Northwest **Power** and **Conservation** Council

October 8, 2019

MEMORANDUM

TO: **Council Members**

FROM: **Mike Starrett**

SUBJECT: **Solar, Battery Storage, and Solar + Battery Storage Reference Plants**

BACKGROUND:

Presenter: Mike Starrett

Summary: A reference plant defines the size, cost, operating characteristics, and maximum build out of a given generating resource type and configuration. A single technology type could have multiple reference plants to differentiate, for example, a Montana-based wind resource from a wind resource located in the Columbia Gorge.

Reference plants serve as a key input for the Council's portfolio expansion modeling tools and are also used by other entities throughout the region.

Draft reference plants are developed in coordination with the Generating Resources Advisory Committee and are then brought to the Council before being incorporated into the tools used in the development of the Plan.

This presentation will introduce the draft reference plants for solar, battery storage, and solar plus battery storage.

Workplan: Prepare for 2021 Power Plan

More Info: Reference plants for the 7th Power Plan are described in Appendix H

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Solar, Battery Storage, and Solar + Battery Storage

Reference Plants for the 2021 Power Plan

Mike Starrett, Ph.D.

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Defining a Reference Plant

A **reference plant** is a collection of characteristics that describe a resource technology and its theoretical application in the region. It includes estimates of typical costs, logistics, and operating specifications.

7th Power Plan – CC Gas

Table H - 3: CCCT Reference Plants

Reference Plant	CCCT Adv 1 Wet Cool East	CCCT Adv 2 Dry Cool East	CCCT Adv 2 Dry Cool West
Configuration	1 gas turbine x 1 steam turbine and wet cooling system	1 gas turbine x 1 steam turbine and dry cooling system	1 gas turbine x 1 steam turbine and dry cooling system
Note	Based on Siemens H-Class. Number of plants with wet cooling may be limited	Based on MHI J-Class	Based on MHI J-Class. Assumed to require gas pipeline expansion on West side
Location	East side	East side	West side
Earliest In-Operation Date	2020	2021	2021
Development Period (Years)	2	2	2
Construction Period (Years)	3	3	3
Economic Life (Years)	30	30	30
Financial Sponsor	IOU	IOU	IOU
★ Capacity (MW)	370	425	426
★ Fuel	Natural Gas East	Natural Gas East	Natural Gas West with pipeline expansion
★ Heat Rate (btu/kWh)	6,770	6,704	6,704
★ Overnight Capital Cost ($/kW)	1,147	1,287	1,282
Fixed O&M Cost ($/kW-yr)	15.37	15.37	15.37
★ Variable O&M Cost ($/MWh)	3.27	3.27	3.27
Transmission	BPA point to point	BPA point to point	BPA point to point with transmission deferral credit
Maximum build-out (MW) as modeled	1,110	5,950	1,278

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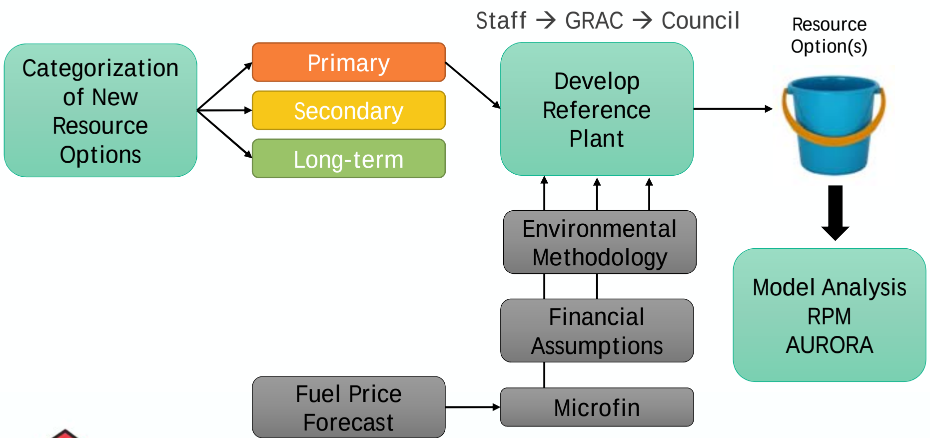
Developing a Reference Plant



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Draft Solar Reference Plant

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Solar in the 7th Plan

1) S. Idaho represented high quality (but somewhat limited) resource

2) W. Washington represented lower quality (but plentiful) resource

3) Max Build Out (*i.e.* potential) set primarily based on commercially available transmission

7th Power Plan - Solar

Table H - 11: Solar PV Reference Plants

Reference Plant	Solar PV S. ID	Solar PV S. ID w/ Transmission Expansion	Solar PV Low Cost S. ID	Solar PV W. WA	Solar PV Low Cost W. WA
Configuration	20 MW_{ac} installation with crystalline silicon panels and single axis tracker system	20 MW_{ac} installation with crystalline silicon panels and single axis tracker system	50 MW_{ac} installation with crystalline silicon panels and single axis tracker system	50 MW_{ac} installation with crystalline silicon panels and single axis tracker system	50 MW_{ac} installation with crystalline silicon panels and single axis tracker system
Note	Mid-range capital cost estimate	Mid-range capital cost estimate	Low range capital cost estimate	Mid-range capital cost estimate	Low range capital cost estimate
Location	Southern Idaho	Southern Idaho	Southern Idaho	Western WA	Western WA
Earliest In-Operation Date	2018	2021	2020	2020	2020
Development Period (Years)	2	2	2	2	2
Construction Period (Years)	1	1	1	1	1
Economic Life (Years)	30	30	30	30	30
Financial Sponsor	IPP	IPP	IPP	IPP	IPP
Investment Tax Credit*	30%/10 %	30%/10 %	30%/10 %	30%/10 %	30%/10 %
Capacity (MW)	17.4	17.4	48	48	48
Capacity Factor	0.26	0.26	0.26	0.19	0.19
Overnight Capital Cost ($/kW)	2,413	2,413	1,685	2,413	1,685
Fixed O&M Cost ($/kW-yr)	16.63	16.63	11.62	16.63	11.62
Variable O&M Cost ($/MWh)	0	0	0	0	0
Transmission	Idaho Power	Transmission Expansion & BPA	Idaho Power	BPA point to point	BPA point to point
Maximum build-out (MW) as modeled	642	989	642	3840	3840

* ITC at 30% through year 2019, stepping down to 10% in 2022

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Detour! What is a "Maximum build-out"

(Applicable to all resource types, not just solar)

Maximum build-out

- ✓ Upper bound limit for potential selection in a portfolio model
- ✓ It is specific to a resource *and* location
- ✓ It is the ceiling. The floor is zero. The model will optimize on cost, accounting for policy requirements and operational constraints

Table H - 11: Solar PV Reference Plants

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Motivation to consider a new approach

Since the 7th Plan, we've seen:

- Significant changes in renewables and storage costs
- Substantial announced retirements + policy driving towards 1000's of MWs of new renewables
- Shrinking inventory for long-term firm point-to-point service, even as physical utilization continues to be modest in most places
  - See https://www.nwcouncil.org/meeting/generating-resources-advisory-committee-webinar-march-1-2019
- As more renewables are added to the system, the paradigm of requiring 24/7/365 firm, point-to-point capacity makes less and less sense (especially with declining incremental capacity value)

Keys

- Utilities still need to be able to deliver sufficient capacity to meet their system peak, but perhaps may be flexible around the makeup of energy
- A higher max build out for any resource type allows the model to test the economics of such a future given all other options, system operational constraints, policy, *etc*. Nothing more.

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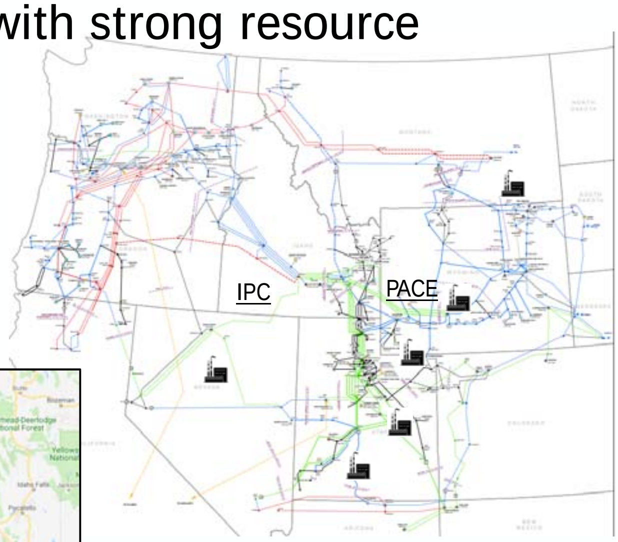
Example: Maximum solar build out in area with strong resource

Thinking about Max Build Out in S. Idaho:

- ~4,500 MW Summer Peak
- + Additional MW's that can be exported out



Shaded area could support ~65,000 MW of solar

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Map of coal plants:
https://www.nwcouncil.org/energy/energy-topics/power-supply/coalmap

Max Build out: 7P to 2021P

- **What changes in max build out**
  - 7p aligned max build out with available commercial transmission
  - 2021P proposal would not make that assumption and would instead test a broader array of credible potential futures
- **How to build a resource supply curve in the 2021P**
  - Potentially increase costs to represent higher interconnection fees as switchyards need to be expanded for the N^{th} MW of solar, *etc.*
  - Could also use transmission rates (utility specific P2P and NT)
- **How to adjust resources in a Coal Retirement Scenario**
  - The maximum build out doesn't change, but the energy/capacity need that the model sees would be quite different
- **How to adjust resources in a Market scenario**
  - Remove fixed transmission cost and wheeling & instead use a dispatch cost adder in $/MWh

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Summary & Impacts

Summary: Consistent approach of limiting new max build potential for all resource types by technical (not commercial) limitations, only. Policy and operational constraints are handled within model.

Does a really large max build out change anything?

- If the resource is free, then yes
- If the resource is really expensive, then no
- If the resource *may* be in the money, we'll have to see.

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Back to Solar: Solar in the News

- **12/14/18: Texas Municipal Utility Signs New Super-Low Solar PPA**
  - "Projects in Arizona and Nevada have also sunk to $21.55 per megawatt hour (with 2.5 percent annual escalation) and $23.76 per megawatt hour, both for 25-year PPAs.
  - https://www.greentechmedia.com/articles/read/utility-signs-new-low-solar-ppa-in-texas#gs.4svxc4
- **3/26/19: Idaho Power invests in clean, affordable solar energy**
  - "Idaho Power signed a 20-year power purchase agreement with Jackpot Holdings, LLC, an Idaho company that plans to complete the [120 MW] solar array by 2022. Idaho Power will initially pay $21.75 per megawatt-hour (MWh)"
- **7/1/19: L.A. Looks to Break Price Records With Massive Solar-Battery Project**
  - [25 year PPA with solar at 19.97 $/MWh for 400 MW (AC) plus a 13 $/MWh price adder for 400 MW/800 MWh (expandable up to 300 MW/1200 MWh storage) for an average price of 32.97$/MWh]
  - "It's also well below the $35 to $38 per megawatt-hour — at that time another low-price record for solar — that developer 8minute offered in its first big solar PPA with LADWP back in 2016."

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Distribution of Solar Project Prices

Spread between best, worst, and average installed cost is narrowing

Solar Prices Bucketed By Cost

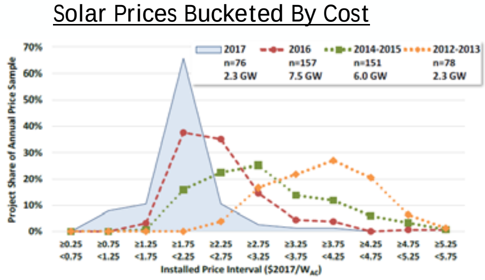

Figure 9. Distribution of Installed Prices by Installation Year

Solar Prices Bucketed By Size

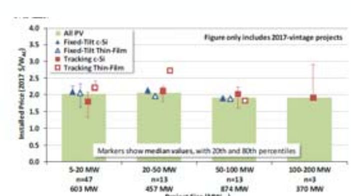

Figure 11. Installed Price of 2017 PV Projects by Size, Module Technology, and Mounting Type

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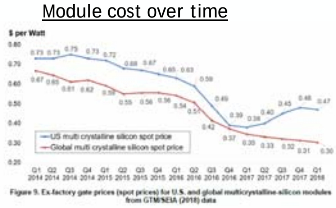
Drivers for Solar Cost Declines

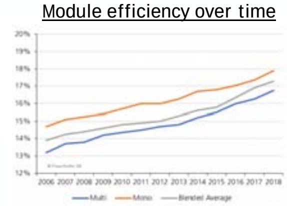
- Downward equity return pressure due to competition
- Market over-supply pushing module and component costs down
- Continual improvements in module efficiency
  - Modules account for ~35-40% of system cost today (& declining) on $/$W_{dc}$ basis

Module cost over time



NREL U.S> Solar PV System Cost Benchmark: Q1 2018

Module efficiency over time



https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

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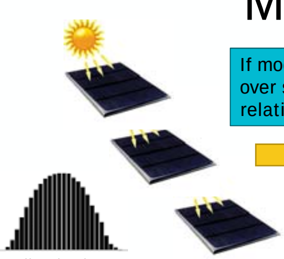
Taking Advantage of Declining Module Prices (1/2)



Daily Solar Shape

Panels (DC)

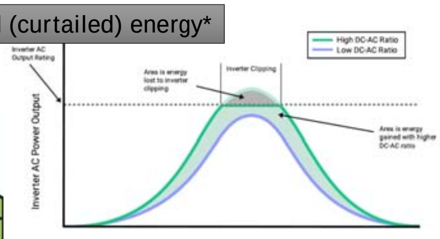
If modules are cheap, over size panels relative to inverter

1 DC:1 AC,
1.2 DC:1 AC,
1.4 DC:1 AC, etc.

Inverter (AC)

Grid (AC)

Clipped (curtailed) energy*



Most of the 8760 hours in a year are not 12-noon on a perfect, moderately warm, blue sky day (sorry!)

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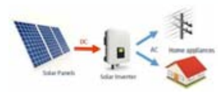
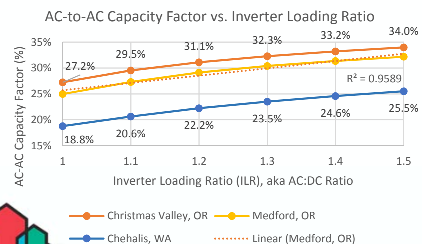
Taking Advantage of Declining Module Prices (2/2)

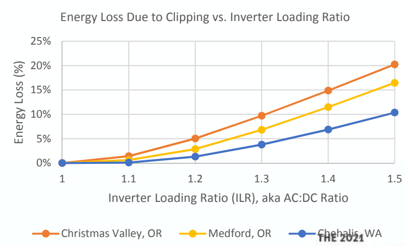
Module price declines have outpaced inverter price declines



Accordingly, developers are over-sizing their panels beyond the inverter capability (1.3:1, 1.4:1, *etc.*) and doing a bit of curtailment as needed

The price over an overbuilt (ILR > 1.0) system in \$/kW_{AC} is higher (more DC panels are purchased, but the AC capability stays the same), **however** the LCOE/PPA price could be lower if enough extra energy is captured





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Trends in Solar Capital Cost

Source	Tech Vintage	\$2016/ kW_{AC}	ILR
Avista 2017 IRP	2018	1119	-
Avista 2019 IRP	2019	1118	-
NREL '18 ATB - Low	2018	1129	1.2
Lazard LCOE 12.0	2018	1208	-
NREL '18 ATB – Mid	2018	1278	1.2
7P Midterm – Low	2018	1350	1.3
E3 2019 WECC	2018	1401	-
NREL US PV	2018	1420	1.3
NREL '19 ATB – Mid	2018	1425	1.3
GTM, PGE, 7P Mid-term - High	2018	1450-1500	1.2-1.3

Source	Tech Vintage	\$2016/ kW_{AC}	ILR
NREL '18 ATB - Low	2020	1022	1.2
NREL '19 ATB – Low	2020	1153	1.3
NREL '18 ATB – Mid	2020	1157	1.2
GTM	2020	-	1.2*
PAC '19 200 MW ID	2020	1228	1.46
PAC '19 50 MW ID	2020	1320	1.46
NREL '19 ATB – Mid	2020	1373	1.3

	Straight Average	Average normalizing to ILR = 1.3	Average normalizing to ILR = 1.4	Cost Delta
2018	1341	1414	1522	108
2020	1207	1208	1300	92
% Improv.	10.5%	15.7%		

FYI for Boise Area
1300\$/kW_{AC} ~= 27-42\$/MWh
Low = ITC + low cost financing
High = No ITC + conservative financial assumptions

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* Indicated an ILR selection by Council Staff based on source material or judgement

Comparison of Energy Generated

	AC-AC Capacity Factor with ILR = 1.3	AC-AC Capacity Factor with ILR = 1.4
Western Oregon - Medford, OR	30.4%	31.4%
Western Washington - Chehalis, WA	23.7%	24.7%
Eastern Washington - Lind, WA	30.1%	31.2%
Eastern Oregon - Klamath Falls, OR	32.8%	33.7%
Eastern Oregon - Burns, OR	31.9%	32.7%
Idaho - Boise, ID	31.3%	32.3%
Montana - Billings, MT	28.8%	29.8%

FYI, this is using the standard TMY file. May change slightly when FMY files are available. Council waiting to select GCM before working with contract to develop FMY files.

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2021 Plan Reference Plant: Solar PV

	Solar PV - Western Washington	Solar PV - East of Cascades
Configuration	15 MW_{AC} mono PERC c-SI with single axis tracker	100 MW_{AC} mono PERC c-SI with single axis tracker
Location	West of the Cascades in Washington State	Areas with high solar irradiance in ID & MT, Southern OR, and East of the Cascades in OR & WA
Technology Vintage	2019	2019
Development Period (Years)	1	1
Construction Period (Years)	1	1
Capacity (MW)	15	100
Inverter Loading Ratio (DC:AC Ratio)	1.4:1	1.4:1
Capacity Factor	24.7%	32.5%
Overnight Capital Cost ($/kW)	1,465	1,350
Fixed O&M Cost ($/kW-yr)	14.55	14.55
Variable O&M ($/MWh)	0	0
Economic Life (years)	30	30
Financial Sponsor	IPP	IPP
Transmission	PSE NT	TBD
Max Build Out	TBD	10,000 MW+ (Exact # TBD)

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Battery Storage

Goals for today

- In the interest of reducing model complexity, Staff worked with the GRAC to produce **battery** storage cost estimates based on **lithium ion** chemistries, **only**

7th Power Plan – Battery Storage

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Lithium Ion Batteries in the News

- **1/4/19: Hawaiian Electric Announces 'Mind-Blowing' Solar-Plus-Storage Contracts**
  - "That means that from 2016 to 2019 solar-plus-storage PPA prices in the state dropped by 42 percent."
- **5/1/19: APS Plans to Add Nearly 1GW of New Battery Storage and Solar Resources by 2025**
  - "The plan includes outfitting existing utility-owned solar projects with 200 megawatts of batteries, deploying 500 megawatts of new battery resources, and contracting for 150 megawatts of third-party-owned storage — the last of which beat out new-build natural gas peakers in an request for proposals that just concluded. "
- **7/1/19: L.A. Looks to Break Price Records With Massive Solar-Battery Project**
  - [25 year PPA with solar at 19.97 $/MWh for 400 MW (AC) plus a 13 $/MWh price adder for 400 MW/800 MWh (expandable up to 300 MW/1200 MWh storage) for an average price of 32.97$/MWh]
- **9/6/19: A Wide Range of Testing Results on an Excellent Lithium-Ion Cell Chemistry to be used as Benchmarks for New Battery Technologies**
  - "We conclude that the cells of this type should be able to power electric vehicles for over 1.6 million kilometers (1 million miles), and least at least two decades in grid energy storage"

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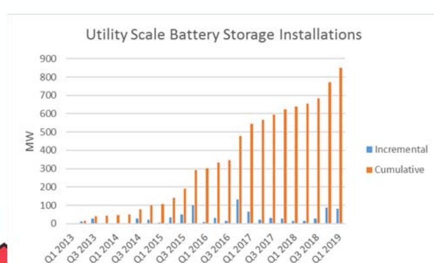
Market Still Growing, Cost Data Improving (but still limited)

- Utility scale battery storage market growing, but still relatively small
- Pipeline of new projects looks substantial, especially given urgency of taking ITC benefit



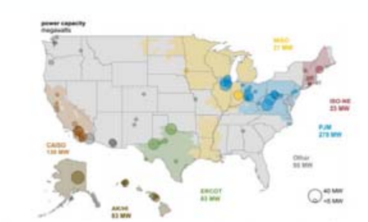


Figure 2.3. Map of U.S. large-scale battery storage installations by region as of 2017.

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Battery Pack Component Still Dominates Installed Cost

It remains typical to report costs in $/kWh

Converting from $/kWh to $/kW:
Multiply the storage cost ($/kWh) times duration (h) to get $/kW.

Example: Given costs in $/kWh for a four hour battery, use

$$400 \frac{\$}{kWh} * 4\ hours = 1{,}600\ \$/kW$$

Limitation: Can't use $/kWh cost for 4 hour battery to calculate costs for 2 hour battery, or vice versa

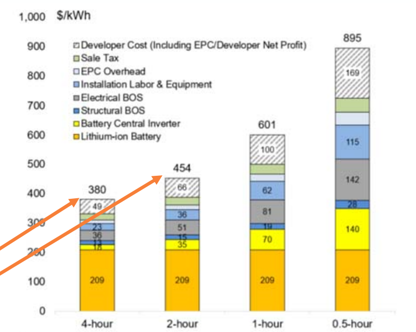

Figure ES-1. 2018 U.S. utility-scale lithium-ion standalone storage costs for durations of 0.5–4 hours (60 MW_{DC})

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Battery Cell/Pack Component

- Battery pack component has seen substantial price declines over last 10 years

"... the volume weighted average battery pack fell 85% from 2010-18, reaching an average of $176/kWh"

Note: This is the battery component of the storage system, only!

https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

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Trends in Standalone Lithium Ion Capital Cost

Source	Tech Vintage	$2016/kW	Hours
Lazard LCOS 4.0 – Low	2018	1102	4
Avista '19 IRP	2020	1390	4
E3 '19 WECC	2018	1450	4
NREL '19 ATB	2018	1459	4
NWPCC Storage Whitepaper - Low	2017	1480	-
GTM - Low	2018	1544	4
PAC '19 IRP (large)	2020	1707	4
Lazard LCOS 4.0 – High	2018	1753	4
PGE '19 IRP	2018	1838	6
GTM – Median	2018	2029	4
GTM – High	2018	2512	4
PSE '19 IRP	2018	2590	4
PAC '19 IRP (small)	2020	3297	4
NWPCC Storage Whitepaper - High	2017	3600	-

Source	Tech Vintage	$2016/kW	Hours
PGE '19 IRP	2018	884	2
GTM - Low	2018	1160	2
GTM – Median	2018	1377	2
PSE '19 IRP	2018	1498	2
GTM - High	2018	1619	2
PAC '19 IRP (small)	2018	2527	2

	2018 - 2020 Average $2016/kW (Large only)	Implied $2016/kWh
2 Hour	1308	654
4 Hour	1761	440

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2021 Plan Reference Plant: Battery Storage

	Standalone Battery Storage – Four Hour
Configuration	100 MW, 400 MWh Lithium Ion Battery Storage
Capacity (MW)	100
Energy (MWh)	400
Round Trip Efficiency	88%
Financial Sponsor	IOU
Economic Life (years)	15
Overnight Capital Cost ($/kW)	1400
Fixed O&M Cost ($/kW-yr)	31

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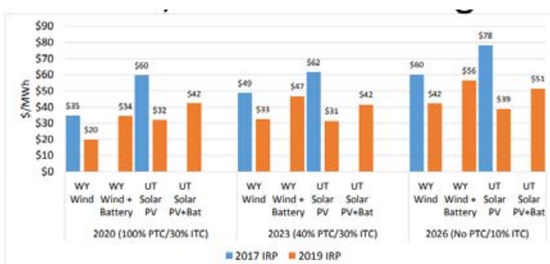
Solar + Battery Storage

Renewables + Storage – A new frontier?

- Co-locating renewables with storage helps avoid curtailment, reduce integration needs, provide grid services, and reduce transmission costs
- Solar + Storage is also ITC eligible, if charged from solar

From PAC 2019 IRP Process



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Cost Saving Benefit of Co-Located Solar + Storage

- **AC Coupled:** Reduces some balance of system costs around siting, land, interconnection and fixed transmission cost. Eligible for ITC.
- **DC Coupled**: All of the benefits of AC coupling, plus shared inverter and reduced clipping for solar systems with ILR > 1.0. Requires DC/DC converter, offsetting some of the cost savings.

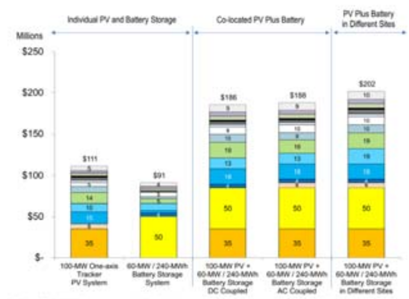

Figure ES-2. 2018 Cost benchmarks for PV-plus-storage systems (4-hour duration) in different sites and the sa AC-coupled cases)

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Proposal for Solar + Storage

Solar + Storage (DC-Coupled)

- ✓ Remove transmission cost on storage
- ✓ Assume 13% savings on storage component vs. standalone for both CapEx and OpEx
- ✓ Allow model to take care of avoided clipping (possibly through re-defined resource shape)

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2021 Plan Reference Plant: Solar + Battery Storage

	Solar + Battery Storage
Configuration	100 MW_{AC} Solar Co-Located with DC-Coupled 100 MW, 400 MWh Battery
Capacity (MW)	100
Energy (MWh)	200
Round Trip Efficiency	88%
Financial Sponsor	IOU
Economic Life (years)	15
Overnight Capital Cost ($/kW)	2568
Fixed O&M Cost ($/kW-yr)	31