Task 3.II: Backup Power Valuation Methodology: *Develop a methodology to value backup power, including: lost economic output, loss of critical and non-critical services, security, etc.*

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Overview:

Sovereign has conducted a thorough review of research literature created by the Department of Energy National Laboratories to present the Peninsula Advanced Energy Communities (PAEC) with a methodology to value backup power. The literature synthesized in this summary are the following reports:

- *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers*, Christina Hamachi LaCommare and Joseph H. Eto, Ernesto Orlando Lawrence Berkeley National Laboratory, September 2004
- *New York Solar Smart DG Hub-Resilient Solar Project: Economic and Resiliency Impact of PV and Storage on New York Critical Infrastructure*, Kate Anderson, Kari Burman, and Travis Simkins, Erica Helson, Lars Lisell, National Renewable Energy Laboratory, June 2016

Frameworks for Valuing Backup Power:

Both papers present methodologies for valuing resiliency. At its most basic level, the value of resiliency to a site is equal to the cost the site incurs during a power outage. That site-specific cost depends on multiple factors including: frequency of service outage, duration of outage, timing of outages (peak vs on peak), type of use specific to the facility, and availability of backup power systems.

The NREL document suggest two approaches to determining the cost of grid interruption; macroscopic and microscopic:

"In the macroscopic approach, the value is based on national or utility-wide estimates of outage costs that have been experienced in the past. This method requires relatively little data, but may not capture site-specific values well. In the microscopic approach, the value is based on a survey

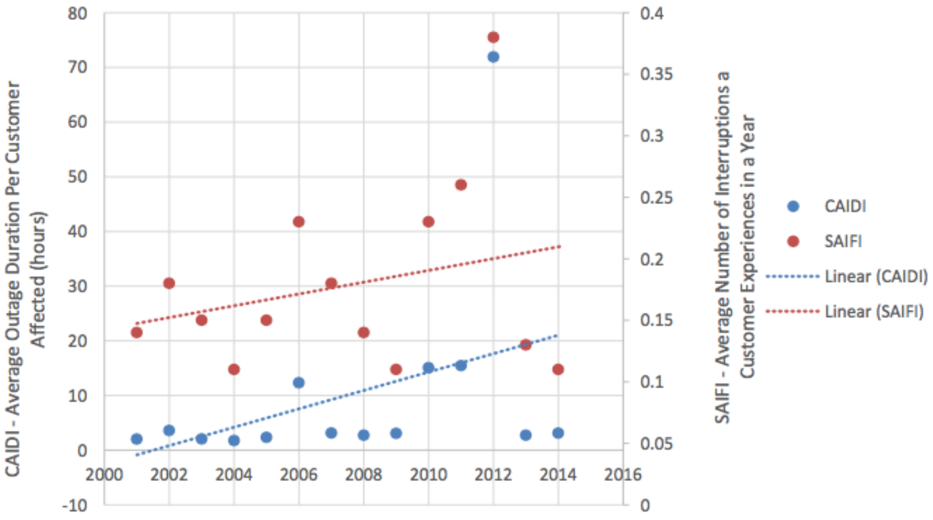
of the site-specific installation of outage costs. This may be more accurate, but is much more time-consuming to determine."

The macroscopic approach looks at system-wide outage statistics, which are reported by all regulated utilities. These metrics are:

1. SAIFI: average number of interruptions a customer experiences in a calendar year
2. SAIDI: average outage duration across all customers served
3. CAIDI: average outage duration per utility customer affected (in hours)

The below example shows these utility metrics for Consolidated Edison Company of New York. The graphic shows that both the frequency and duration of outages has increased over the past 14 years. In terms of monetary cost of storms, 7 of the 10 most costly storms have occurred in the last 10 years.[1]

Figure 1: Outage metrics for Consolidated Edison



NREL has developed a tool utilizing SAIFI, SAIDI, and CAIDI metrics, number of customers, customer classes, location, and average energy use to calculate an average hourly cost of interruption. The NREL study uses this tool to develop a value of resiliency for three specific building types: school shelter, fire station, and senior center (cooling center). It is important to note that all of these facilities play a role in disaster response, which increased the monetary value ascribed to them in the study:

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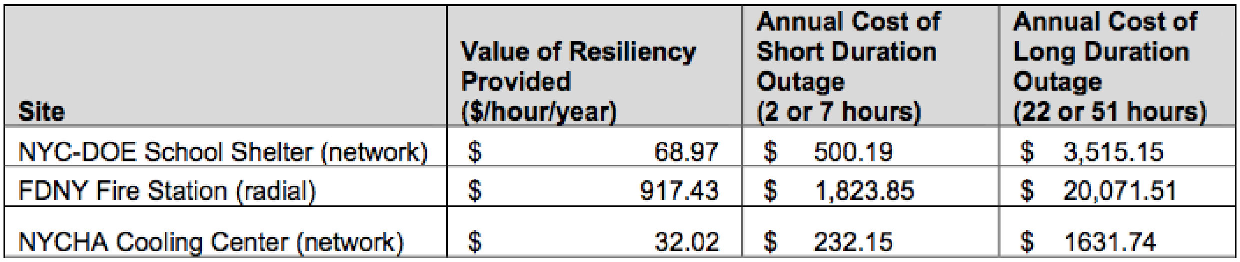
[1] Executive Office of the President. 2013. *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*. http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf.

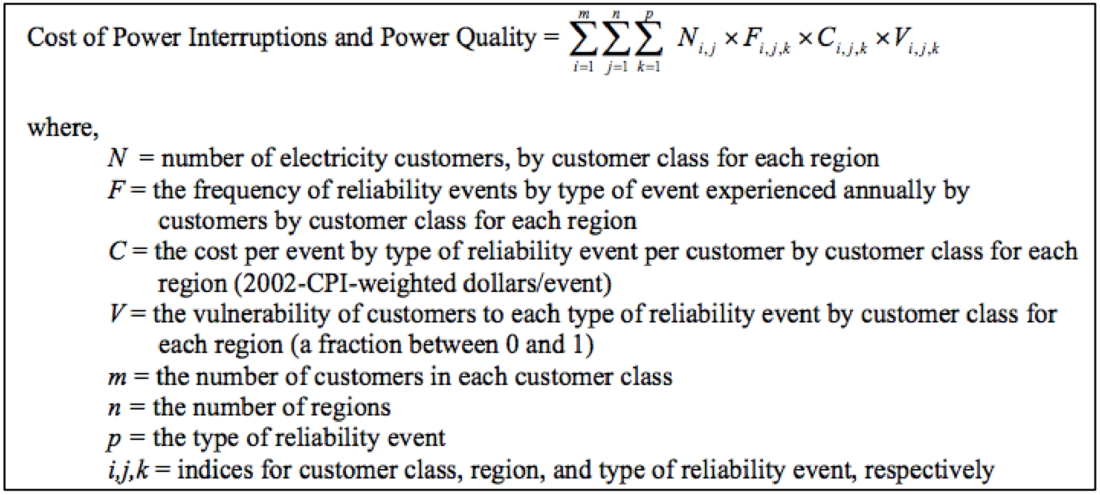
Figure 2: Value of resiliency by facility type for NREL study



Site	Value of Resiliency Provided ($/hour/year)	Annual Cost of Short Duration Outage (2 or 7 hours)	Annual Cost of Long Duration Outage (22 or 51 hours)
NYC-DOE School Shelter (network)	$ 68.97	$ 500.19	$ 3,515.15
FDNY Fire Station (radial)	$ 917.43	$ 1,823.85	$ 20,071.51
NYCHA Cooling Center (network)	$ 32.02	$ 232.15	$ 1631.74

The Lawrence Berkeley National Lab (LBNL) describes a complex end-use framework for estimating the economic cost of power interruptions and power quality:

Figure 3: LBNL Economic Cost of Power Interruption Formula



$$\text{Cost of Power Interruptions and Power Quality} = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p} N_{i,j} \times F_{i,j,k} \times C_{i,j,k} \times V_{i,j,k}$$

where,

N = number of electricity customers, by customer class for each region
F = the frequency of reliability events by type of event experienced annually by customers by customer class for each region
C = the cost per event by type of reliability event per customer by customer class for each region (2002-CPI-weighted dollars/event)
V = the vulnerability of customers to each type of reliability event by customer class for each region (a fraction between 0 and 1)
m = the number of customers in each customer class
n = the number of regions
p = the type of reliability event
i,j,k = indices for customer class, region, and type of reliability event, respectively

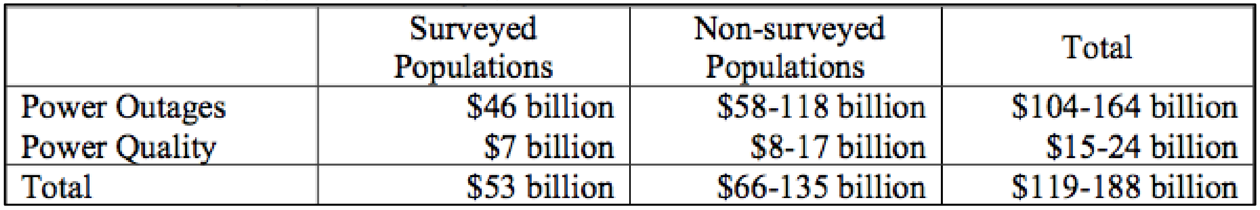
The LBNL analysis breaks down the cost of power interruptions by customer class; residential, C&I, and the cost borne by the infrastructure of society. Costs borne by firms are easier to quantify, but it is important to calculate net losses, not gross losses, because shifts are often rescheduled to accommodate a power failure. The study as determines that there is not a direct correlation between duration of power failure and monetary loss; some instantaneous power losses can result in extremely high cost, especially when dealing with critical infrastructure.

The LBNL paper cites three academic approaches to estimate the economic cost of reliability events. A 1993 paper (Clemmensen) estimated an annual cost of $26B for the US Manufacturing sector. This cost was based on annual spending of industrial equipment to address power quality problems. Extrapolated outside of the manufacturing industry this annual cost estimate increases to $50B. In the analysis, Clemmensen estimated that $1.5 – 3 cents of every manufacturing sales dollar was being spent on power quality equipment.

The second paper sites a 1998 paper (Swaminatha and Sen) estimates total US Power quality spending at $150B per year. This estimate was based on a 1992 study by Duke Power, which focused on that utility service territory's industrial segment. The authors then used that data to extrapolate across the US electricity market.

Lastly, LBNL cites a 2001 EPRI paper (Primen), which estimated that annual national spending on power quality issues to be $119B. This was the most granular report, interviewing 985 firms across 3 industries (digital economy, continuous process manufacturing, and fabrication and essential services) to discern spending habits on reliability and power quality. See the results of the Primen study below:

Figure 4: Results of Primen Study on Reliability (2001)



	Surveyed Populations	Non-surveyed Populations	Total
Power Outages	$46 billion	$58-118 billion	$104-164 billion
Power Quality	$7 billion	$8-17 billion	$15-24 billion
Total	$53 billion	$66-135 billion	$119-188 billion

Conclusions:

- The value of resiliency is heavily dependent on the type of facility at risk of a power failure.
- For state facilities in New York City, resiliency values have been calculated between $68 and $917 $/hour/year.
- For longer duration outages, the value of resiliency can increase to $20,000 for a 22 – 51 hour outage at an emergency facility (Fire Department on radial circuit).

PV + Storage Resiliency Use Cases:

The EPRI study performed an economic analysis of 4 different technology scenarios at three different facility types to assess cost effectiveness. The facility types are a school, a fire station, and a mixed-use senior living complex. For purposes of this report, we will focus on the mixed-use complex as our example. The technology scenarios are the following:

- **Scenario 1:** Resilient PV sized for economic savings; no resiliency requirement imposed. The model selects a solar + storage system sized to be cost-effective for the host site.

- **Scenario 2:** Resilient PV sized to meet resiliency needs. The model selects a solar + storage system sized to support critical electric loads for short and long outages.

- **Scenario 3:** Resilient PV and a generator (hybrid system) sized to meet resiliency needs. The model chose from solar, storage, and diesel generator resources to size a hybrid system that supports critical electric loads for short and long outages.

- **Scenario 4:** Generator sized to meet resiliency needs The model sized a diesel generator to support critical electric loads for short and long outages.

The results of the study indicate that PV + Storage study indicate the following:

“If a technology solution is being implemented primarily to provide emergency power, the results of the analysis indicate that a hybrid system (Scenario 3) that includes resilient PV and a generator is the most cost-effective technology solution, when measured by lifecycle cost savings. The savings the battery (and sometimes PV) provides during normal grid-connected operation make the hybrid system more economical than a diesel generator alone. However, the hybrid system has a higher initial cost and is more complex than a stand-alone generator.

If lifecycle cost savings is the primary goal, and emergency power is secondary, the results of the study show storage (and sometimes PV) to be the best solution out of the options evaluated for the three sites analyzed under this study. These systems provide maximum cost savings over the project lifecycle with some resiliency benefit. A generator-only solution (Scenario 4), while having the least expensive initial cost, provided lower lifecycle cost savings because this type of asset does not provide value during normal, on-grid operations in this analysis.

The analysis also found that energy storage was cost-effective at all three locations. This is due to the high demand rates and the shape of the load profile at each of these sites. A modestly sized battery system can be strategically charged and discharged such that it shaves the monthly peak loads and therefore captures significant demand savings. It is expected that batteries would also be economically viable at other critical infrastructure sites with high *demand rates and similarly shaped load profiles."*[2]

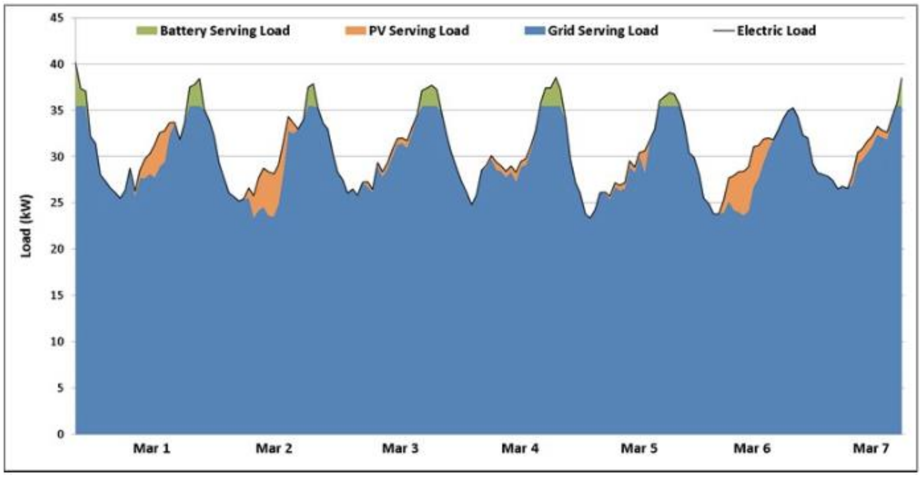
The core message of the NREL economic analysis is that PV + Storage systems already create economic value for customers by generating energy and cutting facility peaks. If a resiliency value is added to the equation, it will increase the economic value proposition. Although diesel generators are more widely used today, in urban areas they are only more economically valuable than PV + Storage systems if there are frequent long duration electricity outage events. In order to justify a resiliency value in a project, developers should perform a site specific $/hour analysis of the value of resiliency for the specific facility.

Figure 5: Mixed use facility, Scenario 1: Resilient PV Sized for Economics Savings, No Resiliency Requirement Imposed

Cooling Center			
Scenario 1: PV + Storage Sized for Economic Savings			
	System 1.1: No resiliency value captured	**System 1.2: Short duration resiliency value captured**	**System 1.3: Long duration resiliency value captured**
PV Size (kW-DC)	7	8	8
Battery Size (kWh)	25	25	25
Battery Size (kW)	7	7	7
Total Capital Cost	$46,286	$50,120	$50,538
NPV	$413	$1,683	$1,862
Simple Payback (years)	15.6	14.1	11.1

If a resiliency value metric is added to a PV + Storage project economic pro-forma model, the payback period will decrease and the net present value will increase

Figure 5: Under Scenario 1, PV + Storage is being dispatched to lower peak demand



Under scenario 1, the battery is both reducing peak demand at the facility to lower demand

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[2] NREL Study, page 6

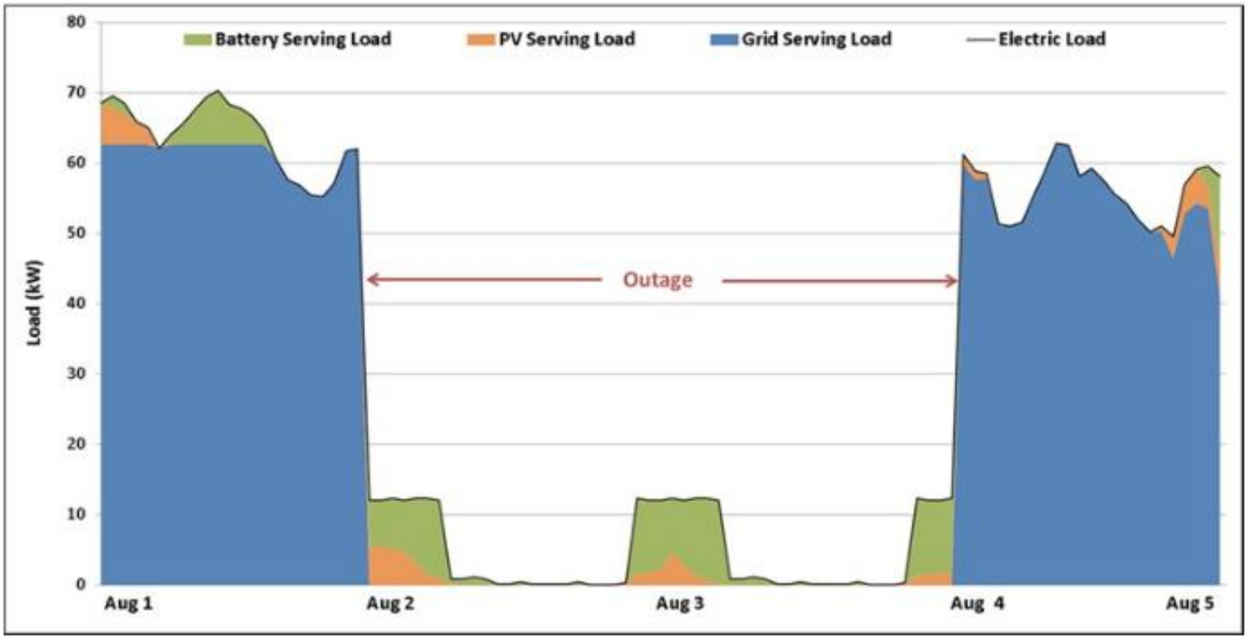
charges, as well as providing resiliency service. The system is not capable of providing long duration backup power service for multiple days.

Figure 7: Scenario 2 - PV + Storage to Meet Resiliency Needs, Large Amount of Storage are Installed Only for Reliability Purposes

Cooling Center				
Scenario 2: PV+Storage Sized to Meet Resiliency Needs				
	System 2.1A: Short outage; resiliency not valued	**System 2.1B: Short outage; resiliency valued**	**System 2.2A: Long outage; resiliency not valued**	**System 2.2B: Long outage; resiliency valued**
PV Size (kW-DC)	2	2	9	9
Battery Size (kWh)	104	104	230	230
Battery Size (kW)	12	12	12	12
Total Capital Cost	$74,907	$74,907	$167,006	$167,006
NPV	-$45,555	-$41,516	-$181,636	-$153,244
Simple Payback (years)	14.9	14.3	25.5	20.4

Long duration energy storage with a relatively small ratio of PV will provide significantly less economic value; the battery system cost is too large to be compensated solely by peak demand savings and resiliency value.

Figure 8: Scenario 2 - PV + Storage Provides Backup To A Small Amount Of Critical Load During Grid Outage Events



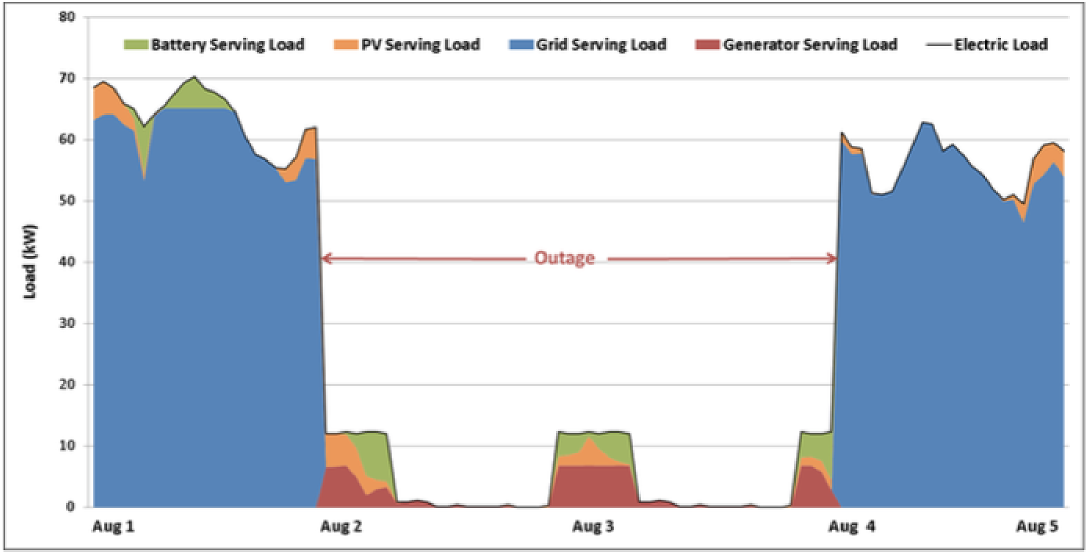
The PV system is re-charging the battery each day of a prolonged power outage. The facility is able to serve a limited number of critical loads during a prolonged power outage; however, there is a high cost associated with such a long duration battery.

Figure 9: Scenario 3, Resilient PV, Storage,
and a Generator Are Used to Backup Critical Loads in a Facility

Cooling Center				
Scenario 3: PV+Storage+Generator Sized to Meet Resiliency Needs				
	System 3.1A: Short outage; resiliency not valued	System 3.1B: Short outage; resiliency valued	System 3.2A: Long outage; resiliency not valued	System 3.2B: Long outage; resiliency valued
PV Size (kW-DC)	0	2	0	9
Battery Size (kWh)	25	28	25	35
Battery Size (kW)	7	7	7	8
Diesel Generator Size (kW)	9	9	10	7
Diesel Fuel Used (gallons/yr)	8	7	41	30
Total Capital Cost	$33,798	$42,261	$34,376	$70,893
NPV	$430	$0	$1,008	$9,329
Simple Payback (years)	11.4	12.2	11.3	12.3

With the addition of a small diesel generator, the battery system provides peak demand shaving service, and the system as a whole can provide longer duration resiliency for a lower cost that a large battery on its own.

Figure 10: Scenario 3, Facility Achieves Marginally Greater Backup Service
than PV + Storage Only



During a pro-longed outage the PV system, battery, and generator work together to provide power to a larger set of critical loads, at a lower cost than PV + Storage only.

Figure 11: Scenario 4, Stand Alone Generator Provide Resiliency Service and No Additional Economic Benefit

Cooling Center				
Scenario 4: Generator Sized to Meet Resiliency Needs				
	System 4.1A: Short outage; resiliency not valued	**System 4.1B: Short outage; resiliency valued**	**System 4.2A: Long outage; resiliency not valued**	**System 4.2B: Long outage; resiliency valued**
Diesel Generator Size (kW)	12	12	12	12
Diesel Fuel Used (gallons/yr)	9	9	48	48
Total Capital Cost	$18,600	$18,600	$18,600	$18,600
NPV	-$25,411	-$21,372	-$24,246	$2,562
Simple Payback (years)	None	None	None	11.0

A diesel generator on its own cannot provide economic value because it does not perform peak demand management services for the facility

Conclusions:

1. Resilient PV + Storage systems can be Net Present Value (NPV) positive with and without a resiliency value stream evaluated.
2. For New York Power Authority customers, economics of resilient PV are greater than stand-alone solar PV, due to the battery's ability to reduce facility demand charges.
3. Projects economics for all modeled systems are greatly improved for radial customers when a resiliency value is included due to a higher frequency of outages on radial vs. network grids.
4. Level of resiliency depends on when outage occurs, state of charge of the battery, and load size.
5. Resilient PV sized for cost-savings-only will have limited resiliency benefits.
6. In some cases, inclusion of a value for avoiding utility power outages can more than offset the additional costs incurred by sizing resilient PV for resiliency rather than utility cost savings alone.
7. Generators as a resiliency solution are not NPV-positive except when resiliency is valued for long outages.