SCE's Production Cost Modeling and Simulation Results for the CPUC's Reference System Plan and Hybrid Conforming Case

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Summary

Objectives

- SCE performed production cost model (PCM) simulations on the CPUC's Reference System Plan (RSP) and Hybrid Conforming case to assess operational feasibility. Analyses focused on answering two questions:
  - Is the system is operationally feasible to meet demand and ancillary service (A/S) requirements?
  - Can the GHG emissions target be met?

Methodology

- For this study, SCE used a commercial software package, Plexos, to perform zonal PCM simulations, and mimic CAISO's day-ahead market operations
- SCE connected and ensured consistency between the PCM and the capacity expansion model for key modeling assumptions, such as generation dispatch, import/export energy, and emission factors
  - The PCM simulation case for the CPUC's RSP was tuned iteratively to ensure that the total energy of major generation resources (e.g., hydro, renewables, gas/import) were largely consistent between PCM and RESOLVE results
  - The PCM simulation case for the CPUC's Hybrid Conforming case maintained the same modeling assumptions as the tuned RSP PCM case, except for the new renewable/storage build-out (the aggregated hybrid conforming renewable/storage build-out was applied)

Summary (continued)

- SCE performed PCM simulations on three scenarios:
  - CPUC's RSP
  - CPUC's RSP assuming gas generators over 40 years old retire (~3,000 MW retired by 2030)
  - CPUC's Hybrid Conforming case assuming gas generators over 40 years old retire

Results

- For all three scenarios, the CAISO system was operable, all loads were served, and A/S requirements were satisfied
- For the CPUC's RSP, SCE's Plexos zonal model returned GHG emissions of ~34.2 MMT for the CAISO area, slightly higher than the RESOLVE results (34 MMT)
  - 0.7 MMT less GHG emissions in CAISO when considering 40-year gas generator retirements, since more efficient gas generators were dispatched
- For the CPUC's Hybrid Conforming case with 40-year old gas generator retirement, the total GHG emissions was ~35.9 MMT, ~1.9 MMT higher than the RSP (34 MMT)
  - ~1,400 MW of geothermal was replaced with 892 MW of solar, 856 MW of wind and 163 MW of biomass/biogas, resulting in a lower energy from renewables
- The CPUC's Hybrid Conforming case resulted in a higher net-load, higher import/gas generation and higher ramping requirements than the RSP

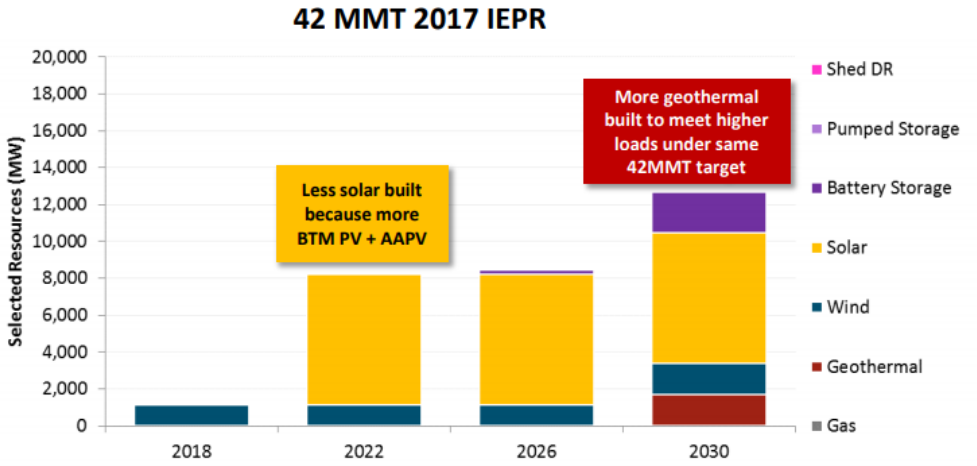
SCE's Plexos PCM

- Production cost simulation works to commit and dispatch available generation resources to meet demand and reliability requirements at the least cost, subject to transmission and individual resource constraints
- SCE's PCM simulations mimic CAISO's day-ahead market simulations (e.g., the optimization window is 24 hours)
  - Incorporates a detailed representation of generation, demand and transmission system
  - Performs simulations on an hourly chronological order, and for considered years
- SCE has the ability to create both the CAISO zonal and nodal models for its PCM simulations
  - Only major interface limits are enforced on the CAISO zonal model, while the individual line and interface constraints are enforced on the CAISO nodal model
  - Computation time is significantly reduced when running on the zonal model
- California imports/exports are modeled as pseudo generators/price sensitive loads at major interties
- More details about the modeling assumptions are shown on pages 16-18 in Appendix

Connections between Capacity Expansion and PCM

- The purpose of conducting PCM is to consider more detailed information to validate whether the proposed electricity system is operable, and that the environmental objectives are achievable, given available resources
- Consistency between capacity expansion and PCM is required
- Key assumptions for PCM come from capacity expansion modeling
  - Renewable build-out and existing renewable for capacity and energy
  - Storage build-out and existing storage devices for capacity and energy
  - Hydro condition
  - Gas fleet for capacity and energy
  - Imports and exports for energy and transmission utilization
  - Total GHG emissions
- The annual total energy (GWh) of the resources from the RESOLVE RSP results were used to calibrate key assumptions for the PCM

CPUC's RSP – Plexos PCM Assumptions



- Plexos zonal simulation was performed for year 2030
- Main modeling assumptions:
  - 2017 IEPR load forecast
  - CPUC's RSP renewable build-out
  - RESOLVE gas and GHG price
  - 2,104 MW, 1.3 hour duration generic battery storage
  - No import energy limit
  - 5,000 MW export limit

CPUC's RSP – Plexos PCM Simulation Results

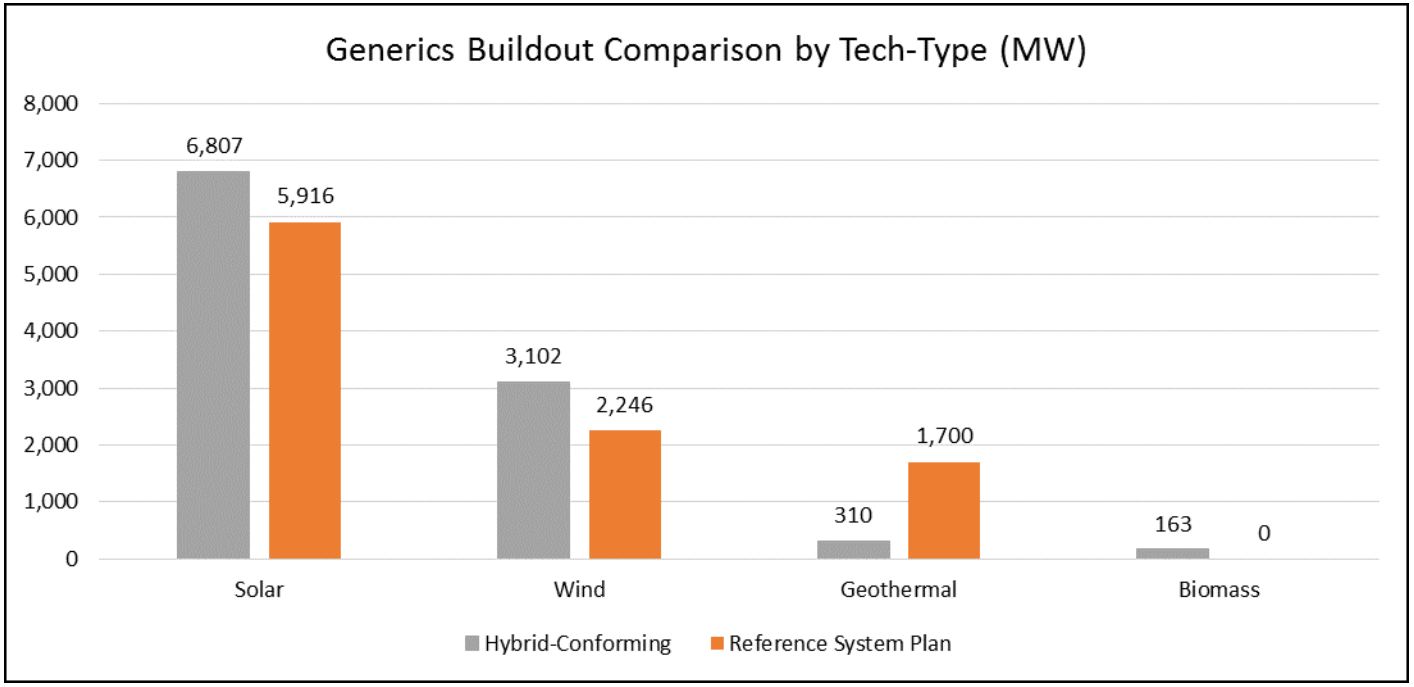
- SCE tuned the CPUC's RSP PCM simulation case iteratively. The major generation dispatch amounts and total GHG emissions were largely consistent with RESOLVE results

	Resource Type	RESOLVE	SCE Plexos PCM	
		CPUC RSP	CPUC RSP	CPUC Reference Gas Retirement
Total Energy (GWh)	Gas Generation	69,397	69,525	73,327
	CHP	14,759	14,549	9,496
	Nuclear	5,004	5,563	5,563
	Hydro	25,317	21,363	21,363
	Renewables (incl. BTM PV)	137,348	142,468	142,768
	DR	0	0	0
	Storage Losses	-1,961	-1,255	-1,247
	Renewable Curtailment	-2,923	-4,136	-3,836
	Imports	12,709	15,213	15,765
	Exports	-5,686	-10,233	-9,842
Total Emissions (MMT)	**Emission Type**			
	CAISO Generator Emissions	31.4	31.0	30.0
	Import Emissions	5.4	6.1	6.3
	Offset*	-2.8	-2.8	-2.8
	Total CAISO Emissions	34.0	34.2	33.5

* Assumed 2.8 MMT of GHG emission offset from the 8,000 GWh of Pacific Northwest hydro imports to California (82% of California imports to CAISO), according to RESOLVE assumptions

CPUC's Hybrid Conforming Case – Plexos PCM Assumptions

- PLEXOS zonal simulation was performed for year 2030
- Main modeling assumptions consistent with the CPUC RSP with gas retirement, but
  - Aggregated CPUC hybrid conforming renewable build-out
  - 1,227 MW, 4 hour duration generic battery storage and 177 MW, 1 hour duration generic battery storage



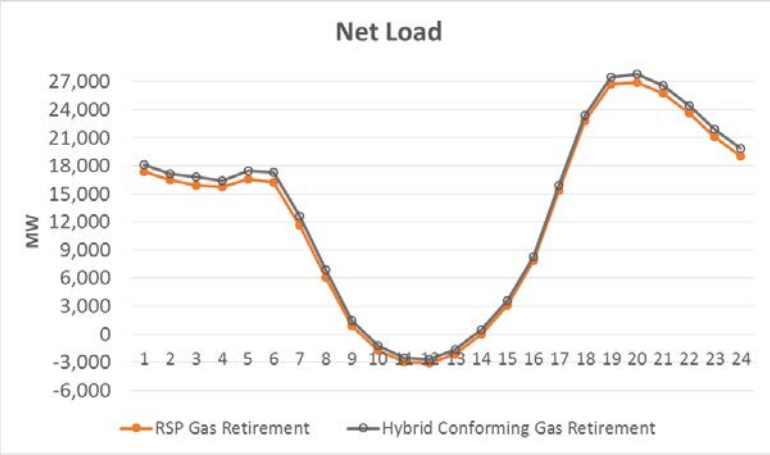
CPUC's Hybrid Conforming Case Plexos PCM Results – Generation Dispatch and Emissions

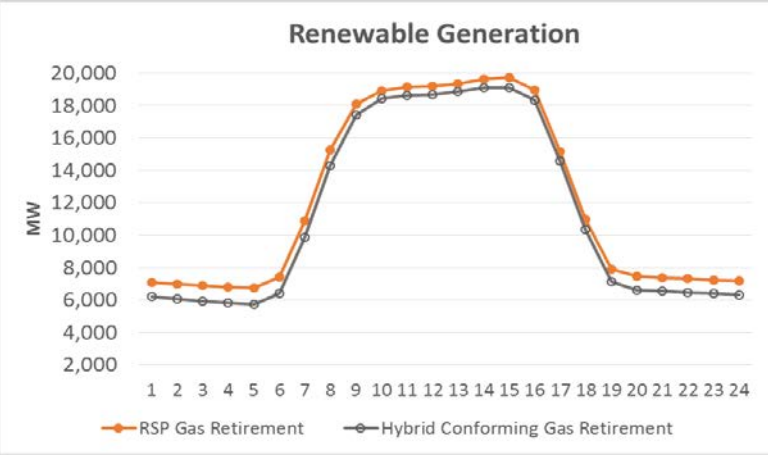
- Compared to the RSP, the Hybrid Conforming case had lower renewable generation (see details on page 19 in Appendix) and higher gas generation/imports, resulting in higher emissions

	Resource Type	RESOLVE	SCE Plexos PCM	
		CPUC RSP	CPUC RSP Gas Retirement	CPUC Hybrid Conforming Gas Retirement
Total Energy (GWh)	Gas Generation	69,397	73,327	78,251
	CHP	14,759	9,496	9,899
	Nuclear	5,004	5,563	5,563
	Hydro	25,317	21,363	21,363
	Renewables (incl. BTM PV)	137,348	142,768	136,081
	DR	0	0	1
	Storage Losses	-1,961	-1,247	-1,365
	Renewable Curtailment	-2,923	-3,836	-4,157
	Imports	12,709	15,765	16,661
	Exports	-5,686	-9,842	-9,261
Total Emissions (MMT)	**Emission Type**			
	CAISO Generator Emissions	31.4	30.0	32.0
	Import Emissions	5.4	6.3	6.7
	Offset	-2.8	-2.8	-2.8
	Total CAISO Emissions	34.0	33.5	35.9

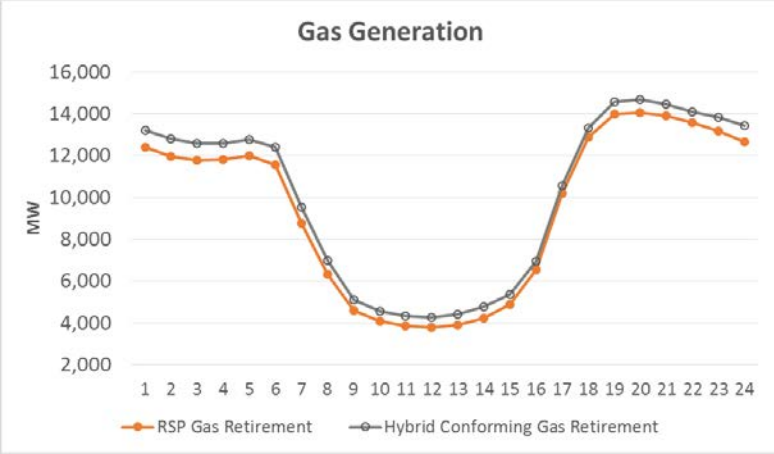
CPUC's Hybrid Conforming Case Plexos PCM Results – 24 hour Average Shapes

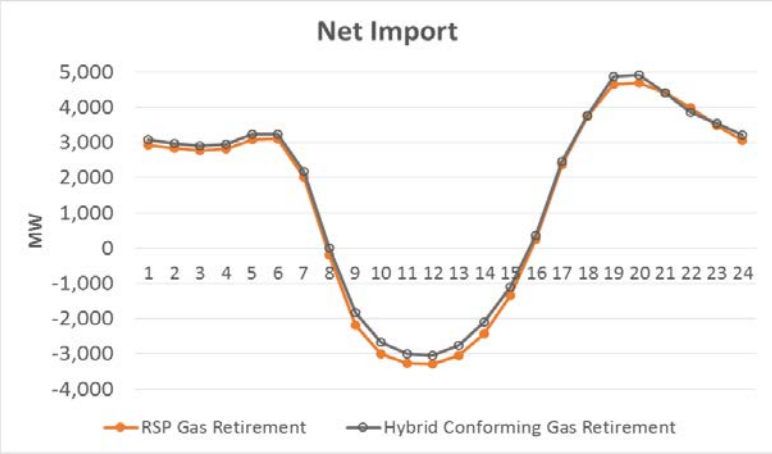
- Hourly net loads of the Hybrid Conforming case were higher than the RSP, especially during the early morning and late evening hours





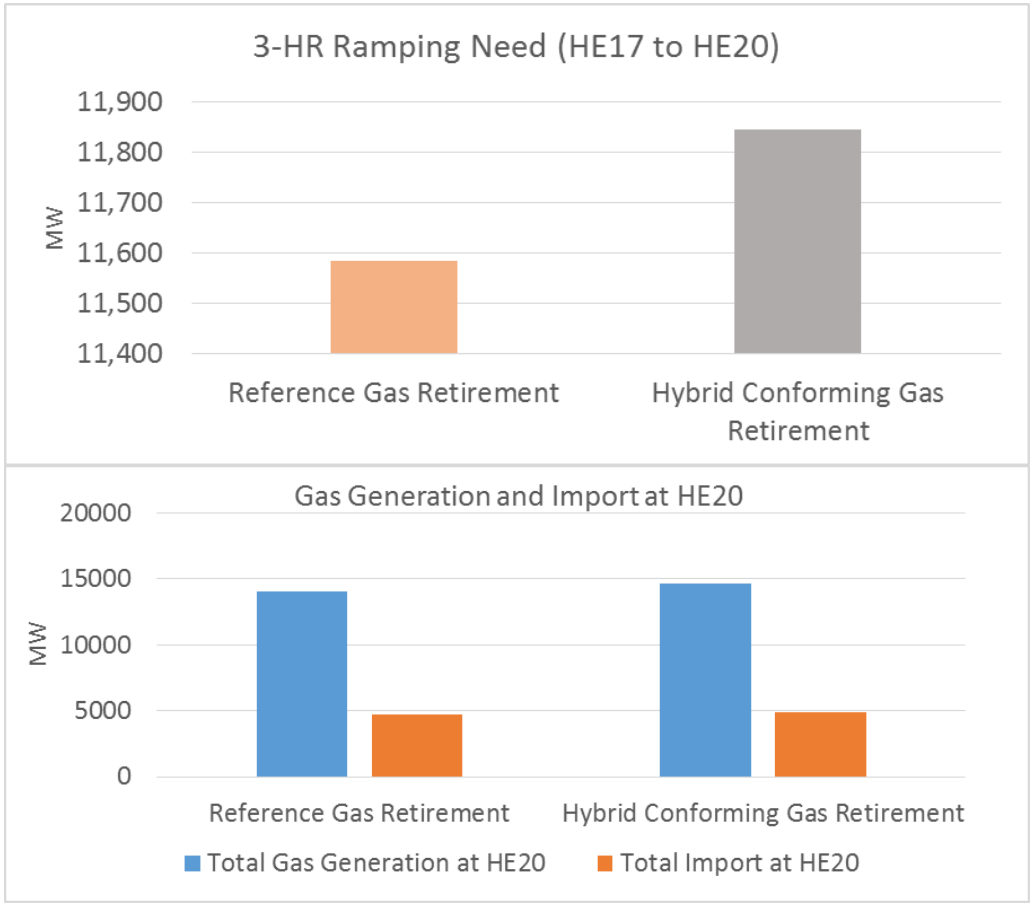
- The higher net loads of the Hybrid Conforming case led to the higher gas generation and higher net import





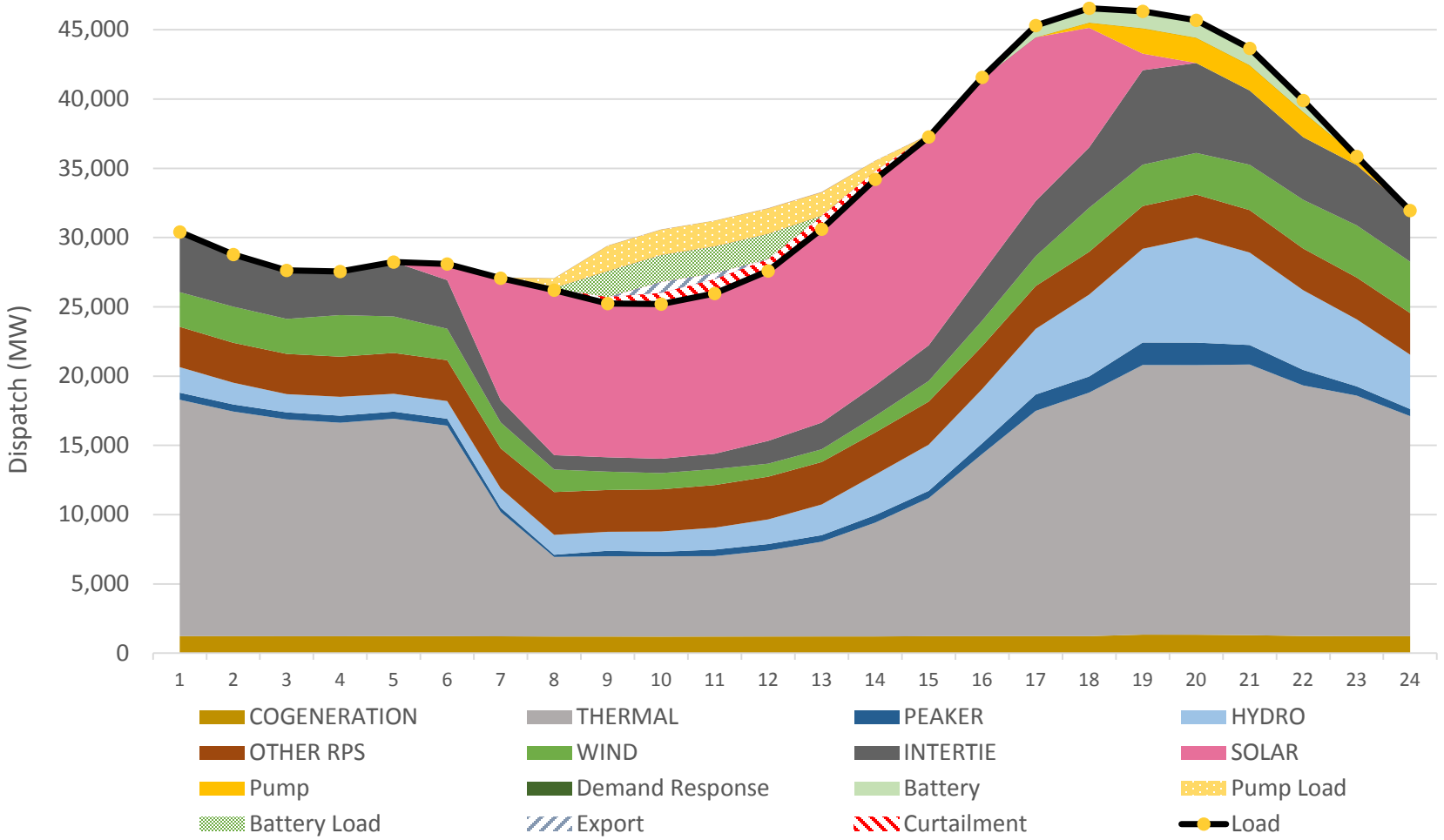
CPUC's Hybrid Conforming Case Simulation Results – Ramping Requirements

- The Hybrid Conforming case also resulted in higher ramping need during the evening ramping hours



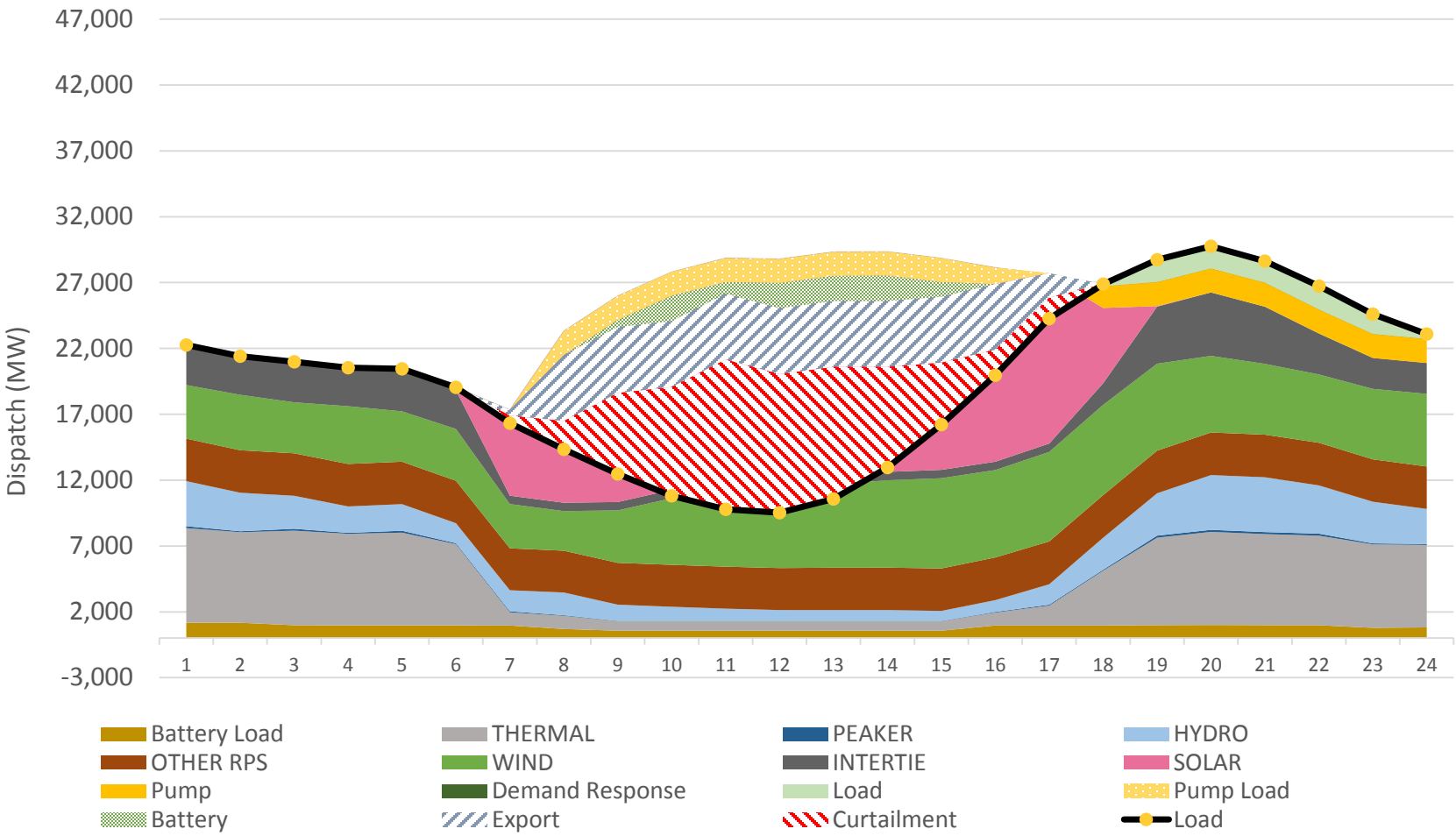
CPUC's Hybrid Conforming Case Simulation Results – Summer Peak Load (8/1/2030)

- Exports and curtailments were minimal in the peak day
- Evening ramp was served by a combination of thermal, storage, imports and hydro



CPUC's Hybrid Conforming Case Simulation Results – Spring Low Net-Load (4/14/2030)

- The hourly renewable curtailment was as high as 46% on hour 12, and total renewable curtailment was 22% on this day; exports were maximized to the 5,000 MW limit from Hour 8 to 16
- Evening ramp was served by a combination of thermal, storage, imports and hydro



Recommendations

- In the IRP process, consistency between the PCM and capacity expansion modeling is necessary to meaningfully assess proposed portfolios
- California import/export capability are key assumptions in conducting reliability studies. The resource availability and transmission capability at interties should be further investigated
- Hydro conditions have significant impact on the total GHG emissions and system reliability. In-state and out-of-state hydro availability should be further examined
- The gas generation dispatch pattern is highly responsive to the emission rate of out-of-state imports (0.428 MT CO2/MWh in IRP). The emission rate of imports should be further studied
- Various reliability indices should be considered to evaluate the impact of portfolios on system reliability, such as the change of system net load, gas generation dispatch, ramping capability, etc.
- In order to study the impact of individual retired gas generators and new renewable/storage projects on local transmission congestion and regional reliability, more detailed nodal PCM simulations are needed

Appendix

Major Required Inputs for SCE's Plexos PCM Model

- *Generation*
  - Generating capacity
  - Heat rates
  - O&M costs
  - Start-up and ramp rates
  - Start-up and no-load costs
  - Minimum up/down constraint
  - Maintenance and forced outage rates
  - Gas and emission prices
- *Battery*
  - Capacity and Max power
  - Charge and discharge efficiency
- *Transmission*
  - Transmission topology/power flow case
  - Transmission line/interface constraints
- *Hourly Profiles*
  - Hourly forecasted demand
  - Hourly generation profiles for wind, solar and other renewables

SCE's Plexos PCM Model – Conventional Generation Assumptions

- Model generation resources according to technology type and map them to project locations at the bus level
  - Incremental update on an annual basis to exclude/include retired and new generation resources
- Conventional generation resources
  - Natural Gas-Combined Cycle, Natural Gas-Combustion Turbine, Hydro, Nuclear, Cogeneration, Pumped Storage
  - Generation assumptions including location, capacity, heat rate, operating costs, and operating constraints
    - SCE's resource assumptions are obtained from internal database
    - Non-SCE's resource assumptions are obtained from CAISO's transmission planning case and other resources

SCE's Plexos PCM Model – Renewable Generation Assumptions

- Renewable generation resources
  - Solar thermal, Solar PV, Wind, Geothermal, Biomass, and Small Hydro
  - Generic resource capacity and build-out schedule are determined by RESOLVE
  - Wind and solar hourly profiles are created based on the internal database and WECC model
  - Disaggregate to individual locations using allocation factors, calculated based on the locations and capacities of existing renewable projects
  - Economic bids for solar and wind projects to allow economic curtailment
  - Out-of-state renewables are not explicitly modeled
- Pumped storage and battery storage are modeled
  - Generic battery storage capacity and build-out schedule are determined by RESOLVE

CPUC's Hybrid Conforming Case Simulation Results – Renewable Generation

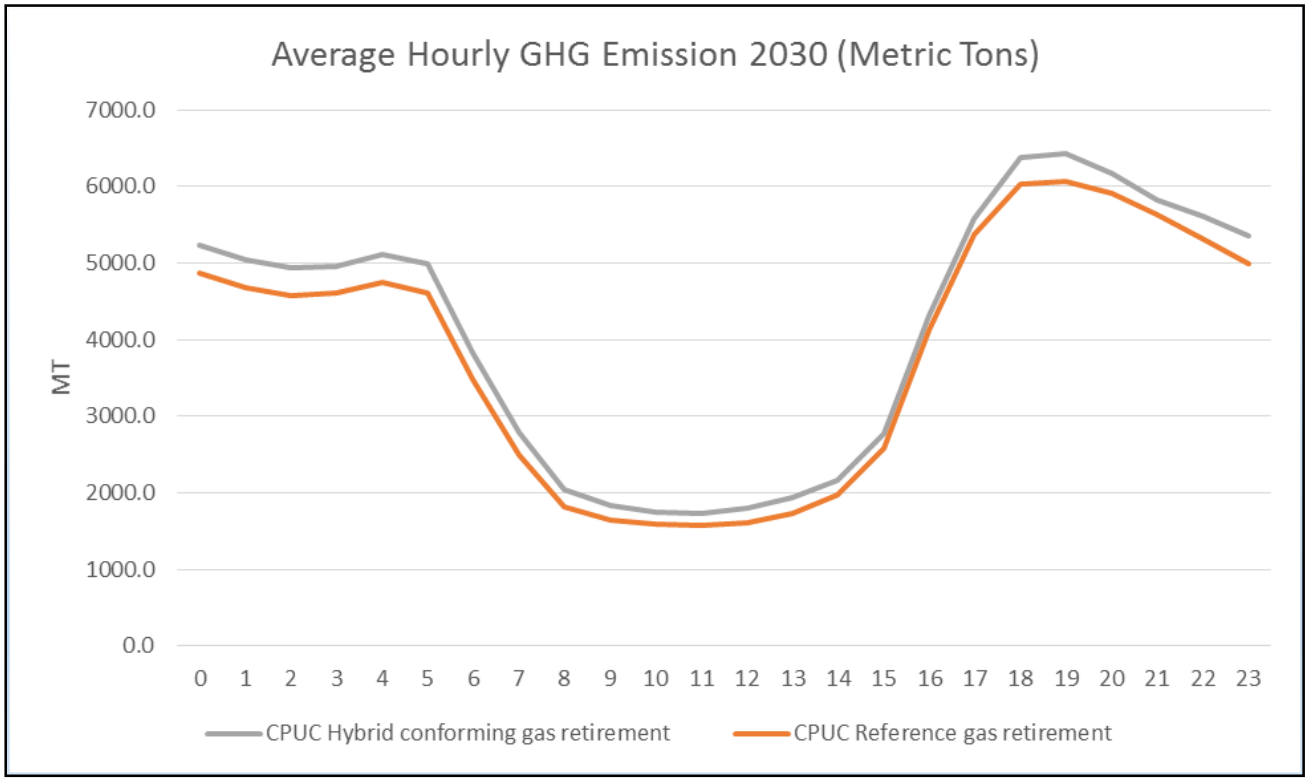
- Total renewable generation for the Hybrid Conforming case was significantly less than the RSP, mainly due to ~1,000 MW less of generic geothermal build-out

Total Energy (GWh)	RESOLVE	SCE Plexos	
	CPUC Reference	CPUC Reference Gas Retirement	CPUC Hybrid Conforming Gas Retirement
Small_Hydro	4,249	4,249	4,249
Geothermal	24,357	26,431	14,254
Biomass	6,792	6,804	8,026
Wind	21,914	22,378	25,116
Solar	47,990	46,613	48,141
All Renewables	105,302	106,473	99,786

Backup

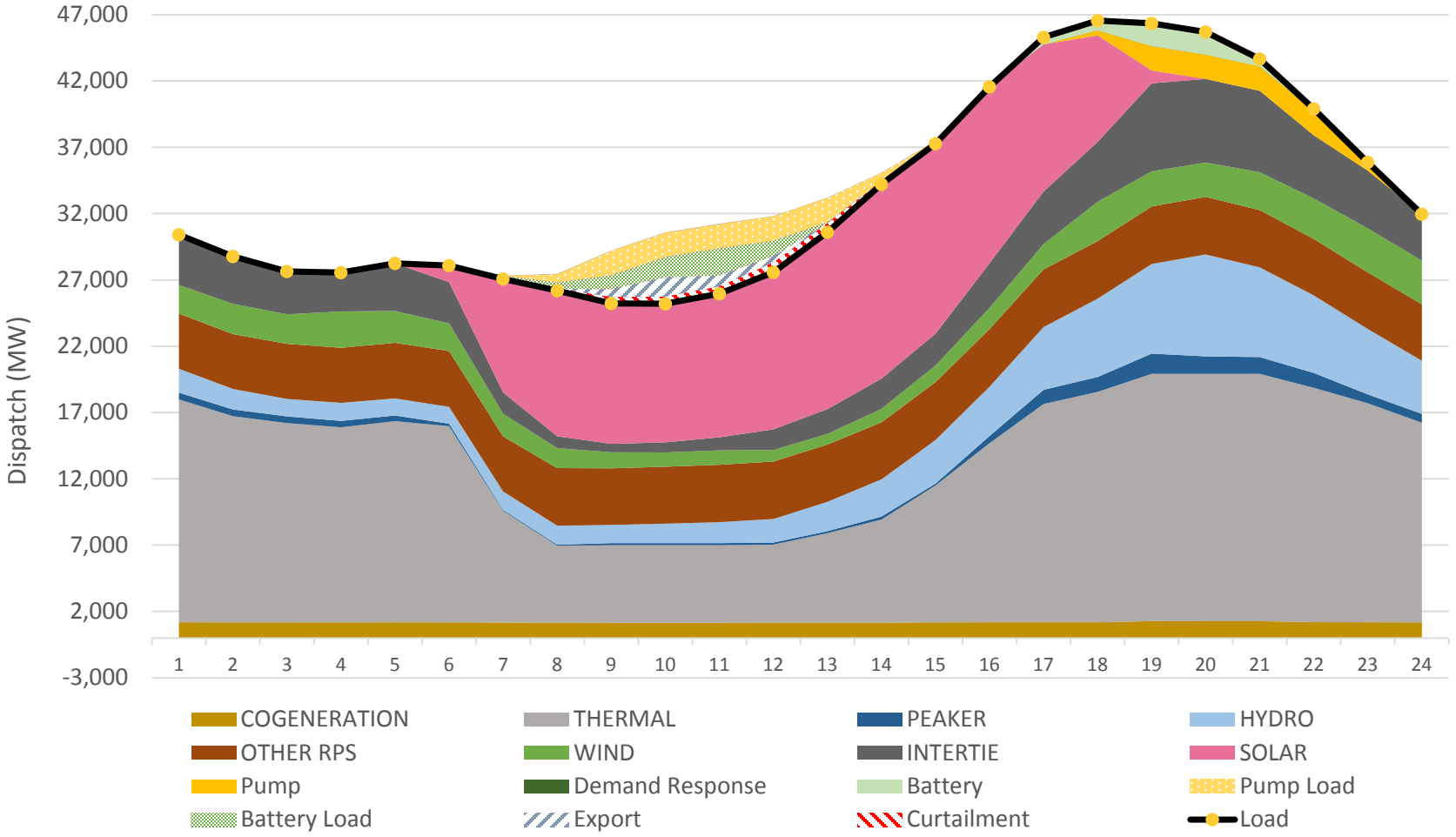
CPUC's Hybrid Conforming Case Simulation Results – 24 hour Average GHG emission

- The hourly average GHG emission shape is consistent with the hourly net load shape
  - Higher GHG emissions of the Hybrid Conforming case are observed during the early morning and evening peak hours

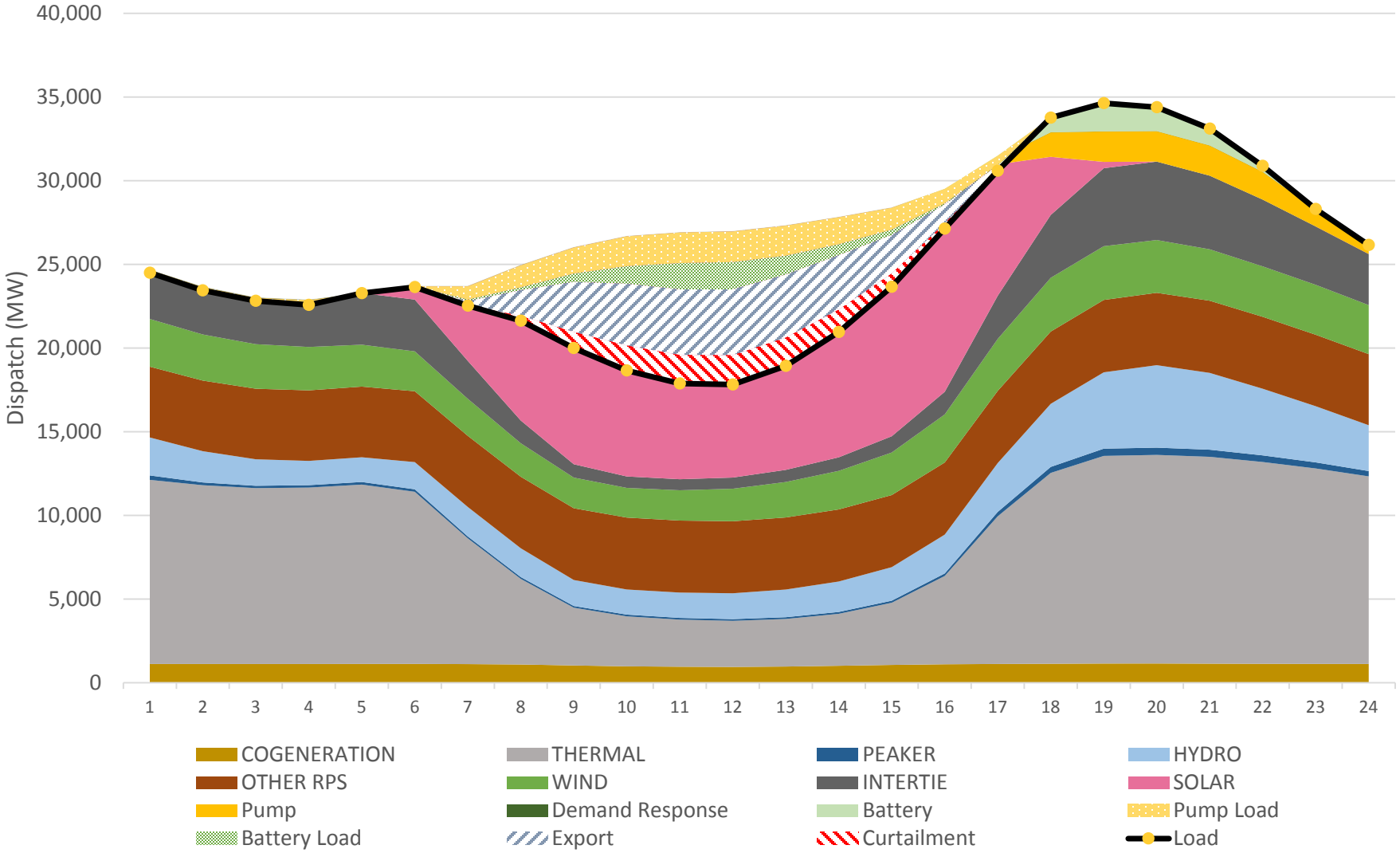


CPUC's RSP with Gas Retirement Simulation Results – Summer Peak Load (8/1/2030)

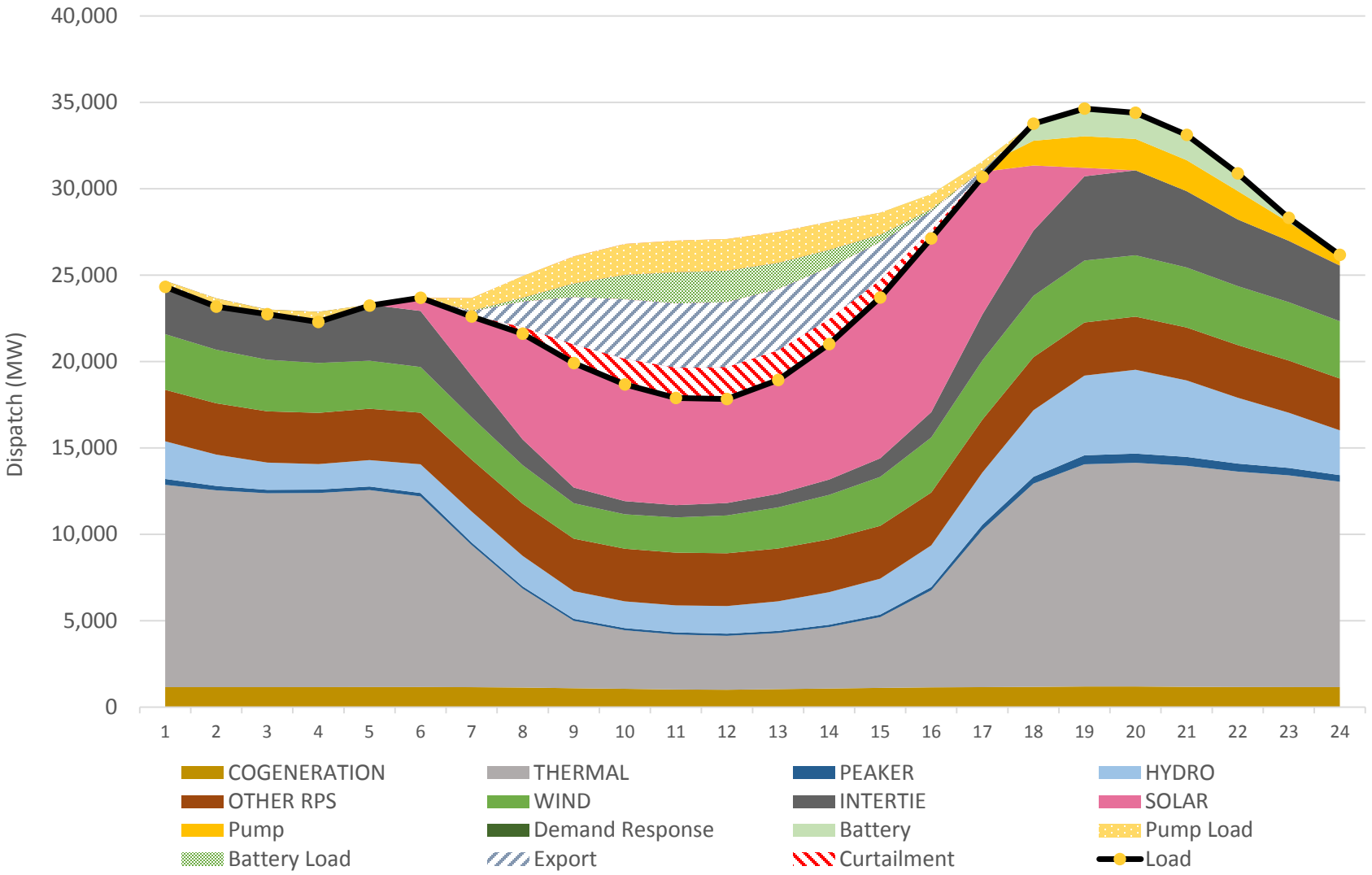
- Exports and curtailments are minimal in the peak day. Evening ramp is served by a combination of thermal, hydro, storage, and imports



CPUC's RSP with Gas Retirement Simulation Results – Average 24-hour Resource Dispatch in 2030



CPUC's Hybrid Conforming Case Simulation Results – Average 24-hour Resource Dispatch



Consistency Among Modeling Tools Should be Maintained

- In the IRP process, multiple modeling tools are used for different purposes, in analyzing and validating resource portfolios
  - Develop the optimize the resource portfolio using the Capacity Expansion (CE) Model
  - Validate the operational feasibility and performance of the portfolio using the Production Cost Model (PCM)
  - Further check the emission constraints for GHG, NOx and PM2.5 using the Clean Net Short (CNS) calculator
- It is important to maintain consistency among CE, PCM and CNS tools about key modeling assumptions, such as
  - Generation dispatches
  - Import/export energy
  - Emission factors