Energy Exchange[SM]

Connect • Collaborate • Conserve
An educated approach to resiliency

U.S. Department of Energy Federal Energy Management Program

Energy Storage Economics

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Overview

- Market Overview
- Battery Basics
- Value Streams
- Challenges
- Behind-the-meter (BTM) Economics

Types of Energy Storage

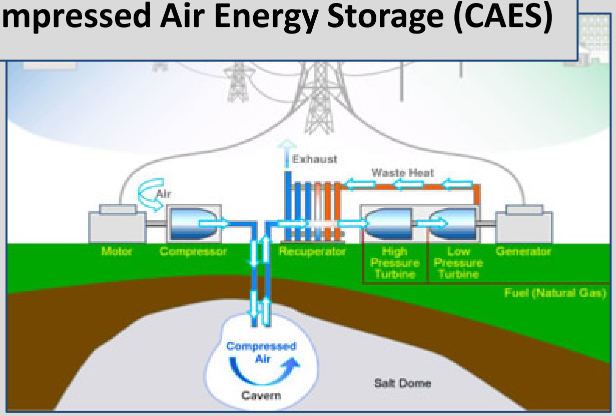
Bulk Storage

Good: Cost, large capacity

Bad: Siting, lead time

Pumped Hydro Storage (PHS)

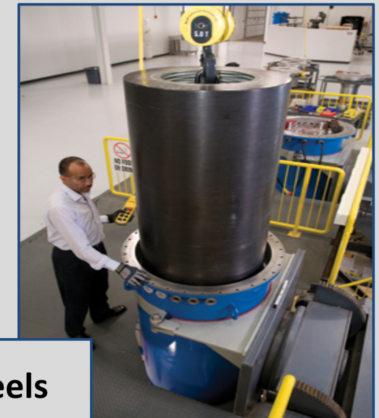
Compressed Air Energy Storage (CAES)



Distributed Storage

Good: Siting, lead time, use options

Bad: Cost



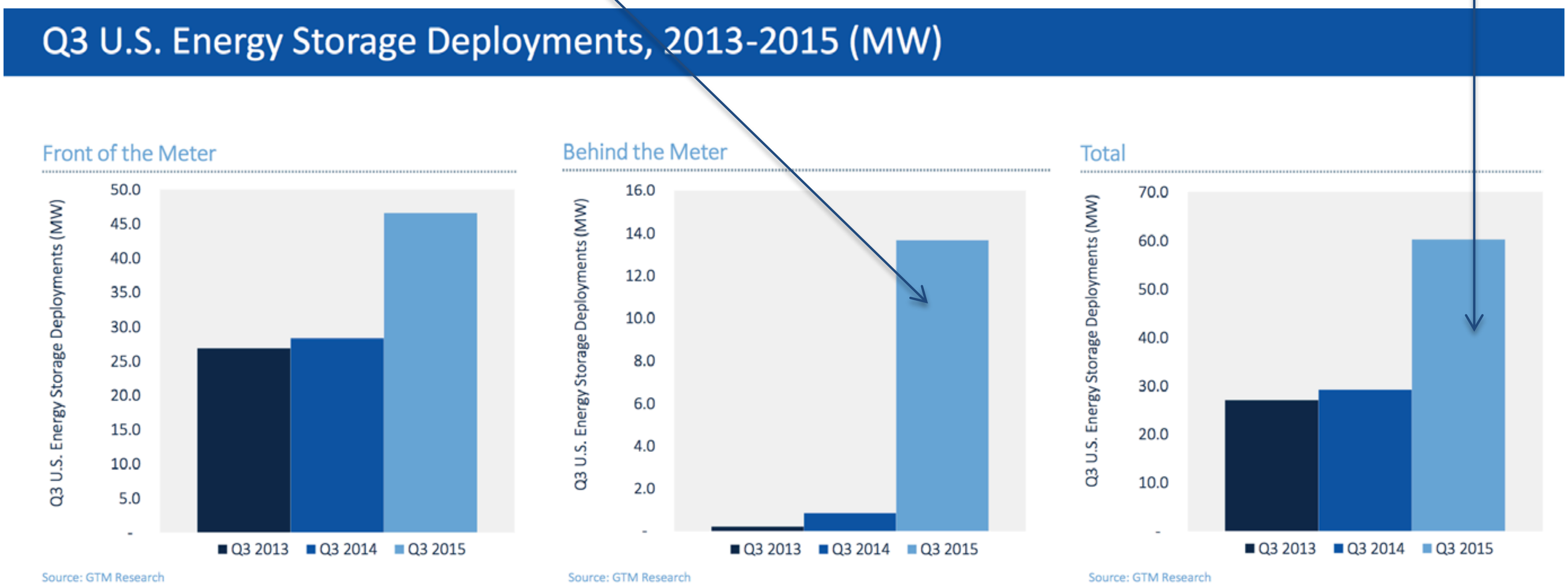
Flywheels

Batteries:
Flow
Lead Acid
Sodium Beta
Lithium Ion

Energy Storage Market Growth

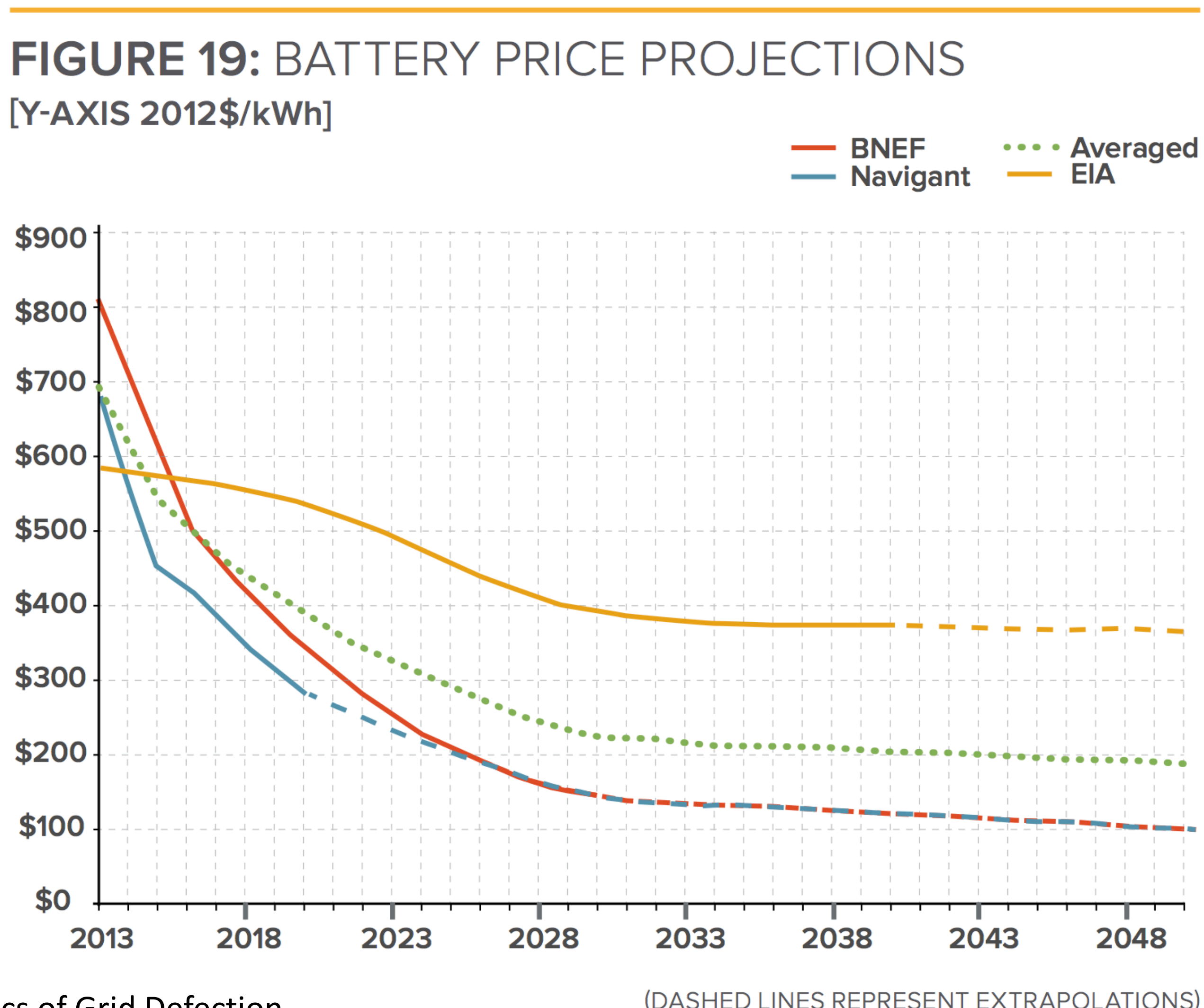
Huge growth in Behind-the Meter Storage

60 MW Storage Deployed in 2015



GTM (2015) Energy Storage Monitor

Sharp Decrease in Battery Price Projections



RMI (2014) Economics of Grid Defection

Power vs. Energy Capacity

- Power : Energy ratio is primary specification for battery
  - Can generally specify the power : energy ratio
- Power
  - How fast you can charge or discharge the battery
  - Measured in kW or MW
- Energy Capacity
  - How much energy you have available
  - Measured in kWh or MWh
- Common configurations
  - 1 MW : 3 MWh (C/3)
  - 4 MW : 2 MWh (2C)
- Optimal configuration depends on application
  - Which of these buckets is more useful?

Value Streams for Storage

Opportunities for income and to avoid costs/losses

Service	Description	Potential Value	Grid	Commercial	Residential
Demand charge reduction	Use stored energy to reduce demand charges on utility bills	H		✔	✔
Energy arbitrage	Buying energy in off-peak hours, consuming during peak hours	H		✔	✔
Demand response	Utility programs that pay customers to lower demand during system peaks	H		✔	✔
Resiliency / Back-up power	Using battery to sustain a critical load during grid outages	H	✔	✔	✔
Frequency regulation	Stabilize frequency on moment-to-moment basis	H	✔	✔	
Capacity markets	Supply spinning, non-spinning reserves	M	✔	✔	
Voltage support	Insert or absorb reactive power to maintain voltage ranges on distribution or transmission system	L	✔		
T&D Upgrade Deferral	Deferring the need for transmission or distribution system upgrades, e.g. via system peak shaving	Site specific	✔		

Balancing multiple uses

- Every battery system can be employed for multiple use-cases. Each use may only require a few hours per year or a few minutes per day. This allows system operators to tap multiple value streams.

- Discharging the battery for one purpose may prohibit its use for another purpose, until it is recharged. This means that uses must be prioritized in order to maximize return on investment.

- A battery that is discharged to provide demand charge reduction may not be at full capacity to serve critical load, in the event of a grid outage.

- In addition, battery cycling (charging and discharging) produces wear and tear and shortens the lifetime of the battery. System operators must determine whether the value obtained from cycling the battery outweighs the cost of battery degradation.

Challenges

- No standard assumptions regarding:
  - Use-case/Project design
  - Temperature
  - Charge-discharge rate
  - Assumed battery end of life (EOL)
- Lack of ancillary service markets/inability to tap all potential value streams
  - Need for service aggregators and clear market rules
- Need to identify optimal system configurations for various use-cases
- Interconnection processes not defined
- Lack of incentive to track and share cost and performance data
- Inability to quantify and monetize the value of resiliency

PV vs. Batteries

- PV is simple
  - Put it on the roof
  - The sun shines
  - Electricity is produced
  - Your utility bill is lowered
- Batteries are complicated
  - Put one in the basement or in a shed
  - Nothing happens
- Batteries can usually only do one thing at a time
  - To maximize Return on Investment (ROI), must determine how to operate the battery

Energy Storage Economics in a Nutshell

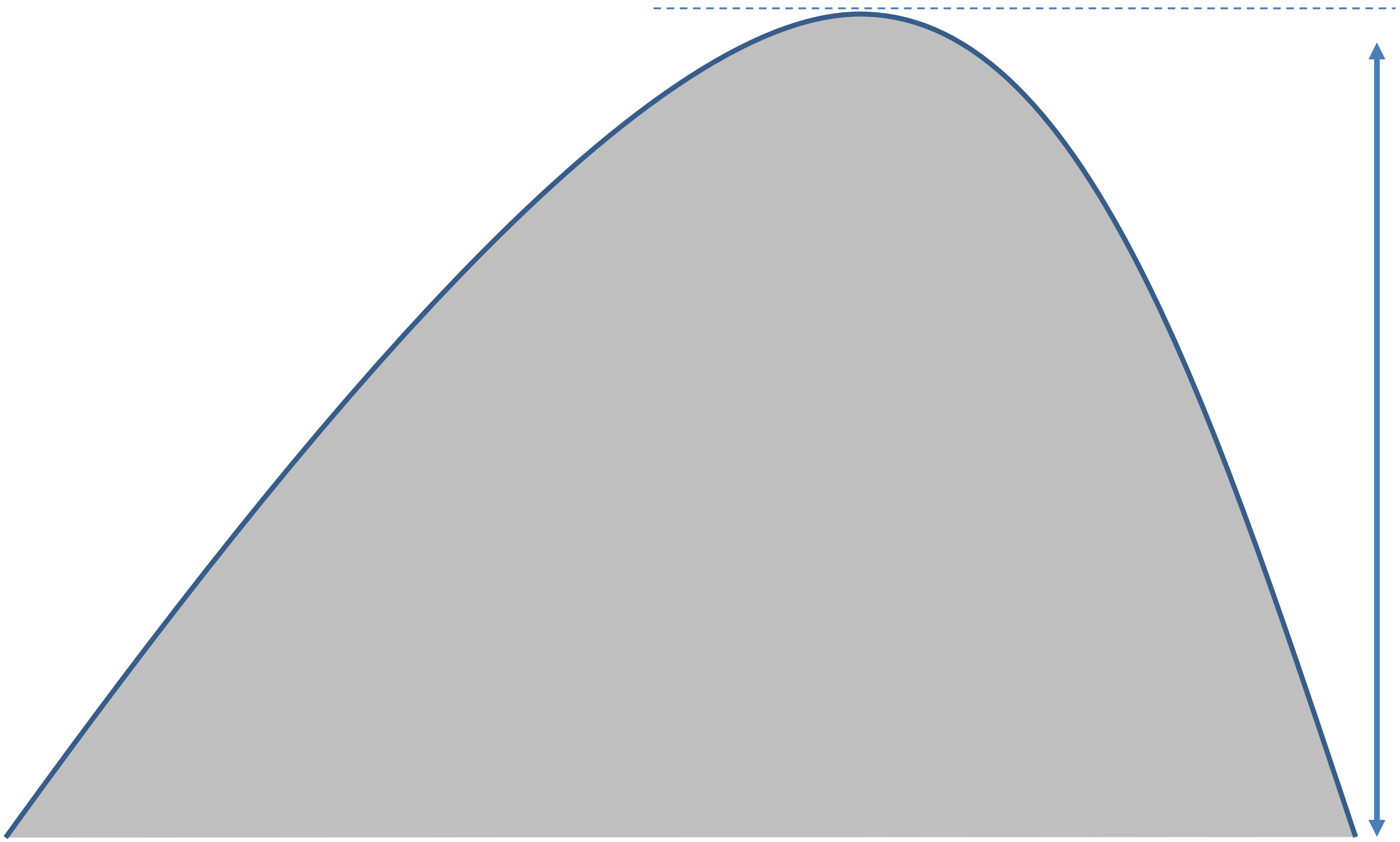
Energy storage: A bucket that moves energy from one time period to another

- Need to decide:
  - When to fill the bucket
  - When to empty the bucket
  - How big of a bucket to buy

- Factors to consider:
  - How fast can the bucket be filled or emptied?
  - How much does the bucket cost?
  - How long will the bucket last?
  - Will using the bucket in a certain way cause it to fail faster?

- The value of the energy must be worth more at the time you empty the bucket than it was at the time you filled the bucket

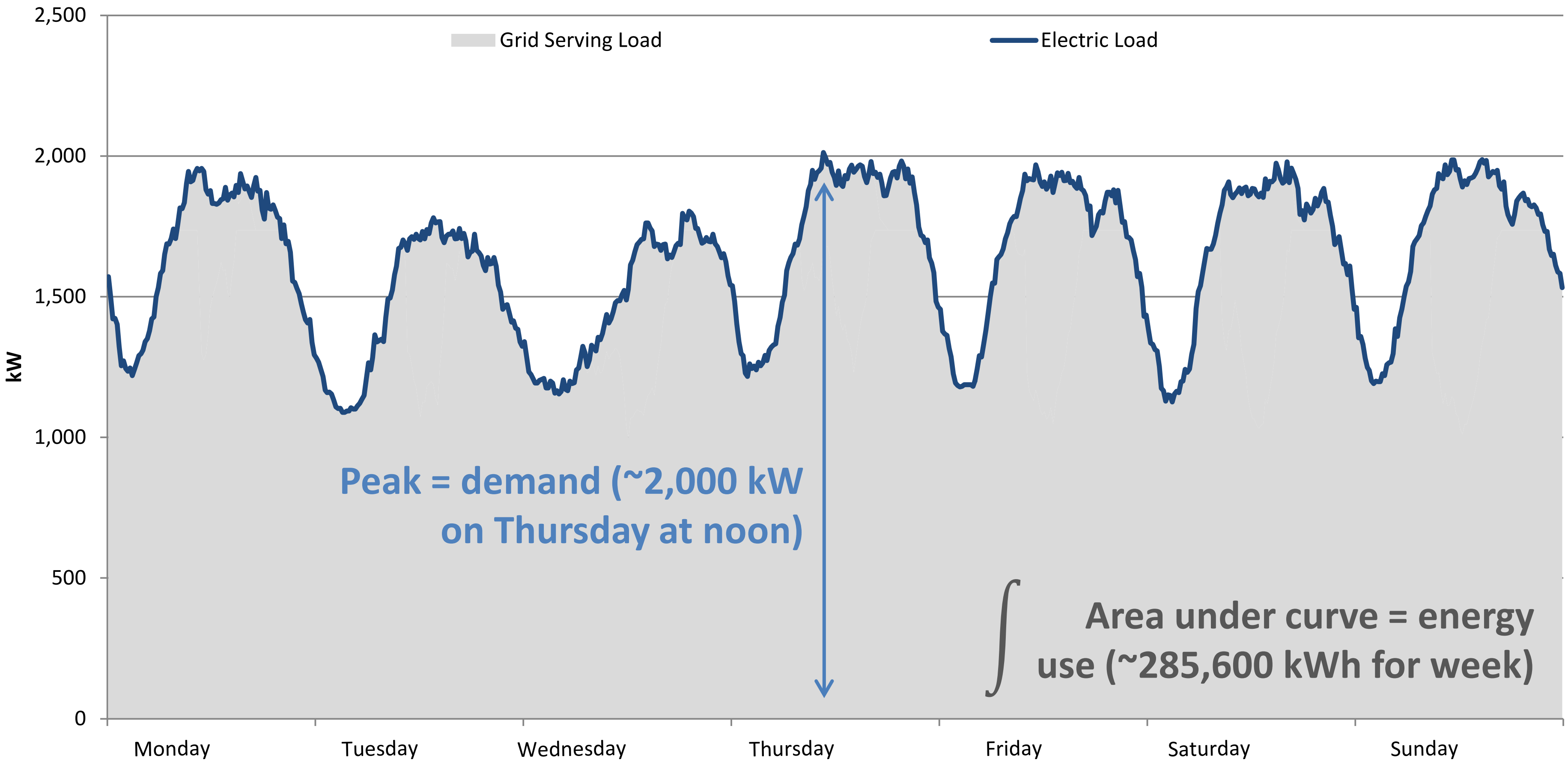
Electricity Use: KWh vs. kW



Instantaneous use: demand – measured in kilowatts (kW)

Area under the curve: Energy use – measured in kilowatt hours (kWh)

Energy Charge vs. Demand Charge

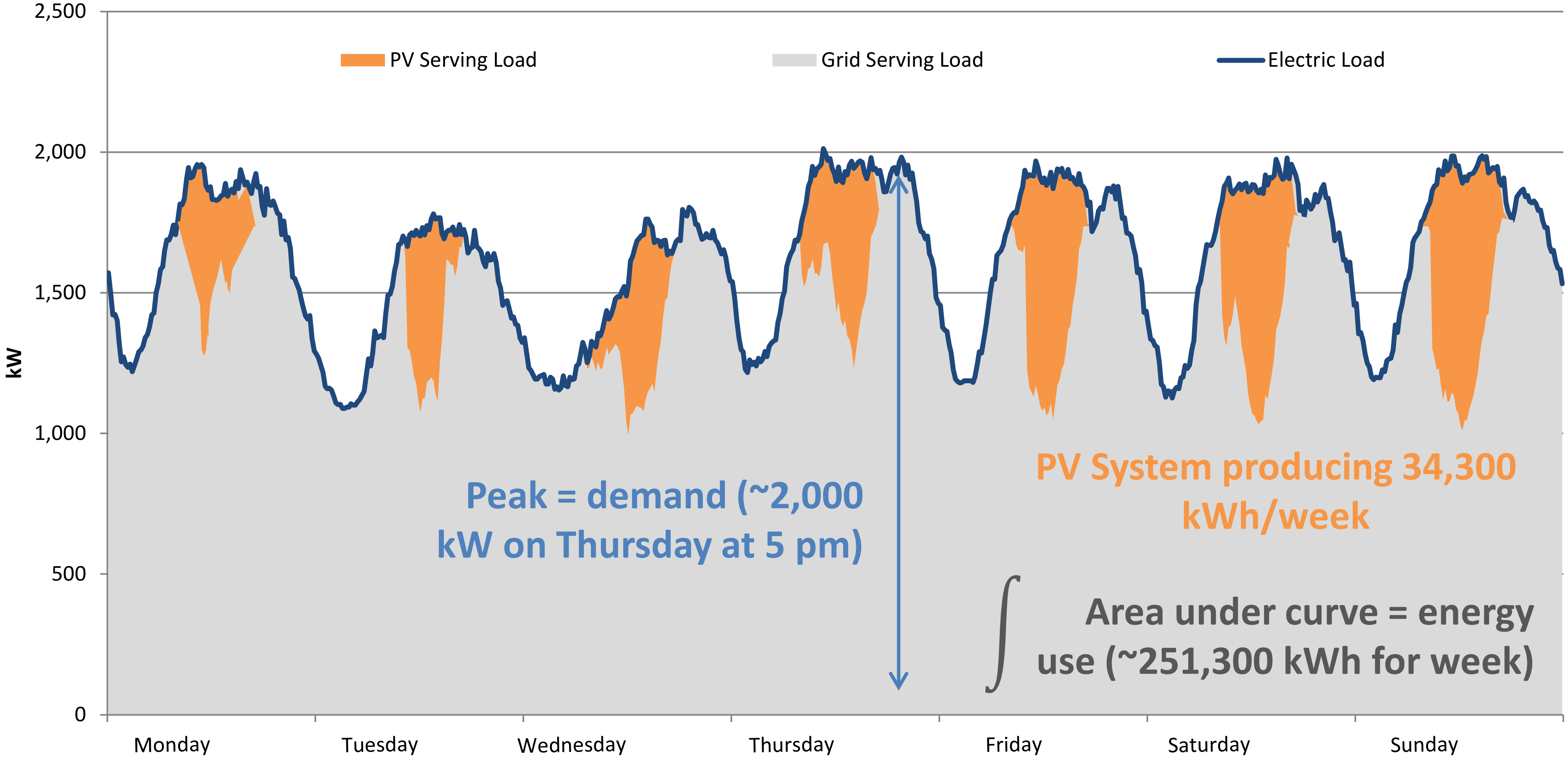


Demand Charge:
$15/kW for highest peak
$15/kW x 2,000 kW = $30,000

Energy Charge:
$0.11/kWh for all energy used
$0.11/kWh x 285,600 kWh = $31,415

One week is shown here, but utilities determine and charge these on a monthly basis

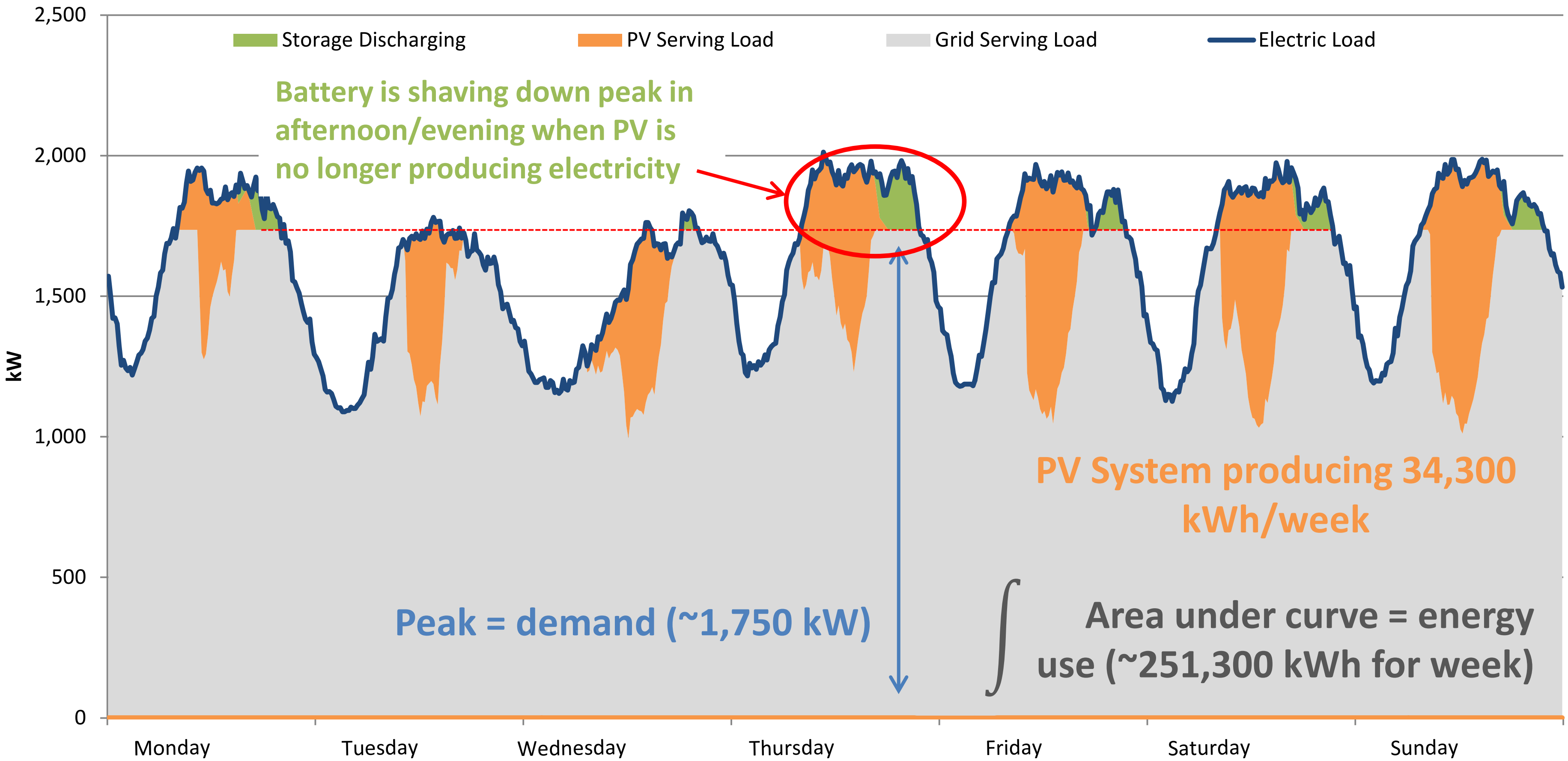
Energy Savings from PV Generation



Demand Charge:
$15/kW for highest peak
$15/kW x 2,000 kW = $30,000

Energy Charge:
$0.11/kWh for all energy used
$0.11/kWh x 251,300 kWh = $27,643
Savings of $3,772/week

Demand Savings from Peak Shaving



Demand Charge:
$15/kW for highest peak
$15/kW x 1,750 kW = $26,250
Savings of $3,750/week

Energy Charge:
$0.11/kWh for all energy used
$0.11/kWh x 251,300 kWh = $27,643
Savings of $3,772/week

Renewable Energy Screening Tools & Resources

Renewable Energy Screening Tools

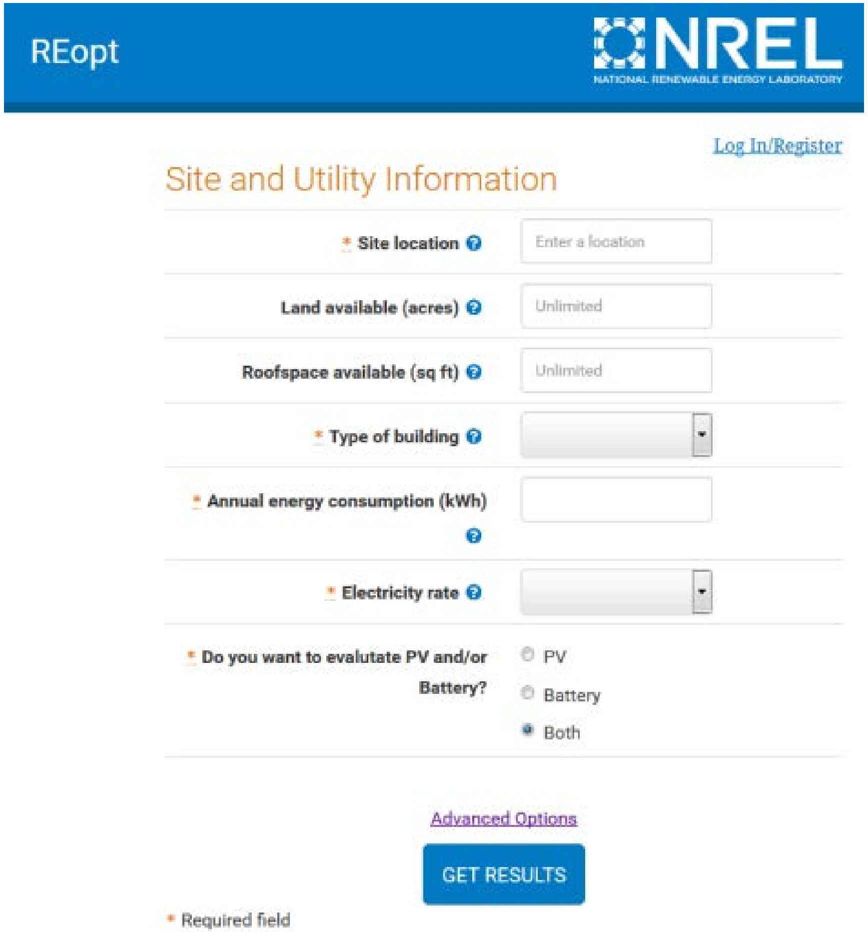
- LCOE Calculator
  - www.nrel.gov/analysis/tech_lcoe.html
- PVWatts
  - http://pvwatts.nrel.gov/
- REopt Lite Web Tool ← Storage
  - https://reopt.nrel.gov/
- System Advisor Model (SAM)
  - https://sam.nrel.gov/ ← Storage

Renewable Energy Screening Resources

- Technology Cost and Performance Matrix
  - http://www.nrel.gov/analysis/tech_cost_dg.html
- Resource Maps
  - http://maps.nrel.gov/femp
- Incentives and Utility Policies
  - http://www.dsireusa.org/

REopt Lite Web Tool

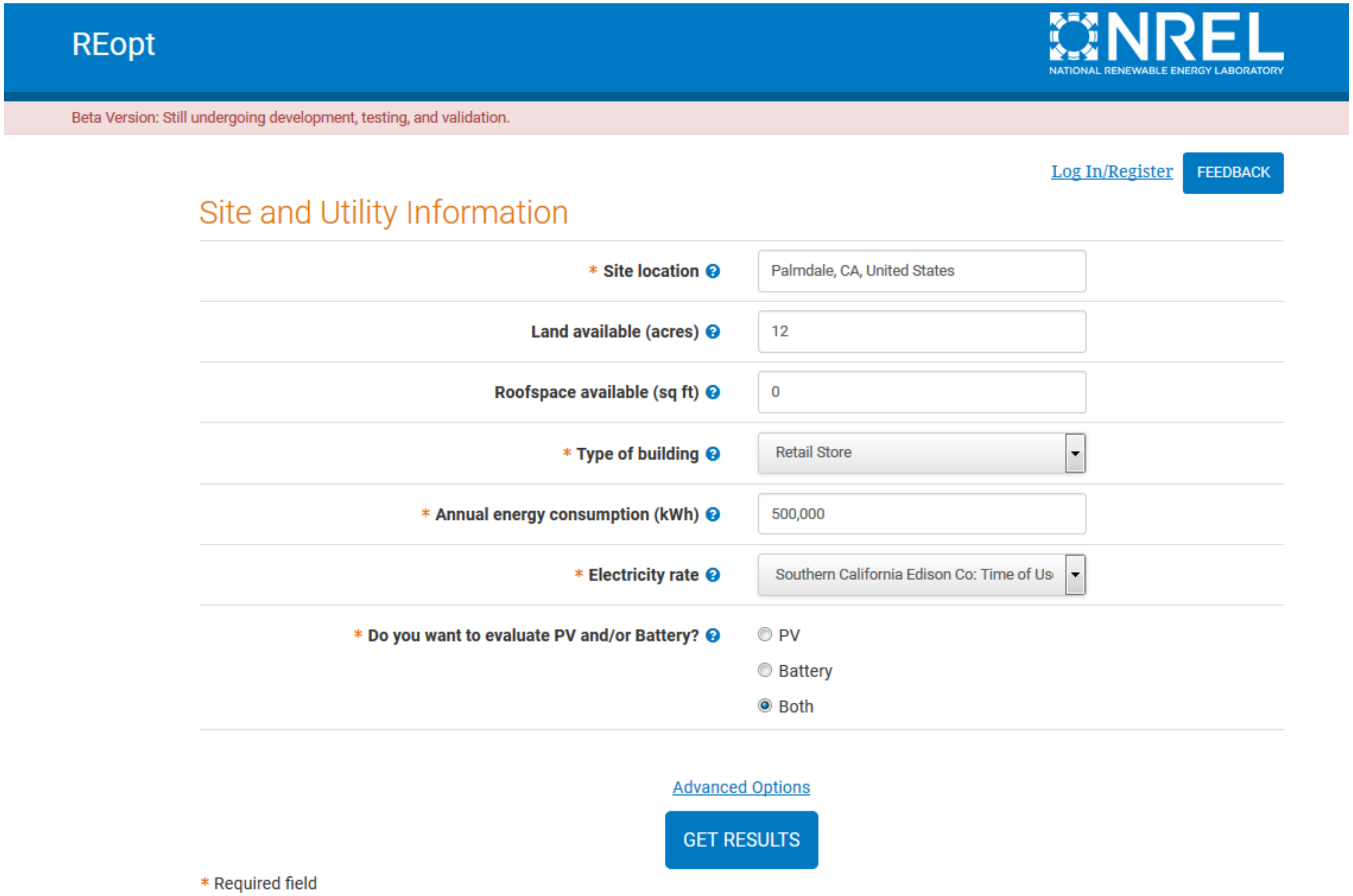
- Publicly available web version of REopt launching September 2017
- evaluates the economics of grid-connected PV and battery storage at a site
- Allows building owners to identify the system sizes and battery dispatch strategy that minimize their life cycle cost of energy



https://reopt.nrel.gov/tool.html

Web Interface Inputs (Basic)

Only a few inputs describing the site's characteristics are required in order to run the tool



Web Interface Inputs (Advanced)

Additional (advanced) inputs can be accessed by user if desired; all advanced options are pre-populated with default values

Site
Financial
PV
Battery

Financial

Analysis period (years)	25
Host real discount rate (%)	8%
Host effective tax rate (%)	30%
Electricity escalation rate (%)	2%
Inflation rate (%)	1%

PV

PV Costs

System capital cost ($/kW)	$2000
O&M cost ($/kW per year)	$20

PV System Characteristics

Minimum size desired (kW DC)	0
Maximum size desired (kW DC)	Unlimited
Module type	Premium
Array type	Rooftop, Fixed
Array azimuth (deg)	180
Array tilt (deg)	5
DC to AC size ratio	1.1
System losses (%)	14%

Site
Financial
PV
Battery

Battery Characteristics

Minimum energy capacity (kWh)	0
Maximum energy capacity (kWh)	Unlimited
Minimum power capacity (kW)	0
Maximum power capacity (kW)	Unlimited
Rectifier efficiency (%)	96%
Round trip efficiency (%)	90%
Inverter efficiency (%)	96%
Total AC-AC round trip efficiency	82.9%
Minimum state of charge (%)	20%
Initial state of charge (%)	50%
Allow grid to charge battery	Yes

Battery Incentives and Tax Treatment

Capital Cost Based Incentives

	Percentage-based incentive (%)	Maximum incentive ($)	Rebate ($/kW)	Maximum rebate ($)
Federal	30%	Unlimited	$0	Unlimited
State	0%	Unlimited	$0	Unlimited
Utility	0%	Unlimited	$0	Unlimited

Tax Treatment

MACRS schedule	5 years

Results Output – Economics Summary

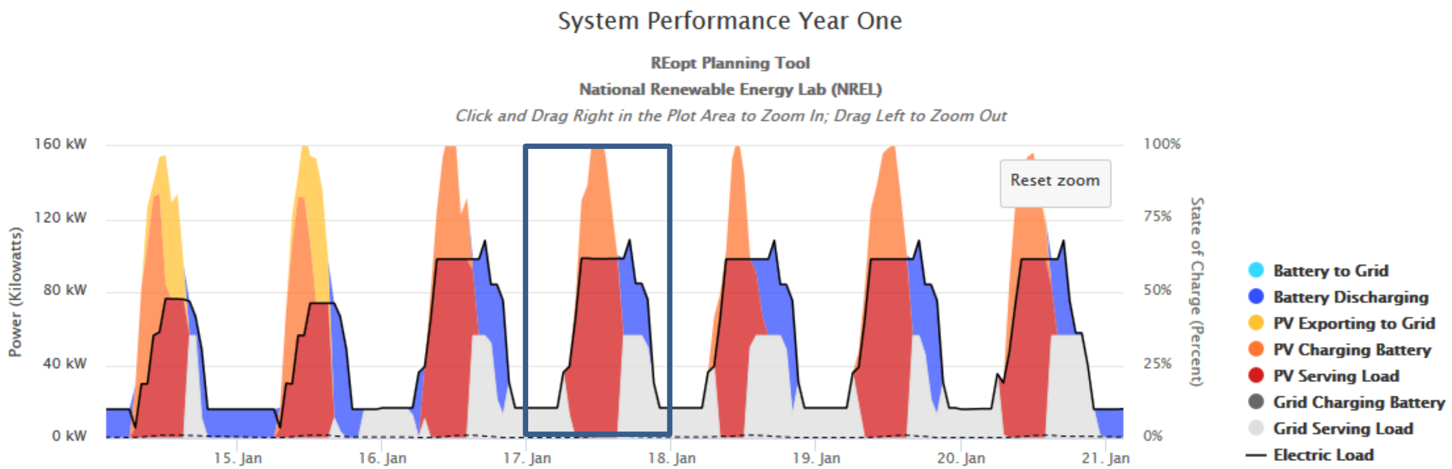
The summary table compares the optimal case with the business as usual case. If no technologies are recommended the two are the same

Results

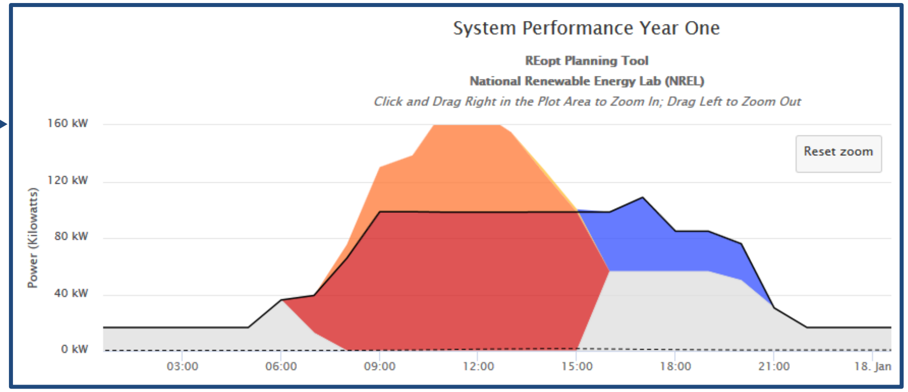
	Business As Usual	Optimal Case	Difference
PV Size (kW)	0 kW	235 kW	235 kW
Annualized PV Energy Production (kWh)	0 kWh	420,160 kWh	420,160 kWh
Battery Power (kW)	0 kW	63 kW	63 kW
Battery Capacity (kWh)	0 kWh	323 kWh	323 kWh
Average Resiliency (hours)	0 hours	2,849 hours	2,849 hours
Minimum Resiliency (hours)	0 hours	2 hours	2 hours
Maximum Resiliency (hours)	0 hours	7,422 hours	7,422 hours
DG System Cost (Net CAPEX + O&M)	$0	$310,894	$310,894
Year 1 Utility Energy Payments	$44,593	$9,765	$34,828
Year 1 Utility Demand Payments	$32,981	$10,436	$22,544
Year 1 Energy Supplied From Grid (kWh)	500,000 kWh	82,376 kWh	417,624 kWh
Total Utility Energy Cost	$576,480	$126,241	$450,238
Total Utility Demand Cost	$426,357	$134,914	$291,443
Net Present Value	$0	$180,549	$180,549
Total Lifecycle Energy Cost	$651,844	$471,295	$180,549
Internal Rate of Return	0%	14%	14%

Results Output –Dispatch Graph

The hourly dispatch graph allows the user to see how the battery and PV systems are operating on an hourly basis. The zoom feature allows the user to look at different time periods (full year, month, week, day etc.)



Hourly dispatch for one week



Hourly dispatch for one day

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