Proposed Preferred System Portfolio for IRP 2017-18: System Analysis and Production Cost Modeling Results

January 7, 2019

California Public Utilities Commission

Background

- A September 24, 2018 ruling presented a PCM framework for assessing system reliability and operational performance of the CAISO system
  - Attachment A described guidelines for PCM studies
  - Attachment B presented PCM results with the Reference System Plan with the 2017 IEPR demand forecast
- Parties provided formal comments and replies in October 2018
- Staff held a October 31, 2018 workshop to propose changes to the PCM framework and to present the aggregation of LSE portfolios to be modeled with the revised framework
  - Since then staff also completed an analysis of the feasibility of hydro generation included in LSE plans and presents the results here
- A November 15, 2018 ruling formalized revisions to the PCM framework and the aggregation of LSE portfolios to be modeled
  - Attachment A described the revised guidelines for PCM studies
  - The aggregation of LSE portfolios along with various input revisions is defined as the Hybrid Conforming Portfolio – data required for PCM studies is posted to the CPUC IRP website
  - The ruling laid out the schedule for PCM activities to inform the Preferred System Plan

The Hybrid Conforming Portfolio

- The Hybrid Conforming Portfolio represents a combination of the existing baseline resources with the Conforming new resource build-out proposed in the aggregated LSE portfolios, adjusted for assumed physical limitations. It also includes various improvements to PCM input assumptions that were found necessary as a result of comparisons with RESOLVE and party feedback.
- Steps used to build the Hybrid Conforming Portfolio:
  1. Began with the PCM inputs to SERVM for the Reference System Plan with the 2017 IEPR demand forecast that was described in the September 24, 2018 ruling
  2. Replaced the "Selected Resources" (new build) in SERVM to reflect the LSE new build portfolio preferences as submitted in their IRP plans
     - The adjusted aggregation of LSE portfolios merged with the existing SERVM dataset was reposted to the CPUC website. Where necessary, new resources were shifted to different regions than were indicated in LSE portfolios to correct for the transmission potential / resource potential issues described in the October 31 workshop, such that triggering of new transmission build is minimized
  3. Implemented a 40 year age-based retirement assumption for fossil-thermal units
  4. Implemented other model input changes as was described in the November 15, 2018 ruling and in more detail on the following slides.

FEASIBILITY OF HYDROELECTRIC GENERATION USE IN LSE PLANS

Background

- LSEs filed conforming plans showing significant use of in-state and out-of-state hydro, comprising approximately 19% of total energy across the IRP planning horizon
- In their comments filed on LSE Plans…
  - Some parties expressed concern over possible over-reliance on Pacific Northwest (PNW) hydro, with feasibility and emissions impacts needing assessment
  - Other parties stated that planned use of PNW hydro is in-line with historical use
- CPUC staff set out to determine whether the LSEs' proposed hydro purchases are feasible

Analytic Approach

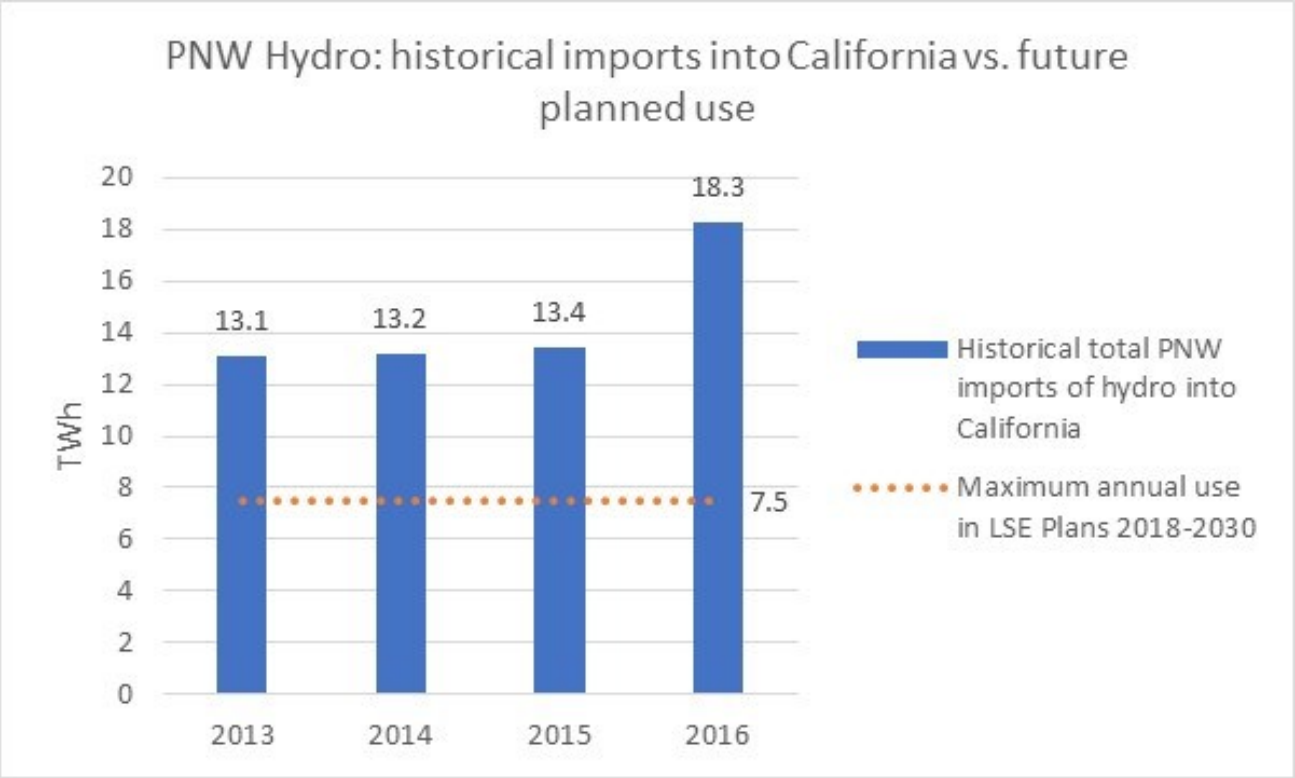
- Key questions analyzed:
  1. Is planned used of PNW feasible (i.e., is resource availability within reasonable expectations)?
  2. Similarly, is planned use of in-state hydro feasible?
- Staff gathered data on:
  - Historical hydro imports
  - Historical in-state hydro production
  - LSEs' planned use of hydro
- Analysis required addition of publicly-owned utilities' (POUs) forecast hydro usage to enable like-for-like comparison to statewide hydro production data

Total Statewide Hydro Use

Planned use of hydro energy by Californian entities, by source region and type, TWh

Source Region	Entity Type	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CAISO	LSE	19.28	20.83	20.58	19.47	20.10	19.95	19.88	19.76	19.58	19.30	19.26	19.17	19.11
Non-CAISO CA	LSE	1.62	1.61	1.69	1.49	1.48	1.87	1.86	0.02	0.02	0.03	0.03	0.03	0.00
Non-CAISO CA	POU	4.92	4.86	4.82	4.79	4.71	4.71	4.70	4.51	4.52	4.73	4.73	4.73	4.73
Out-of-State	LSE	4.87	7.50	6.43	6.58	6.31	6.54	6.61	6.69	6.50	6.56	6.50	6.44	6.39
Total	ALL	30.69	34.78	33.53	32.33	32.59	33.08	33.05	30.99	30.62	30.61	30.51	30.37	30.23

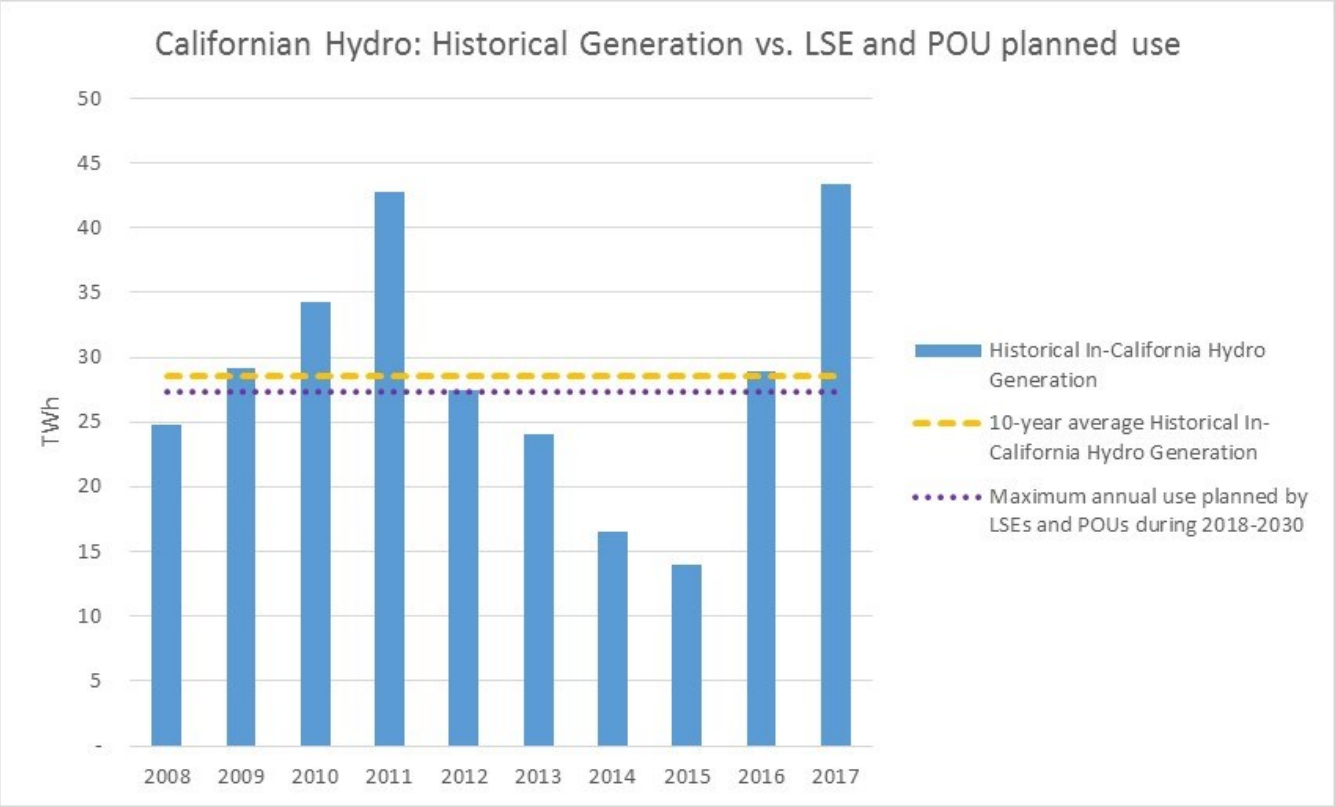
Findings on PNW Hydro



Planned use of PNW hydro is feasible based on historical data

- There appears to be sufficient PNW hydro energy (> 13 TWh/year, even during drought years 2013-2015) to serve the maximum expected LSE need (~7.5 TWh/year)
- Staff have cross-checked this with Northwest Power and Conservation Council's findings from a preliminary study, based on 80 historical water years
- LSEs' planned use of PNW hydro is for energy-only, not capacity

Findings on In-state Hydro



Some risks in planned use of in-state hydro based on historical data

- The maximum planned use of in-state hydro (~27 TWh/year) is only slightly below the average historical generation of years 2008-2017 (~28 TWh/year)
- Historical data indicates high sensitivity to drought conditions, as apparent in years 2013-2015

Conclusions and Next Steps

- The aggregation of LSE portfolios (i.e., Hybrid Conforming Portfolio) is feasible with respect to LSEs' planned use of PNW hydro, based on historical data
- The Hybrid Conforming Portfolio's use of in-state hydro presents some risks based on historical data
- Considerations for the 2019-20 IRP cycle:
  - Revisit RESOLVE's assumption of 8.02 TWh/year of specified hydro from the PNW, which appears too low given historical data
  - Require LSEs to provide a description in their Plans of hedging strategies to address risks of in-state drought
  - Revise the Clean Net Short Calculator to more clearly distinguish between inputs for in-state vs. out-of-state hydro resources
  - Develop filing requirements that enable CPUC staff to analyze and monitor the potential risk of resource shuffling

PCM STUDY OVERVIEW AND INPUT UPDATES

Overall PCM Framework

- The overall modeling approach was described in detail in the September 24, 2018 ruling Attachment B.
- Probabilistic reliability planning approach (e.g. security-constrained planning) – primary goal is to reduce risk of insufficient generation to an acceptable level
- Uses the Strategic Energy Risk Valuation Model (SERVM),* a probabilistic system-reliability planning and production cost model
  - Configured to assess a given portfolio in a target study year under a range of future weather (35 weather years), economic output (5 weighted levels), and unit performance (outages)
  - Simulate hourly economic unit commitment and dispatch
    - With reserve targets to reflect provision of subhourly balancing and ancillary services
    - Multiple day look-ahead informs unit commitment
    - Individual generating units and all 8,760 hours of year are simulated
  - Pipe and bubble representation of transmission system
    - 8 CA regions, 16 rest-of-WECC regions
    - Includes region to region flow limits and simultaneous flow limits

*Commercially licensed through Astrape Consulting: http://www.astrape.com/servm/

Probabilistic Reliability Model Definitions

- Reliability metrics (frequency, duration, and magnitude of reliability events) are reported as expected values (probability weighted averages)
  - To keep run times and file sizes manageable many outputs are aggregated up and/or only reported as an expected value, without reporting the entire distribution.
- Reliability metric definitions – frequency, duration, magnitude:
  - **Loss-of-load event: event** where hourly unit dispatch is unable to serve firm electric demand or necessary reserves (spinning reserves and regulation-up) either by providing capacity or economically curtailing load
  - **Loss-of-Load Expectation (LOLE):** expected **frequency** of loss-of-load events, where multiple events within one day count as one **event** towards the annual total
  - **Loss-of-Load Hours (LOLH):** expected **duration** of unserved electric demand expressed in hours per year, where multiple hours within one day accumulate towards the annual total
  - **Expected Unserved Energy (EUE):** expected **magnitude** of unserved energy, expressed in total MWh of firm electric demand or reserves unserved per year
  - **LOLH/LOLE:** expected average duration of each LOLE event expressed as **hours/event**
  - **Normalized EUE: EUE** normalized by the average annual load level for the target study year
  - **0.1 LOLE per year target:** value for LOLE that corresponds to the "1 day in 10 year" industry standard for probabilistic system reliability, where > 0.1 LOLE indicates a less reliable system and < 0.1 LOLE indicates a more reliable system. There are no commonly accepted standards for the other forms of reliability metrics.

Study Definitions

- Study type definitions:
  - **As-found loss-of-load study:** reliability and production cost study of a given portfolio "as-found" with no changes to the portfolio
  - **Calibrated loss-of-load study:** reliability and production cost study of a given portfolio where additional generation has been added or removed to calibrate the LOLE metric to 0.1 LOLE per year
- Study results presented in the following section compare four types of studies as shown in the table below. All results are for year 2030 unless stated otherwise.

RSP with 2017 IEPR, RESOLVE	RSP with 2017 IEPR, SERVM	Hybrid Conforming, SERVM	Hybrid Conforming, SERVM calibrated LOLE
RESOLVE capacity expansion for the Reference System Plan calibrated to the 2017 IEPR. Results were previously shown in the September 24, 2018 ruling.	SERVM as-found loss-of-load study for the Reference System Plan calibrated to the 2017 IEPR. Results were previously shown in the September 24, 2018 ruling.	SERVM as-found loss-of-load study for the Hybrid Conforming portfolio (which includes a 40 year age-based retirement assumption).	SERVM calibrated loss-of-load study for the Hybrid Conforming portfolio. Additional generation (beyond those retired by the 40 year age-based retirement assumption) has been removed to bring the system to a reliability level of 0.1 LOLE.

Input Updates (1)

- The overall description of inputs was in the September 24, 2018 ruling Attachment B. Inputs have been updated as summarized in the November 15, 2018 ruling.
- The adjusted new build proposed in LSE filings was incorporated.
- Existing units Inland Empire Energy Center Unit 2 (INLDEM_5_UNIT 2, 366 MW) and Gates Peaker (GATES_6_PL1X2, 46 MW) were retired according to the CAISO's recently announced retirement/mothball list.
- BTM PV energy production was scaled down approximately 10% by changing the assumed inverter overloading ratio from 1.1 to 1.0. This more closely matched with the annual energy in the 2017 IEPR demand forecast mid cases.
- Solar PV shapes in SERVM were improved to cap output at AC nameplate. Previously, inverter overloading ratios greater than 1.0 scaled profiles upward without capping output at AC nameplate.

Input Updates (2)

- All fossil-fueled thermal generation units, including cogeneration, were modeled as permanently retired if older than 40 years, unless the unit has a contract that extends its life beyond that point.
- The table below represents the marginal effect of the 40-year assumption in 2030. Note that the previously presented SERVM dataset for the Reference System Plan calibrated to the 2017 IEPR included planned/announced retirements (e.g. once-thru-cooled units). The amounts below represent the ADDITIONAL capacity assumed retired by January 2030 due to the 40-year assumption.

Additional capacity assumed retired by 2030 due to the 40-year assumption, Nameplate MW						
	CCGT	**CT**	**Cogeneration**	**Steam**	**ICE**	**Total**
PGE Bay	0	384	131	0	0	514
PGE Valley	78	25	787	0	0	890
SCE	0	143	1,064	49	0	1,255
SDGE	0	0	109	0	0	109
CAISO	78	552	2,090	49	0	2,768

Input Updates (3)

- Existing out-of-state (OOS) renewables in SERVM were cross-checked with the CPUC's RPS contracts database to determine whether the unit should be modeled as delivering to and balancing within the CAISO, or not. The table below shows the total existing renewables capacity that was changed to deliver to and balance within its home region.
- Certain non-CAISO or OOS gas-fired units are no longer modeled as dynamically scheduled direct imports into the CAISO area. They are now modeled as units economically dispatched primarily into the regions where they are located. This is due to a revised understanding of how dynamically-scheduled resources are used in the CAISO market.

Capacity changed to being economically dispatched in its home region		
Region	**Resource Type or Unit Name**	**Nameplate MW**
IID	Solar PV	75
Various	Wind	2,136
WALC	ARLINT_5_SCEDYN	565
WALC	GRIFFI_2_LSPDYN	570
LADWP	Intermountain_CC_ANAHEIM	159
LADWP	Intermountain_CC_PASADENA	72
LADWP	Intermountain_CC_RIVERSIDE	91
WALC	MSQUIT_5_SERDYN	625
AZPS	YumaCogenCC_Total	63

PCM STUDY SYSTEM RELIABILITY RESULTS

Probabilistic system reliability studies

- Following the steps outlined in the Attachment to the November 15, 2018 ruling, staff used SERVM to conduct probabilistic system reliability and production cost modeling studies for the CAISO area in 2030 with the Hybrid Conforming portfolio
- Staff studied the system "as-found" and found very few loss-of-load events
- Staff then performed a calibrated LOLE study by removing more capacity from the "as-found" system to surface loss-of-load events, up until the point where the LOLE metric reached 0.1 per year
- The following slides present system reliability results and details on the additional capacity that was removed from the "as-found" system to get to the 0.1 LOLE target
- Refer to the preceding PCM Study Overview and Input Updates section for reliability metric and study definitions

Probabilistic system reliability results for the CAISO area, 2030

	RSP w/ 2017 IEPR	Hybrid Conforming	Hybrid Conforming, calibrated LOLE
LOLE frequency (expected outage events/year)	0.00014	0.003	0.142
LOLH duration (hours/year)	0.00014	0.003	0.173
LOLH/LOLE (hours/event)	1.00	1.04	1.22
EUE magnitude (MWh)	0.207	1.21	103.4
annual load (TWh)	254.6	254.6	254.6
normalized EUE (fraction of load)	8.16E-10	4.77E-09	4.06E-07

Findings:

- All loss-of-load metrics (LOLE, LOLH, and EUE) were very small for the Hybrid Conforming Portfolio – the system performed significantly more reliably than the 0.1 LOLE standard (i.e. orders of magnitude less than 0.1)
- The process of calibrating to an LOLE target by removing capacity was coarse. The amount of capacity removed resulted in 0.142 LOLE, moderately overshooting the 0.1 LOLE target
- EUE was approximately 100 MWh for the calibrated LOLE study

EUE MWh, by hour and month, for Hybrid Conforming and Hybrid Conforming Calibrated LOLE

	EUE (MWh), Hybrid Conforming											
Hour Ending	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
19	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.31	0.04	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.02	0.00	0.00	0.13

	EUE (MWh), Hybrid Conforming Calibrated LOLE											
Hour Ending	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
9	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.11
19	0.01	0.02	0.00	0.00	0.00	0.00	0.02	4.74	40.53	0.17	0.07	0.59
20	0.04	0.00	0.00	0.00	0.00	0.00	4.66	33.90	10.91	0.03	0.01	0.11
21	0.00	0.05	0.00	0.00	0.00	0.00	0.54	2.24	3.70	0.06	0.09	0.02
22	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.05
23	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
24	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Findings:

- The approximately 100 MWh EUE for the calibrated LOLE system mostly occurred in July-September, Hour Ending 19, 20, and 21 (6 PM – 9 PM).

NOTE: The table only shows hours with nonzero EUE in at least one month. The graded color scale shows the magnitude of the EUE in a given month-hour. Red indicates the largest EUE, followed by orange, yellow, and green.

Methodology for removing capacity in calibrated LOLE study

- Capacity was removed according to the modeling convention described in the November 15, 2018 ALJ ruling attachment:
  - Conventional thermal generators that have announced their retirement will be removed first. If LOLE remains below the target level, additional conventional thermal generation will be removed from CAISO areas in amounts proportional to service area load in each area. The oldest generation in each area will be removed first. No hydro generation or renewable generation will be removed.
- Removed capacity is not indicative of specific excess resources or lack of need for resources in local areas. It is purely an effort to surface system reliability events that do not occur when modeling the Hybrid Conforming Portfolio as found.

Capacity removed from CAISO by 2030, by resource type and region (MW), in order to calibrate to 0.1 LOLE

	CCGT	CT	Cogeneration	Steam	ICE	Total
PGE Bay	102	0	234	0	0	336
PGE Valley	637	192	91	12	49	980
SCE	855	306	82	0	0	1,243
SDGE	0	193	43	0	0	236
CAISO	1,594	691	450	12	49	2,795

NOTE: The capacity removed in the table above is in addition to the capacity assumed permanently retired by 2030 due to the Hybrid Conforming Portfolio 40 year age-based retirement assumption

Interpreting the system reliability results

- The “as-found” system was significantly more reliable than the 0.1 LOLE industry standard (i.e. much less than 0.1)
- Additional capacity was removed to surface reliability events. This could be representative of excess system capacity existing above what is sufficient to adequately meet load and reserves. The purpose of doing this and showing these results is to demonstrate how much of a margin we have with regards Loss of Load specifically, and what that fleet does in operating terms.
- Capacity was removed according to a modeling convention and is not meant to predict retirement of units individually or in aggregate. The calibrated LOLE system does not represent a projection of future resource levels or mixes.
- This does not represent a complete reliability assessment, as CPUC staff did not explicitly evaluate sub-hourly flexibility (ramping) needs nor Local Resource Adequacy (RA) needs
- Hybrid Conforming Portfolio reliability results did record events of shortages of targeted non-spinning reserves. These events occurred somewhat more often than loss-of-load events. However, shortages of targeted non-spinning reserves were not defined as a reliability event and were not analyzed.

PCM STUDY OPERATIONAL RESULTS

System operational results

- The SERVM probabilistic system reliability studies also report production cost modeling metrics and represent the operational performance of a given portfolio and study year, under a range of future weather and economic output
- Staff studied the 2030 Hybrid Conforming portfolio, and the 2030 Hybrid Conforming portfolio calibrated to a 0.1 LOLE target. The following slides report these results and compare them to previously presented results from (1) the RESOLVE RSP with the 2017 IEPR demand forecast, and (2) the SERVM RSP with the 2017 IEPR. Those results were previously presented in the September 24, 2018 ALJ ruling seeking comment.
- Reported on the following slides:
  - System energy balance and generation by resource class
  - Monthly import and export flows
  - Monthly curtailment
  - Hourly dispatch and market price for selected days
  - Annual RPS % for CAISO area
  - Annual production costs for CAISO area

CAISO system balance in 2030

CAISO System balance verification, GWh	RSP with 2017 IEPR, RESOLVE	RSP with 2017 IEPR, SERVM	Hybrid Conforming, SERVM	Hybrid Conforming, SERVM calibrated LOLE
Generation serving CAISO load: includes BTMPV and direct imports; excludes storage discharge and non-PV load modifiers	254,749	269,484	247,300	239,046
Unspecified Imports	12,709	10,985	25,621	32,214
Load after reduction from non-PV load modifiers	255,038	254,601	254,597	254,584
Unspecified Exports	5,686	13,862	9,377	8,424
Battery and Pumped Storage Hydro losses (net of charge and discharge)	3,811	949	1,080	1,129
Curtailment	2,923	11,055	7,866	7,124

- The Hybrid Conforming Portfolios have more imports, less exports, and less curtailment than the RSP with 2017 IEPR, due to decreased in-CAISO generation, including base load resources such as geothermal and cogeneration

NOTES:

- *Green items are "credits" that increase energy in a region, red items are "debits." Total credits minus total debits equals 0*
- *Non-PV load modifiers are the net effect of AAEE, EV, and TOU rates*
- *Generation serving CAISO load amounts are BEFORE curtailment*
- *RESOLVE uses the hourly net of charge and discharge (storage losses) for hourly energy balance (shown in table above). Subhourly charge and discharge is separately tracked in RESOLVE and not included in the RESOLVE value above.*

CAISO generation by resource class in 2030

Generation serving CAISO load by resource type in GWh including in-CAISO generation and direct (specified) imports	RSP with 2017 IEPR, RESOLVE	RSP with 2017 IEPR, SERVM	Hybrid Conforming, SERVM	Hybrid Conforming, SERVM calibrated LOLE
Combined Cycle Gas Turbine (CCGT)	69,371	71,208	74,512	68,271
Combustion Turbine (CT)	26	2,328	2,934	3,450
Steam	0	141	67	0
Coal	0	0	0	0
Biomass	6,792	1,931	2,591	2,630
BTMPV	36,295	42,621	38,746	38,746
Solar PV Fixed + Tracking and Solar Thermal	50,248	52,560	53,587	53,585
Wind	22,579	28,060	24,720	24,720
Scheduled Hydro Plus Run-of-River Hydro	25,317	28,490	28,490	28,491
Geothermal	24,357	23,729	11,293	11,291
Cogeneration	14,759	12,779	5,080	2,696
Nuclear	5,004	5,459	5,459	5,459
Internal Combustion Engine (ICE)	0	179	268	154
Generation subtotal before curtailment	254,748	269,485	247,748	239,493
Curtailment	-2,923	-11,055	-7,866	-7,124
Generation total after curtailment	251,825	258,430	239,882	232,369

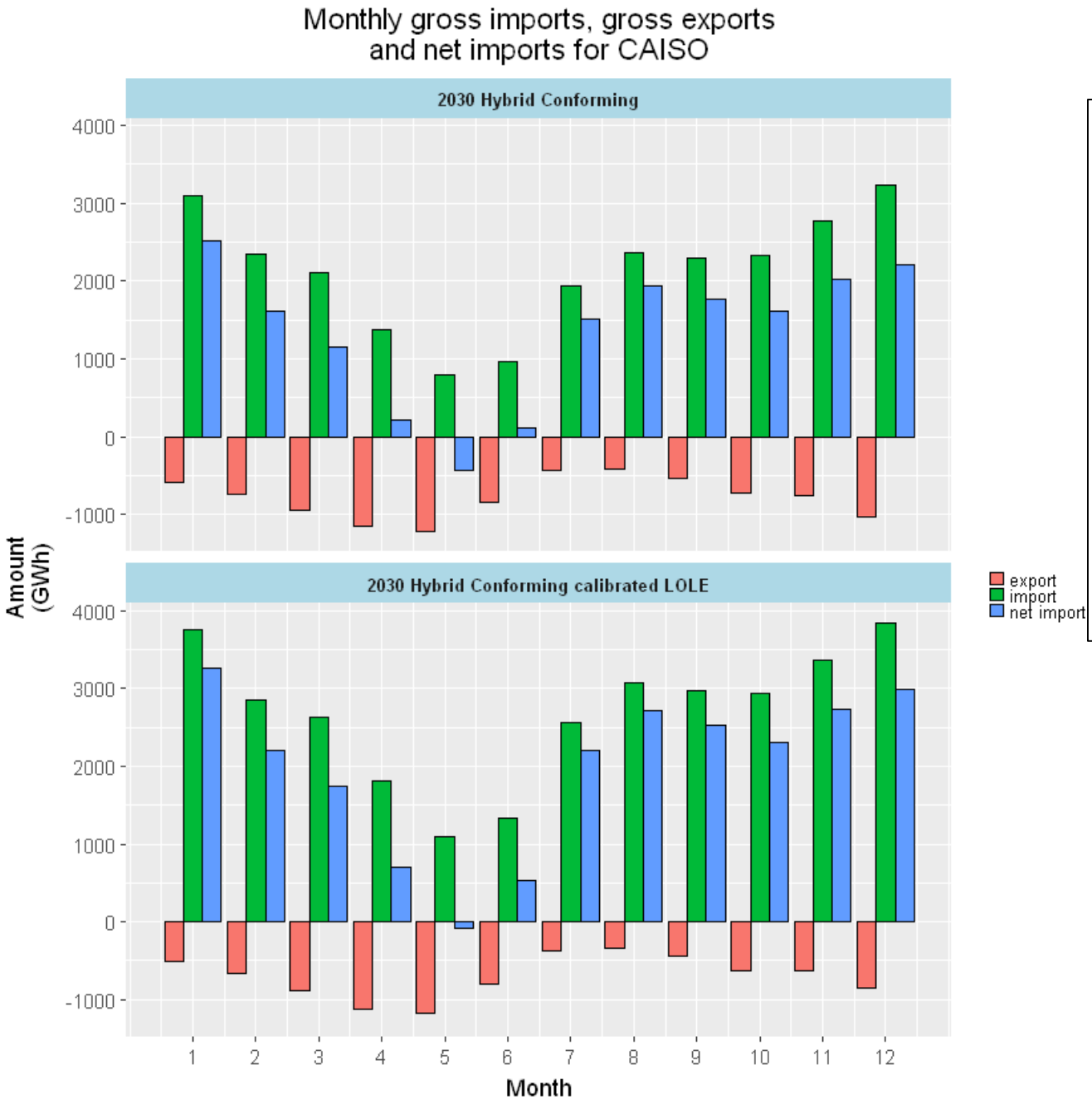
- By default, RESOLVE reports wind and solar generation after curtailment and does not report generation before curtailment. Staff calculated RESOLVE wind and solar generation before curtailment to produce the comparison values in the table above.
- Storage charge/discharge and unspecified imports/exports are not included in this table.

Differences between RESOLVE and SERVM for the RSP with the 2017 IEPR

- Comparisons between RESOLVE and SERVM for the RSP with the 2017 IEPR (first two numerical columns in the preceding table) were previously explained in the September 24, 2018 ruling. In summary:
  - SERVM's dispatchable thermal units were in aggregate less flexible than assumed in RESOLVE, which would contribute to SERVM relying on more peaker use over CCGT use to provide flexibility
  - Some of SERVM's "must-run" units could have a portion of their output economically dispatched whereas RESOLVE's "must-run" units were always running at full output. Thus, SERVM's "must-run" production tended to be less than RESOLVE's.
  - Relative to RESOLVE, SERVM counted more OOS renewables as delivering to CAISO load, and more OOS gas generation as directly importing to the CAISO area, thus contributing to differences in wind and gas generation totals, and import totals.

Differences between SERVM's modeling of the RSP with the 2017 IEPR and the Hybrid Conforming Portfolio

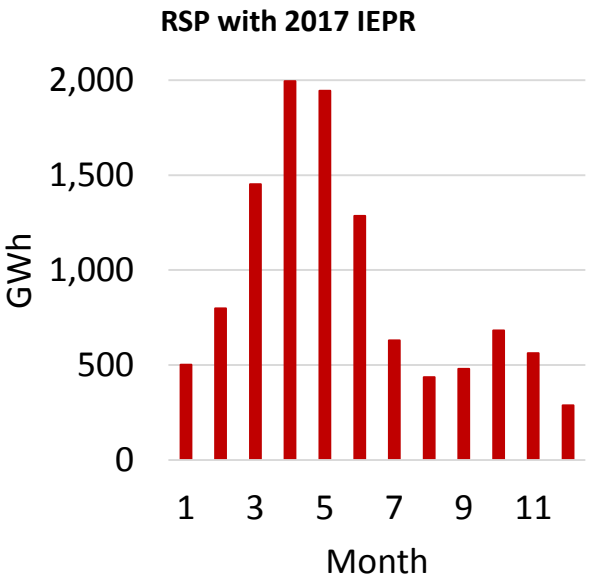
- The Hybrid Conforming Portfolio had less installed capacity from geothermal, wind, and fossil thermal (CCGTs, CTs, and cogeneration), as well as lower assumed BTM PV energy production (reduced capacity factor), each contributing to reductions in annual generation
- The Hybrid Conforming Portfolio had significantly higher unspecified imports to make up for the reduced amounts of in-CAISO generation
- Curtailment in the Hybrid Conforming Portfolio went down because the system had less "must-take" generation
- When additional capacity was removed in the Hybrid Conforming Portfolio calibrated LOLE study, unspecified imports further increased and curtailment further decreased. The additional capacity removed contributed to increased ability to use more renewable output to serve load and increased peaker use to integrate the renewables.
- The changes in the Hybrid Conforming Portfolio from the RSP with the 2017 IEPR also resulted in emissions differences as will be explained later in this presentation.

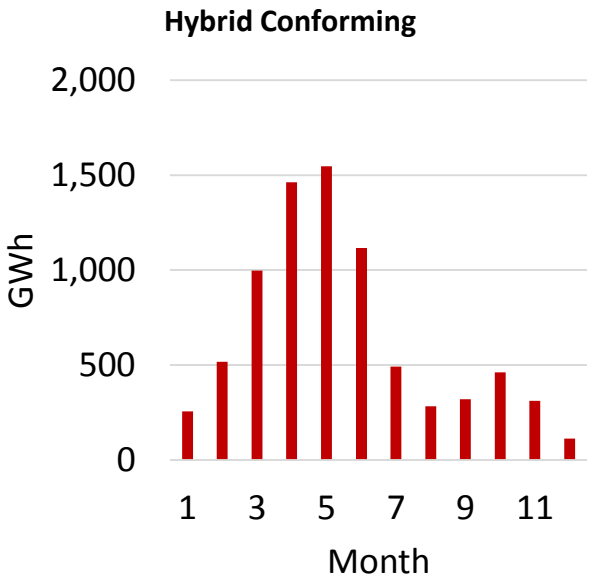


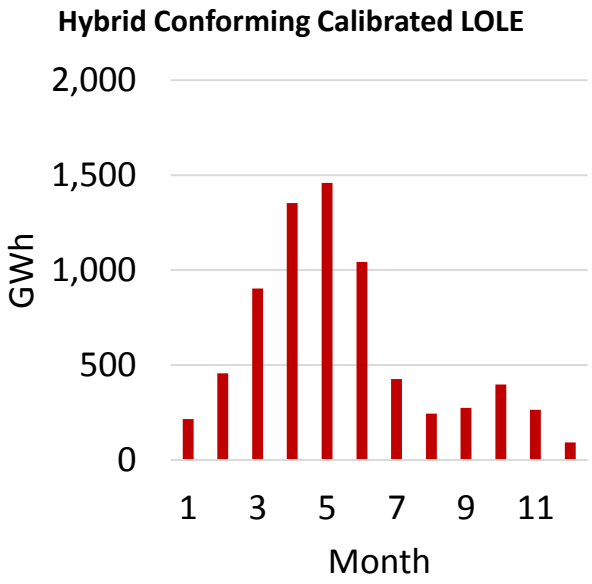
Unspecified imports and exports

CAISO is a net importer for 11 out of 12 months in both the Hybrid Conforming and Calibrated LOLE cases. This is due to decreased reliance on in-CAISO generation due to retiring old plants.

Hybrid Conforming Portfolio CAISO area curtailment decreased moderately relative to RSP with 2017 IEPR SERVM results







Case	2030 Curtailment GWh
RSP with 2017 IEPR	-11,055
Hybrid Conforming	-7,866
Hybrid Conforming Calibrated LOLE	-7,124

- Monthly pattern of curtailment was consistent across all SERVM cases, highest in late spring months.
- Overall level of curtailment dropped between RSP with 2017 IEPR case and the Hybrid Conforming cases – due to input changes including less BTM PV energy, less wind capacity counted as within CAISO, and less baseload geothermal and cogeneration capacity.
- Curtailment dropped a bit more in Hybrid Conforming Calibrated LOLE case – due to even less cogeneration capacity left in the system.

Explanation of how curtailment is modeled in SERVM

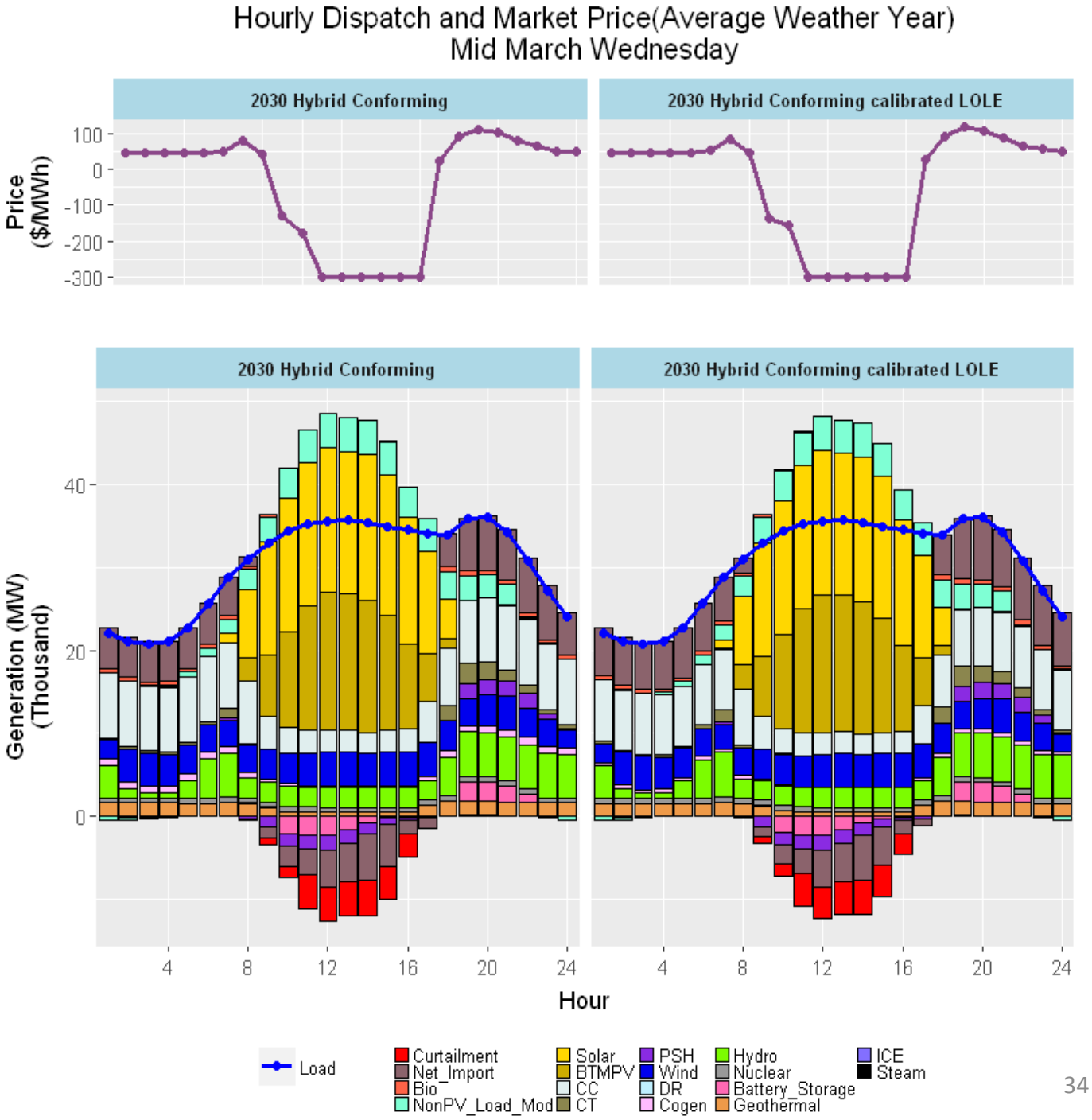
- Energy is dispatched to meet load, but when there is excess energy, some is curtailed.
  - SERVM attempts to sell excess generation over what is needed to meet load.
  - When that ceases to be economical, dispatchable generation is shut down to the extent possible, but sometimes generation cannot be immediately shut down or must be kept at minimum to enable it to serve load later in the day or to provide operational reserves.
  - When generation cannot be economically shut down and energy cannot be sold economically or used to charge storage there is curtailment.
  - In the presence of curtailment, an overgeneration penalty is applied. At low levels of curtailment, the penalty does not overwhelm the other market transactions, but at high levels of curtailment, energy prices have fallen below zero due to the large size of the penalty ($300/MWh) applied in SERVM.
  - Market energy pricing as implemented is a gradient, and negative pricing depends on the quantity of curtailment or if some units have free or low cost curtailment specified.

Hourly Generation Mix and Energy Price

- The purpose of showing hourly dispatch plots is to validate that the model shows realistic dispatch and market price patterns, and to compare with similar results from other production cost models
- The following slides show samples of hourly generation mix and energy price for the Hybrid Conforming portfolio and the Hybrid Conforming calibrated to 0.1 LOLE, under the following conditions:
  - Wednesday mid March, typical weather
  - Wednesday mid March, hot weather
  - Wednesday mid August, typical weather
  - Wednesday mid August, hot weather
- Significant amounts of spring midday excess energy were exported and curtailed, or used to charge storage for use later in the day, consistent with observations shown on earlier slides
- Dispatch patterns were similar between the Hybrid Conforming portfolio and the Hybrid Conforming calibrated to 0.1 LOLE SERVM cases, despite the latter having about 2,800 MW less fossil thermal. The exception was somewhat higher net imports in the latter case, consistent with results shown earlier.

50th percentile March weather (1989, case 43 of 175)

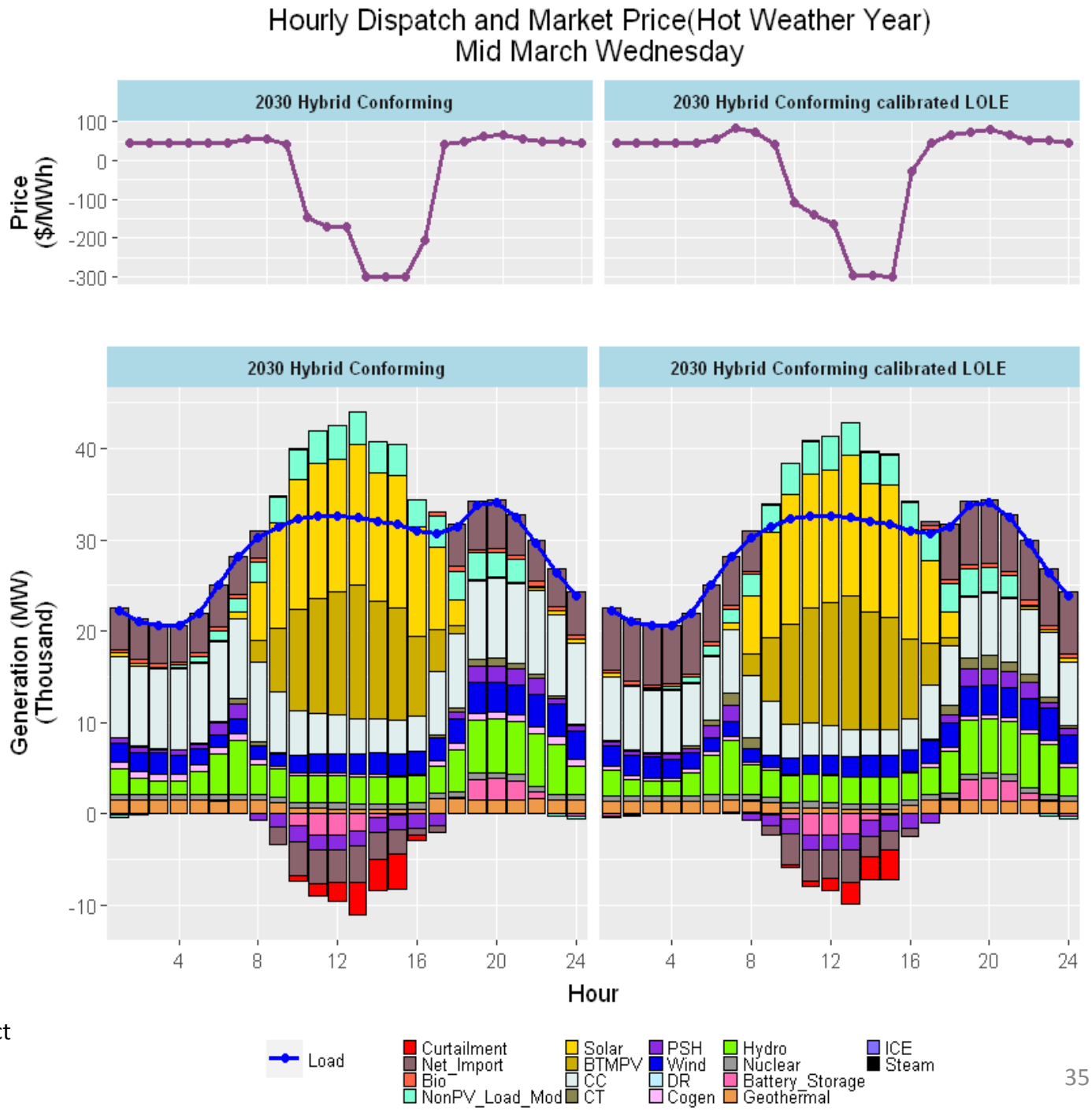
A spring day with median temperatures, negative midday price, and curtailment. System is a net importer when solar is unavailable.



PSH = Pumped Storage Hydro
NonPV_Load_Mod = net effect of AAEE, EV load, and TOU

90th percentile March weather (2004, case 118 of 175)

A spring day with hot temperatures, negative midday price, and curtailment. System is a net importer when solar is unavailable.

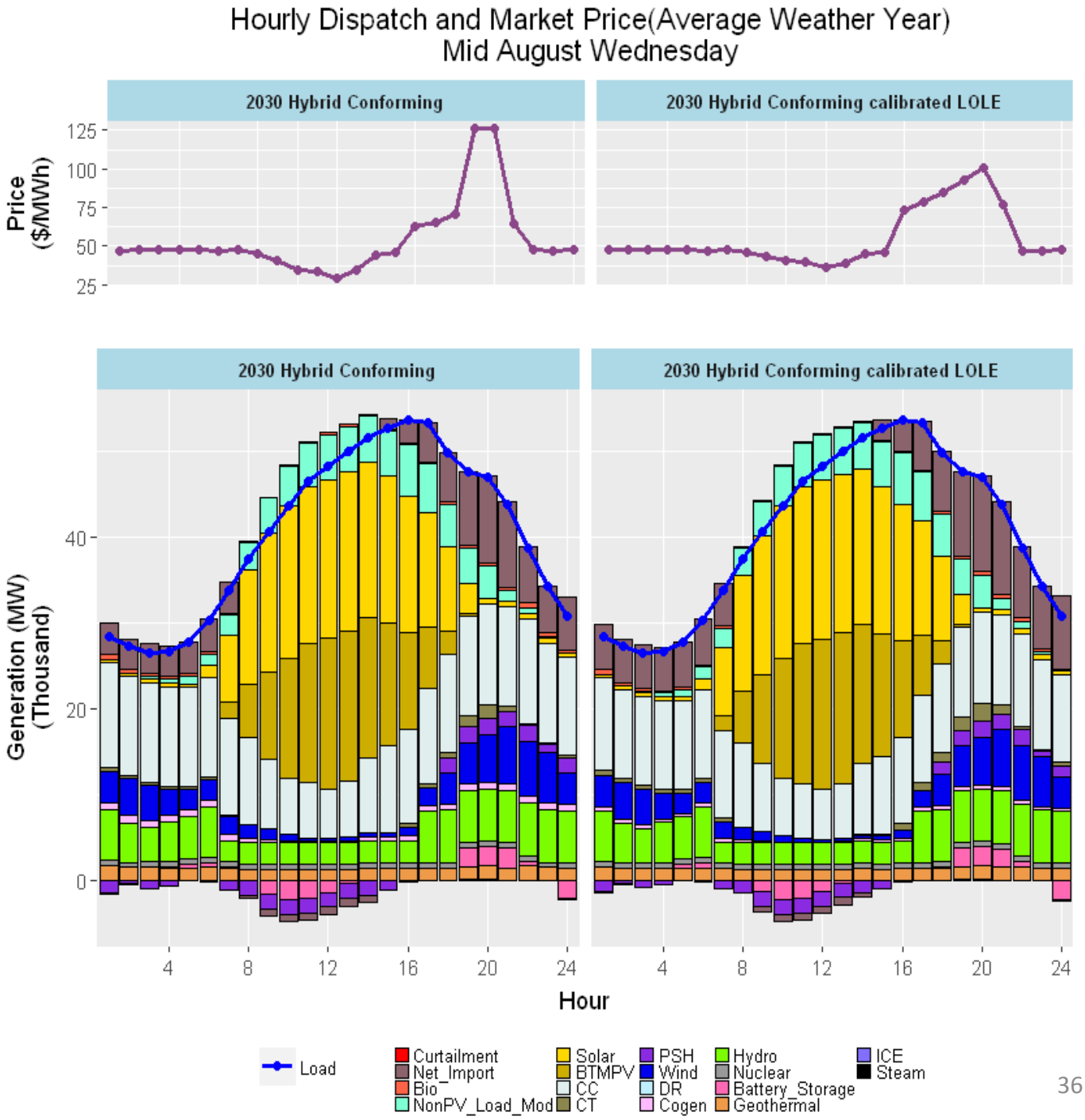


PSH = Pumped Storage Hydro
NonPV_Load_Mod = net effect of AAEE, EV load, and TOU

50th percentile August weather (1986, case 28 of 175)

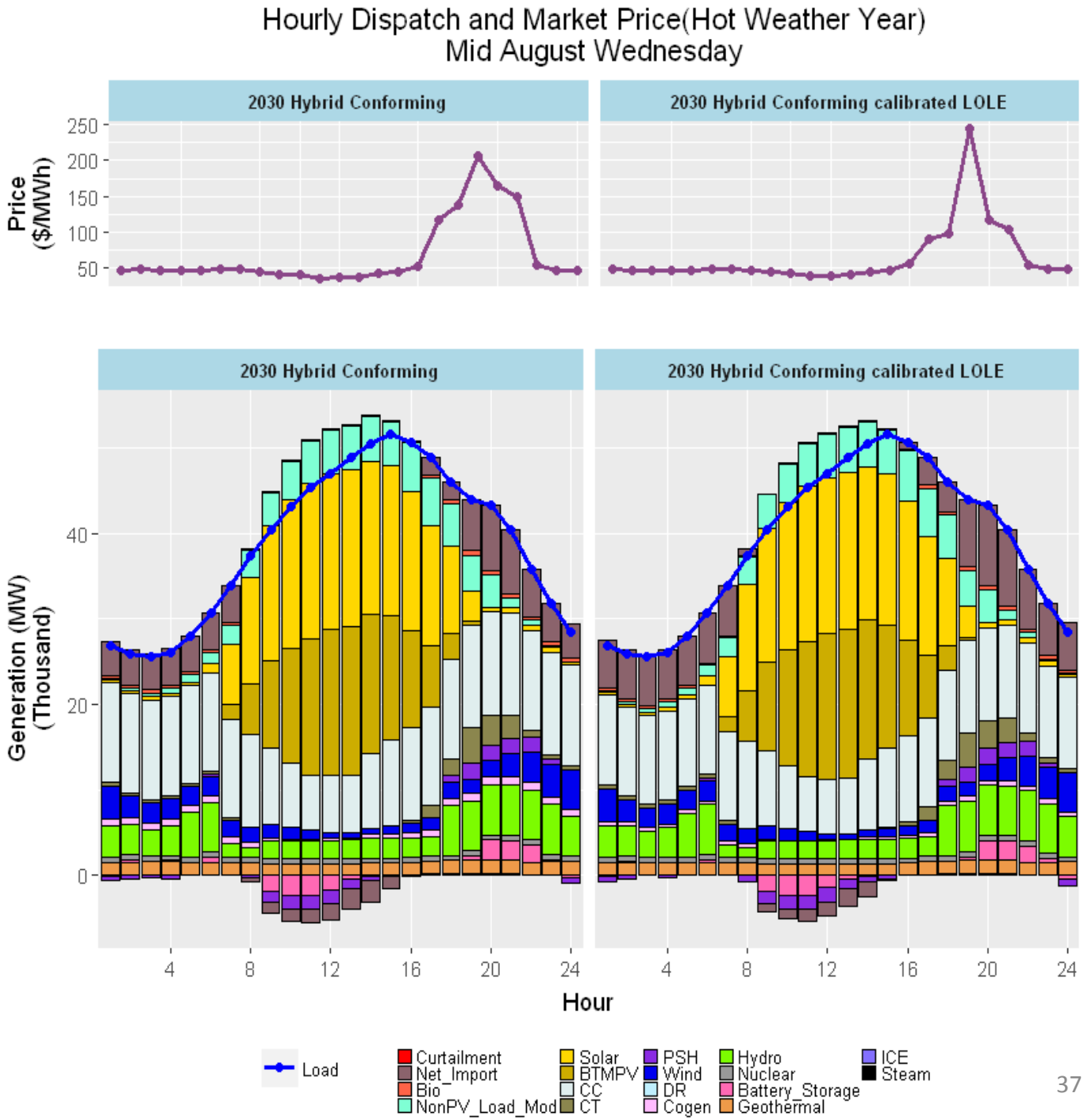
A summer day with median temperatures. There is a price spike for the Hybrid Conforming system around 7-8 PM, possibly due to start up costs of CTs to meet the evening ramp. CTs start up more gradually in the LOLE case, thus the price spike is gradual and spread over a few hours. Curtailment is not significant since load is generally high enough when supply is plentiful.

PSH = Pumped Storage Hydro
NonPV_Load_Mod = net effect of AAEE, EV load, and TOU



90th percentile August weather (2009, case 143 of 175)

A summer day with hot temperatures and higher prices in the 6-9pm hours. Again this is seemingly due to startup of CTs in a group to meet evening ramp.



PSH = Pumped Storage Hydro
NonPV_Load_Mod = net effect of AAEE, EV load, and TOU

Hybrid Conforming Portfolio achieves at least 50% RPS in 2030

CAISO area RPS% calculation comparison		RESOLVE	SERVM	Hybrid Conforming	Hybrid Conforming Calibrated LOLE
Metric	***Unit***	**2030**	2030	2030	2030
T&D Losses	*%*	7%	7%	7%	7%
Pumping Loads - not grossed up for losses	*GWh*	8,781	8,781	8,781	8,781
Customer_PV (btmpv)	*GWh*	36,295	42,621	38,746	38,746
System Load after non-btmpv load-modifiers & before btmpv reductions	*GWh*	255,038	254,601	254,597	254,584
Metric	***Unit***	**2030**	2030	2030	2030
Delivered RPS Renewables after Scheduled Curtailment	*GWh*	109,136	101,949	91,051	91,826
Non-Modeled RPS Renewables (AESO wind mainly)	*GWh*	2,655			
RPS Spent Bank	*GWh*	8,441	8,441	8,441	8,441
Storage Losses Subtracted from RPS	*GWh*	1,961	949	1,080	1,129
Scheduled Curtailment	*GWh*	2,923	11,055	7,866	7,124
Subhourly Curtailment	*GWh*	1,936			
RPS-bound Retail Sales	*GWh*	193,929	187,661	191,248	191,236
Curtailment (scheduled and subhourly)	*% of RPS Renew.*	4.2%	9.8%	8.0%	7.2%
Curtailment and Storage Losses	*% of RPS Renew.*	5.9%	10.6%	9.0%	8.3%
Delivered Effective RPS Percentage - Excl. Spent Bank	*% of Retail Sales*	55.6%	53.8%	47.0%	47.4%
Spent Bank	*% of Retail Sales*	4.4%	4.5%	4.4%	4.4%
Delivered Effective RPS Percentage - Incl. Spent Bank	*% of Retail Sales*	60.0%	58.3%	51.5%	51.8%

- **Hybrid Conforming had less geothermal, moderately less existing OOS wind counted as in-CAISO, and moderately higher retail sales from less BTM PV energy – leading to a lower calculated CAISO RPS percent**
- Delivered renewables energy including banked RECs must be a certain percentage of "RPS-bound Retail Sales"
- RPS-bound Retail Sales = [System Consumption Load – (Load Modifiers + Btm Pv)] * [1 – T&D Losses] – Pumping Load
- In this context, "PumpingLoad" refers to agricultural/CDWR water pumping load, not pumped hydro storage charging
- Delivered renewables energy = RPS-eligible production – Total Curtailment – Net Losses from storage charging and discharging

2030 CAISO operating costs, $MM

CAISO area operating cost comparison	RSP with 2017 IEPR, RESOLVE	RSP with 2017 IEPR, SERVM	Hybrid Conforming, SERVM	Hybrid Conforming Calibrated LOLE, SERVM
Emissions (from fuel)	859	Operating costs were not calculated for this case due to a small error in fuel prices which would have distorted costs. This error did not materially affect dispatch, so the previously presented dispatch results for this case remain valid.	945	845
Fuel (includes starts)	2,728 (does not include start fuel)		3,266	3,001
Starts	404		30	29
VOM	525		334	313
Direct Imports (cost)	Counted as in-CAISO generation		132	132
Unspecified Imports (cost, including CO2 adder)	555		1,234	1,844
Direct Exports (revenue)	N/A		(1)	(1)
Unspecified Exports (revenue)	(195)		(310)	(282)
Energy credit for OOS renewables contracted to CAISO	(271)		Not calculated	
Total Operating Costs	**4,605**	**N/A**	**5,631**	**5,880**

- **Hybrid Conforming Portfolios relied more heavily on imports, thus the import cost category was higher, consistent with results shown earlier. This may contribute to overall higher operating costs.**
- Positive numbers represent costs from in-region generation and imports, negative numbers represent revenues (from sales of power to neighboring regions)
- Some of the cost categories in RESOLVE do not match well with the cost categories in SERVM, adding to the comparison challenge. More RESOLVE and SERVM model alignment work is planned for the 2019 IRP Reference System Plan development process.
- "Energy credit for OOS renewables contracted to CAISO" represents revenue from energy sales to non-CAISO areas from renewables contracted to CAISO LSEs. This credit was not calculated for the Hybrid Conforming Portfolios.

PCM STUDY EMISSIONS RESULTS

Refresher: IRP GHG planning targets and previously presented emissions results

- The February 2018 IRP decision, D.18-02-018, adopted an electric sector 42 MMT in 2030 planning target, statewide
- This translated to a 34 MMT in 2030 planning target for the CAISO footprint, assuming CAISO share of statewide electric sector emissions is about 81%
- RESOLVE does not count BTM CHP emissions as part of electric sector emissions, whereas CARB's California Greenhouse Gas Emissions Inventory and Scoping Plan do. Results compiled from SERVM attempt to follow the same counting convention as RESOLVE, excluding any emissions from BTM CHP (generally the non-PV self-generation component of the IEPR demand forecast).
- Previously presented SERVM modeling of the RSP with the 2017 IEPR reported higher emissions (38 MMT in 2030) than RESOLVE (34 MMT in 2030). This was due to a number of differences between the two models that remain to be reconciled. Much better agreement between the two models is anticipated in the next (2019) IRP RSP development process.
- The Hybrid Conforming Portfolio is significantly different from the current RSP with the 2017 IEPR and will have different emissions. Results for CO2 emissions as well as criteria pollutants (NOx, PM2.5) are presented in the following slides.

2030 CO2, NOx, PM2.5 emissions, by region

CAISO	Units	RSP with 2017 IEPR, SERVM	Hybrid Conforming, SERVM	Hybrid Conforming, SERVM calibrated LOLE
CO2	MMT	38.2	42.7	41.9
NOx Total	Metric Ton	4,019	3,491	3,173
NOx Steady-state	Metric Ton	3,650	3,190	2,877
NOx Starts	Metric Ton	370	301	296
PM2.5	Metric Ton	2,056	1,943	1,736
California	**Units**	RSP with 2017 IEPR, SERVM	Hybrid Conforming, SERVM	Hybrid Conforming, SERVM calibrated LOLE
CO2	MMT	48.1	49.6	49.2
NOx Total	Metric Ton	5,116	4,659	4,404
NOx Steady-state	Metric Ton	4,586	4,198	3,932
NOx Starts	Metric Ton	530	461	471
PM2.5	Metric Ton	2,594	2,525	2,342
WECC	**Units**	RSP with 2017 IEPR, SERVM	Hybrid Conforming, SERVM	Hybrid Conforming, SERVM calibrated LOLE
CO2	MMT	266.45	270.42	270.07

NOTES:

For CAISO and California:

- *CO2 emissions are from all generation to serve load including unspecified imports.*
- *NOx and PM2.5 emissions are from in-state generation and specified imports only.*

For the entire WECC region:

- *CO2 emissions are equal to the sum of CO2 emissions from all generators in the WECC.*

CAISO CO2 Emissions in 2030: Detailed breakdown

Thermal generation serving CAISO load and CO2 emissions	RSP with 2017 IEPR, RESOLVE	RSP with 2017 IEPR, SERVM	Hybrid Conforming, SERVM	Hybrid Conforming, SERVM calibrated LOLE
In-CAISO and gross direct imports thermal generation in GWh	84,156	86,635	82,861	74,571
In-CAISO and gross direct imports CO2 emissions in MMT	31.38	36.29	34.53	30.86
In-CAISO and gross direct imports average emissions factor in MT/MWh	0.373	0.419	0.417	0.414
Gross unspecified imports in GWh	12,709	10,985	25,621	32,214
Gross unspecified imports CO2 emissions in MMT	5.44	4.70	10.97	13.79
Gross unspecified imports average emissions factor in MT/MWh	0.428	0.428	0.428	0.428
NW Hydro Credit in MMT	-2.8	-2.8	-2.8	-2.8
Total CO2 emissions in MMT	**34.0**	**38.2**	**42.7**	**41.9**

NOTES:

- *These emissions totals only include fossil resources. They do not include emissions from biomass, biogas, or geothermal.*
- *The NW Hydro Credit is an adjustment inherited from RESOLVE to account for assumed amounts of specified hydro imports coming from the Pacific Northwest into California.*
- *The unspecified imports in all cases likely include some amount of GHG free resources that are under energy and REC contracts with CAISO LSEs. This implies that the CO2 emissions contribution from unspecified imports are likely a high bookend estimate.*

Conclusions on CO2 Emissions

- Although CAISO thermal generation is lower in the Hybrid Conforming than in the RSP (partially due to moving OOS Combined Cycles to their "home" region), emissions are higher in the Hybrid Conforming plans due to:
  - An increased reliance on unspecified imports (to replace generation removed with the 40 year retirement assumption for thermal resources)
  - Less geothermal and existing OOS wind serving CAISO load, and lower BTM PV energy production.
  - LSEs in their IRP plans are partially responsible for the increased emissions, as they recommended greater reliance on solar and wind and less on geothermal, which resulted in less baseload renewable generation, less RPS eligible energy, and greater reliance on imported energy.
- The Hybrid Conforming calibrated LOLE results show that removing even more fossil thermal may reduce some curtailment of renewables, and thereby lower emissions modestly. However, this increases the likelihood of loss-of-load.

Conclusions on CO2 Emissions (cont'd)

- Comparing the Hybrid Conforming study to the Hybrid Conforming Calibrated LOLE study, WECC-wide CO2 emissions decreased only slightly (by 0.35 MMT CO2) due to the retirement of in-CAISO fossil resources. This is because these generators were replaced by increased use of out-of-state thermal resources, especially coal and CC plants.
- Overall emissions declined however due to removal of some generation that was likely to contribute to curtailment (like cogeneration).
- This is shown in the table below. Green numbers represent reductions in carbon emissions, red numbers represent increases.

Change in MMT of CO2 emissions by region and unit type, Hybrid Conforming Study minus Hybrid Conforming Calibrated LOLE study

	CAISO	Non-CAISO CA	OOS	**Total**
CC	-2.72	0.30	1.11	**-1.32**
Coal	0.00	0.00	1.34	**1.34**
CT	0.33	0.12	0.40	**0.84**
Cogen	-1.15	0.00	0.00	**-1.15**
ICE	-0.06	0.00	0.00	**-0.06**
Steam	-0.05	0.00	0.05	**0.00**
Total	**-3.66**	**0.42**	**2.90**	**-0.35**

Methods and assumptions for estimating criteria pollutant emissions

- CPUC staff estimated total NOx and PM 2.5 emissions as the sum of emissions from steady-state operations and hot, warm, and cold starts
  - Staff used fuel burn, number of hot/warm/cold starts, and MWh generation output from SERVM, applying appropriate emissions factors
  - For NOx, staff used higher emissions factors for hot, warm, and cold starts compared to steady-state
  - Where information on generator subtype was available (e.g. CCGTs can be divided into Aero CC, Single Shaft CC, Industrial CC, etc.), staff used that subtype to determine emissions factor, as emissions can vary substantially across subtype
  - No factors for "warm" starts were available, so staff used a simple average of hot and cold factors as an estimate
  - Data sources were itemized in the September 24, 2018 ruling
- Criteria pollutant emissions were counted from in-CAISO thermal generation only. Unspecified import criteria pollutants are not counted.
- Staff calculated emissions for all of CA, and grouped by whether the plant was located in a Disadvantage Community (DAC) area or not. Staff used this list to determine the location of plants with respect to DACs: RESOLVE Post-Processing Air Pollution and DAC Analysis 2017-09-19

Corrections to previous criteria pollutant results

- The results presented in the September 24, 2018 ruling contained a minor error in calculating start emissions from NOx. Warm start and cold start emissions factors were mistakenly transposed and mislabeled. Warm start factors were erroneously applied to cold starts, and vice versa. Staff appreciates parties finding this error and has corrected it.
- Staff investigated the impact of this error on the SERVM results for the RSP with the 2017 IEPR and found that California NOx emissions were overstated by about 100 metric tons in 2030. The old result is 5,245 metric tons NOx (statewide), and the new corrected result is 5,116 metric tons (statewide).
- Staff has posted the updated emissions factors table at the URL below: ftp://ftp.cpuc.ca.gov/resources/electric/irp2019/Table1_Clarifications.PNG
- This table also contains a correction for a data entry error in the hot start values, but this was a copy-paste error that was introduced when posting the table, after the calculations were performed. Staff confirmed that the correct hot start value was used in the calculation.

Details: Hybrid Conforming 2030 California NOx, PM2.5 emissions

NOx emissions in metric tons, by operation state and resource type							
	CC	CT	Coal	Cogen	ICE	Steam	TOTAL
steady state	3,314	391	0	429	60	5	4,198
hot start	87	40	0	3	2	0	132
warm start	21	209	0	2	11	0	244
cold start	32	48	0	2	3	0	86
total	3,455	688	0	436	76	5	4,659

PM 2.5 emissions in metric tons, by resource type							
	CC	CT	Coal	Cogen	ICE	Steam	TOTAL
steady state	2,187	155	0	168	12	3	2,525

NOTES:

- *NOx and PM2.5 emissions are from in-state generation. CC = Combined Cycle, CT = Combustion Turbine, ICE = Internal Combustion Engine.*
- *The Sept. 2017 Proposed Reference System Plan analysis estimated NOx from CCs in steady state as roughly 2,700 metric tons in 2030, statewide. This SERVM analysis estimates 3,314 metric tons in 2030, statewide. SERVM's higher number is due to multiple factors: some of SERVM's CCs were assigned higher NOx emissions factors based on technology, and CCs run more in SERVM than in RESOLVE.*

Details: 2030 Hybrid Conforming NOx and PM2.5 emissions (Metric Tons) for all California, grouped by plants located inside/outside Disadvantaged Communities areas

		Inside DAC Emissions							Outside DAC Emissions						
		CC	CT	Coal	Cogen	ICE	Steam	TOTAL	CC	CT	Coal	Cogen	ICE	Steam	TOTAL
NOx emissions, by operation state and resource type	steady state	761	146	0	55	0	0	962	2,553	244	0	374	60	5	3,236
	hot start	29	16	0	1	0	0	46	58	25	0	1	2	0	86
	warm start	1	52	0	0	0	0	53	21	158	0	2	11	0	191
	cold start	1	10	0	0	0	0	11	31	38	0	1	3	0	74
	total	792	223	0	57	0	0	1,072	2,663	465	0	379	76	5	3,587
PM 2.5 emissions	total	543	55	0	23	0	0	621	1,644	100	0	145	12	3	1,904
Capacity in region, MW		5,466	3,106	0	299	0	0	8,871	16,678	7,274	0	957	211	12	25,132

NOTE: This table estimates emissions from plants and groups them by location inside and outside DAC areas. This DOES NOT estimate how these emissions impact air quality inside or outside of DAC areas. Air quality is influenced by multiple factors including accounting for wind patterns and other emissions sources, and requires analysis beyond what was done here.

PCM STUDY CONCLUSIONS AND RECOMMENDATIONS

High Level Conclusions

- Significant progress has been made developing the SERVM model dataset and exercising Energy Division staff's production cost modeling process both modeling the Reference System Portfolio and the Hybrid Conforming Portfolio
- Staff modeled the Hybrid Conforming Portfolio and found:
  - Minimal LOLE orders of magnitude less than the 0.1 LOLE industry standard and minimal EUE when implementing the 40 year retirement assumption.
  - When surfacing LOLE by removing about 2,800 MW of fossil capacity from the system, staff observed LOLE mostly in the summer months.
  - Some reliability and production cost effects observed from differences between the Reference System Portfolio with the 2017 IEPR and the Hybrid Conforming Portfolio which was based on LSE filings
- The Hybrid Conforming Portfolio produced higher emissions and energy balance than the Reference System Portfolio
  - Curtailment decreased from retirement of some baseload generation, less geothermal, less BTM PV energy production, and less existing OOS wind counted as in-CAISO
  - In-CAISO generation replaced by some increase in imports, which result in higher production cost and total emissions

High Level Recommendations

- Staff recommendations:
  - The Commission should adopt the Hybrid Conforming Portfolio as the 2018 Preferred System Portfolio for this IRP 2017-18 cycle.
  - The Hybrid Conforming Portfolio reflects LSE planning preferences and is a reliable and operable portfolio that can be studied further in the CAISO's TPP to assess transmission implications.
  - Aligning inputs to RESOLVE and SERVM and converging outputs at the beginning of the next Reference System Plan development process is a major goal.
  - After sufficient alignment between RESOLVE and SERVM, the GHG target can be recalibrated to ensure policy goals can be met