Connecticut Green Bank Residential Solar PV + Energy Storage Analysis

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Analysis Overview

- NREL was tasked with evaluating the economics of residential behind-the-meter (BTM) storage and PV in Connecticut to inform the impact of potential incentive levels for two utilities:
  - Eversource
  - United Illuminating (UI)

- NREL used a model called REopt which determines the most cost effective mix, size, and dispatch of renewable energy and conventional energy generation technologies, including the grid.

  - PV capacity is assumed to be the average installed size for Eversource and UI customers

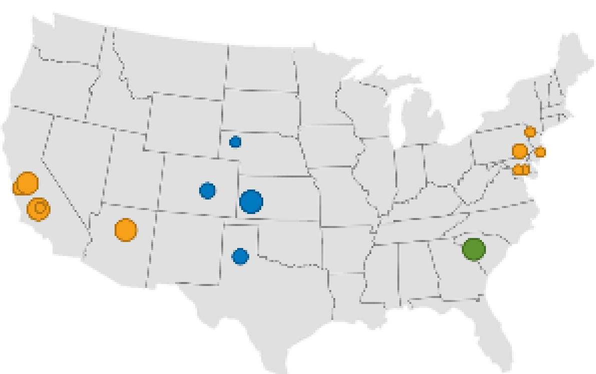
  - The following battery sizes were considered:
    - 5 kW/13.5 kWh battery
    - Most cost effective battery size
    - 2.5 kW/6 kWh battery

- This analysis considers the dispatch strategy which maximizes BTM savings for the home owner customer for the battery

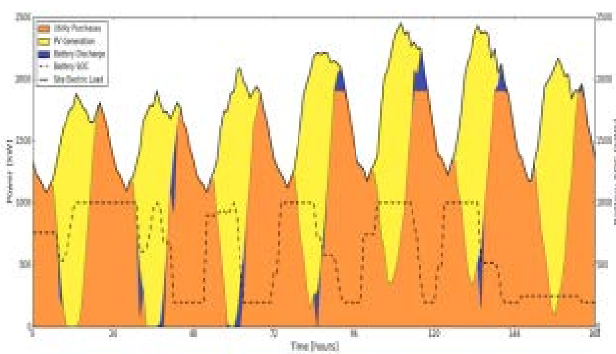
REopt: Decision Support Throughout the Energy Planning Process

Optimization • Integration • Automation

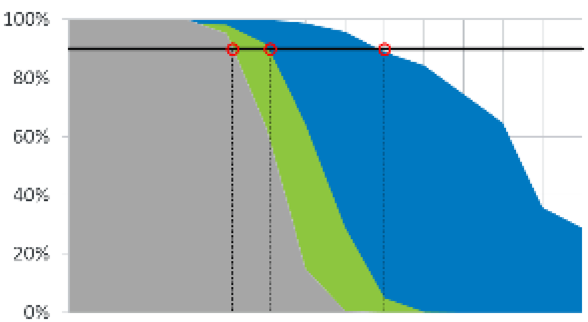
Master Planning	Economic Dispatch	Resiliency Analysis
• Portfolio prioritization • Cost to meet goals	• Technology types & sizes • Optimal operating strategies	• Microgrid dispatch • Energy security evaluation



Cost-effective RE at Army bases

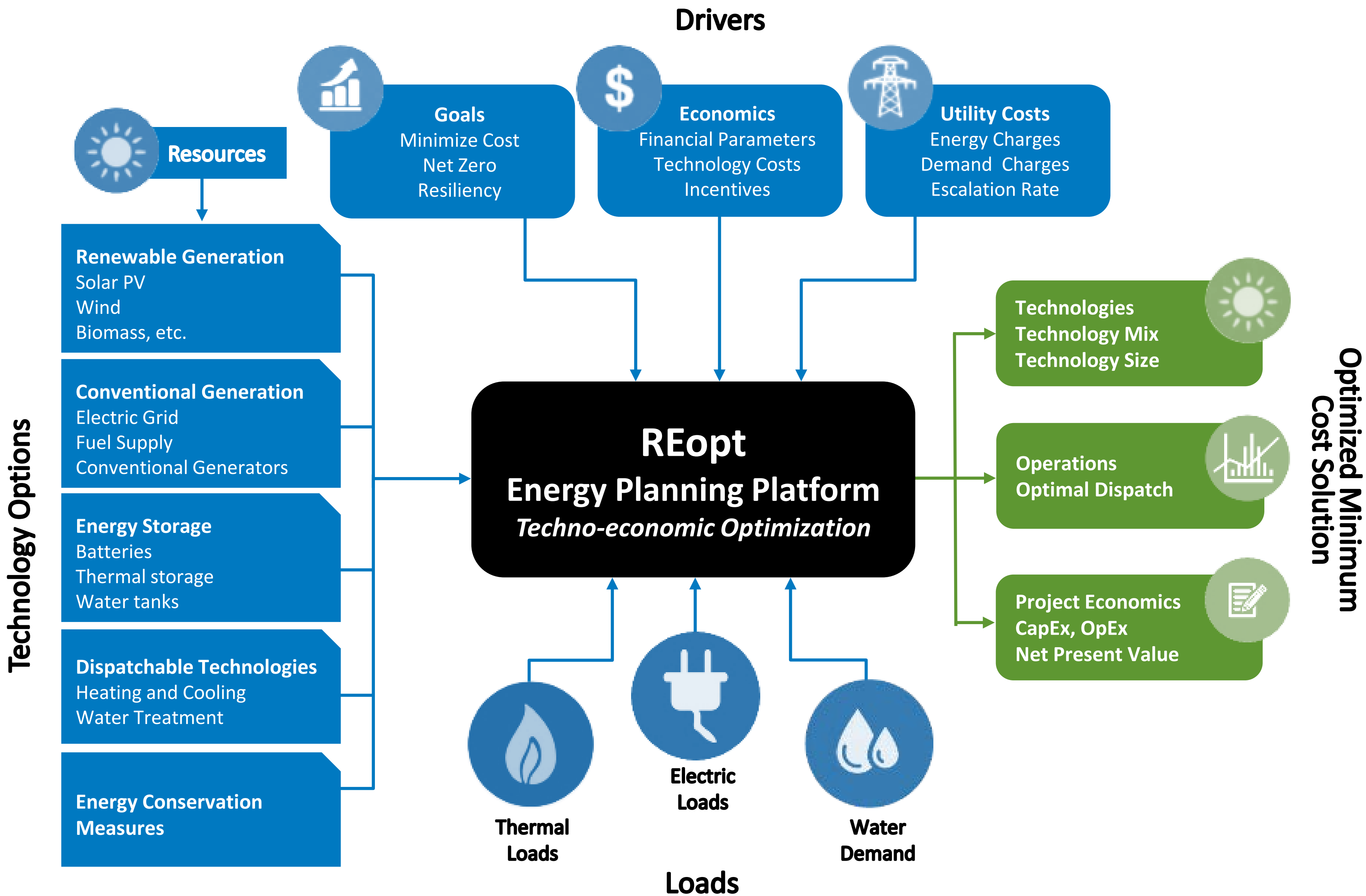


Cost-optimal Operating Strategy



Extending Resiliency with RE

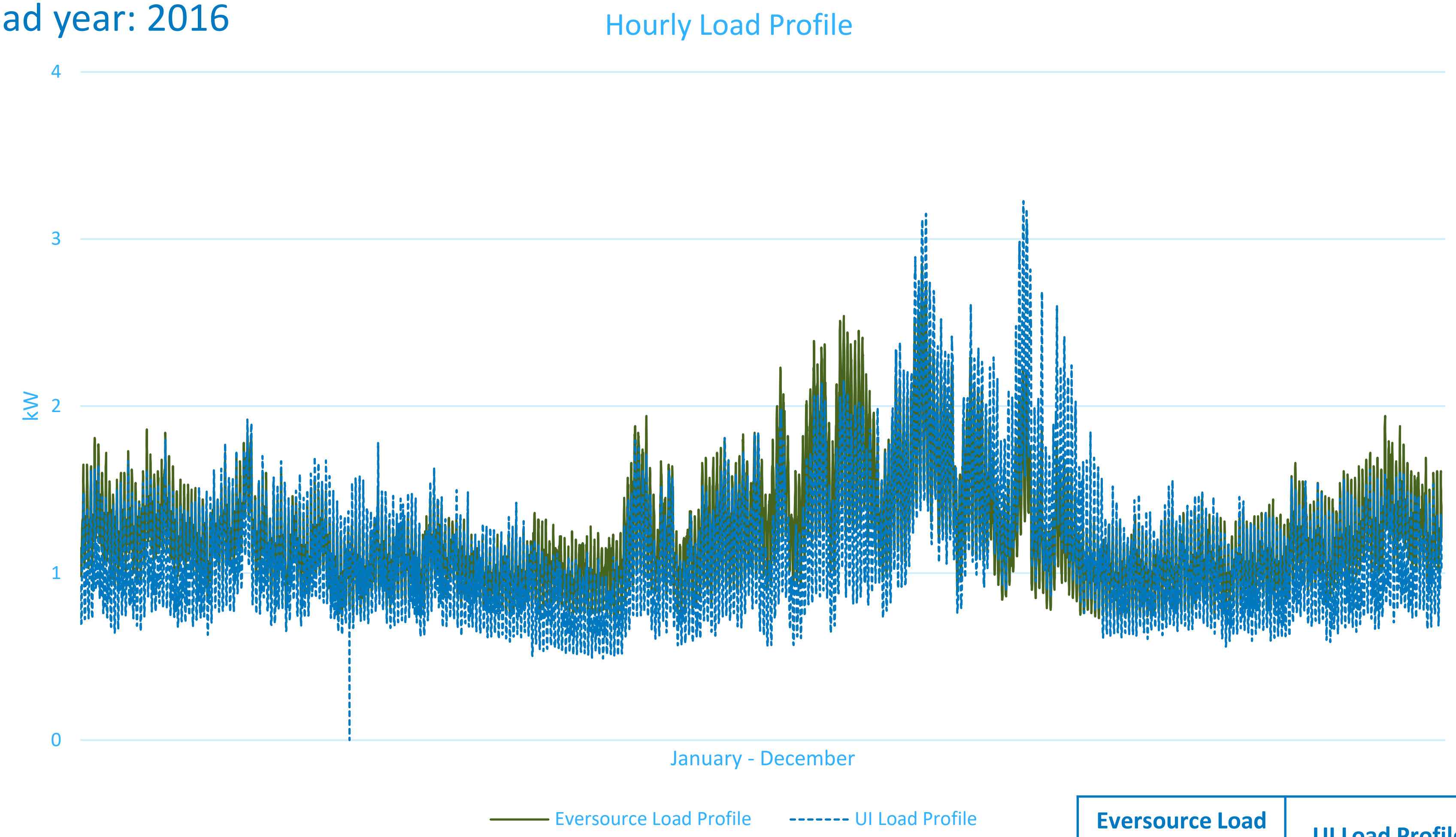
REopt Inputs and Output



Electric Load Profile

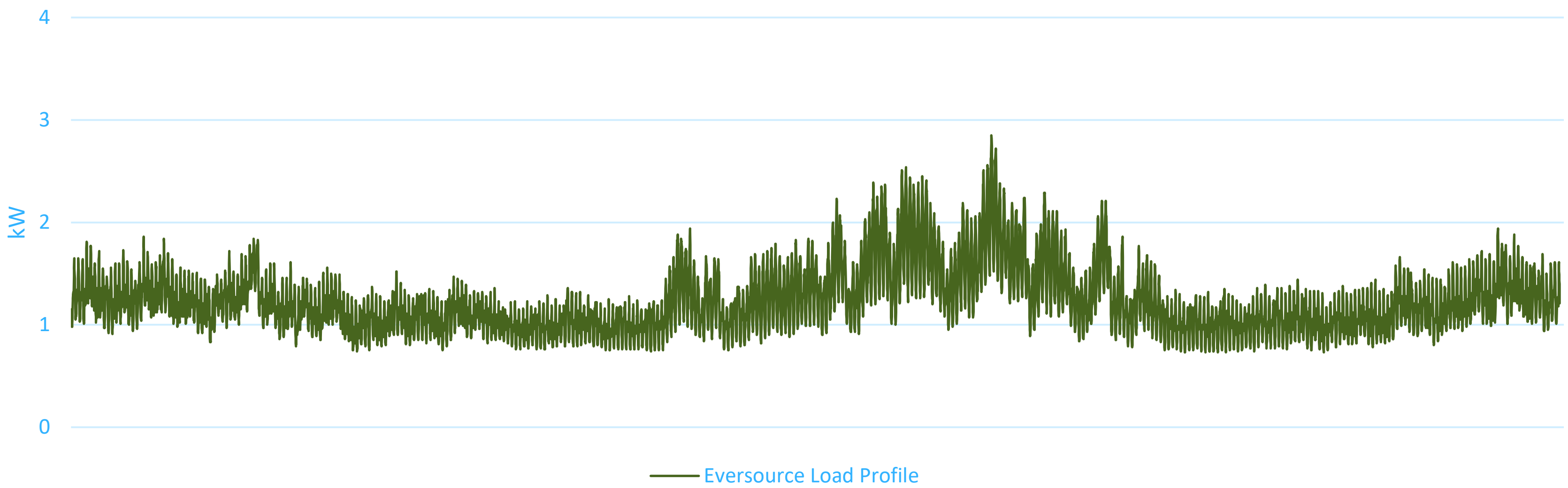
CTGB provided a representative load profile for each utility, and scaled to a typical annual energy consumption for a UI and Eversource customer *that has implemented solar.*

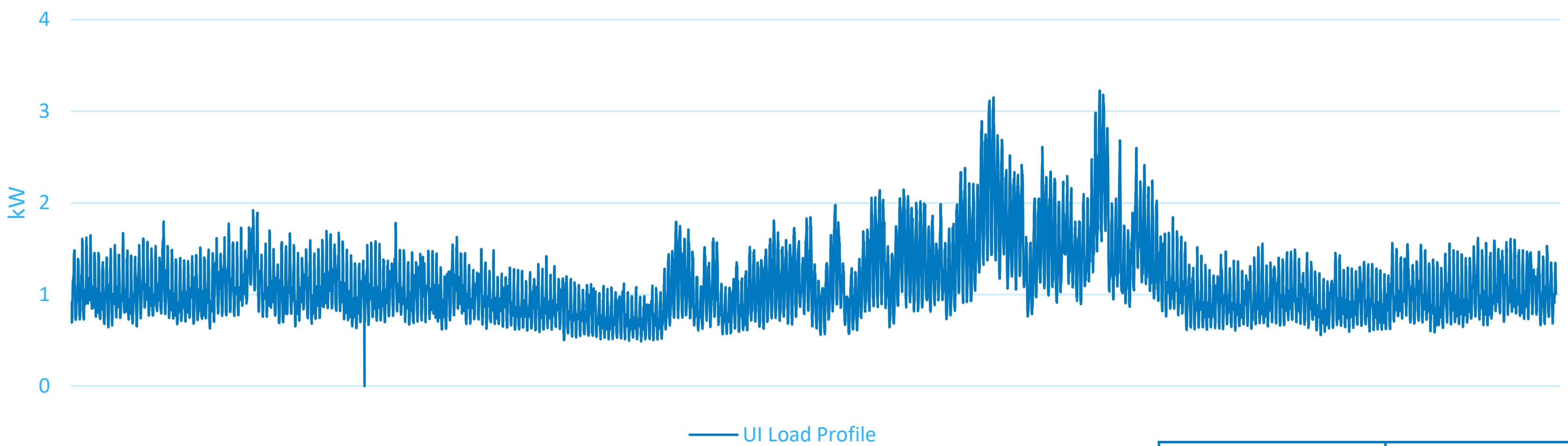
Load year: 2016



Eversource Load Profile	UI Load Profile
10,740 kWh	9,726 kWh

Electric Load Profile by Utility (January – December)





Eversource Load Profile	UI Load Profile
10,740 kWh	9,726 kWh

United Illuminating And Eversource Utility Rates

Current Rate

Eversource - RATE 1	On-peak (Noon- 8 pm)	Off Peak
Year Around	$0.1670 /kWh	

Fixed Charge $ 19.25/month not included

UI - RATE R	On-peak (Noon- 8 pm)	Off Peak
June-September	$0.2356 /kWh	
October-May	$0.2264 /kWh	

Fixed Charge $ 9.67/month not included

Proposed Rate

Eversource- RATE 7	On-peak (Noon- 8 pm)	Off Peak
Year Around	$0.1939/kWh	$0.1589 /kWh

Fixed Charge $ 19.25/month not included

UI - RATE R TOU	On-peak (Noon- 8 pm)	Off Peak
June-September	$0.3539 /kWh	$0.1584 /kWh
October-May	$0.3218 /kWh	$0.1584 /kWh

Fixed Charge $ 10.81/month not included

Proposed RSIP Incentive Structure

RSIP Incentive Step	EPBB ($/W) or PBI ($/kWh) for Grid Mod Pilot	LMI PBI ($/kWh)	Battery Storage Capacity (14 kWh Max) And Power Rating (8 kW Max) ($/kWh)	($/kW)
11	$0.487 / $0.039	$0.110	$60.00	$50.00
12	$0.487 / $0.039	$0.110	$60.00	$50.00
13	$0.487 / $0.039	$0.110	$60.00	$50.00

Table 7. Schedule of Incentives for Steps 11 through 13 for Grid Modernization and Climate Change Pilot

- The Residential Solar Investment Program (RSIP) incentive for battery storage, since storage is a part of the balance of plant for the solar PV system, is in addition to the existing incentives for solar PV.
- For example, if a 7-kW solar PV system is installed and a 14-kWh storage capacity/8-kW power rating battery storage is included, then the RSIP incentive will be $4,649, which includes:
  - $3,409 (at $0.487/W) for the solar PV system and an additional
  - $840 (at $60/kWh storage capacity) and $400 (at $50/kW nominal power rating) for the battery storage.
- Given that a smart inverter must be installed as part of the solar PV system, the homeowner will also be required to go on their EDC's Time-Of-Day billing rate (Eversource's Rate 7 or United Illuminating's Rate RT) and discharge their battery during on-peak hours when utility power is available[1]. Discharging the battery storage system during peak hours will reduce the generation cost of electricity to the homeowner during peak periods.

[1]This analysis considers only the dispatch strategy that maximizes BTM savings for the home owner

Additional Analysis Assumptions

	Assumption
Technologies	Solar PV, storage
Objective	Minimize lifecycle cost (cost-effective projects)
Ownership model	Direct purchase by homeowner
Analysis period	20 years
Discount Rate	6.2% for homeowner
Utility Cost Escalation rate	1.98% per EIA utility cost escalation rates for 21 regions (R5)
Inflation rate	2.1% per EIA
Incentives	30% ITC for PV $0.487/W RSIP EPBB incentive for PV $60/kWh + $50/kW RSIP incentive for storage UI Pilot Program
Net metering limit	No net metering and up to annual load (no cap)
Electricity sellback over net metering	$0.029/kWh based on average LMP
Interconnection limit	None
Technology costs	PV: $3.65/W (CTGB) installed; $21/kW/yr. O&M (NREL ATB) Storage: $300/kWh plus $700/kW (Tesla); replacement in year 10 of $200/kWh plus $200/kW
Technology resource	Bridgeport, CT TYM3 weather file
PV system losses	25.98% per CTGB (PVwatts standard losses 14%)

Analysis Scenarios

- The following scenarios were considered:
  1. Eversource with net metering
  2. Eversource without net metering
  3. UI with net metering
  4. UI without net metering

- The following rate/technology combinations were evaluated in each scenario:
  - Current Residential Rate
  - Current Residential Rate + PV
  - Proposed Residential TOU Rate + PV
  - Proposed Residential TOU Rate + PV + storage

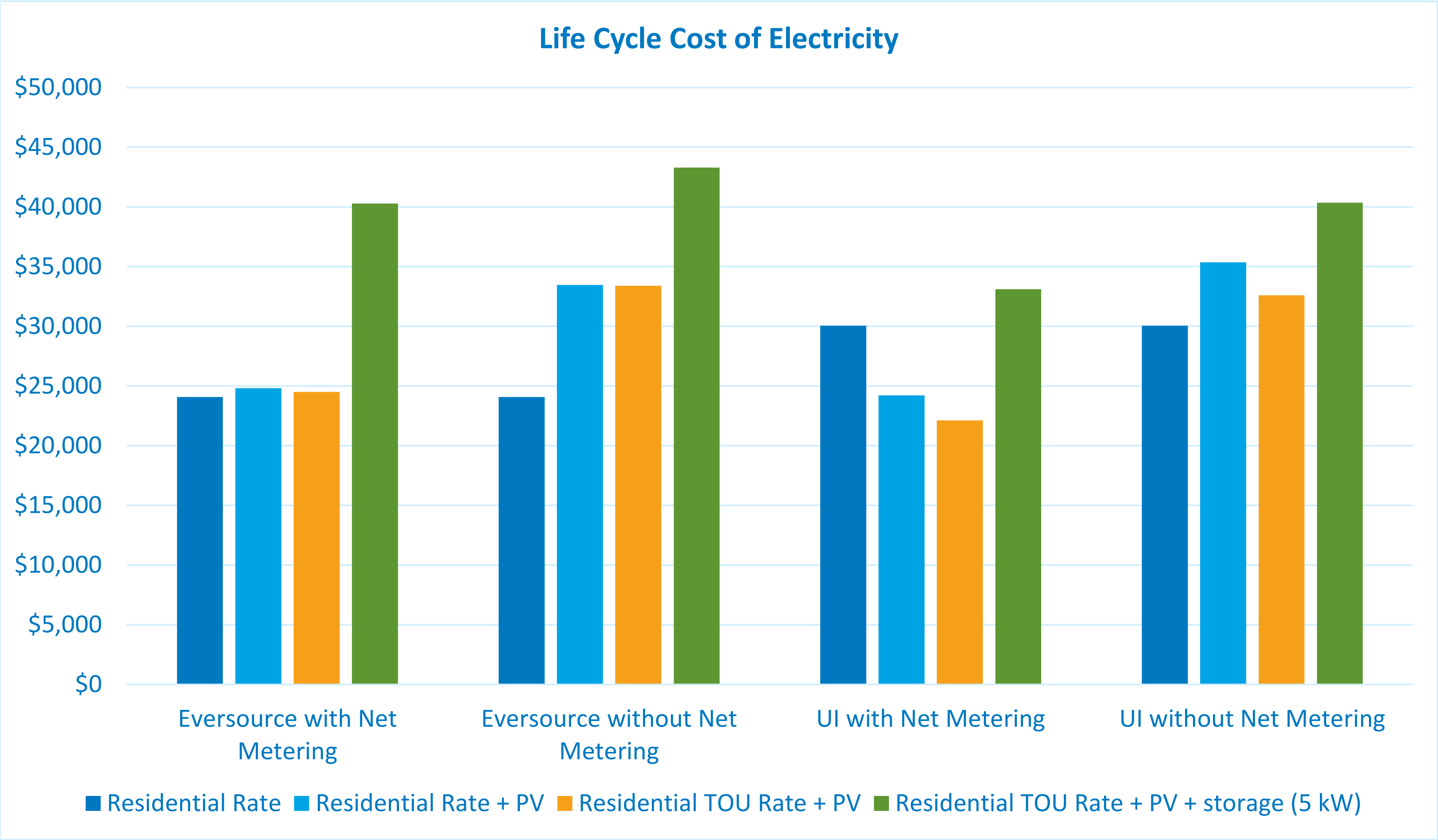
System Sizes

- The PV systems are sized to meet ~100% of the load on an annual basis
  - o Eversource PV size: 8 kW-DC
  - o UI PV size: 7 kW-DC

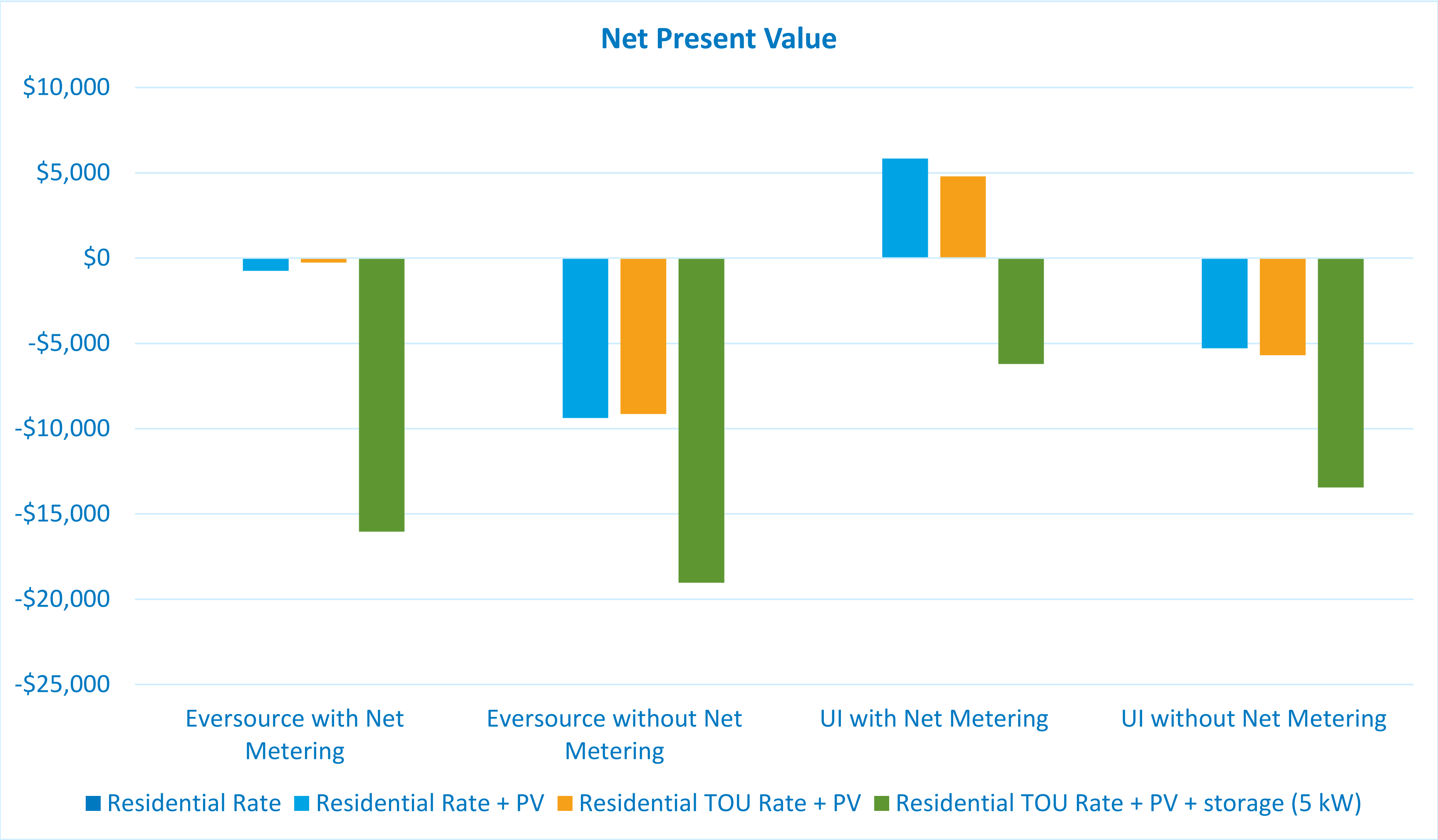
- The battery systems are sizes according to the specifications of the Tesla Powerwall
  - o 13.5 kWh
  - o 5 kW continuous

[1]PV systems are sized to meet the annual load using the average PV production of the 20 year analysis period, assuming a 0.5% annual degradation factor.

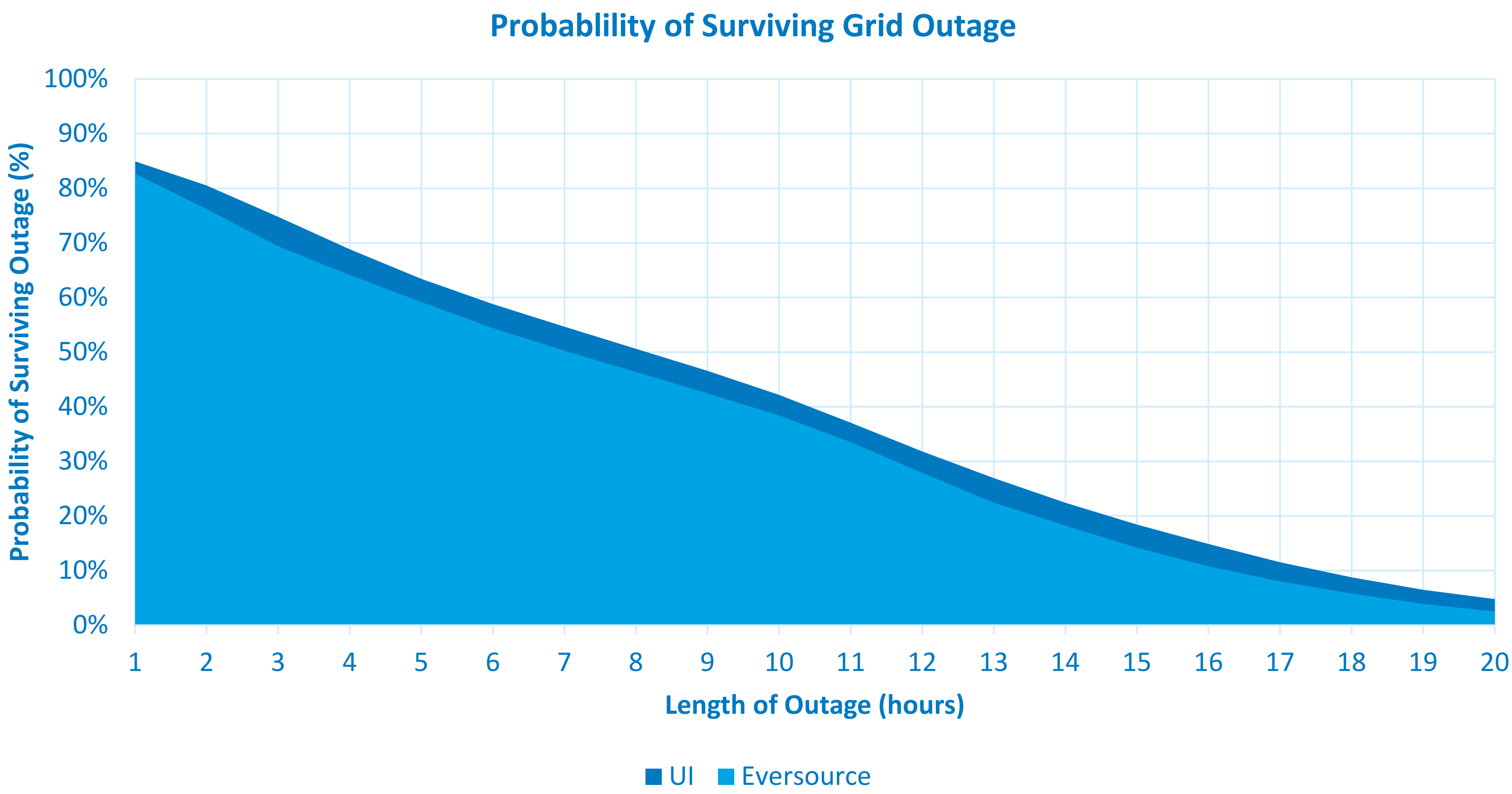
Life Cycle Cost of Electricity Summary



Net Present Value Summary



Probability of Surviving Grid Outage



- Given cost optimal dispatch of a 5 kW/13.5 kWh battery, the customer would be able to survive a 1-hour grid outage ~80% of the year and an 8-hour grid outage ~50% of the year

Eversource Results with Net Metering

	Eversource 1	Eversource 1 with PV & NM	Eversource 7 TOU with PV & NM	Eversource 7 TOU with PV, Storage & NM
PV Size (kW-DC)	0	8	8	8
Battery Size (kW)	0	0	0	5
Initial Cost (less Incentives)	$0	$29,200	$29,200	$45,065
Annual Electric Usage (kWh/yr)	10,740	6,617	6,617	6,412
Annual Electric Costs ($)	$1,794	$327	$304	$297
Life Cycle Cost ($)	$24,081	$24,826	$24,513	$40,292
Net Present Value ($)	$0	-$745	-$257	-$16,036

Eversource Results without Net Metering

	Eversource 1	Eversource 1 with PV, no NM	Eversource 7 TOU with PV, no NM	Eversource 7 TOU with PV & Storage, no NM
PV Size (kW-DC)	0	8	8	8
Battery Size (kW)	0	0	0	5
Initial Cost (less Incentives)	$0	$29,200	$29,200	$45,065
Annual Electric Usage (kWh/yr)	10,740	6,617	6,617	3,417
Annual Electric Costs ($)	$1,794	$970	$965	$520
Life Cycle Cost ($)	$24,081	$35,459	$33,394	$43,286
Net Present Value ($)	$0	-$9,378	-$9,138	-$19,030

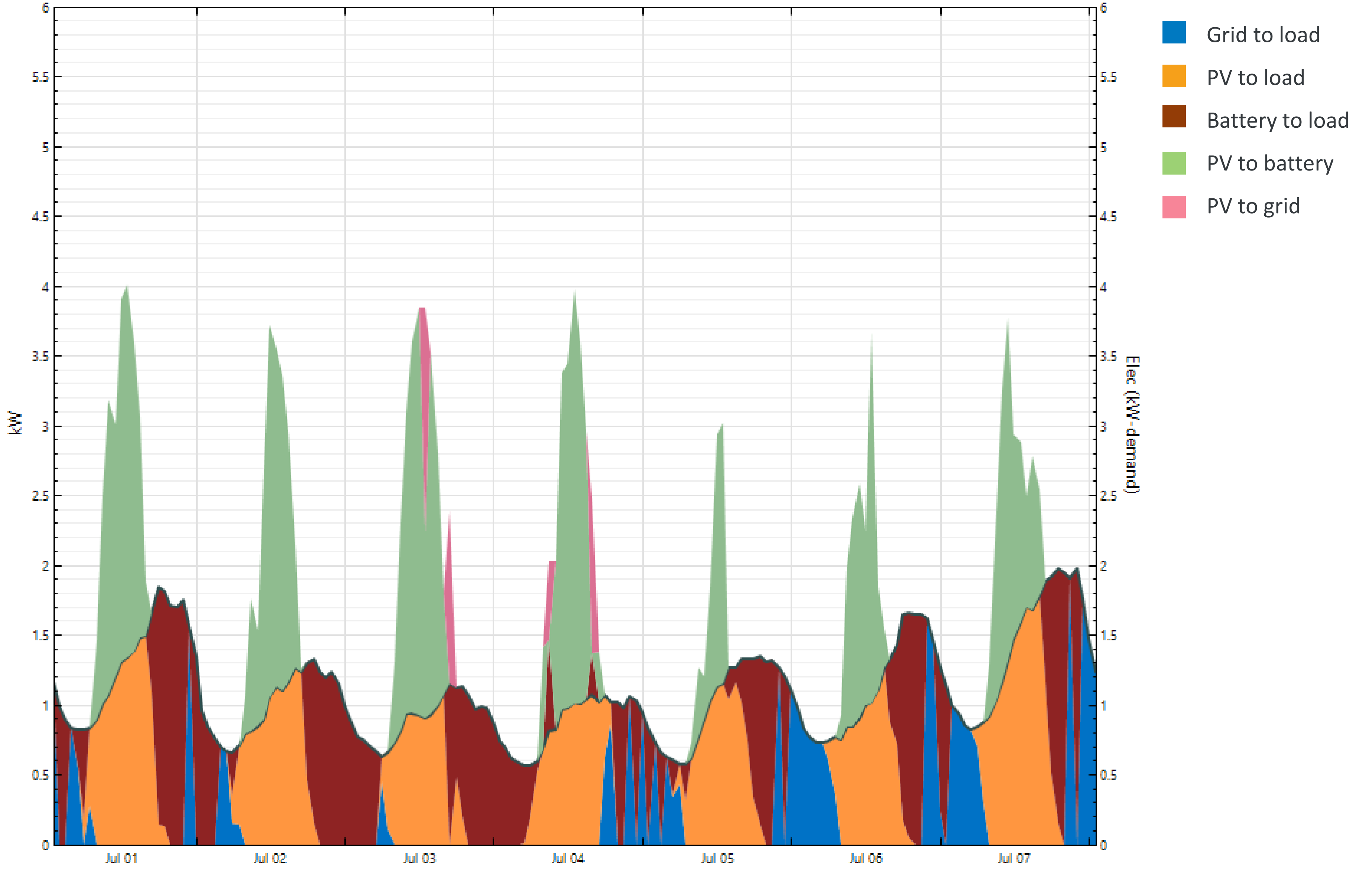
UI Results with Net Metering

	UI R	UI R with PV & NM	UI R TOU with PV & NM	UI R TOU with PV, Storage & NM
PV Size (kW-DC)	0	7	7	7
Battery Size (kW)	0	0	0	5
Initial Cost (less Incentives)	$0	$25,550	$25,550	$41,415
Annual Electric Usage (kWh/yr)	9,726	6,177	6,177	5,861
Annual Electric Costs ($)	$2,239	$472	$315	-$48
Life Cycle Cost ($)	$30,055	$24,221	$22,109	$33,107
Net Present Value ($)	$0	$5,835	$4,789	-$6,209

UI Results without Net Metering

	UI R	UI R with PV, no NM	UI R TOU with PV, no NM	UI R TOU with PV & Storage, no NM
PV Size (kW-DC)	0	7	7	7
Battery Size (kW)	0	0	0	5
Initial Cost (less Incentives)	$0	$25,550	$25,550	$41,415
Annual Electric Usage (kWh/yr)	9,726	6,177	6,177	3,191
Annual Electric Costs ($)	$2,239	$1,301	$1,096	$492
Life Cycle Cost ($)	$30,055	$35,349	$32,596	$40,346
Net Present Value ($)	$0	-$5,293	-$5,699	-$13,448

Dispatch – First Week of July UI No Net Metering PV + Storage



Impact of UI Pilot Incentive Program

United Illuminating "Localized Targeting of DERs" Pilot

- United Illuminating (UI) will be running a pilot program in 2018 to look at the impact of high saturation of DERs on a single circuit (penetration >10%) and their effectiveness for deferring distribution capacity upgrades. UI will offer several incentives to customers during the pilot to spur DER adoption. They hope to defer a forecasted 2 circuit overload of 1MW, that would require a $625,000 infrastructure investment to address.

- Program Requirements and Incentives:
  - Customers in the pilot will be required to install a "smart inverter" with storage and ride through capabilities, estimated at a $200 incremental cost over a traditional inverter

- UI will offer a 5-year rate rider to customers participating in the pilot for solar or battery storage production:
  - From June 1st to September 30th customers will receive $0.05/kWh for electricity generated on-site between 15:00 and 18:00h.
  - UI's goal is 137 residential participants

Value of UI Pilot Incentive

- The UI pilot incentive has minimal impact on the lifecycle cost of installing PV and/or storage

- Value of PV incentive (all scenarios)
  - Annual PV production: 7,684 kWh
  - PV production June 1st to September 30th 15:00 - 18:00: 366 kWh
  - Incentive value = 366 kWh*4.19*1.04*$0.05/kWh = **$79**

- Value of storage incentive (with net metering)
  - Storage discharge June 1st to September 30th 15:00 - 18:00: 422kWh (same as without incentive)
  - Incentive value = 422 kWh *4.19*$0.05/kWh = **$93**

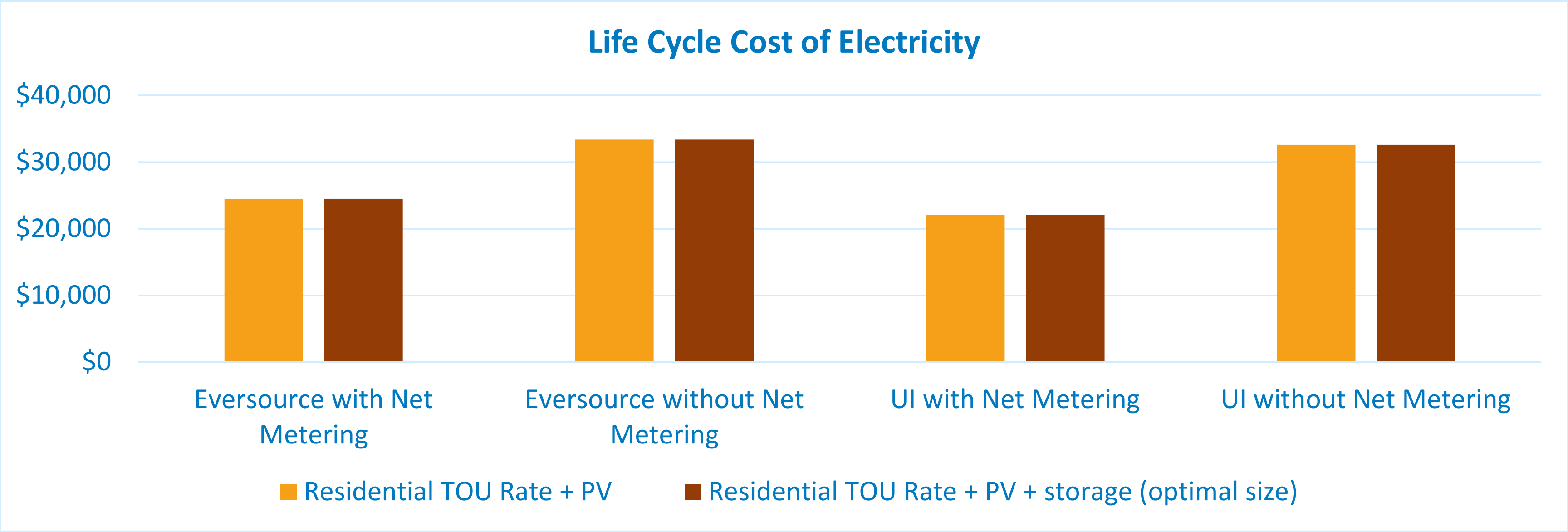
- Value of storage incentive (without net metering)
  - Storage discharge June 1st to September 30th 15:00 - 18:00: 294 kWh (compared to 217 kWh without incentive)
  - Incentive value = 294 kWh *4.19*$0.05/kWh = **$61**

Value of incentive calculated based on average of first 5 years of PV production (1.04% of average PV production for 20 years)
Present value of 5 year incentive taking into account discount rate and escalation rate: 4.19

Impacts of Varying Battery Sizing

Results for Optimal Storage Size (TOU with PV)

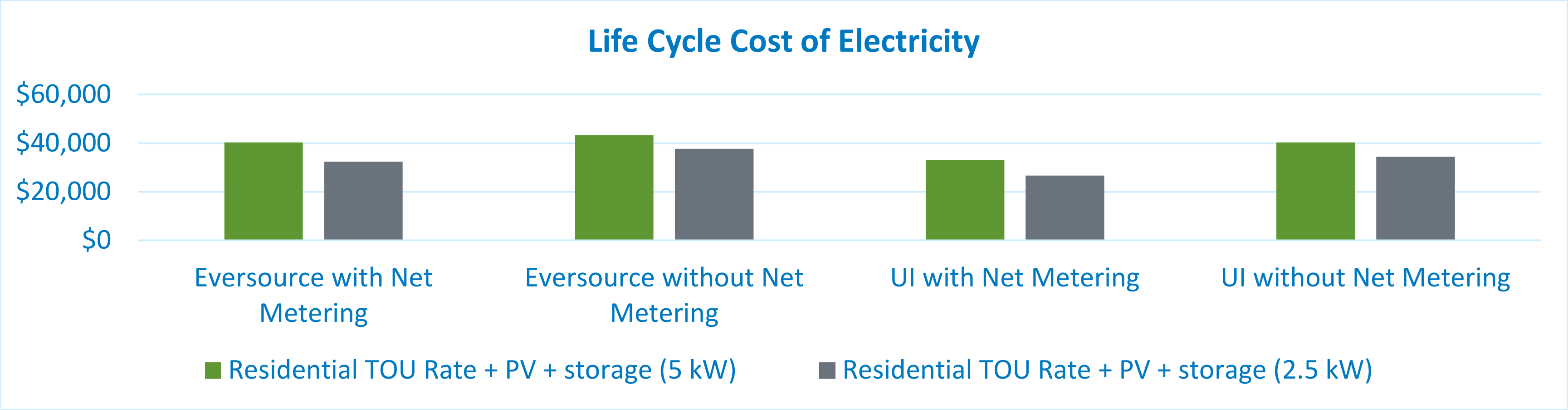
When the model is allowed to determine the optimal size of storage, storage does not appear cost effective (model does not ‘choose’ to add it)

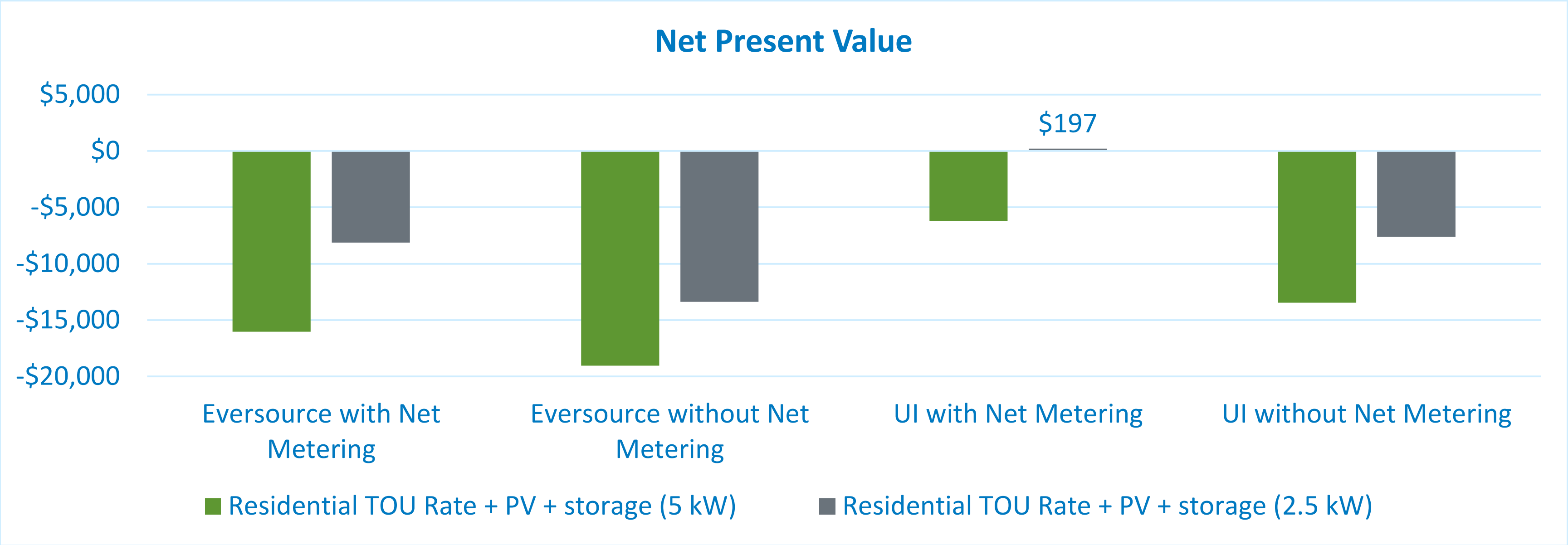


Site Name	Eversource with Net Metering	Eversource without Net Metering	UI with Net Metering	UI without Net Metering
Basecase lifecycle cost	$24,513	$33,394	$22,109	$32,596
Optimal Storage Size	0	0	0	0
Lifecycle cost	$24,513	$33,394	$22,109	$32,596
Decrease in lifecycle cost	$0	$0	$0	$0

Results for 2.5 kW Battery

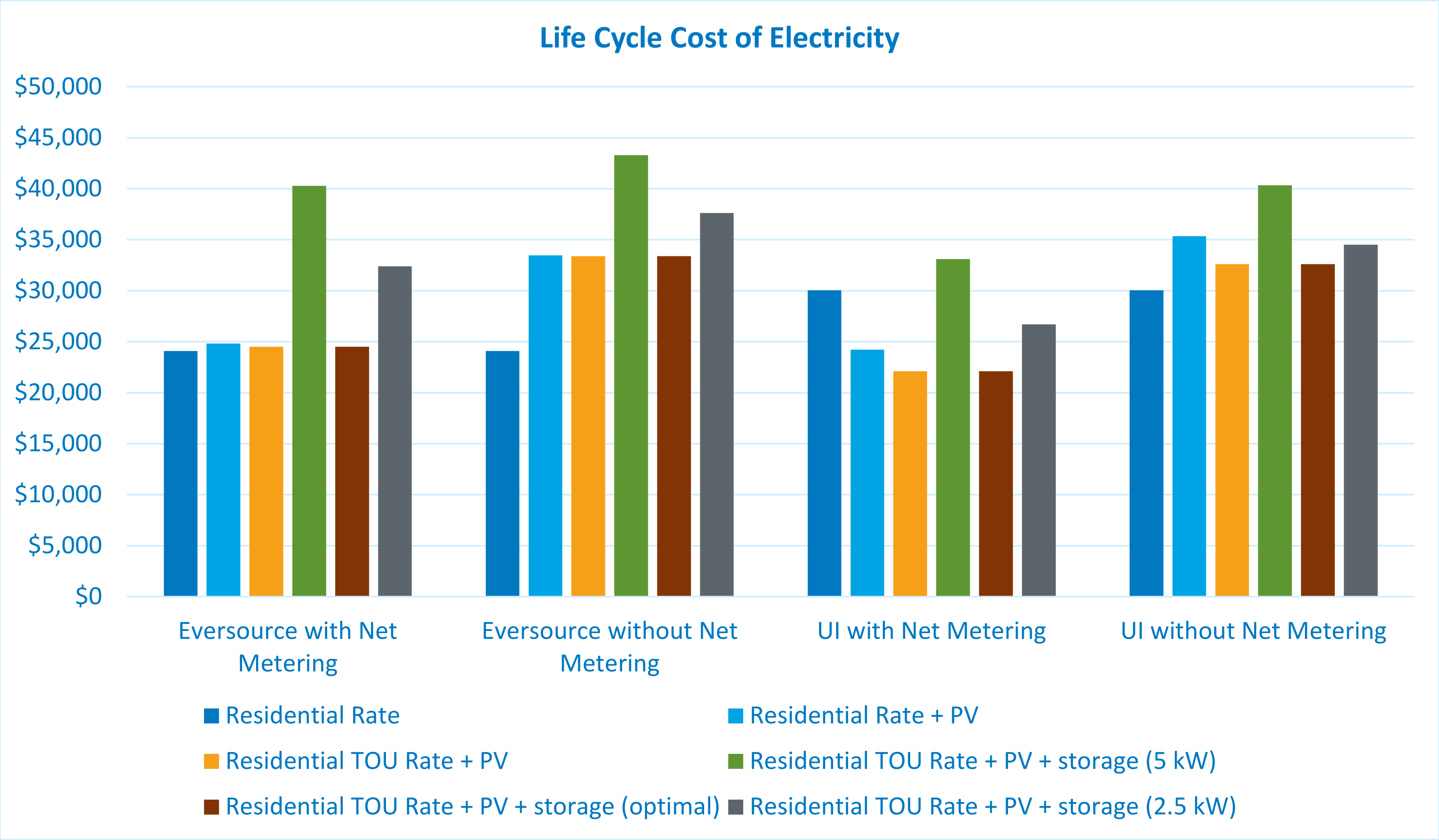
Compared to the 5 kW battery, the 2.5 kW battery has a lower lifecycle cost and greater net present value, however the net present value is still negative for 3 of 4 scenarios



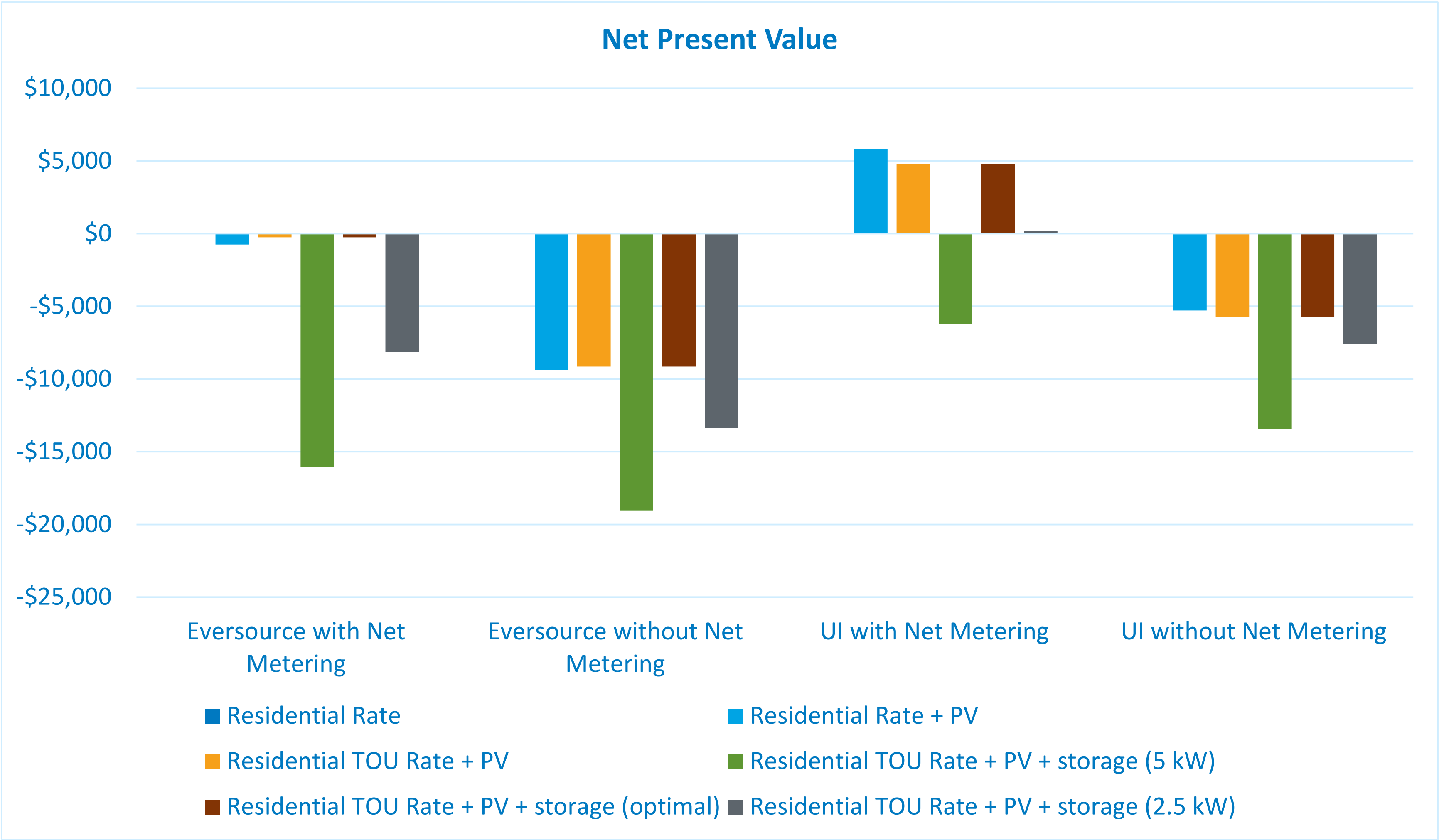


Summary

Summary Lifecycle Costs



Summary Net Present Value



Results Summary

- Eversource impacts of PV and storage:
  - Installing PV on either Eversource rate has *minimal* impact on the NPV with current net metering rules
  - Without net metering, the lifecycle cost of energy will *increase* when installing PV only
  - Installing a battery at current incentive levels will *increase* the lifecycle cost of energy both with and without net metering

- UI impacts of PV and storage:
  - Installing PV on either UI rate will *decrease* the lifecycle cost of energy with current net metering rules
  - Without net metering, the lifecycle cost of energy will *increase* when installing PV only
  - Installing a battery has *minimal impact* on the life cycle cost with net metering, but will *increase* the lifecycle cost without net meting
  - The UI pilot incentive has minimal impact on the lifecycle cost of installing PV and/or storage

- Impacts of battery sizing:
  - When the model is allowed to determine the optimal size of storage, storage does not appear cost effective
  - Compared to the 5 kW battery, the 2.5 kW battery has a lower lifecycle cost and greater net present value, however the net present value is still negative for 3 of the 4 scenarios

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- This analysis relies on site information provided to NREL by CTGB that has not been independently validated by NREL.

- This analysis is a starting point for additional research and consideration of investment or policy options. Other factors that can inform decision-making are not considered here.

- The analysis results are not intended to be the sole basis of investment, policy, or regulatory decisions.

- The data, results, conclusions, and interpretations presented in this document have not been reviewed by technical experts outside NREL *or* CTGB.

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Appendix

REopt PV + Battery Assumptions

Li Ion Battery

- Bucket model moves energy from one time period to another
- Sizes energy capacity / power independently
- Tracks and costs battery degradation
  - Simple throughput
  - Cycles
  - Cycles / Depth of Discharge

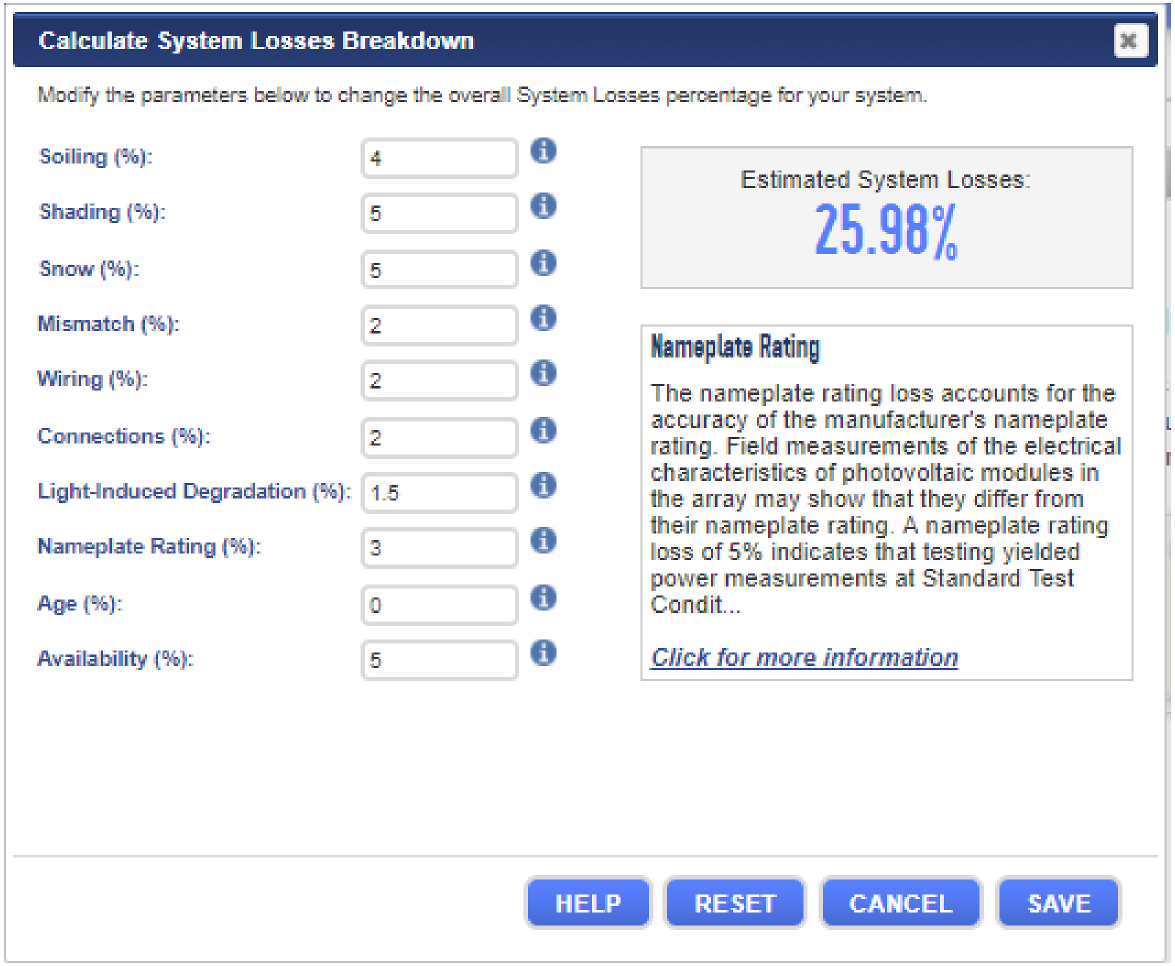
Li Ion Battery Characteristics	
Total Round Trip Efficiency	82.9%
Battery Throughput	90%
Inverter Efficiency	96%
Rectifier Efficiency	96%
Minimum Charge	0%
Initial SOC	0%

Solar PV

- Fixed tilt; oriented due south with tilt = latitude
- Hourly solar radiation data from Typical Meteorological Year 3 (NREL 2008).
- Represents 1,020 locations in the US. Derived from 1991–2005 National Solar Radiation Data Base.

Solar PV Characteristics	
Annual Degradation (%)	-0.5%
Inverter Efficiency (%)	96%
BOS Efficiency	74%

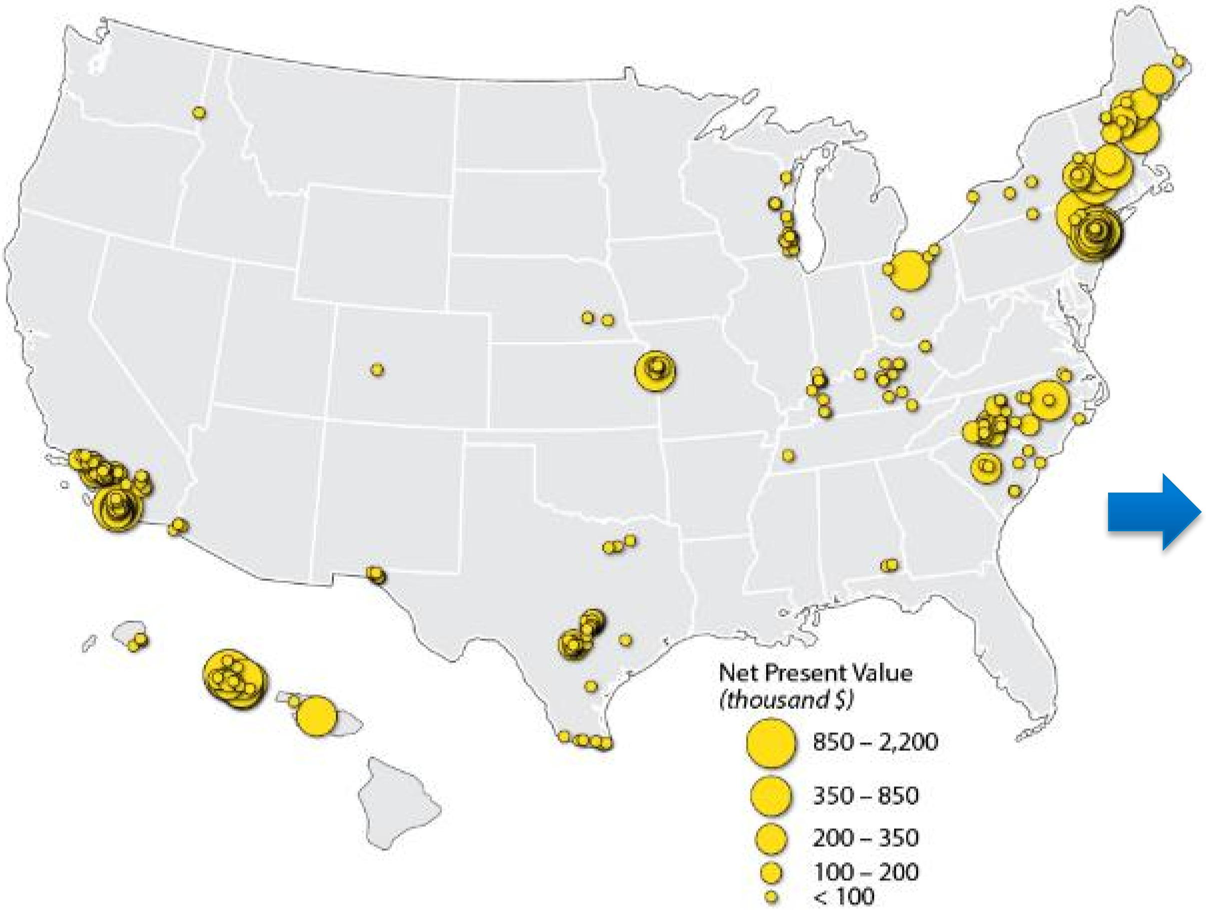
Losses in Pvwatts (from CTGB)



Project Example: Identifying & Prioritizing Projects across a Portfolio

REopt portfolio screening can help:

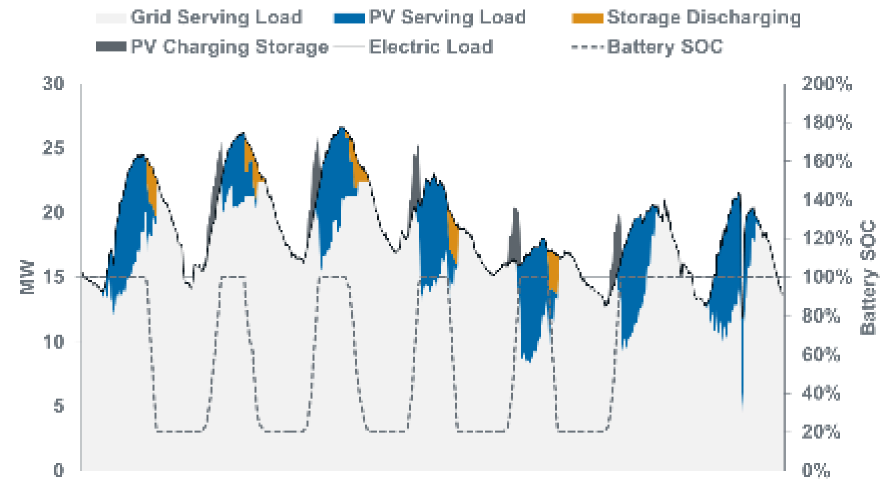
- Identify & prioritize cost-effective projects to minimize lifecycle cost of energy or achieve net zero
- Estimate cost of meeting renewable energy goals



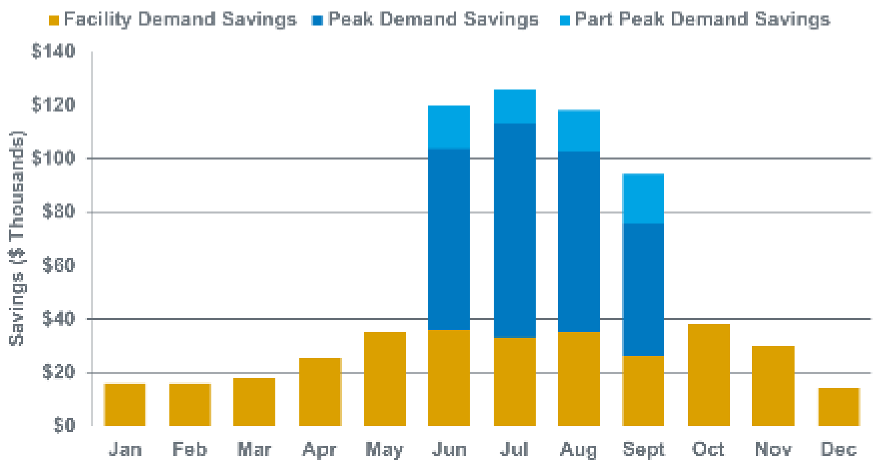
Sites Evaluated	696
Cost-Effective PV	306
Size	38.79 MW
NPV	$37 million
RE Generation	64.7 GWh
RE Penetration	10.5 %

Project Example: PV + Battery Sizing in Southern CA

- Determine economically optimal PV + storage system size & dispatch using:
  - o 15-minute electric load
  - o Southern California Edison utility tariff TOU-8
- Results show 12.4 MW PV + 2.4 MW:3.7 MWh storage can provide $19.3 million NPV
- Battery is only economical when paired with PV at this site due to wide peaks
- Optimal battery dispatch strategy reduces all three demand charges



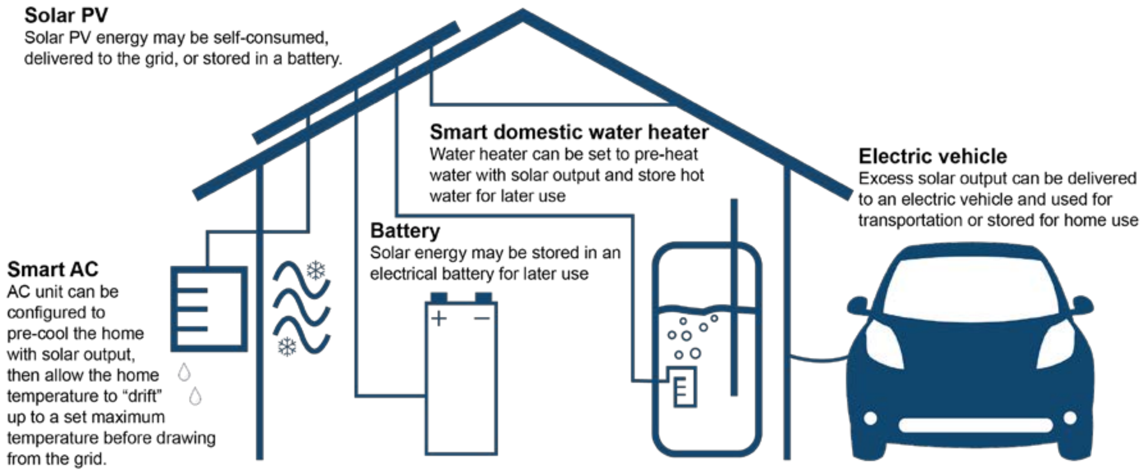
Optimal Dispatch for Week in July



Savings from Demand Reduction

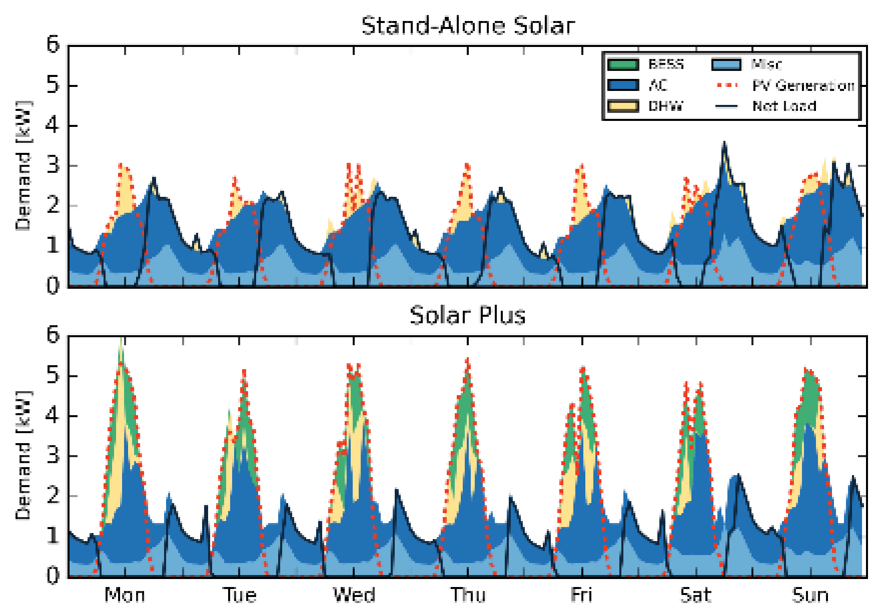
Solar "Plus" – Residential Solar + Storage

- Determined optimal mix/size of solar and solar "plus" for post-net metering residential utility tariffs (including time-of-use and demand tariffs)
- 5 Case studies across emerging tariffs: HI, CA, NV, AZ (demand), AZ (TOU-SP)



Graphic is conceptual, EV's and other dispatchable loads were not included

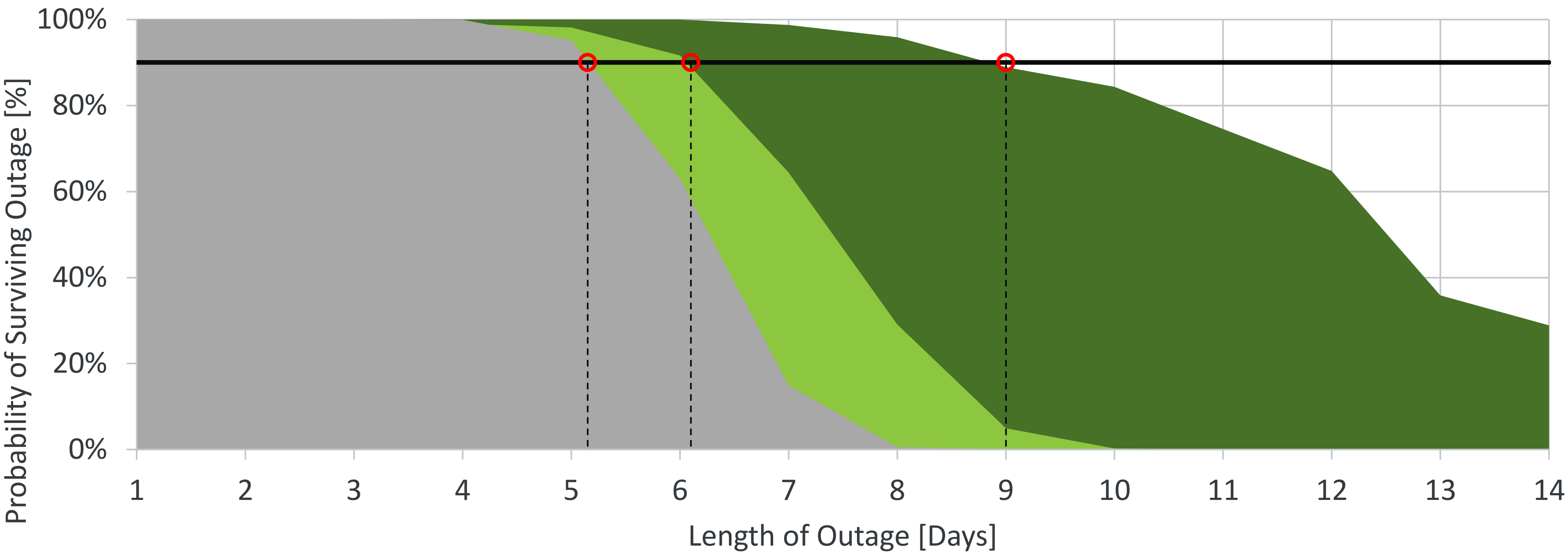
	Solar	Solar Plus
PV Size	4.6 kW	8 kW
Battery Size	-	7.8/1.3
Smart Water Heater & AC	-	Deployed
Annual PV Generation	6,247 kWh	11,663 kWh
Annual Savings	$957	$2,690
NPV	$5,684	$16,851



Project Example: Using RE to Extend Survivability

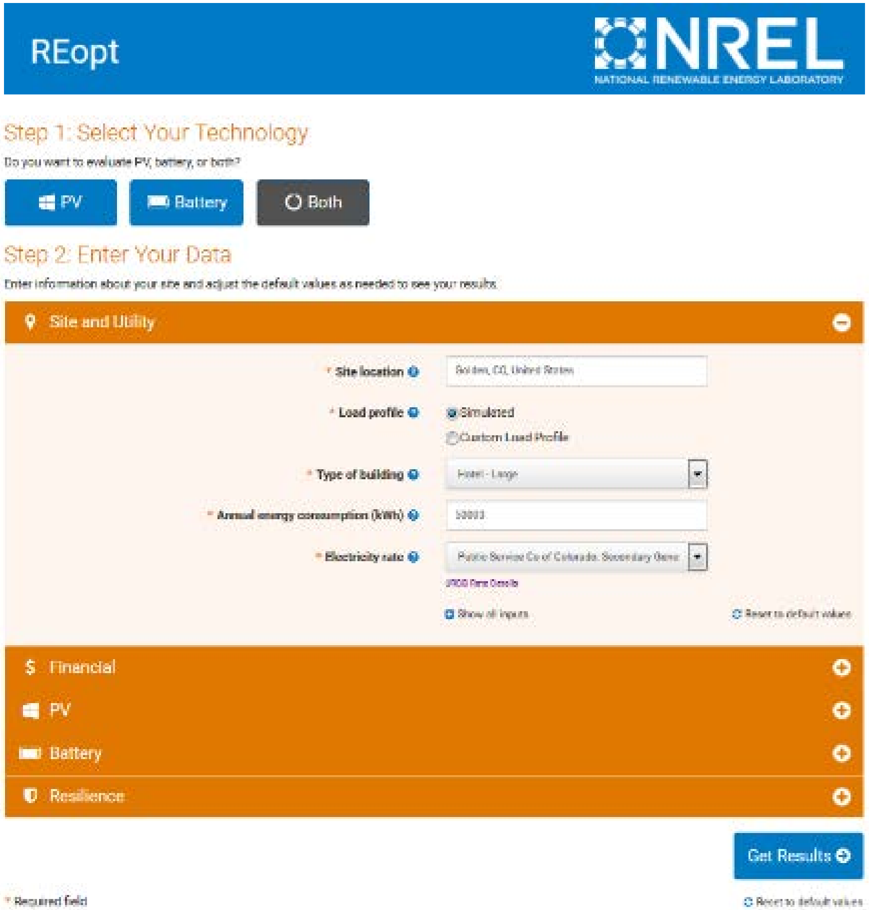
NREL evaluated thousands of random grid outages and durations throughout the year and compared number of hours the site could survive with a diesel generator and fixed fuel supply vs. generator augmented with PV and battery

	Generator	Solar PV	Storage	Lifecycle Cost	Outage
1. Base case	2.5 MW	-	-	$20 million	5 days
2. Lowest cost solution	2.5 MW	625 kW	175 kWh	$19.5 million	6 days
3. Proposed system	2.5 MW	2 MW	500 kWh	$20 .1million	9 days



REopt Lite Web Tool

- 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



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