Developments in Solar + Storage

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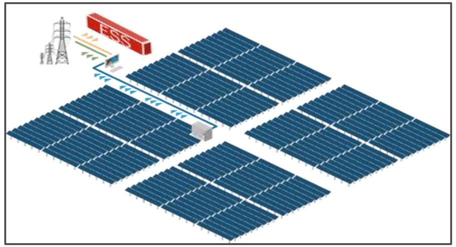
First Solar

LEADING THE WORLD'S SUSTAINABLE ENERGY FUTURE

Key Takeaways – Developments in Solar + Storage

- Cost of **Utility-scale PV Solar** energy is **already lower** than new conventional generation cost in many places

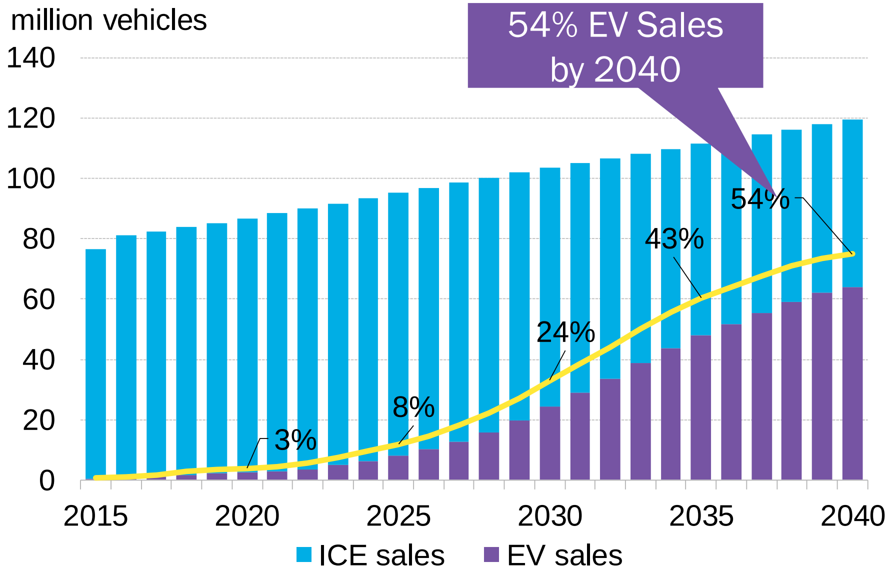
- **Battery Energy Storage Cost** is Rapidly Declining … driven by EV growth



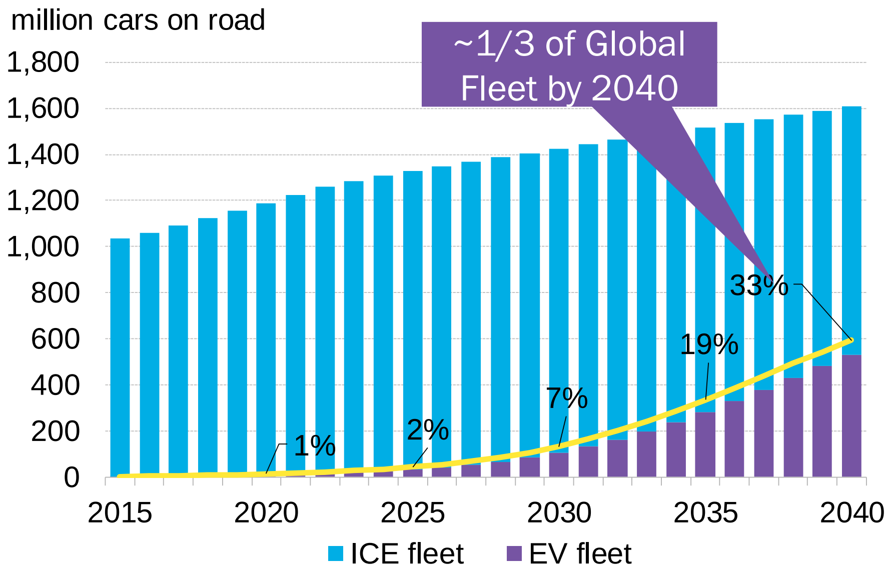
- **PV + Storage (PVS) plants** are becoming more cost-effective than conventional generation
  - *Low cost **clean energy plant** that is fully dispatched*

Electric Vehicle (EV) Outlook To 2040

Annual global light duty vehicle sales

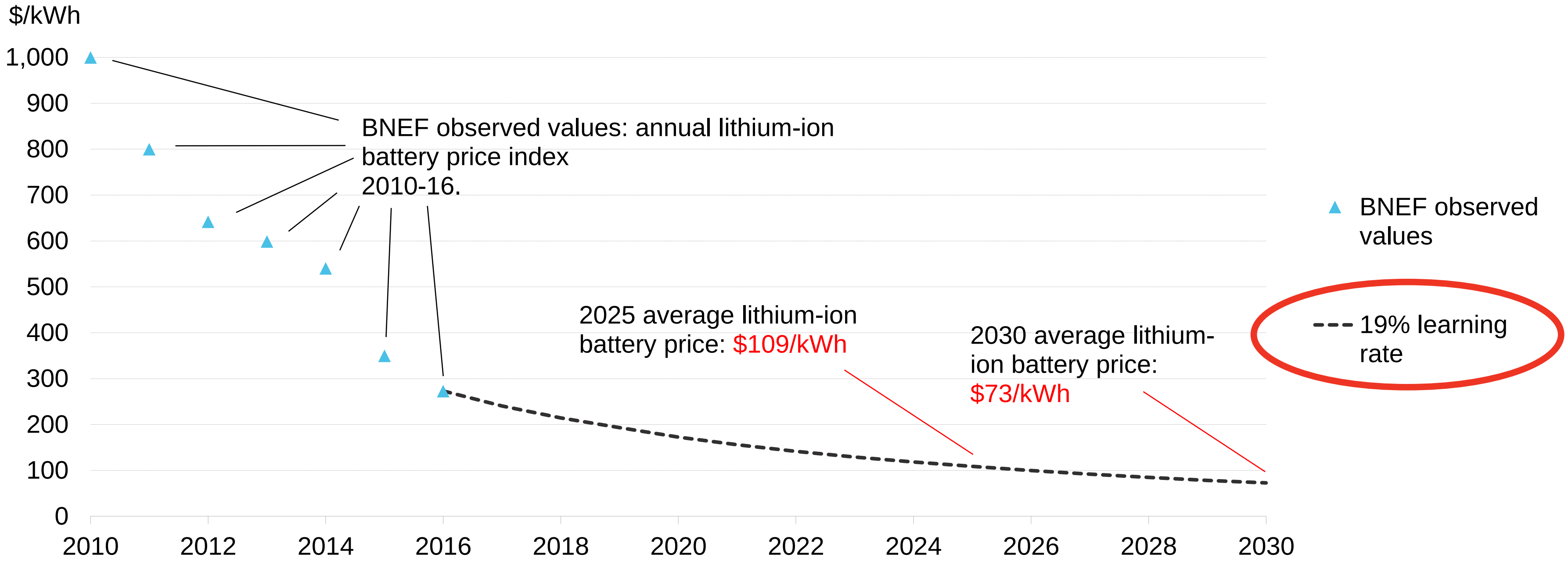


Global light duty vehicle fleet



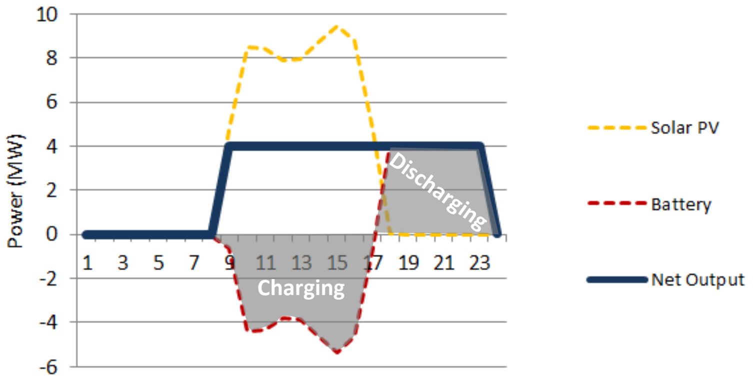
Source: Bloomberg New Energy Finance [EVO 2017]

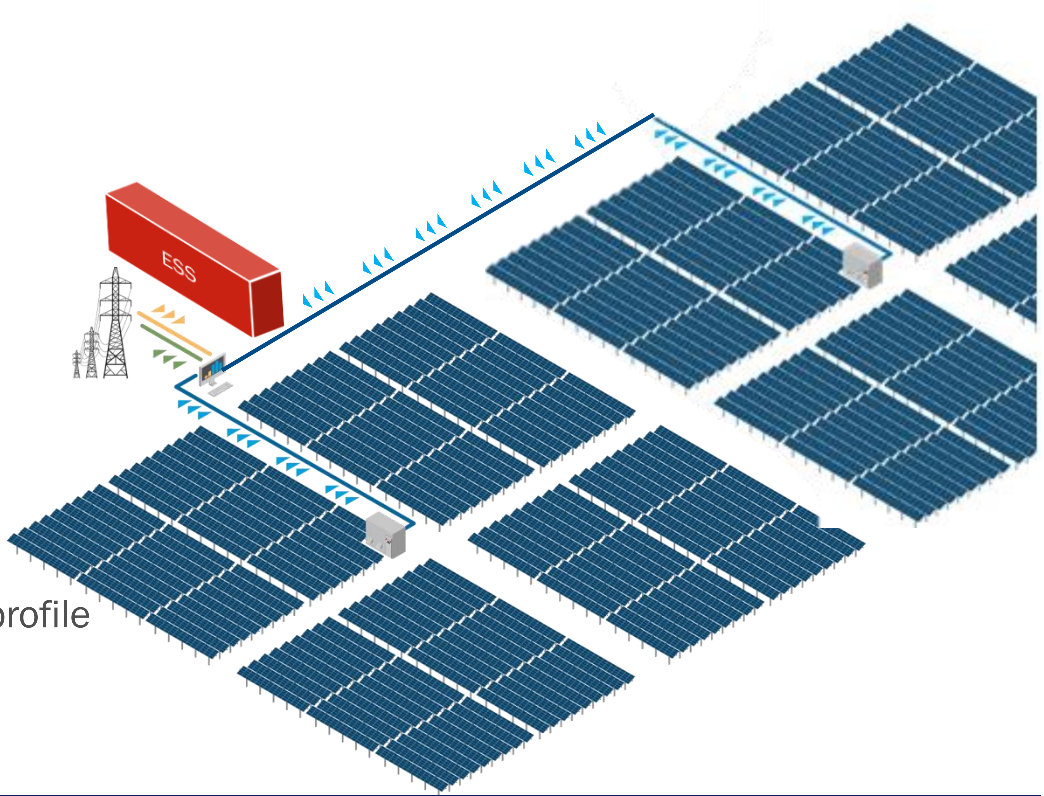
Lithium-ion Battery Prices, Historical And Forecast



Source: Bloomberg New Energy Finance EVO 2017; Note: Prices are an average of BEV and PHEV batteries and include both cell and pack costs. Cell costs alone will be lower. Historical prices are nominal, future ones are in real 2016 U.S. dollars.

PV + Storage (PVS): Fully Dispatchable Clean Energy Plant

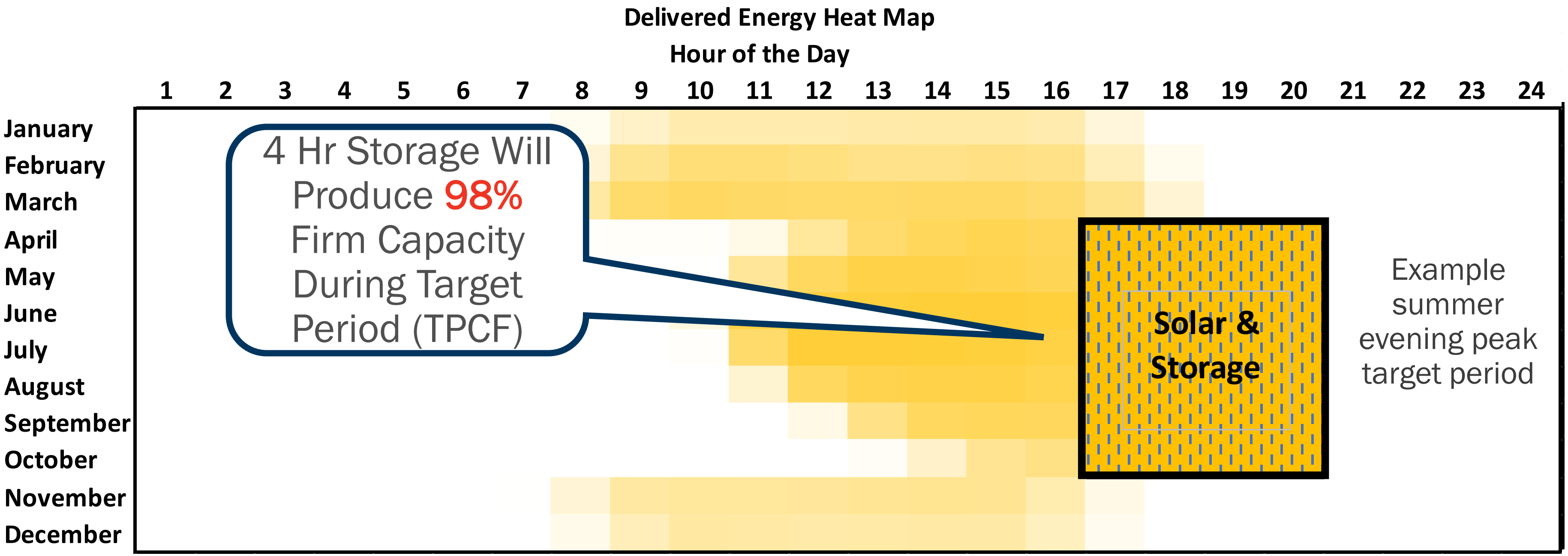




- Increase the PV array size
- Store excess energy in Energy Storage
- ESS provides flexibility to generate desired profile
- Amount of battery capacity is set by desired dispatch profile and solar irradiance
- Shared Infrastructure costs (interconnect, development, O&M)

Game Changer: Clean energy plant
More cost-effective than conventional generation?

Using Storage to Increase Output During Target Period



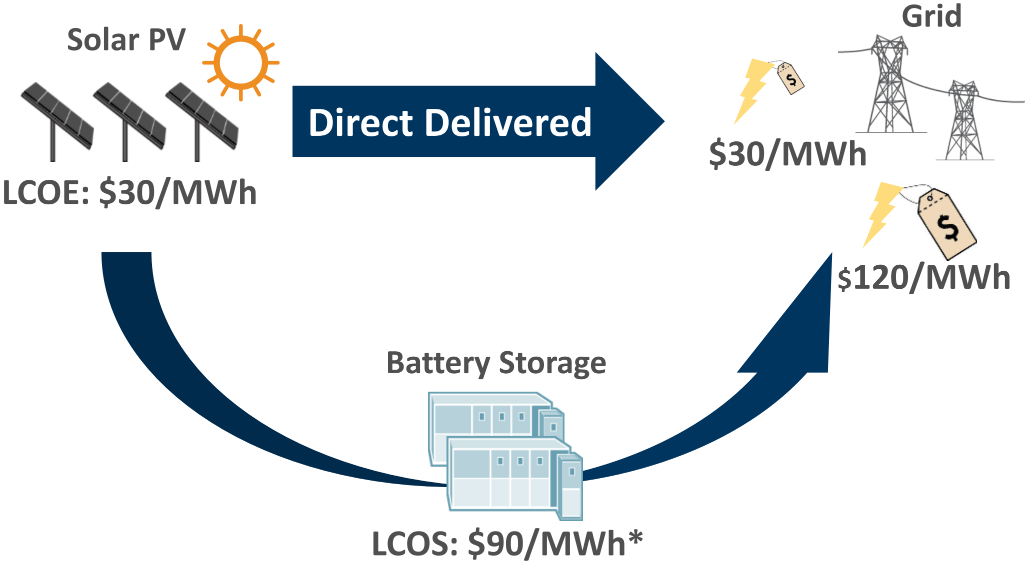
Storage (hrs)	TPCF
0	25%
1	48%
2	72%
4	98%

Game Changer: Clean Energy Plant
Less Costly than New Conventional Generation

PV + Storage LCOE (Levelized Cost of Electricity)

1. Cost of direct delivered energy from PV plant is equal to PV LCOE
2. Cost of shifted energy (delivered via storage) is: PV LCOE + Storage LCOS

Overall LCOE is weighted average of (1) and (2), depending on how much energy is delivered directly and how much is shifted



Example:

- 50% delivered directly
- 50% energy shifted

Overall PVS LCOE becomes:

0.5*$30 + 0.5*$120 =

$75/MWh

**storage LCOS includes costs of energy losses, 1 cycle per day*

Replacing New Peaking Gas Generation – PV+Storage (PVS)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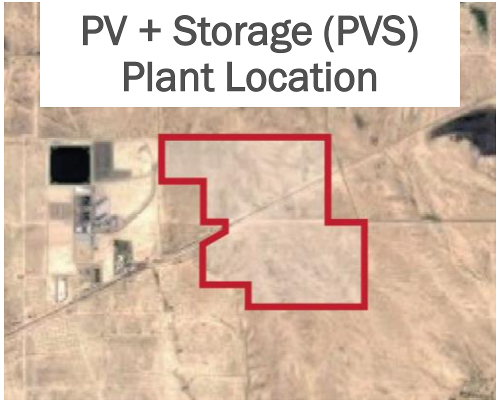
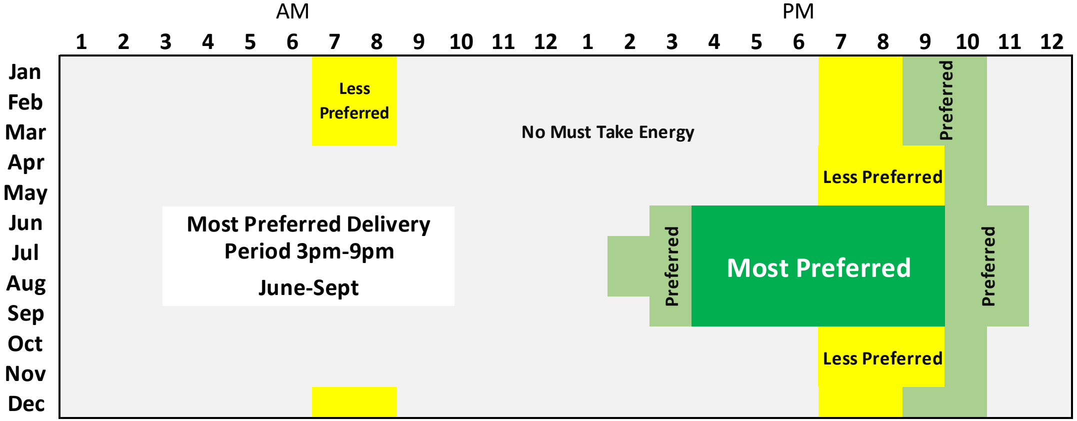
APS, First Solar to install Arizona's largest battery system

The Arizona-based module manufacturer will install a 50 MW battery system charged by a 65 MW solar farm under a 15-year power contract with the U.S. state's largest utility.

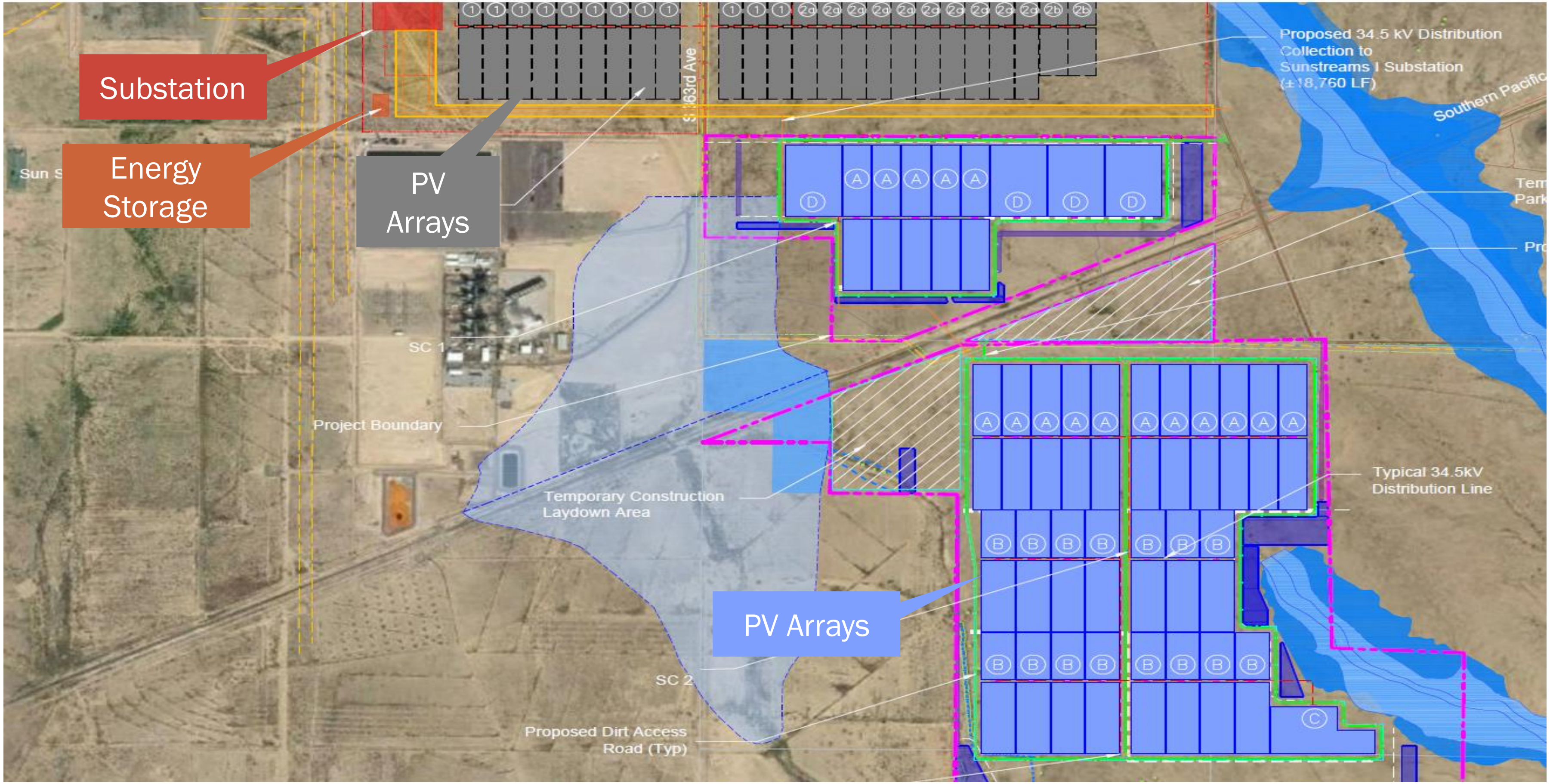
FEBRUARY 13, 2018 FRANK ANDORKA

APS: *"We had just about every technology you could think of producing during those time windows bid on this RFP(request for proposals). All the way from stand-alone battery storage to natural-gas fuel peaking units. This (First Solar PVS) was the winning proposal."*





Site layout – Example for 65 MW PV + 50MW Storage



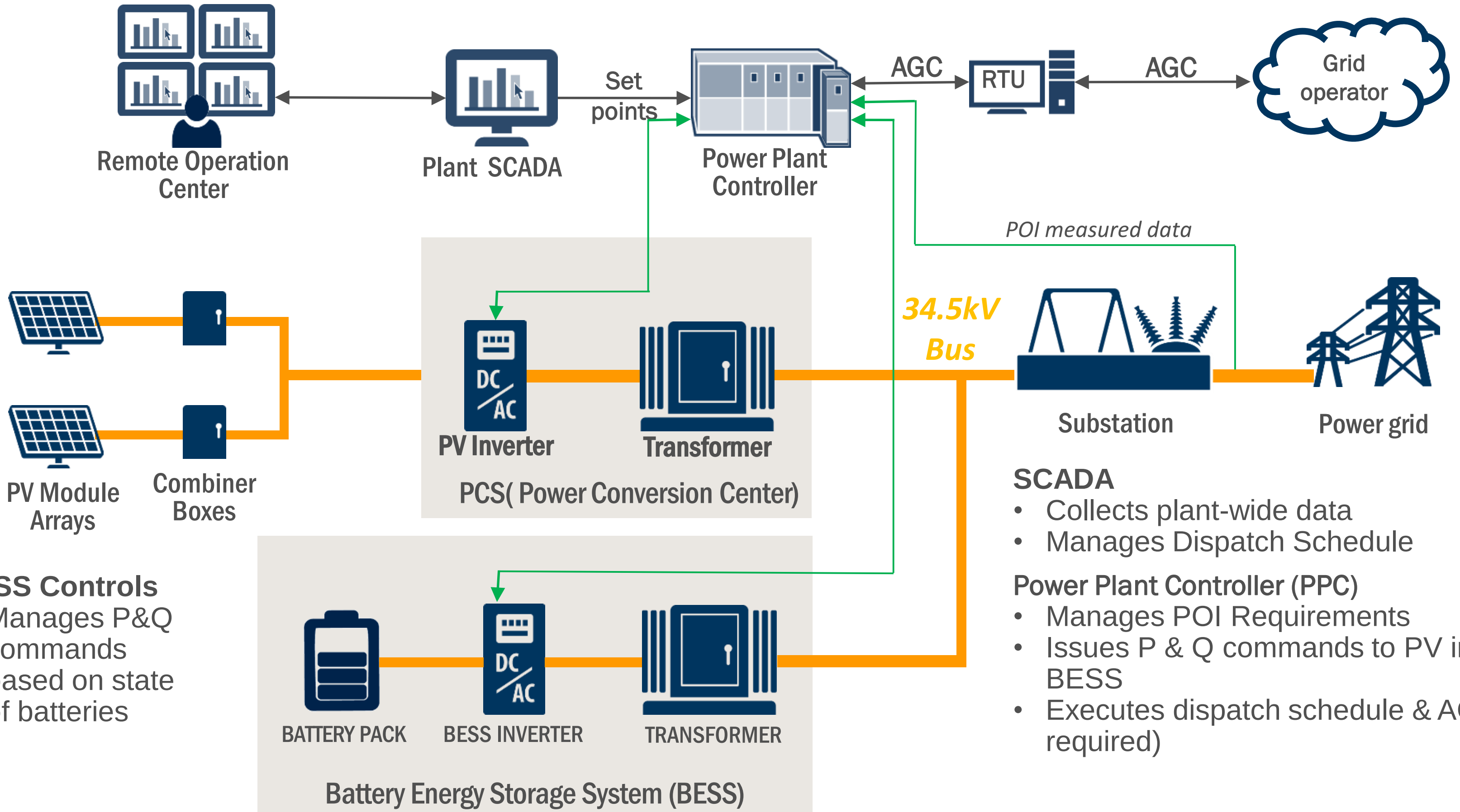
Design Considerations

- Configuration of PV Plant (MWac, MWdc) vs Battery Storage (MWac, MWh)
- AC vs DC Coupled Design
- Battery Degradation Modeling
- Safety … Buildings vs Containerized Enclosures

Pros and Cons on AC vs DC Coupled for Utility-Scale Plants

	Pros	Cons
AC-Coupled	• Commercial availability of Storage PCS systems • Separability of PV and S ownership leading to easier contracting (lower IRRs) • Ability to dispatch both PV and S • Simplicity of control and site design • Centrality of storage lowers capex and O&M costs	• Reduced efficiency due to more passes through inverters and transformers • Somewhat higher capital cost due to duplication of inverter stages and transformers
DC-Coupled	• Lower capital cost due to sharing of inverter components • Ability to capture clipped DC energy • Increased Efficiency due to fewer conversions	• Increased PCS controls complexity around simultaneously managing MPPT of PV and SOC of battery • Lack of available dual-port inverters (two DC/DC stages) at utility-scale price points • Potential for inferred storage risk to "contaminate the IRR" of PV plant through intermixing • Inverters and IC must be oversized to simultaneously dispatch PV and S

Plant Controls & SCADA System



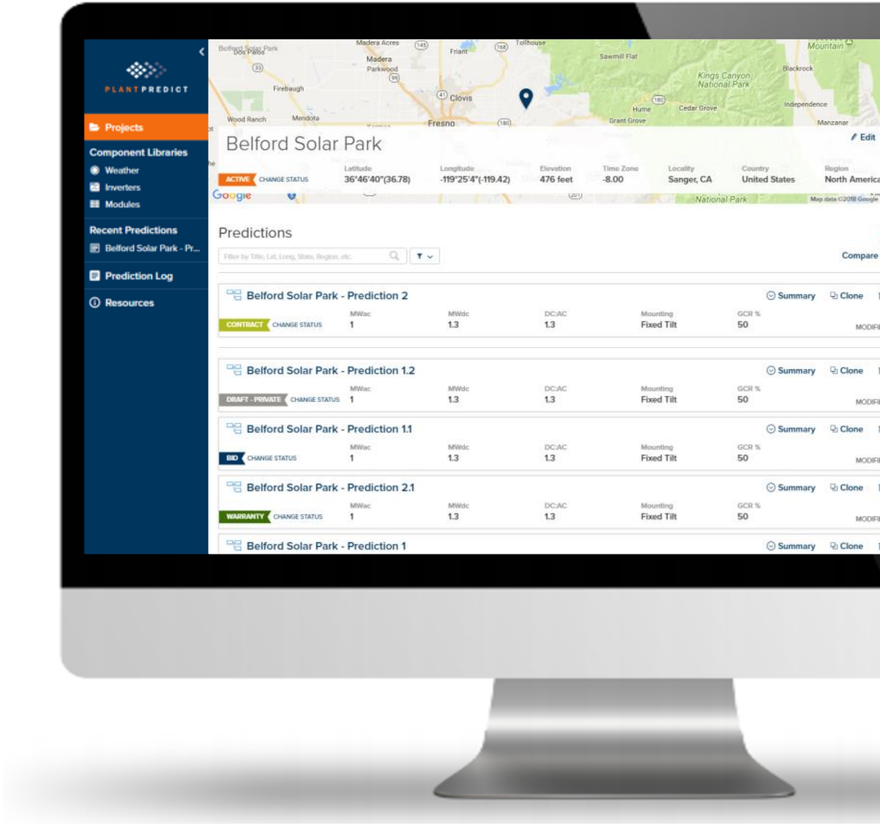
BESS Controls
- Manages P&Q commands based on state of batteries

SCADA
- Collects plant-wide data
- Manages Dispatch Schedule

Power Plant Controller (PPC)
- Manages POI Requirements
- Issues P & Q commands to PV inverters & BESS
- Executes dispatch schedule & AGC (if required)

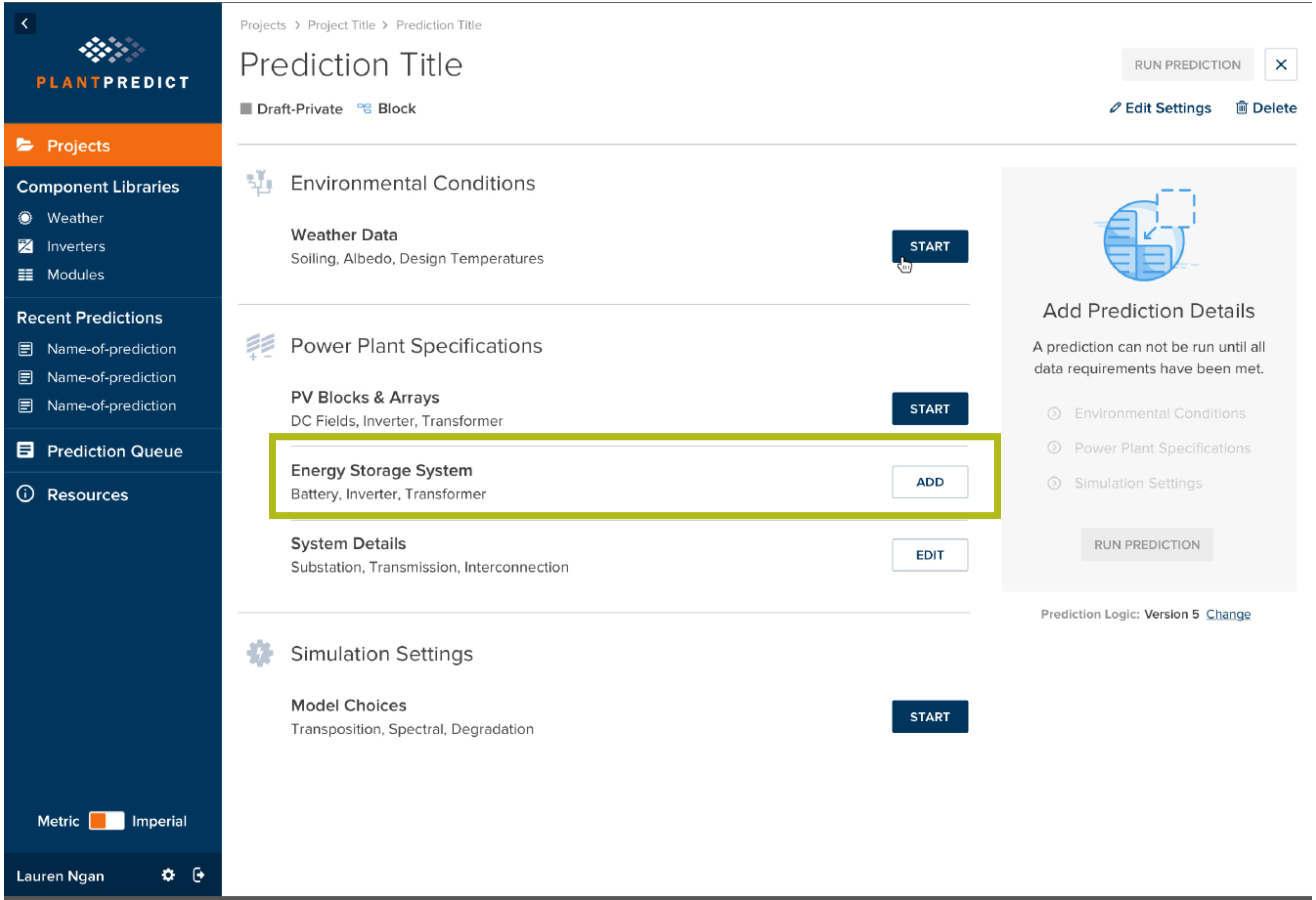
PLANT PREDICT

- *Intuitive* – Designed with the utility-scale PV industry in mind
- ***Efficient*** – Reduce prediction time by up to 75%
- *Bankable* – Used in over 350 MWAC of contracted utility-scale PV projects
- *Transparent* – All algorithms documented and published on www.plantpredict.com
- *Reliable* – Independently reviewed and benchmarked against over 1 GW of operating facilities

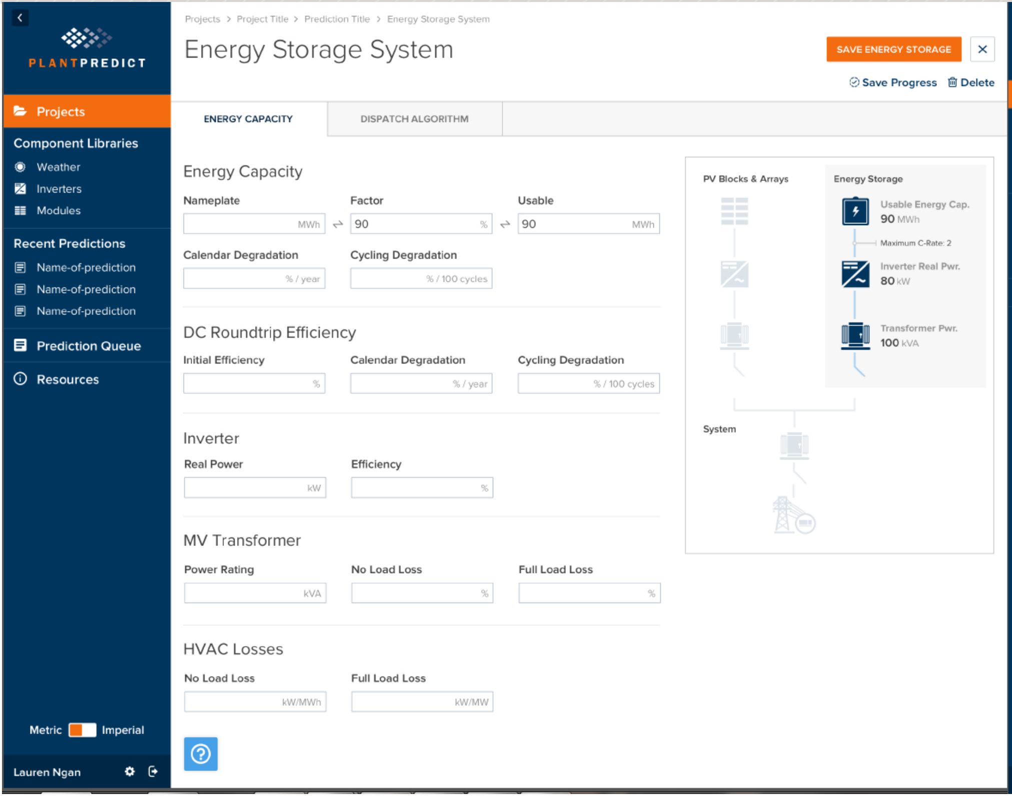


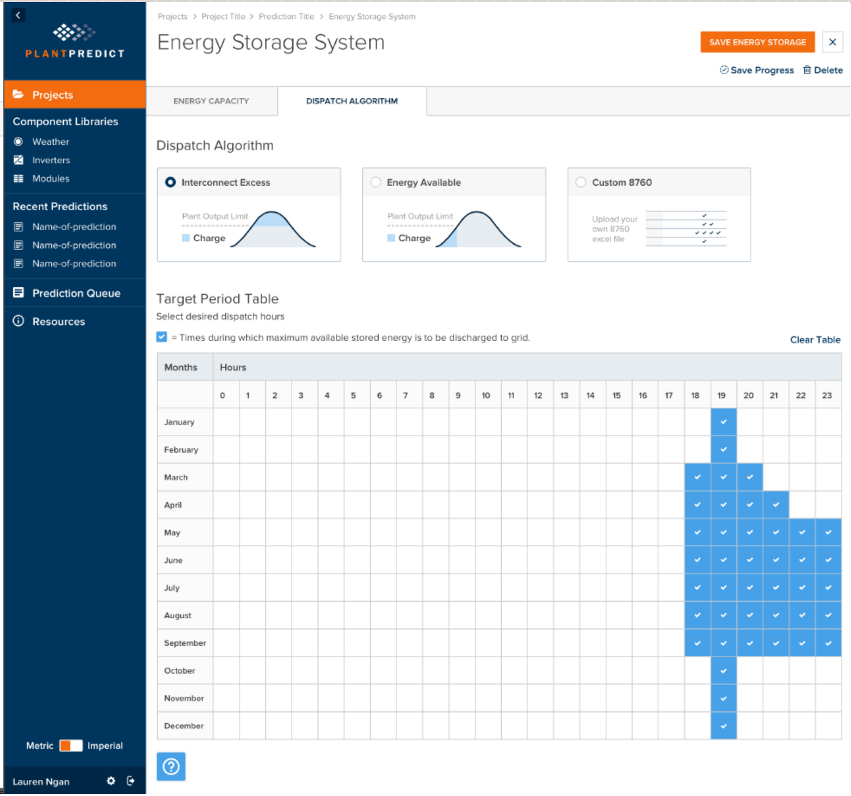
Reviewed by: DNV·GL, RV, leidos, ICF

PLANTPREDICT - Adding a storage system



PLANTPREDICT Battery User Interfaces – Define Inputs





PLANTPREDICT Battery User Interfaces – Results

PLANTPREDICT

- Projects
- Component Libraries
  - Weather
  - Inverters
  - Modules
- Recent Predictions
  - Name-of-prediction
  - Name-of-prediction
  - Name-of-prediction
- Prediction Queue
- Resources

Metric | Imperial

Lauren Ngan

Projects > Project Title > Prediction Title > Prediction Results

Prediction Title Results

EXPORT RESULTS ✕

Edit Prediction

OVERVIEW | BLOCKS | CHARTS | 12 X 24

One-Year Prediction

Prediction Start 03 MAR 2016 Prediction End 03 MAR 2017

◉ PV + Energy Storage ○ PV Only ○ Storage Only

Months	Hours																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
January	0	0	0	0	0	0	0	0	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0.24	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	0.24	0.04	0	0	0	0	0
March	0	0	0	0	0	0	0	1.48	4.81	4.81	4.81	4.81	4.81	4.81	4.81	4.81	4.81	1.48	1.48	0	0	0	0	0
April	0	0	0	0	0	0	0	1.61	4.85	4.85	4.85	4.85	4.85	4.85	4.85	4.85	4.85	1.61	1.61	0	0	0	0	0
May	0	0	0	0	0	0	0.03	1.58	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	1.58	1.58	0.03	0	0	0	0
June	0	0	0	0	0	0	0.03	0.86	3.93	3.93	3.93	3.93	3.93	3.93	3.93	3.93	3.93	0.86	0.86	0.03	0	0	0	0
July	0	0	0	0	0	0	0.01	0.78	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	0.78	0.78	0.01	0	0	0	0
August	0	0	0	0	0	0	0	1.04	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.98	1.04	1.04	0	0	0	0	0
September	0	0	0	0	0	0	0	2.13	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	3.58	2.13	2.13	0	0	0	0	0
October	0	0	0	0	0	0	0	2.64	2.36	2.36	2.36	2.36	2.36	2.36	2.36	2.36	2.36	2.64	2.64	0	0	0	0	0
November	0	0	0	0	0	0	0	1.66	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97	1.66	1.66	0	0	0	0	0
December	0	0	0	0	0	0	0	0.02	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	0.02	0.02	0	0	0	0	0

Note: All units displayed are MWh

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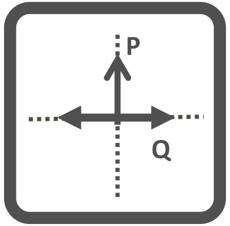
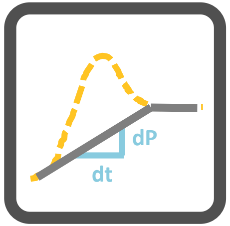
Role of Storage? … Further Enhances Grid Capability of PV Plant

Voltage Support



Ramp Control



Power Regulation

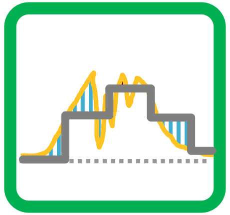
- AGC
- Up-Regulation
- Down-Regulation
- Frequency Regulation

Base Capability

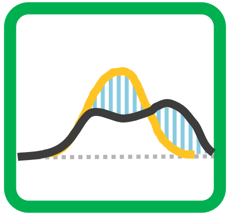
Grid Reliability Services

+

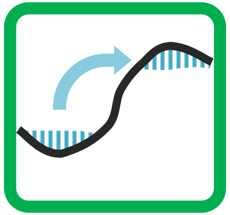
Capacity Firming



Energy Shifting



Flexibility



Grid Capabilities Enhanced with Storage

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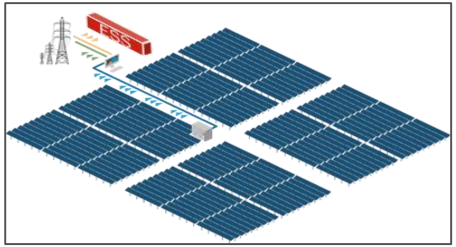
- **Battery Energy Storage Cost** is Rapidly Declining … driven by EV growth



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