NREL
NATIONAL RENEWABLE ENERGY LABORATORY

When Solar+Storage Make Sense

Nick Laws
Research Engineer, Integrated Applications Center

June 13th 2018
NAESCO Technology & Financing Workshop, Milwaukee, WI

When Solar+Storage Make sense

Costs vs. Benefits: Costs are easy, what about the benefits...

Financial benefits can be achieved by:

1. Utility bill reduction
   - Peak shaving (demand charge reduction)
   - Time-shifting PV production (energy arbitrage)
2. Providing ancillary services
3. Meeting critical load during outages

When Solar+Storage Make sense

Costs vs. Benefits: Costs are easy, what about the benefits...

Financial benefits can be achieved by:

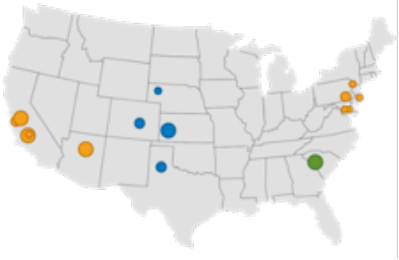
1. Utility bill reduction
   - Peak shaving (demand charge reduction)
   - Time-shifting PV production (energy arbitrage)
2. Providing ancillary services
3. Meeting critical load during outages

To accomplish any of these things well, one needs controls (and ideally good forecasts).

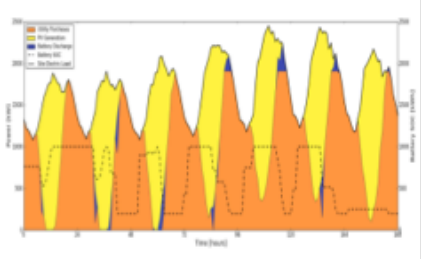
REopt Integration and Optimization

REopt: Decision Support throughout the Energy Planning Process

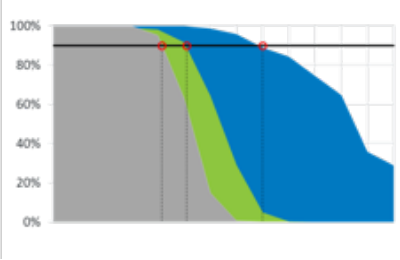
Master Planning	Economic Dispatch	Resiliency Analysis
• Portfolio prioritization • Cost to meet goals	• Technology types & sizes • Optimal operating strategies	• Microgrid dispatch • Energy security evaluation



Cost-effective RE at Army bases



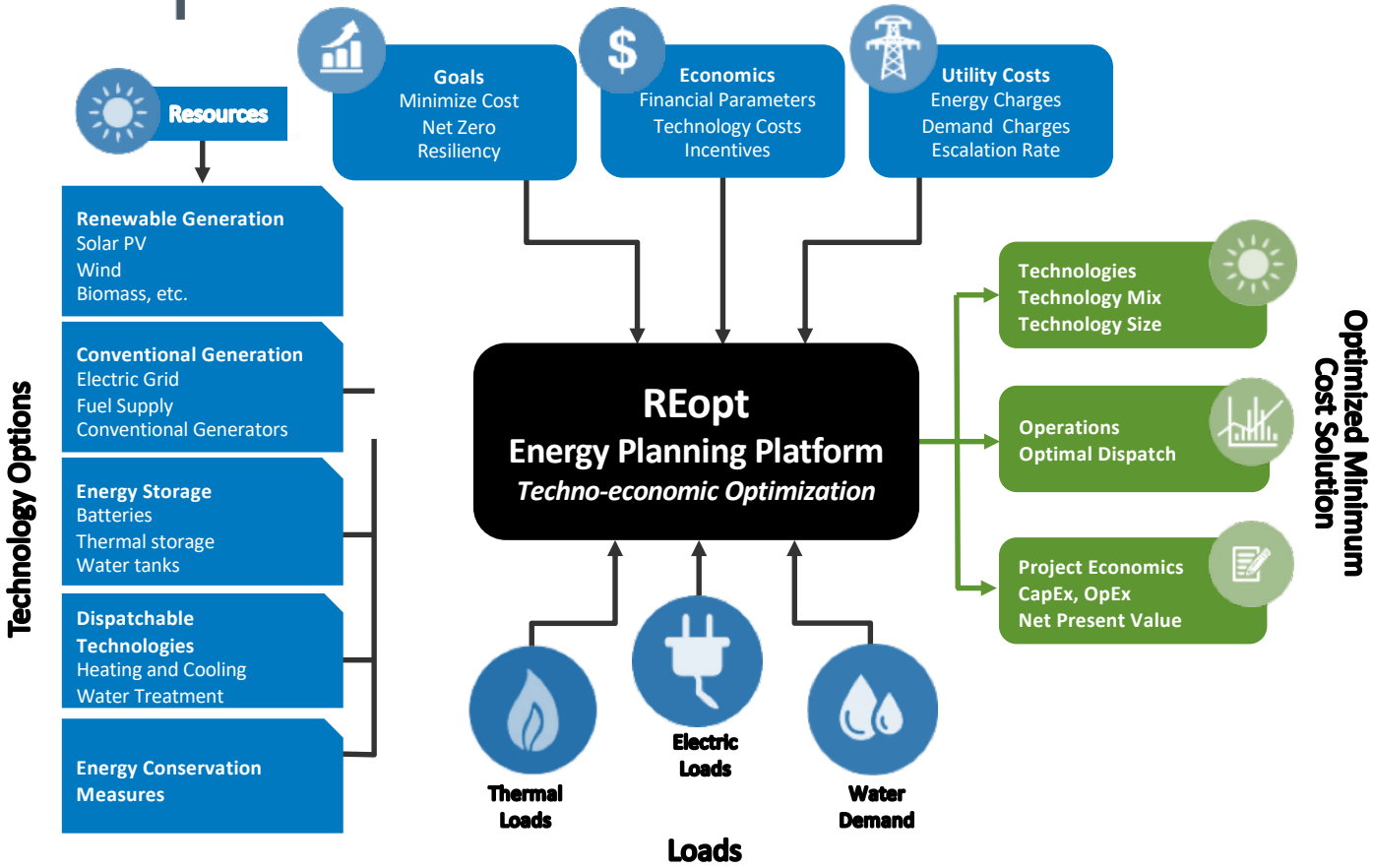
Cost-optimal Operating Strategy



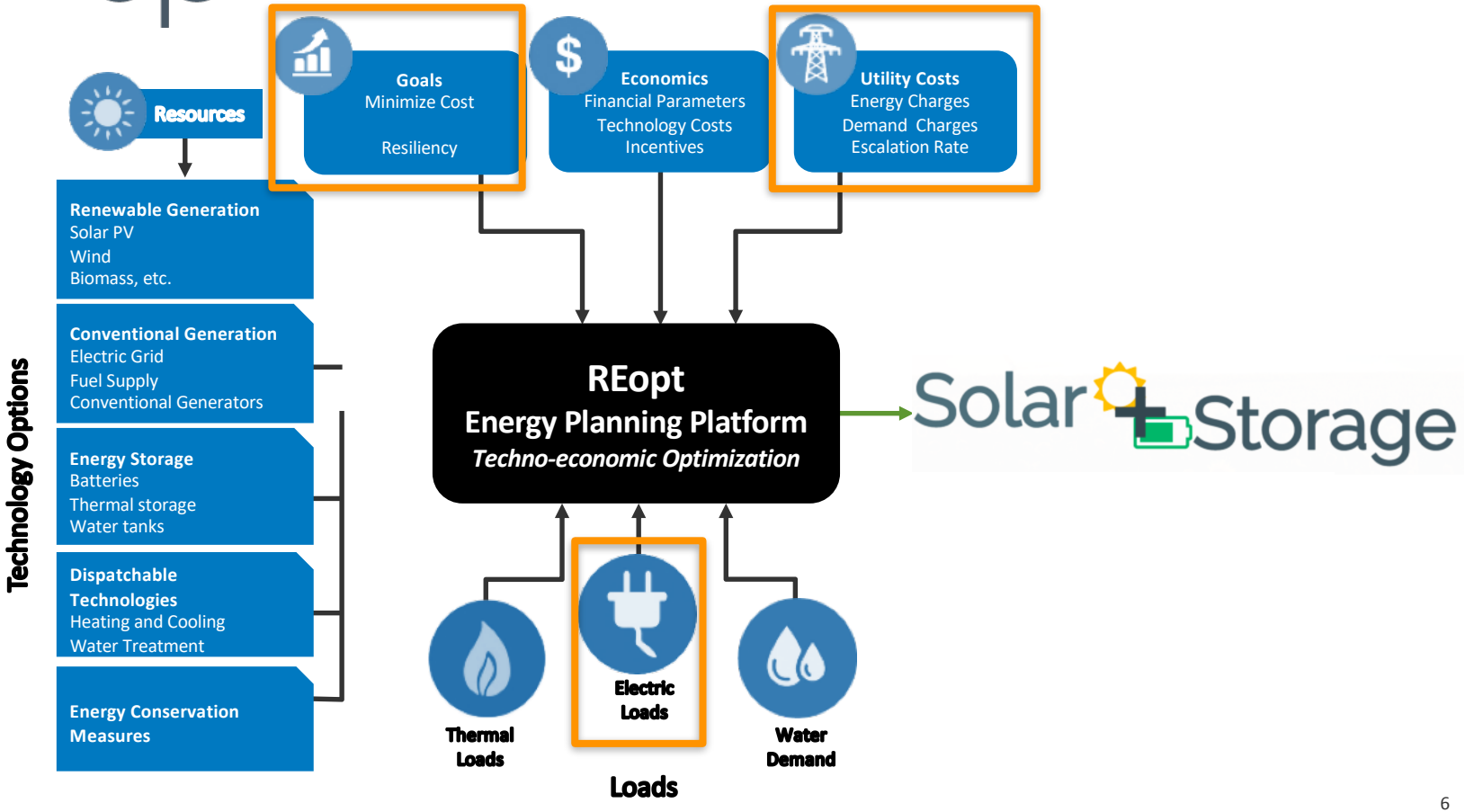
Extending Resiliency with RE

REopt website: https://reopt.nrel.gov/

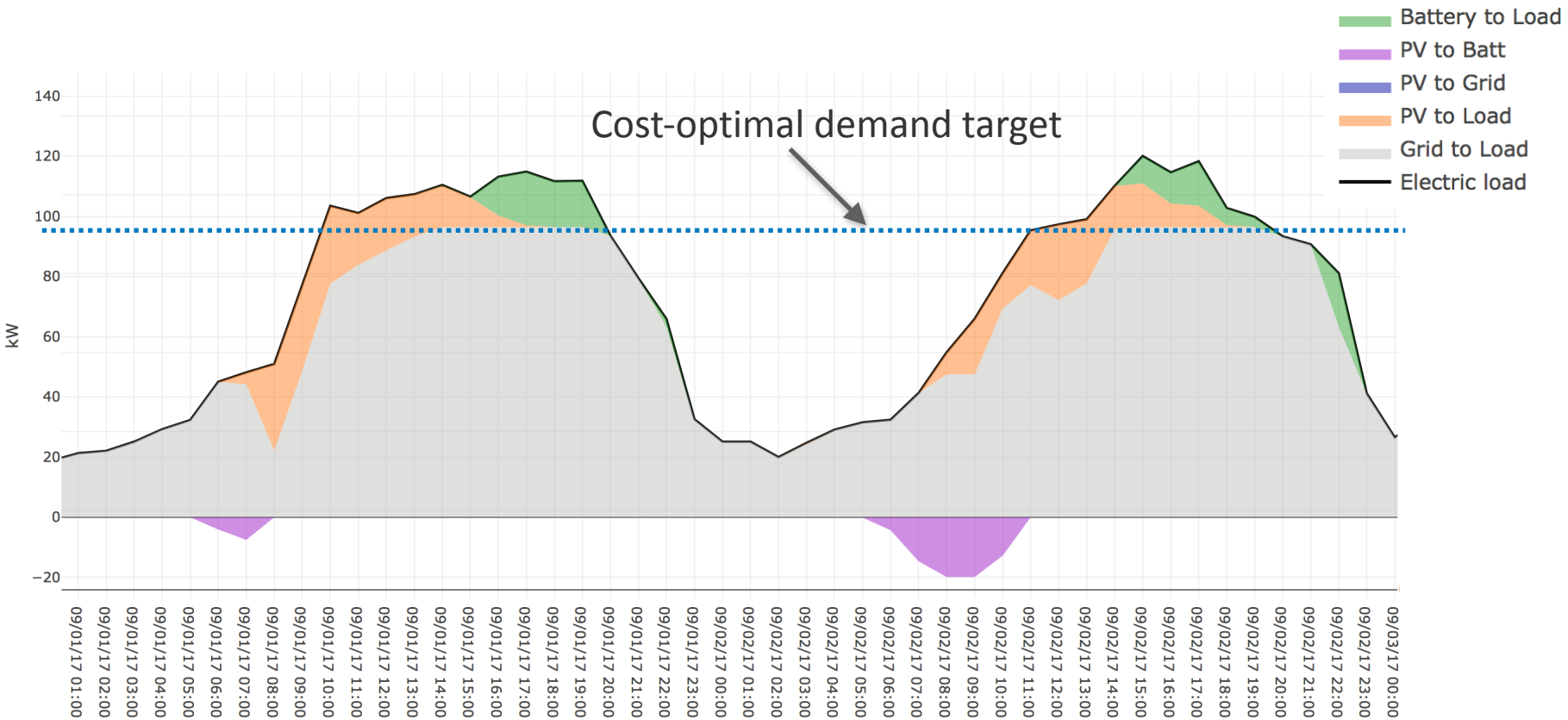
REopt


Resources
Goals
Minimize Cost
Net Zero
Resiliency
Economics
Financial Parameters
Technology Costs
Incentives
Utility Costs
Energy Charges
Demand Charges
Escalation Rate
Technology Options
Renewable Generation
Solar PV
Wind
Biomass, etc.
Conventional Generation
Electric Grid
Fuel Supply
Conventional Generators
Energy Storage
Batteries
Thermal storage
Water tanks
Dispatchable Technologies
Heating and Cooling
Water Treatment
Energy Conservation Measures
REopt
Energy Planning Platform
Techno-economic Optimization
Thermal Loads
Electric Loads
Water Demand
Loads
Technologies
Technology Mix
Technology Size
Operations
Optimal Dispatch
Project Economics
CapEx, OpEx
Net Present Value
Optimized Minimum Cost Solution

REopt


Goals
Minimize Cost
Resiliency
Economics
Financial Parameters
Technology Costs
Incentives
Utility Costs
Energy Charges
Demand Charges
Escalation Rate
Resources
Technology Options
Renewable Generation
Solar PV
Wind
Biomass, etc.
Conventional Generation
Electric Grid
Fuel Supply
Conventional Generators
Energy Storage
Batteries
Thermal storage
Water tanks
Dispatchable Technologies
Heating and Cooling
Water Treatment
Energy Conservation Measures
REopt
Energy Planning Platform
Techno-economic Optimization
Solar + Storage
Thermal Loads
Electric Loads
Water Demand
Loads

Solar+Storage with flat demand charges



A step back

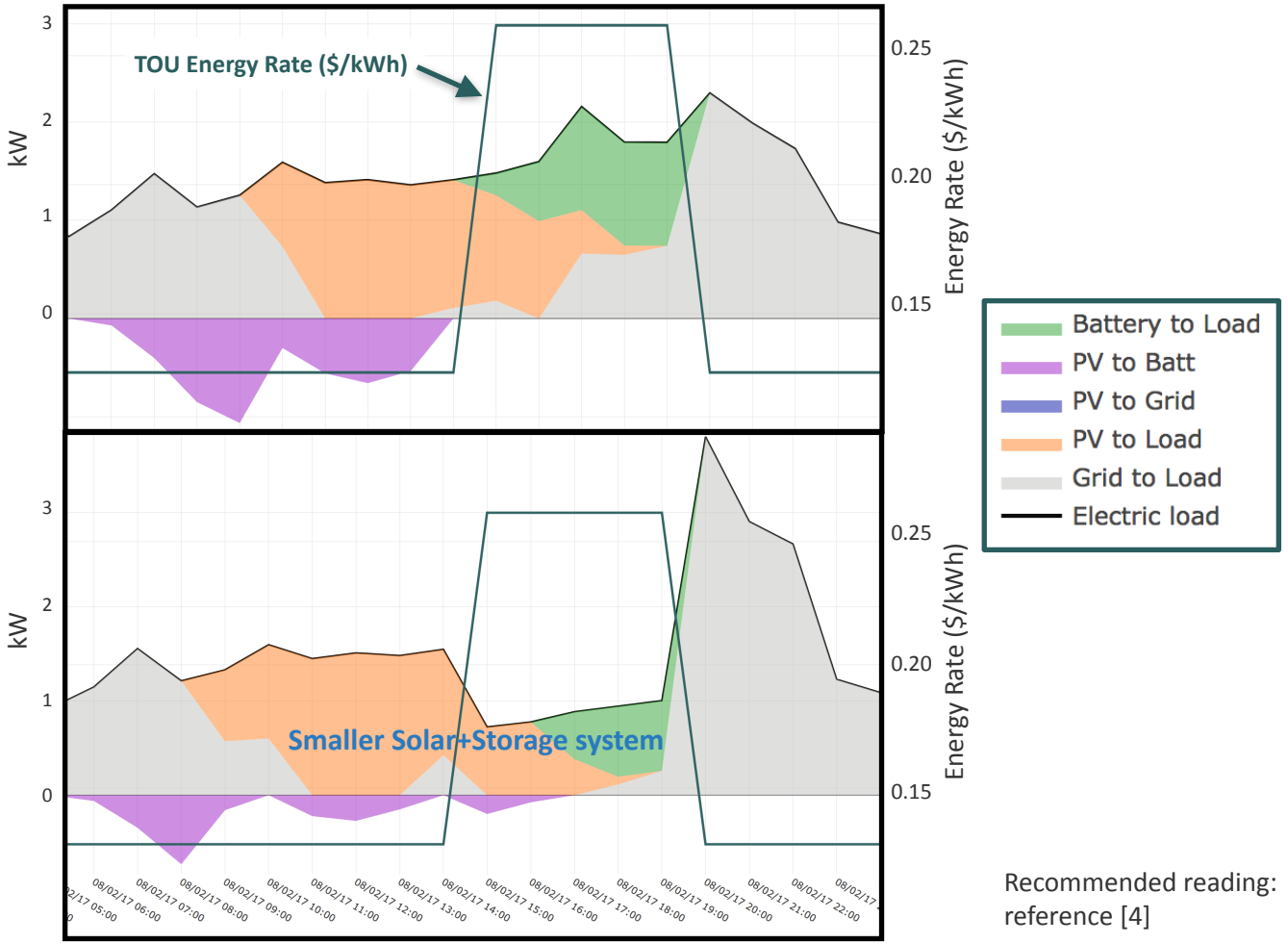
1. Efficiency measures come first
2. Demand management (depends on cost to implement)
3. Solar + Storage

Ability to shift load affects storage sizing and dispatch

No demand management

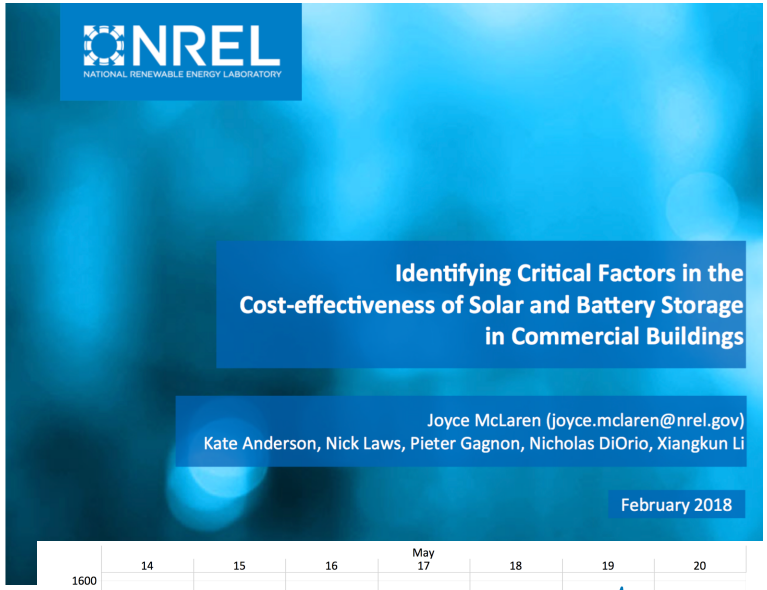
Cost-optimal dispatches from REopt

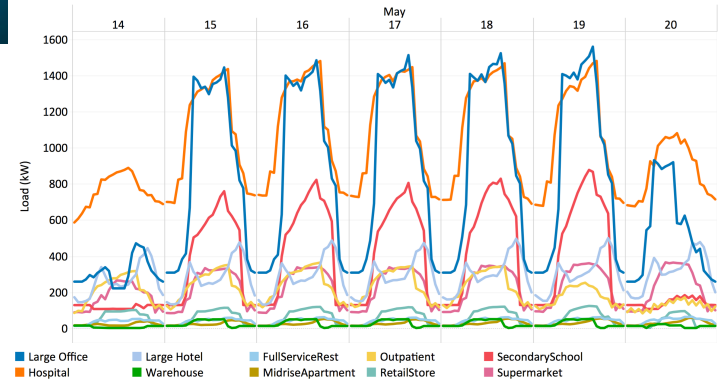
With demand management



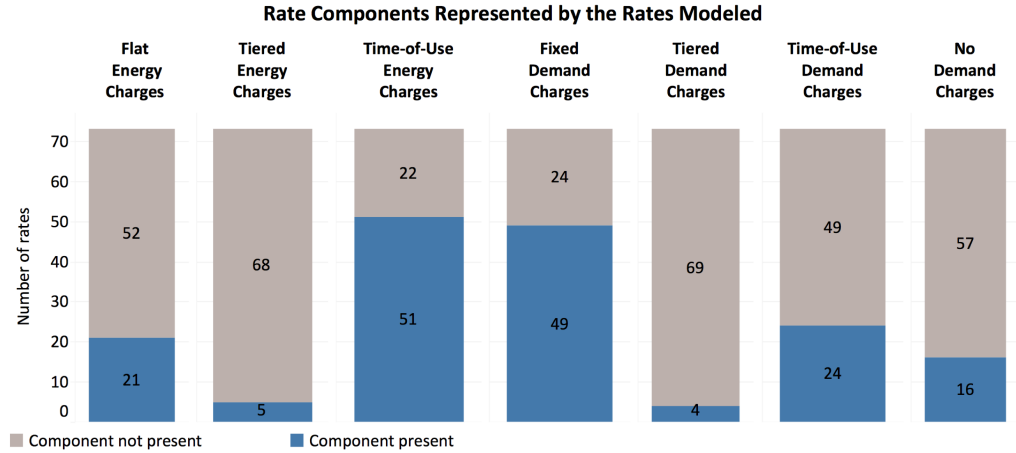
Recommended reading: reference [4]

Sunlamp Study



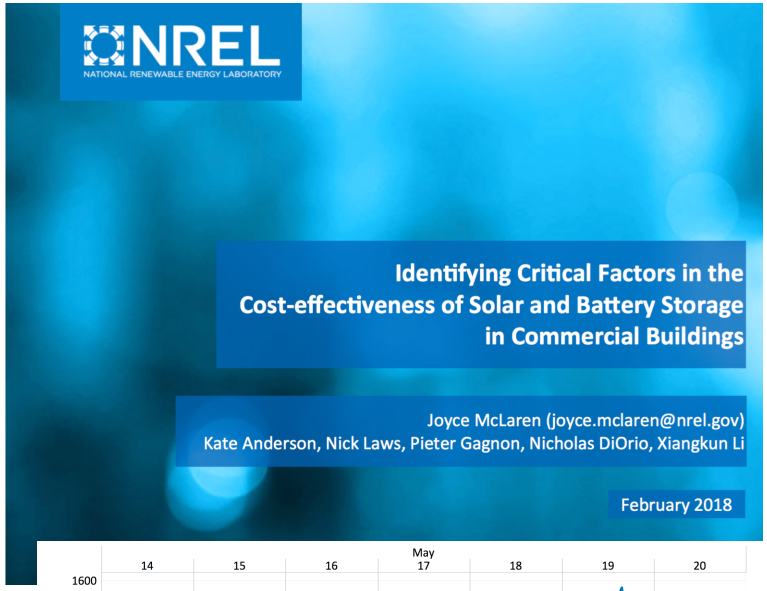


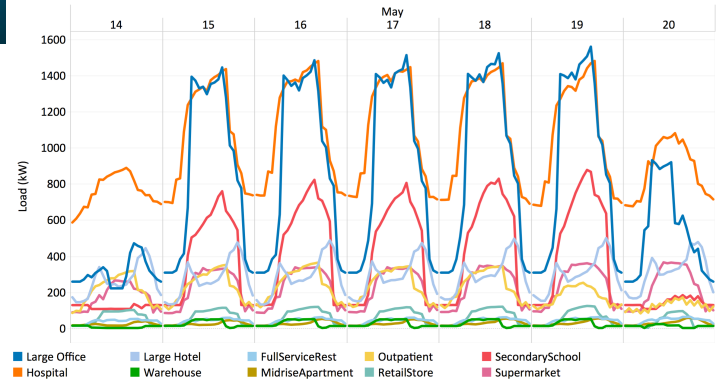
Cost Point	PV System Installed Cost ($/w)	PV O&M Cost ($/kW)	Battery Storage System Installed Cost for Power Rating* ($/kW)	Battery Storage System Installed Cost for Energy Rating ($/kWh)	Battery Storage Replacement Cost ($/kW)	Battery Storage Replacement Cost ($/kWh)
High Cost Point	$1.37	$8	$1,332	$290	$441	$256
Mid Cost Point	$1.11	$8	$1,062	$256	$407	$238
Low Cost Point	$0.97	$8	$1,193	$151	$326	$106
Stretch Cost Point	$0.90	$8	$787	$106	$276	$97



reference [1]

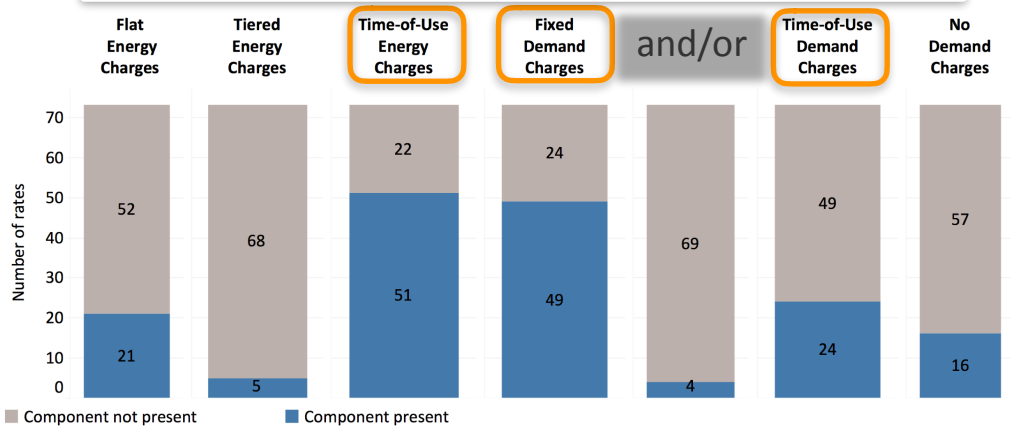
Sunlamp Study





Cost Point	PV System Installed Cost ($/w)	PV O&M Cost ($/kW)	Battery Storage System Installed Cost for Power Rating* ($/kW)	Battery Storage System Installed Cost for Energy Rating ($/kWh)	Battery Storage Replacement Cost ($/kW)	Battery Storage Replacement Cost ($/kWh)
High Cost Point	$1.37	$8	$1,332	$290	$441	$256
Mid Cost Point	$1.11	$8	$1,062	$256	$407	$238
Low Cost Point	$0.97	$8	$1,193	$151	$326	$106
Stretch Cost Point	$0.90	$8	$787	$106	$276	$97

All scenarios resulting in Solar+Storage had:



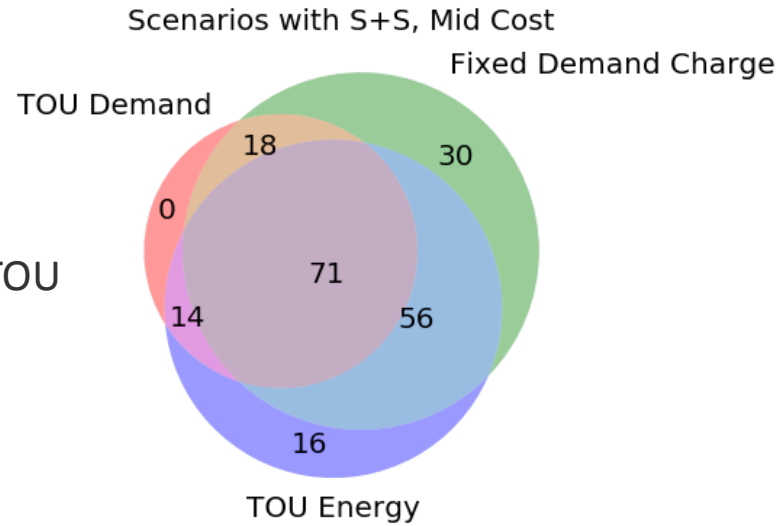
reference [1]

Sunlamp Results
Rate Structure when S+S is economical

Every scenario with a cost-optimal Solar+Storage system had either:

- Demand charges (TOU and/or flat)
- TOU Energy rates
- or Both

However, not all scenarios with demand charges and/or TOU energy rates result in S+S systems.

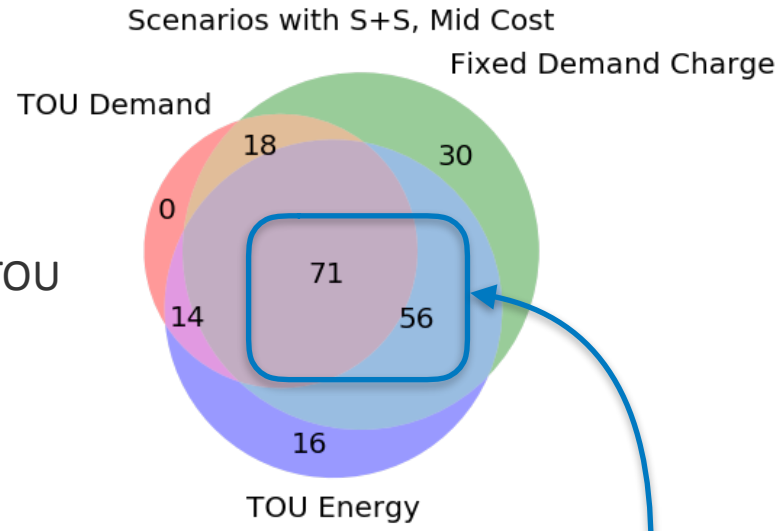


Sunlamp Results
Rate Structure when S+S is economical

Every scenario with a cost-optimal Solar+Storage system had either:

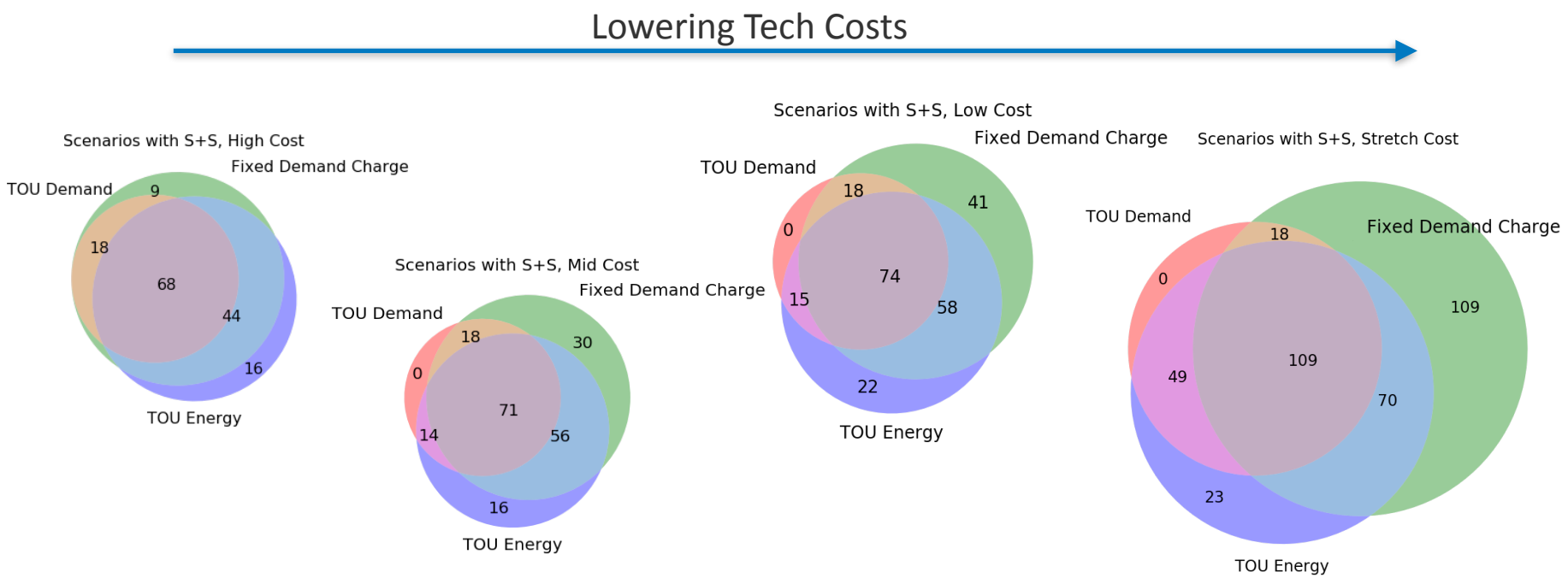
- Demand charges (TOU and/or flat)
- TOU Energy rates
- or Both

However, not all scenarios with demand charges and/or TOU energy rates result in S+S systems.



Sunlamp: Lowering Tech Costs

As costs lower, Solar+Storage is economical with less complex rate structures.



Other potential benefits

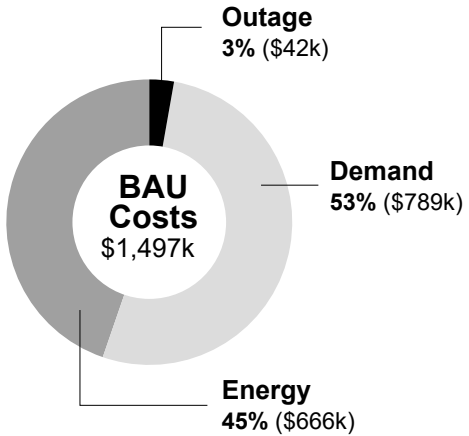
- Ancillary service markets
- Feed-in Tariffs and Net Energy Metering
- Resiliency

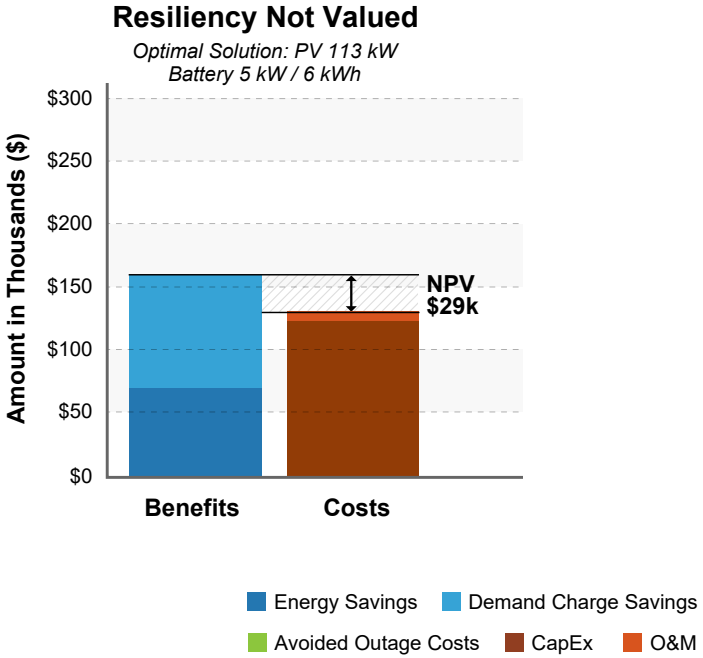
Other potential benefits

- Ancillary service markets
- Feed-in Tariffs and Net Energy Metering
- Resiliency

Value of Resilience

Balance cost of system with grid-connected benefits (bill reduction)

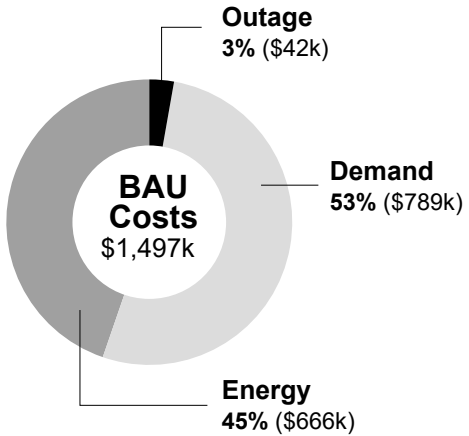


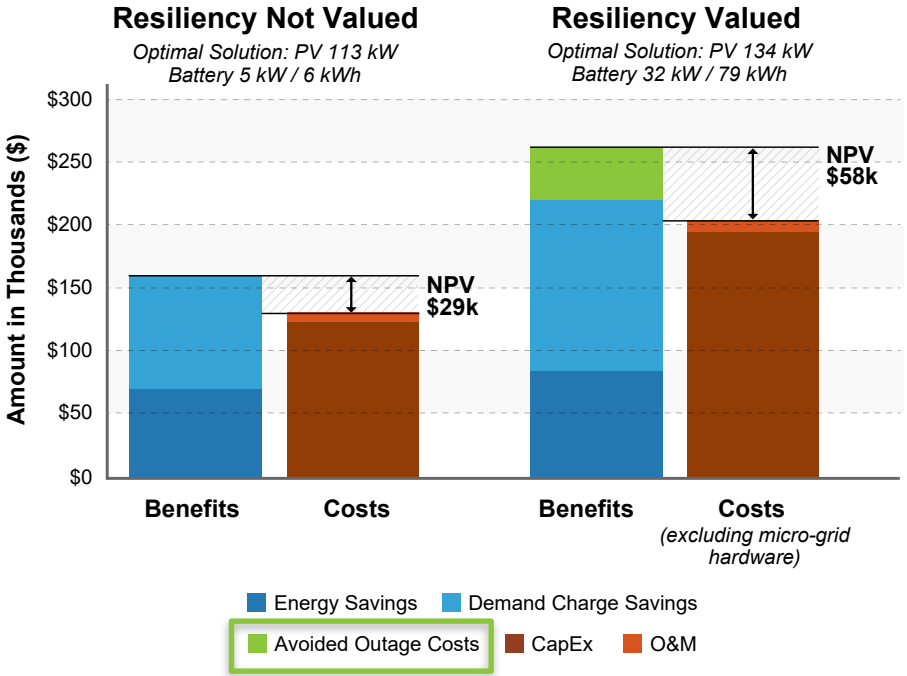


reference [2]

Value of Resilience

Balance cost of system with grid-connected benefits (bill reduction) *and* resiliency benefits.

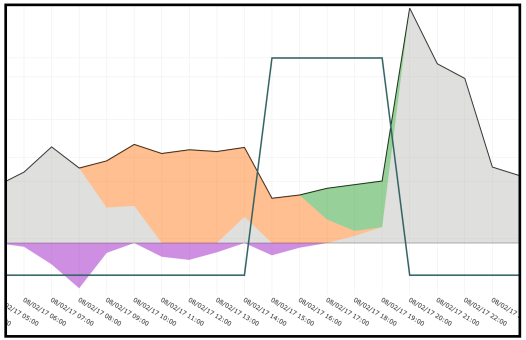




reference [2]

Challenges

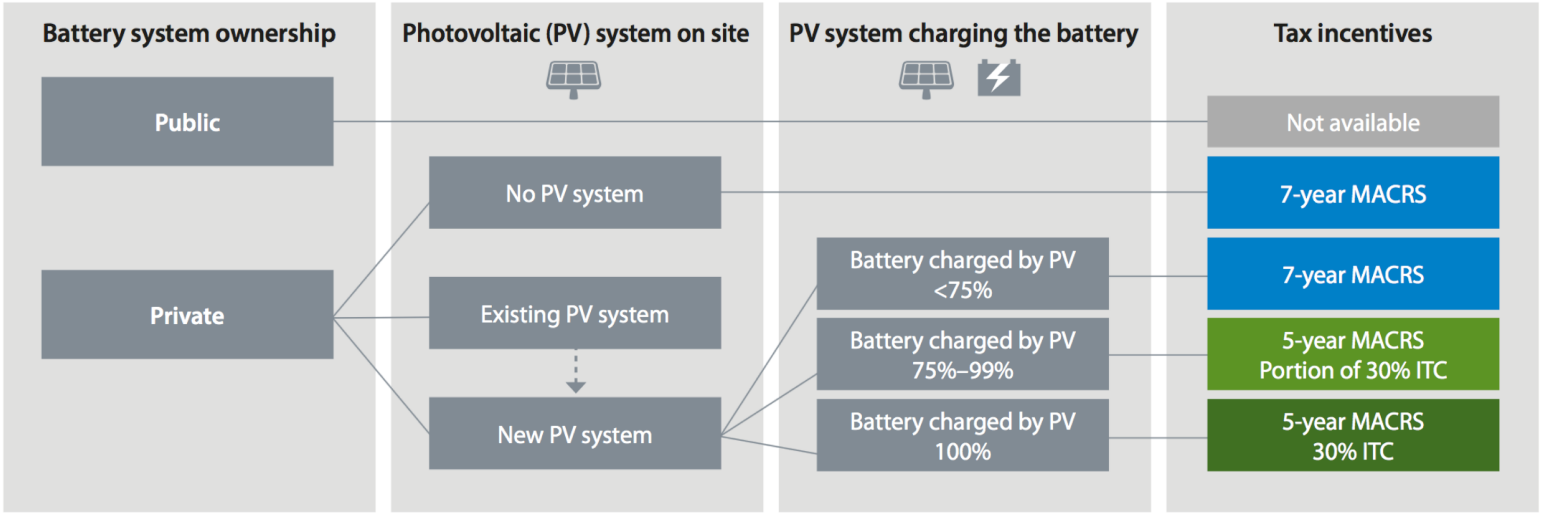
- Controls
  - Numerous active and proposed research activities
- Benefits are difficult to understand and quantify
  - **REopt Lite** designed to help
- Resiliency
  - Microgrids can be expensive
  - Difficult to determine value of lost load
  - Difficult to monetize resilience



Recommended reading: reference [7]

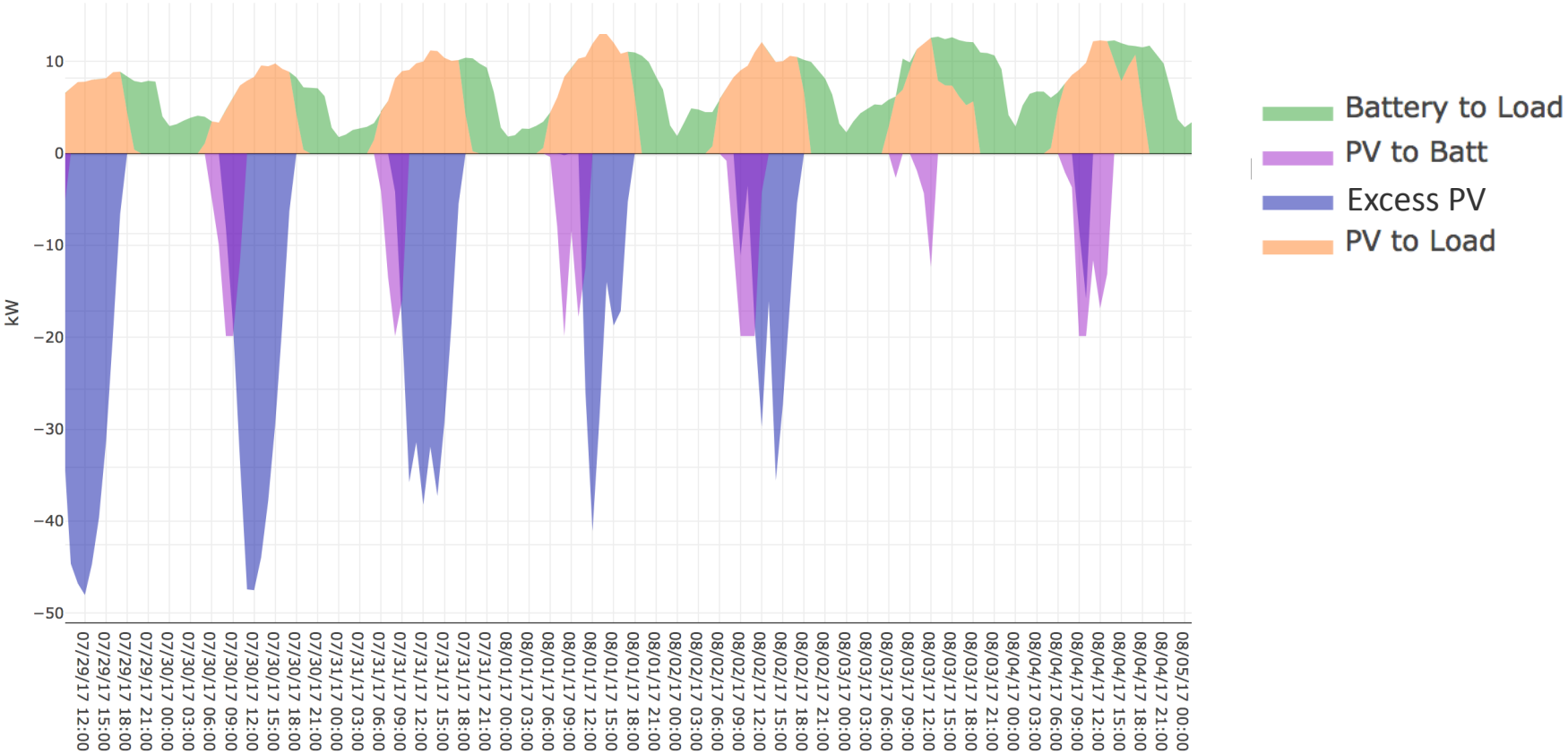
Challenges: Controls
What charges the battery matters

Federal Tax Incentives for Energy Storage Systems



reference [3]

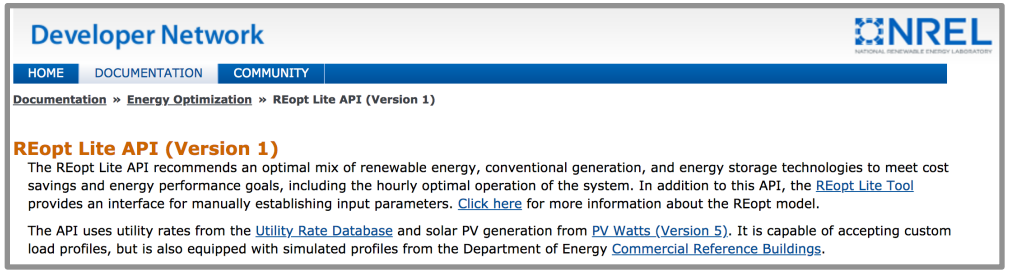
Challenges: Controls
Dispatching and Islanding



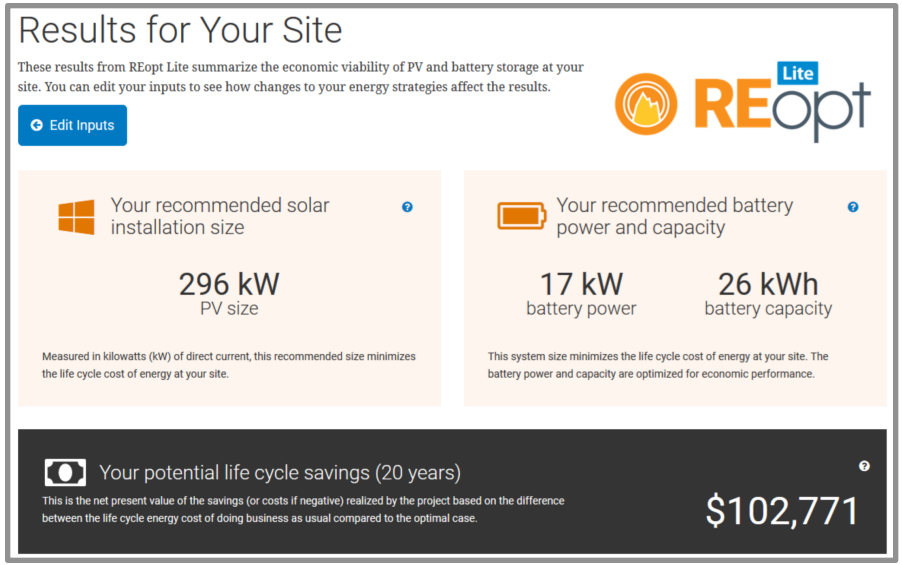
Challenges: Understanding and Quantifying Benefits

- Publicly available web version of REopt launched September 2017
- Evaluates the economics of grid-connected PV and battery storage at a site
- Allows users to identify system sizes & dispatch strategy that minimize life cycle cost of energy

reopt.nrel.gov/tool



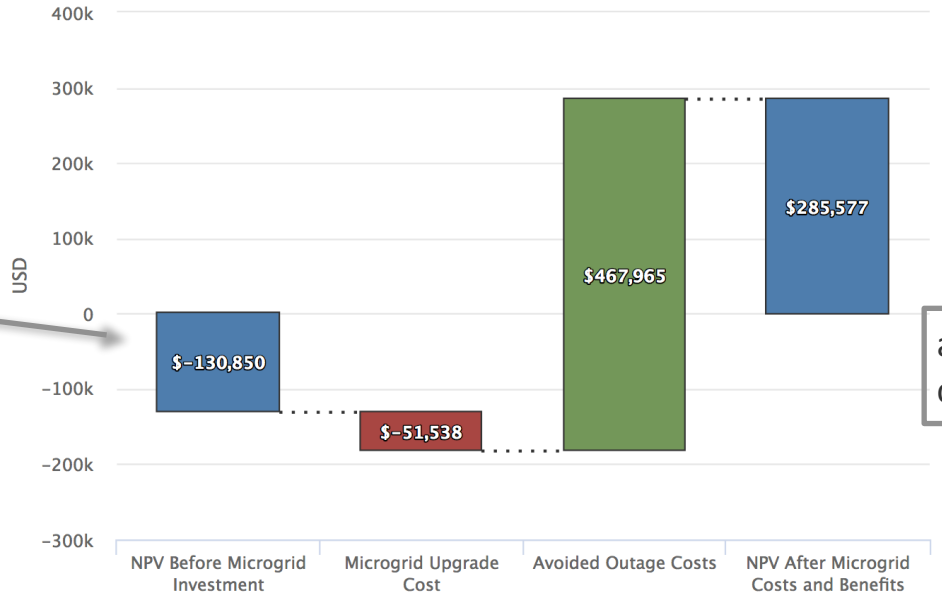
developer.nrel.gov/docs/energy-optimization/reopt-v1



New Resilience Capabilities released June 2018

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

30% of system capital cost

Avoided Outage Costs

$625 per kWh

system designed to survive 24 hour outage has negative NPV

accounting for Avoided Outage Costs can make project NPV positive

Summary

When Solar+Storage Make Sense

- Grid-connected benefits from tariff with demand charges and/or time-of-use energy charges
- Ancillary service markets
- Value of Resilience

Hurdles

- Control systems
- Difficult to quantify benefits, especially to place a value on resilience

Thank you

www.nrel.gov

NREL/PR-7A40-71813

References

https://openei.org/wiki/Solar+Storage
reopt.nrel.gov

[1] Joyce McLaren, Kate Anderson, Nick Laws, Pieter Gagnon, Nicholas DiOrio, Xiangkun Li,
Identifying Critical Factors in the Cost-effectiveness of Solar and Battery Storage in Commercial Buildings,
NREL/PR-6A20-70813, February 2018

[2] Nicholas D. Laws, Kate Anderson, Nicholas A. DiOrio, Xiangkun Li, Joyce McLaren,
Impacts of valuing resilience on cost-optimal PV and storage systems for commercial buildings,
Renewable Energy, Volume 127, 2018, Pages 896-909, https://doi.org/10.1016/j.renene.2018.05.011.

[3] Emma Elgqvist, Kate Anderson, and Edward Settle.
Federal Tax Incentives for Energy Storage Systems,
NREL/FS-7A40-70384, January 2018

[4] Eric O'Shaughnessy, Dylan Cutler, Kristen Ardani, Robert Margolis,
Solar plus: Optimization of distributed solar PV through battery storage and dispatchable load in residential buildings,
Applied Energy, Volume 213, 2018, https://doi.org/10.1016/j.apenergy.2017.12.118.

[5] Kate Anderson, Dylan Cutler, Nick DiOrio, Emma Elgqvist, Nick Laws, Dan Olis, Andy Walker
Optimizing Storage and Renewable Energy Systems with REopt,
NREL/PO-7A40-70333, December 2017

[6] Otto VanGeet, Emma Elgqvist
Campus Energy Approach, REopt Overview, and Solar for Universities,
NREL/PR-7A40-70252, October 2017

[7] Kate Anderson, Nicholas D. Laws, Spencer Marr, Lars Lisell, Tony Jimenez, Tria Case, Xiangkun Li, Dag Lohmann, Dylan Cutler
Quantifying and Monetizing Renewable Energy Resiliency.
Sustainability, 10(4), 933, 2018, https://doi.org/10.3390/su10040933

Disclaimer

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 U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Federal Energy Management Program, by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office, and by the Clean Energy Group. The views expressed in the article 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 article 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.