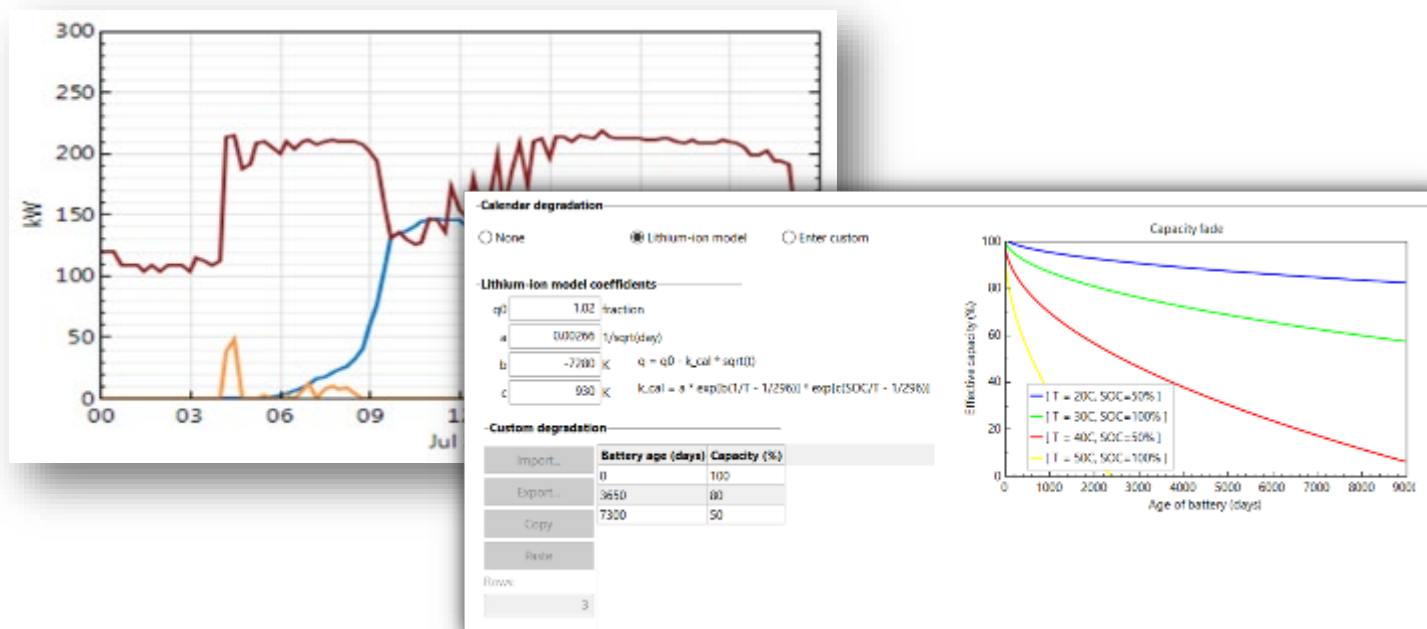




PV + Storage, Resiliency, Capacity, and Ancillary Services in SAM

Janine Freeman
2019 PV Systems Symposium/ 12th PVPMC
May 16, 2019

Only publicly available tool with detailed battery model that accounts for voltage characteristics, calendar and cycle degradation, etc



- ✓ Currently integrated with PV and "Generic System" model
- ✓ Available on DC or AC side of PV system
- ✓ Multiple automated dispatch strategies for different markets
- ✓ Behind-the-meter or front-of-the-meter operation



Photovoltaic (detailed)

SAM 2016.3.14

File Add Commercial Battery

Photovoltaic, Commercial **Enable Battery**

Location and Resource

Module

Inverter

System Design

Shading and Snow

Losses

Lifetime

Battery Storage

System Costs

Financial Parameters

Incentives

Electricity Rates

Electric Load

Battery Bank Sizing

Specify desired bank size Specify cells

Desired bank capacity kWh Number of cells in series

Desired bank voltage V Number of strings in parallel

Chemistry

Battery type

Voltage Properties

Cell nominal voltage V Internal resistance Ohm

C-rate of discharge curve

Fully charged cell voltage V

Exponential zone cell voltage V

Nominal zone cell voltage V

Charge removed at exponential point %

Charge removed at nominal point %

Current and Capacity

Cell capacity Ah Max C-rate of charge

Max C-rate of discharge

Computed Properties

Nominal bank capacity kWh Maximum power

Nominal bank voltage V Time at maximum power

Cells in series Maximum charge current

Strings in parallel Maximum discharge current

Power Converters

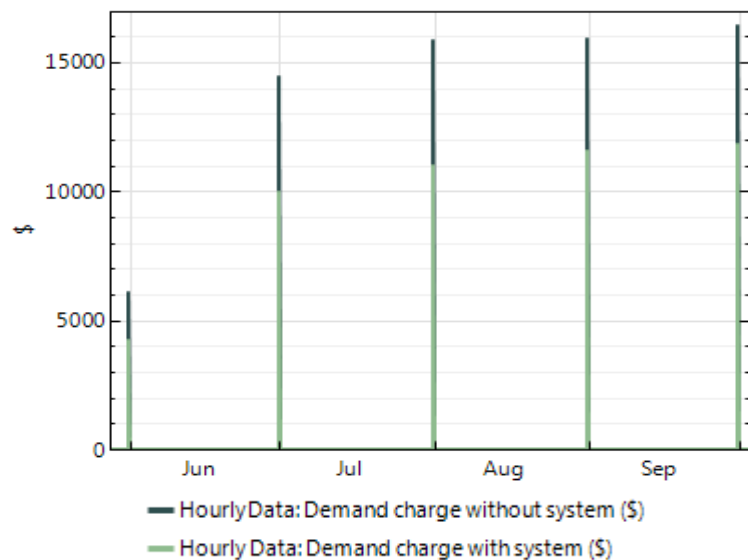
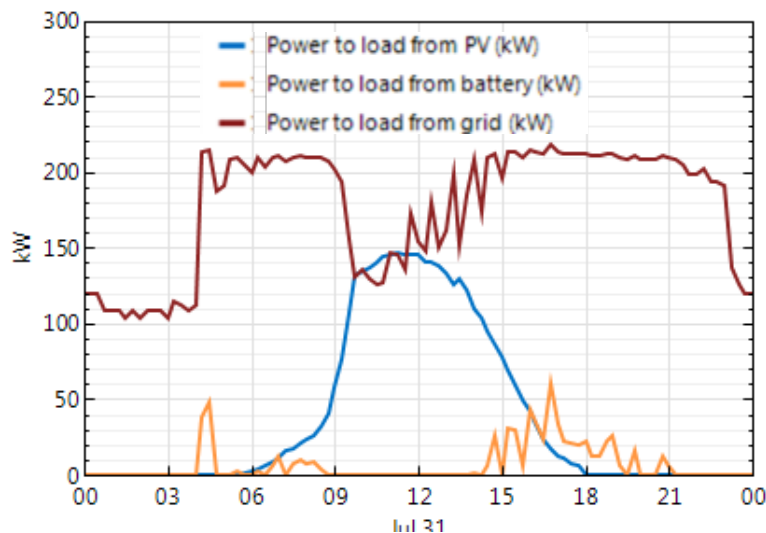
AC to DC conversion efficiency %

Ability to configure

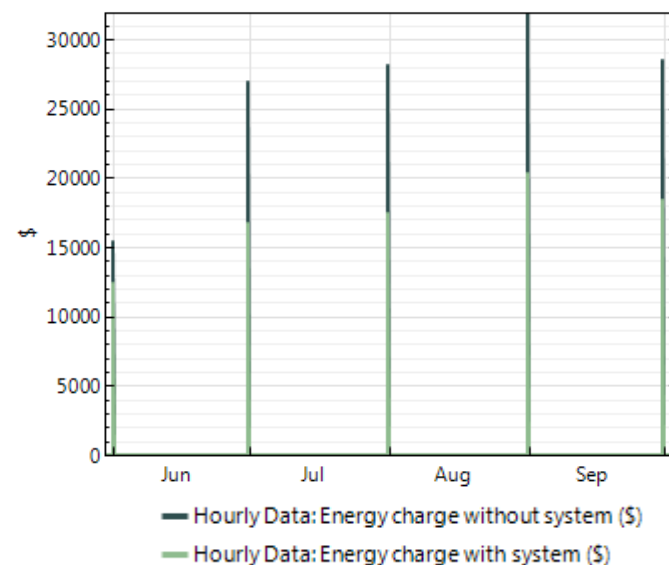
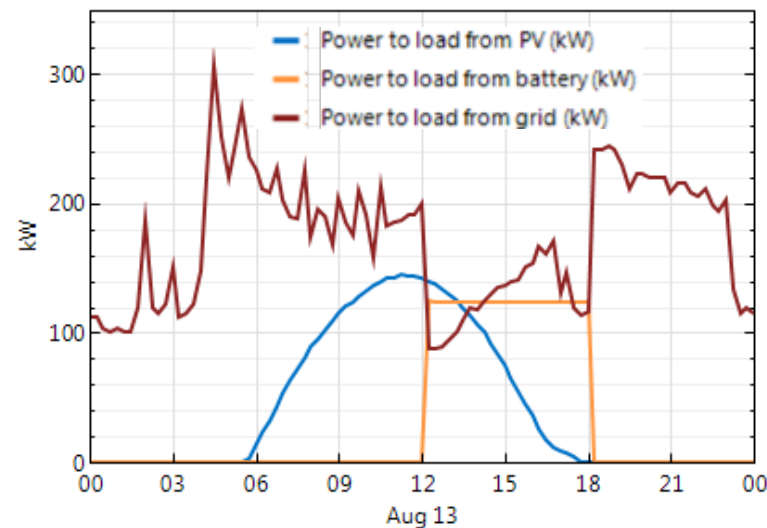
- Battery size
- Battery voltage
- Cell properties
- Chemistry type
- Max charge, discharge rates
- Battery configuration
- Power electronics efficiencies
- Battery operational limits
- Battery dispatch
- Battery lifetime properties
- Battery replacement preferences
- Battery thermal properties



Peak shaving for demand charge reduction



Manual dispatch for energy arbitrage





Storage Dispatch Controller

Choose Dispatch Model

Auto DC-connected dispatch: 1-day look ahead
 Auto DC-connected dispatch: 1-day look behind
 Auto DC-connected dispatch: Input forecast
 Input battery dispatch
 Manual dispatch

For all non-manual dispatch options, select how the battery can be charged

Battery charge options

Battery can charge from grid
 Battery can charge from system
 Battery can charge from clipped system power

Automated DC-connection options

Choose Weather forecast file

Browse...

Dispatch options

Frequency to update dispatch hours
Look-ahead period hours

Battery cycle costs

When using the automated dispatch control, the model will cycle the battery only if the benefit is greater than the damage to the battery.

Battery cycle cost choice

Battery cycle costs \$/cycle-kWh

Input Battery Dispatch

Input a custom battery power dispatch (<0 for charging, >0 for discharging)

Input battery dispatch kWdc

- Recently added automated control strategies for large plants with DC-connected battery systems
- Optimize dispatch to charge from PV, capture clipping, and maximize value



Behind-the-meter price signal optimal dispatch (end of 2019)

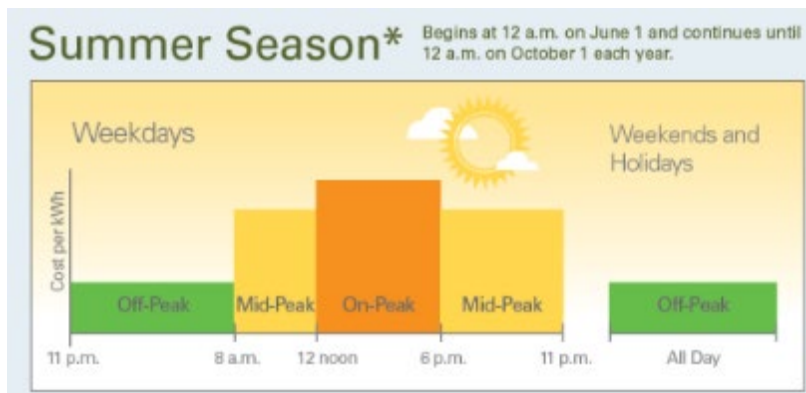
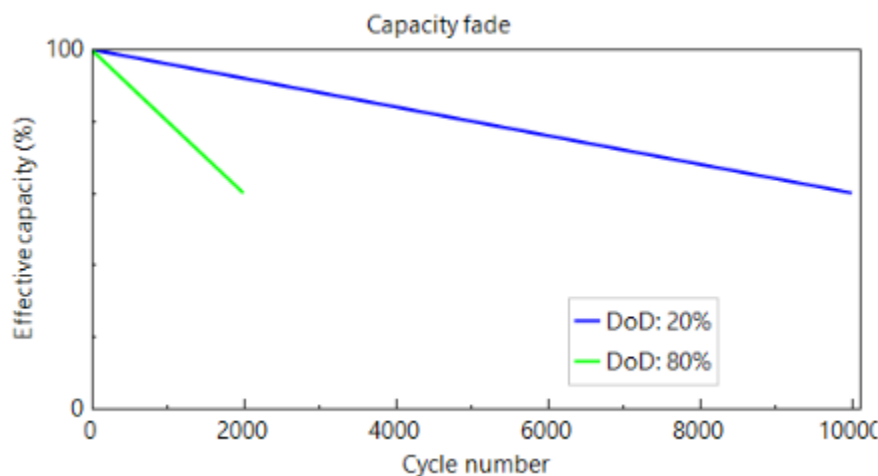


Image from SCE TOU-GS-2 Option B datasheet

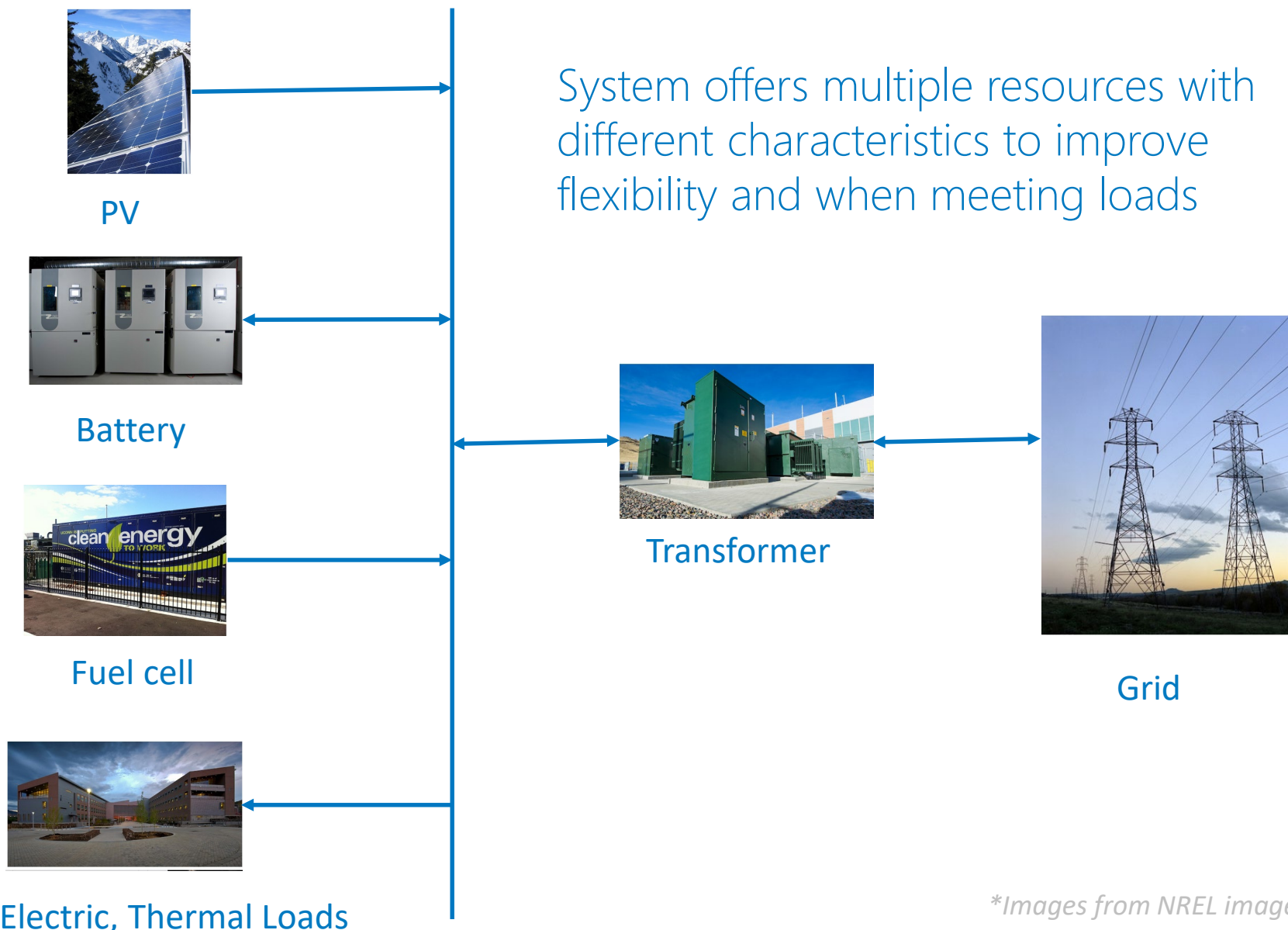
Given the utility rate tariff, forecast PV generation, battery wear costs, generate optimal dispatch strategy

Improved battery lifetime model

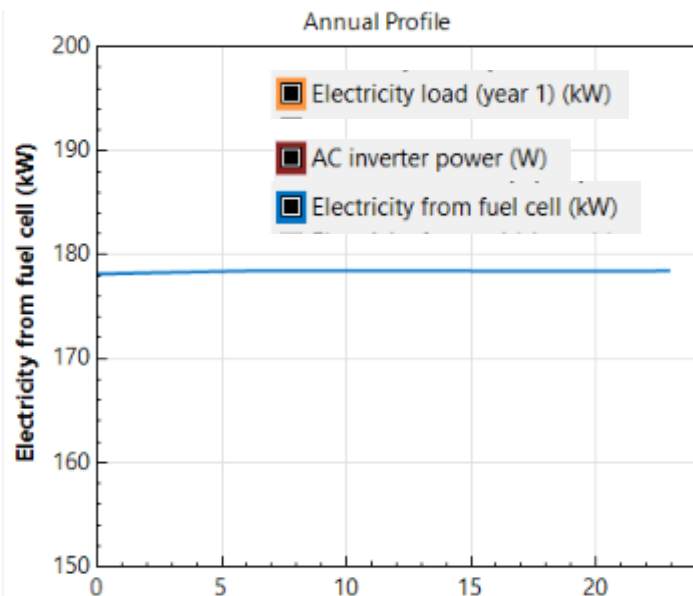


Add predictive model which computes degradation based on battery characteristics and cycling

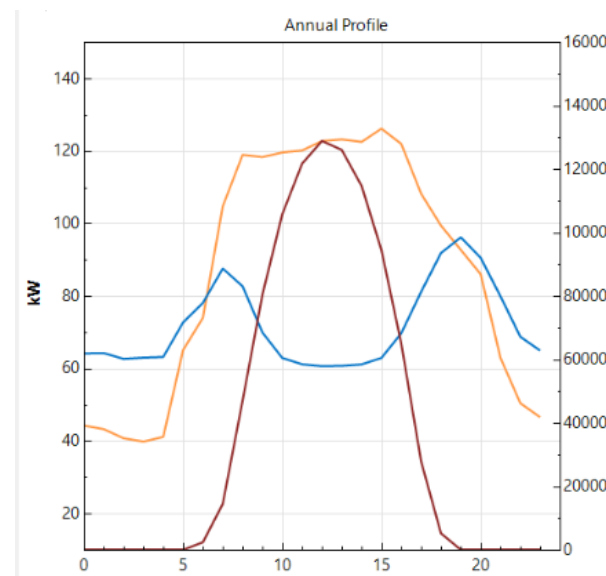
Hybrid PV + Battery + Fuel Cell



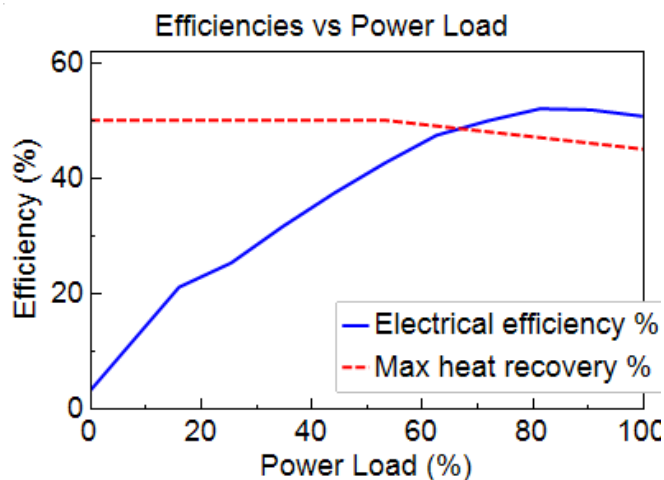
**Images from NREL image gallery*



Fixed output



Load following



- Fuel cell operates with defined ramp rate limits, degradation rate
- Efficiencies govern fuel usage and thermal generation
- Multiple fuel cell chemistries
- Battery makes up difference between fuel cell operational limits and load following



- Leverage the NREL REopt Lite methodology to:
 - Size PV+Storage systems to **sustain critical load**
 - Optimize PV and battery system sizes and dispatch strategy to **minimize life cycle cost of energy**
- Then run the optimally sized system through SAM's more detailed technology & financial models to **understand realistic system performance**



Step 1: Select Your Technology

Do you want to evaluate PV, battery, or both?

Step 2: Enter Your Data

Enter information about your site and adjust the default values as needed to see your results.

Site and Utility (required) ✖

* **Site location** ⓘ * Required field

* **Load profile** ⓘ Simulated
 Custom Load Profile

* **Type of building** ⓘ

* **Annual energy consumption (kWh)** ⓘ

* **Electricity rate** ⓘ
URDB Rate Details

Financial ⓘ

PV ⓘ

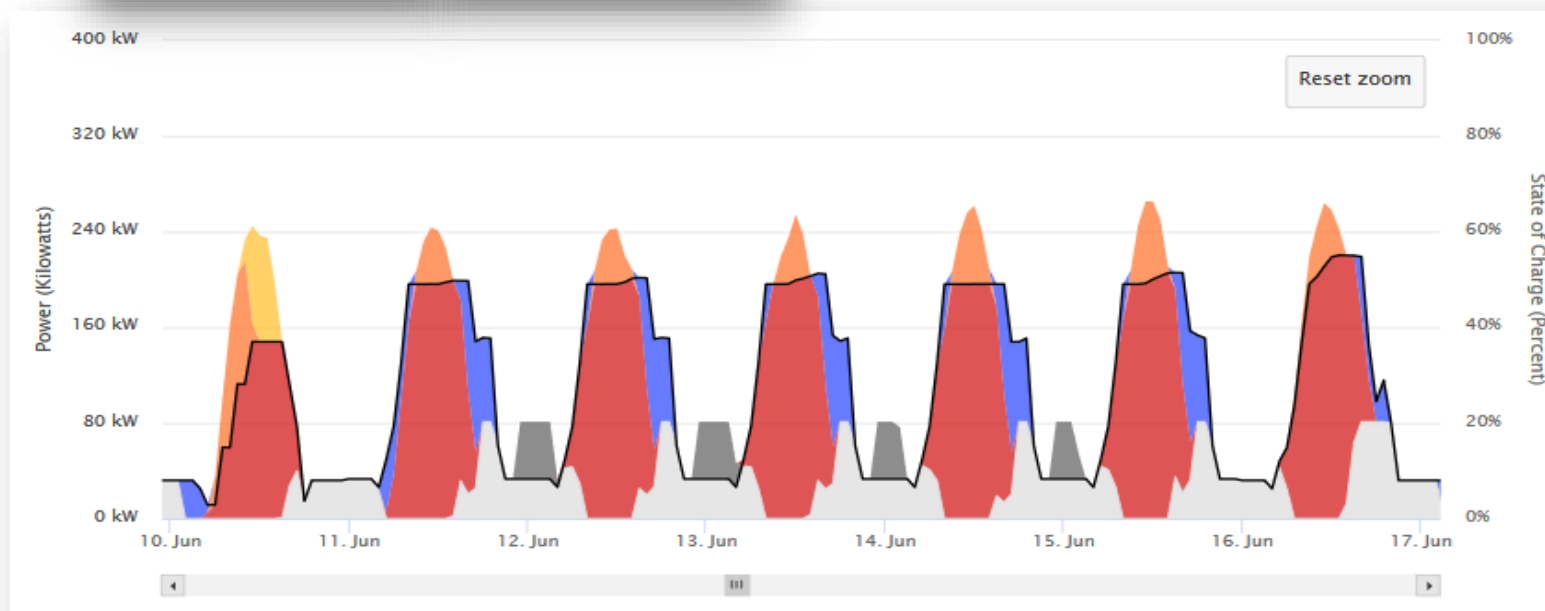
Battery ⓘ

Resilience ⓘ

ⓘ



Output metrics quantifying resiliency of your site to withstand outages for full load, critical loads





The screenshot shows the SAM software interface with a financial summary table. The table has columns for years 0 through 8. The rows are categorized into Production, Revenues, Operating Expenses, and Depreciation and Tax State.

	0	1	2	3	4	5	6	7	8
PRODUCTION (AC/kWh)									
Energy (kWh)	0	27,260,896	27,064,680	26,868,464	26,672,248	26,476,032	26,279,816	26,083,600	25,887,384
REVENUES									
PPA price (cents/kWh)	0	5.68810	6.12460	6.56110	6.99760	7.43410	7.87060	8.30710	8.74360
PPA revenue (\$)	0	2,482,278	2,492,871	2,503,464	2,514,057	2,524,650	2,535,243	2,545,836	2,556,429
plus PFI if available for data service:									
Subgroup value (\$)	0	0	0	0	0	0	0	0	0
Total revenue (\$)	0	2,482,278	2,492,871	2,503,464	2,514,057	2,524,650	2,535,243	2,545,836	2,556,429
OPERATING EXPENSES									
O&M fixed expense (\$)	0	0	0	0	0	0	0	0	0
O&M production-based expense (\$)	0	0	0	0	0	0	0	0	0
O&M capacity-based expense (\$)	0	180,000	180,000	180,000	180,000	180,000	180,000	180,000	180,000
Property tax expense (\$)	0	0	0	0	0	0	0	0	0
Insurance expense (\$)	0	180,000	180,000	180,000	180,000	180,000	180,000	180,000	180,000
Total operating expenses (\$)	0	360,000	360,000	360,000	360,000	360,000	360,000	360,000	360,000
DEPRECIATION AND TAX STATE									
MACRS 5-yr		52.78	26,425,724.00						
MACRS 15-yr		1.00	681,638.75						
Straight Line 5-yr		0	0						
Straight Line 15-yr		2.50	36,7418.28						
Straight Line 20-yr		4.00	681,638.75						
Straight Line 40-yr		0	0						
Property		0	0						

Adding ability for commercial and utility-scale systems to participate in capacity markets

- Include revenue in cash flow in addition to PPA revenue
- Accounting for capacity credit of renewable systems



Mimic merchant plant operation allowing battery to dispatch according to cleared market capacity

Multiple available revenue streams (reserves, frequency regulation, etc)



Thank you! Questions?

Janine Freeman - project lead, photovoltaic and wind models

Nick DiOrio - code architecture, battery storage models

Nate Blair - emeritus lead, financials, costs, systems

Darice Guittet – software development, photovoltaic models

Steve Janzou - programming, utility rate structures (subcontractor)

Paul Gilman - user support and documentation (subcontractor)

Ty Neises - concentrating solar power models

Mike Wagner - concentrating solar power models

Matt Boyd- concentrating solar power models

www.nrel.gov

<http://sam.nrel.gov>

