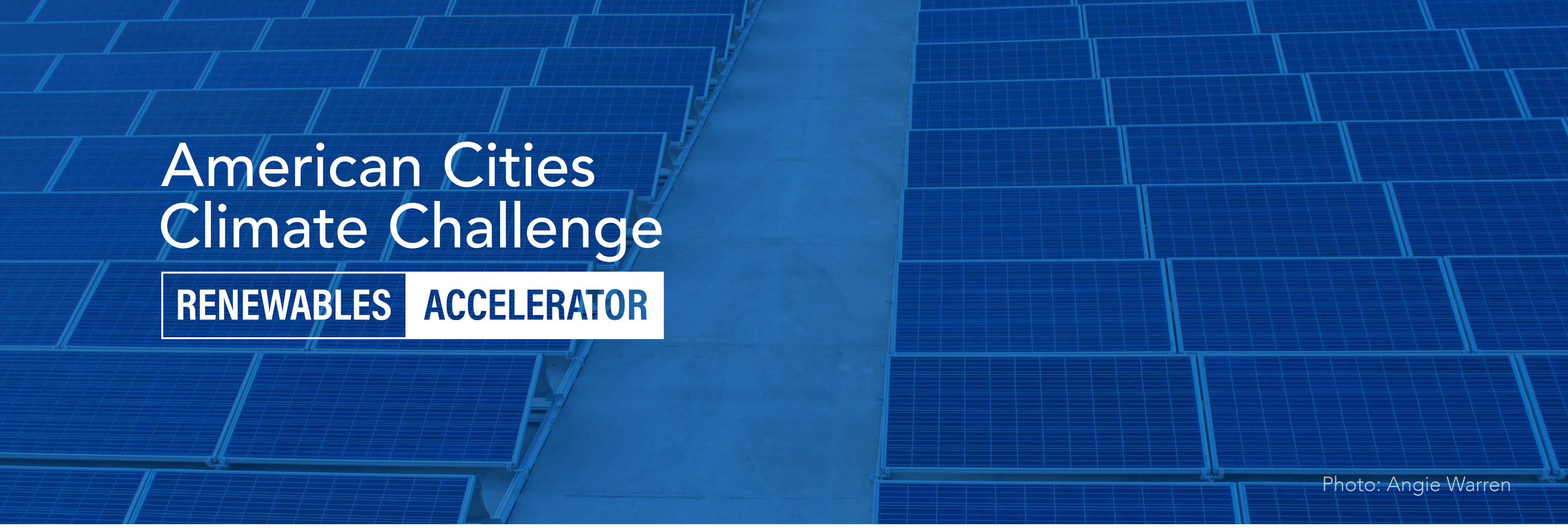


Photo: Angie Warren

SOLAR AND STORAGE FOR CITIES

Solar photovoltaic (PV) systems are an increasingly cost-effective technology that cities are deploying to make and use their own electricity as they progress towards their renewable energy, climate action, and sustainability goals. However, there are numerous circumstances in which cities may have a need for solar electricity even if the sun is not shining or in other circumstances, such as a grid outage or the need for emergency power following an extreme weather event. An increasingly common, cost-effective, and beneficial solution is to pair the PV system with a battery energy storage system (BESS): this is commonly referred to as solar-plus-storage.

This resource focuses on two distinct applications for behind-the-meter (BTM) solar-plus-storage installations at city/county facilities (considered roughly analogous to commercial energy users):

a. **Peak load shaving or peak demand shifting:** City facilities, like other industrial or commercial energy users, often must make payments based not only upon the amount of their overall energy consumption, but also the rate at which they use electricity (i.e., demand) during specific periods. These "demand charges," depending upon the utility provider, are based on the maximum amount of electric power that a facility draws during a specific 15- or 60-minute period. Depending on how and when a facility uses electricity and the utility rate structure, demand charges can be 10-70% of a monthly electricity bill. Peak shaving refers to reducing the peak demand, often by using batteries, load shedding or potentially with solar PV. Peak demand shifting refers to using batteries to shift the peak facility demand to a time of day when lower demand charges apply. In both cases, the objective is to lower the rate of electricity usage during the critical window in order to reduce the demand portion of the city's electric bill.

b. **Emergency power (resilience):** Resilience can encompass very different needs and requirements, ranging from simply keeping critical loads operational during a short-duration grid outage to providing emergency power for critical services for multiple days. Battery systems can simply be used to provide electricity to critical loads for a prescribed duration when the grid is unavailable. If coupled with PV, this duration may be extended by generation from the PV system. Combined systems can be designed for longer duration in extended disaster response situations. In addition, solar-plus-storage resilience solutions avoid the air and noise pollution emitted by diesel generators (the other common backup solution) during both their emergency operation and monthly testing—which is of particular concern in densely populated urban areas.

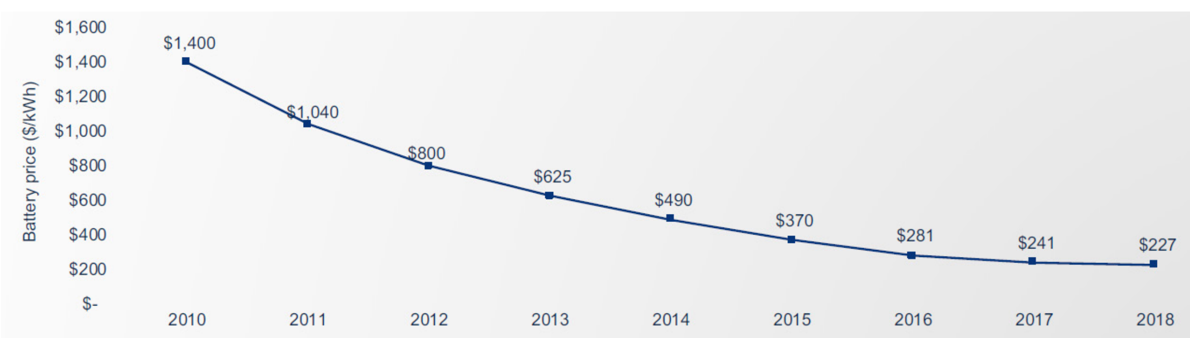
The objective of this resource is to provide guidance for city staff to conduct an initial assessment and investigation of solar-plus-storage systems to determine suitable system size and performance information that could be incorporated into a planned PV procurement. For simplicity, this resource focuses on assessing storage for a **single city facility** and explains the data analysis, system sizing, software analysis, and decision-making process that is typically required; and provides guidance on the inclusion of BESS in a solar RFP. For each application, critical decision-making factors and parameters need to be established that are consistent with the city's needs and priorities. For more complex situations and multiple buildings, we recommend working with an experienced consultant. Moreover, there are links throughout this resource and a reference section at the end that lists energy storage resources, tools, and information addressing a much wider set of applications and potential solutions.

BATTERY ENERGY STORAGE MARKET AND COST TRENDS

The energy storage market has shifted toward lithium-ion (Li-ion) batteries over the past 6-8 years. The predominance of Li-ion was initially driven by its relatively high energy density, which made it suitable for powering electric vehicles, and has continued in part due to continually decreasing costs. Over the previous decade and a half, Li-ion has represented 80% of installed stationary battery power capacity (the maximum electrical output, typically expressed in megawatts) in the U.S. and 84% of energy capacity (the maximum electricity that can be delivered over a specific period of time, typically expressed in megawatt-hours). Li-ion system benefits include relative ease of permitting, modularity, locational independence, and declining costs. Combined, these attributes have enabled Li-ion to compete effectively against pumped storage hydropower, the predominant stationary energy storage technology (which makes up 95% of utility-scale storage in U.S.) across a wide range of submarkets, including customer-sited systems.

Battery prices (largely Li-ion) have declined 85% from 2010 to 2018 (see Figure 1). Continued price declines are projected, albeit at a slower rate, over the next five years. As a result of cost declines, battery storage can be cost-effective for end users in some regions of the U.S., particularly where customer demand charges are high.

Figure 1. Historical Battery Price Trends, 2010-2018



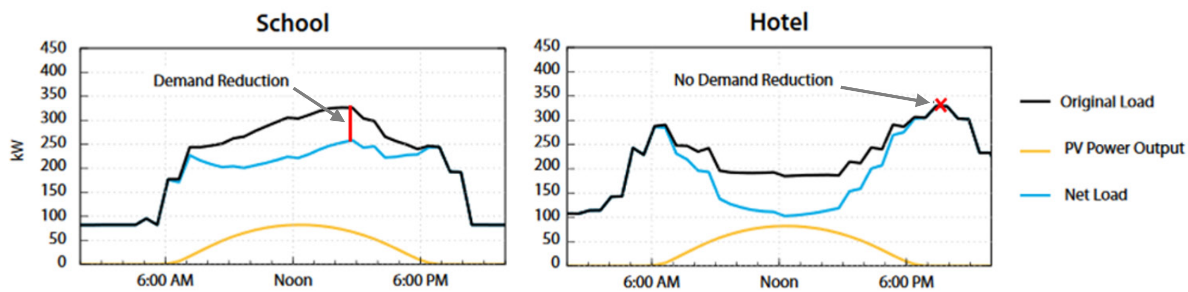
Source: Energy Storage Summit, December 2019. www.woodmac.com

COMBINING STORAGE WITH SOLAR PV ALLOWS PEAK SHIFTING

For cities interested in managing peak demand, the benefits of a PV system may be limited if it is not coupled with energy storage. A PV system provides power to reduce the net load (or demand for grid electricity) of the building. Maximum PV power is typically generated in the middle of the day, thereby reducing a building's demand for power from the grid during those hours. In Figure 2, the school, with its peak demand for electricity in the early afternoon, benefits from the ~80 kilowatt (kW) demand reduction provided by the PV system. However, since the hotel's peak demand does not occur until 7-8 p.m. after the sun has gone down, the PV system does not lower the hotel's peak demand.

Of course, on any given day of the month, the sun may not be shining, in which case the PV-driven demand reduction will not occur regardless of the facility's daily usage. However, by incorporating batteries into their systems, cities can reliably reduce their demand at critical times even if the sun is not shining.

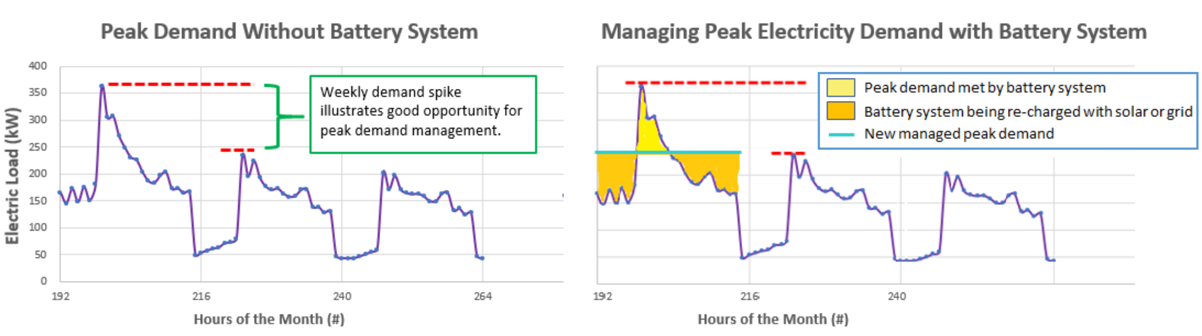
Figure 2: Simulated Reduction in Peak Demand from PV on a School and Hotel



Source: How to Estimate Demand Charge Savings from PV on Commercial Buildings, NREL. https://www.nrel.gov/docs/fy17osti/69016.pdf

In an optimal case, the PV system would fully charge the batteries in the morning and, if peak loads are near the middle of the day, peak demand could be reduced by both the PV and the battery system working in concert to ensure the peak is much lower than it otherwise would be. For an example of this, consider Figure 3 below. In this situation, demand is fairly "peaky," with the daily maximum peaks typically lasting 3-4 hours. However, the chart shows a more extreme peak on the first day of the week, as might occur when a building operator brings the building back up to operating condition after a weekend with reduced electricity loads. This presents a significant peak demand shaving opportunity.

Figure 3: Impact of Load-Shifting on Peak Demand Using a Battery System



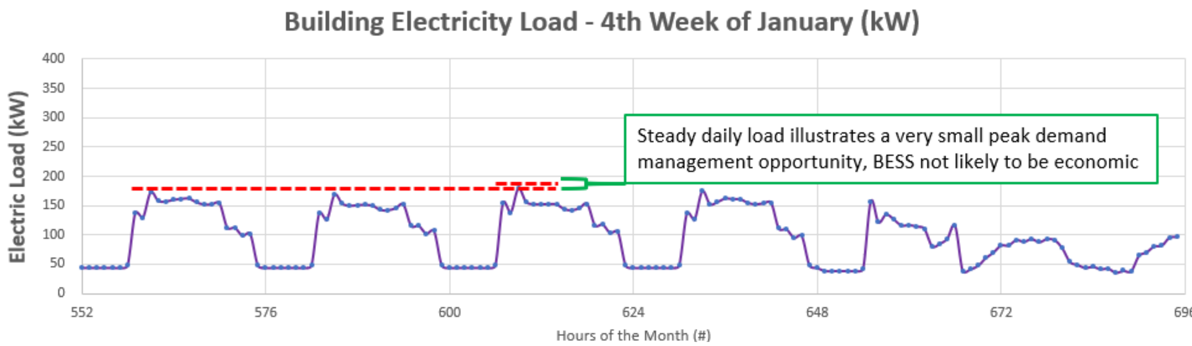
Note: At left, an REopt Lite medium office building hourly load for three days in January in Cedar Rapids, Iowa illustrates high peak loads. At right, the same building load and days with a managed battery system reduces peak demand.

Source: NREL. https://reopt.nrel.gov/tool/

As illustrated in the graph on the right side of Figure 3, battery energy could be used to reduce the peak demand by ~130 kW. As shown in Figure 7, the savings from these reductions in demand, combined with the energy savings provided by solar-plus-storage systems, can reduce energy bills up to 24%, with higher savings generally seen in regions with higher energy prices and/or demand charges.

By way of comparison, as illustrated in Figure 4, a building with consistent peak power loads provides much smaller opportunities for achieving peak demand savings with battery storage.

Figure 4: Load Profile Showing Small Opportunity for Peak Demand Shaving



Note: An REopt Lite medium office building hourly load in the second week of January in Cedar Rapids, Iowa illustrates low peak loads.

COMBINING STORAGE WITH SOLAR PV FOR RESILIENCE

When considering emergency power operations for a city building, solar alone does not provide the reliability needed for resilience. Solar-plus-storage can provide resilience, though several decisions must be made during the preliminary design phase regarding the primary type of emergency for which the system is being planned, the critical loads that need to be powered, and the expected duration of the outage. Decision-making for emergency power application system size and operational design are not typically based on expected (or easily monetized) financial returns, but rather the value the system can deliver in times of emergency. For complex situations, we recommend that the city hire an experienced energy system/resilience consultant.

Solar-plus-storage systems can be designed to provide both demand savings and emergency power, broadening benefits for the city. While neither application will be optimized, the economics of the system can be improved if it is operated more frequently, provides more services, and accesses more value streams. Energy/sustainability managers should consider the types of events that may impact the building and how foreseeable these events are (e.g., hurricanes can be anticipated days in advance, while earthquakes may occur with very little warning), and then determine the optimal operational strategy for their system.

SOLAR-PLUS-STORAGE EVALUATION PROCESS

For city energy/sustainability managers considering solar-plus-storage for either peak load management or emergency power (resilience) applications at a single facility, there are several steps in the evaluation process, including:

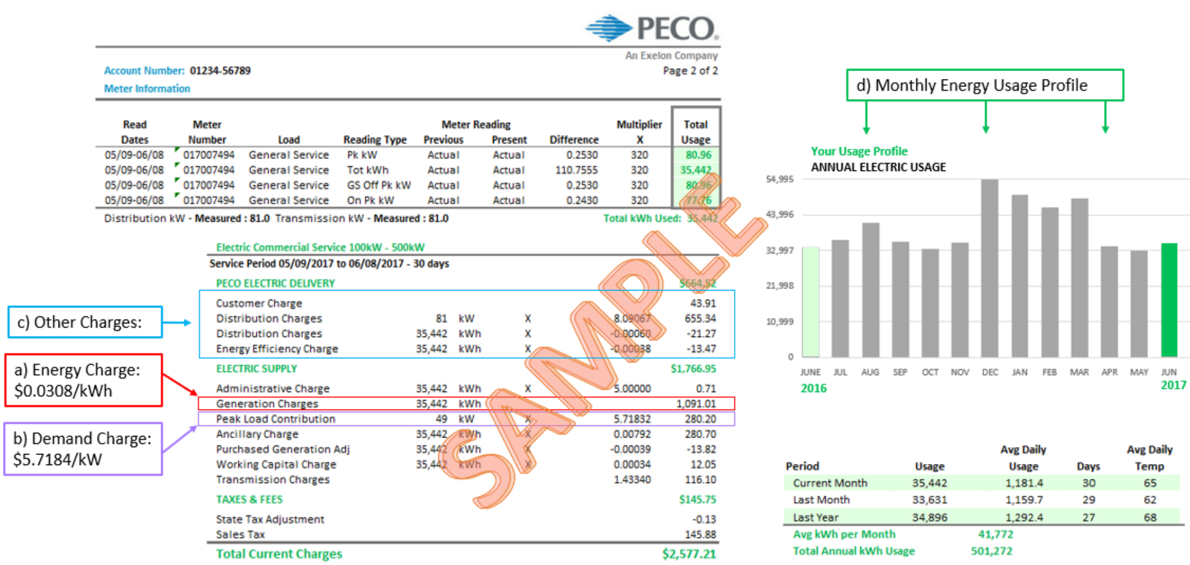
1. Analyzing the facility's electricity bills (demand charge reduction only)
2. Conducting a building site and solar PV system sizing assessment
3. Sizing the battery energy storage system
4. Considering adding battery storage to the solar RFP

1. Analyze the Facility's Electricity Bills (Demand Charge Reduction Only)

City energy/sustainability managers should review and analyze the monthly electricity bills of a facility to determine what portion of the bills are based on energy consumed, peak demand during the month, and other fixed or variable charges. Understanding these costs will help city staff determine if augmenting a PV system with battery energy storage makes economic sense.

The utility rate structure for a municipal or commercial building often includes an energy charge ($/kWh) based on the amount of electricity consumed during the month, and a demand charge ($/kW) based on the highest 15- or 60-minute load period during the month (or during a specific period of high overall demand relative to electricity generation). A range of fixed or variable service, connection, distribution, or transmission charges are often included in the bill as well. A sample utility bill provided in Figure 5 shows the: a) energy charge, b) demand charge, and c) other charges; in addition to d) the monthly energy usage profile. In this example, the energy charge is 42% and demand charge is 11% of the monthly electricity bill. If all or most months have as low a demand charge as the example month, the economics of battery storage for peak demand management may not be favorable.

Figure 5: Sample Monthly Electricity Bill


PECO
An Exelon Company

Account Number: 01234-56789
Page 2 of 2

Meter Information

Read Dates	Meter Number	Load	Reading Type	Meter Reading Previous	Meter Reading Present	Difference	Multiplier X	Total Usage
05/09-06/08	017007494	General Service	Pk kW	Actual	Actual	0.2530	320	80.96
05/09-06/08	017007494	General Service	Tot kWh	Actual	Actual	110.7555	320	35,442
05/09-06/08	017007494	General Service	GS Off Pk kW	Actual	Actual	0.2530	320	80.96
05/09-06/08	017007494	General Service	On Pk kW	Actual	Actual	0.2430	320	77.76

Distribution kW - **Measured : 81.0** Transmission kW - **Measured : 81.0** Total kWh Used: 35,442

Electric Commercial Service 100kW - 500kW

Service Period 05/09/2017 to 06/08/2017 - 30 days

PECO ELECTRIC DELIVERY					$664.52
Customer Charge					43.91
Distribution Charges	81	kW	X	8.09067	655.34
Distribution Charges	35,442	kWh	X	-0.00060	-21.27
Energy Efficiency Charge	35,442	kWh	X	-0.00038	-13.47
ELECTRIC SUPPLY					$1,766.95
Administrative Charge	35,442	kWh	X	5.00000	0.71
Generation Charges	35,442	kWh			1,091.01
Peak Load Contribution	49	kW	X	5.71832	280.20
Ancillary Charge	35,442	kWh	X	0.00792	280.70
Purchased Generation Adj	35,442	kWh	X	-0.00039	-13.82
Working Capital Charge	35,442	kWh	X	0.00034	12.05
Transmission Charges				1.43340	116.10
TAXES & FEES					$145.75
State Tax Adjustment					-0.13
Sales Tax					145.88
Total Current Charges					$2,577.21

Period	Usage	Avg Daily Usage	Days	Avg Daily Temp
Current Month	35,442	1,181.4	30	65
Last Month	33,631	1,159.7	29	62
Last Year	34,896	1,292.4	27	68
Avg kWh per Month		41,772		
Total Annual kWh Usage		501,272		

Source: Edited from PECO. https://www.peco.com/MyAccount/MyBillUsage/Pages/Business500kWBillpg1.aspx

Some utilities have high energy prices but low demand charges, while others have high demand charges and low energy charges, and the rest have various mixes in between. On average, in the U.S. commercial sector, 72% of utility charges are for energy, 25% are for demand and 3% are for customer charges. In city office buildings, monthly peak demand may be driven by summertime air conditioning load or wintertime heating load (if electric). For other types of city buildings, the peak demand may be caused by its primary functions, such as a recreation center whose peak begins on weekdays after schools close. In the future, building-connected EV charging loads may drive peak demand.

If the facility demand charges are high, it is due to a combination of a high demand charge rate ($/kW) or a building load that has occasional high demand spikes (kW) that vary quite a bit from the average demand. Analyzing electricity bills should provide clarity on the key factors that impact a facility's demand charges.

Facilities with high energy charges ($/kWh) typically offer the best opportunities for PV systems to provide cost savings by reducing the amount of high-priced electricity that will need to be purchased—assuming the facility is using a significant amount of electricity during daytime. Facilities with high demand charges ($/kW) offer the best opportunity for solar-plus-storage to provide cost savings by either reducing or shifting the peak demand load.

2. Conduct a Building Site Assessment and a Solar PV System Sizing Assessment

For city managers, it is important to determine the size of the PV system before evaluating storage. A PV system may be designed with different purposes in mind and its size may be limited by roof age, available space on the roof or on adjacent ground, funding, or other factors. PV Watts and Project Sunroof software can provide reasonable estimates of system sizing potential, performance, and cost. Once the PV system's size has been established, city staff can proceed to sizing the battery. Note that including a battery system may ultimately change the optimal PV system size. Cityrenewables.org hosts multiple presentations, tools, and resources to help city energy/sustainability managers size a PV system depending on the electricity load of a particular building.

3. Size the Battery Energy Storage System

Battery storage systems are sized based on two factors: 1) how fast the battery can deliver power (kW) and 2) how much energy in total the system can deliver (kWh). For example, a battery may be listed as: 50 kW/200 kWh. The 50 kW indicates how much power the battery can provide at one time. The 200 kWh indicates how much energy it can provide over time. In this case, if the battery is discharging at a rate of 50 kW, it has the energy capacity to do so for four hours (200 kWh ÷ 50 kW = 4 hours).

SOFTWARE TOOLS FOR SOLAR-PLUS-STORAGE SYSTEM OPTIMIZATION

As the interaction between solar PV, battery systems, and building load can become exceedingly complex, we recommend that city energy/sustainability managers use software designed to facilitate the system and component optimization process based on building load and solar-plus-storage operational priorities. There are a number of potential software packages available, including:

- REopt Lite: A free, simplified optimization software tool produced by the National Renewable Energy Laboratory that optimizes system size for renewable energy and storage projects by using effective default assumptions (e.g., multiple building types across 16 climate zones) or user-provided data. Users can optimize energy production for solar, wind, or both, as well as storage sizing to achieve cost savings from peak demand management. If one chooses to optimize for resilience (i.e., emergency power), a fossil fuel generator can be added for comparison to batteries.
- HOMER **(Hybrid Optimization of Multiple Energy Resources):** A systems optimization software tool originally developed for distributed generation applications that has evolved to include microgrid applications, encompassing renewable generation, storage, and fossil fuel technologies. There are multiple versions for specific applications, and HOMER Grid is recommended for cities considering solar-plus-storage. We also recommend that new users take a training course to make best use of this powerful software.
- SAM **(System Advisor Model):** A free, multi-technology, open-source, techno-economic software program produced by NREL intended to facilitate decision-making when comparing renewable energy technologies, ownership models, and financing schemes. NREL provides webinars, seminars, a support forum, and a YouTube Channel to teach users how to effectively utilize the wide-ranging features of this versatile program.

GETTING STARTED WITH REOPT LITE APPLICATIONS

To illustrate, two simple optimization examples are provided below using REopt Lite. There are a few caveats to note: REopt Lite assumes direct purchase of the system; the cost-effectiveness of other financing schemes (e.g., PPAs) have to be manually calculated;[1] and the REopt User Manual cautions that investment decisions should not be made based on REopt Lite results alone.

Table 1: REopt Lite – Basic Inputs with Optimization for Cost Savings from Peak Demand Management and Energy Performance for Resilience (Blue Text)

MODELING PROCESS STEPS	INPUTS AND DESCRIPTORS
Step 1: Choose Optimization Focus	**Select:** Financial (cost savings from peak demand management) or **Resilience (emergency preparedness)**
Step 2: Enter Site Data	• **Site and Utility Data Input:** Location, Electricity Rate, Net Metering Limit, Wholesale Rate, Space Available for PV – Ground-mount or Rooftop PV • **Select:** Building Type • **Input:** Annual Electricity Consumption or Upload Actual, Granular Building Load Data • **Financial Inputs:** Discount Rate, Electricity Cost Escalation Rate, Analysis Period, Tax Rate, O&M Cost Escalation Rate • **Resilience Inputs:** Critical Load Factor, Outage Duration, Outage Start, Type of Outage Event
Step 3: Select Technologies	• Select: PV (and/or Wind) and Battery • Input: Capital Cost or System Size-Based Incentives • Input: Battery Costs, Characteristics, Incentives, and Tax Benefits (Note: for **Resilience Optimization**, a generator option is included)
Get Results	Output: Business as Usual (BAU), PV Size, Battery Size, Energy Cost, Demand Cost, Life Cycle Cost, Net Present Value (NPV)

REOPT LITE INPUTS AND RESULTS FOR COST SAVINGS OPTIMIZATION FROM PEAK DEMAND MANAGEMENT

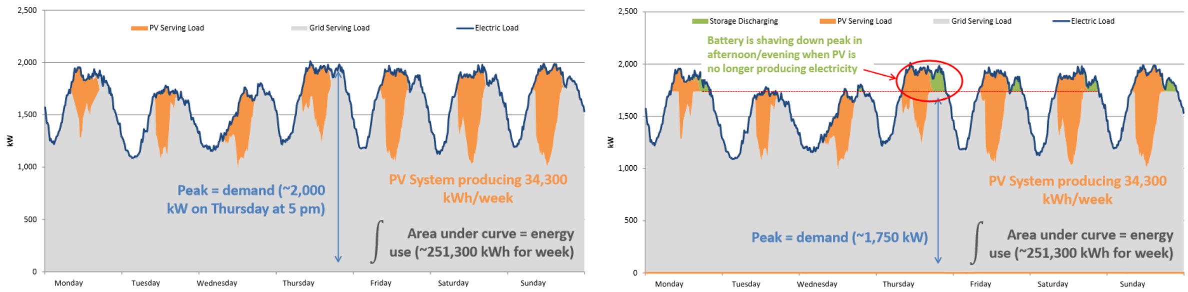
When sizing the PV system, the city energy/sustainability manager may have already obtained the monthly or annual load data for the building. If not, request that data, with the same time interval as the demand charge interval (e.g., 15- or 60-minute increments), from the utility provider. Using actual building load data, as well as realistic solar-plus-storage factors, can greatly increase the accuracy and reliability of the model's economic predictions for a particular building.

The potential reduction in demand (represented by the horizontal red line in the graph on the right) and energy (orange-shading for PV, green-shading for BESS) provided by grid are illustrated in Figure 6.

REOPT LITE INPUTS FOR RESILIENCE (EMERGENCY PREPAREDNESS) OPTIMIZATION

REopt Lite is best suited for a simplified case of powering critical loads during a short-duration (1-6 hour) utility outage. In this case, the battery system design will be heavily impacted by several parameters including: outage duration in hours; critical load factor (i.e., what percentage of the typical load requires power during the outage); outage start date and time; and type of outage event, where 'major' events occur once in a project's lifetime while 'typical' events might occur annually.

Figure 6: REopt Lite results show PV serving the load and BESS serving the load



Source: https://www.nrel.gov/docs/fy17osti/70035.pdf

With these simplified inputs, the resilience capability modeled does not represent the full realm of city needs in emergency preparedness. Planning for lengthier, complex, catastrophe-driven emergency situations requires integrated engagement with multiple city departments. For these types of projects, we recommend that the city hire an experienced consultant specializing in resilient electricity systems to guide the planning, evaluation, and sizing process utilizing HOMER, SAM, or other energy modeling software to more accurately model the energy and duration requirements of multiple emergency scenarios.

While outside the scope of this resource, city sustainability/energy managers may also want to consider whether a solar-plus-storage system's backup power capabilities could be extended through complementary energy efficiency efforts. Purchasing more efficient appliances, installing more insulation, or other efforts could increase the critical "hours of safety" that a solar-plus-storage system may be able to provide to critical facilities.

Consider Adding Battery Storage to the Solar RFP

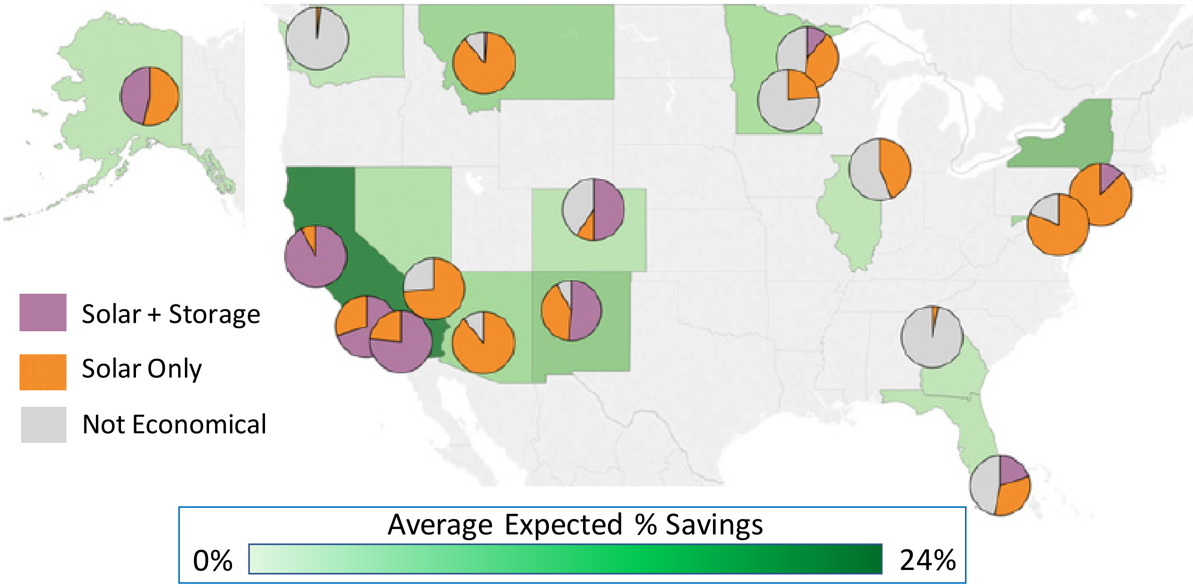
Some local governments have issued RFPs for solar-plus-storage projects, including the City of Henderson, Kentucky. Additional sample RFPs for PV procurement alone can be found on cityrenewables.org. For the purposes of this resource, there are two options to include BESS in an RFP for solar-plus-storage for a single building:

- **a.** Include the battery type and size (kW/kWh) that was obtained from modeling (e.g., REopt Lite) in the Scope of Work (SOW) section of the RFP document. This approach may be most effective if HOMER or another detailed energy simulation model was used.
- **b.** Specify in the RFP's SOW that a peak demand management storage system is required; provide the 15- or 60-minute load data; and have proposers determine system size, energy, and economic performance. This approach may be preferable if the city has only used REopt Lite to determine the size of the storage system, as it puts the onus on proposers to provide a detailed analysis and optimized system design.

STUDIES OF INTEREST

An insightful study by NREL, Solar-Plus-Storage Economics: What Works Where, and Why?, focused on impacts of location, building load profile, technology cost, utility rate structure, and policies on solar-plus-storage economic viability. The study modeled over 24,000 individual cases, considering 17 U.S. city locations, 16 building types, and 73 utility rate tariffs combined with a variety of incentives and potential electricity prices. The study, whose findings are visually summarized in Figure 7, identified numerous cases in which solar alone or solar-plus-storage could yield electricity bill savings. Savings are generally most common in areas with high electricity prices, and particularly in regions that also have demand charges greater than $10/kW. Among economic systems, lifetime savings averaged 7-10%. As solar and battery prices continue to decline in the future, more markets and building types will become economic.

Figure 7: Potential Electricity Bill Savings Utilizing Solar Only and Solar-Plus-Storage Systems



Source: https://www.osti.gov/servlets/purl/1493868

In regard to resilience, a case study for buildings in North Carolina provides useful information on planning and executing resilience with solar-plus-storage by comparing results from two software tools, REopt Lite and DER-CAM. The study examines solar-plus-storage systems at six buildings capable of providing 50% of normal building load (critical load factor) for up to 48 hours during a grid outage. A key finding was that, in addition to being able to provide resilience, the solar-plus-storage system could also serve 20-28% of a facility's annual electricity consumption, highlighting the potential for resilience systems to support daily facility operations in addition to providing backup power.

SAFETY WITH SOLAR-PLUS-STORAGE

Safety is a necessary consideration with any electricity generating system, such as PV, but is particularly important if batteries are included. Safety issues apply to electrical systems, fire prevention/suppression, airborne hazard chemicals or off-gassing and ventilation system requirements, temperature regulation, etc. The National Fire Protection Association offers a comprehensive listing of current standards as well as safety training programs. Planning for and enacting an Energy Storage Safety Strategic Plan is recommended.

ENDNOTE

1. Guidance on how to conduct these calculations can be found in this document: RE-PLUG On-site Solar Cohort Workshop #3 (slides 29-37).

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