

NREL Publicly Available Tools for Resiliency and Hybrid Systems

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PV Modeling Workshop, Sandia 2019

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, utilityscale.
- 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

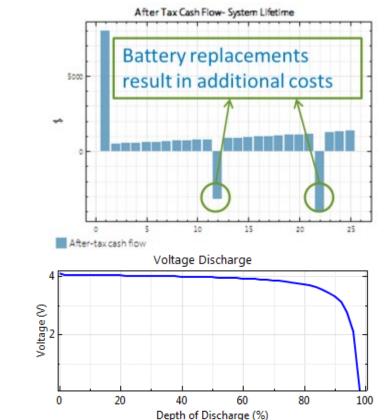
> REOpt-Lite REOpt Battery Modeling Resiliency Metrics

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

PVWatts, Commercial	Curtan Dana dana						
ocation and Resource	-System Parameters System na	ameplate size	199.752	kWdc			
ystem Design	-	Module type]	•		
		OC to AC ratio	1.2]			
ystem Costs	Rateo	d inverter size	166.46	kWac			
ifetime	Inver	rter efficiency	96	%			
inancial Parameters	Orientation						
ncentives		Tilt	A	rray type	Fixed open rac	k	•
lectricity Rates	N=0	90 • /ert.		Tilt	2	degrees	
	W E 90	Horiz.		Azimuth	18) degrees	
lectric Load	S 180		Ground cover	age ratio	0.	1	
	Losses						
						0.5	1
	Soiling		2 % 3 % Light-ind		inections	0.5	
	Snow		/ % Light-ind	duced deg	ameplate		%
	Mismatch		2 %		Age		%
	Wiring	2	2 %	Av	/ailability	3	%
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			1	otal syste	em losses	14.08	%
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	system outages or other ev				om periods: No		
	Battery Bank						
	Enable battery	100					
	Battery capacity				try Lithium Ior		▼
	Battery power	30 k	vv Batt	ery dispat	ch Peak Shavi	ig (look ah	ead) 🔻

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.

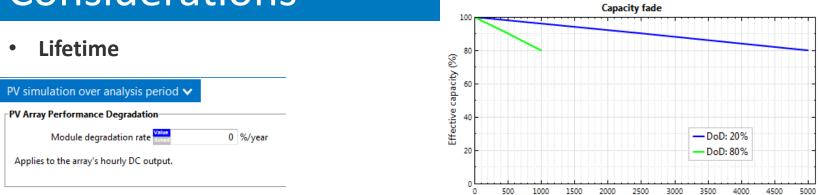
Detailed Battery Model (with Detailed PV Model)

* SAM 2016.3.14	Conceptual Name Annual N	-				
File 🗸 🕂 Add Comm	ercial Battery 🗸					
Photovoltaic, Commercial	Enable Battery 🗸					
Location and Resource	Battery Bank Sizing					
Module	Specify desired bank	size		0	Specify cells	
Inverter	Desired bank capaci	ty	3 kWh	Numb	er of cells in se	ries
System Design	Desired bank volta	ge	12 V	Number of	f strings in para	llel
, ,	Chemistry					
Shading and Snow	Battery type Lithiu	ım Ion: Nickel N	/langanes	e Cobalt Oxide ((NMC)	
Losses	Voltage Properties					
Lifetime	Cell nominal vol	tage 3.6	V	Internal re	esistance	0.1 Ohm
Battery Storage	с	-rate of discharg	ge curve	0.2]	
System Costs	Fu	ully charged cell	voltage	4.1	V	
Financial Parameters		nential zone cell	-	4.05		
		minal zone cell	-	3.4		
Incentives	-	/ed at exponent noved at nomir		88.9		
Electricity Rates		noved at norm			78	
Electric Load	Current and Capacity Cell capacity	2.25	Ah	Max C-	rate of charge	
					e of discharge	
	-Computed Properties					
	Nominal bank capacity	3.0132	kWh	Ma	ximum power	3.0
	Nominal bank voltage	14.4	v		ximum power	
	Cells in series	4			harge current	20
	Strings in parallel	93		Maximum disc	harge current:	20
	- Power Converters					
	AC to DC conversi	on efficiency		99 %		

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



Cycle number

Battery capacity fades with cycling, depends on depthof-discharge

• System Costs

Direct Capit	al 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	

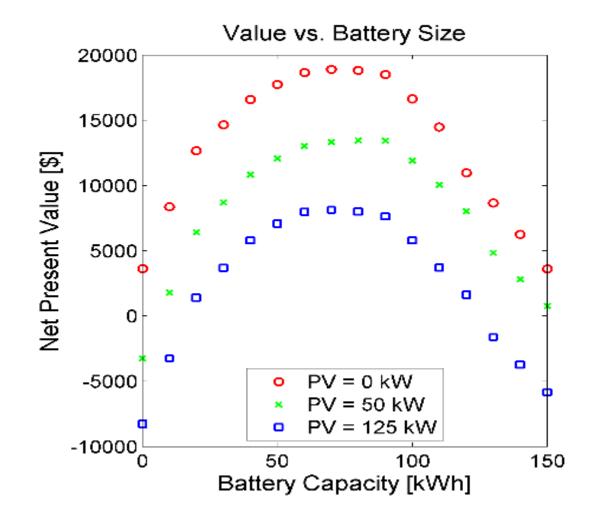
• Battery Bank Replacement (Battery Storage page)

Battery Bank Replacement		
battery bank Replacement		
No replacements	Battery bar	ik replacement threshold 20 % capacity
Replace at specified capacity		
	Battery ba	nk replacement schedule Edit data
Replace at specified schedule		
		SAM applies both inflation and escalation to the first year cost to calculate
Battery bank replacement cost	600 \$/kWh	out-year costs. See Help for details.
	0.0%	,
Battery cost escalation above inflation	0 % %/year	

Battery Dispatch

-Choose D	spatch	Mo	lel-								- C	harg	je l	imi	ts a	ndl	Prio	rity	—								_	-	Aut	om	ate	d Gr	id Po	owe	r T	arge	et M	lode	el—				
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-Manual Di	spatch	Mo	lel-																																								
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Parametric sizing results



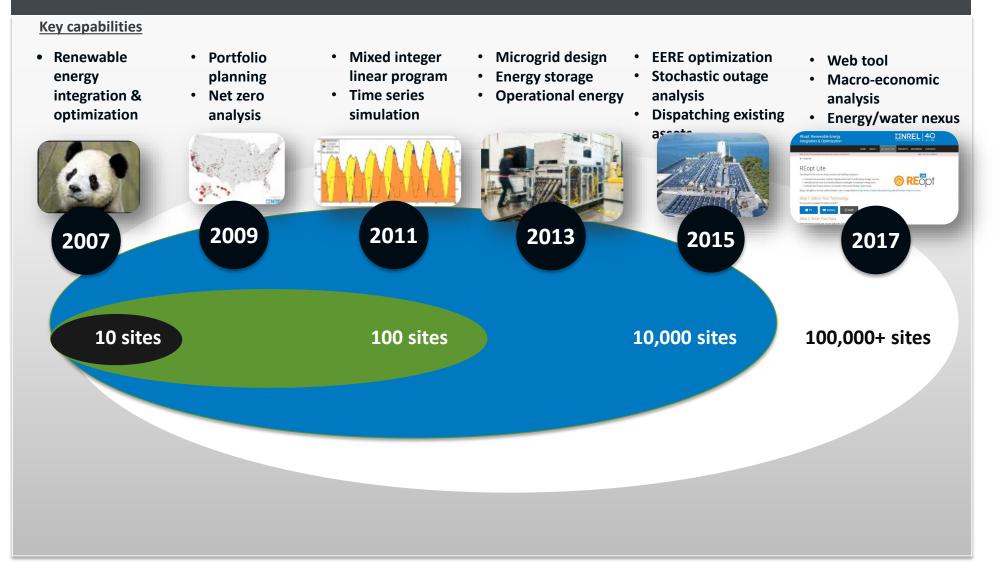
- NPV maximized for no PV system, battery bank capacity of 70 kWh
- Illustrates simulationbased method to approximate 'optimal' sizing.

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



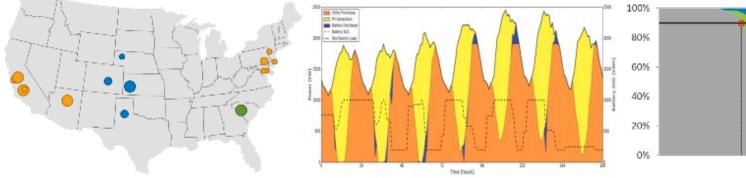
REopt Platform: Decision Support through the Energy Planning Process

Optimization • Integration • Automation



- Portfolio prioritization
- Cost to meet goals

- Technology types & sizes
- Optimal operating strategies
- 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

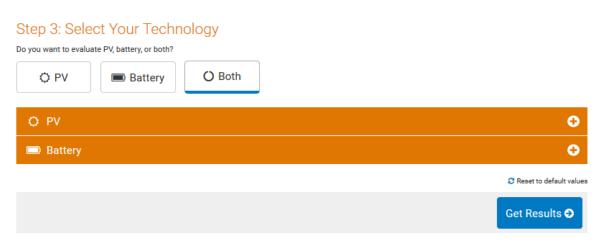




Step 2: Enter Your Data

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

Site and Utility (required)		Θ
* Site location 😧 * Electricity rate 😧	San Diego County, CA, USA San Diego Gas & Electric Co: AL-TOU Secondary V URDB Rate Details	* Required field
	Show more inputs	C Reset to default values
I Load Profile (required)		•
\$ Financial		•



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.

G 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.

(

Ø

Your recommended battery opwer 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

2

Additional Required Site Specific Inputs (Resilience Mode)

Load Profile (required)		0	· · · · · · · · · · · · · · · · · · ·	se Your Focus
* Critical load How would you like to enter the critical energy load profile? % Percent Lupload		* Required field		The for financial savings or energy resilience?
* Critical load factor 🥹	50%]		- simulated or actual
2 Download critical load profile		📥 Chart critical load data		
		•		
* Outage duration (hours) 😵	120			Outage start longth
* Outage start date 🥹	January 1 🗶 🗮	View critical load profile 🔞	4	Outage start, length and reoccurrence
* Outage start time 😵	12 AM 🗸			
Type of outage event 😵	Major Outage - Occurs once per project lifetime			
	Existing diesel generator? 😮			

Resilience vs. Financial Benefits

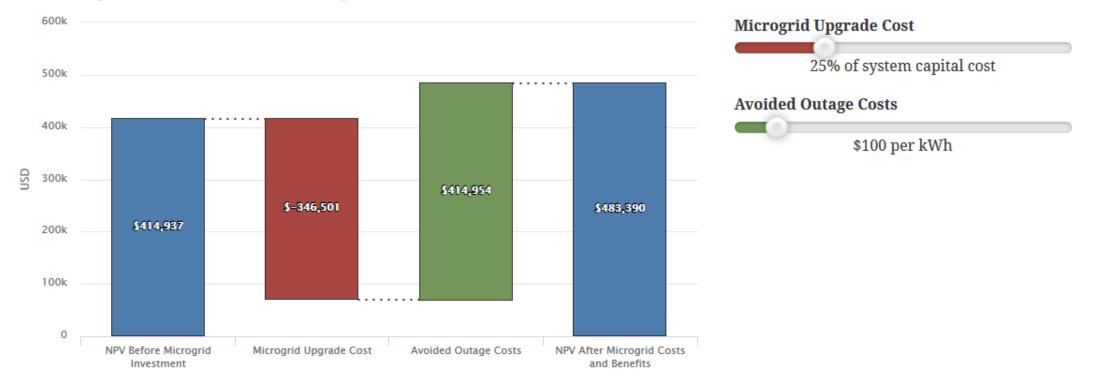
These results provide a high-level comparison between a system designed for resilience and a system designed for financial benefits.

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



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 <u>high fidelity system operations model</u> 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: <u>https://reopt.nrel.gov/tool</u> SAM website: <u>https://sam.nrel.gov</u>

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) <u>https://www.nrel.gov/docs/fy18osti/70679.pdf</u>

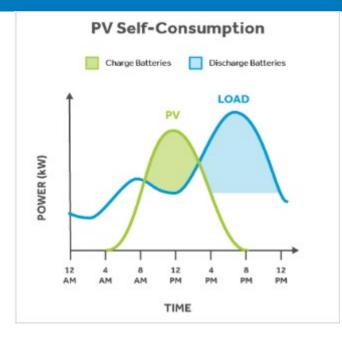
International US-AID Resilient Energy Platform <u>https://www.nrel.gov/usaid-partnership/resilient-energy-platform.html</u> Thank You! Nate Blair, NREL Nate.blair@nrel.gov

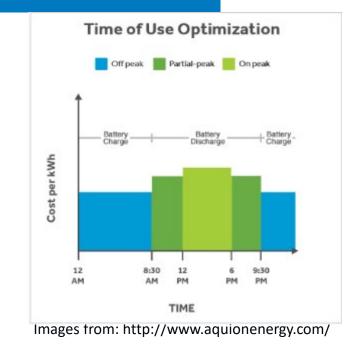
www.nrel.gov

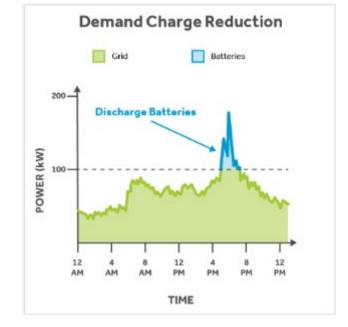
This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Federal Energy Management Program. The views expressed in the presentation do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the presentation for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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Behind-the-meter storage







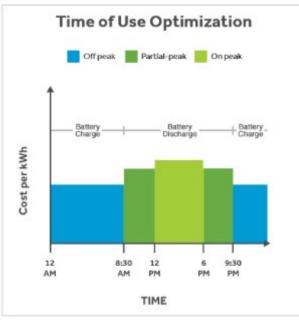
- Batteries charged primarily from PV eligible for Federal ITC subject to 75% cliff
- End of NEM in some states

- 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/



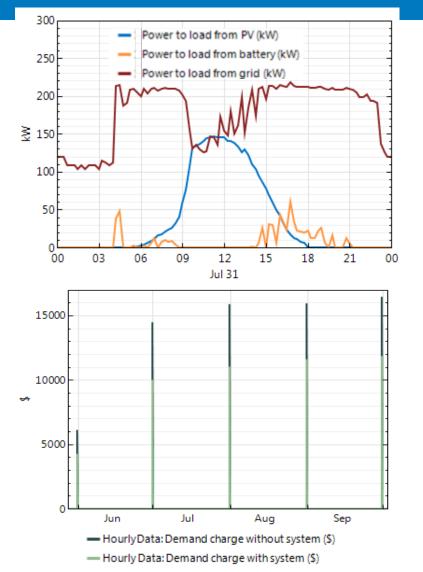
- PPA time-of-use optimization for changing PPA sell rates.
- Charge from PV when rate is low, discharge when rate is high

What does SAM not do?

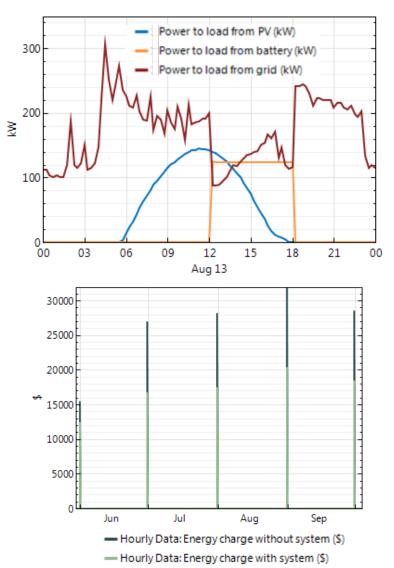
- SAM does not size your equipment although we are discussing linkages with the Solar water heating professor.
- Batteries not connected to all technologies yet (i.e. onshore wind)
- SAM, at this time, doesn't have any real resiliency metrics (such as serious storms/year) but we anticipate adding them 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 ft² 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

Choose a performance model, and then choose	from the available financial models.
Photovoltaic (detailed)	Residential (distributed)
Photovoltaic (PVWatts)	Commercial (distributed)
High concentration PV	Third party ownership
Wind	PPA single owner (utility)
Biomass combustion	PPA partnership flip with debt (utility)
Geothermal	PPA partnership flip without debt (utility)
Solar water heating	PPA sale leaseback (utility)
Generic system	LCOE calculator (FCR method)
CSP parabolic trough (physical)	No financial model
CSP parabolic trough (empirical)	
CSP power tower molten salt	
CSP power tower direct steam	
CSP linear Fresnel molten salt	
CSP linear Fresnel direct steam	
CSP dish Stirling	
CSP generic model	
CSP Integrated Solar Combined Cycle	

Behind the meter models

Residential, Commercial

- Specify electric load
- Specify utility rate structure

Third Party ownership

• 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

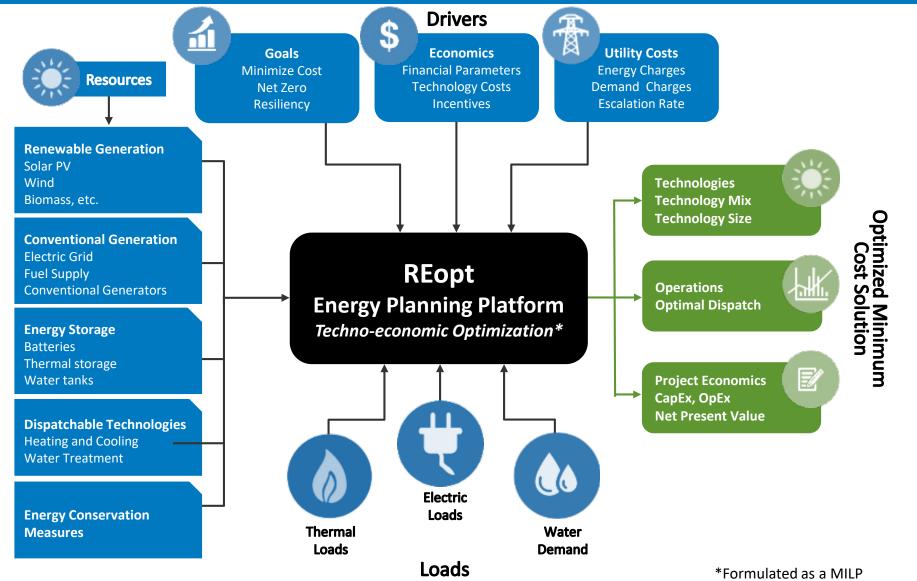
Table 3: Tesla Powerwall Specifications [13]

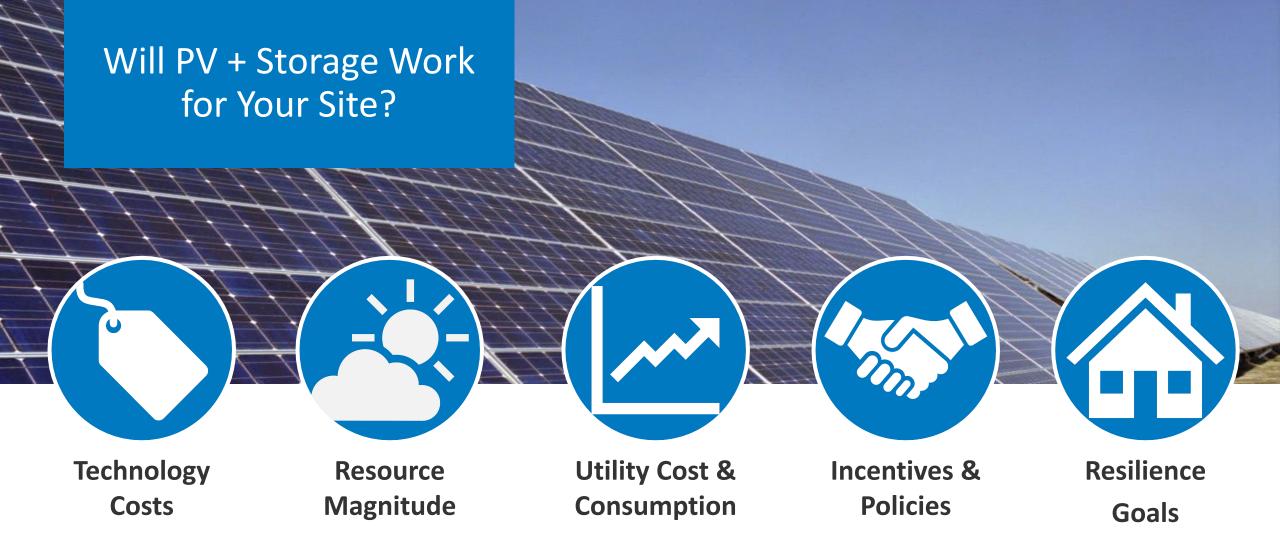
Property	Value
Price	\$3000
Capacity	7 kWh
Power	2.0 kW continuous, 3.3 kW peak
Efficiency	92%
Voltage	350 – 450 V
Current	5.8 A nominal, 8.6 A peak
Weight	100 kg
Dimensions	1300 mm x 860 mm x 180 mm



Image from teslamotors.com/powerwall

REopt Platform Inputs and Output

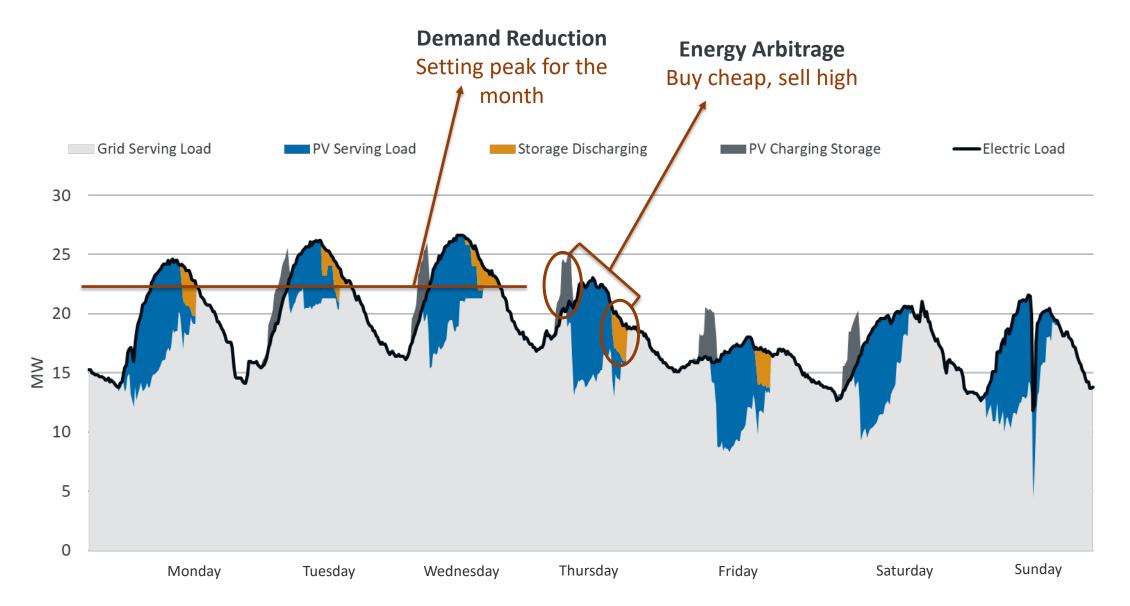




Required Site Specific Inputs (Financial Mode)

 Site and Utility (required) * Site location * Electricity rate 	San Diego County, CA, USA San Diego Gas & Electric Co: AL-TOU Secondary V URDB Rate Details	 Required field Use sample site Reset to default values 	Step 1: Choose Your Focus Do you want to optimize for financial savings or energy res Financial Resilience	Location and utility
I Load Profile (required)		• Required field		rate
 * Typical load How would you like to enter the typical energy load profile? 		, kednied lied		
* Type of building @ * Annual energy consumption (kWh) @	Office - Large		4	Load profile – simulated or actual
Download typical load profile Financial		🗠 Chart typical load data		
Step 3: Select Your Technology Do you want to evaluate PV, battery, or both? PV Battery O Both PV Battery Battery		○	4	Technologies to evaluate

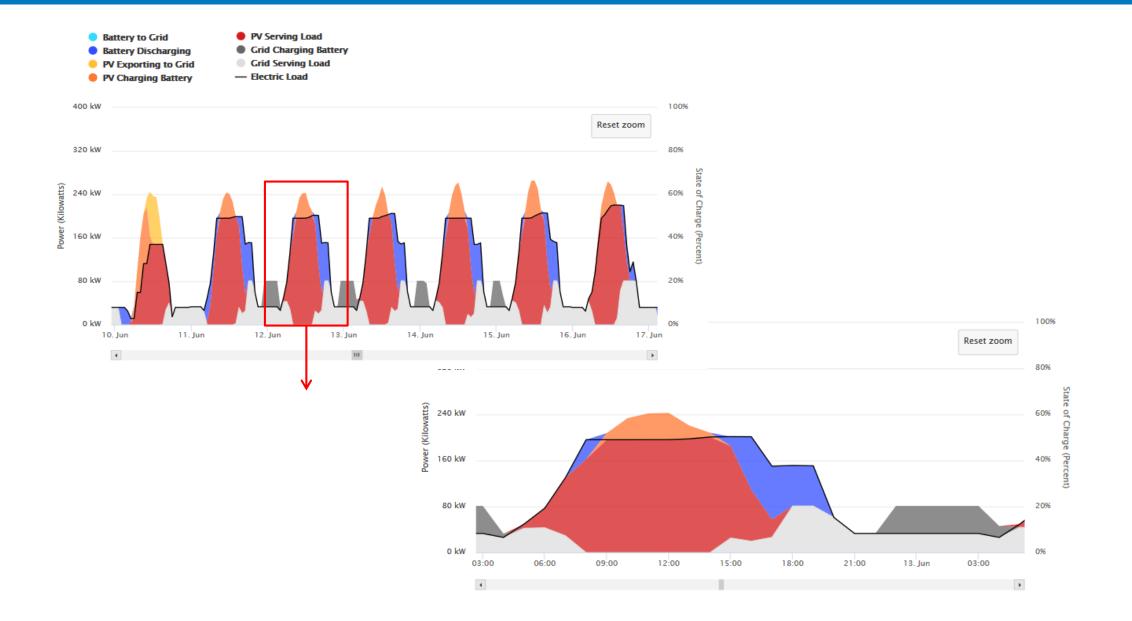
PV and Storage for Demand Reduction and Energy Arbitrage



Additional Results Output: Economics Summary

	Business As Usual 😧	Optimal Case 🧿	Difference 🛛
System Size, Energy Production	on, 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 Uti	lity Cost — After Tax		
Life Cycle Energy Cost 💡	\$1,170,644	\$932,194	\$238,450
Net Present Value 💡	\$0	\$238,450	\$238,450

Additional Results Output: Hourly Dispatch Graph



Resources

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