

PV+battery hybrids

Overview of empirical data from operating and announced projects

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109 PV hybrid projects that we're tracking (page 1)

State	Project			Actual or Expected COD (PV/Wind/Battery)	Capacity (MW-AC)			Battery Storage		Battery:PV Capacity Ratio	Levelized PPA Price (2019 \$/MWh)	Levelized Storage Premium (2019 \$/MWh-PV)
	Name	Sponsor	Offtaker		PV	Wind	Battery	Duration	MWh			
AL	Redstone Arsenal	SunPower	Redstone Arsenal	Dec-17	10	0	1	2.0	2	10%		
AR	Searcy	NextEra / Entergy	Entergy	Dec-21	100	0	10	3.0	30	10%	#N/A	#N/A
AZ	Pinal Central	NextEra	SRP	Apr-18	20	0	10	4.0	40	50%	70.5	
AZ	Wilmot	NextEra	TEP	Dec-20	100	0	30	4.0	120	30%	39.9	14.2
AZ	Redhawk(?)	First Solar	APS	Jun-21	65	0	50	2.7	135	77%		
AZ	Sonoran Energy Center	NextEra	Salt River Project	Jul-23	250	0	250	4.0	1000	100%		
AZ	Storey	NextEra	Salt River Project	Jul-23	88	0	88	3.0	264	100%		
AZ	Cotton Center	APS	APS	Nov-11/Dec-21	17	0	17			100%	#N/A	#N/A
AZ	Paloma	APS	APS	Sep-11/Dec-21	17.6	0	17			97%	#N/A	#N/A
AZ	Hyder	APS	APS	Oct-11/Dec-21	16	0	16			100%	#N/A	#N/A
AZ	Hyder II	APS	APS	Jan-13/Dec-21	14	0	14			100%	#N/A	#N/A
AZ	Foothills	APS	APS	Mar-13/Dec-21	37.44	0	38			101%	#N/A	#N/A
AZ	Gila Bend	APS	APS	Oct-14/Dec-21	37.12	0	36			97%	#N/A	#N/A
AZ	Desert Star	APS	APS	Jun-15/Dec-21	11.2	0	10			89%	#N/A	#N/A
AZ	Atlas	174 Power Global		Dec-22	300	0	300			100%		
CA	Desert Harvest II	EDF-RE / Masdar	SCPPA	Dec-20	70	0	35	4.0	140	50%	LMP plus \$15.25	
CA	RE Slate 2	ReCurrent	MBCP and SVCE	Jun-21	150	0	45	4.0	180	30%	≤32.3	
CA	BigBeau	EDF-RE / Masdar	MBCP and SVCE	Dec-21	128	0	40	4.0	160	31%	≤31.1	
CA	Arlington	NextEra	Kaiser Permanente	Dec-20/Dec-21/Dec-21	131	50	110	4.0	440	84%		
CA	Arlington	NextEra	Clean Power Alliance	Oct-22	233	0	132	4.0	528	57%		
CA	Sonrisa	EDPR	SJCE & EBCE	Dec-22	200	0	40	4.0	160	20%		
CA	Raceway	sPower	EBCE	Dec-22	125	0	80	2.0	160	64%		
CA	Eland	8minute Solar	LADWP/Glendale	Dec-23	400	0	300	4.0	1200	75%	28.4	14.1
CA	Camino	Avangrid	Riverside	May-22	44	0	11	4.0	44	25%	27.1	4.9
CA	High Desert	Middle River Power	Clean Power Alliance	Aug-21	100	0	50	4.0	200	50%		
CA	Garland	Southern Power	SoCalEd	Nov-16/Aug-21	185	0	88	4.0	352	48%		
CA	Tranquility	Southern Power	SoCalEd	Sep-16/Aug-21	200	0	72	4.0	288	36%		
CA	Sanborn	TerraGen	SoCalEd	Aug-21	300	0	50	4.0	200	17%		
CA	Blythe 2	NextEra	SoCalEd	Oct-16/Aug-21	131.2	0	115	4.0	460	88%		
CA	Blythe 3	NextEra	SoCalEd	May-20/Aug-21	136.8	0	115	4.0	460	84%		
CA	McCoy	NextEra	SoCalEd	Jun-16/Aug-21	270.6	0	230	4.0	920	85%		
CA	Blythe 110	NextEra	PG&E	Apr-16/Aug-21	110	0	63	4.0	252	57%		
CA	Aratina	8minute Solar	MBCP and SVCE	Dec-23	200	0	50	3.0	150	25%		
CA	Rabbitbrush	First Solar	MBCP and SVCE	Jun-22	100	0	20	2.5	50	20%		
CA	Crow Creek	NextEra	CleanPowerSF	Dec-23	20	0	20	3.0	60	100%		
CA	Azalea	Solar Frontier Americas	Clean Power Alliance	Dec-22	60	0	38	4.0	152	63%		
CA	Rexford 1	8minute Solar	Clean Power Alliance	Oct-23	300	0	180	3.0	540	60%		
CA	Chalan	Origis	Clean Power Alliance	Dec-23	64.9	0	25	4.0	100	39%		
CA	Maverick 6	EDF-RE	CleanPowerSF	Dec-21	100	0	100	2.0	200	100%		
CA	Daggett	Clearway Energy	Clean Power Alliance	Mar-23	123	0	61.5	4.0	246	50%		

109 PV hybrid projects that we're tracking (page 2)

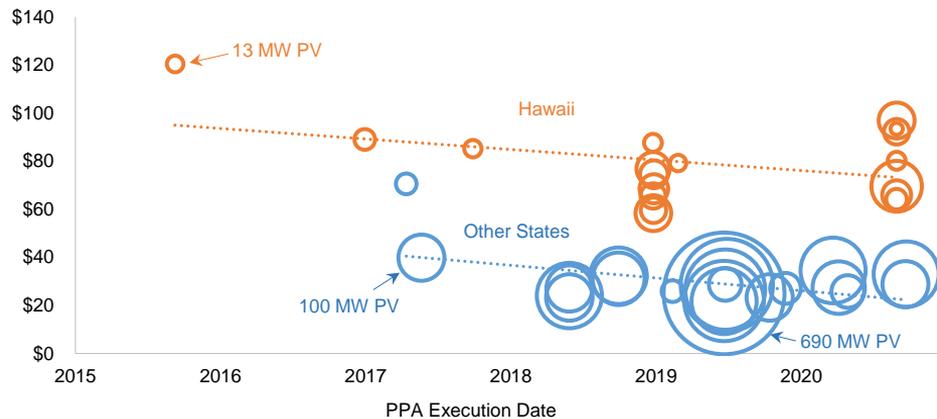
State	Project			Actual or Expected COD (PV/Wind/Battery)	Capacity (MW-AC)			Battery Storage		Battery:PV Capacity Ratio	Levelized PPA Price (2019 \$/MWh)	Levelized Storage Premium (2019 \$/MWh-PV)
	Name	Sponsor	Offtaker		PV	Wind	Battery	Duration	MWh			
CO	Rawhide Prairie	DEPCOM Power	PRPA	Dec-20	22	0	1	2.0	2	5%	26.0	2.4
CO	Pike	juwi	Colorado Springs	Dec-23	175	0	25	4.0	100	14%		
CO	Thunder Wolf	NextEra	Xcel / PSCo	Dec-22	200	0	100	4.0	400	50%		
CO	Neptune	NextEra	Xcel / PSCo	Dec-22	250	0	125	4.0	500	50%		
FL	Babcock	NextEra / FPL	FPL	Dec-16/Mar-18	74.5	0	10	4.0	40	13%	#N/A	#N/A
FL	Citrus	NextEra / FPL	FPL	Dec-16/Mar-18	74.5	0	4	4.0	16	5%	#N/A	#N/A
FL	Manatee	NextEra / FPL	FPL	Dec-16/Nov-21	74.5	0	409	2.2	900	549%	#N/A	#N/A
FL	FL Solar 6	Origis	Gainesville Regional Utilities	Dec-22	50	0	12	2.0	24	24%	25.8	
FL	Imeson (SunPort)	174 Power Global	Jacksonville Electric Authority	Dec-19	5	0	1.5	2.5	3.8	30%		
FL	Lake Placid	Duke Energy Florida	Duke Energy Florida	Dec-19/Dec-21	45	0	18			40%	#N/A	#N/A
GA	Broken Spoke (Hickory Park)	RWE Renewables	Georgia Power	Dec-21	195.5	0	40	2.0	80	20%		
GA	Cool Springs	NextEra	Georgia Power	Dec-21	213	0	40	2.0	80	19%		
HI	Kapaia	Tesla	KIUC	Apr-17	13	0	13	4.0	52	100%	120.4	
HI	Lawai	AES	KIUC	Oct-18	20	0	20	5.0	100	100%	89.0	
HI	Kekaha	AES	KIUC	Dec-19	14	0	14	5.0	70	100%	85.2	
HI	AES Waikoloa Solar	AES	Hawaiian Electric	Jul-21	30	0	30	4.0	120	100%	59.6	
HI	Kuihelani Solar	AES	Hawaiian Electric	Jul-21	60	0	60	4.0	240	100%	58.3	
HI	West Oahu	AES	Hawaiian Electric	Sep-21	12.5	0	12.5	4.0	50	100%	79.2	
HI	Ho'Ohana Solar 1	174 Power Global	Hawaiian Electric	Dec-21	52	0	52	4.0	208	100%	76.8	
HI	Mililani I Solar	Clearway	Hawaiian Electric	Dec-21	39	0	39	4.0	156	100%	68.5	
HI	Waiawa Solar	Clearway	Hawaiian Electric	Dec-21	36	0	36	4.0	144	100%	74.5	
HI	Hale Kuawehi	Innergex	Hawaiian Electric	Jun-22	30	0	30	4.0	120	100%	65.5	
HI	Paeahu	Innergex	Hawaiian Electric	Jun-22	15	0	15	4.0	60	100%	87.6	
HI	Puako	Engie EPS	Hawaiian Electric	Jul-05	60	0	60	4.0	240	100%		
HI	Waikoloa	EDF-RE	Hawaiian Electric	2023	60	0	60	4.0	240	100%		
HI	Kahana	Innergex	Hawaiian Electric	2023	20	0	20	4.0	80	100%	64.1	
HI	Pulehu	Longroad	Hawaiian Electric	2023	40	0	40	4.0	160	100%	65.9	
HI	Kupehau	Hanwha	Hawaiian Electric	Jun-22	60	0	60	4.0	240	100%	97.0	
HI	Kupono	Bright Canyon Energy	Hawaiian Electric	Jul-05	42	0	42	4.0	168	100%		
HI	Barbers Point	Innergex	Hawaiian Electric	Jul-05	15	0	15	4.0	60	100%	80.2	
HI	Mahi	Longroad	Hawaiian Electric	Jul-05	120	0	120	4.0	480	100%	69.6	
HI	Mountain View	AES	Hawaiian Electric	Jul-05	7	0	7	5.0	35	100%	93.4	
HI	Waiawa Phase 2	AES	Hawaiian Electric	Jul-05	30	0	30	8.0	240	100%	92.2	

109 PV hybrid projects that we're tracking (page 3)

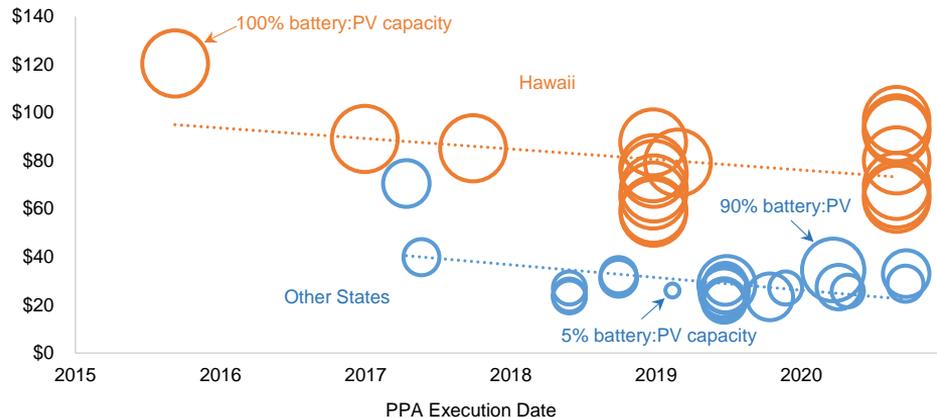
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	Name	Sponsor	Offtaker		PV	Wind	Battery	Duration	MWh			
IN	Greensboro Solar	NextEra	NIPSCO	Jul-23	100	0	30	3.0	90	30%		
MO	Green City Renewable Energy Center	Ameren Missouri	Ameren Missouri	Dec-21	10	0	2.5	4.0	10	25%	#N/A	#N/A
MO	Richwoods Renewable Energy Center	Ameren Missouri	Ameren Missouri	Dec-21	10	0	4	4.0	16	40%	#N/A	#N/A
MO	Utica Renewable Energy Center	Ameren Missouri	Ameren Missouri	Dec-21	10	0	2	4.0	8	20%	#N/A	#N/A
MN	Ramsey/Athens	Engie/NextEra	Connexus	Dec-18	10	0	15	2.0	30	150%		
MS	MS Solar 5 (Golden Triangle)	Origis	TVA	Oct-22	200	0	50	4.0	200	25%		
NE	Norfolk	N Solar	NPPD	Dec-21	8.5	0	1	2.0	2	12%		
NM	Angel Fire	Torch Clean Energy	Kit Carson Electric Co-op	Jun-21	6	0	3	2.0	6	50%		
NM	Taos Mesa	Torch Clean Energy	Kit Carson Electric Co-op	Jun-21	15	0	12	2.0	24	80%		
NM	Buena Vista	NextEra	El Paso Electric	May-22	100	0	50	4.0	200	50%	23.3	7.4
NM	Arroyo	Clenera	PNM	Jun-22	300	0	150	4.0	600	50%	26.6	12.4
NM	Jicarilla 1	Hecate	PNM	Apr-22	50	0	20	4.0	80	40%	28.8	13.5
NM	San Juan Solar 1	Photosol	PNM	Jun-22	200	0	100	4.0	400	50%	33.0	12.6
NM	Rockmont	8minute Solar	PNM	Jun-22	100	0	30	4.0	120	30%	28.8	7.6
NV	Battle Mountain	Cypress Creek	NV Energy	Jun-21	101	0	25	4.0	100	25%	23.3	3.4
NV	Dodge Flat	NextEra	NV Energy	Dec-21	200	0	50	4.0	200	25%	24.1	4.2
NV	Fish Springs Ranch	NextEra	NV Energy	Dec-21	100	0	25	4.0	100	25%	27.0	4.6
NV	Townsite	Capital Dynamics	Munis/Co-op	Dec-21	180	0	90	4.0	360	50%		
NV	Arrow Canyon (Moapa)	EDF-RE	NV Energy	Dec-22	200	0	75	5.0	375	38%	21.8	
NV	Southern Bighorn	8minute Solar	NV Energy	Sep-23	300	0	135	4.0	540	45%	21.9	
NV	Gemini	Quinbrook/Arevia	NV Energy	Dec-23	690	0	380	3.8	1460	55%	25.0	
NV	Dry Lake	NV Energy	NV Energy		150	0	100	4.0	400	67%	#N/A	#N/A
NV	Boulder Solar 3	174 Power Global	NV Energy	Dec-23	128	0	58	4.0	232	45%	27.4	9.6
NV	Chuckwalla	EDF-RE	NV Energy	Dec-23	200	0	180	4.0	720	90%	34.6	17.5
NV	Yellow Pine Energy Center	NextEra	MBCP and SVCE	Dec-22	125	0	65	4.0	260	52%		
NV	Storey County	Switch/Capital Dynamics			127	0	60	4.0	240	47%		
NY	Garnet Energy Center	NextEra	NYSERDA	Jun-23	200	0	20	4.0	80	10%	#N/A	#N/A
NY	South Ripley	ConnectGen	NYSERDA		270	0	20	4.0	80	7%	#N/A	#N/A
NY	Excelsior	NextEra		Dec-22	280	0	20	4.0	80	7%		
OK	Skeleton Creek	NextEra	WFEC	Dec-23/Dec-20/Dec-23	250	250	200	4.0	800	80%		
OR	Wheatridge	NextEra	PGE	Dec-21/Dec-20/Dec-21	50	300	30	4.0	120	60%		
TX	Castle Gap (Upton 2)	Luminant	Luminant	Jun-18/Dec-18	180	0	10	4.2	42	6%	#N/A	#N/A
TX	Lily	Enel		Jul-21	146	0	50	1.5	75	34%		
TX	Permian Energy Center	Orsted	ExxonMobil	Jul-21	420	0	40	1.0	40	10%		
VA	Scott Solar	Dominion	Dominion	Dec-16/Dec-20	17	0	12	4.0	48	71%	#N/A	#N/A
VA	Correctional Solar	Dominion	Dominion	Dec-17/Dec-20	20	0	2	2.0	4	10%	#N/A	#N/A

Levelized PPA prices of PV+battery hybrid projects

Levelized PPA Price (2019 \$/MWh-PV)



Levelized PPA Price (2019 \$/MWh-PV)

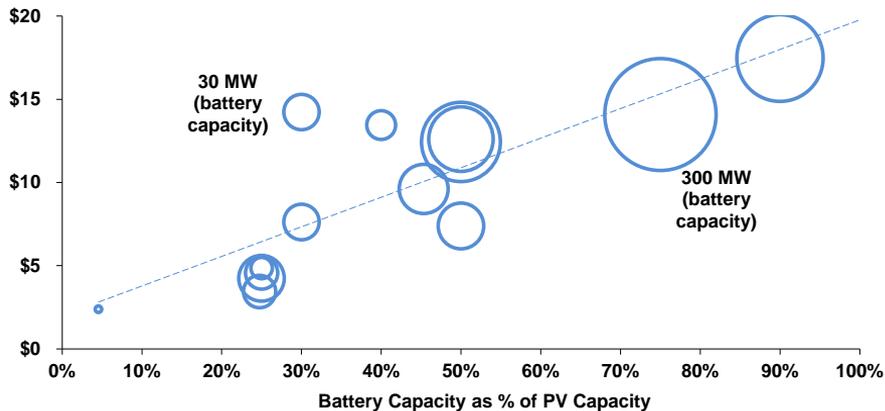


Both graphs show the same 39 projects totaling 4.2 GW_{AC} of PV and 2.3 GW_{AC} of batteries

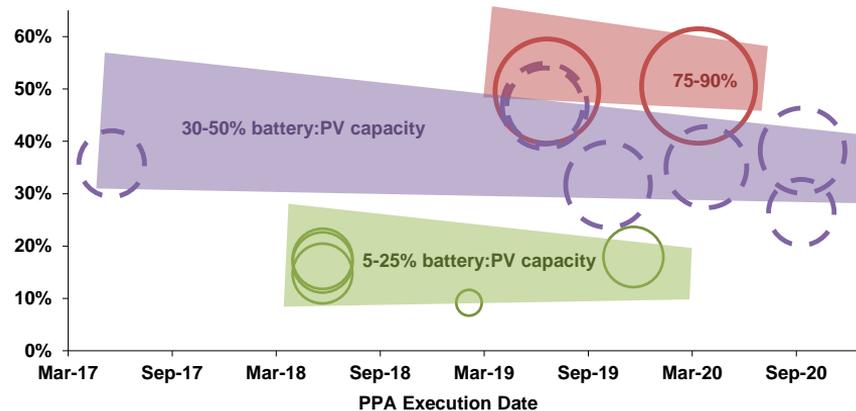
- 18 of these projects are in HI (614 MW_{AC} PV and 614 MW_{AC} battery); rest are on mainland
- Battery durations range from 2-8 hours, PV:battery capacity ranges from 5%-100%
- Hawaiian projects are a little hard to compare (even to each other) due to how the pricing is expressed
- In the top graph, the bubbles represent PV capacity; in the bottom graph, the bubbles represent the battery:PV capacity ratio
 - HI projects all at 100%, due to isolated island grid; highest on mainland is 90%

Levelized storage adder

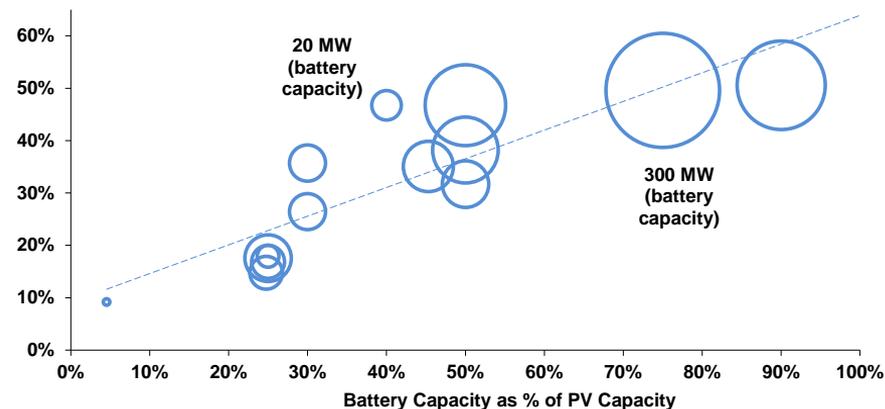
Levelized Storage Adder (2019 \$/MWh-PV)



Storage Premium (Adder / Full PPA Price)



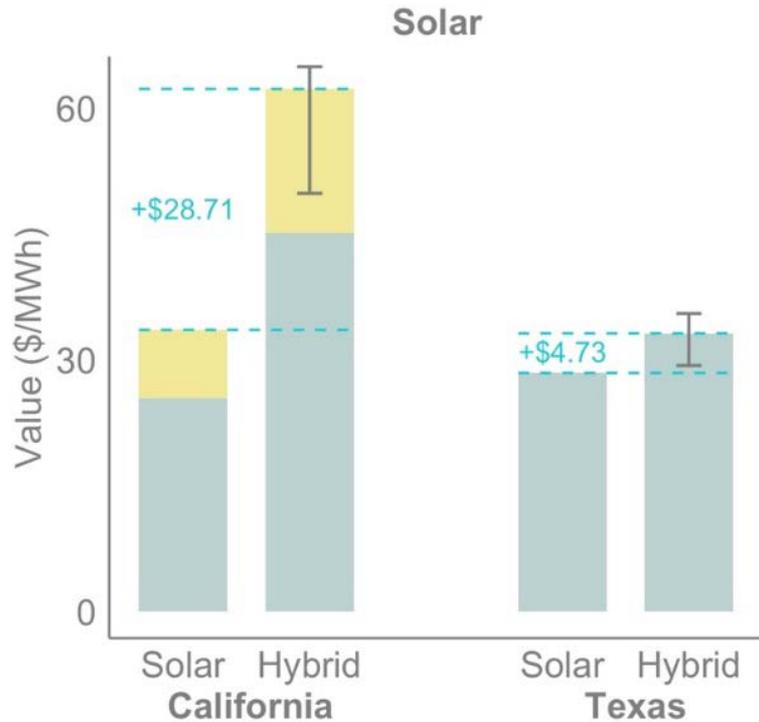
Storage Premium (Adder / Full PPA Price)



14 of these 39 PPAs break out the PV and battery pricing, enabling us to calculate the incremental cost of adding batteries—i.e., the “levelized storage adder”

- ~\$5/MWh-PV at 25% battery:PV capacity, ~\$10/MWh at 50%, ~\$20/MWh at 100% (top left graph)
- Can also express this adder as a percentage of the overall PPA price (improves the r^2 fit—bottom left graph)
- These adders seem to (?) have decreased slightly over time (top right graph)

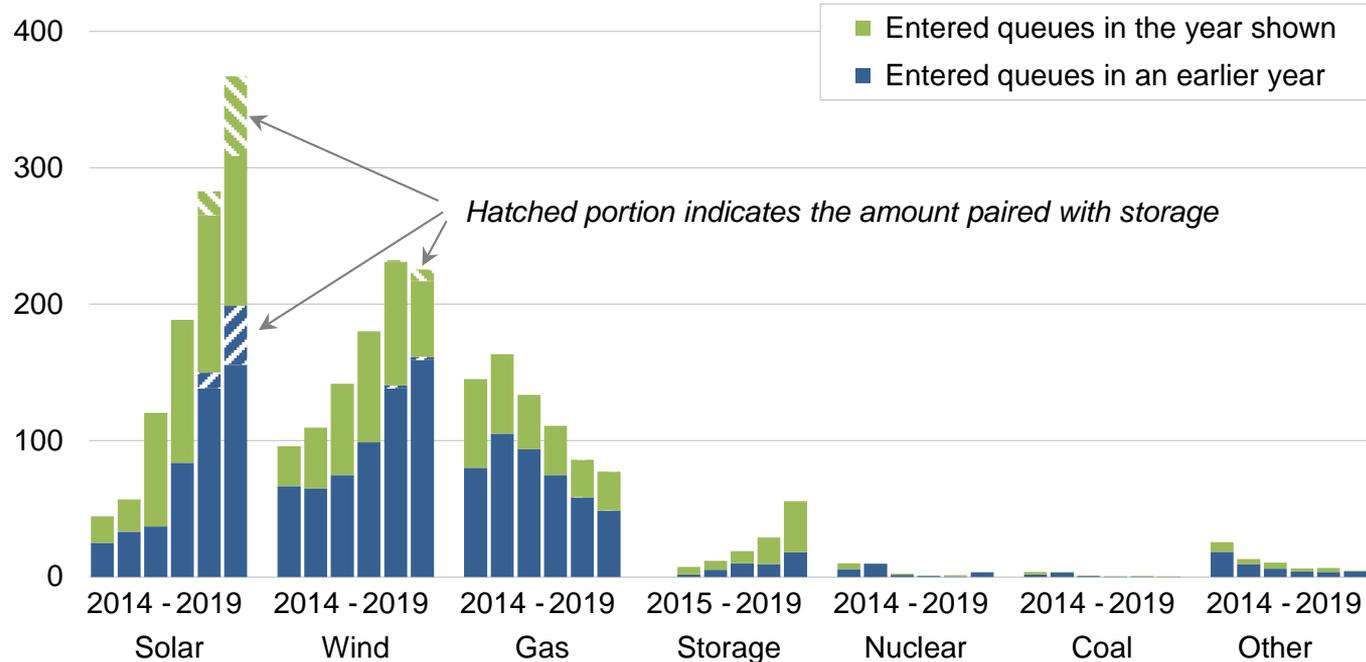
Strong value proposition, particularly in solar-saturated grids like CAISO



- LBNL analysis of adding a 4-hour duration battery (sized to 50% of PV nameplate capacity) to a standalone PV project increased the overall market value by ~\$28/MWh in CAISO
- This value boost exceeds the empirical ~\$10/MWh levelized storage cost adder discussed on the previous slide
- Value of hybridization is less-evident in ERCOT (which has no capacity market, and where solar has a much lower market share)

Solar has rocketed to the top of grid interconnection queues across the country

Capacity in Queues at Year-End (GW)

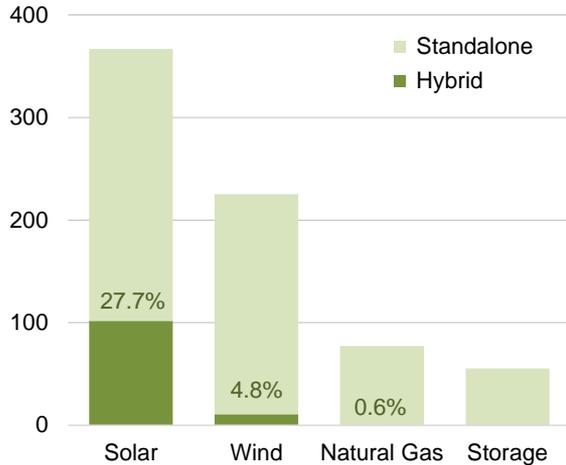


- These 37 queues cover ~80% of non-coincident demand in the U.S.
- Solar, storage, and—until 2019, wind—have been growing; everything else declining
- Solar ranked 3rd in the queues as recently as 2016, but is now 1st by far
- 28% of PV capacity in the queues is paired with battery storage (compared to just 5% of wind capacity)

Not all of this capacity will be built—much of it will languish in the queues

Antidote for market saturation? Strong interest in adding battery storage—particularly to solar projects, and particularly in CAISO

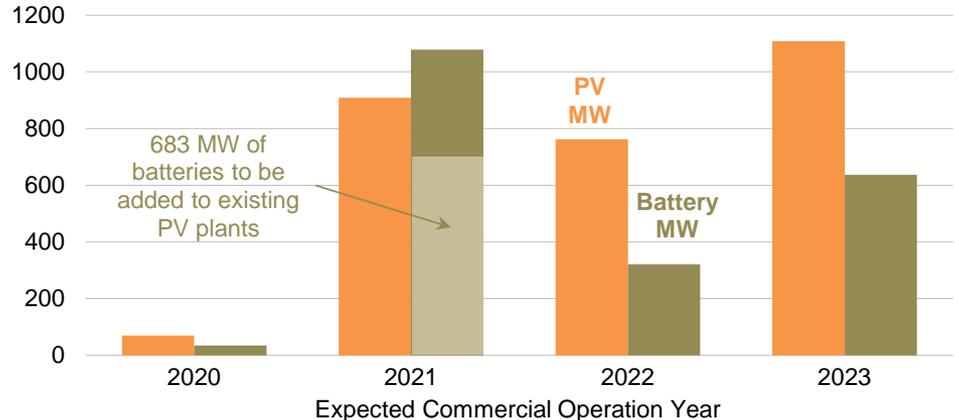
Capacity in Queues at end of 2019 (GW)



- Interconnection queue data show 28% of all PV capacity in the queues is paired with battery storage (compared to just 5% of wind capacity)—much of this hybrid capacity is in CAISO’s queue
- Though queue data are highly speculative, PPA announcements are less so—and suggest that **at least 2 GW** of battery storage will be built in CA through 2023 as part of PV hybrid plants

Region	Percentage of Proposed Generators Hybridizing in Each Region		
	Solar	Wind	Nat. Gas
CAISO	67%	50%	0%
ERCOT	13%	3%	0%
SPP	22%	1%	0%
MISO	17%	2%	0%
PJM	17%	0%	1%
NYISO	5%	1%	4%
ISO-NE	0%	6%	0%
West (non-ISO)	50%	6%	0%
Southeast (non-ISO)	6%	0%	0%
TOTAL	27.7%	4.8%	0.6%

Contracted New PV+battery hybrid capacity (MW) in CA, by COD



Possible muni/co-op projects to take a closer look at...

- Kit Carson (NM): Angel Fire and Taos Mesa projects are a combined 21 MW PV/15 MW battery (2 hours)
- Connexus Energy (MN): Ramsey/Athens project is 10 MW PV/15 MW battery (2 hours)
- Jacksonville Electric Authority (FL): Imeson (SunPort) project is 5 MW PV/1.5 MW battery (2.5 hours)
- Platte River Power Authority (CO): Rawhide Prairie project is 22 MW PV/1 MW battery (2 hours)
- NPPD (NE): Norfolk project is 8.5 MW PV/1 MW battery (2 hours)
- Gainesville Regional Utilities (FL): FL Solar 6 is 50 MW PV/12 MW battery (2 hours)
- Sterling Municipal Light (MA): I don't track this one, but 2 MW PV/2 MW battery (2 hours)
- Green Mountain Power (VT): Not a muni/co-op, but has been out in front in terms of installing batteries to cut its peak load charges from ISO-NE—has publicized the customer savings in recent years

SMUD's Energy StorageShares Program – “community storage”

- Commercial customers buy a share in a centralized (FTM, not BTM) battery
- Starting with a 4 MW/8 MWh battery, but by 2022 may install an additional 9 MW/18 MWh battery
- Battery placement and dispatch will optimize grid needs (NOT customer's bills—that's done virtually)
 - Helps SMUD to defer new infrastructure investments—which saves customers money
- Captures economies of scale – in the same way that community solar does
- Accelerates the timing of SMUD's investment in storage, because customers are contributing roughly half of the up-front cost
- Tied in with EV charging stations

<https://www.publicpower.org/periodical/article/smud-unveils-unique-energy-storageshares-program>