

# Developments in Solar + Storage

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ESIG Fall Technical Workshop  
Oct 2, 2018



LEADING THE WORLD'S  
SUSTAINABLE ENERGY FUTURE



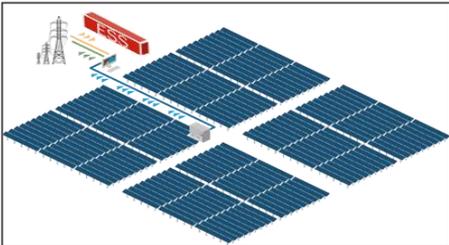
# Key Takeaways – Developments in Solar + Storage



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



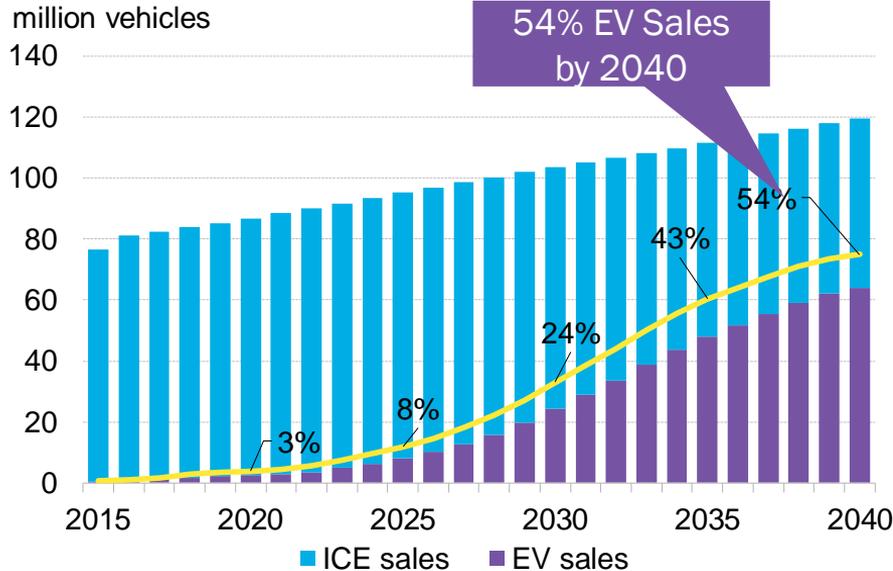
- **Battery Energy Storage Cost** is Rapidly Declining ... driven by EV growth



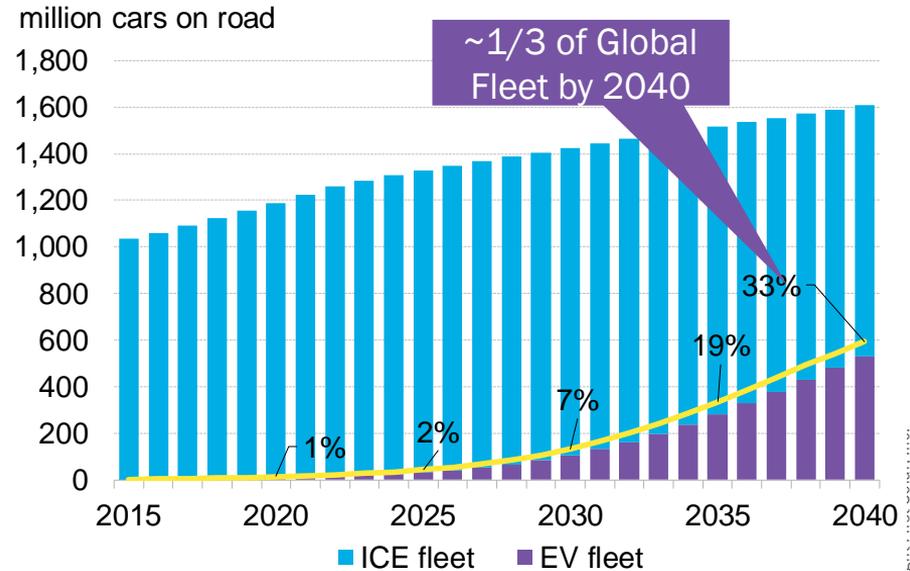
- **PV + Storage (PVS) plants** are becoming more cost-effective than conventional generation
  - *Low cost **clean energy plant** that is fully dispatched*

# Electric Vehicle (EV) Outlook To 2040

## Annual global light duty vehicle sales

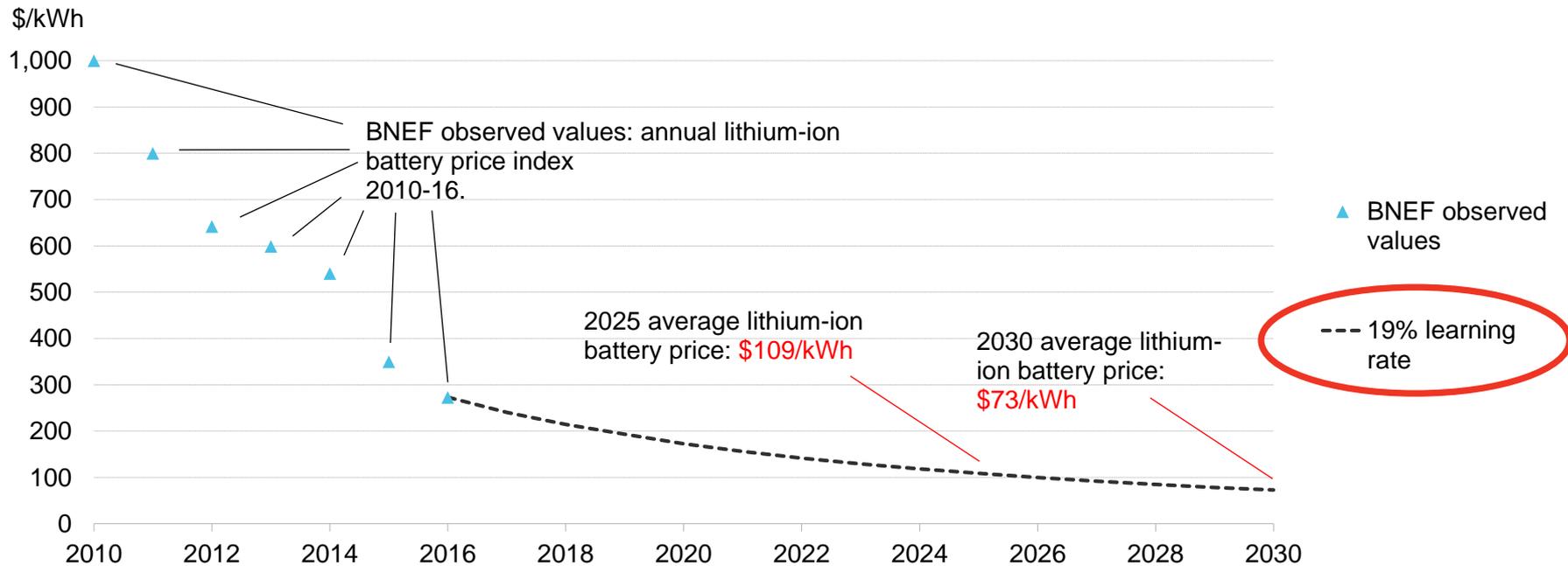


## Global light duty vehicle fleet



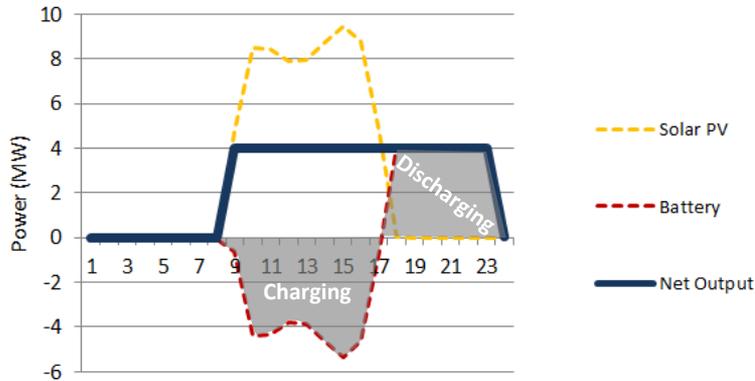
Source: Bloomberg New Energy Finance [EVO 2017](#)

# Lithium-ion Battery Prices, Historical And Forecast

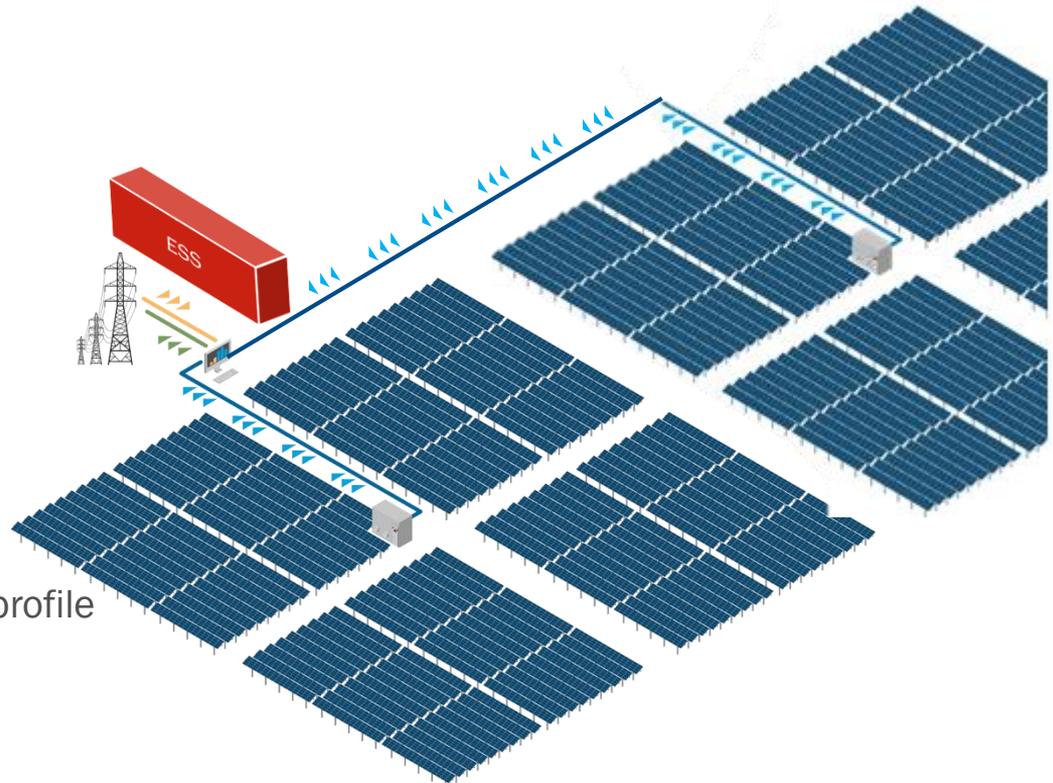


Source: Bloomberg New Energy Finance [EVO 2017](#); Note: Prices are an average of BEV and PHEV batteries and include both cell and pack costs. Cell costs alone will be lower. Historical prices are nominal, future ones are in real 2016 U.S. dollars.

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

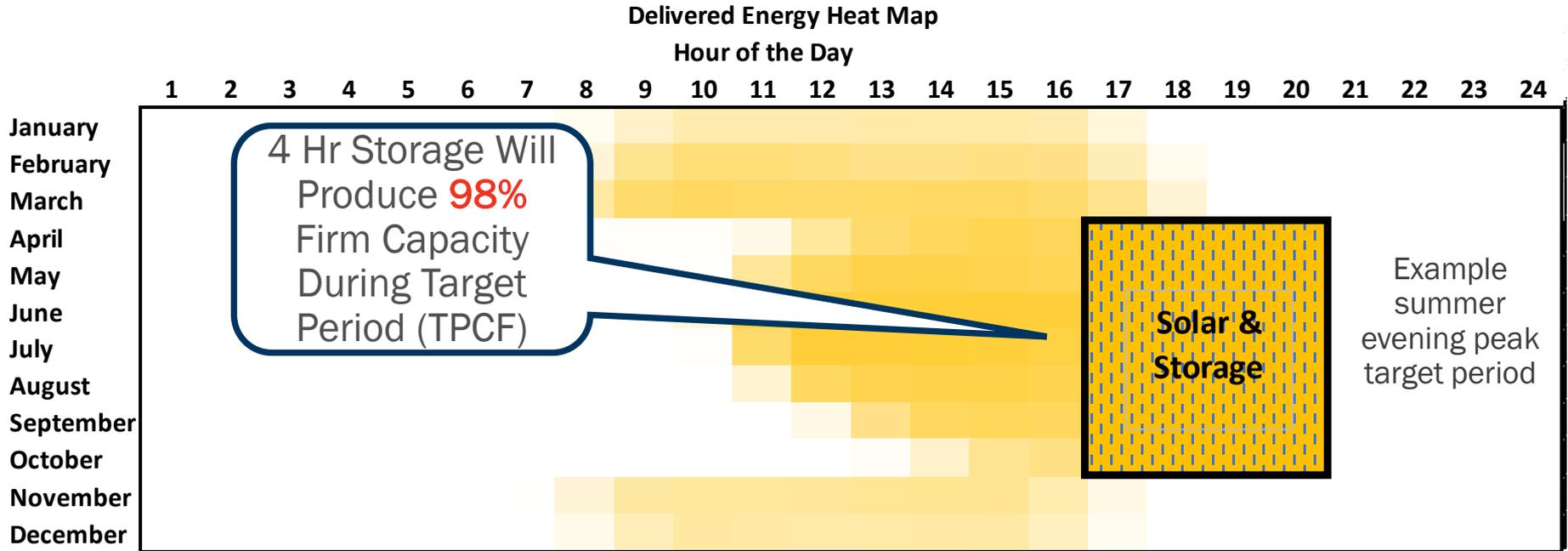


- Increase the PV array size
- Store excess energy in Energy Storage
- ESS provides flexibility to generate desired profile
- Amount of battery capacity is set by desired dispatch profile and solar irradiance
- Shared Infrastructure costs (interconnect, development, O&M)



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

# Using Storage to Increase Output During Target Period



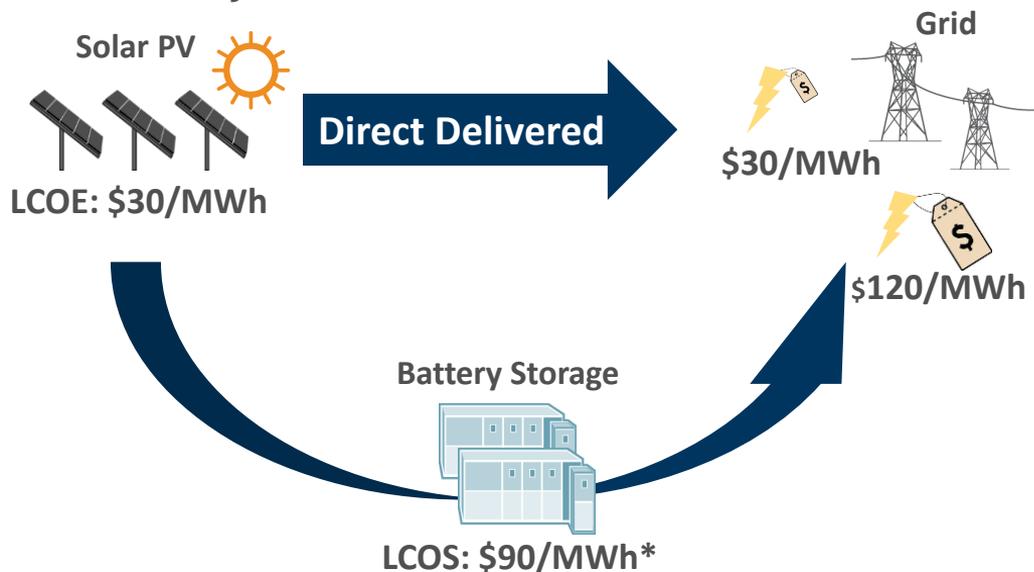
Storage (hrs)	TPCF
0	25%
1	48%
2	72%
4	98%

**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

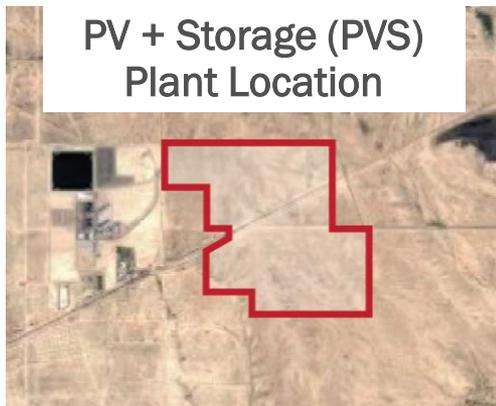
# Replacing New Peaking Gas Generation – PV+Storage (PVS)

## APS, First Solar to install Arizona's largest battery system

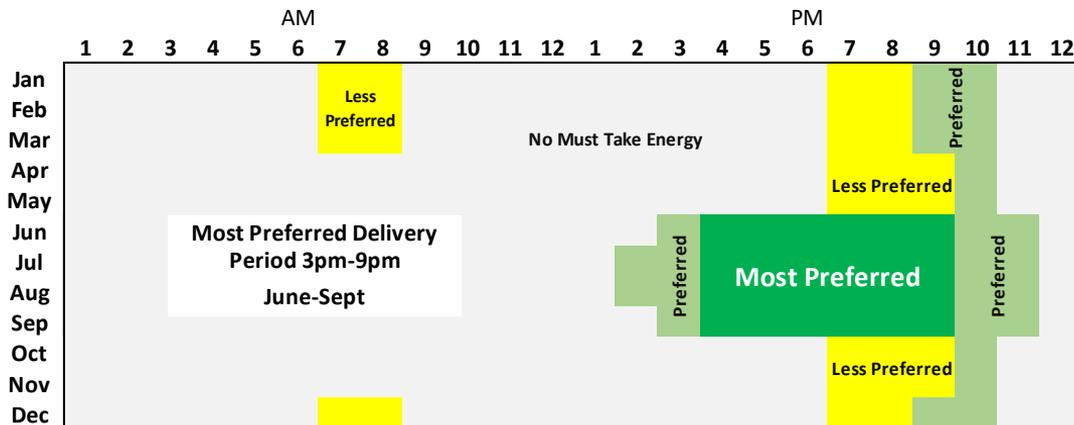
The Arizona-based module manufacturer will install a 50 MW battery system charged by a 65 MW solar farm under a 15-year power contract with the U.S. state's largest utility.

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."



PV + Storage (PVS)  
Plant Location





# Design Considerations

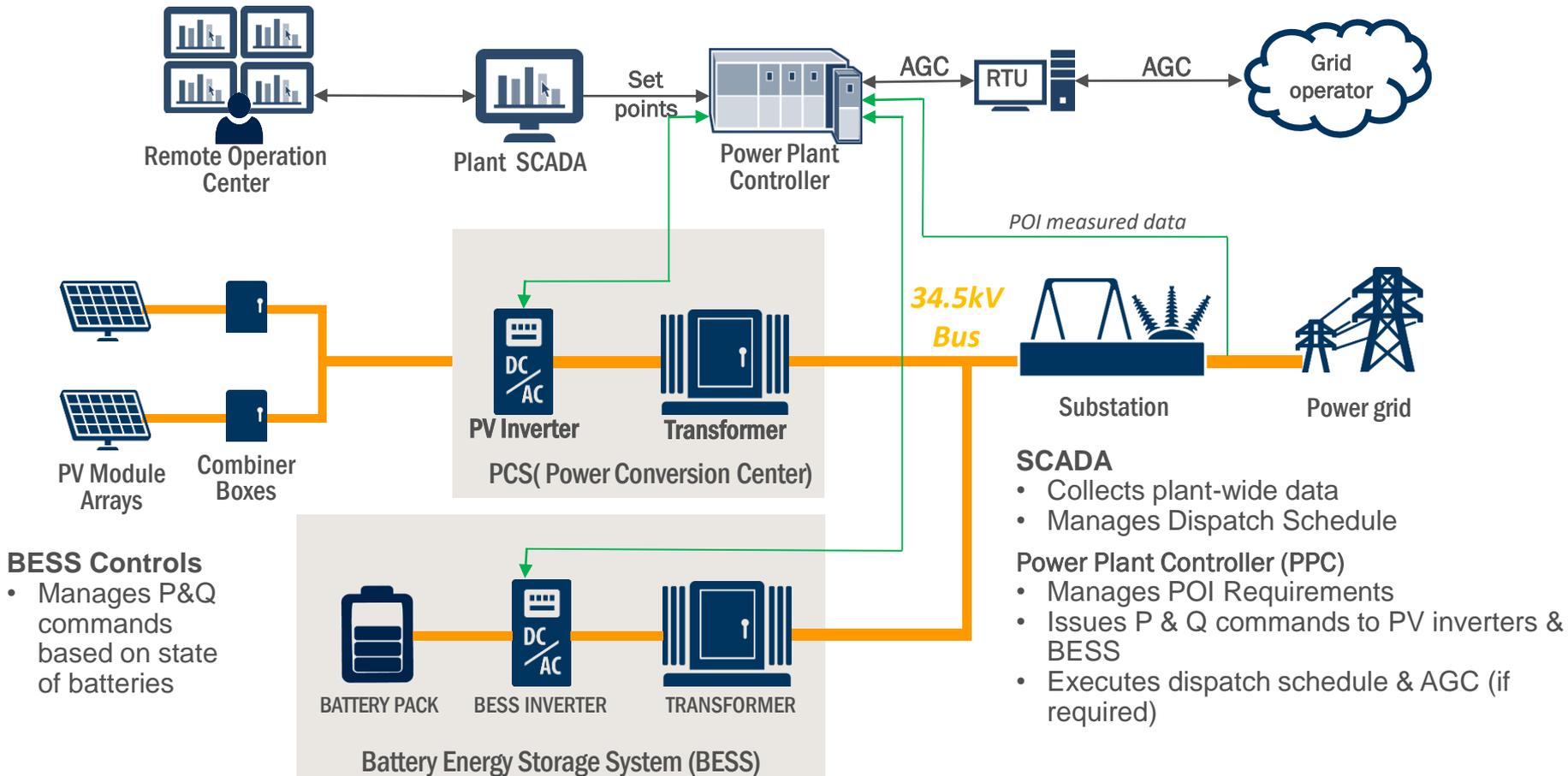
- Configuration of PV Plant (MWac, MWdc) vs Battery Storage (MWac, MWh)
- AC vs DC Coupled Design
- Battery Degradation Modeling
- Safety ... Buildings vs Containerized Enclosures



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

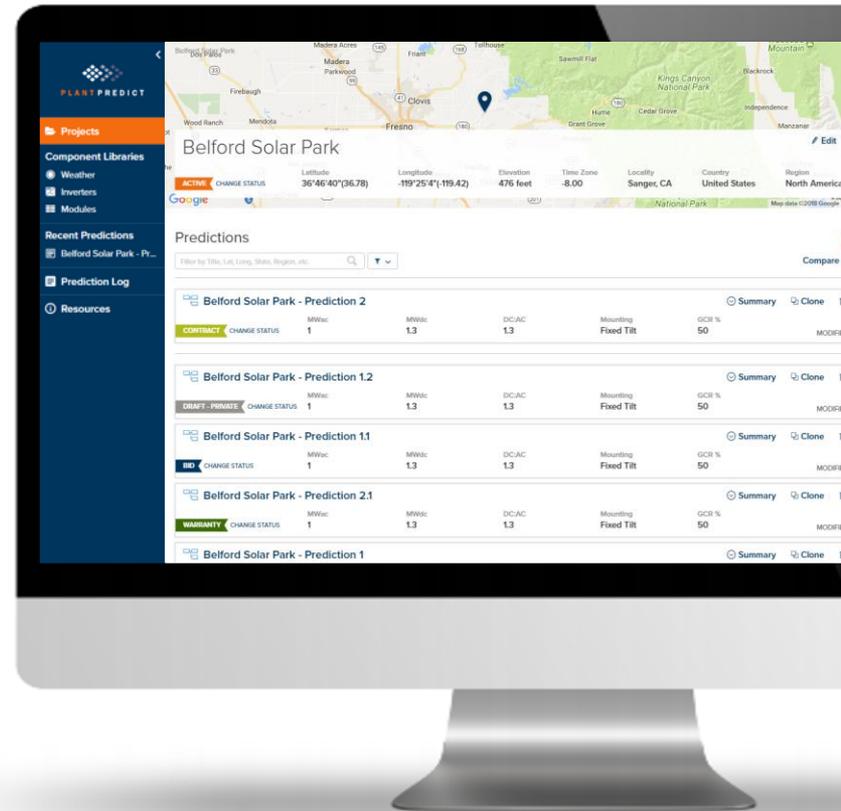
	Pros	Cons
AC-Coupled	<ul style="list-style-type: none"> <li>Commercial availability of Storage PCS systems</li> <li>Separability of PV and S ownership leading to easier contracting (lower IRRs)</li> <li>Ability to dispatch both PV and S</li> <li>Simplicity of control and site design</li> <li>Centrality of storage lowers capex and O&amp;M costs</li> </ul>	<ul style="list-style-type: none"> <li>Reduced efficiency due to more passes through inverters and transformers</li> <li>Somewhat higher capital cost due to duplication of inverter stages and transformers</li> </ul>
DC-Coupled	<ul style="list-style-type: none"> <li>Lower capital cost due to sharing of inverter components</li> <li>Ability to capture clipped DC energy</li> <li>Increased Efficiency due to fewer conversions</li> </ul>	<ul style="list-style-type: none"> <li>Increased PCS controls complexity around simultaneously managing MPPT of PV and SOC of battery</li> <li>Lack of available dual-port inverters (two DC/DC stages) at utility-scale price points</li> <li>Potential for inferred storage risk to “contaminate the IRR” of PV plant through intermixing</li> <li>Inverters and IC must be oversized to simultaneously dispatch PV and S</li> </ul>

# Plant Controls & SCADA System



- *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](http://www.plantpredict.com)
- *Reliable* – Independently reviewed and benchmarked against over 1 GW of operating facilities

Reviewed by:



# PLANTPREDICT - Adding a storage system

The screenshot displays the PLANTPREDICT web interface. On the left is a dark blue sidebar with navigation options: Projects, Component Libraries (Weather, Inverters, Modules), Recent Predictions, Prediction Queue, and Resources. The main content area is titled "Prediction Title" and shows a breadcrumb trail: Projects > Project Title > Prediction Title. Below the title, there are status indicators for "Draft-Private" and "Block". Action buttons for "RUN PREDICTION", "Edit Settings", and "Delete" are visible. The main content is organized into sections: "Environmental Conditions" with a "START" button; "Power Plant Specifications" containing "PV Blocks & Arrays" (with a "START" button) and "Energy Storage System" (with an "ADD" button, highlighted by a yellow box); "System Details" with an "EDIT" button; and "Simulation Settings" with a "START" button. A right-hand panel titled "Add Prediction Details" contains a warning message: "A prediction can not be run until all data requirements have been met." and a list of required data points: Environmental Conditions, Power Plant Specifications, and Simulation Settings. At the bottom of this panel is a "RUN PREDICTION" button and a "Prediction Logic: Version 5 Change" link. The bottom of the sidebar shows a metric selector (Metric Imperial) and the user name "Lauren Ngan".

# PLANTPREDICT Battery User Interfaces – Define Inputs

Projects > Project Title > Prediction Title > Energy Storage System

## Energy Storage System

SAVE ENERGY STORAGE X

Save Progress Delete

**ENERGY CAPACITY** DISPATCH ALGORITHM

### Energy Capacity

Nameplate:  MWh ↔ Factor:  90 % ↔ Usable:  90 MWh

Calendar Degradation:  % / year    Cycling Degradation:  % / 100 cycles

### DC Roundtrip Efficiency

Initial Efficiency:  %    Calendar Degradation:  % / year    Cycling Degradation:  % / 100 cycles

### Inverter

Real Power:  kW    Efficiency:  %

### MV Transformer

Power Rating:  kVA    No Load Loss:  %    Full Load Loss:  %

### HVAC Losses

No Load Loss:  kW/MWh    Full Load Loss:  kW/MWh

Metric  Imperial

Lauren Ngan

**PV Blocks & Arrays**

**Energy Storage**

- Usable Energy Cap. 90 MWh
- Maximum C-Rate: 2
- Inverter Real Pwr. 80 kW
- Transformer Pwr. 100 kVA

Projects > Project Title > Prediction Title > Energy Storage System

## Energy Storage System

SAVE ENERGY STORAGE X

Save Progress Delete

**ENERGY CAPACITY** DISPATCH ALGORITHM

### Dispatch Algorithm

Interconnect Excess     Energy Available     Custom 8760

Plant Output Limit: Charge

### Target Period Table

Select desired dispatch hours

Times during which maximum available stored energy is to be discharged to grid. Clear Table

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																									
February																									
March																									
April																									
May																									
June																									
July																									
August																									
September																									
October																									
November																									
December																									

Metric  Imperial

Lauren Ngan

# PLANTPREDICT Battery User Interfaces – Results

**Projects**

Component Libraries

- Weather
- Inverters
- Modules

Recent Predictions

- Name-of-prediction
- Name-of-prediction
- Name-of-prediction

Prediction Queue

Resources

Metric  Imperial

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Projects > Project Title > Prediction Title > Prediction Results

## Prediction Title Results

[EXPORT RESULTS](#) X

[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	0.24	0.04	0	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	1.48	1.48	0	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	1.61	1.61	0	0	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	1.58	1.58	0.03	0	0	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	0.86	0.86	0.03	0	0	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	0.78	0.78	0.01	0	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	1.04	1.04	0	0	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	2.13	2.13	0	0	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	2.64	2.64	0	0	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	1.66	1.66	0	0	0	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	0.02	0.02	0	0	0	0	0	0	0

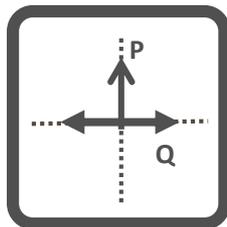
Note: All units displayed are MWh

[Copy to Clipboard](#)

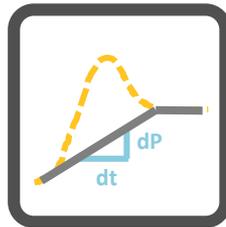
# Role of Storage? ... Further Enhances Grid Capability of PV Plant



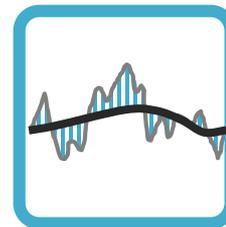
Voltage Support



Ramp Control



Power Regulation



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



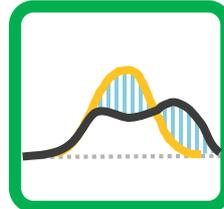
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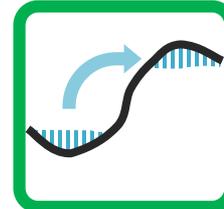
Capacity Firming



Energy Shifting



Flexibility



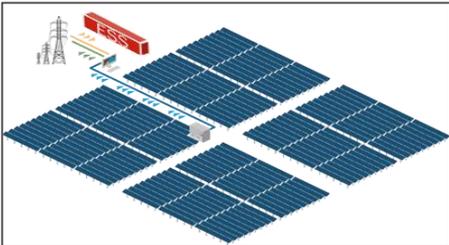
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