DRAFT ELECTRICITY GENERATION SCENARIOS SUMMARY for EPC-19-060

(Deliverable for Subtask 3.4)

April, 2022

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Executive Summary

This Draft Electricity Generation Technology Summary gives an overview of how we plan to model the electricity generation using RESOLVE. The inputs for SWITCH are summarized elsewhere. This document includes a summary of the inputs for

- the baseline that will be used to test the revisions to the RESOLVE code
- a revised baseline that will be used for the more extensive calculations to assess the value of long-duration energy storage, and
- modifications to the baseline to test which of these have a large effect on the value of long-duration energy storage.

California is blessed with abundant solar resource that is widely estimated to be adequate to supply all of California's energy needs. California also has access to hydropower, wind energy, geothermal, and biomass as valuable, but less abundant, generation resources that will complement solar to provide reduced need for storage.

The Preferred System Portfolio (PSP)[1] has been defined using substantial public input, so we have chosen to use it as the starting point for our generation sources. This unmodified version will be used to consider the effects of 8760-hour evaluations using the two-step method of optimizing the capacity-expansion plan based on critical time points and then optimizing the hourly dispatch for the selected capacity-expansion plan.

A modification we will make for the extensive analyses of the value of long-duration energy storage include:

- Inclusion of solar resources with south-facing tilt
- Addition of a solar thermal (concentrated solar power – CSP) resource

The following will be included for a subset of the studies to identify how they affect the value of long-duration energy storage.

- Inclusion of two new on-shore wind resources that show winter-dominant generation
- Effect of low hydro resource
- Biomass converter that uses oxycombustion to provide negative carbon emissions
- Two new zero-emissions generators with 1) optimistic cost or 2) conservative cost that may simulate a new technology that can generate electricity without carbon dioxide emissions

We anticipate that the seasonal dispatch of some of these generators may help to reduce the need for seasonal storage.

[1] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-power-procurement/long-term-procurement-planning/2019-20-irp-events-and-materials

1. Introduction

This “Draft Proposed Electricity Generation Scenarios Summary” (deliverable 3.4) leverages the “Draft electricity generation technology summary” (deliverable 3.3) that was completed in August 2021. That summary and related studies that we have published, concluded that the choice of the generation technology will have a profound effect on how storage will be used by a zero-carbon emissions grid.

Modeling grid operation to fully understand the potential value of long-duration storage is built on an understanding of the generation profiles. The sun shines during the day, though some days are cloudy. The wind blows more at night, but not every day. The storage that is needed to fill the gaps will be intimately dependent on the details of the generation. Though the generation profiles will be unpredictable in some ways (we don’t know when the wind will stop blowing), the profiles are very predictable in other ways (the sun sets every night leaving us without solar electricity each night).

Prices for solar and wind plants have dropped impressively. The prices for geothermal, biomass, and others could also drop in the coming years. The best values to assume for modeling have significant uncertainty. We choose to leverage the results of the IRP process both because a lot of thought has gone into that and because it will allow us to compare the effects of our different modeling capabilities with baselines such as the PSP that have been well established.

2. Existing Generation Resources Available in California

For consistency with the ongoing IRP process, we will use the preferred system plan (PSP) documentation of existing resources as a starting point to test the code. "38MMT_20211005_PSP_LSEplan_2020IEPR_2020IEPRHighEV". Some additions will be made from the PSP as indicated.

2.1 Existing Solar Resources

Solar resources included in the PSP as existing and planned resources are tabulated in Tables 2.1 and 2.2.

Table 2. 1 Existing Solar Resources

Resource name	Zone	Variable_cost_per_MWh	Curtailment_cost_per_MWh	RPS eligible
BANC_Solar_for_Other	BANC	0	30	0
CAISO_Solar_for_Other	CAISO	0	-	0
IID_Solar_for_Other	IID	0	30	0
LDWP_Solar_for_Other	LDWP	0	30	0
NW_Solar_for_Other	NW	0	30	0
SW_Solar_for_Other	SW	0	30	0
CAISO_Solar_for_CAISO	CAISO	0	-	1
IID_Solar_for_CAISO	IID	0	-	1
SW_Solar_for_CAISO	SW	0	-	1
Customer_PV	CAISO	0	-	0

Table 2. 2 Planned Installed Capacities for Solar Resources

Resource name	2025	2030	2035	2040	2045
BANC_Solar_for_Other	2915	3747	3747	3747	3747
CAISO_Solar_for_Other	12	12	12	12	12
IID_Solar_for_Other	139	116	116	116	116
LDWP_Solar_for_Other	3256	3459	3459	3459	3459
NW_Solar_for_Other	2606	2601	2601	2600	2600
SW_Solar_for_Other	1855	1831	1652	1647	1637
CAISO_Solar_for_CAISO	16405	16405	16405	16405	16405
IID_Solar_for_CAISO	50	50	50	50	50
SW_Solar_for_CAISO	65	65	65	65	65
Customer_PV	16483	21706	26928	32151	37374
Distributed_Solar*	114.8	125.2	125.2	125.2	125.2
Southern_NV_Eldorado_Solar*	0	785.7	785.7	785.7	785.7
Greater_Kramer_Solar*	451.7	850.3	850.3	850.3	850.3
River_Side_Solar*	2451.0	4001.3	4001.3	4001.3	4001.3
Tehachapi_Solar*	1445.9	2969.5	2969.5	2969.5	2969.5
Southern_PGAE_Solar*	1058.2	1238.0	1238.0	1238.0	1238.0

*The model may select to build more, but this is the minimum.

The generation profiles for the existing solar generators have been defined in the PSP and will be used without modification other than to use a full year of data with 2007 being the benchmark.

2.2 Existing Wind Resources

Similarly, the existing wind resources for the PSP are summarized in Tables 2.3 and 2.4.

Table 2. 3 Existing Wind Resources

Resource name	Zone	Variable_cost_per_MWh	Curtailment_cost $/MWh	RPS eligible
BANC_Wind_for_Other	BANC	0	30	0
CAISO_Wind_for_Other	CAISO	0	-	0
IID_Wind_for_Other	IID	0	30	0
LDWP_Wind_for_Other	LDWP	0	30	0
NW_Wind_for_Other	NW	0	30	0
SW_Wind_for_Other	SW	0	30	0
CAISO_Wind_for_CAISO	CAISO	0	-	1
LDWP_Wind_for_CAISO	LDWP	0	-	1
NW_Wind_for_CAISO	NW	0	-	1
SW_Wind_for_CAISO	SW	0	-	1
Arizona_Wind	CAISO	0	-	1
Idaho_Wind	CAISO	0	-	1
Utah_Wind	CAISO	0	-	1
Pacific_Northwest_Wind	CAISO	0	-	1

Table 2. 4 Planned Installed Capacities (MW) for Existing Wind Resources

Resource name	2025	2030	2035	2040	2045
BANC_Wind_for_Other	0	0	0	0	0
CAISO_Wind_for_Other	280	280	280	280	280
IID_Wind_for_Other	0	0	0	0	0
LDWP_Wind_for_Other	705	705	705	705	705
NW_Wind_for_Other	11090	10989	10989	10989	10989
SW_Wind_for_Other	2290	1877	1877	1877	1877
CAISO_Wind_for_CAISO	6690	6690	6690	6690	6690
LDWP_Wind_for_CAISO	5	5	5	5	5
NW_Wind_for_CAISO	1417	1417	1417	1417	1417
SW_Wind_for_CAISO	50	50	50	50	50
Arizona_Wind*	0	0	0	0	0
Idaho_Wind*	0	0	0	0	0
Utah_Wind*	0	0	0	0	0
Pacific_Northwest_Wind*	0	0	0	0	0
Humboldt_Wind**	31	31	31	31	31
Kern_Greater_Carrizo_Wind**	0	15	15	15	15
Northern_California_Wind**	0	25	25	25	25
Solano_Wind**	5	25	25	25	25
Southern_Nevada_Wind**	177	177	177	177	177
SW_Ext_Tx_Wind**	265	265	265	265	265
Tehachapi_Wind**	275	275	275	275	275
Morro_Bay_Offshore_Wind**	0	75	75	75	75

* These are effectively "turned off" because they aren't controlled by California, but may be relevant to the outcome. They are documented for times when they are allowed to participate.
**The model may build more, but these are the minimum.

The generation profiles for the existing wind generators have been defined in the PSP and will be used without modification other than to use a full year of data with 2007 being the benchmark.

2.3 Existing Small and Large Hydro Resources

Similarly, the existing hydro resources for the PSP are summarized in Tables 2.5 and 2.6 and in Figures 2.1 and 2.2.

Table 2. 5 Existing Hydro Resources

Resource name	Zone	Variable_cost_per_MWh	RPS eligible	Available capacity fraction
CAISO_Small_Hydro_for_CAISO	CAISO	0	1	0.5
BANC_Small_Hydro_for_CAISO	BANC	0	1	0.5
NW_Small_Hydro_for_CAISO	NW	0	1	0.5
CAISO_Small_Hydro_for_Other	CAISO	0	0	
BANC_Small_Hydro_for_Other	BANC	0	0	
IID_Small_Hydro_for_Other	IID	0	0	
LDWP_Small_Hydro_for_Other	LDWP	0	0	
NW_Small_Hydro_for_Other	NW	0	0	
SW_Small_Hydro_for_Other	SW	0	0	
CAISO_Hydro	CAISO	0	0	By day*
NW_Hydro	NW	0	0	By day*
SW_Hydro	SW	0	0	By day
LDWP_Hydro	LDWP	0	0	By day
BANC_Hydro	BANC	0	0	By day*
IID_Hydro	IID	0	0	By day
NW_Hydro_for_CAISO	CAISO_NW_Hydro	0	0	By day

* See Figs. 2.1 and 2.2.

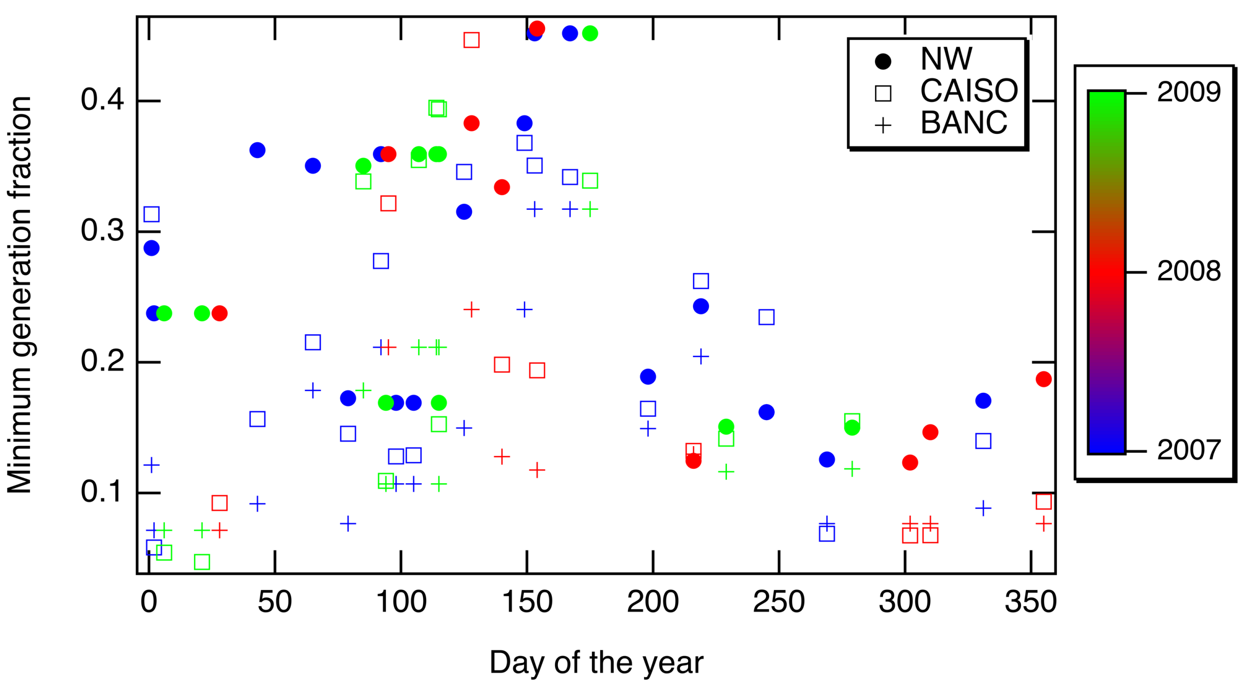

Fig. 2. 1 Minimum generation fraction for hydro resources (as in PSP).

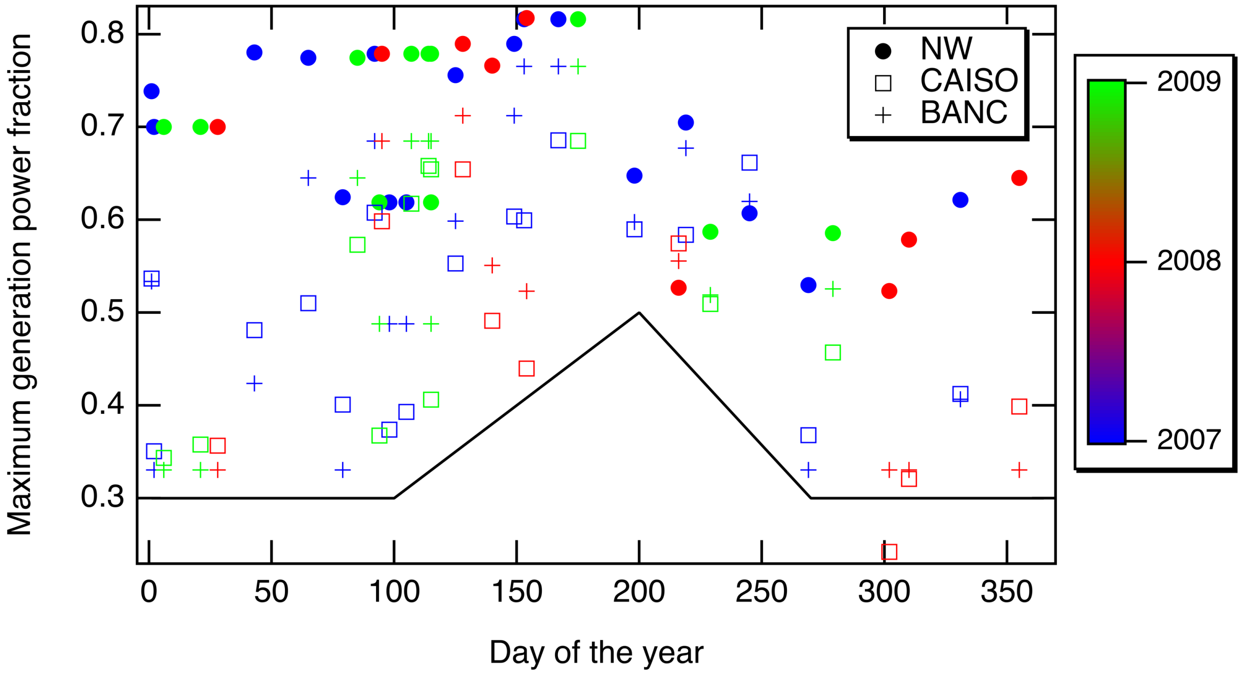

Fig. 2. 2 Maximum generation power fraction for some hydro resources (as in PSP.)

Table 2. 6 Planned Installed Capacities (MW) for Existing Hydro Resources

Resource name	2025	2030	2035	2040	2045
CAISO_Small_Hydro_for_CAISO	944.5	944.5	944.5	944.5	944.5
BANC_Small_Hydro_for_CAISO	0	0	0	0	0
NW_Small_Hydro_for_CAISO	6.9	6.9	6.9	6.9	6.9
CAISO_Small_Hydro_for_Other	13.8	13.8	13.8	13.8	13.8
BANC_Small_Hydro_for_Other	41.2	41.2	41.2	41.2	41.2
IID_Small_Hydro_for_Other	0	0	0	0	0
LDWP_Small_Hydro_for_Other	56	56	56	56	56
NW_Small_Hydro_for_Other	41	41	41	41	41
SW_Small_Hydro_for_Other	0	0	0	0	0
CAISO_Hydro	7073.4	7072.8	7072.8	7072.8	7072.8
NW_Hydro	31478	31295	31295	31295	31288
SW_Hydro	2680.3	2532.4	2532.4	2532.4	2532.4
LDWP_Hydro	233.7	233.7	233.7	233.7	233.7
BANC_Hydro	2724.1	2724.1	2724.1	2724.1	2724.1
IID_Hydro	83.5	83.5	83.5	83.5	83.5
NW_Hydro_for_CAISO	2851.8	2851.8	2851.8	2851.8	2851.8

The minimum and maximum generation profiles for the various hydro sources are highly variable from year to year as shown in Figs. 2.1 and 2.2. By our assessment, the ability to generate hydropower as a dispatchable load can be very helpful in reducing the need for storage, but in a year when there is extreme drought, the available water may limit the value of the hydropower. We will implement the three years from 2007-2009, and also will add a "worst case" hydro scenario using the black line in Fig. 2.2 to limit the maximum flow on any day and limiting the entire annual generation to the worst-case values for each hydro resource.

2.4 Existing Geothermal and Biomass Resources

Similarly, the existing geothermal and biomass resources for the PSP are summarized in Tables 2.7 and 2.8.

Table 2. 7 Existing Geothermal and Biomass Resources

Resource name	Zone	Variable_cost_ per_MWh	RPS eligible
BANC_Biomass_for_Other	BANC	1.55	0
BANC_Geothermal_for_Other	BANC	1.09	0
CAISO_Biomass_for_Other	CAISO	1.55	0
CAISO_Geothermal_for_Other	CAISO	1.09	0
IID_Biomass_for_Other	IID	1.55	0
IID_Geothermal_for_Other	IID	1.09	0
LDWP_Biomass_for_Other	LDWP	1.55	0
LDWP_Geothermal_for_Other	LDWP	1.09	0
NW_Biomass_for_Other	NW	1.55	0
NW_Geothermal_for_Other	NW	1.09	0
SW_Biomass_for_Other	SW	1.55	0
SW_Geothermal_for_Other	SW	1.09	0
CAISO_Biomass_for_CAISO	CAISO	1.55	1
CAISO_Geothermal_for_CAISO	CAISO	1.09	1
IID_Geothermal_for_CAISO	IID	1.09	1
NW_Biomass_for_CAISO	NW	1.55	1
NW_Geothermal_for_CAISO	NW	1.09	1

Table 2. 8 Planned Installed Capacities (MW) for Existing Geothermal and Biomass Resources

Resource name	2025	2030	2035	2040	2045
BANC_Biomass_for_Other	17.5	17.5	17.5	17.5	17.5
BANC_Geothermal_for_Other	31	31	31	31	31
CAISO_Biomass_for_Other	11.7	11.7	11.7	11.7	11.7
CAISO_Geothermal_for_Other	8.7	8.7	8.7	8.7	8.7
IID_Biomass_for_Other	77	77	77	77	77
IID_Geothermal_for_Other	401	401	401	401	401
LDWP_Biomass_for_Other	0	0	0	0	0
LDWP_Geothermal_for_Other	0	0	0	0	0
NW_Biomass_for_Other	584	544	544	544	544
NW_Geothermal_for_Other	164	154	154	154	154
SW_Biomass_for_Other	113	107.5	107.5	107.5	107.5
SW_Geothermal_for_Other	815	778	778	778	778
CAISO_Biomass_for_CAISO	797.9	796	796	796	796
CAISO_Geothermal_for_CAISO	1578.8	1578.8	1578.8	1578.8	1578.8
IID_Geothermal_for_CAISO	83	83	83	83	83
NW_Biomass_for_CAISO	46	46	46	46	46
NW_Geothermal_for_CAISO	0	0	0	0	0
Greater_Imperial_Geothermal*	100	102.3	102.3	102.3	102.3

*Minimum planned build

2.5 Existing Fossil-fuel and Nuclear Resources

Similarly, the existing fossil-fuel and nuclear resources for the PSP are summarized in Tables 2.9 and 2.10.

Table 2. 9 Existing Fossil-fuel and Nuclear Resources

Resource name	Zone	Variable_cost_ per_MWh	GHG emissions /MMBTU	Fuel use slope MMBTU/MWh	Fuel use intercept MMBTU/h
CAISO_CHP	CAISO	1.49	0.053	7.61	0.00
CAISO_Nuclear	CAISO	1.80	0	11.36	695.45
CAISO_CCGT1	CAISO	0.25	0.053	6.54	272.20
CAISO_CCGT2	CAISO	0.41	0.053	7.84	112.07
CAISO_Coal	CAISO	2.48	0.094	9.16	840.48
CAISO_Peaker1	CAISO	1.34	0.053	8.09	74.57
CAISO_Peaker2	CAISO	1.41	0.053	9.48	110.97
CAISO_ST	CAISO	0.30	0.053	9.03	254.86
NW_Nuclear	NW	1.80	0	10.91	0.00
NW_Coal	NW	2.48	0.094	10.20	182.29
NW_CCGT	NW	0.25	0.053	6.57	233.32
NW_Peaker	NW	1.40	0.053	8.71	51.42
SW_Nuclear	SW	1.80	0	10.54	0.00
SW_Coal	SW	2.48	0.094	9.81	207.23
SW_CCGT	SW	0.26	0.053	6.68	257.63
SW_Peaker	SW	1.50	0.053	8.34	100.76
SW_ST	SW	0.30	0.053	9.99	133.78
LDWP_Nuclear	LDWP	1.80	0	10.54	0.00
LDWP_Coal	LDWP	2.48	0.094	9.16	840.48
LDWP_CCGT	LDWP	0.27	0.053	6.51	202.85
LDWP_Peaker	LDWP	0.98	0.053	7.05	127.34
LDWP_ST	LDWP	0.30	0.053	9.31	84.37
IID_CCGT	IID	0.24	0.053	6.77	142.33
IID_Peaker	IID	1.12	0.053	8.91	88.47
BANC_CCGT	BANC	0.24	0.053	6.68	134.13
BANC_Peaker	BANC	1.60	0.053	7.54	92.96

Table 2. 10 Planned Installed Capacities (MW) for Existing Fossil-fuel and Nuclear Resources

Resource name	2025	2030	2035	2040	2045
CAISO_CHP	1997	1892	946	0	0
CAISO_Nuclear	635	635	635	635	635
CAISO_CCGT1	13449	13449	13449	13449	13449
CAISO_CCGT2	2921	2921	2921	2921	2921
CAISO_Coal	0	0	0	0	0
CAISO_Peaker1	4941	4941	4941	4941	4941
CAISO_Peaker2	1309	1309	1309	1309	1309
CAISO_ST	0	0	0	0	0
NW_Nuclear	1170	1756.6	1756.6	1756.6	1756.6
NW_Coal	8125.8	8125.8	8125.8	8125.8	8125.8
NW_CCGT	9573.4	9573.4	9573.4	9573.4	9573.4
NW_Peaker	2993	2993	2993	2737.5	2587.5

SW_Nuclear	2998	2998	2998	2998	2998
SW_Coal	6787.6	6140.6	6140.6	6140.6	6140.6
SW_CCGT	1710.8	19741.1	19152.6	18498.1	16156.7
SW_Peaker	6808.1	6301.9	6237.9	5481.9	5481.9
SW_ST	1318.5	966.5	824.5	824.5	824.5
LDWP_Nuclear	407	407	407	407	407
LDWP_Coal	0	0	0	0	0
LDWP_CCGT	2291.7	2754.7	2754.7	2754.7	2754.7
LDWP_Peaker	1545	1647	1647	1647	1647
LDWP_ST	371	197	197	197	197
IID_CCGT	255.3	255.3	255.3	255.3	255.3
IID_Peaker	327	327	327	327	327
BANC_CCGT	1863.1	1797.5	1797.5	1797.5	1797.5
BANC_Peaker	867	867	867	867	867

3. Candidate Generation Resources

For consistency with the ongoing IRP process, we will use the preferred system plan (PSP) documentation of candidate resources "38MMT_20211005_PSP_LSEplan_2020IEPR_2020IEPRHighEV". These can be selected by the model to provide the lowest cost approach to providing resource adequacy. Some additions will be made, as indicated.

3.1 Candidate Solar Generators

Descriptions of solar resources included in the PSP as candidate resources are tabulated in Tables 3.1 – 3.4. A solar thermal option is included based on NREL Annual Technology Baseline cost numbers with 30-year lifetime. This asset is not selected by the model, but we include it for completeness and in anticipation of it becoming cost-effective in the future.

Table 3. 1 Candidate Solar Resources

Resource name	Zone	RPS eligible	Fix O&M $/kW-yr
Distributed_Solar	CAISO	1	22.08
Southern_NV_Eldorado_Solar	CAISO	1	18.86
Imperial_Solar	CAISO	1	19.40
Greater_Kramer_Solar	CAISO	1	19.40
Northern_California_Solar	CAISO	1	19.40
Riverside_Solar	CAISO	1	19.40
Tehachapi_Solar	CAISO	1	19.40
Southern_PGAE_Solar	CAISO	1	19.40
Arizona_Solar	CAISO	1	18.79
Greater_LA_Solar	CAISO	1	19.40
New Solar Thermal - CSP	CAISO	1	52

Table 3. 2 Capacity Limits (MW) for Candidate Solar Resources

Resource name	2025	2030	2035	2040	2045
Distributed_Solar	83516	78294	73072	67849	125.2
Southern_NV_Eldorado_Solar	148848	148848	148848	148848	148848
Imperial_Solar	35868	35868	35868	35868	35868
Greater_Kramer_Solar	30410	30410	30410	30410	30410
Northern_California_Solar	79975	79975	79975	79975	79975
Riverside_Solar	106392	106392	106392	106392	106392
Tehachapi_Solar	6289	6289	6289	6289	6289
Southern_PGAE_Solar	91663	91663	91663	91663	91663
Arizona_Solar	77080	77080	77080	77080	77080
Greater_LA_Solar	3000	3000	3000	3000	3000
New Solar Thermal - CSP	0	50000	100000	150000	150000

Table 3. 3 Annualized Capital Costs ($/kW) for Candidate Solar Resources by Installed Year

Resource name	2025	2030	2035	2040	2045
Distributed_Solar	70.55	82.90	79.15	75.42	71.69
Southern_NV_Eldorado_Solar	45.65	52.90	51.08	49.25	47.43
Imperial_Solar	46.66	54.09	52.22	50.34	48.46
Greater_Kramer_Solar	46.66	54.09	52.22	50.34	48.46
Northern_California_Solar	46.66	54.09	52.22	50.34	48.46
Riverside_Solar	46.66	54.09	52.22	50.34	48.46
Tehachapi_Solar	46.66	54.09	52.22	50.34	48.46
Southern_PGAE_Solar	46.66	54.09	52.22	50.34	48.46
Arizona_Solar	45.52	52.75	50.93	49.11	47.30
Greater_LA_Solar	46.66	54.09	52.22	50.34	48.46
New fixed-latitude tilt solar	43.39	50.30	48.56	46.82	45.07
New Solar Thermal - CSP	372	320	290	273	265

Table 3. 4 Annual O&M Costs ($/kW-yr) for Candidate Solar Resources by Installed Year

Resource name	2025	2030	2035	2040	2045
Distributed_Solar	12.22	9.12	8.60	8.06	7.53
Southern_NV_Eldorado_Solar	12.89	9.84	9.41	8.97	8.54
Imperial_Solar	13.26	10.13	9.68	9.23	8.79
Greater_Kramer_Solar	13.26	10.13	9.68	9.23	8.79
Northern_California_Solar	13.26	10.13	9.68	9.23	8.79
Riverside_Solar	13.26	10.13	9.68	9.23	8.79
Tehachapi_Solar	13.26	10.13	9.68	9.23	8.79
Southern_PGAE_Solar	13.26	10.13	9.68	9.23	8.79
Arizona_Solar	12.84	9.81	9.37	8.94	8.51
Greater_LA_Solar	13.26	10.13	9.68	9.23	8.79
New fixed-latitude tilt solar	12.33	9.42	9.00	8.58	8.17
New Solar Thermal - CSP	61	52	52	52	52

The solar PV O&M costs are lower than those reported in the NREL ATB, consistent with our expectations. These lower costs are offset by the higher capital costs so that the sum of the two are fairly similar. The current supply chain issues associated with the pandemic and the Russian invasion of Ukraine raise questions about the evolution of future costs/prices, reflecting the uncertainty anticipated for any simulation of the future.

The PSP generation-profile data will be used to evaluate the effect of the two-step calculations.

For the more detailed studies, the resources will be duplicated offering both the traditional one-axis tracked solar generators and south-facing latitude tilt. These systems are anticipated to be slightly lower in cost than tracked systems because of having no moving parts. The cost will be taken at about 93% of the more standard cost, as tabulated in Tables 3.3 and 3.4. The generation profile is much more consistent through the year, as shown in Fig. 2.3. for one of the systems (BV_CA_9, as indicated in the documentation). It may also be useful to include one-axis tracked tilted systems – data not shown here.

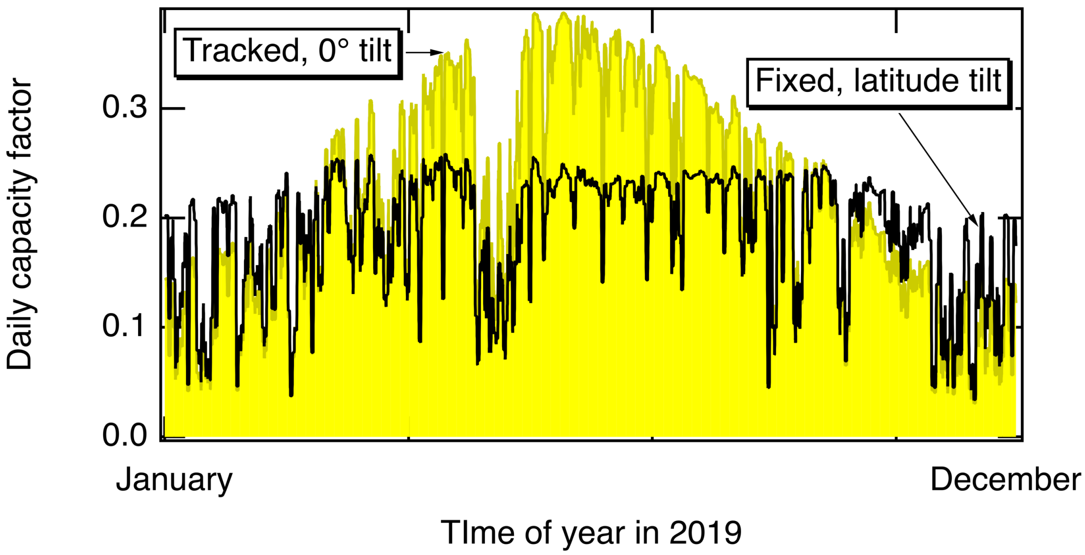

Fig. 2. 3 Daily solar output for 0° and latitude-tilt solar installations (site BV_CA_9)

3.2 Candidate Wind Generators

Wind resources included in the PSP as candidate resources are tabulated in Tables 3.5 - 3.8. Two new winter-dominant wind resources are identified to include as a sensitivity analysis.

Table 3. 5 Candidate Wind Resources with O&M Costs for Planned Capacity

Resource name	Zone	Offshore?	RPS eligible	Fixed O&M $/kW-yr
Carrizo_Wind	CAISO	-	1	45.73
Central_Valley_North_Los_Banos_Wind	CAISO	-	1	45.73
Humboldt_Wind	CAISO	-	1	45.73
Kern_Greater_Carrizo_Wind	CAISO	-	1	45.73
Northern_California_Wind	CAISO	-	1	45.73
NW_Ext_Tx_Wind	CAISO	-	1	45.79
Solano_Wind	CAISO	-	1	45.73
Southern_Nevada_Wind	CAISO	-	1	44.84
SW_Ext_Tx_Wind	CAISO	-	1	44.39
Tehachapi_Wind	CAISO	-	1	45.73
Baja_California_Wind	CAISO	-	1	44.26
New_Mexico_Wind	CAISO	-	1	44.39
Wyoming_Wind	CAISO	-	1	44.76
Riverside_Palm_Springs_Wind	CAISO	-	1	-
Diablo_Canyon_Offshore_Wind	CAISO	X	1	127.52
Humboldt_Bay_Offshore_Wind	CAISO	X	1	124.44
Morro_Bay_Offshore_Wind	CAISO	X	1	129.74
Cape_Mendocino_Offshore_Wind	CAISO	X	1	128.55
Del_Norte_Offshore_Wind	CAISO	X	1	129.74
New onshore sites	CAISO	-	1	45.73

Table 3. 6 Capacity Limits (MW) for Candidate Wind Resources

Resource name	2025	2030	2035	2040	2045
Carrizo_Wind	287	287	287	287	287
Central_Valley_North_Los_Banos_Wind	173	173	173	173	173
Humboldt_Wind	34	34	34	34	34
Kern_Greater_Carrizo_Wind	60	60	60	60	60
Northern_California_Wind	866	866	866	866	866
NW_Ext_Tx_Wind	1500	1500	1500	1500	1500
Solano_Wind	560	560	560	560	560
Southern_Nevada_Wind	442	442	442	442	442
SW_Ext_Tx_Wind	500	500	500	500	500
Tehachapi_Wind	275	275	275	275	275
Baja_California_Wind	600	600	600	600	600
New_Mexico_Wind	0	1500	34580	34580	34580
Wyoming_Wind	0	1500	33862	33862	33862
Riverside_Palm_Springs_Wind	0	0	0	0	0
Diablo_Canyon_Offshore_Wind	0	0	0	0	0
Humboldt_Bay_Offshore_Wind	0	1607	1607	1607	1607
Morro_Bay_Offshore_Wind	0	3220	3100	3100	3100
Cape_Mendocino_Offshore_Wind	0	0	0	0	0
Del_Norte_Offshore_Wind	0	0	0	0	0
New Winter Dominant California site North (41.38, -122.20)	0	1000	2000	3000	4000
New Winter Dominant California site South (36.5, -118.51)	0	1000	2000	3000	4000

Table 3. 7 Annualized Capital Costs ($/kW-y) for Candidate Wind Resources by Installed Year

Resource name	2025	2030	2035	2040	2045
Carrizo_Wind	90.61	123.42	116.46	109.27	101.86
Central_Valley_North_Los_Banos_Wind	89.73	122.49	115.53	108.34	100.93
Humboldt_Wind	68.84	107.24	101.66	95.93	90.08
Kern_Greater_Carrizo_Wind	92.85	124.02	117.06	109.87	102.46
Northern_California_Wind	93.71	125.90	118.99	111.86	104.51
NW_Ext_Tx_Wind	137.27	170.72	163.75	156.55	149.13
Solano_Wind	88.32	122.11	115.30	108.27	101.04
Southern_Nevada_Wind	95.36	126.41	119.58	112.54	105.27
SW_Ext_Tx_Wind	148.13	189.18	183.77	178.21	172.53
Tehachapi_Wind	66.39	103.78	98.09	92.23	86.23
Baja_California_Wind	67.15	107.27	101.79	96.15	90.37
New_Mexico_Wind	142.04	187.14	183.50	179.81	176.07
Wyoming_Wind	154.47	199.97	196.19	192.36	188.49
Riverside_Palm_Springs_Wind	-	-	-	-	-
Diablo_Canyon_Offshore_Wind	119.75	128.99	120.96	187.64	179.40
Humboldt_Bay_Offshore_Wind	116.51	125.59	117.73	183.82	175.71
Morro_Bay_Offshore_Wind	119.39	128.48	120.30	187.79	179.34
Cape_Mendocino_Offshore_Wind	111.16	119.93	112.26	178.20	170.22
Del_Norte_Offshore_Wind	116.94	126.01	118.10	184.43	176.27
New onshore candidates	90.61	123.42	116.46	109.27	101.86

Table 3. 8 Annual O&M Costs ($/kW-y) for Candidate Wind Resources by Installed Year

Resource name	2025	2030	2035	2040	2045
Carrizo_Wind	43.10	41.23	39.68	38.14	36.59
Central_Valley_North_Los_Banos_Wind	43.10	41.23	39.68	38.14	36.59
Humboldt_Wind	43.10	41.23	39.68	38.14	36.59
Kern_Greater_Carrizo_Wind	43.10	41.23	39.68	38.14	36.59
Northern_California_Wind	43.10	41.23	39.68	38.14	36.59
NW_Ext_Tx_Wind	43.15	41.28	39.73	38.18	36.63
Solano_Wind	43.10	41.23	39.68	38.14	36.59
Southern_Nevada_Wind	42.26	40.42	38.91	37.39	35.88
SW_Ext_Tx_Wind	43.10	41.23	39.68	38.14	36.59
Tehachapi_Wind	43.10	41.23	39.68	38.14	36.59
Baja_California_Wind	41.71	39.89	38.40	36.90	35.41
New_Mexico_Wind	41.84	40.02	38.52	37.02	35.52
Wyoming_Wind	42.18	40.35	38.84	37.33	35.81
Riverside_Palm_Springs_Wind	-	-	-	-	-
Diablo_Canyon_Offshore_Wind	79.71	65.86	56.90	50.27	45.01
Humboldt_Bay_Offshore_Wind	76.56	63.30	54.74	48.39	43.35
Morro_Bay_Offshore_Wind	78.34	64.72	55.92	49.41	44.23
Cape_Mendocino_Offshore_Wind	79.37	65.74	56.94	50.43	45.26
Del_Norte_Offshore_Wind	79.71	65.86	56.90	50.27	45.01
New onshore candidates	43.10	41.23	39.68	38.14	36.59

The winter-summer difference is calculated from the capacity factors (CF) according to

Winter-summer difference = (*winter CF – summer CF*) / (*annual CF*).

In some cases, the difference is more than 100% as in the case of the Carrizo Wind which shows a difference in capacity factor of 43% which is greater than the annual capacity factor of 31%. The methodology for calculating this metric has been published.[2] This metric has been used to characterize the RESOLVE wind resources in Table 3.9 using the weighted 37 days and using the full year of data for 2007, 2008, and 2009 based on downloads from the NREL WindToolKit. The weighted 37 days were selected to match the expected annual capacity factor and histogram of wind resource, not the seasonal distribution, so it is not surprising that the full-year analysis differs significantly from the weighted-37-days analysis.

The two new sites were selected based on existing locations of wind turbines exhibiting more generation in winter than in summer. The potential wind resource at these sites has not been evaluated. The potential wind resource has been taken to duplicate that associated with the Carrizo Wind resource, as listed in Table 3.7 so that the impact of using such resources can be evaluated. If we find the use of winter-dominant onshore California wind to have an effect on the needed storage, we suggest that further evaluation of the true potential for such wind resource is needed.

[2] "Geographical variability of summer- and winter-dominant onshore wind" Journal of Renewable and Sustainable Energy 14, 023303 (2022); https://doi.org/10.1063/5.0070430.

Table 3. 9 Seasonal Capacity Factors for Candidate Wind Resources

	Weighted 37 days				2007	2008	2009
Resource name	**Annual**	**Winter (D-J-F)**	**Summer (J-J-A)**	**W-S difference**	**W-S difference**		
Carrizo_Wind	31.1%	11.3%	54.3%	-138%	+11%	+22%	+17%
Central_Valley_North_Los_Banos_Wind	31.1%	11.3%	54.3%	-138%	-85%	-80%	-89%
Humboldt_Wind	29.2%	21.4%	29.4%	-27%			
Kern_Greater_Carrizo_Wind	31.1%	11.3%	54.3%	-138%	+11%	+22%	+17%
Northern_California_Wind	29.2%	21.4%	29.4%	-27%			
NW_Ext_Tx_Wind	30.4%	26.7%	30.7%	-13%			
Solano_Wind	30.4%	2.8%	59.1%	-185%	-67%	-66%	-82%
Southern_Nevada_Wind	28.1%	19.1%	32.9%	-49%			
SW_Ext_Tx_Wind	36.2%	55.9%	18.5%	+103%			
Tehachapi_Wind	34.3%	27.1%	44.0%	-49%	-31%	-27%	-32%
Arizona_Wind	29.9%	24.2%	31.3%	-24%			
Baja_California_Wind	36.2%	42.8%	37.2%	+15%			
Idaho_Wind	31.8%	33.4%	29.3%	+13%			
New_Mexico_Wind	44.0%	61.3%	28.1%	+75%			
Utah_Wind	30.8%	17.5%	35.0%	-57%			
Wyoming_Wind	44.2%	52.0%	22.1%	+68%			
Pacific_Northwest_Wind	32.1%	28.6%	32.5%	-12%			
Riverside_Palm_Springs_Wind	33.9%	40.7%	35.0%	+17%	-11%	-21%	-14%
Diablo_Canyon_Offshore_Wind							
Humboldt_Bay_Offshore_Wind					-34%	-35%	-20%
Morro_Bay_Offshore_Wind					-62%	-42%	-46%
Cape_Mendocino_Offshore_Wind							
Del_Norte_Offshore_Wind							
New Winter Dominant California site North (41.38, -122.20)					+123%	+96%	+108%
New Winter Dominant California site South (36.5, -118.51)					+110%	+84%	+86%

3.3 Candidate Hydropower Generators

No candidate hydropower generators are offered by the PSP. Some pumped hydro generators are under development, but these will be treated as storage rather than as generators.

3.4 Candidate Geothermal and Biomass Generators

Candidate geothermal and biomass generators presented in the PSP are summarized in Tables 3.10-3.13. The “New – Biomass using oxycombustion” candidate resource would use biogas. This biogas could be used in the Allam cycle – an oxycombustion cycle that simplifies the capture of carbon dioxide from the waste stream and avoids emission of NO_x and other criteria pollutants. Any cost evaluation of this approach has high uncertainty because the technology is not yet mature. Here, we have used the same assumptions as are used for the InState Biomass with the exception that we add the sequestration of the captured carbon dioxide, resulting in negative emissions (-0.053/MMBTU) associated with operation of these plants. The potential scale-up is estimated in Table 3.11 based on the existence of a 50 MW oxycombustion plant (by NetPower) in Texas and plans for multiple 250 MW plants to come online in 4 years.

Table 3. 10 Candidate Geothermal and Biomass Resources

Resource name	Zone	Geothermal?	RPS eligible	Variable cost $/MWh	Available capacity fraction
InState_Biomass	CAISO	-	1	1.55	85%
Greater_Imperial_Geothermal	CAISO	X	1	1.09	88%
Inyokern_North_Kramer_Geothermal	CAISO	X	1	1.09	80%
Northern_California_Geothermal	CAISO	X	1	1.09	81%
Riverside_Palm_Springs_Geothermal	CAISO	X	1	1.09	84.3%
Solano_Geothermal	CAISO	X	1	1.09	90%
Southern_Nevada_Geothermal	CAISO	X	1	1.09	84.3%
New – Biomass using oxycombustion	**CAISO**	**-**	**1**	**1.55**	**85%**

Table 3. 11 Capacity Limits (MW) for Candidate Geothermal and Biomass Resources

Resource name	2025	2030	2035	2040	2045
InState_Biomass	1146.9	1146.9	1146.9	1146.9	1146.9
Greater_Imperial_Geothermal	114	1352.1	1352.1	1352.1	1352.1
Inyokern_North_Kramer_Geothermal	0	24	24	24	24
Northern_California_Geothermal	0	469	469	469	469
Riverside_Palm_Springs_Geothermal	0	32	32	32	32
Solano_Geothermal	0	135	135	135	135
Southern_Nevada_Geothermal	0	320	320	320	320
New – Biomass using oxycombustion	**0**	**500**	**1000**	**1000**	**1000**

Table 3. 12 Annualized Capital Costs ($/kW-y) for Candidate Geothermal and Biomass Resources by Installed Year

Resource name	2025	2030	2035	2040	2045
InState_Biomass	595.10	618.91	610.71	601.65	593.68
Greater_Imperial_Geothermal	361.16	366.63	357.83	349.26	340.90
Inyokern_North_Kramer_Geothermal	396.68	405.28	396.48	387.91	379.55
Northern_California_Geothermal	372.96	379.47	370.67	362.10	353.74
Riverside_Palm_Springs_Geothermal	354.31	359.17	350.38	341.80	333.45
Solano_Geothermal	352.48	357.19	348.40	339.82	331.47
Southern_Nevada_Geothermal	351.29	356.68	348.15	339.83	331.72
New – Biomass using oxycombustion	**595.10**	**618.91**	**610.71**	**601.65**	**593.68**

Table 3. 13 Annual O&M Costs ($/kW) for Candidate Geothermal and Biomass Resources by Installed Year

Resource name	2025	2030	2035	2040	2045
InState_Biomass	135.1	135.1	135.1	135.1	135.1
Greater_Imperial_Geothermal	140.1	135.2	135.2	135.2	135.2
Inyokern_North_Kramer_Geothermal	140.1	135.2	135.2	135.2	135.2
Northern_California_Geothermal	140.1	135.2	135.2	135.2	135.2
Riverside_Palm_Springs_Geothermal	140.1	135.2	135.2	135.2	135.2
Solano_Geothermal	140.1	135.2	135.2	135.2	135.2
Southern_Nevada_Geothermal	135.9	131.2	131.2	131.2	131.2
New – Biomass using oxycombustion	**135.1**	**135.1**	**135.1**	**135.1**	**135.1**

3.5 Candidate Fossil Fuel and Other Dispatchable Generators

Candidate fossil fuel and other generators are summarized in Tables 3.14-3.17.

Table 3. 14 Candidate Fossil-fuel Resources

Resource name	Zone	Variable cost $/MWh	GHG emissions /MMBTU	Fuel use slope MMBTU/MWh	Fuel use intercept MMBTU/MWh
CAISO_Advanced_CCGT	CAISO	0.25	0.053	6.00	500.00
CAISO_Aero_CT	CAISO	0.25	0.053	6.12	345.46
CAISO_Reciprocating_Engine	CAISO	1.03	0.053	8.59	1.21
New Clean Source Optimistic	**CAISO**	**0.25**	**0**	**6.00**	**345**
New Clean Source Conservative	**CAISO**	**1.80**	**0**	**11.36**	**695.45**

Table 3. 15 Capacity Limits (MW) for Candidate Fossil-fuel Resources

Resource name	2025	2030	2035	2040	2045
CAISO_Advanced_CCGT	0.001	99999	99999	99999	99999
CAISO_Aero_CT	0.001	99999	99999	99999	99999
CAISO_Reciprocating_Engine	255.3	99999	99999	99999	99999
New Clean Source Optimistic	**0**	**500**	**1000**	**2000**	**4000**
New Clean Source Conservative	**0**	**500**	**1000**	**2000**	**4000**

Table 3. 16 Annualized Capital Costs ($/kW-y) for Candidate Fossil-fuel Resources by Installed Year

Resource name	2025	2030	2035	2040	2045
CAISO_Advanced_CCGT	92.1	94.9	93.2	91.8	90.7
CAISO_Aero_CT	112.5	115.4	113.2	111.6	110.2
CAISO_Reciprocating_Engine	112.5	115.4	113.2	111.6	110.2
New Clean Source Optimistic	**92.1**	**94.9**	**93.2**	**91.8**	**90.7**
New Clean Source Conservative	**595.10**	**618.91**	**610.71**	**601.65**	**593.68**

Table 3. 17 Annual O&M Costs ($/kW) for Candidate Geothermal and Biomass Resources by Installed Year

Resource name	2025	2030	2035	2040	2045
CAISO_Advanced_CCGT	14.3	14.3	14.3	14.3	14.3
CAISO_Aero_CT	13.5	13.5	13.5	13.5	13.5
CAISO_Reciprocating_Engine	13.5	13.5	13.5	13.5	13.5
New Clean Source Optimistic	**13.5**	**13.5**	**13.5**	**13.5**	**13.5**
New Clean Source Conservative	**135.1**	**135.1**	**135.1**	**135.1**	**135.1**

The "New Clean Source Optimistic" and "New Clean Source Conservative" are constructed to reflect the least cost of today's dispatchable generations and the highest cost, respectively, but with zero carbon dioxide emissions. These could represent enhanced geothermal, oxycombustion using the Allam cycle, small-scale nuclear, or another new technology. We assume that these are not ready to be built in 2025, but they could be built at 500 MW scale in 2030 and double in installed capacity every 5 years after that. Each of these will be introduced separately to identify how much each affects the use of storage.