NREL Publicly Available Tools for Resiliency and Hybrid Systems

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With Help
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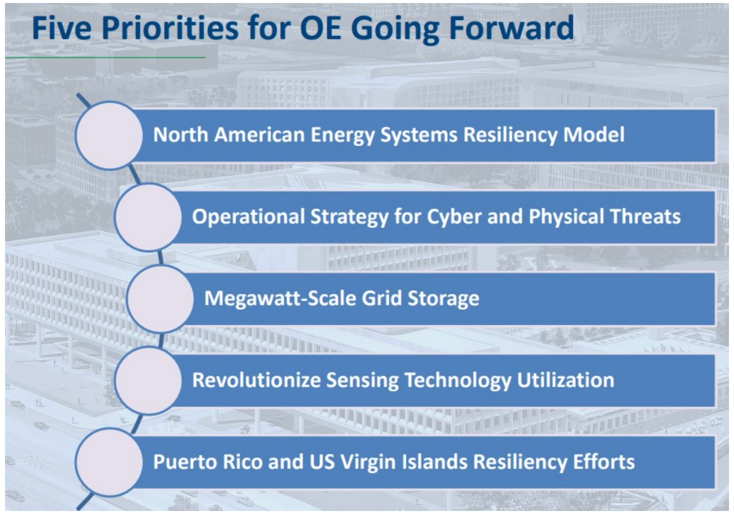
Why Resiliency and Why Now?

- Growing focus at DOE (and USG broadly) on power grid disaster planning, disaster recovery and resilience
- PV and batteries now seen as cost-effective method to supply resilience for long periods while contributing significantly outside of disaster
- Tools we have been building for many years now filling these growing roles – at all scales (residential, industrial backup, community, mini-grid, utility-scale.
- Value streams are changing – not just an energy game anymore.
- International usage of our tools growing.

Hurricane Maria in Puerto Rico

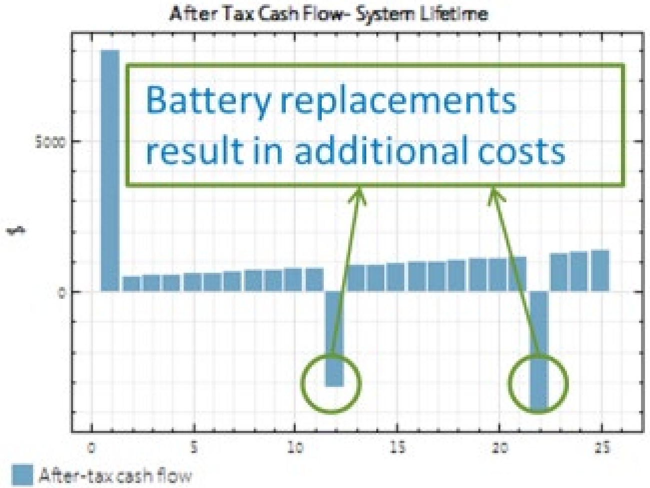


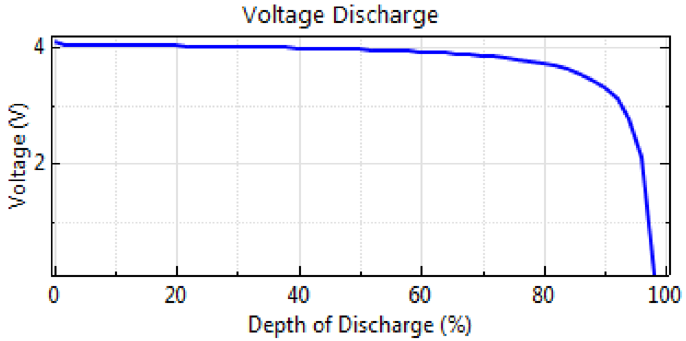
Key Tools to be Discussed

- System Tools
  - SAM
    - Battery Model
    - PVWatts
  - REOpt-Lite
    - REOpt
    - Battery Modeling
    - Resiliency Metrics
- Related Tools

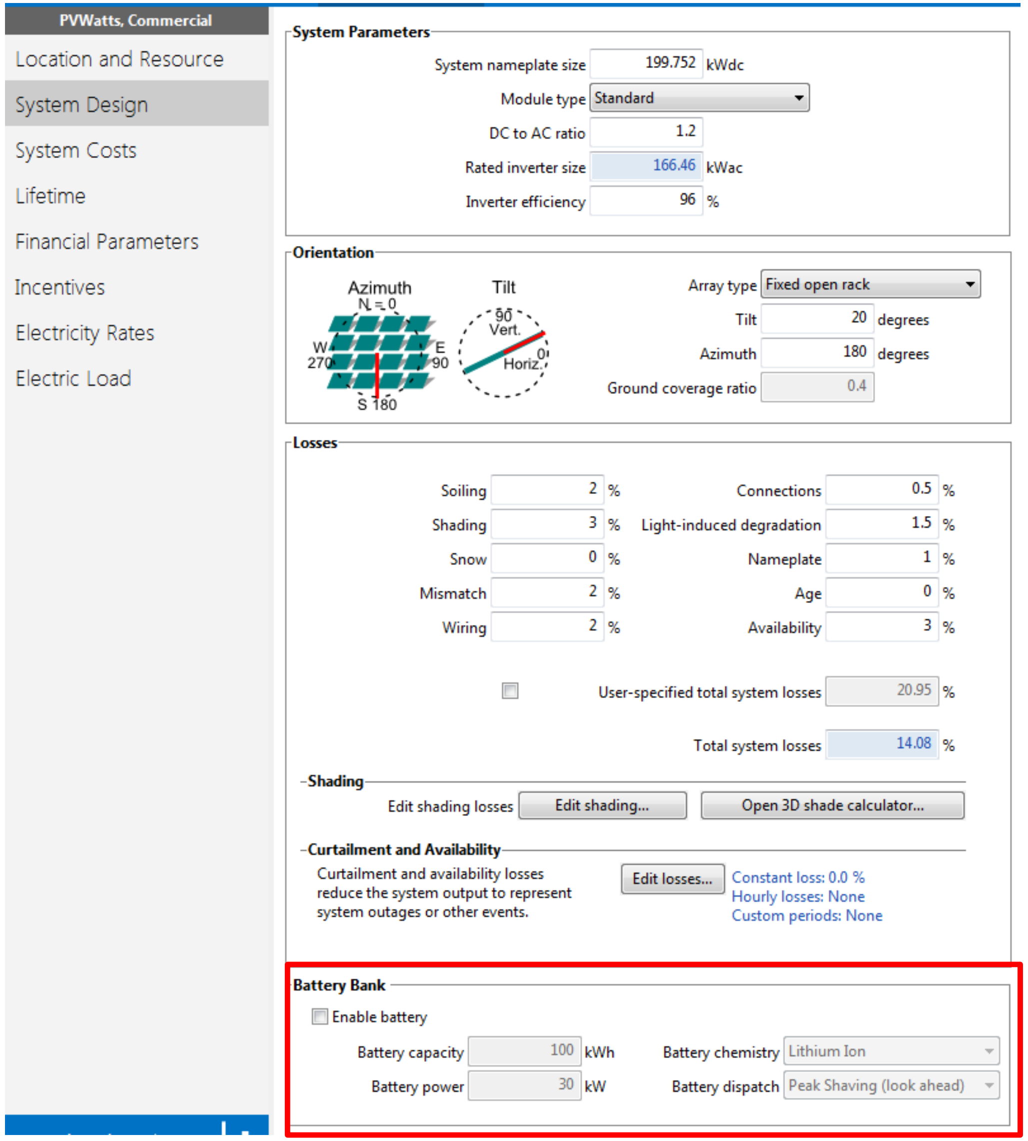
SAM Battery Model Overview

- Techno-economic model for behind-the-meter and front-of-meter scenarios.
  - Lead acid & lithium ion battery chemistries
  - System lifetime analysis including battery replacement costs
  - Models for terminal voltage, capacity, temperature
  - Multiple dispatch controllers available





PVWatts + Simple battery model



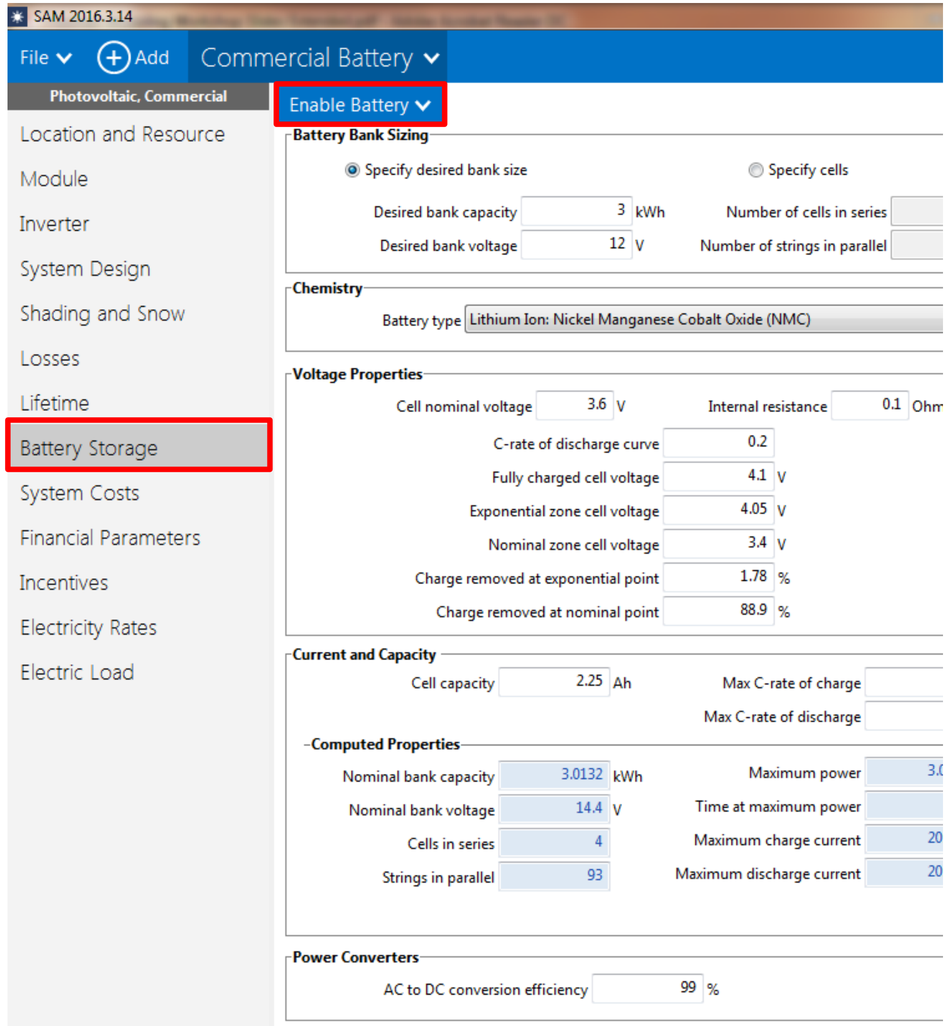
Ability to configure

- Battery capacity
- Battery power
- Battery chemistry
- Forecast preference for peak shaving algorithm

Note

- The battery in PVWatts is set to perform peak shaving for demand charge reduction. There is no ability to manual schedule the dispatch.

Detailed Battery Model (with Detailed PV Model)



Ability to configure

- Battery Capacity
- 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

Battery Financial Considerations

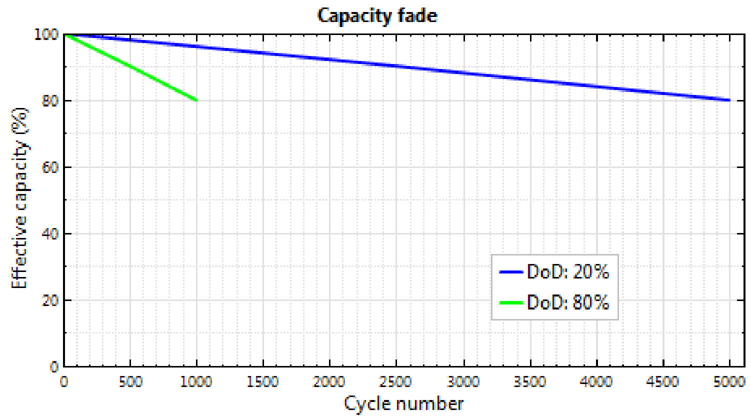
- **Lifetime**

PV simulation over analysis period

PV Array Performance Degradation

Module degradation rate Value 0 %/year

Applies to the array's hourly DC output.



Battery capacity fades with cycling, depends on depth-of-discharge

- **System Costs**

Direct Capital Costs

Module	928	units	0.2	kWdc/unit	199.8	kWdc	0.71	$/Wdc
Inverter	5	units	36.0	kWac/unit	180.0	kWac	0.21	$/Wdc
				Battery bank	3.0	kWh dc	600.00	$/kWh dc

- **Battery Bank Replacement (Battery Storage page)**

Battery Bank Replacement

- No replacements
- Replace at specified capacity
- Replace at specified schedule

Battery bank replacement threshold 20 % capacity

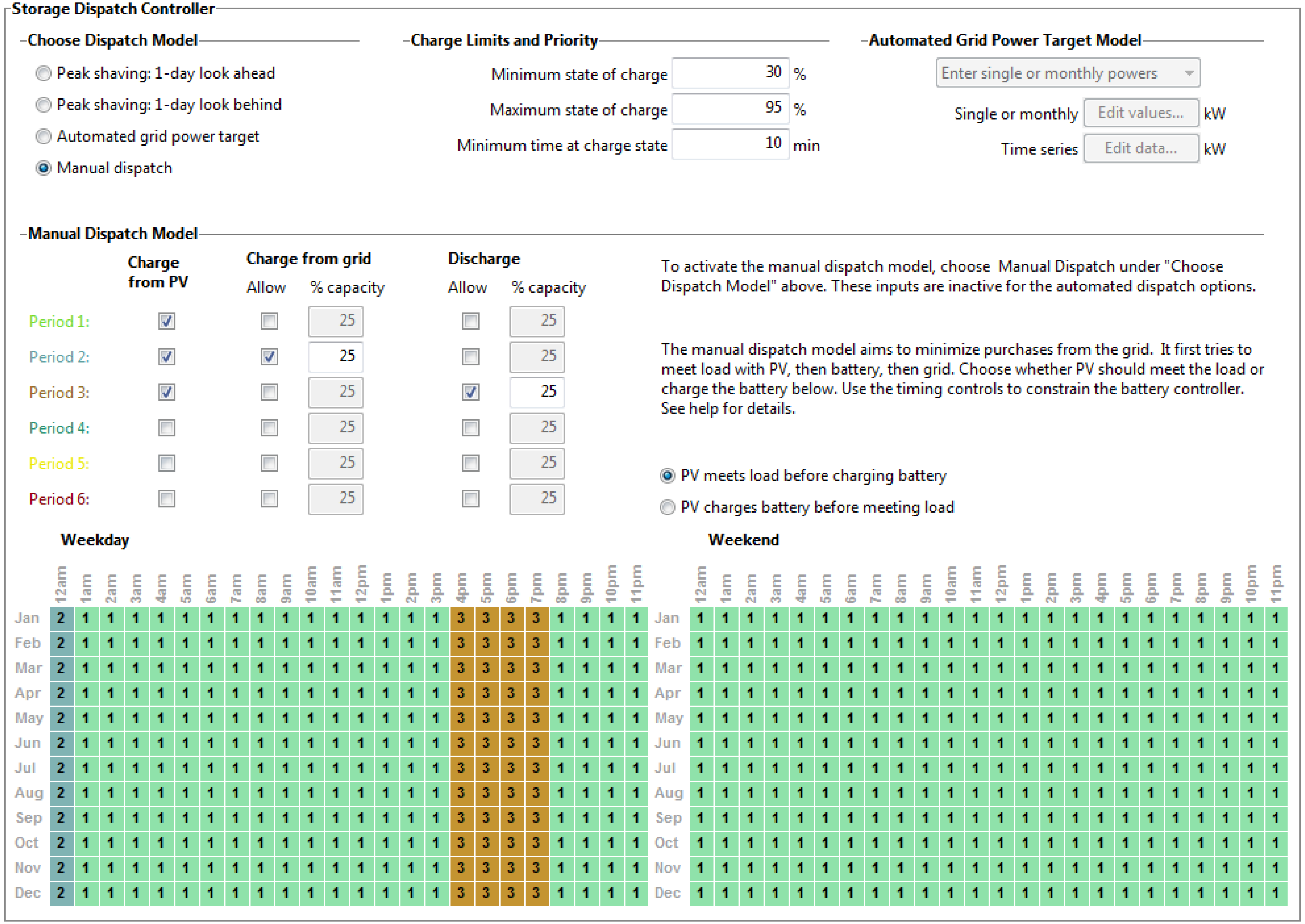
Battery bank replacement schedule Edit data...

Battery bank replacement cost 600 $/kWh

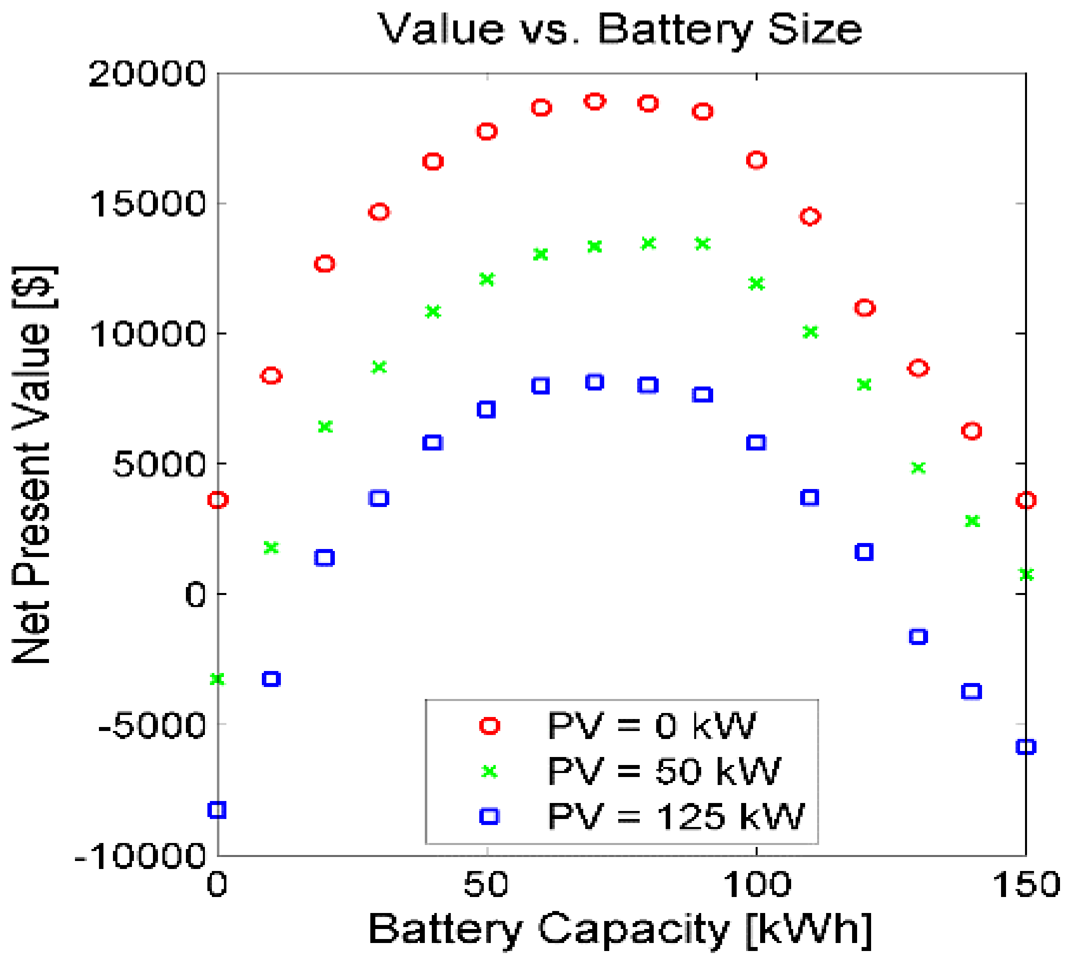
Battery cost escalation above inflation 0 % %/year

SAM applies both inflation and escalation to the first year cost to calculate out-year costs. See Help for details.

Battery Dispatch



Parametric sizing results



- NPV maximized for no PV system, battery bank capacity of 70 kWh
- Illustrates simulation-based method to approximate ‘optimal’ sizing.

Battery summary

- Battery model adds on to SAM's powerful PV and inverter modeling capabilities to evaluate behind-the-meter storage systems.
- Can answer questions like:
  - What sizes of battery/PV system will provide value over the system lifetime?
  - How will battery replacement costs affect economic viability?
  - How does the dispatch strategy affect bill savings?
  - How does battery configuration affect performance and policy considerations?
- SAM does not optimally size the battery nor the PV system to the loads

History of REopt™

REopt evolved from an RE screening tool to a platform for energy systems integration and optimization

<u>Key capabilities</u>

- Renewable energy integration & optimization

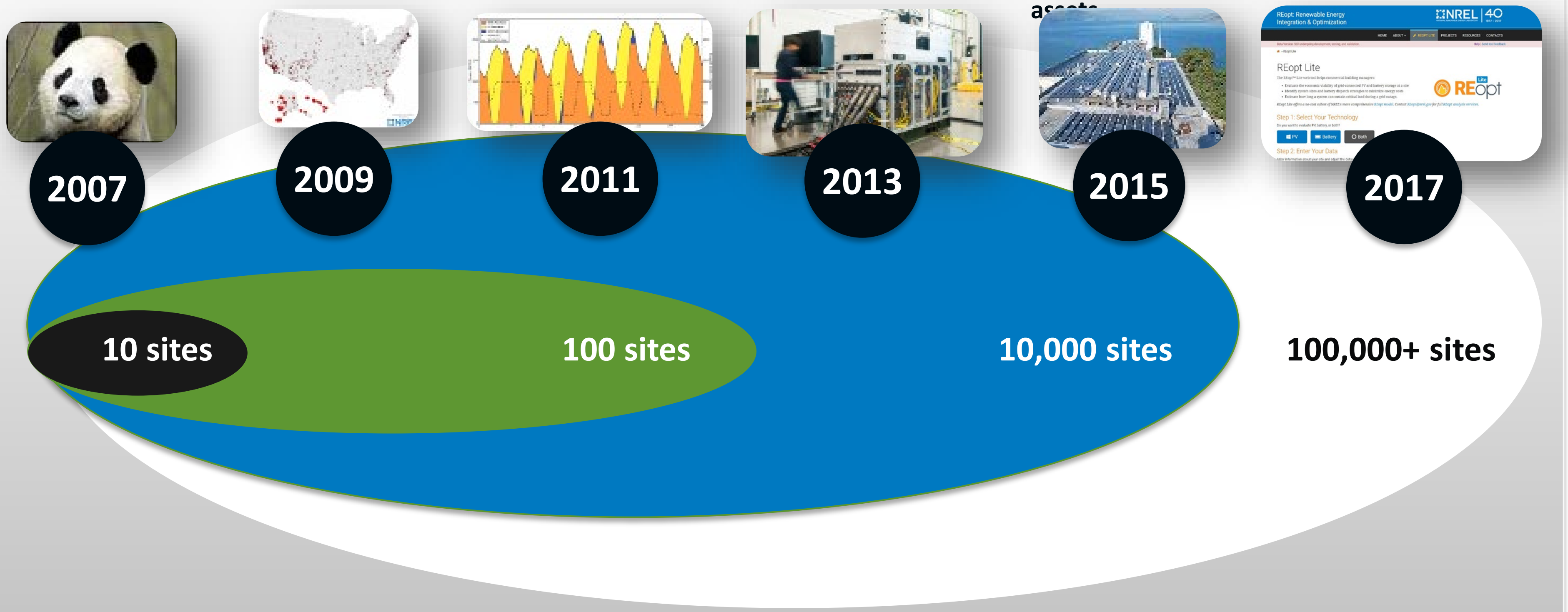
- Portfolio planning
- Net zero analysis

- Mixed integer linear program
- Time series simulation

- Microgrid design
- Energy storage
- Operational energy

- EERE optimization
- Stochastic outage analysis
- Dispatching existing assets

- Web tool
- Macro-economic analysis
- Energy/water nexus



REopt Platform: Decision Support through the Energy Planning Process

Optimization • Integration • Automation

Master Planning

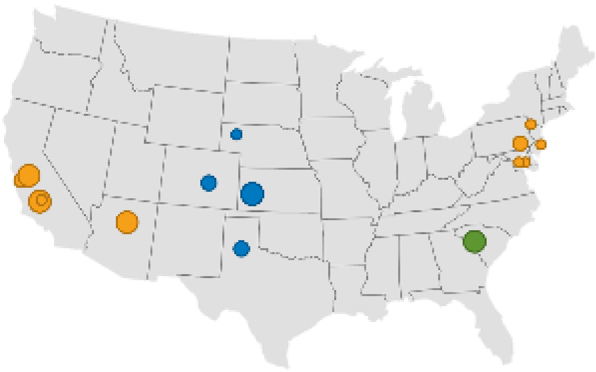
- Portfolio prioritization
- Cost to meet goals

Economic Dispatch

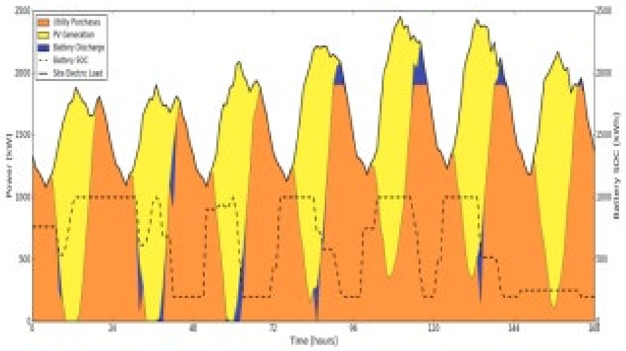
- Technology types & sizes
- Optimal operating strategies

Resiliency Analysis

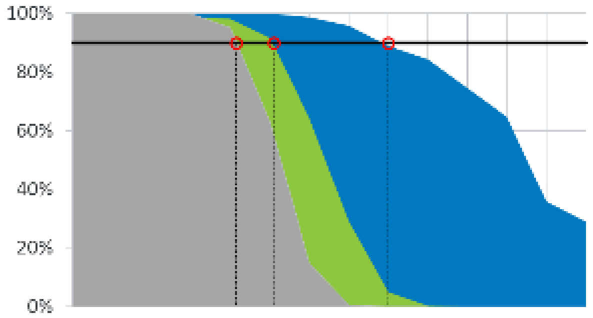
- Microgrid dispatch
- Energy security evaluation



Cost-effective RE at Army bases



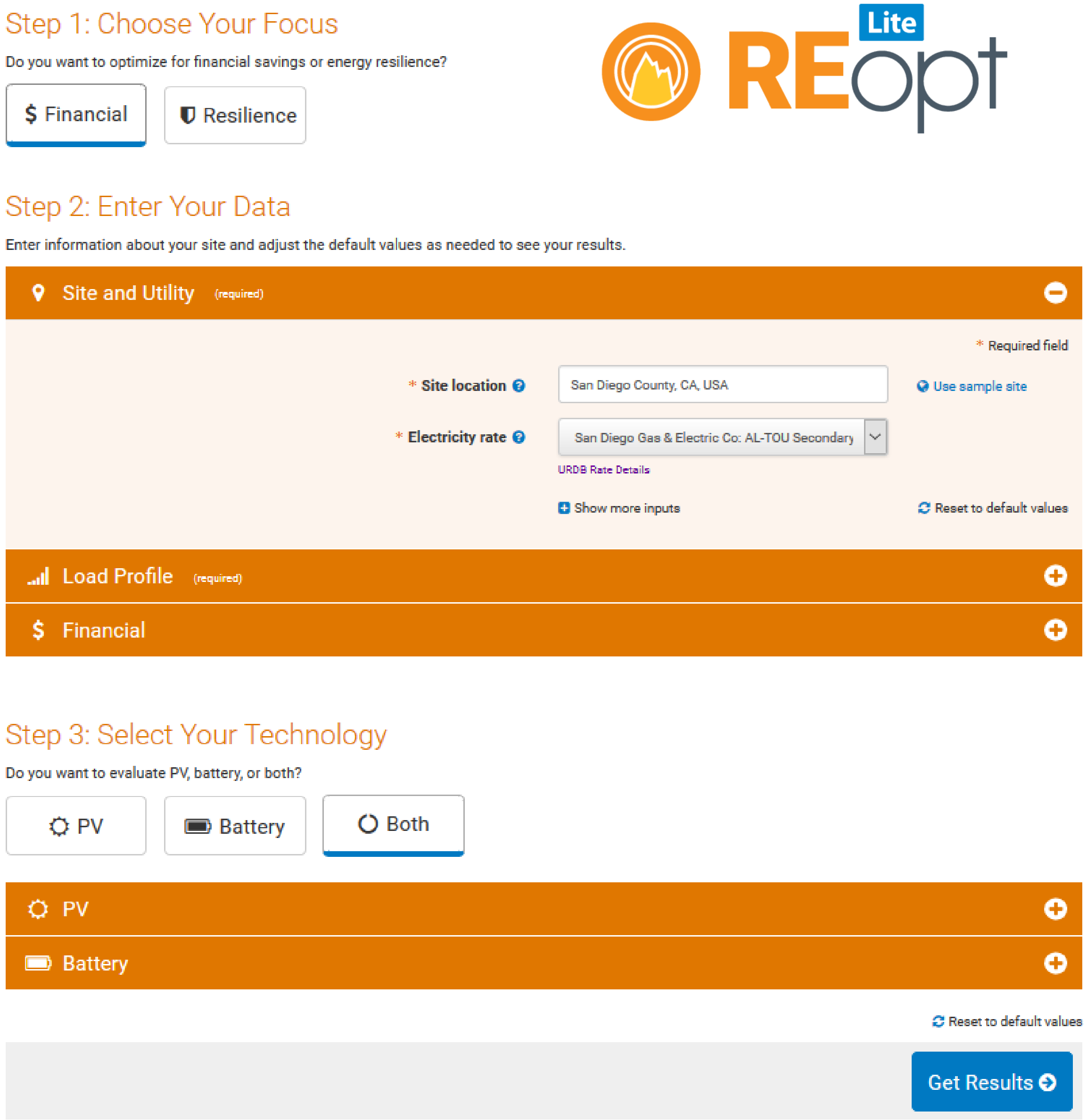
Cost-optimal Operating Strategy



Extending Resiliency with RE

REopt Lite

- The REopt Lite Web Tool offers a no-cost subset of NREL's more comprehensive REopt model
- Beta version of web tool launched September 2017; additional features added through 2018 and beyond
- **Financial mode** optimizes PV and battery system sizes and battery dispatch strategy to minimize life cycle cost of energy
- **Resilience mode** sizes PV+storage systems to sustain critical load during grid outages



Summary Results Include System Sizes and Savings

Results for Your Site

These results from REopt Lite summarize the economic viability of PV and battery storage at your site. You can edit your inputs to see how changes to your energy strategies affect the results.

Edit Inputs

Your recommended solar installation size

781 kW
PV size

Measured in kilowatts (kW) of direct current, this recommended size minimizes the life cycle cost of energy at your site.

Your recommended battery power and capacity

131 kW
battery power

556 kWh
battery capacity

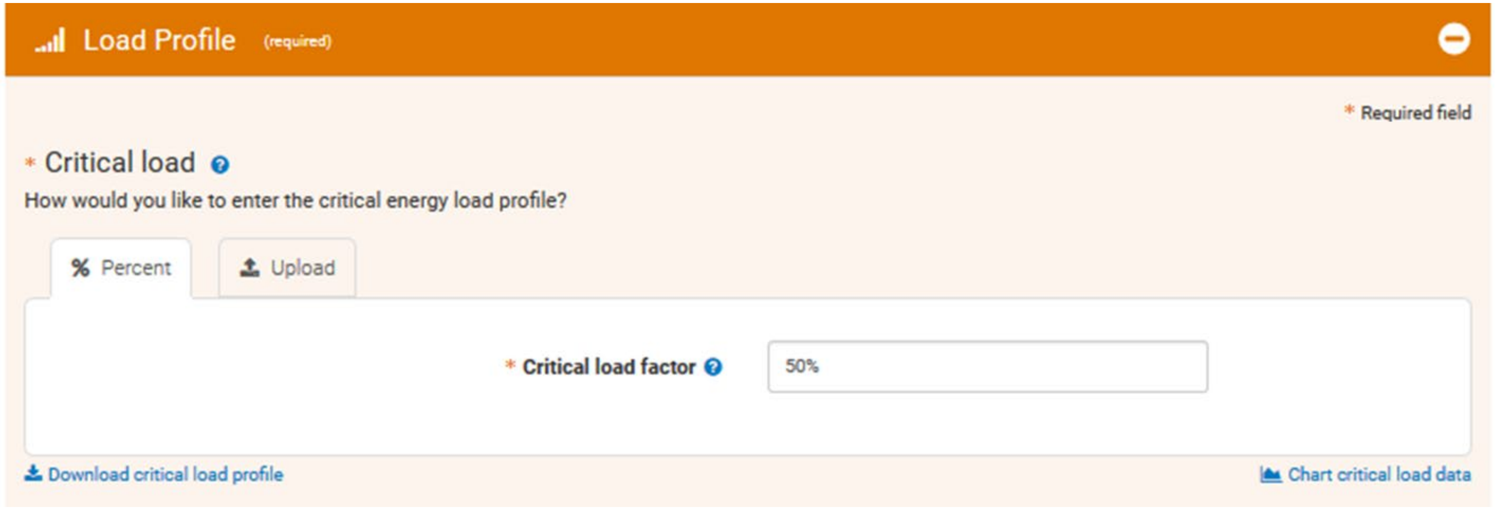
This system size minimizes the life cycle cost of energy at your site. The battery power and capacity are optimized for economic performance.

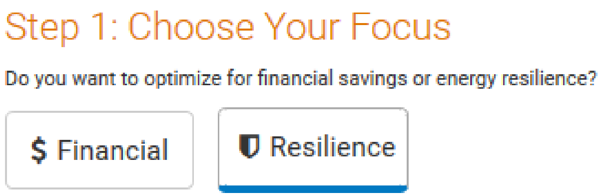
Your potential life cycle savings (20 years)

This is the net present value of the savings (or costs if negative) realized by the project based on the difference between the life cycle energy cost of doing business as usual compared to the optimal case.

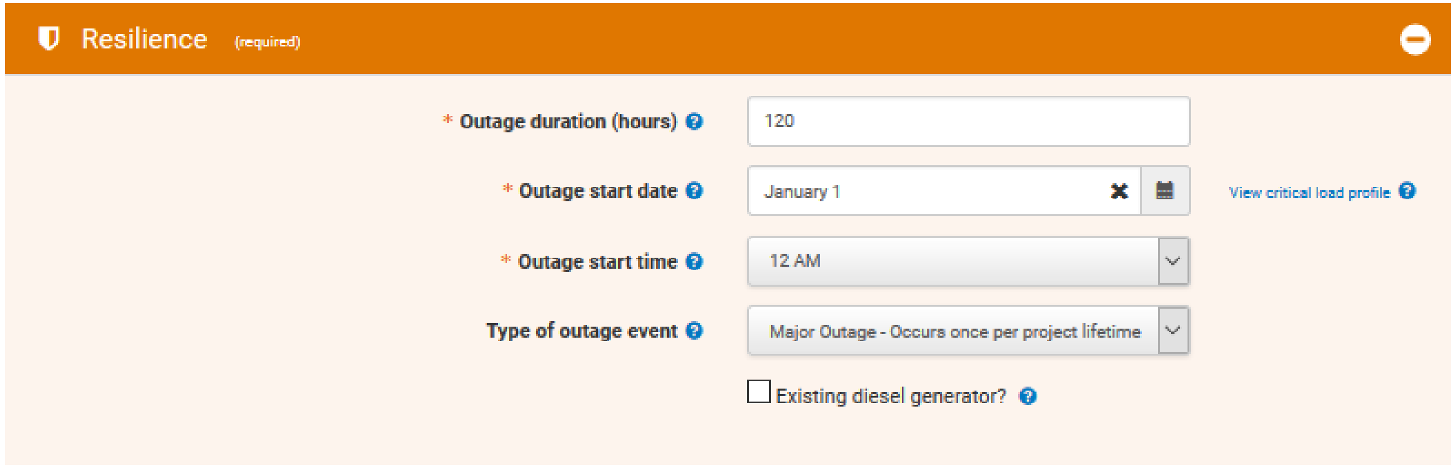
$439,275

Additional Required Site Specific Inputs (Resilience Mode)





CRITICAL load profile – simulated or actual



Outage start, length and reoccurrence

Additional Outputs: Resilience Mode

Resilience vs. Financial Benefits

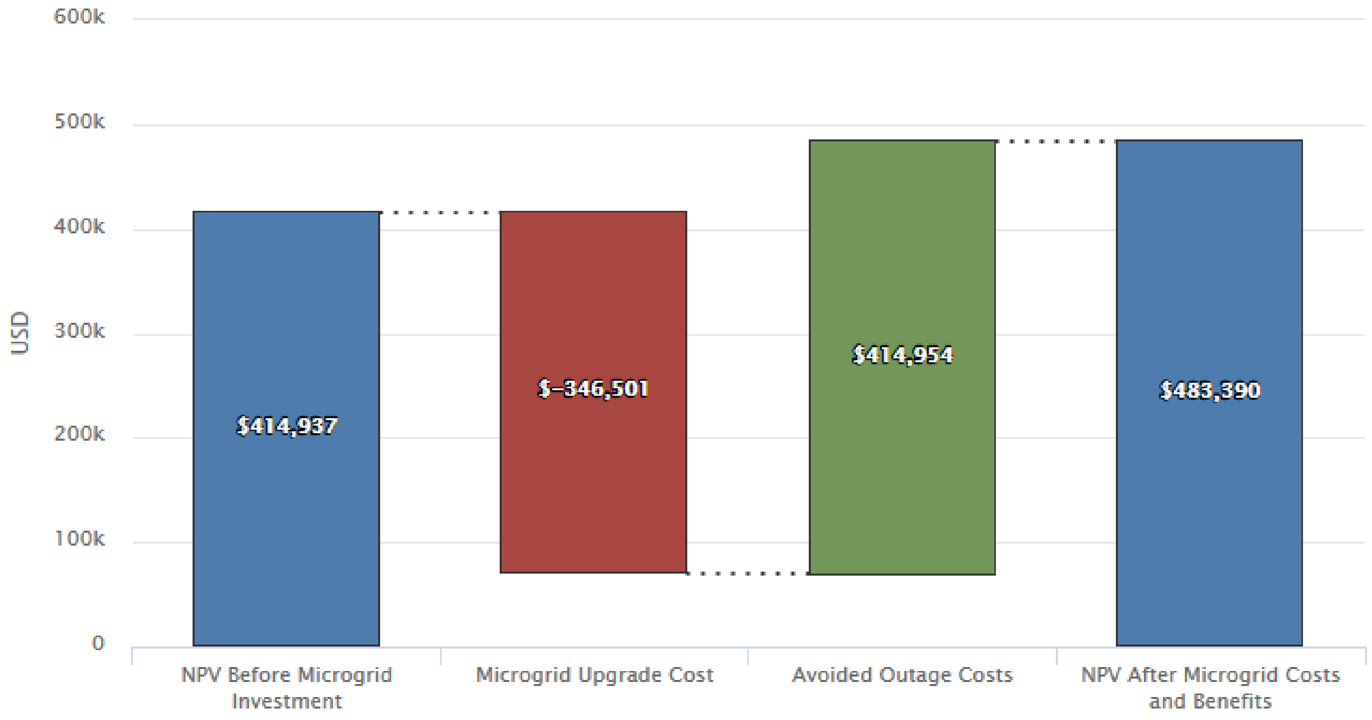
These results provide a high-level comparison between a system designed for resilience and a system designed for financial benefits.

Parameter	Resilience	Financial
PV Size	1,112 kW	781 kW
Battery Power	330 kW	131 kW
Battery Capacity	2,095 kWh	556 kWh
Net Present Value	$235,242	$439,275
Average Resiliency	968 hours	8 hours

Additional Outputs: Resilience Mode

Effect of Resilience Costs and Benefits

This chart shows the cumulative effect of resilience costs and benefits on the project's net present value (NPV). The microgrid upgrade cost and avoided outage costs are not factored into the optimization results



Microgrid Upgrade Cost

25% of system capital cost

Avoided Outage Costs

$100 per kWh

What about the resilient grid?

For Puerto Rico, Leverage NREL developed FESTIV and MAFRIT tools

- FESTIV – Steady-state power system operations model that captures all temporal horizons of scheduling problem from day-ahead operations through automatic generation control
- MAFRIT – Dynamics model that captures operation horizons from automatic generation control through sub-second system transients.

Combining these tools produces a high fidelity system operations model which can be used to study:

- Interaction among the energy and reserve scheduling and system dynamic response
- AGC methodologies and techniques
- Impact of different markets design on system reliability
- Value of short-term resource forecasting (e.g., load, wind, and solar)
- Primary, fast-frequency, inertia response of system during normal operations and contingency events caused by natural disasters

Grid Investment (Capacity Expansion) modeling tools also taking more resiliency issues into account

- Hawaii-specific capacity expansion tool being retooled for Puerto Rico currently.
- ReEDS (CONUS) model being augmented with improved detailed grid-scale storage options
- RPM (regional) being used to look at storage and other issues with Los Angeles goal of 100% RE

Additional Resources on Tools for Resiliency

NREL OpenSource Tools on Github: https://github.com/NREL

- SAM, REOpt-Lite, FESTIV are all here plus 200+ other repositories

REopt Lite web tool: https://reopt.nrel.gov/tool
SAM website: https://sam.nrel.gov

A few examples of other sites and tools:

NREL summary of projects and documents on resilience
https://www.nrel.gov/energy-solutions/resilient-systems.html

Valuing the Resilience Provided by Solar and Battery Energy Storage Systems (Fact Sheet)
https://www.nrel.gov/docs/fy18osti/70679.pdf

International US-AID Resilient Energy Platform
https://www.nrel.gov/usaid-partnership/resilient-energy-platform.html

Thank You!

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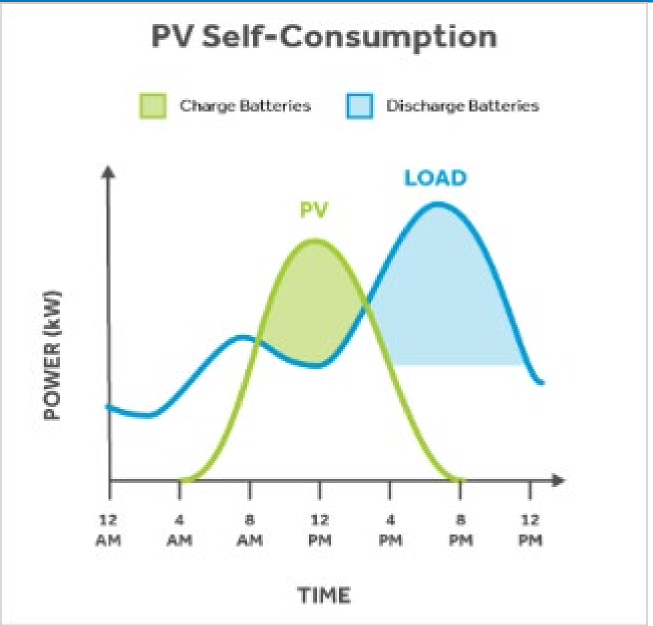
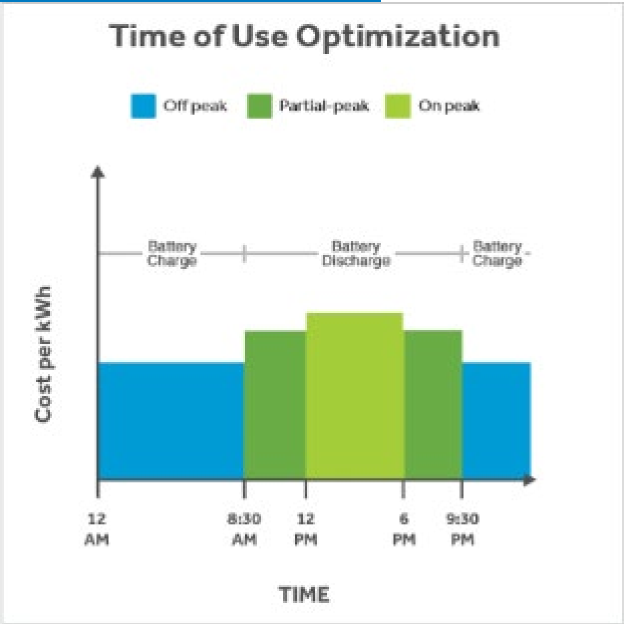
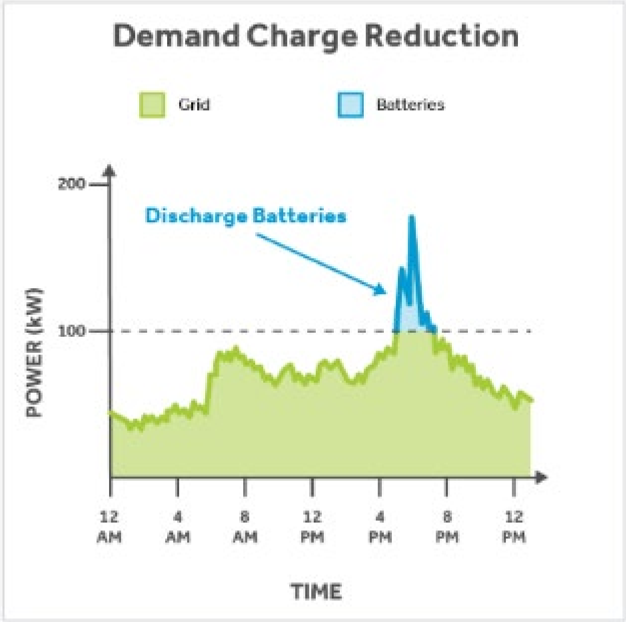
Behind-the-meter storage







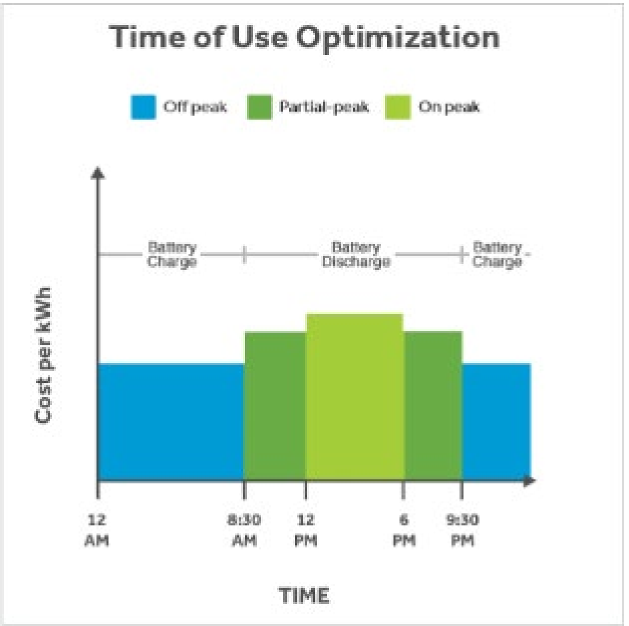
Images from: http://www.aquionenergy.com/

- Batteries charged primarily from PV eligible for Federal ITC subject to 75% cliff
- End of NEM in some states

- Residential and commercial utility rate structures with high TOU charges.
- Charge when rate is low, discharge when rate is high

- Commercial utility structures can have very high TOU demand charges.

Front-of-the-meter storage



Images from: http://www.aquionenergy.com/

- PPA time-of-use optimization for changing PPA sell rates.
- Charge from PV when rate is low, discharge when rate is high

What does SAM not do?

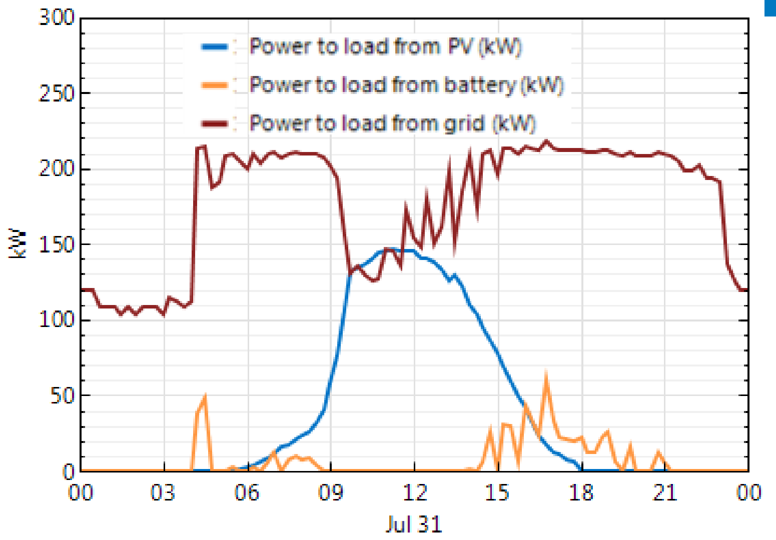
- SAM does not size your equipment – although we are discussing linkages with the Solar water heating professor.
- Batteries not connected to all technologies yet (i.e. onshore wind)

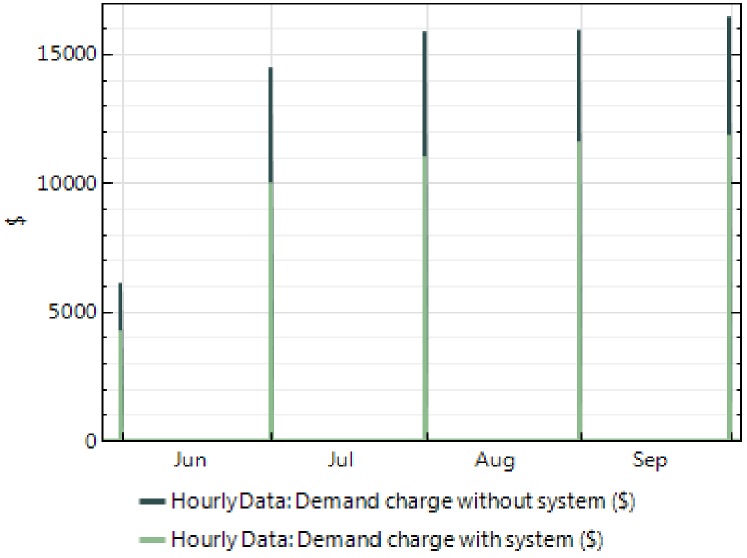
- SAM, at this time, doesn't have any real resiliency metrics (such as serious storms/year) but we anticipate adding them in the future.

- Compared to the other tools, one can examine both the PV system and the batteries in much greater detail.

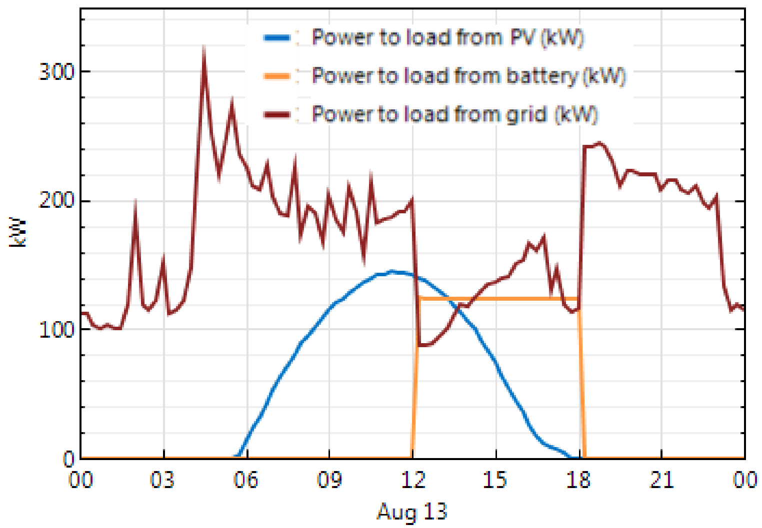
Dispatch Visualization

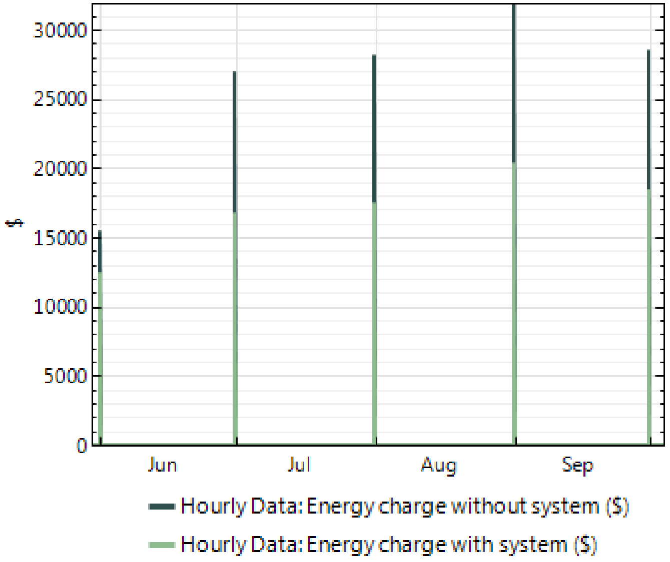
Peak shaving for demand charge reduction





Manual dispatch for energy arbitrage





Example Case Study

- Evaluate economics of installing PV-coupled battery system for demand-charge reduction:
  - Los Angeles, CA
  - 27,625 ft^2 building with 247 kW peak load
  - Southern California Edison TOU-GS-2 Option B

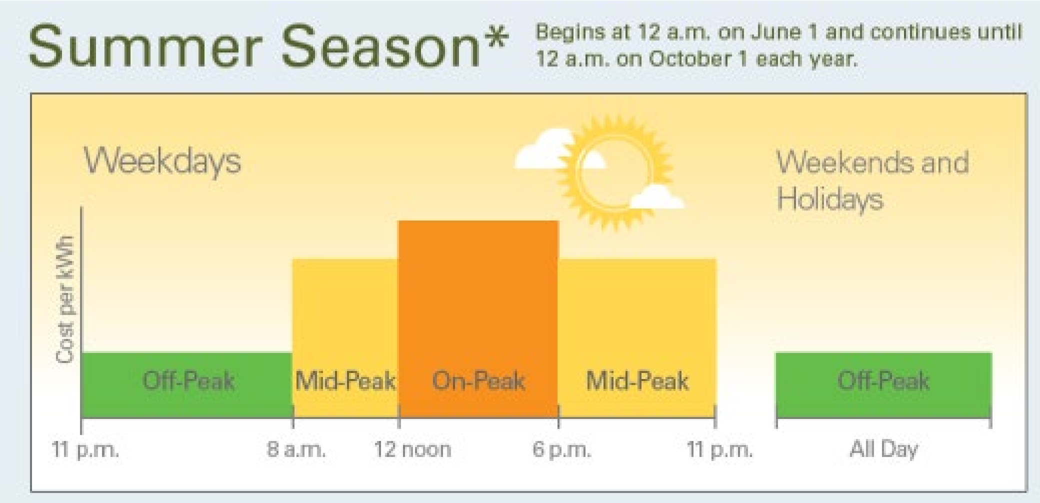
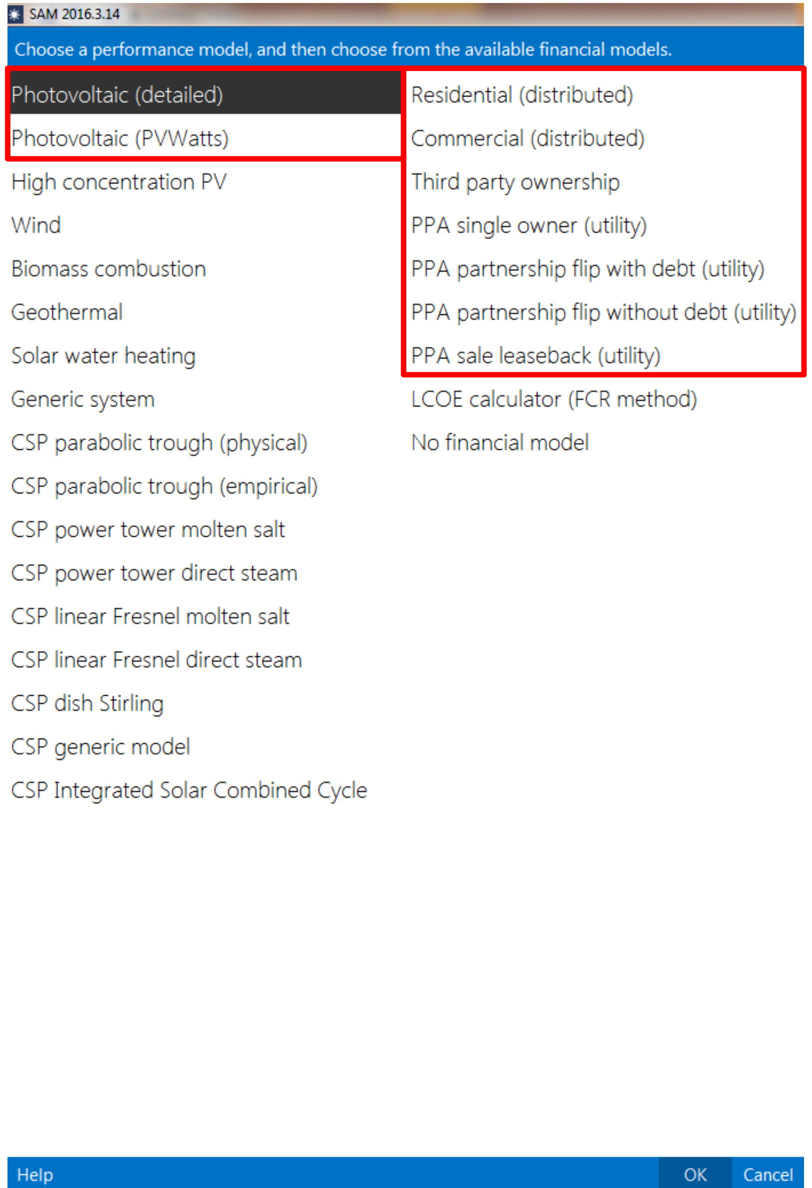


Image from SCE TOU-GS-2 Option B datasheet

Implementation in SAM



Behind the meter models

<u>Residential, Commercial</u>

- Specify electric load
- Specify utility rate structure

<u>Third Party ownership</u>

- From perspective of off-taker (customer)

Front of the meter models (not available with PVWatts)

- Utility scale systems with various ownership structures
- Power purchase agreements specify value of selling power to grid throughout the year

Lithium Ion Battery System

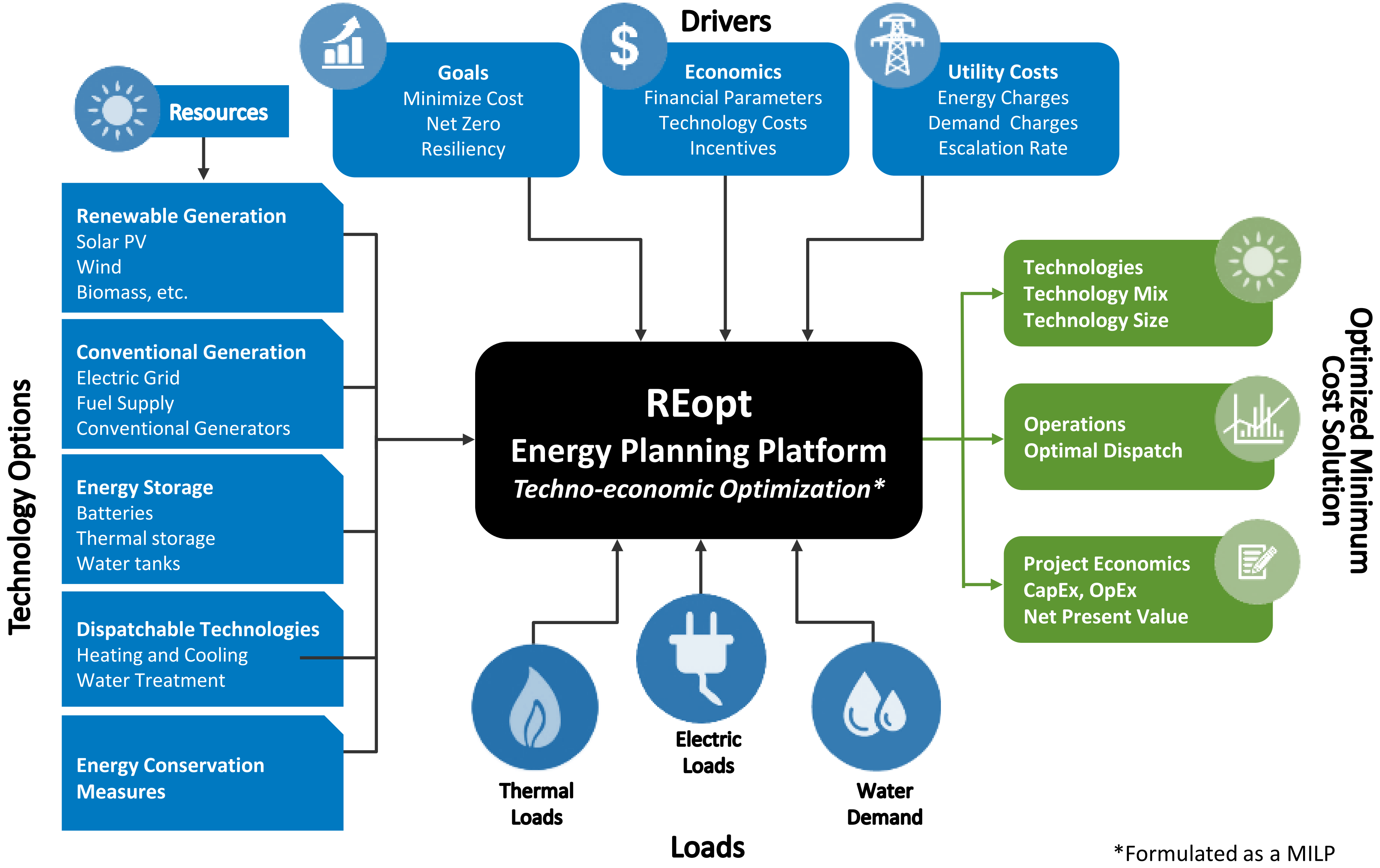
- Model battery similar to Tesla Powerwall
  - Lithium-ion nickel manganese cobalt
  - Assumed can cycle full 7 kWh down to 30% of state-of-charge, for a full capacity of 10 kWh.
  - Price given as ~$300/kWh before balance of system costs.
  - Assumed lifetime of 10-15 years before degrading to 70% of original capacity

Table 3: Tesla Powerwall Specifications [13]

Property	Value
Price	$3000
Capacity	7 kWh
Power	2.0 kW continuous, 3.3 kW peak
Efficiency	92%
Voltage	350 – 450 V
Current	5.8 A nominal, 8.6 A peak
Weight	100 kg
Dimensions	1300 mm x 860 mm x 180 mm

Image from teslamotors.com/powerwall

REopt Platform Inputs and Output



*Formulated as a MILP

Will PV + Storage Work for Your Site?

Technology Costs

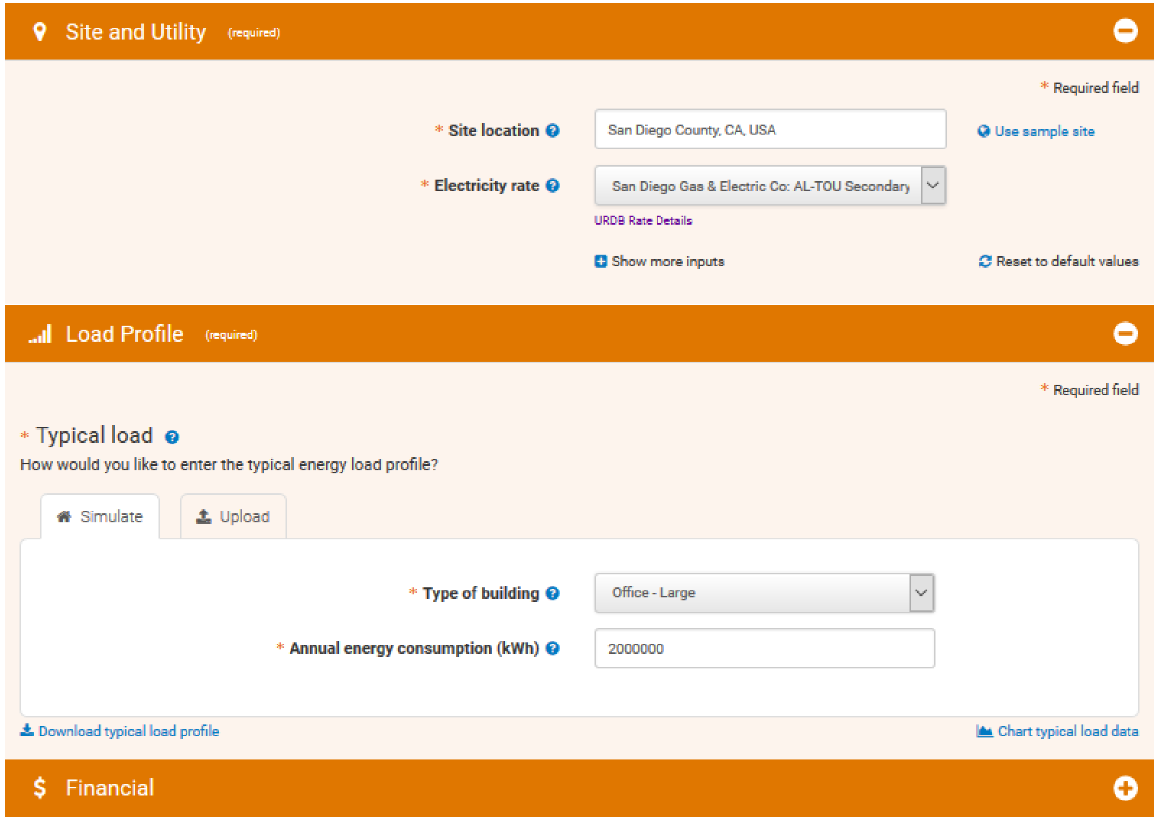
Resource Magnitude

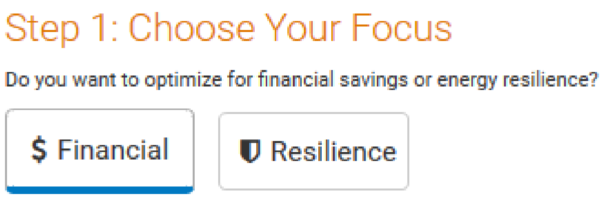
Utility Cost & Consumption

Incentives & Policies

Resilience Goals

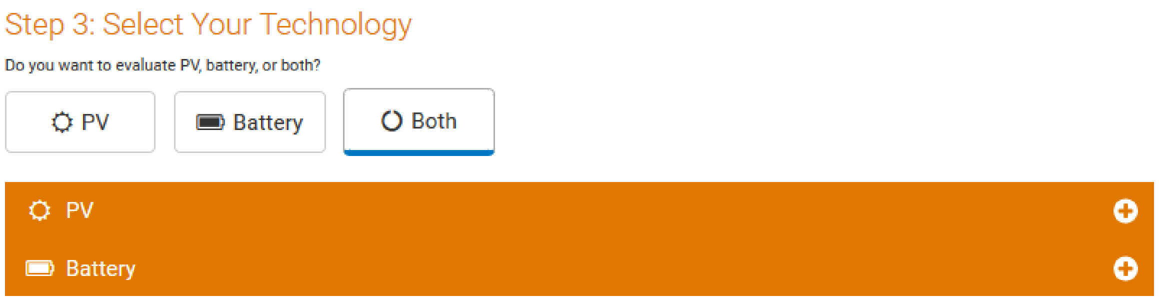
Required Site Specific Inputs (Financial Mode)





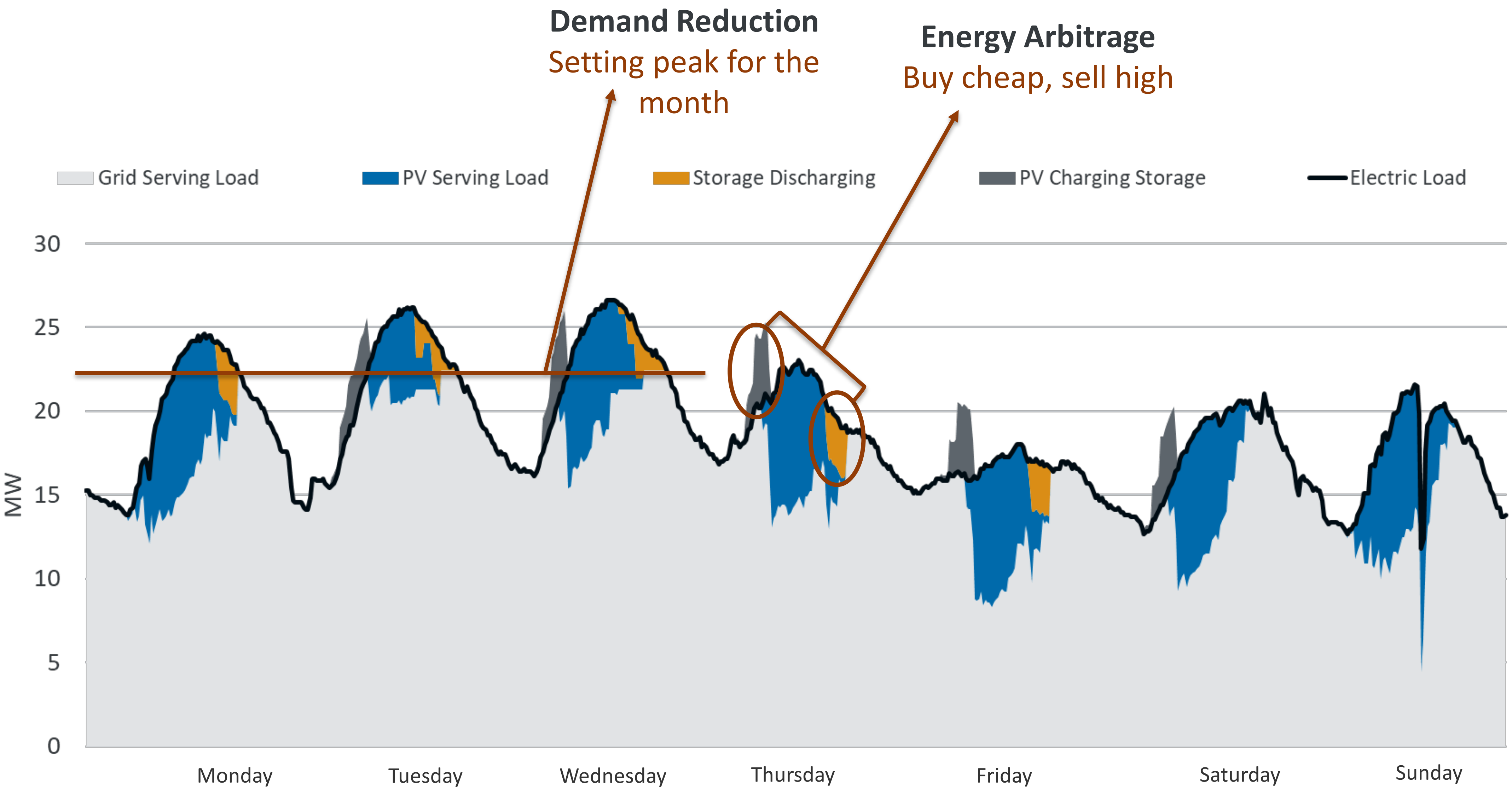
Location and utility rate

Load profile – simulated or actual



Technologies to evaluate

PV and Storage for Demand Reduction and Energy Arbitrage



Additional Results Output: Economics Summary

	Business As Usual	Optimal Case	Difference
System Size, Energy Production, and System Cost			
PV Size	0 kW	392 kW	392 kW
Annualized PV Energy Production	0 kWh	680,826 kWh	680,826 kWh
Battery Power	0 kW	93 kW	93 kW
Battery Capacity	0 kWh	342 kWh	342 kWh
DG System Cost (Net CAPEX + O&M)	$0	$526,342	$526,342
Energy Supplied From Grid in Year 1	1,000,000 kWh	358,623 kWh	641,377 kWh
Year 1 Utility Cost — Before Tax			
Utility Energy Cost	$118,263	$34,216	$84,047
Utility Demand Cost	$40,008	$18,623	$21,385
Utility Fixed Cost	$3,110	$3,110	$0
Utility Minimum Cost Adder	$0	$0	$0
Life Cycle Utility Cost — After Tax			
Utility Energy Cost	$857,868	$248,200	$609,668
Utility Demand Cost	$290,213	$135,089	$155,124
Utility Fixed Cost	$22,562	$22,562	$0
Utility Minimum Cost Adder	$0	$0	$0
Total System and Life Cycle Utility Cost — After Tax			
Life Cycle Energy Cost	$1,170,644	$932,194	$238,450
Net Present Value	$0	$238,450	$238,450

Download ProForma Spreadsheet

Additional Results Output: Hourly Dispatch Graph

Resources

- REopt website: https://reopt.nrel.gov/
- REopt Lite web tool: https://reopt.nrel.gov/tool
- REopt technical report: https://www.nrel.gov/docs/fy17osti/70022.pdf
- REopt fact sheet: http://www.nrel.gov/docs/fy14osti/62320.pdf