Maximizing the Benefits of Onsite Renewable Energy Generation Using Onsite Energy Storage

About the Series

Over the course of seven sessions, through the Onsite Renewable and Energy Working Group, DOE convened more than 20 partners to identify and highlight ongoing issues and opportunities when planning and deploying onsite renewable energy systems and energy storage systems. This document is part of a series to provide technical recommendations resulting from the discussion among Better Climate Challenge partners, allies, and DOE experts.

Overview

Installing onsite renewable energy systems is a common strategy facility owners can use to save money, reduce their greenhouse gas emissions, and add resiliency to their facilities by generating their own electricity. Many facilities have recognized the advantages of onsite renewable energy generation and are seeking new ways to further enhance the benefits. At the same time, facilities across sectors are also requiring more electricity for the electrification of heating systems and installation of electric vehicle (EV) charging infrastructure. Although several options are available for onsite renewable generation, and the best solution can vary from one location to another, this resource focuses on solar photovoltaic (PV) systems as a specific example of onsite renewable energy generation. To achieve sustainability goals while meeting the increasing electricity demands of electrification, organizations are pairing onsite solar PV generation with onsite energy storage. These systems, which are considered as "behind-the-meter" (BTM) systems, allow facilities to maximize the benefits of onsite renewable generation.

To maximize the benefits to their facility, operators can integrate several different forms of BTM systems and controllable loads, as shown in Figure 1 . This resource provides an overview of common renewable generation, storage, and load management technologies that can be integrated into facilities. It also shows how generation from onsite PV systems can interact with onsite electrical and thermal

Benefits of Behind-the-meter Systems

Cost Savings

- BTM systems give facilities the option to reduce demand charges[1] imposed by the utility and leverage time-of-use rates[2] to lower operational costs.
- BTM systems can be designed to work around electrical service and export limitations that can trigger high upfront costs due to electrical infrastructure upgrades.

Greenhouse Gas Emission Reduction

- BTM systems can be designed to store energy purchased from the grid when the generation profile has the lowest associated greenhouse gas emissions.
- Renewable generation systems can directly reduce greenhouse gas emissions.

Increased Resiliency

- BTM systems designed with battery and thermal storage can provide backup electricity, heating capacity, and cooling capacity in the event of a grid outage.
- If a chiller or boiler becomes inoperable, having thermal storage on-site can extend the amount of time available to bring thermal systems back online.

storage to affect the net load a facility requires from the grid. Finally, this resource provides discussion of how energy efficiency strategies, onsite energy storage, and electric vehicle infrastructure can be used to build capacity for future electrification and the corresponding increases in electrical demands at the facility. These insights can help facility owners communicate the value of applicable systems to project teams and develop innovative BTM solutions to achieve their energy and environmental goals.

Behind-The-Meter Technologies: Generation, Storage, and Load Management

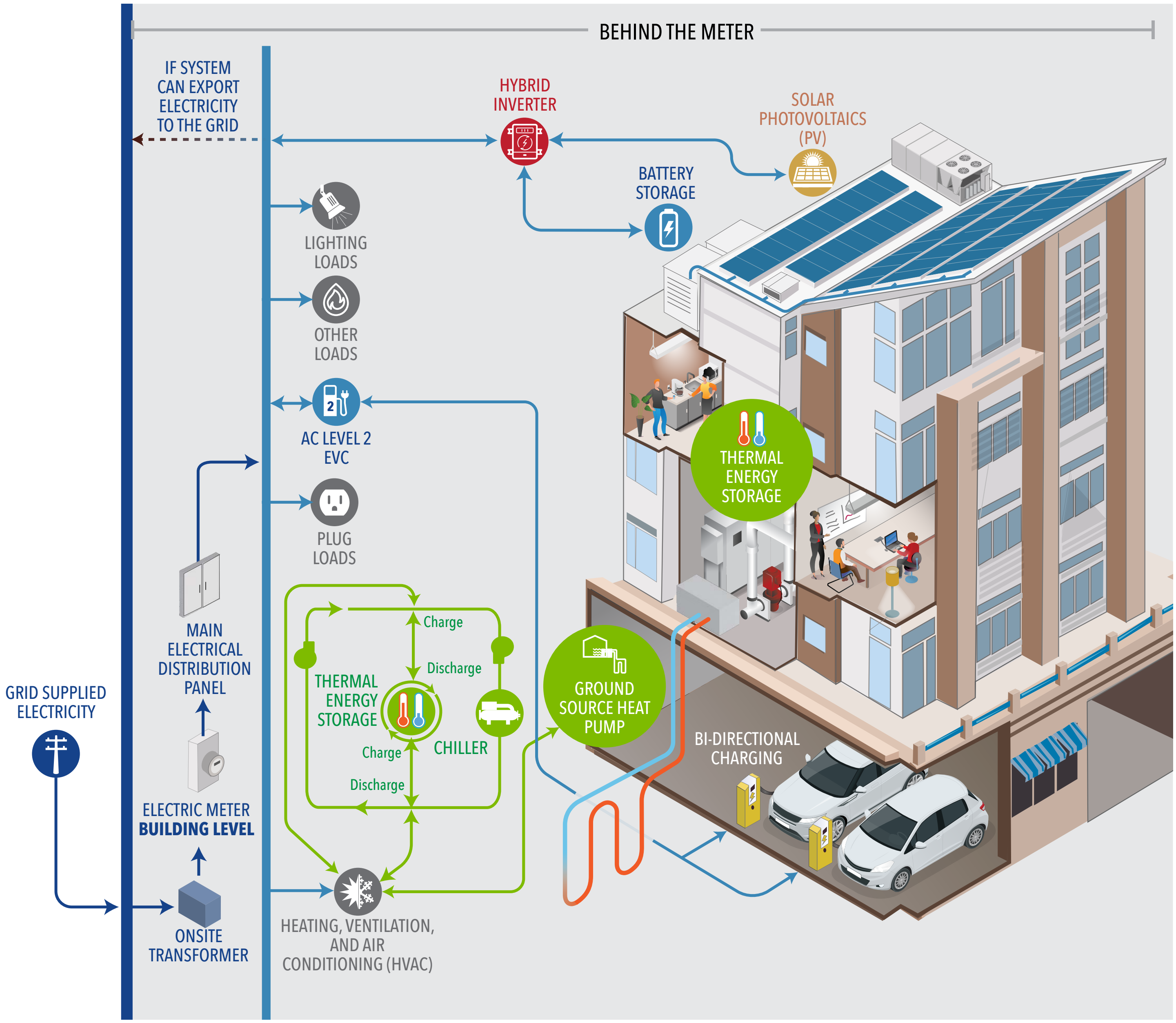

Figure 1. Diagram showing components in a BTM system. BTM systems include generation assets, storage assets, and measurement and control strategies to achieve cost savings, reduce greenhouse gas emissions, and build resiliency.

Overview of Generation, Storage, and Load Management Technologies for Behind the Meter Systems

Solar Photovoltaics (PV)

- **Conventional solar PV** can be installed as a ground mounted array, on a rooftop, carport, covered parking, or other location at the facility depending on aesthetic or structural considerations.
- **PV-thermal hybrid solar collectors (PVT)** can provide simultaneous generation of hot water and electricity while increasing the efficiency of PV generation.
- **Building-integrated photovoltaics (BIPV)**, including solar PV roof tiles, facades, and windows can be incorporated within the facility envelope for additional generation capacity.

Electrical Storage

- **Stationary battery energy storage (BES) systems** provide the most flexibility for electricity storage on-site at a facility.
- **Bidirectional electric vehicle charging infrastructure**[5] can, depending on the vehicle and the configuration of the electrical system, provide backup power for facilities in the event of a grid outage.[6]

Thermal Energy Storage

- **Hot/cold water storage** can provide heating, cooling, or water supply needs to a facility. In this form of storage, water is cooled by a building chiller or heated by the boiler and is stored in large tanks for later use.
- **Ice storage** provides cooling capacity for the facility. Water is frozen using a chiller, stored in ice tanks, and then melted to provide cooling.
- **Phase change storage** releases thermal energy when a phase change material melts or freezes.
- **Solid storage** can store heat for later use. For example, ceramic bricks or other materials are heated to store sensible heat.
- The **building thermal mass** can be used to store energy by pre-cooling or warming the facility using a controllable thermostat.

Load Management

- A **smart/hybrid inverter** has the capability to manage on-site battery charging while serving the building load and maintaining grid connectivity. Due to flexibility in handling both direct and indirect current they are an important component in integrating on-site PV generation and battery storage.
- A **controllable or programmable thermostat** can reduce energy consumption and avoid peak loads by adjusting temperatures at preferential times and turn off heating/cooling when not needed. Thermostat controls can also be used to spread out a facility's "warm up" time.
- At the facility level, **energy management information systems (EMIS)**,[7] **building automation systems (BAS)**, and **smart meters** allow for monitoring and control of the energy used at facilities (HVAC, energy storage operation, etc.).
- **Distributed energy resource management systems (DERMS)**[8] and **open automated demand response (Open ADR**[9]**)** facilitate the communication between BTM resources (e.g. on-site solar PV, on-site storage) and the grid. They can control when BTM systems export to the grid and receive demand response signals from electricity providers.

Onsite Generation

Typical onsite renewable energy systems are designed to offset utility costs and reduce greenhouse gas emissions for electricity used at facilities. Figures 2-6 show the impact of different onsite solar and storage configurations, including variations in size and technology, on the net load required from the grid. The icons to the right of each graph indicate the relative size of each energy resource, for comparison between scenarios. A shaded icon indicates that the energy system component is not present, while larger system components are represented by icons with more rings.

Figure 2 shows how an onsite solar PV system might interact with the base load electricity consumption at a representative facility. The base load data is adapted from a 2021 study10 to represent the facility's average hourly electricity consumption. For the scenario represented in the graph, an onsite solar PV system allows the facility to reduce the amount of electricity drawn from the grid during the middle of the day.

Increasing the amount of solar PV production onsite can provide additional cost and emission reductions and resiliency benefits for facilities. However, the additional generation that can result from larger systems during peak daylight hours must be exported or managed through curtailment onsite. Figure 3 shows a system that is exporting to the grid during peak daylight hours. Depending on the utility (e.g., those with net-metering programs in place), facilities may be able to receive compensation for excess generation during this time. On the other hand, some utility programs and existing infrastructure may limit the ability for facilities to become power producers. For example, load studies and/or transformer upgrades may be necessary for the utility to receive exported electricity from customers. These barriers can lead to extended project timelines

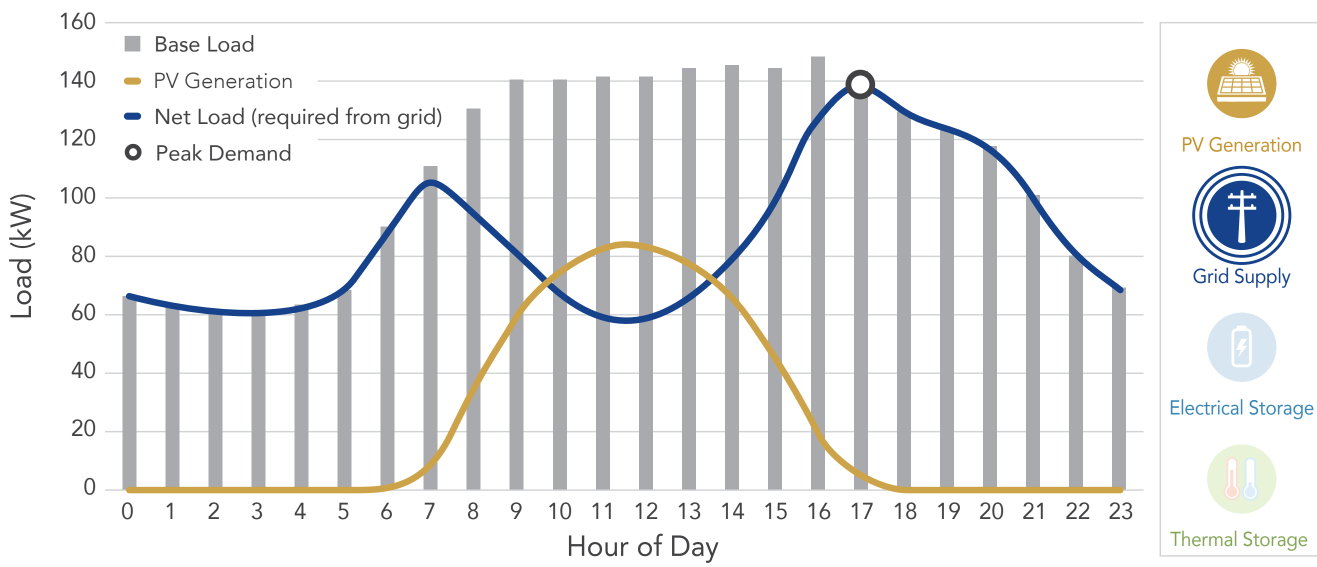

Figure 2. Graph showing onsite solar PV production during a sunny day and its effect on the net load required from grid. The relatively small level of PV generation offsets a portion of the building electrical loads, resulting in a reduced net load through the primary daylight hours.

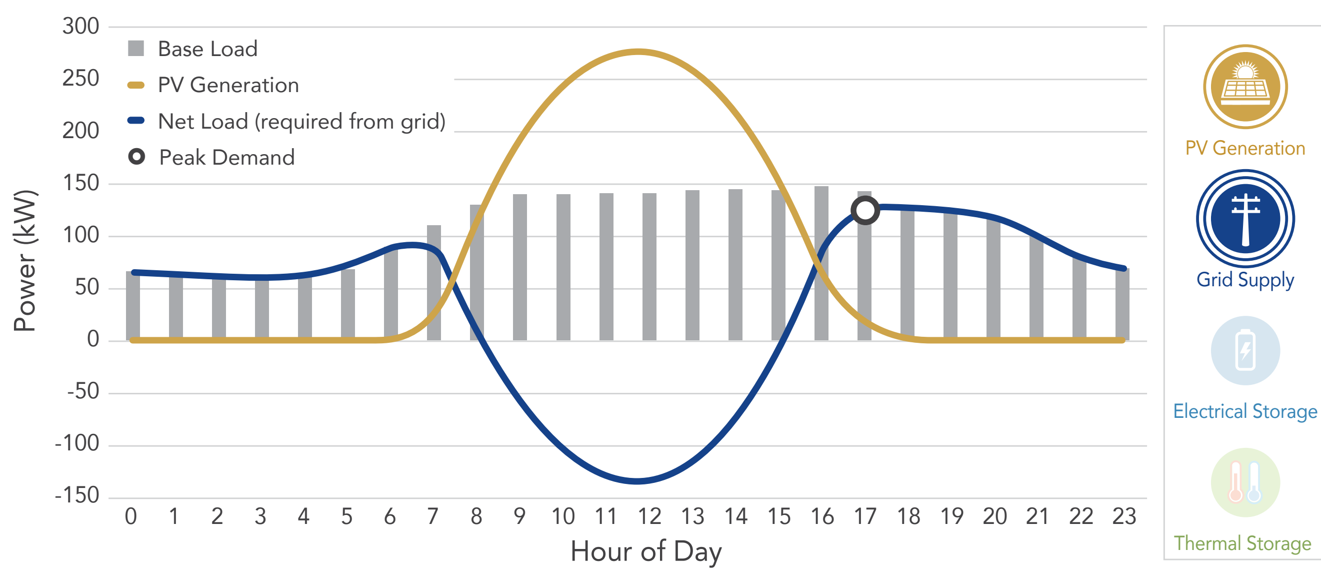

Figure 3. Graph showing production from a larger onsite solar PV array and its effect on the net load the facility requires from the grid. The presence of a negative net load indicates that there is more onsite generation than the facility can consume. In this case, the negative net load values represent excess generation that would need to either be exported to the grid or curtailed.

and costly overruns that restrict the size, and ultimately the benefits, of onsite solar PV.

Additionally, larger onsite solar PV systems may not significantly reduce the peak load required from the grid. As seen by comparing Figures 2 and 3, the peak net load that the facility draws from the grid remains around 140 kW. Because onsite solar PV systems may not result in significant changes to the peak demand (kW), the operating cost benefits from reducing peak demand charges may be limited.

Onsite Generation + Storage

If a utility restricts the exports from a facility to the grid, the use of onsite storage alongside solar PV can provide a solution to avoid costly infrastructure upgrades, thus increasing the feasibility of larger onsite PV installations. Figure 4 shows a facility using a portion of the onsite solar PV generation to charge an onsite battery energy storage (BES) system to manage the excess generation. When compared with Figure 3, it is apparent that the addition of BES allows the facility to reduce the excess generation from approximately 140 kW to 80 kW. While grid exports/curtailment could be further reduced with a larger storage system, even a smaller BES system can allow facilities to remain within their allowable exports while maximizing onsite PV generation.

The integration of onsite storage and solar PV can also mitigate the cost of peak demand charges and reduce consumption during on-peak times. In Figure 4 the BES is operating under a simple control strategy to reduce peak loads from the grid as much as possible. This reduces the peak demand from 130 kW (see Figure 3) to 70 kW. From a cost perspective, facilities can benefit directly from a reduction in demand charges on their utility bill. Operation of the BES has the added financial benefit of reducing net load required from the grid during the on-peak times (typically 4 to 9PM) when electricity is the most expensive.

If grid exports are not allowed, using multiple forms of energy storage may allow a facility to avoid exports to the grid entirely. In Figure 5, the addition of thermal energy storage (TES) allows the facility to use the onsite solar PV to charge both the TES and BES instead of exporting to the grid or curtailing the excess generation. Also, the addition of TES further reduces peak demand from 70 kW to less than 50 kW. While similar results could be achieved with a larger BES system, it would be more expensive. The addition of TES adds storage capacity at a reduced cost. Ultimately, the ideal combination of thermal and electrical storage will be dependent on the utility restrictions and the end uses at the facility.

Finally, the use of onsite solar PV and a larger storage system can complement each other to largely eliminate the need for grid supplied electricity. Figure 6 shows how by implementing a combination of solar PV and thermal and electrical storage, the facility largely eliminates the need for grid supplied electricity even during non-daylight hours. This maximizes the operational cost savings by

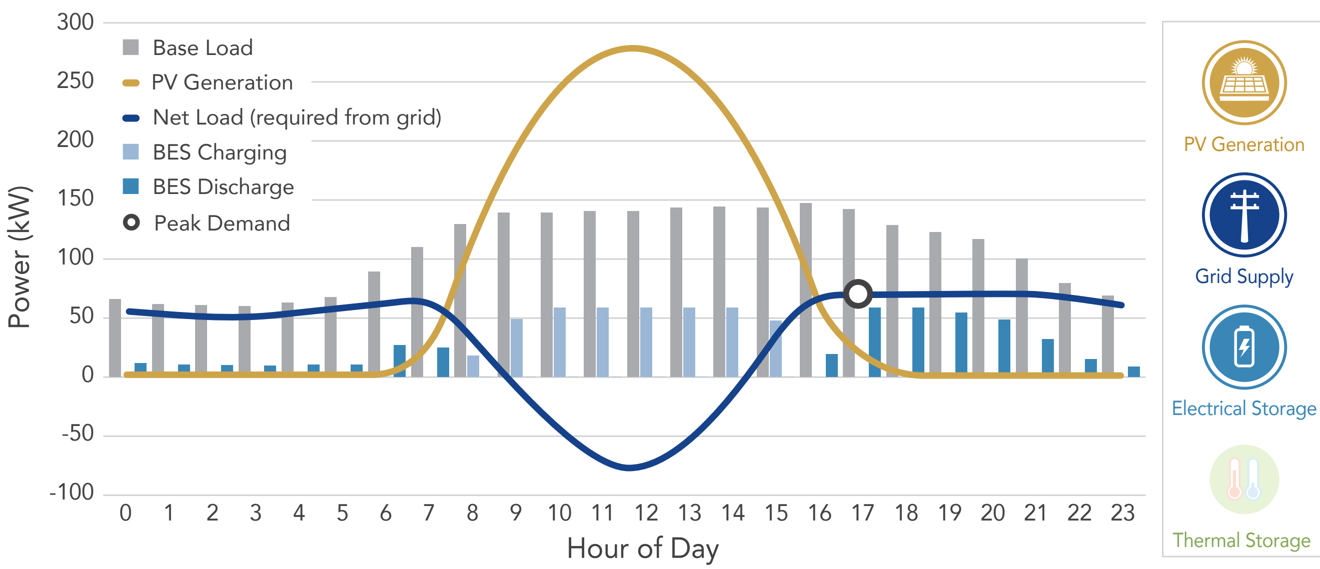

Figure 4. Graph showing production from an onsite solar PV system, the charge/discharge of an electrical storage system, and their combined effect on the net load. While electrical storage is considered in this example, a similar sized thermal energy storage (TES) system could be substituted at a significantly lower cost to account for thermal loads in the building.

largely eliminating the net load required from the grid and the grid draw during peak time-of-use hours. Each facility must identify the relative sizes of onsite generation, thermal storage, and electrical storage to best suit their needs.

Relative Sizing of Onsite Solar PV and Storage Systems

The relative sizing of onsite solar PV and onsite storage systems will be different for every facility since they depend on variable factors such as utility incentives, facility base loads, and the goals for the system (e.g. cost reduction, greenhouse gas emission reduction, or resiliency). The following tools are available for facilities to properly size onsite generation and storage to satisfy their needs.

- **Energy audits and greenhouse gas emission reduction audits.** The Better Climate Challenge[10] has resources for facilities to perform greenhouse gas emission reduction audits[11] and other planning tools to achieve ambitious emissions reduction goals.

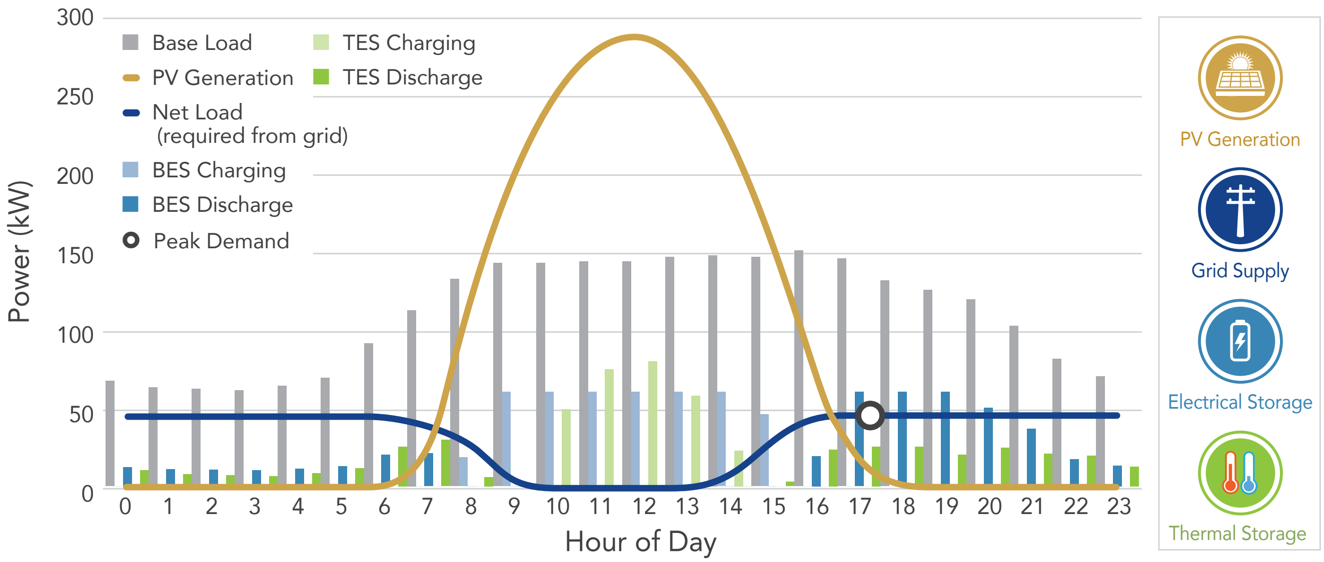

Figure 5. Graph showing production from an onsite solar PV array, the charge/discharge of both a battery and thermal storage system, and their effect on the net load. The combination of storage types allows the facility to further reduce excess generation.

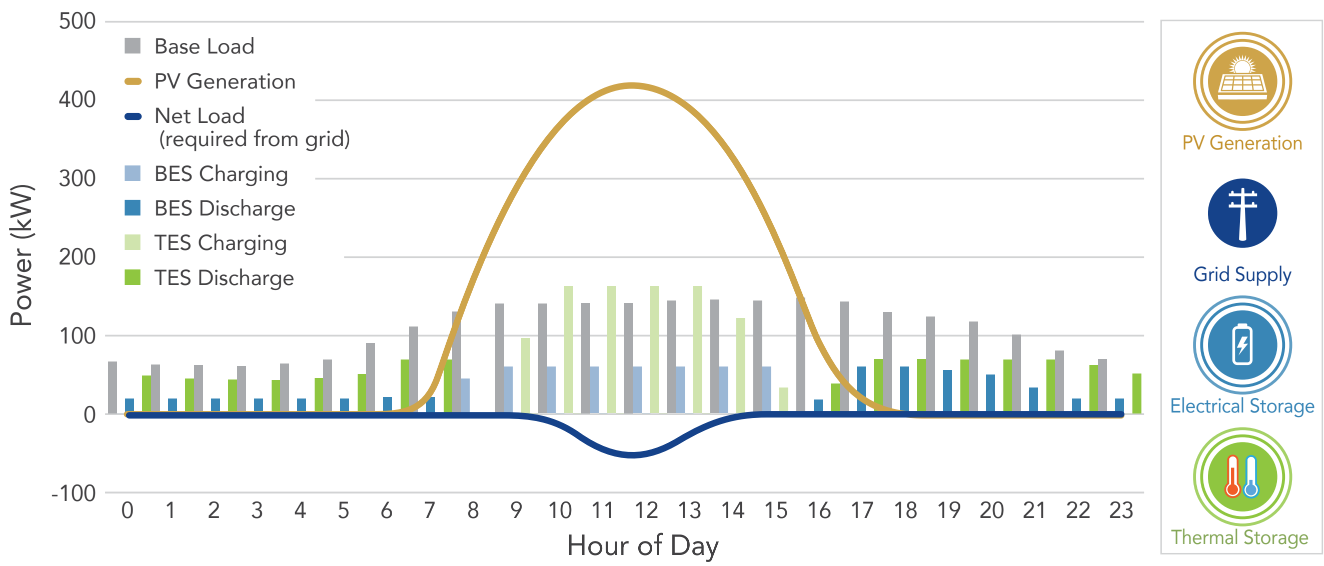

Figure 6. Graph showing the production from an even larger onsite solar PV array, the charge/discharge of both a BES and a larger TES system, and their effect on the net load. To further reduce the grid exports, the facility would need to curtail a fraction of the total onsite generation.

- **PVWatts calculator**[12] This tool models solar generation potential based on a facility's geographic location.
- **ReOpt web tool**[13] This tool models renewable and storage systems including sizing, evaluating their economic viability and optimizing dispatch strategies.
- **Electric Vehicle Infrastructure – Enabling Distributed Generation Energy Storage Model (EVI-EDGES)**[14] EVI-EDGES is a tool for understanding how the use of BTM storage and distributed generation can reduce the costs and impacts of vehicle electrification.
- **Electric Vehicle Infrastructure Toolbox (EVI-X)**[15,16] This suite of tools allows facilities to estimate charging infrastructure needs and electrical demands based on EV adoption scenarios.
- **System Advisor Model (SAM)**[17] SAM facilitates BTM battery storage modeling, demand charge saving calculations, and total cost of ownership calculations.
- **Department of Energy Technical Assistance Opportunities**[18] The Department of Energy provides a variety of no-cost technical assistance to organizations to facilitate the adoption of renewable energy generation and energy storage.

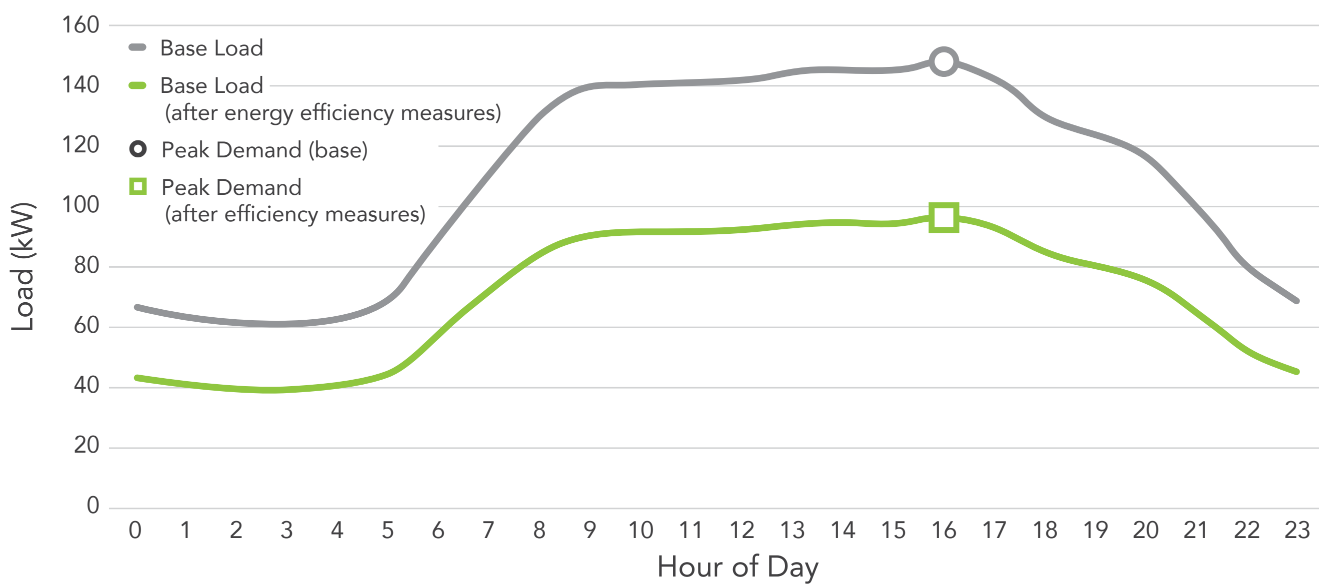

Figure 7. Graph showing the potential of energy efficiency strategies to reduce building energy consumption. Energy efficiency measures can yield large load reductions that can facilitate building electrification without the need for capacity increases.[19]

Onsite Solar PV and Onsite Storage: Building Capacity for Future Electrification

In addition to considering onsite solar PV and storage, many facility owners are beginning to electrify thermal systems and install electric vehicle charging infrastructure on their properties. For both cases, the increased electric loads due to these upgrades can quickly exceed the existing electrical service limitations and infrastructure at the facility. To overcome this, energy efficiency strategies and strategic load management coupled with onsite storage can allow facilities to maximize their electricity use while remaining within current electrical service limitations.

Energy efficiency strategies are the first step facility owners can take to build capacity for future electrification. These strategies can lower peak demand charges and reduce the amount and cost of electricity that is delivered to the facility, even without the need for onsite generation or storage. Figure 7 shows how energy efficiency measures can reduce peak demand and total energy consumed by the grid. Establishing energy efficiency measures before sizing storage systems can reduce the size of generation and storage systems necessary to achieve facility energy goals.

Additional capacity for future electrification can be enhanced by implementing onsite TES, which can enable downsizing of facility HVAC equipment.[20] For example, when traditional gas-fired boilers and electric chillers are designed, they are typically sized to meet the peak load of the facility. When electrified using the same logic, one-to-one "drop in" electrification replacements can lead to significant oversizing of equipment and increased expenses both from a first cost and operations perspective. However, including TES into these systems can allow electric heating and cooling systems to be sized smaller to satisfy the average daily load as opposed to sizing for the maximum load expected over the entire year.[21] TES can then be used to supplement the downsized system to meet the required peak heating or cooling loads of a facility. This integration can significantly reduce the impact of electrified heating systems on the total electric load of the building.

Ground source heat pumps (GSHP) are another technology that can facilitate efficient heating electrification. Since GSHPs use the ground as a heat source/sink, with inherently stable ground temperatures year-round they operate more efficiently than air source heat pumps, particularly during the hottest or coldest weather conditions. Lower electrical loads for heating and cooling allow limited electrical capacity to be used in other places. When installed with onsite renewable energy generation, facilities that use GSHPs in unbalanced climates (either very hot or very cold) could configure these systems to use excess onsite generation to heat or cool the ground, providing seasonal underground TES.[22] This could have the added benefit of avoiding curtailment of onsite renewable energy while further increasing the operational efficiency of the GSHP.

Onsite solar and electrical storage systems can be used to build capacity for electric vehicle charging infrastructure at facilities. Level 2 chargers can draw anywhere from 3 to 20 kW[23] at any given time. These loads can lead to spikes in the facility electricity consumption, resulting in higher demand charges and added costs from greater consumption during peak time-of-use rates. To overcome this, facilities can optimize the control of EV chargers.[24] For example, electric vehicle charging can be limited to periods when excess onsite solar PV is available. Further, the addition of electric storage can allow EV charging installation despite electrical infrastructure constraints.

Conclusion

Facility owners seeking to reduce their operating costs, lower greenhouse gas emissions, and build resiliency at their facilities can benefit from installing onsite renewable energy generation and onsite energy storage systems. When adequately sized and controlled, these systems can provide facilities with a way to reduce demand charges, reduce electricity use during peak time-of-use rates, avoid utility export limitations, and operate during grid outages. While onsite solar PV can be used by itself to achieve substantial benefits, the integration of onsite storage can maximize these benefits and provide a pathway towards decarbonizing the commercial and industrial sectors.

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