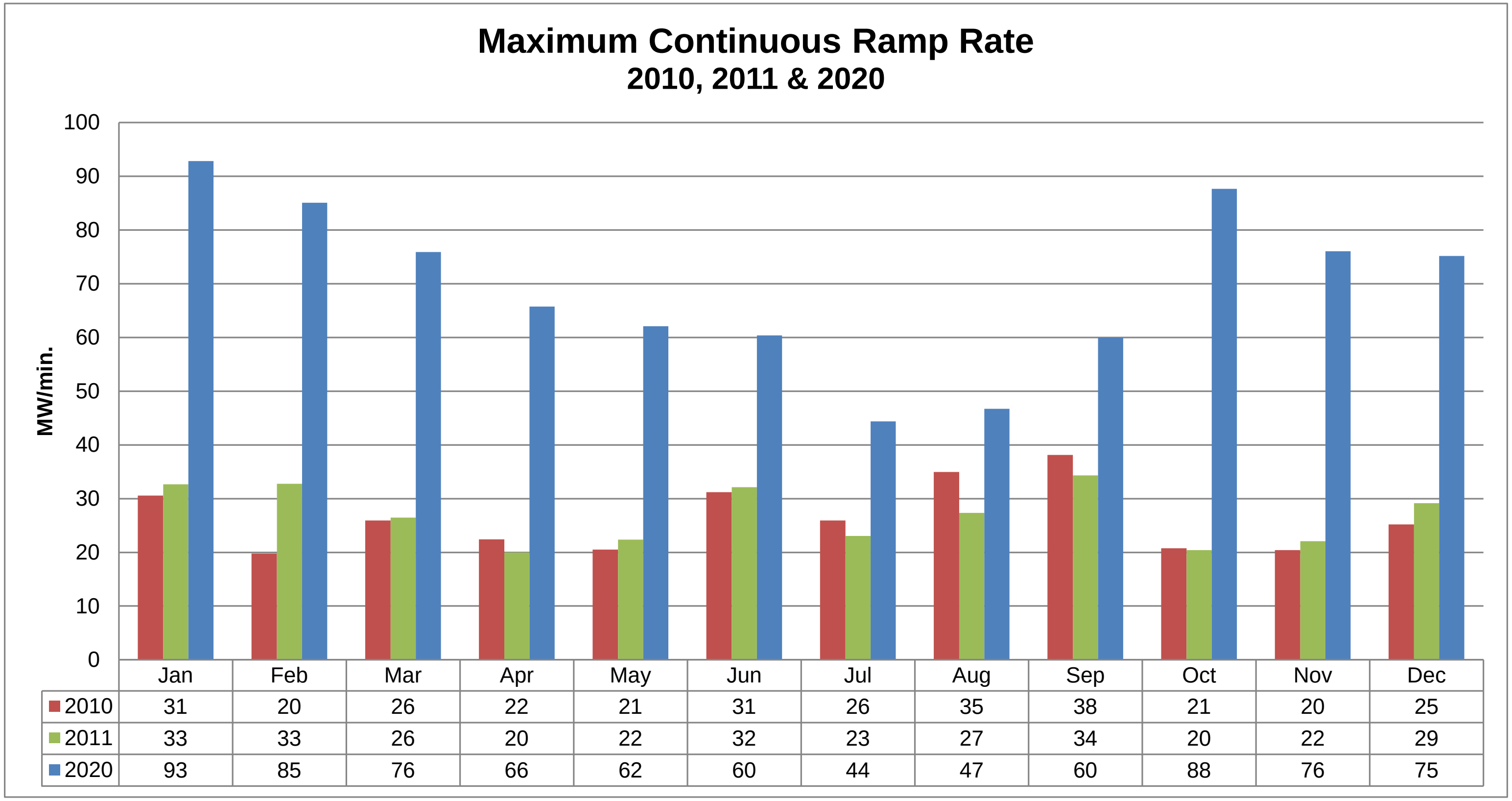
Maximum continuous net-load ramps - 2010 & 2011 actual vs. 2020 estimated



Maximum Continuous Net Load Ramps
2010, 2011 & 2020

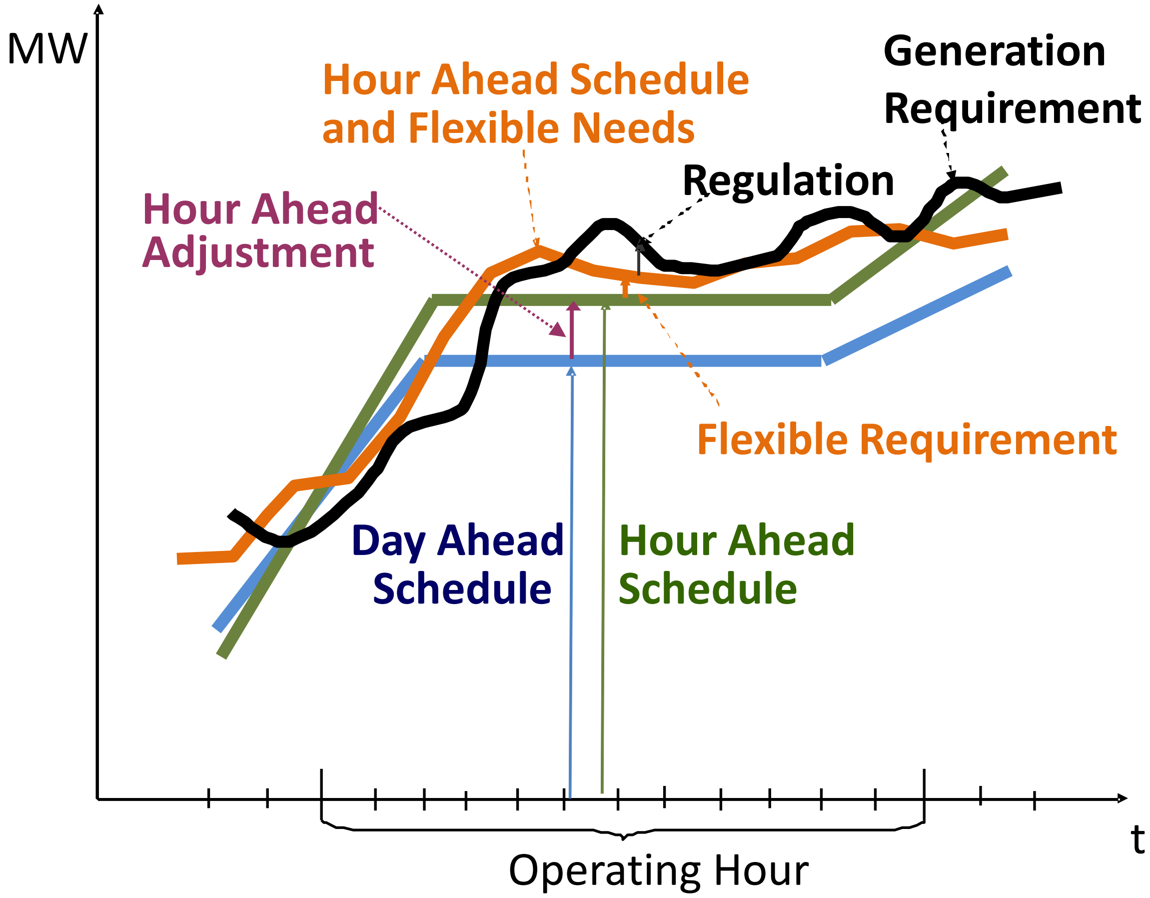
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟥 2010	7,057	8,022	7,594	8,465	6,217	8,337	15,275	19,432	21,732	9,464	8,667	7,706
🟩 2011	8,133	6,982	5,453	8,859	8,000	11,382	13,544	18,181	17,824	9,510	7,855	7,577
🟦 2020	13,459	11,825	15,254	12,298	8,630	9,782	9,496	8,785	9,777	11,483	13,308	13,234

Maximum continuous net-load ramp rates - 2010 & 2011 actual vs. 2020 estimated

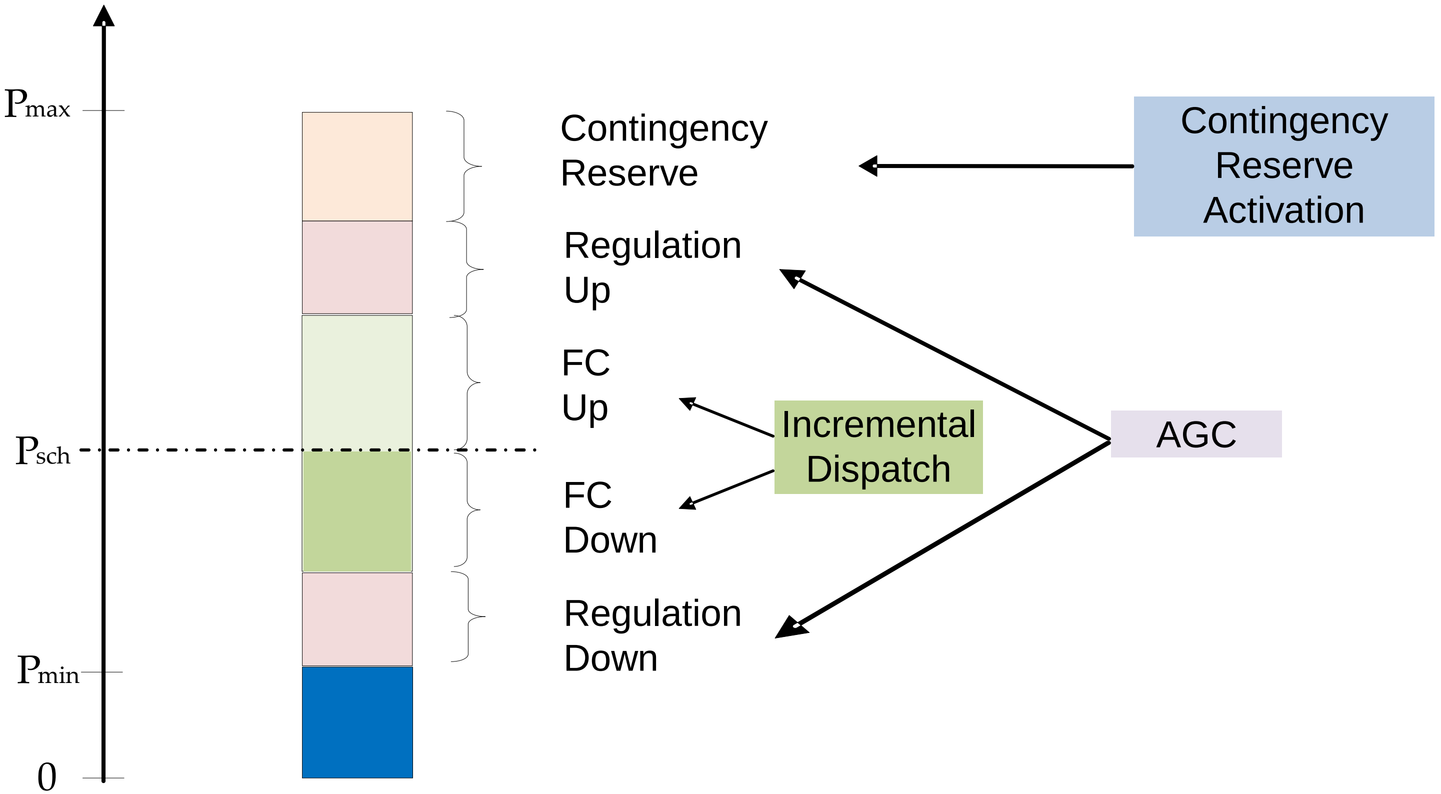

Maximum Continuous Ramp Rate
2010, 2011 & 2020

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟥 2010	31	20	26	22	21	31	26	35	38	21	20	25
🟩 2011	33	33	26	20	22	32	23	27	34	20	22	29
🟦 2020	93	85	76	66	62	60	44	47	60	88	76	75

Flexibility capacity is also need to mitigate intra-hour variations and provide contingency reserves.

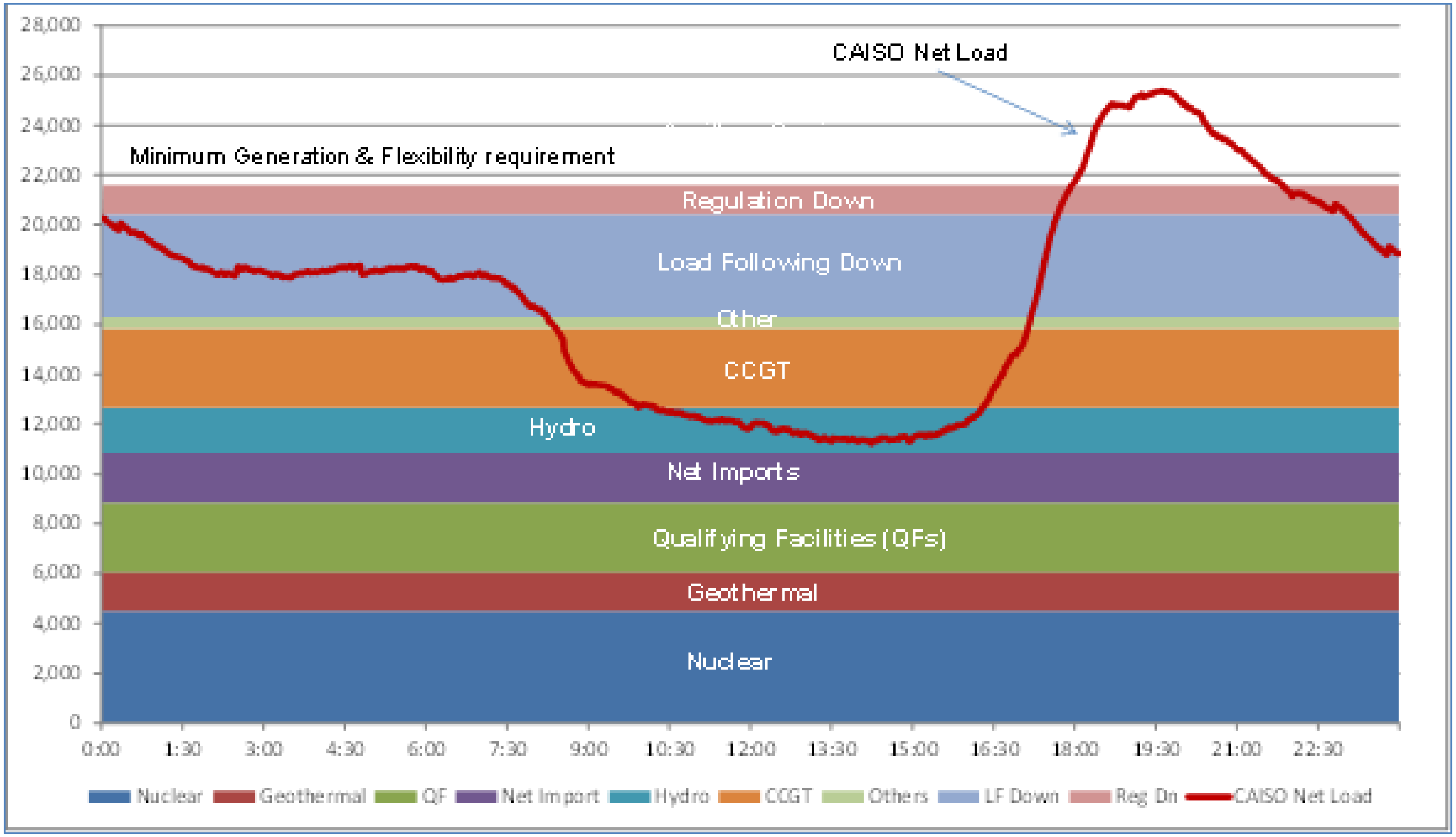


A flexible generation resource can provide multiple services.



FC – Flexible Capacity
AGC – Automatic Generation Control

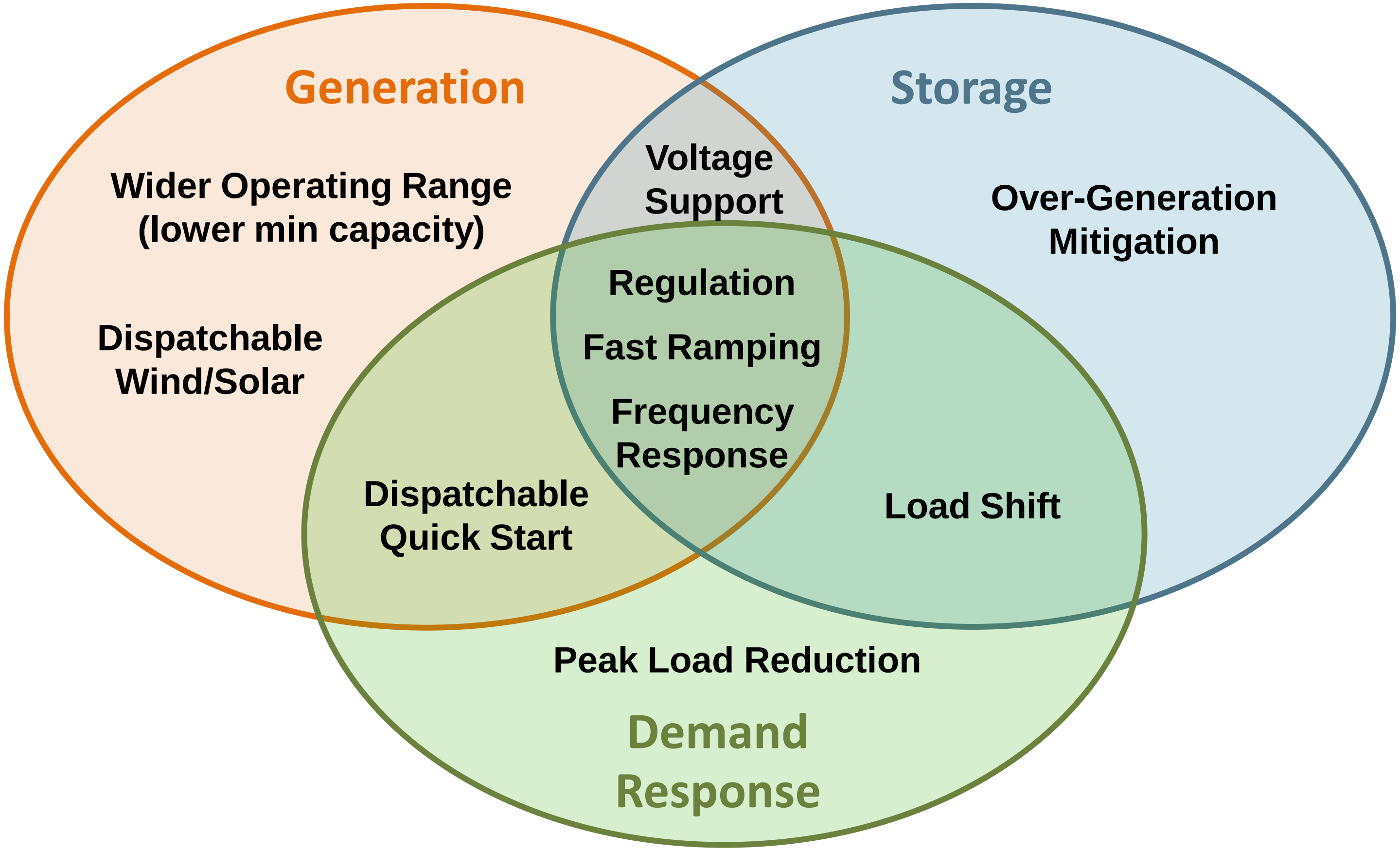
Non-flexible supply may cause over-generation when flexible capacity is needed for later hours.



The CAISO has conducted studies to assess impacts of 33% renewable generation on operation, including:

- Dynamic Transfer
- Frequency Response
- Distributed Generation Visibility and Control
- Renewable Integration and the CPUC LTPP
  - Load Following & Regulation Requirement
  - Production Simulations
  - Stochastic Simulations

Various types of resources can provide the needed flexibility capacity.



Generation

Wider Operating Range (lower min capacity)

Dispatchable Wind/Solar

Storage

Over-Generation Mitigation

Voltage Support

Regulation

Fast Ramping

Frequency Response

Dispatchable Quick Start

Load Shift

Peak Load Reduction

Demand Response

Simulation Studies

- *Deterministic Production simulation*
- *Loss of Load Probability Calculation*
- *Stochastic Simulation*

The ISO renewable integration study tries to answer the following questions:

- Do we have sufficient installed capacity?
- What is proper planning reserve margin (PRM)?
- Is the fleet flexible enough?
- What is the likelihood to have ramping capacity shortage?
- If additional capacity is needed, what types of resource are effective and efficient?

The ISO conducts simulations to find answers.

- Production simulation
  - Capacity and ramping capacity shortage
- Loss of Load Probability (LOLP) calculation
  - PRM needed to meet reliability standards
- Stochastic simulation
  - Probability of ramping capacity shortage

Production simulation - overview

- Deterministic scenarios
- A Plexos model similar to the ISO market model
  - Min-cost solution for unit commitment and dispatch
  - Co-optimization of energy and ancillary services
  - Zonal instead of full network model
- Hourly chronological simulation for the whole year
- Hourly detail results

Production simulation – model structure

- WECC-wide zonal model
  - 25 zones with about 2,000 generation units
- Transmission limits between zones
- Operational constrains for generation units
  - Min and max capacity, ramp rate, maintenance and forced outages, min run and down time, energy usage limit, etc.
- Multiple needs to be met simultaneously
  - Load, ancillary service and load following requirements (upward and downward)

Production simulation – ancillary service and load following requirements and ramping constraints

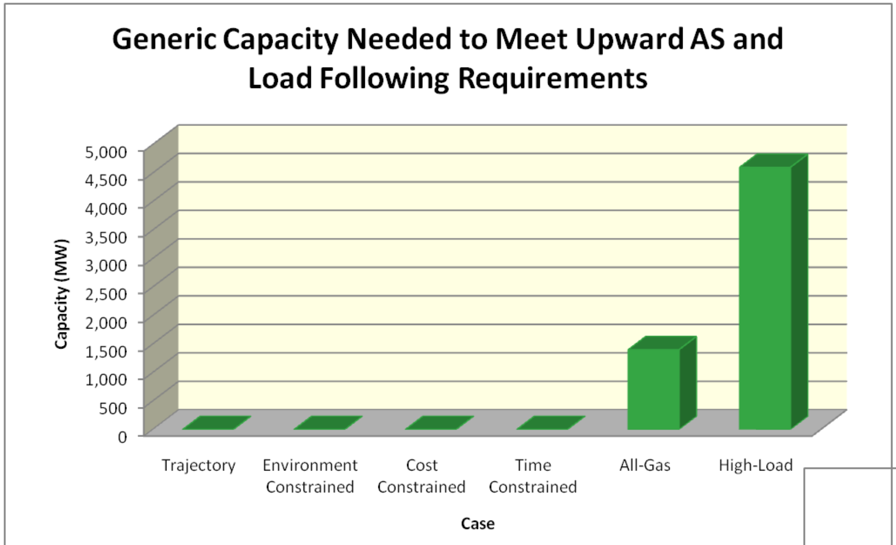
- Contingency reserve requirements – 6% of load
- Regulation and load following (up and down) requirements – calculated using a separate model

- A generator unit's ramping constraints
  - Up to 10-min ramping capacity for ancillary services
  - Up to 20-min ramping capacity for ancillary services and load following
  - Up to 60-min ramping capacity for ancillary service, load following, and inter-hour dispatch

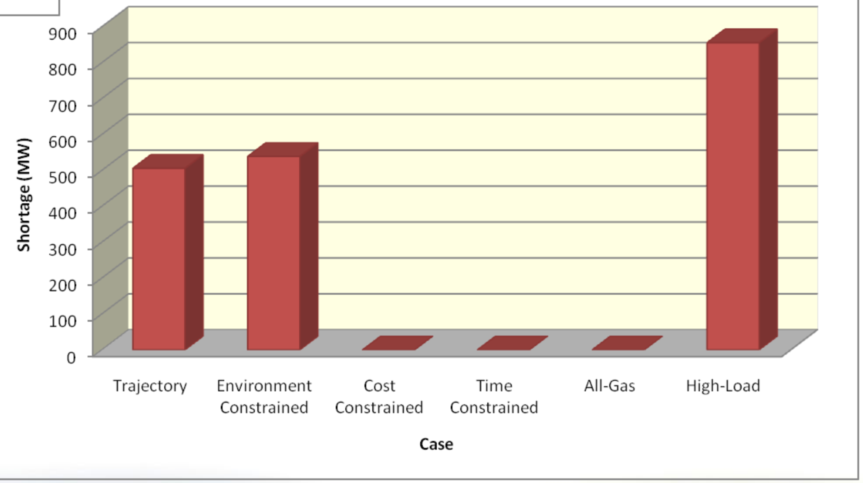
Production simulation – renewable portfolio standard (RPS) scenarios

Scenario	Region	Biomass/ biogas	Geothermal	Small Hydro	Solar PV	Distributed Solar	Solar Thermal	Wind	Total
Trajectory	CREZ-North CA	3	0	0	900	0	0	1,205	**2,108**
	CREZ-South CA	30	667	0	2,344	0	3,069	3,830	**9,940**
	Out-of-State	34	154	16	340	0	400	4,149	**5,093**
	Non-CREZ	271	0	0	283	1,052	520	0	**2,126**
	Scenario Total	338	821	16	3,867	1,052	3,989	9,184	**19,266**
Environmentally Constrained	CREZ-North CA	25	0	0	1,700	0	0	375	**2,100**
	CREZ-South CA	158	240	0	565	0	922	4,051	**5,935**
	Out-of-State	222	270	132	340	0	400	1,454	**2,818**
	Non-CREZ	399	0	0	50	9,077	150	0	**9,676**
	Scenario Total	804	510	132	2,655	9,077	1,472	5,880	**20,530**
Cost Constrained	CREZ-North CA	0	22	0	900	0	0	378	**1,300**
	CREZ-South CA	60	776	0	599	0	1,129	4,569	**7,133**
	Out-of-State	202	202	14	340	0	400	5,639	**6,798**
	Non-CREZ	399	0	0	50	1,052	150	611	**2,263**
	Scenario Total	661	1,000	14	1,889	1,052	1,679	11,198	**17,493**
Time Constrained	CREZ-North CA	22	0	0	900	0	0	78	**1,000**
	CREZ-South CA	94	0	0	1,593	0	934	4,206	**6,826**
	Out-of-State	177	158	223	340	0	400	7,276	**8,574**
	Non-CREZ	268	0	0	50	2,322	150	611	**3,402**
	Scenario Total	560	158	223	2,883	2,322	1,484	12,171	**19,802**
High Load	CREZ-North CA	3	0	0	900	0	0	1,205	**2,108**
	CREZ-South CA	30	1,591	0	2,502	0	3,069	4,245	**11,437**
	Out-of-State	34	154	16	340	0	400	4,149	**5,093**
	Non-CREZ	271	0	0	283	1,052	520	0	**2,126**
	Scenario Total	338	1,745	16	4,024	1,052	3,989	9,599	**20,763**

Production simulation – examples of simulation results



Load Following-Down Shortage



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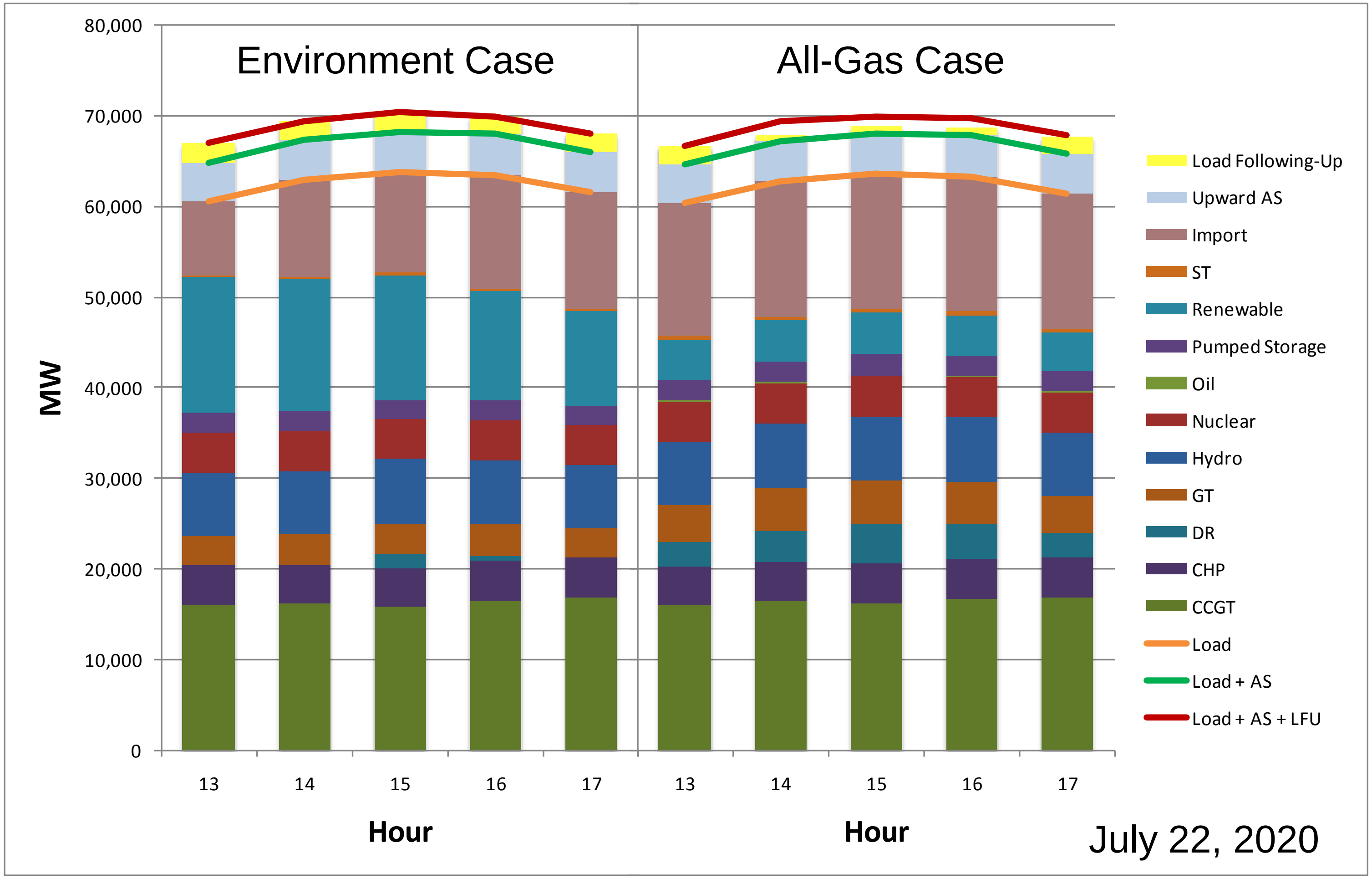
Production simulation – examples of simulation results (cont.)



July 22, 2020

LOLP calculation - overview

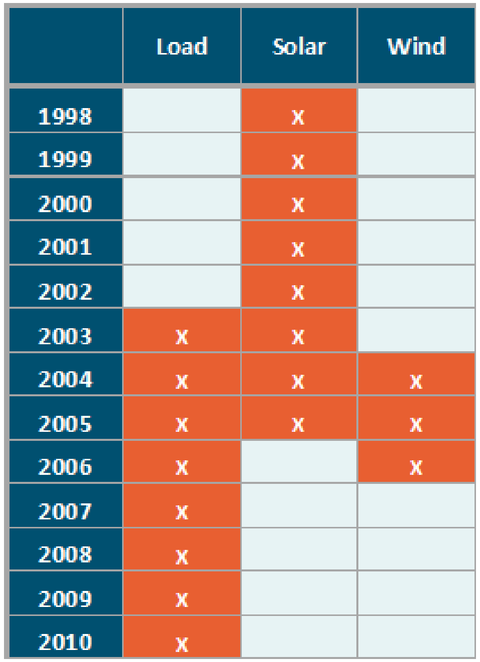
- A probabilistic non-chronological model for calculating
  - Loss of Load Probability (LOLP)
    - probability of load exceeding generation in a given hour
  - Loss of Load Expectation (LOLE)
    - total number of hours wherein load exceeds generation
  - Effective Load Carrying Capability (ELCC)
    - ability of generator capacity to effectively meet load

The LOLP model has the following assumptions:

- Infinitely flexible generation resources with forced outages
- No transmission constraints or local capacity requirements
- Imports available at limits
- Hydro available at its NQC value
- Fixed and reliable policy-driven demand reductions (energy efficiency, CHP, demand response, distributed generation, etc.)

The LOLP model is developed based on 13 years of historical data.

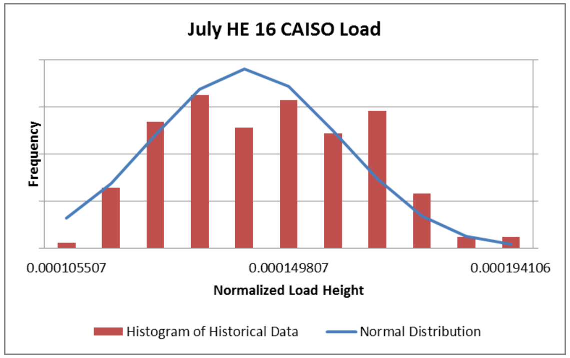
- Load
  - – 2003-2010 hourly load profiles
- Solar
  - – 1998-2005 hourly capacity factor
- Wind
  - – 2004-2006 hourly capacity factor



	Load	Solar	Wind
1998		x	
1999		x	
2000		x	
2001		x	
2002		x	
2003	x	x	
2004	x	x	x
2005	x	x	x
2006	x		x
2007	x		
2008	x		
2009	x		
2010	x		

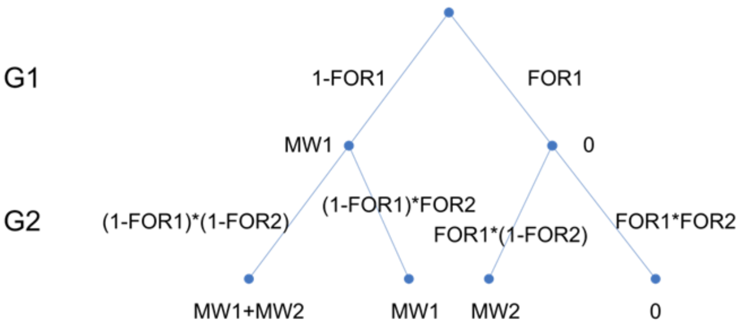
The model assumes load has normal probability distribution.

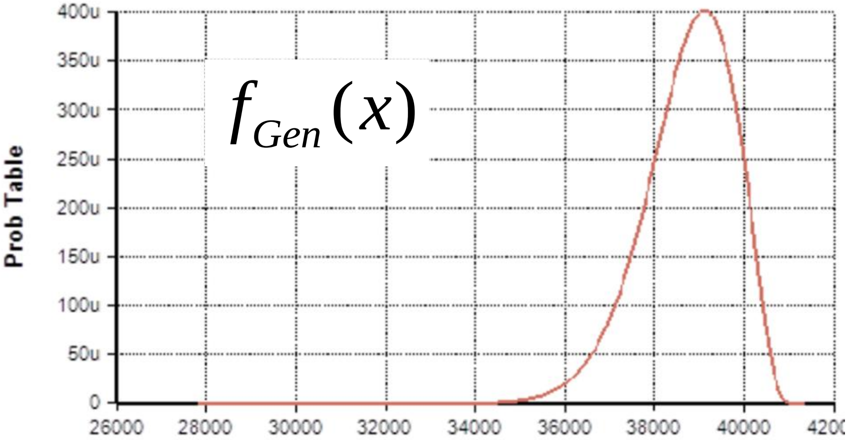
- Historical load data show the pattern of normal distribution
- Means and variances are calculated for each hour based on historical



- *Net Load = 1.03*Mean of Load + Regulation*
  + Load following – Renewable Generation
  – Hydro – Demand Response – Imports
  - 3% of load representing contingency reserves

Available generation capacity probability distribution is derived using a probability tree of forced outage.





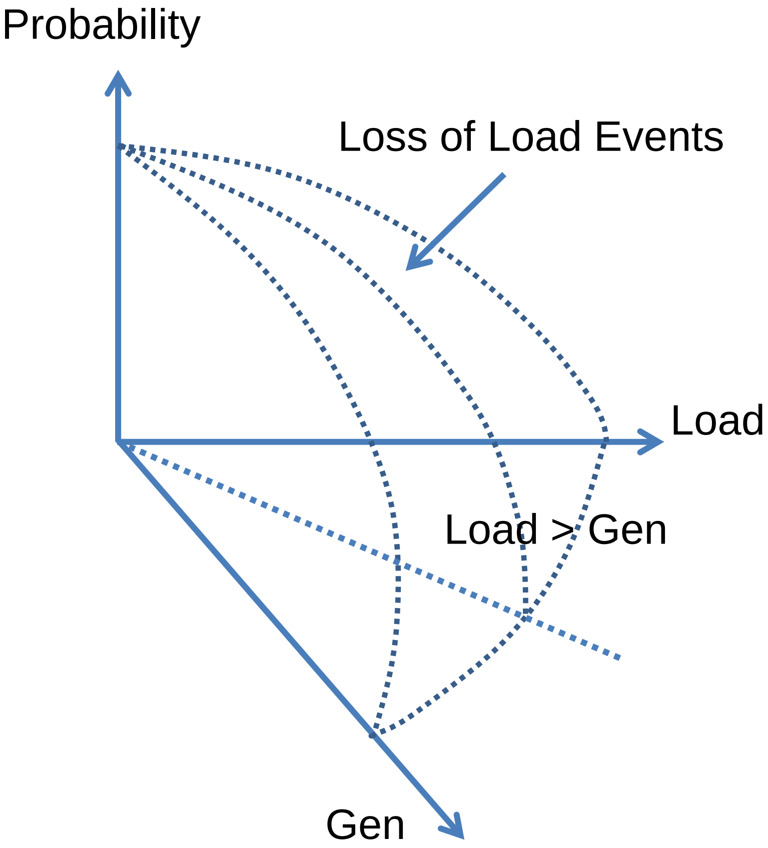
Probability	FOR1*FOR2	FOR1* (1-FOR2)	(1-FOR1) *FOR2	(1-FOR1)* (1-FOR2)
Available Capacity (MW)	0	MW2	MW1	MW1+MW2

LOLP of each hour is calculated as the cumulative probability of load greater than generation.

$$LOLP = \iint_{g<l} f_{Net\ Load,Gen}(l,g)\,dg\,dl$$

$$= \int_{L_{min}}^{+\infty} \int_{G_{min}}^{l} f_{Net\ Load}(l)\, f_{Gen}(g)\,dg\,dl$$

$$= \int_{L_{min}}^{L_{max}} f_{Net\ Load}(l) \left(\int_{G_{min}}^{l} f_{Gen}(g)\,dg \right) dl$$



Loss of Load Expectation is the sum of LOLP of all hours of the year.

- Loss of Load Expectation

$$LOLE = \sum_{h} LOLP_h$$

- Annual LOLP

$$LOLP = LOLE/8760$$

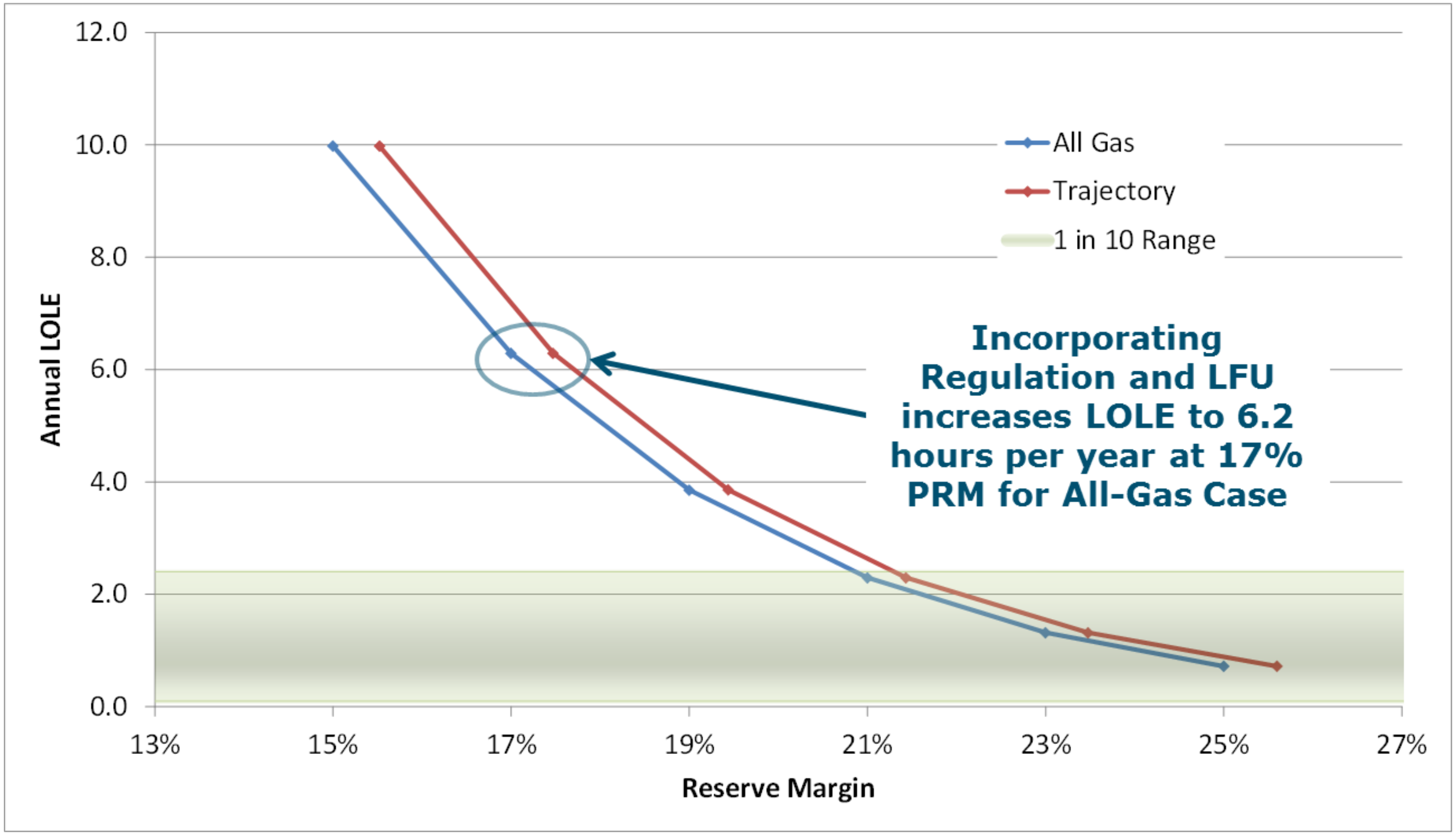
ELCC is the capability of capacity to meet load while maintaining the same LOLE.

- For incremental load ΔL, incremental capacity ΔC is needed to maintain the same LOLP

  then $$ELCC = \Delta L / \Delta C$$

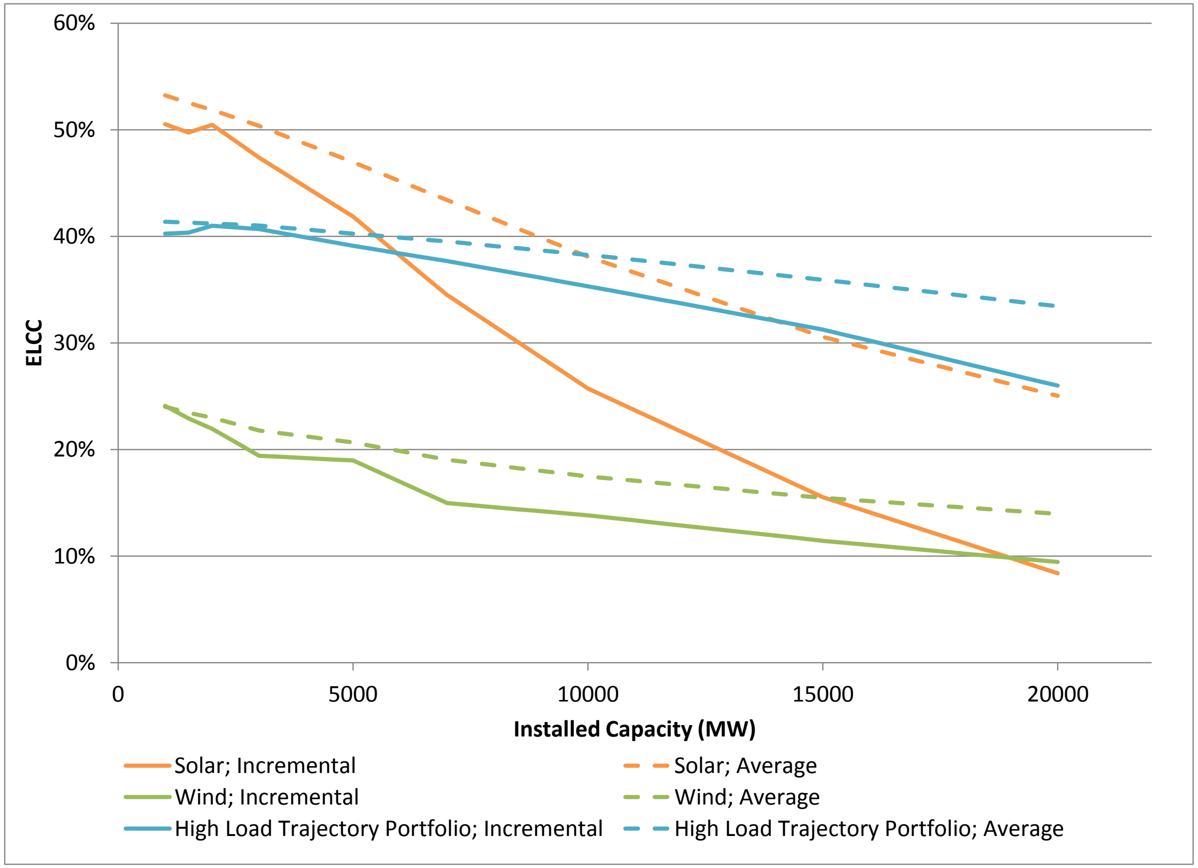
- ELCC is often used to measure effectiveness of renewable resources
- ELCC depends on
  - Existing fleet
  - Type of incremental resources added
  - Penetration of the renewable capacity installed

Example of result – Planning Reserve Margin vs. LOLE



Incorporating Regulation and LFU increases LOLE to 6.2 hours per year at 17% PRM for All-Gas Case

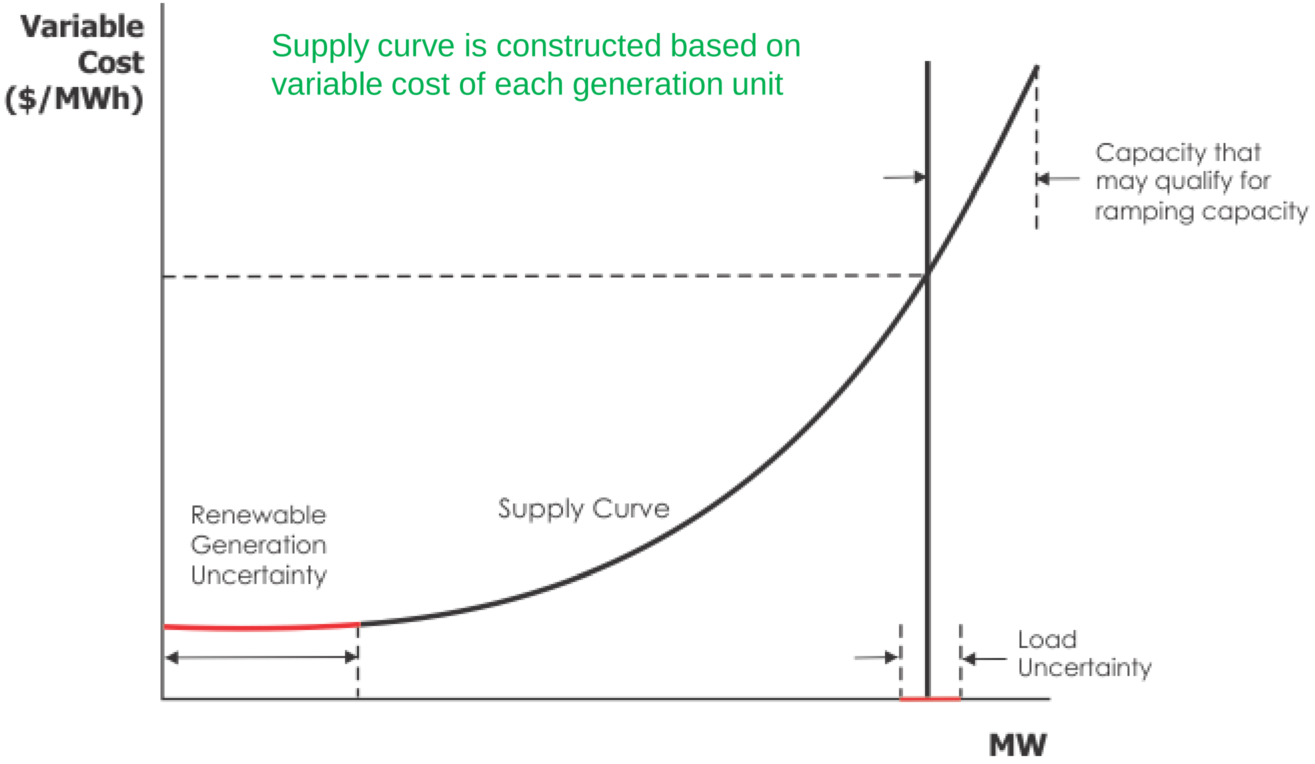
Example of result – ELCC declines with penetration level of renewable capacity.



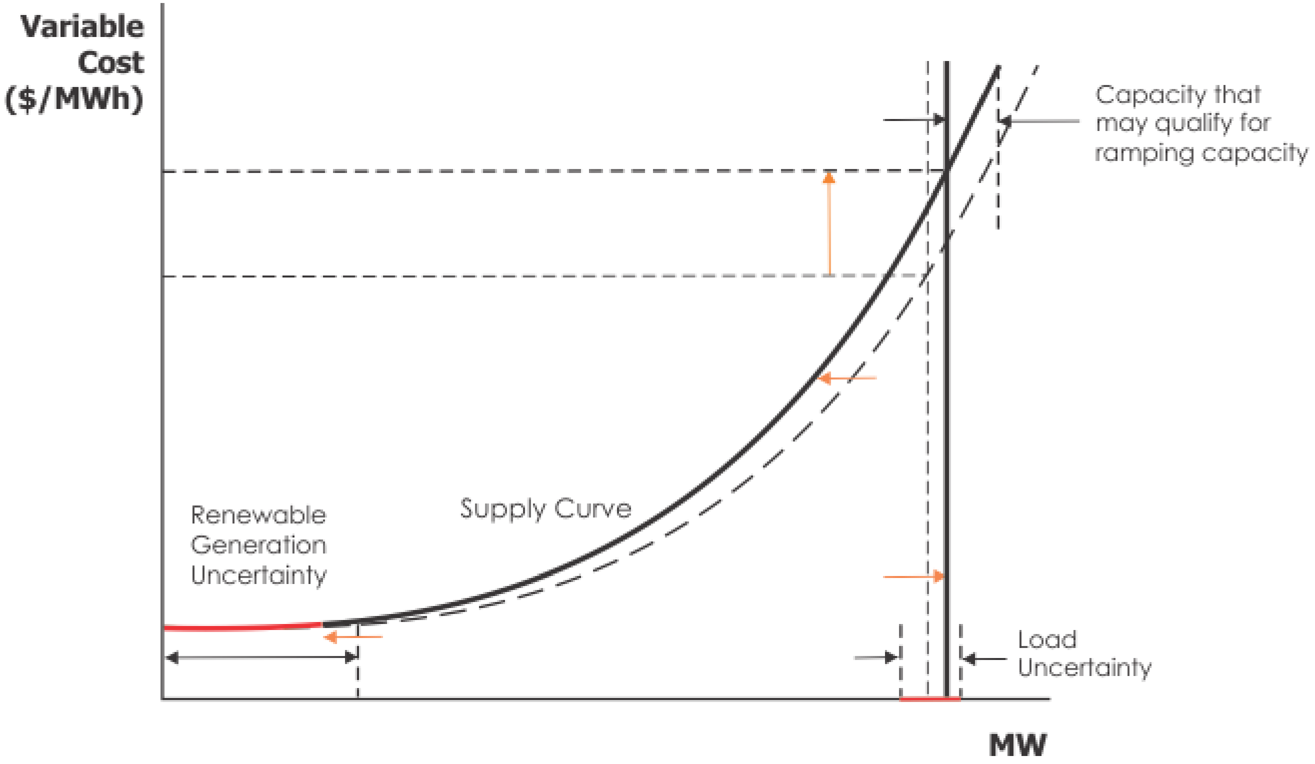
Stochastic simulation - overview

- A stochastic non-chronological model
  - Evaluates various possible input combinations
  - Determines the probability of ramping capacity shortage
- Generator ramping constraints
  - Ancillary service
  - Load following
  - Inter-hour load ramping

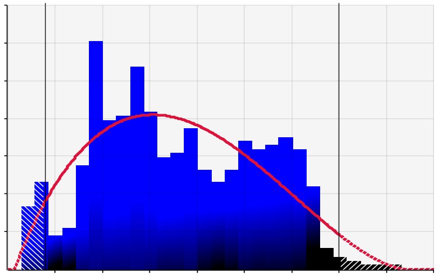
Decision-making is easier if everything is known.



Uncertainties always exist in our life.

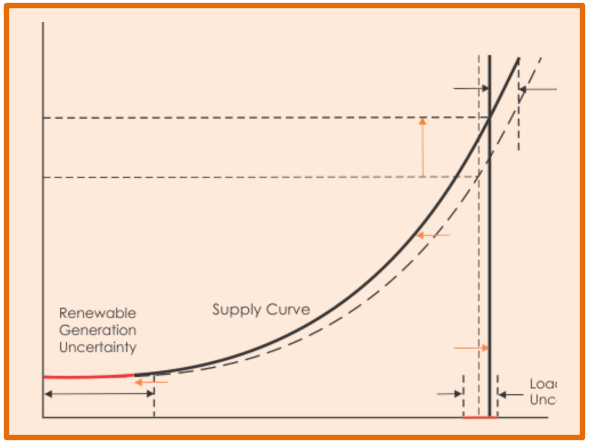


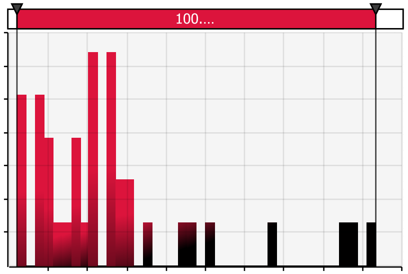
Stochastic simulation model captures the uncertainties in its inputs and produces probabilistic results.



<u>Stochastic Inputs</u>

- Load
- Solar/wind generation
- Hydro generation
- Inter-hour ramp
- Ancillary services
- Load following

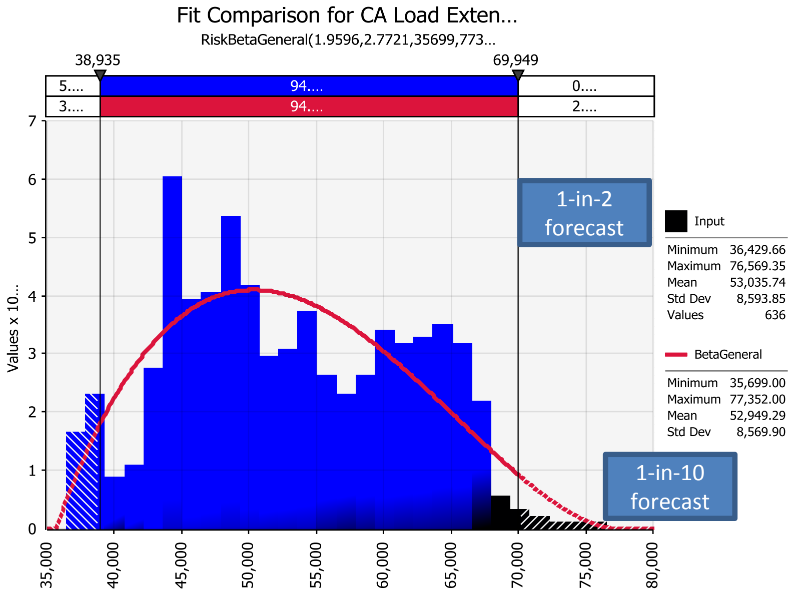




Probability of Ramping Capacity Shortage

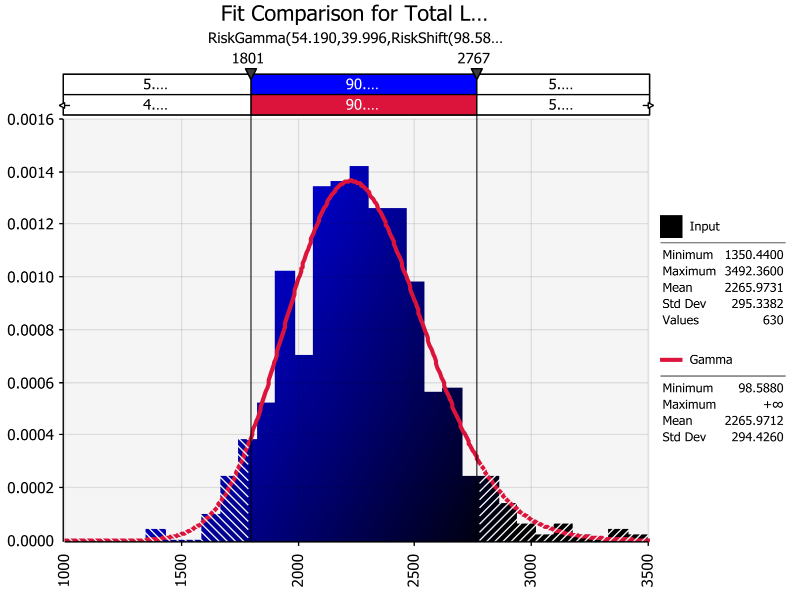
Monte Carlo Simulation
(multiple iterations)

Examples of probability distributions of stochastic input variables

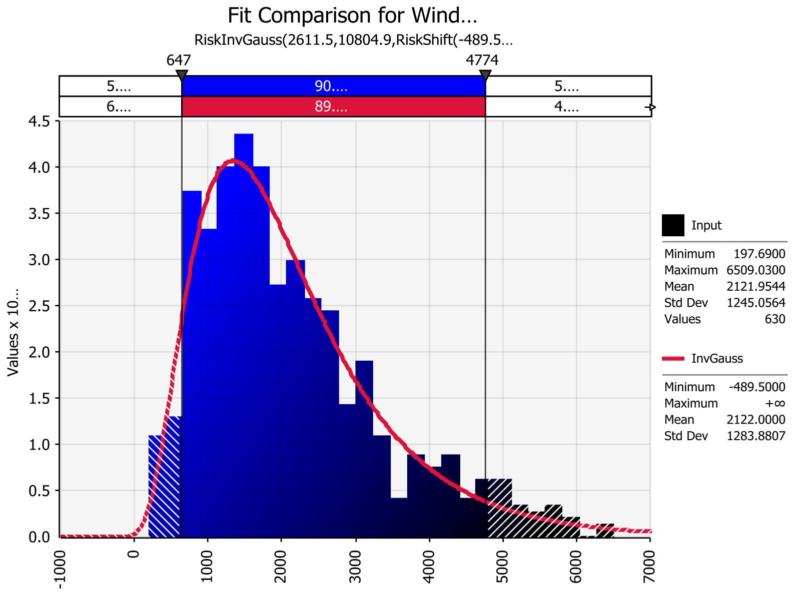


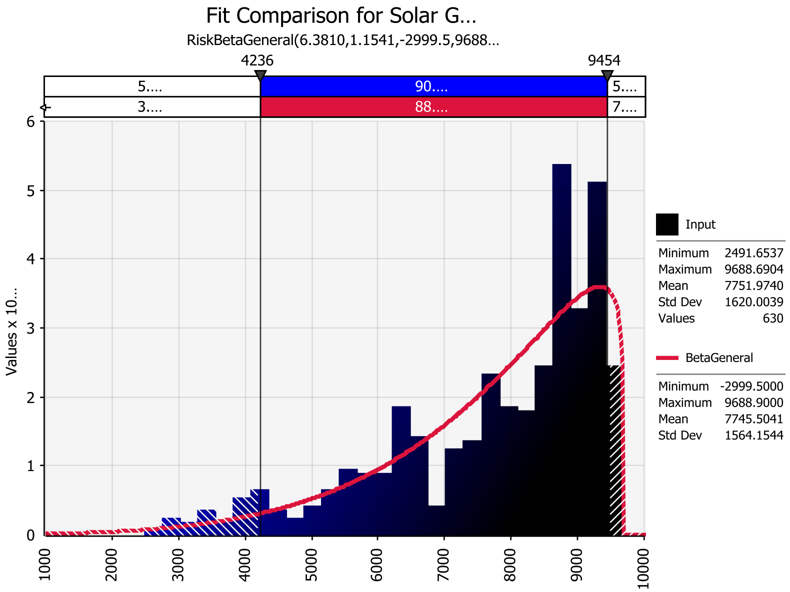
1-in-2 forecast

1-in-10 forecast



Examples of probability distributions of stochastic input variables (cont.)

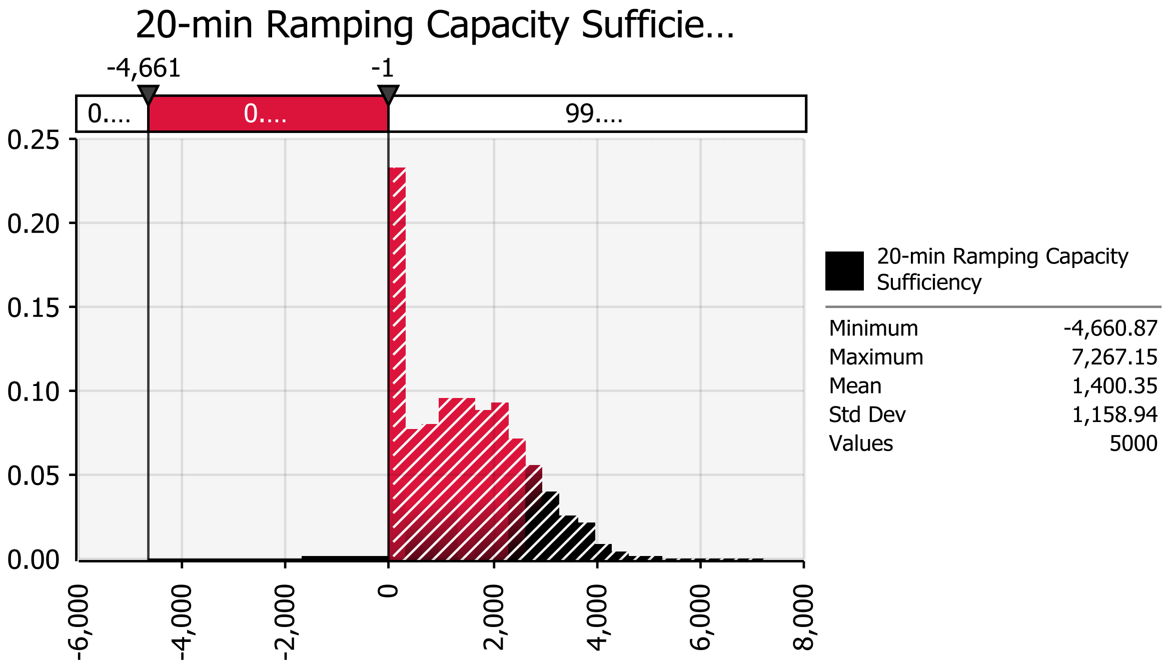




Example of correlations matrix of the stochastic variables

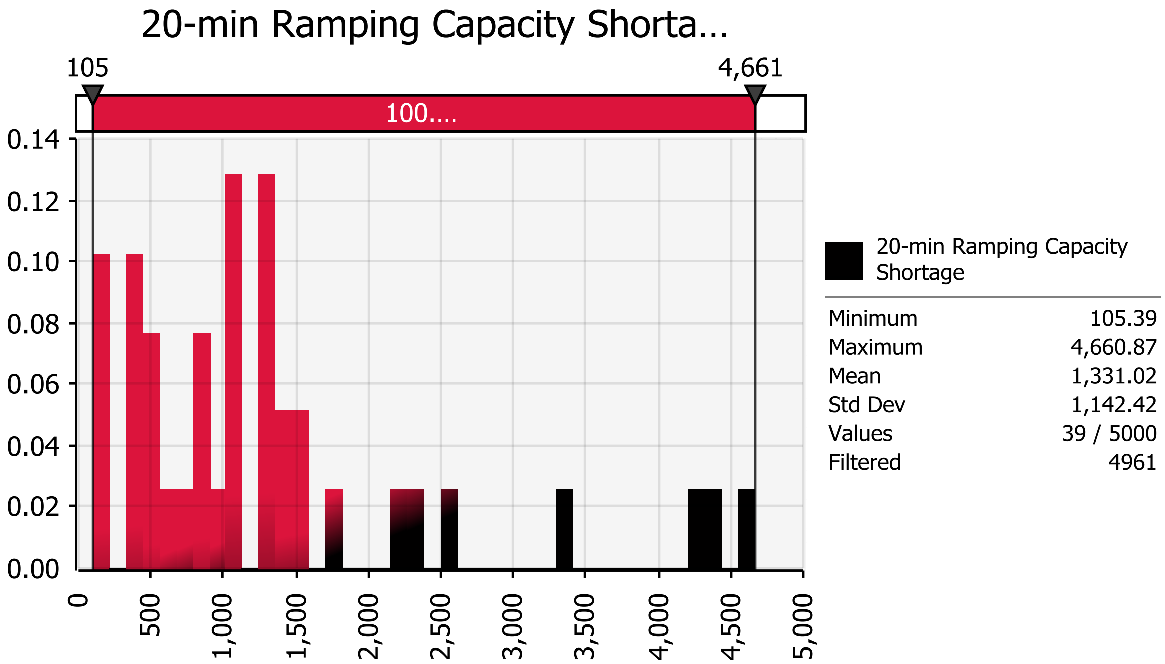
	Load	Load Ramp	Wind Gen	Solar Gen	Hydro Gen	RegU	LFU
Load	1	0.2884	-0.0947	-0.1997	0.4302	0.3801	0.0722
Load Ramp	0.2884	1	-0.3782	0.6156	0.0779	0.2064	-0.3193
Wind	-0.0947	-0.3782	1	-0.1618	0.2855	-0.0108	0.0609
Solar	-0.1997	0.6156	-0.1618	1	0.0254	-0.1101	-0.5064
Hydro	0.4302	0.0779	0.2855	0.0254	1	0.3094	-0.1283
RegU	0.3801	0.2064	-0.0108	-0.1101	0.3094	1	0.1415
LFU	0.0722	-0.3193	0.0609	-0.5064	-0.1283	0.1415	1

This example has a 0.8% probability to have 20-min ramping capacity shortage each hour in this period.



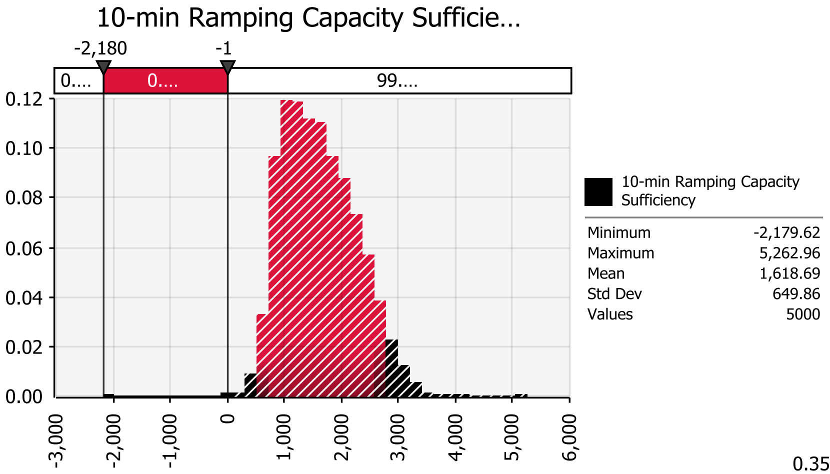
Minimum	-4,660.87
Maximum	7,267.15
Mean	1,400.35
Std Dev	1,158.94
Values	5000

The highest 20-min ramping capacity shortage is 4,661 MW in this example.

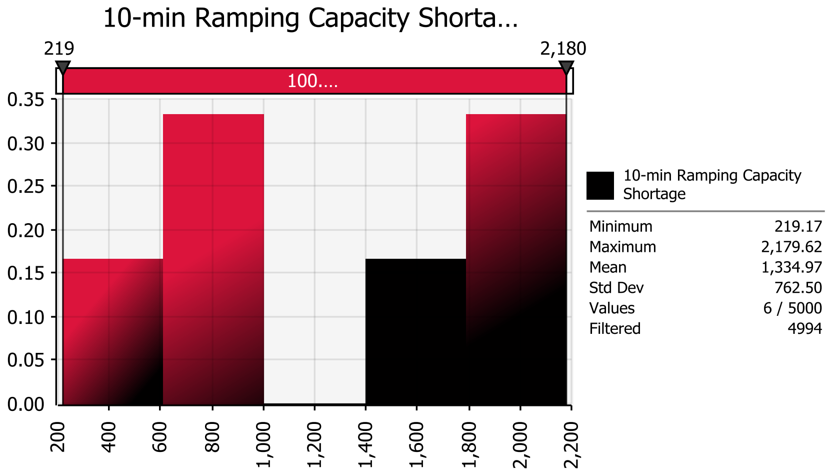


Minimum	105.39
Maximum	4,660.87
Mean	1,331.02
Std Dev	1,142.42
Values	39 / 5000
Filtered	4961

The probability to have 10-min ramping capacity shortage each hour in this period is 0.1%.



10-min Ramping Capacity Sufficiency	
Minimum	-2,179.62
Maximum	5,262.96
Mean	1,618.69
Std Dev	649.86
Values	5000



10-min Ramping Capacity Shortage	
Minimum	219.17
Maximum	2,179.62
Mean	1,334.97
Std Dev	762.50
Values	6 / 5000
Filtered	4994

The Monte Carlo simulation results for all periods are summarized as follows:

	Example Case			
	Super-Peak		Summer Off-Peak	
	10-min	20-min	10-min	20-min
# of Hours in the Period	630	630	2298	2298
Probability of Shortage	0.12%	0.78%	0.04%	0.16%
Max Shortage (MW)	2,180	4,661	1,420	3,855

The cumulative probabilities of ramping capacity shortage are calculated using Binomial distribution.

	Example Case	
i	10-min	20-min
1	81.3%	100.0%
2	49.9%	99.8%
3	23.6%	99.1%
4	8.9%	97.2%
5	2.8%	93.0%
6	0.7%	85.8%
7	0.2%	75.4%
8	0.0%	62.7%
9	0.0%	49.0%
10	0.0%	35.9%
11	0.0%	24.6%
12	0.0%	15.9%
13	0.0%	9.6%
14	0.0%	5.5%
15	0.0%	2.9%
16	0.0%	1.5%
17	0.0%	0.7%
18	0.0%	0.3%
19	0.0%	0.1%
20	0.0%	0.1%
21	0.0%	0.0%
22	0.0%	0.0%

It is the probability to have at least *i* hours with ramping capacity shortage in year 2020.

The expected number of hours with ramping capacity shortage in 2020 are:

Example Case	
10-min	20-min
1.68	8.59