RESOLVE Updates for 2021 PSP / 2022-23 TPP

August 2021

California Public Utilities Commission

Purpose of this Presentation

- Provide a summary of the key changes that were made to the RESOLVE model to develop portfolios for the 2021 Preferred System Plan (PSP) / 2022-2023 Transmission Planning Process (TPP)
- Facilitate a better understanding of how the CPUC configured RESOLVE to assist parties and other stakeholders that want to conduct their own modeling to inform PSP/TPP decision-making
- This presentation is focused on RESOLVE inputs. RESOLVE outputs will be shared via a separate Commission ruling.

Summary of RESOLVE Updates since Dec 2020 '21-22' TPP Version

Update Category	Purpose	Key Changes
Mid-term Reliability	Align reliability need in portfolios with MTR need per D.21-06-035	• Higher PRM and load adders • Lower imports • Thermal generation retirements • Minimum build for long-lead time resources ordered
Baseline Resources	Update baseline generators to latest available data	• Include previously proposed ground truthing updates[1] • Update Gen_List to align with LSE plan data and MTR baseline, update NQC %'s to match MTR model / 2021 CPUC NQC List
Transmission Deliverability Constraints	Incorporate latest CAISO transmission deliverability methodology, transmission limits, and upgrade costs	• Update on-peak and off-peak limits for transmission constraints • Include battery and pumped storage capacity under transmission constraints • Revise solar locations to match batteries • New deliverability methodology to align with CAISO
Resource Costs	Update to latest data vintage of standard IRP data sources	• Resource costs updated to match 2020 NREL ATB, Lazard Levelized Cost of Storage 6.0, NREL offshore wind study
LSE Planned Resources	Allow modeling of LSE planned additions	• Input data updated to allow forcing in of 46 and 38 MMT aggregated additions from 2020 LSE IRP plans, with changes as needed to fit within updated transmission constraints

[1] ftp://ftp.cpuc.ca.gov/energy/modeling/IRP%20Model%20Improvement%20and%20GHG%20Groundtruthing_updated.pdf

Mid-Term Reliability Decision (D.21-06-035) RESOLVE Implementation

- **PRM**: aligned with MTR Need Determination Model[1] "High Need" scenario from 2024
  - Existing requirement (**~15%**) + 2019 RSP Development calibration adder of (***4.3%***) + Operating Reserves adder of (***1.5%***) + Climate Impact adder of (***1.8%***)
  - **Total PRM = 22.5%**
- **Load Adders**: Per High Need scenario, load adders were added[2] for the managed peak impact of:
  - 1) 2020 vs. 2019 IEPR
  - 2) IEPR Low vs. IEPR Mid BTM PV and 3) High Electrification vs. Mid-Demand IEPR (both held at constant values after 2026)
- **Additional Thermal Retirements:** 40-yr age based applied up to and including 2026 (~1 GW nameplate CHP + peakers) per High Need Scenario
- **Unspecified imports:** drop from 5 GW to 4 GW in 2024 per High Need scenario
- **LLTs**: To reflect D.21-06-035 requirements and allowances, 1 GW (NQC) geothermal and 1 GW (NQC) long-duration storage were "forced-in" by 2028 and 2025-2027 reliability need was reduced to minimize PRM overcompliance based on the allowed LLT delay (between 2026 and 2028)
- **Resource NQCs**: RESOLVE NQCs for each resource category were updated to reflect the 2021 CPUC NQC List used by MTR Need Determination Model
- **Persistence of Assumptions**: By default, the "High Need" scenario assumptions persist beyond 2026, though non-persistence of those assumptions was run as a sensitivity

[1] Available at https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/long-term-procurement-planning/more-information-on-authorizing-procurement/irp-procurement-track

[2] Load adders were only added to RESOLVE's PRM constraint. The load forecast used in RESOLVE's dispatch module (i.e. hourly load/resource balance, GHG emissions, etc.) was not changed.

Transmission Updates: Limits and Constraints

- On-peak and off-peak transmission limits updated using CAISO's latest estimates
  - CAISO released a white paper in July 2021 entitled "Transmission Capability Estimates for use in the CPUC's Resource Planning Process" which documents the updated capability estimates
    - Available at http://www.caiso.com/Documents/WhitePaper-2021TransmissionCapabilityEstimates-CPUCResourcePlanningProcess.pdf
- Additional constraints have been added since the 2019 CAISO white paper
  - Available at https://www.caiso.com/Documents/WhitePaper-TransmissionCapabilityEstimates-InputtoCPUCIntegratedResourcePlanPortfolioDevelopment.pdf
- Updated limits generally increase the amount of available capacity on the transmission system relative to the 2019 values, though this is not true for every constraint

Transmission Updates: Deliverability Methodology

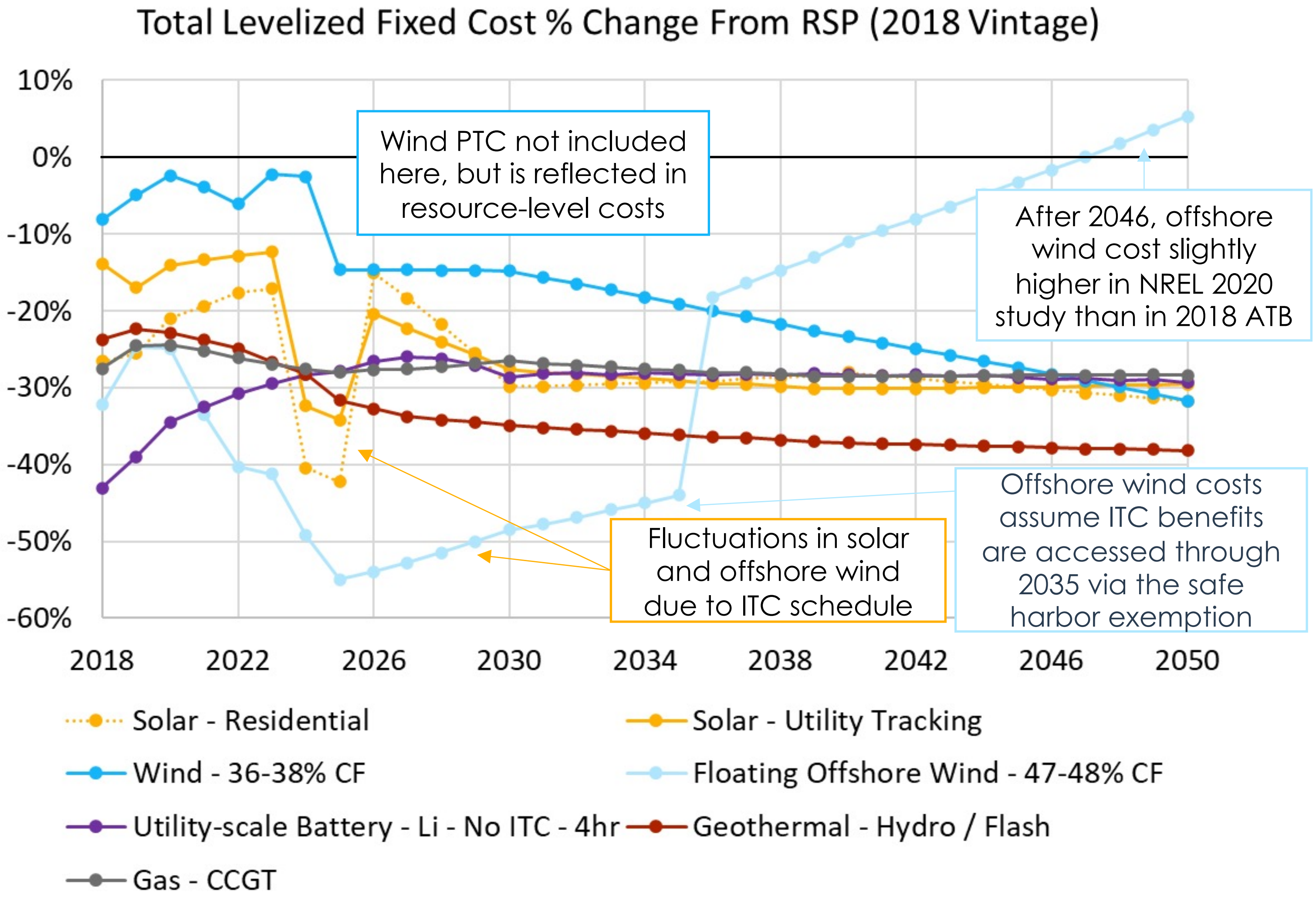
- RESOLVE has been updated to include three limits for each transmission constraint
  - On-Peak, Highest System Need (HSN) – represents net peak hours in early evening when solar output is low
  - On-Peak, Secondary System Need (SSN) – hours of very high demand, represents "shoulder" peak hours where solar output is usually more abundant
  - Off-Peak
- For a resource to receive full deliverability status, it must fit within the available transmission capacity
  - RESOLVE incorporates resource-specific multipliers for each limit (HSN/SSN/off-peak)
  - If economic, available transmission capacity can be expanded by CAISO-identified upgrades

Transmission Updates: Storage + Solar

- Previous RESOLVE modeling did not consider interactions between storage and transmission constraints
  - Instead, interactions were addressed downstream in the bus-bar mapping process
- RESOLVE has been updated to:
  - Ensure that storage capacity has enough available transmission capacity to receive full deliverability
    - Lithium-ion battery and pumped storage resources were previous modeled as a single CAISO-wide resource; multiple resources are now modeled such that transmission limits in different areas of the CAISO grid can be considered
  - Model the interaction between storage charging and off-peak transmission limits by expanding off-peak transmission limits when storage is built
    - Storage consumes on-peak transmission capability
    - Storage creates off-peak transmission capability
  - Solar and battery locations aligned as a step towards modeling co-located and hybrid resources.
    - Full hybrid modeling out of scope – no interactions are modeled between solar and storage in hourly dispatch nor cost benefits of shared infrastructure.

Resource Costs

- Data source updated from 2018 (RSP) to 2020 vintage
  - Most generation technologies: NREL 2020 ATB
  - Offshore wind: NREL OCS Study BOEM 2020-048 [1](RSP: NREL ATB and E3 WECC study)
  - Storage (utility-scale and BTM Li-ion batteries): Lazard LCOS v6.0
- Other updates had smaller impacts on levelized costs compared to data source updates
  - ITC/PTC schedule, solar PV inverter loading ratio, financing lifetime, etc.
  - See details in Appendix



[1] For more information on this study, refer to 8/27/2020 Modeling Advisory Group material available at: https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/long-term-procurement-planning/2019-20-irp-events-and-materials

Appendix A: Resource Cost and Build Updates

Summary of cost and build updates

- **Update to NREL 2020 ATB as data source for most technology costs**
  - Exceptions are batteries (Lazard) and offshore wind (NREL OCS study) – see below
- **Battery costs**
  - Update to Lazard v6.0
  - Including capex, fixed O&M, annual warranty and augmentation costs (% of capex)
- **Offshore wind costs**
  - Update to incorporate final numbers from NREL OCS Study BOEM 2020-048
- **ITC/PTC schedules**
  - Update to reflect statute and IRS guidance as of Dec 2020
  - Solar (PV, thermal), wind (offshore, offshore), battery with ITC (hybrid with solar PV)
- **Updated solar annual build constraints to reflect updated ITC schedule**
  - 2021 – 3.1 GW; 2022 – 3.5 GW; 2023 – 1.2 GW, 2025 – 3.2 GW
- **Financing lifetimes**
  - Update to align with latest E3 assumptions based on recent LBNL studies
  - Utility and commercial solar PV, onshore wind, and gas
- **Solar PV inverter loading ratios**
  - Align with latest E3 assumptions based on recent LBNL research
  - Specifically, utility solar PV changed from 1.35 to 1.3 to align with assumption used for solar profile simulation
- **Interconnection cost for storage**
  - Utility-scale Li-ion, flow batteries, pumped hydro

ITC/PTC schedules

- **Solar (commercial PV, utility PV, solar thermal)**
  - ITC extends for projects coming online through 2025 (ITC drops to 10% afterward – same as previous)
- **Residential solar**
  - ITC drops to 0% after 2025
- **Onshore wind**
  - PTC extends through 2025; values adjusted for inflation
- **Offshore wind**
  - ITC extends through 2035 (to reflect assumption that developers will access 10-year safe harbor by end 2025 for projects on federal land / waters)
- **Battery with ITC (hybrid with solar PV) - not used for PSP model runs**
  - ITC extends through 2025 (to be consistent with solar PV)

Financing lifetimes

Technology	Before	After	Source of E3 proforma
Solar - Commercial	35	30	LBNL, 2020, Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes: Results from a Survey of U.S. Solar Industry Professionals
Solar - Utility Tracking	35	30	LBNL, 2020, Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes: Results from a Survey of U.S. Solar Industry Professionals
Wind - Onshore	25	30	LBNL, 2019, Benchmarking Anticipated Wind Project Lifetimes: Results from a Survey of U.S. Wind Industry Professionals
Gas CC/CT	20	25	E3

Solar PV inverter loading ratio

Technology	Before	After	Source of E3 proforma
Solar - Residential	1.35	1.15	LBNL, 2019, Tracking the Sun
Solar - Commercial	1.35	1.15	LBNL, 2019, Tracking the Sun
Solar - Utility Tracking	1.35	1.3	E3 assumptions for profile simulation

Storage interconnection costs

- **Apply $100/kW interconnection cost to utility-scale Li-ion batteries, flow batteries, and pumped hydro storage**
  - Rationale for including interconnection cost: Previously assumed zero interconnection cost for storage. Given the low and aggressive storage cost estimates in Lazard v6.0, interconnection costs were included to be conservative.
  - Rationale for $100/kW: A lot of storage will be connected at low costs at existing solar or gas points of interconnection. The interconnection cost for solar in the Resource Costs & Build workbook is $200/kW based on the Black & Veatch study. The $200/kW for storage is currently considered to be rather high and could mean that solar + storage is effectively double paying for interconnection. Therefore, the interconnection cost of new gas resources was adopted as a proxy, which is $100/kW in the Resource Costs & Build workbook.
  - Same interconnection cost applied to pumped hydro for consistency
- **$100/kW interconnection cost ~ $10/kW-yr cost increase on a levelized basis**
  - For utility-scale Li-ion batteries, $10/kW-yr in 2020 → $8/kW-yr in 2029 and onward

Overview of resource cost comparison

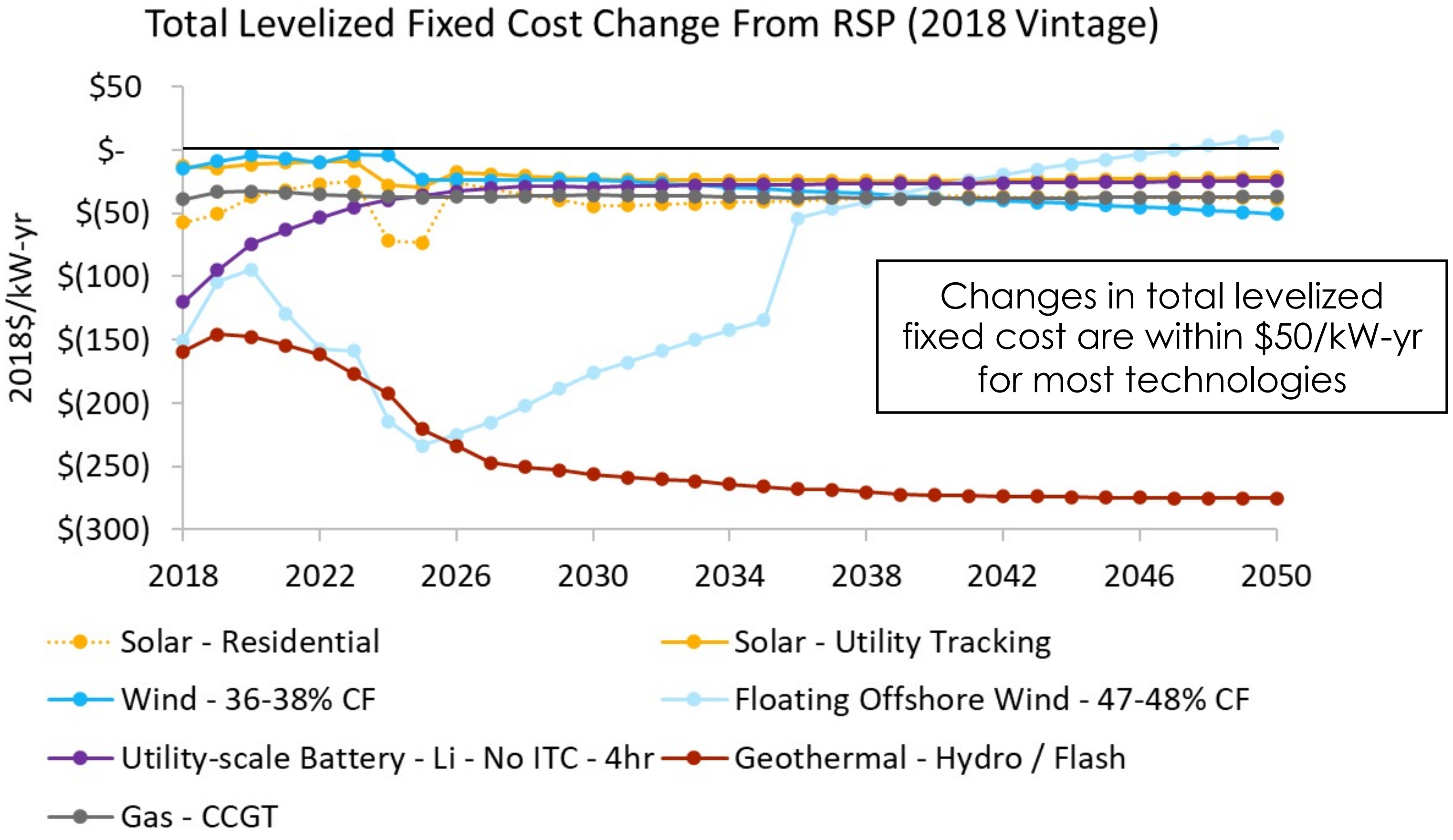
<u>High-level takeaways:</u> Resource cost vintage (e.g., NREL 2020 vs. 2018 ATB, Lazard v6.0 vs. v5.0) has the highest impacts on costs. Most of the recent ("2022-23 TPP") updates only affect levelized costs and have relatively small impacts.

Three sets of resource costs are compared:

- **"2018"**
  - Resource costs prior to summer 2020 updates
  - 2018 vintage (NREL 2018 ATB, Lazard 4.0)
- **"2020"**
  - Resource costs updated (and presented to CPUC) in summer 2020
  - 2020 vintage (NREL 2020 ATB, Lazard 5.0)
- **"2021 PSP / 2022-23 TPP"**
  - Updates for TPP and PSP runs, summer 2021
  - Changes described in previous section (slides 11-14) are relative to "2020" costs

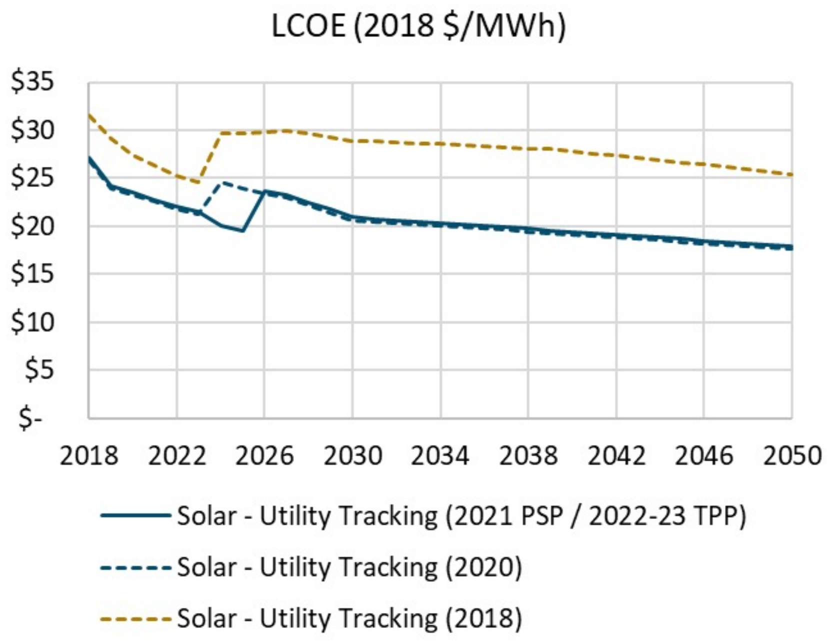
Note: LCOEs shown here are illustrative. All-in levelized costs are the primary cost inputs for new resources in RESOLVE. LCOEs are inferred from dispatch results.

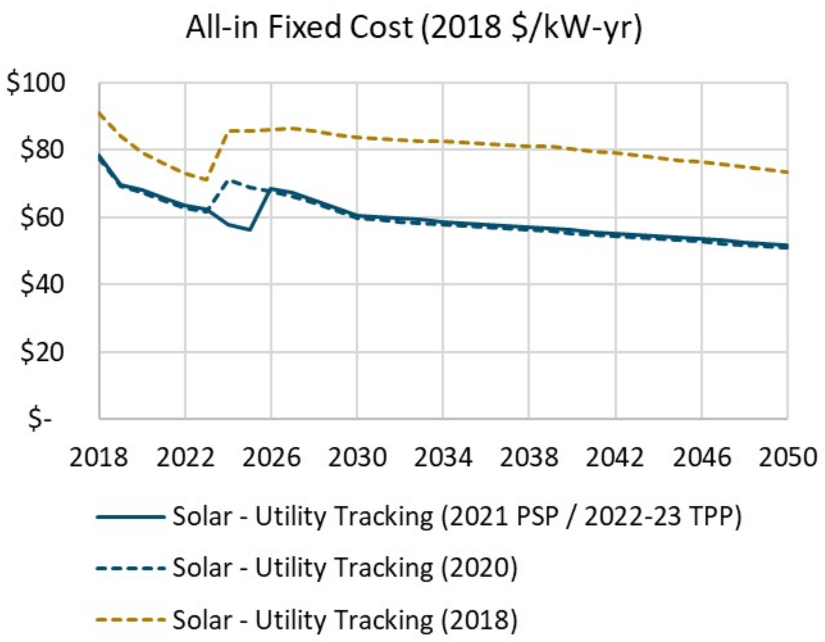
Changes in total levelized fixed cost
2021 PSP / 2022-23 TPP vs. RSP (2018 vintage)



Utility-scale solar PV

- Biggest differences due to resource cost vintage (2020 vs. 2018 NREL ATB)
- Among the other updates, ITC schedule had the biggest impact

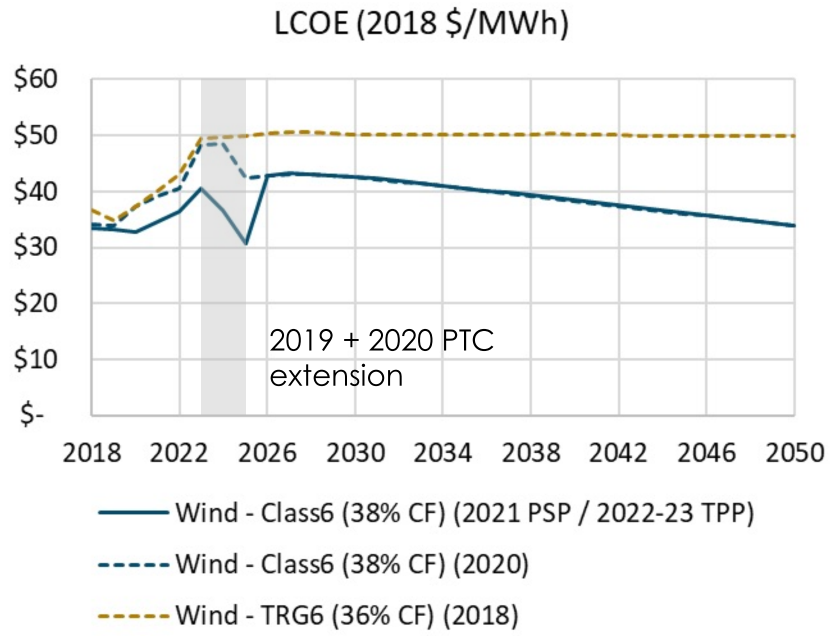




Onshore wind, Class 6 (36-38% capacity factor)

- Biggest differences due to resource cost vintage (2020 vs. 2018 NREL ATB)
- Among the other updates, PTC schedule had the biggest impact

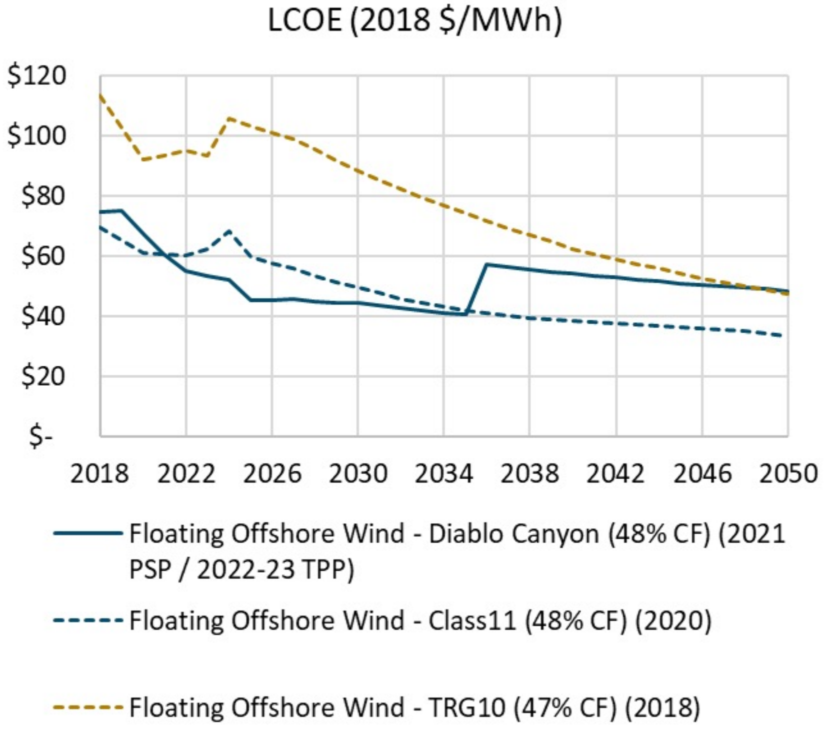
PTC timeline:
- Previous legislation: PTC decreases to **40%** by the end of **2023** (online date)
- Dec 2019: PTC extension at **60%** to the end of **2024** (online date)
- Dec 2020: PTC extension at **60%** to the end of **2025** (online date)

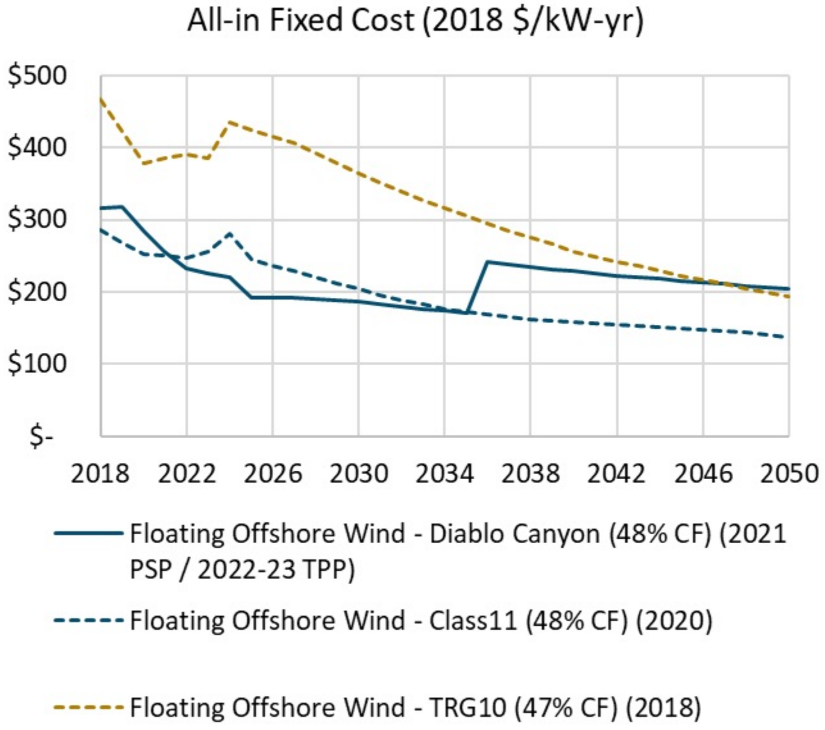


Note: wind bins (Techno-Resource Groups or Classes) changed between 2019 and 2020 ATB, resulting in small differences in capacity factor.

Floating offshore wind, 47-48% capacity factor

- Biggest differences due to resource cost data source (NREL OCS Study vs. NREL ATB/E3)
- Among the other updates, ITC schedule had the biggest impact

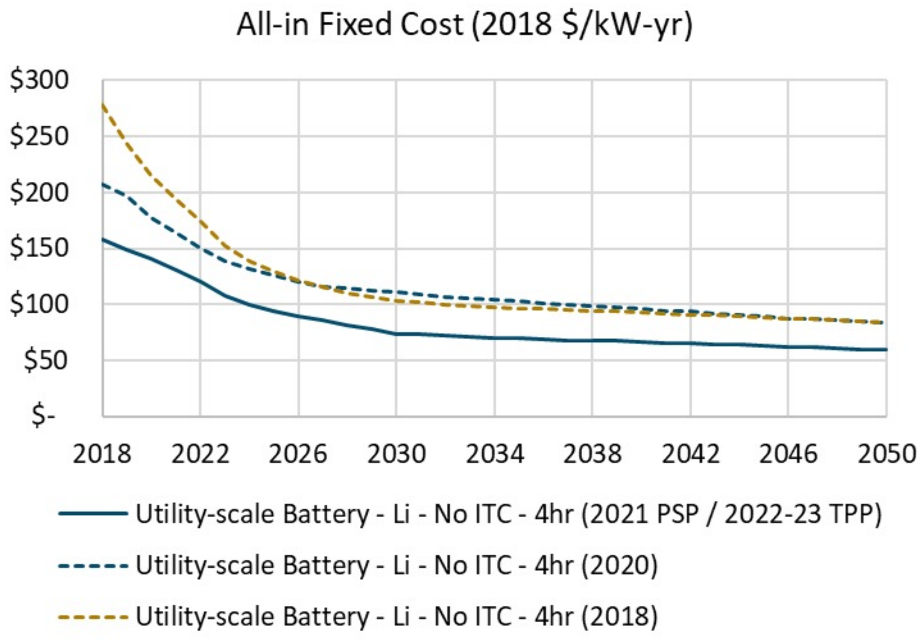




Note: wind bins (Techno-Resource Groups or Classes) changed between 2019 and 2020 ATB, resulting in small differences in capacity factor.

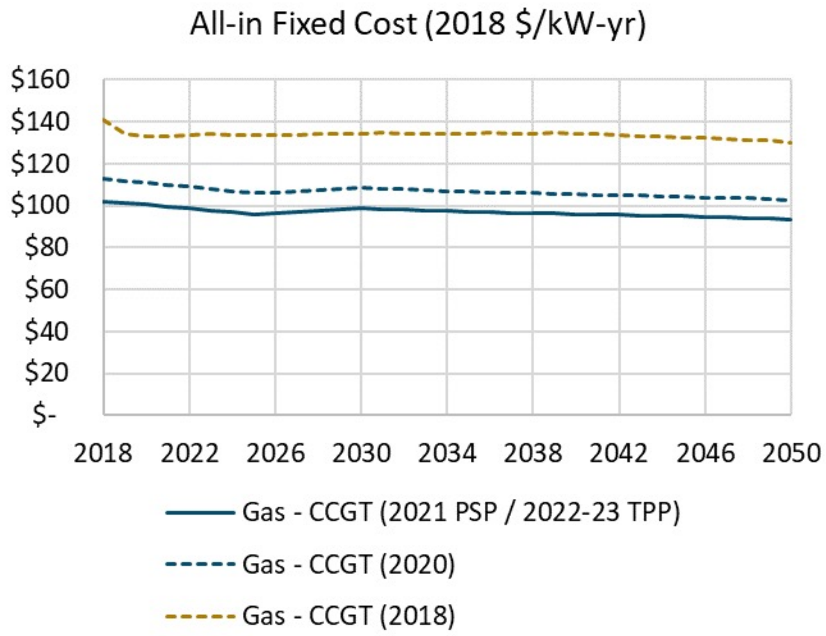
Utility-scale standalone Li-ion battery

- Biggest differences come from resource cost vintage
  - Lazard 6.0 assumed substantial cost reductions



Gas CCGT

- Biggest differences due to resource cost vintage (2020 vs. 2018 NREL ATB)
- Assumption for financing lifetime had relatively small impacts



Note: LCOE not shown because the capacity factor of gas resources is a RESOLVE output. The capacity factor can change over time and cannot be predicted prior to each model run.

Appendix B: Transmission Updates

Objective of RESOLVE Transmission Updates

- E3 updated RESOLVE to incorporate additional information on the transmission system in order to refine locational information provided with resource portfolios
- The RESOLVE updates use new and updated data described in CAISO's white paper, which includes:
  - More detail on how resources and transmission constraints interact via resource output factors
  - Additional detail on the timing of peak needs via highest and secondary on-peak transmission constraints
  - An expanded set of transmission constraints
  - Details of how transmission upgrades impact on-peak and off-peak capability
  - Estimates of time to construct transmission upgrades

White paper available at http://www.caiso.com/Documents/WhitePaper-2021TransmissionCapabilityEstimates-CPUCResourcePlanningProcess.pdf

Transmission Capability Update Approach

1. Create transmission capability constraint equations
2. Input new transmission capability data
    - Existing transmission capabilities
    - Upgrade cost and first available year
    - Upgrade effectiveness at increasing on-peak and off-peak deliverablitiy
3. Assign RESOLVE resources to each constraint
    - Use CAISO's resource output factors for deliverability
        - Offshore and out of state wind data not provided by CAISO; E3 scaled land-based CAISO wind resource output factors by capacity factor

- Implementation relies on RESOLVE's new "custom constraint" functionality, enabled by an updated code base

EODS = Energy Only Deliverability Status
FCDS = Full Capacity Deliverability Status

Fully Deliverable vs. Energy Only

Total Renewable Capacity Selected

Capacity:
For solar, wind, and geothermal resources, RESOLVE selects deliverability status

Energy:
All capacity contributes to dispatch on 37 representative days (no direct link between deliverability status and dispatch)

Fully Deliverable (FCDS) capacity contributes to resource adequacy (the planning reserve margin)

Energy Only (EODS) capacity does NOT contribute to resource adequacy (the planning reserve margin)

Transmission Deliverability Constraints

On-Peak HSN: Highest System Need

On-Peak SSN: Secondary System Need

Off-Peak

Fully Deliverable renewable capacity must "fit" within both on-peak transmission capability limits (including upgrades)

All renewable capacity requires off-peak transmission capability

Transmission Constraint – On-Peak HSN Example

Constraint Type	Existing Transmission System Capability Estimate (MW)	Transmission Upgrade Capacity (MW)		Non-Storage Resource (r) Capability Required (MW)	Storage Resource (sr) Capability Required (MW)
On-Peak HSN: Highest System Need	Fully Deliverable (FCDS)	Upgrade FCDS MW	≥	$\sum_{r}\left(\begin{matrix}\text{Fully Deliverable Capacity}_r * \\ \text{Resource HSN Output Factor}_r\end{matrix}\right)$	$+\sum_{sr}(\text{Installed Capacity}_{sr})$

There are three different limits for each transmission constraint; HSN limit used as example here

CAISO estimates of existing network capability and how upgrade would increase capability

Each resource has an output factor ranging from 0 to 1, representing capacity factor during periods when the constraint is limiting

Storage discharge (On-Peak) requires transmission capability; Storage charging (Off-Peak) increases transmission capability

Generalized Constraint Equations

Constraint Type	Existing Transmission System Capability Estimate (MW)	Transmission Upgrade Capacity (MW)		Non-Storage Resource (r) Capability Required (MW)	Storage Resource (sr) Capability Required (MW)
On-Peak HSN: Highest System Need	Fully Deliverable (FCDS)	Upgrade FCDS MW	≥	$\sum_r \left(\text{Fully Deliverable Capacity}_r * \text{Resource HSN Output Factor}_r \right)$	$+\sum_{sr}(\text{Installed Capacity}_{sr})$
On-Peak SSN: Secondary System Need	Fully Deliverable (FCDS)	Upgrade FCDS MW	≥	$\sum_r \left(\text{Fully Deliverable Capacity}_r * \text{Resource SSN Output Factor}_r \right)$	$+\sum_{sr}(\text{Installed Capacity}_{sr})$
Off-Peak	Energy Only (EODS)	Upgrade EODS MW	≥	$\sum_r \left(\text{Installed Capacity}_r * \text{Resource Off–Peak Output Factor}_r \right)$	$-\sum_{sr}(\text{Installed Capacity}_{sr})$

EODS = Energy Only Deliverability Status
FCDS = Full Capacity Deliverability Status

Transmission Upgrades

- CAISO provided 44 constraints of which 28 were modelled in RESOLVE
  - Upgrades without a RESOLVE candidate resource weren't modeled
- Transmission upgrades are not made available for selection until the First Available Year
  - Ensures that upgrades can be built on a feasible development timeline

Constraint	Resource Constraint Area	First Available Year	Upgrade size - On-peak (MW)	Upgrade size - Offpeak (MW)	Levelized Cost ($2020/MW-yr)
Delevan Cortina 230	Northern California	2034	2,838	N/A	87,364
Contra Costa Delta Switchyard 230	Northern California	2030	1,476	N/A	26,009
Humboldt Trinity 115	Northern California	2031	57	N/A	205,153
Gates Arco Midway 230	Southern PGAE	2031	3,137	332	3,374
Gates 500 230 Transformer	Southern PGAE	2026	4,453	1,603	732
Los Banos 500 230 Transformer	Southern PGAE	2028	446	N/A	65,595
Tesla Westley 230	Southern PGAE	2027	114	N/A	63,617
Gates Panoche 230	Southern PGAE	2027	378	6,723	55,275
Morro Bay Templeton 230	Southern PGAE	2031	739	123	125,914
Los Banos Gates 500 OPDS	Southern PGAE	2031	N/A	2,246	2,250
Moss Landing Los Banos 230 OPDS	Southern PGAE	2031	N/A	1,822	2,773
Tehachapi Antelope	Tehachapi	2024	2,700	N/A	476
South Kramer Victor	Greater Kramer	2029	430	480	22,883
South Kramer Victor Lugo	Greater Kramer	2025	430	N/A	51,832
Lugo Transformer	Greater Kramer	2026	980	N/A	6,906
Eldorado 500 230	El Dorado SNV	2026	400	N/A	16,920
GLW VEA	El Dorado SNV	2027	1,000	1,110	14,118
Mohave Eldorado 500	El Dorado SNV	No upgrade identified			
Serrano Alberhill	SCE Eastern/SDGE	2031	3,648	N/A	35,528
Colorado River 500 230	SCE Eastern/SDGE	2026	1,000	1,000	7,155
Devers Red Bluff	SCE Eastern/SDGE	2031	3,100	1,876	28,870
East of Miguel	SCE Eastern/SDGE	2032	1,412	943	223,754
Imperial Valley	SCE Eastern/SDGE	2031	400	N/A	46,850
Encina San Luis Rey	SCE Eastern/SDGE	2032	3,718	N/A	2,355
Internal San Diego	SCE Eastern/SDGE	2024	2,067	274	4,331
San Luis Rey San Onofre	SCE Eastern SDGE	2032	4,269	N/A	4,766
Silvergate Bay Boulevard	SCE Eastern SDGE	2028	2,119	N/A	1,360
Greater LA	Greater LA	No upgrade identified *			

* Upgrade modeled in RESOLVE with an extremely high cost to act as an "overflow" zone for long-run (~2040+ timeframe) planning

Input Data: Resource Output Factors for Transmission Capability Estimates

- Transmission capability varies with:
  - Resource type
  - Time of delivery
    - Highest System Need
    - Secondary System Need
    - Offpeak
  - Location
- CAISO provided **resource output factors** to reflect this:
  - The fraction of installed resource capacity that requires transmission space under different constraint scenarios
- Storage resources expand EODS limits via charging off-peak (negative 100% in EODS table)

Resource output factors – Full Capacity Deliverability Status (FCDS) Capability Estimates

On Peak Scenario	Highest System Need (HSN)			Secondary System Need (SSN)		
Load Serving Entity	SDG&E	SCE	PG&E	SDG&E	SCE	PG&E
Solar	3.0%	10.6%	10.0%	40.2%	42.7%	55.6%
Wind	33.7%	55.7%	66.5%	11.2%	20.8%	16.3%
Pumped Hydro	100%					
Li Battery	100%*					
Geothermal	100%					

Resource output factors – Energy Only Deliverability Status (EODS) Capability Estimates

Constraint Area Type	"Wind" Area			"Solar" Area		
Load Serving Entity	SDG&E	SCE	PG&E	SDG&E	SCE	PG&E
Solar	68.0%	68.0%	68.0%	79.0%	77.0%	79.0%
Wind	69.0%	64.0%	64.0%	44.0%	44.0%	44.0%
Pumped Hydro	-100%					
Li Battery	-100% *					
Geothermal	100% **					

* Discharge power capacity used for Li storage regardless of duration
**100% of Geothermal nameplate capacity assumed to need off-peak deliverability

Data Source: CAISO Whitepaper - Transmission Deliverability Study

Resource Constraint Assignment
Northern California

Resources

Transmission Constraints	Northern California Wind	Solano Wind	Humboldt Wind	Humboldt Bay Offshore Wind	Solano Geothermal	Northern California Geothermal	Northern California Solar	Northern California Li Battery	Northwest Wind on Existing Transmission
Delevan Cortina 230	1	1	1	1	1	1	1	1	1
Contra Costa Delta Switchyard 230	0	1	0	0	1	0	0	0	1
Humboldt Trinity 115	0	0	1	1	0	0	0	0	0

1 indicates that the resource is included in the constraint;
0 indicates that it is not

Resource Constraint Assignment Southern PG&E

	Kern Greater Carrizo Wind	Carrizo Wind	Central Valley North Los Banos Wind	Diablo Canyon Offshore Wind	Morro Bay Offshore Wind	Southern PGAE Solar	Southern PGAE Li Battery
Gates Arco Midway 230	1	1	0	0	1	0	0
Gates 500 230 Transformer	1	1	1	0	1	0	0
Los Banos 500 230 Transformer	0	0	1	0	0	0	0
Tesla Westley 230	0	0	1	0	0	0	0
Gates Panoche 230	0	1	0	1	1	1	1
Morro Bay Templeton 230	1	1	1	0	1	0	0
Los Banos Gates 500 OPDS	1	1	0	0	0	0	0
Moss Landing Los Banos 230 OPDS	1	1	1	0	0	0	0

Resource Constraint Assignment Tehachapi, Greater Kramer, & El Dorado

El Dorado

	Southern NV Eldorado Solar	Southern NV Eldorado Li Battery	Southern Nevada Wind	Southern Nevada Geothermal	Wyoming Wind
Eldorado 500 230	1	1	1	1	1
GLW VEA	0	0	1	1	0
Mohave Eldorado 500	0	0	0	1	0

Tehachapi

	Tehachapi Wind	Tehachapi Solar	Tehachapi Li Battery	Tehachapi Pumped Storage
Tehachapi Antelope	1	1	1	1

Greater Kramer

	Greater Kramer Solar	Greater Kramer Li Battery	Inyokern North Kramer Geothermal
South Kramer Victor	0	0	1
South Kramer Victor Lugo	0	0	1
Lugo Transformer	1	1	1

Resource Constraint Assignment
SCE + Eastern SDG&E

	Riverside Solar	Riverside Li Battery	Riverside Palm Springs Geothermal	Riverside Palm Springs Wind	Arizona Solar	Arizona Li Battery	New Mexico Wind	SW Ext Tx Wind	Imperial Solar	Imperial Li Battery	Greater Imperial Geothermal	Riverside East Pumped Storage	San Diego Pumped Storage	Baja California Wind	San Diego Li Battery
Serrano Alberhill	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Colorado River 500 230	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Devers Red Bluff	0	0	0	1	1	1	1	1	0	0	0	1	0	0	0
East of Miguel	0	0	0	0	1	1	1	1	1	1	1	0	0	1	0
Imperial Valley	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
Encina San Luis Rey	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1
Internal San Diego	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1
San Luis Rey San Onofre	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1
Silvergate Bay Boulevard	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1

Resource Constraint Assignment Greater LA Constraint

- CAISO identified additional transmission capability near the Los Angeles area that is not included in other transmission constraints
  - The Greater LA constraint was created to include this transmission capability in RESOLVE.
- The Greater LA constraint combines the existing system capability for the following CAISO-identified constraints:
  - Orange County Area
  - Laguna Bell – Mesa Flow Limit
  - SCE Metro Area
- The Greater LA solar resource was limited to 3,000 MW based on interconnection queue activity

	Riverside West Pumped Storage	Greater LA Solar	Greater LA Li Battery
Greater LA	1	1	1

Serrano – Alberhill Tx Constraint Example
Transmission Constraint Data

Constraint Attributes	
Full Capacity Deliverability	5,700 MW
Energy Only Deliverability	11,800 MW
Upgrade type	Adds peak deliverability
Upgrade size	3,648 MW
Upgrade cost	$1.48 Bn
Construction time	105 Months (+ 12 months for approval process)
Area constraint type (for off-peak deliverbality factors)	Solar

- Existing transmission lines provide:
  - 5.7 GW on-peak space
  - 11.8 GW off-peak space
- RESOLVE can build up to 3,648 MW of new **on peak** transmission capability
  - The upgrade creates 0 MW of off-peak capability
- Levelized cost of **35,528 $/MW-year** (2020 $)
  - This includes AFUDC* costs
- New transmission capability available from **2031** at the earliest

*Allowance for Funds Used During Construction (AFUDC)

Serrano – Alberhill Example: Resources

Used to look up resource output factors

Resource Output Factors

Resource Name	LSE Zone	Resource Type	HSN	SSN	Offpeak
Riverside Palm Springs Geothermal	N/A	Geothermal	100%	100%	100%
Greater Imperial Geothermal	N/A	Geothermal	100%	100%	100%
Riverside Li Battery	N/A	Li Battery	100%	100%	-100%
Arizona Li Battery	N/A	Li Battery	100%	100%	-100%
Imperial Li Battery	N/A	Li Battery	100%	100%	-100%
San Diego Li Battery	N/A	Li Battery	100%	100%	-100%
Riverside East Pumped Storage	N/A	PSH	100%	100%	-100%
San Diego Pumped Storage	N/A	PSH	100%	100%	-100%
Riverside Solar	SCE	Solar	11%	43%	77%
Arizona Solar	SCE	Solar	11%	43%	77%
Imperial Solar	SCE	Solar	11%	43%	77%
Baja California Wind	SDG&E	Wind	34%	11%	44%
New Mexico Wind	SCE	Wind	79%	29%	62%
Riverside Palm Springs Wind	SCE	Wind	61%	23%	48%
SW Ext Tx Wind	SCE	Wind	65%	24%	51%

The Serrano – Alberhill constraint has 15 associated resources in the SCE + Eastern SDG&E region

The constraint is in a solar constrained area and therefore the corresponding offpeak resource output factors are used

Serrano – Alberhill Example: On-Peak HSN

Constraint Type	Existing Transmission System Capability Estimate (MW)	Transmission Upgrade Capacity (MW)		Non-Storage Resource (r) Capability Required (MW)	Storage Resource (sr) Capability Required (MW)
On-Peak HSN: Highest System Need	5,700 MW (constant)	Transmission Upgrade FCDS MW (RESOLVE decision variable)	≥	$0.106 * (FCDS\_Capacity_{Riverside\_Solar} + FCDS\_Capacity_{Imperial\_Solar} + FCDS\_Capacity_{Arizona\_Solar})$ + $1 * (FCDS\_Capacity_{Riverside\_Palm\_Springs\_Geothermal} + FCDS\_Capacity_{Greater\_Imperial\_Geothermal})$ + $0.607 * FCDS\_Capacity_{Riverside\_Palm\_Springs\_Wind}$ + $0.788 * FCDS\_Capacity_{New\_Mexico\_Wind}$ + $0.647 * FCDS\_Capacity_{SW\_Ext\_Tx\_Wind})$	+ $Installed\_Capacity_{Riverside\_Li\_Battery}$ + $Installed\_Capacity_{Riverside\_East\_Pumped\_Storage}$ + $Installed\_Capacity_{Imperial\_Li\_Battery}$ + $Installed\_Capacity_{Arizona\_Li\_Battery}$

Only Fully Deliverable (FCDS) renewable capacity included in On-Peak constraints.

Serrano – Alberhill Example: On-Peak SSN

Constraint Type	Existing Transmission System Capability Estimate (MW)	Transmission Upgrade Capacity (MW)		Non-Storage Resource (r) Capability Required (MW)	Storage Resource (sr) Capability Required (MW)
On-Peak SSN: Secondary System Need	5,700 MW (constant)	Transmission Upgrade FCDS MW (RESOLVE decision variable)	≥	→ $0.427 * (FCDS\_Capacity_{Riverside\_Solar} + FCDS\_Capacity_{Imperial\_Solar} + FCDS\_Capacity_{Arizona\_Solar})$ + $1 * (FCDS\_Capacity_{Riverside\_Palm\_Springs\_Geothermal} + FCDS\_Capacity_{Greater\_Imperial\_Geothermal})$ + $0.227 * FCDS\_Capacity_{Riverside\_Palm\_Springs\_Wind}$ + $0.294 * (FCDS\_Capacity_{New\_Mexico\_Wind}$ + $0.242 * FCDS\_Capacity_{SW\_Ext\_Tx\_Wind})$	+ $Installed\_Capacity_{Riverside\_Li\_Battery}$ + $Installed\_Capacity_{Riverside\_East\_Pumped\_Storage}$ + $Installed\_Capacity_{Imperial\_Li\_Battery}$ + $Installed\_Capacity_{Arizona\_Li\_Battery}$

→ Note that the coefficients change between HSN and SSN. Solar resources here require more on-peak space in the SSN constraint than the HSN

Serrano – Alberhill Example: Off-Peak

Constraint Type	Existing Transmission System Capability Estimate (MW)	Transmission Upgrade Capacity (MW)		Non-Storage Resource (r) Capability Required (MW)	Storage Resource (sr) Capability Required (MW)
Off-Peak	11,800 MW (constant)	0 MW (The Serrano – Alberhill upgrade provides no additional off-peak deliverability)	≥	$0.77 * (FCDS\_Capacity_{Riverside\_Solar} + FCDS\_Capacity_{Imperial\_Solar} + FCDS\_Capacity_{Arizona\_Solar})$ + $1 * (FCDS\_Capacity_{Riverside\_Palm\_Springs\_Geothermal} + FCDS\_Capacity_{Greater\_Imperial\_Geothermal})$ + $0.480 * FCDS\_Capacity_{Riverside\_Palm\_Springs\_Wind}$ + $0.643 * (FCDS\_Capacity_{New\_Mexico\_Wind}$ + $0.511 * FCDS\_Capacity_{SW\_Ext\_Tx\_Wind})$	$- Installed\_Capacity_{Riverside\_Li\_Battery}$ $- Installed\_Capacity_{Riverside\_East\_Pumped\_Storage}$ $- Installed\_Capacity_{Imperial\_Li\_Battery}$ $- Installed\_Capacity_{Arizona\_Li\_Battery}$

Note: Many of the CAISO-identified upgrades do increase off-peak deliverability

-1 coefficient for storage resources represents charging off-peak. Storage charging decreases available energy in the constraint zone off-peak.