Solar+: Enabling Clean Energy in Disadvantaged Communities with Integrated PV + Storage

DR18.06

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EXECUTIVE SUMMARY

INTRODUCTION

The project EPC 16-068 (DR18.06) *Solar+: Enabling Clean Energy in Disadvantaged Communities w/ Integrated PV + Storage* is a demonstration of community-level resource integration and controls at an affordable housing property in a low-income, disadvantaged neighborhood in Compton. The project featured deployment of the following technology innovations:

- High-Efficiency Bifacial Solar PV:
- Battery Energy Storage:
- DC-coupled Bi-directional Inverters
- Energy Efficient Direct Current (DC) Loads
- Multi-Level Controls Integration through a Cloud-Based platform
- Innovative A Community-Sharing Business Model (Virtual Net Energy Metering)

This technology deployment took place at a significant moment in California history as it marked the confluence of State of California policy and program initiatives advancing decarbonization, zero net energy, the multifamily segment, solar PV + storage, and equitable access to energy innovations and their economic and environmental benefits. All of these policy initiatives informed the project design:

- Gas reduction landmark bill Assembly Bill (AB) 32 and State Bill 32, 100 and 350. To achieve carbon neutrality by 2045 will require replacement of fossil fuel use in buildings with renewable generation and techniques.
- The Long-Term Energy Efficiency Strategic Plan, which set the "Big Bold Goal" that all new homes in California be Zero Net Energy by 2020.[1] Extending these goals, the State committed to making all new public buildings ZNE by 2020, and all new commercial buildings ZNE by 2030, and to reduce energy use in existing buildings by 50 percent by 2030 (SB 350).
- Title 24 code: One of the big needs was models around community solar as it is very difficult to establish enough properly oriented roof space in new home communities and to inform development of the 2019 Title 24 code, which was aimed at achieving Zero Net Energy in residential communities.
- AB 693: This project provided technologies and implementation strategies in low income multifamily housing to address two major constraints for implementing solar in affordable housing are technology – site fit and the business models. This project sought

[1] http://www.cpuc.ca.gov/NR/rdonlyres/D4321448-208C-48F9-9F62-1BBB14A8D717/0/EEStrategicPlan.pdf; Section 1, p6

to address both of these constraints as California scales solar in multifamily affordable housing to 300 MW.

- 2022 State Energy Code: This project provides critical learnings in anticipation of the CEC's proposed requirement that new multifamily buildings be equipped with solar PV AND storage.
- Enabling Self Generation Incentive Program (SGIP): This project sought to bridge the gap through load shaping with loads and storage that will make storage implementation more effective and enable SGIP installations to be better tuned to enabling distribution systems.
- AB 2514: With SCE as a highly engaged partner and co-funder of this effort, the team addressed business models to enable utilities to implement their targets for storage

PROJECT PURPOSE

The primary objective of the project was to identify scalable community models to maximize the economic and environmental benefits of solar photovoltaic energy systems for low-income populations and affordable housing facility operators. With Southern California Edison as a key partner and local utility, this resource integration project also evaluated how to further scale and to enable grid flexibility, reliability and greenhouse gas emission reduction that is beneficial to the entire rate base.

The technology innovations noted above were selected based on their potential to align with the policy direction of California targeting the low income multifamily sector. Emphasis was placed on business models that supported the economic and environmental advancement of low income residents as California Investor Owned Utilities transition all residential customers, including those on affordable discount rates, to time of use (TOU) rates with time differentiation and peak pricing and that benefitted utilities and the larger rate base including balancing solar to avoid distribution upgrades and shave peaks, reducing GHG from the California electric system and managing bulk system capacity through demand response (DR).

Most of the chosen innovations are emerging technologies, which were challenging to deploy due in part to limited product availability, lack of familiarity by permitting authorities and stakeholders, code limitations and compatibility issues. Still, this resource integration project has garnered heightened attention not only for its energy efficiency and DR benefits but as a realized demonstration of DC distribution and appliances that could be expanded with the provision of automatic transfer switch to offer low income community resiliency as it could provide backup power and a resiliency center during local outages to support critical loads like medical devices and air conditioning.

PROJECT RESULTS

EPRI partnered with Linc Housing (Linc), a California-based affordable housing owner, on siting this demonstration project at a 61-unit low-income multifamily property in Compton, California called Mosaic Gardens at Willowbrook (Willowbrook). EPRI also partnered and received funding from Southern California Edison, the local electrical utility. In 2020 and 2021, the team successfully deployed and tested the resource integration demonstration comprised of the following technologies:

- 2 battery cells 60 kW / 2-hour, provided by EnergPort
- 2 60-kW bifacial solar photovoltaic (PV) arrays, provided by Canadian Solar
- DC-coupled PV and storage system, with inverter provided CE+T
- Inverter meeting CA Rule 21 Phase mandates for grid supportive functions
- A local controller coordinating PV, battery, and inverter, provided by GridScape
- A level up is the Open Demand Side Resources Integration Platform (OpenDSRIP), developed by EPRI and funded through another CEC grant (EPC 15-075), coordinating overall system controls
- This project utilizes Virtual Net Energy Metering (VNEM). The production and operation of the PV and battery will be distributed (allocated) across each of the residential unit meters and the Common Building meter
- The project will include common area lighting and air conditioning DC loads, directly coupled with the battery system.

First, EPRI followed a process that involved working with the technology integrator Gridscape and EPRI technical staff to simulate and fine tune the integrated system within a lab setting at its own facility before deploying the field. The project partners had to delay construction by approximately one year to conduct comprehensive due diligence. Willowbrook is a tax credit financed property with multiple lenders, one of which had had a poor experience with previous solar projects (leaking from roof penetrations). The second challenge was the prolonged sourcing, testing, permitting, and interconnection processes associated with implementing the emerging technologies of the project scope, especially the direct current (DC) distribution and appliance demonstration elements.

This project was unique in its DC side connection of solar and storage with a single inverter. Getting through the permitting process required a significant amount of work with the County of Los Angeles, the local permitting authority, as it was unfamiliar with a DC side connection. It was also difficult to obtain local utility SCE approval, but it was enabled by prior work the vendor had completed with PG&E on a software based monitoring solution for non-export Rule 21 interconnect. On the DC demonstration, several iterations of plans were submitted, and parts were not readily stocked or available as market demand was low. For example, DC lighting in this project used low voltage, low power controls that are being used and accepted elsewhere with no UL listing. LA County in this case forced the project team to obtain a UL field evaluation for low voltage lighting controls. Simply the cost and scope of getting an NRTL to provide a field evaluation would prevent most customers from considering this route.

The systems were ultimately installed in two phases by Staten Solar: the solar + storage followed by the DC demonstration and monitoring and verification instrumentation. During this time, the Covid-19 virus emerged and ensuing global pandemic resulted in elevated precautionary measures to avoid transmission and exposure among crews and property occupants and staff, supply chain issues for some of the components and related setbacks to on-site work and supervision. To address these challenges, the project team took time, hired a dedicated construction manager, addressed issues in recurring weekly meetings, followed Covid safety protocol and engaged external stakeholders. Furthermore, a technical advisory committee

(TAC) was formed and met two times throughout the duration of the project, during which some of these issues were addressed.

High level results are summarized based on the anticipated outcomes of the technology deployment:

Evaluate new solar technologies that can address space constraints through higher efficiencies to assist multifamily buildings with roof area constraints to meet Zero Net Energy Goals

The project team installed bifacial solar PV with target efficiency around 23 percent. Results showed actual DC production was, in fact, 84 percent of modeled production and AC generation was 78 percent of modeled production, most likely resulting from non-uniform mounting conditions, including mixed string orientations connected to single maximum power point tracking, modules not located to maximize received ground reflected irradiance (GRI), string mismatch due to mixed orientations and variable GRI and soiling.

Demonstrate integration of solar and storage with smart inverters with segmentation of storage for meeting various needs – peak demand management and utility-controlled distribution grid flexibility

The controls strategy was guided by the objectives of minimizing use of grid power during time of use (TOU) peak pricing periods, shaving electric vehicle charging system peaks, balancing solar to avoid distribution upgrades, reducing GHG from the California electric system and finally managing bulk system capacity through DR. Levers for implementing the controls strategy were the battery controller and a Willowbrook-specific behavioral DR program developed in partnership with OhmConnect that used gamification and monetary rewards to encourage residents to consistently reduce energy upon demand, especially during TOU peak periods.

Improve near-term grid flexibility and reliability using connected Distributed Energy Resources (DER) with DR capability

EPRI evaluated multiple battery control scenarios including one simulated at scale across multiple communities on the same residential feeder, in which it was able to reduce peak load by 10 percent while meeting other controls objectives (TOU rate offset, EV peak shaving and GHG emission reduction) 97 percent of the time throughout the year. It bore the highest financial returns of all the scenarios evaluated as part of this project, which are further discussed in Chapter 4: Project Results

EPRI also collected energy performance data during a summer and shoulder month season, finding post-installation energy performance resulting in a net benefit to the community in terms of reducing their energy costs as well as Scope 1 and Scope 2 emissions.

Roughly one-third of the site host residents also enrolled in the Willowbrook-specific behavioral DR program. Energy consumption during the 4-9 PM TOU peak pricing period fell 25 percent compared to the previous year as a result of behavioral reductions in energy use.

INTEGRATION OF DC MINI GRIDS THAT WILL ELIMINATE CONVERSION LOSSES FOR SOLAR PV TO HEATING, VENTILATION AND AIR CONDITIONING (HVAC) AND LIGHTING LOADS

HVAC

Due to lack of compatibility between the CET Stabiliti 30C3 multiport inverter and Gree VRF, a Ground Fault Detector Interrupter (GFDI) fuse blew. As a rectification plan, the VRF outdoor unit control board was replaced, and the unit was connected directly to the solar instead of the inverter. Measured performance differed from rated performance, owing to different test conditions. Non-monotonic performance indicates that steady-state conditions are not reachable with brief test campaigns. Statistically significant DC vs. AC performance comparison will require long-term alternate-day testing. Overall system performance is, otherwise, in line with expectations. EPRI expects to perform this testing for one month upon installation of the automatic transfer switch in February 2022.

LIGHTING

Because the Amatis sensors and switches did not carry UL listings yet were the only compatible controls for available DC lighting (Lamar 24VDC), a UL 2108 Low Voltage Lighting System field evaluation was completed by a National Research Testing Lab (NRTL). As compared to the pre-existing LED AC lighting fixtures, which were already quite efficient at 49/42W 5500 lumens, the replacement 24W 2600 lumen DC light fixtures resulted in a 3.6 percent efficiency gain in terms of lumens per watt. Potential cable losses in the Willowbrook project were mitigated by using a 250VDC lighting driver that is located as close as possible to the light fixtures themselves, which are 24Vdc. The primary opportunities identified during this lighting implementation are the need to explore expanding availability of 380VDC or higher voltage DC lighting for optimal efficiency as well as the need to establish availability of UL-listed DC lighting controls.

EVALUATE VARIOUS BUSINESS MODELS AROUND COMMUNITY-SCALE SOLAR AND STORAGE AND HOW IT CAN ENABLE BENEFITS SUCH AS ECONOMICS AND RELIABILITY WHILE ALSO PROVIDING GRID BENEFITS

The economics of solar + storage for low income communities is nascent/ non-existent with current rates. Employing the Virtual Net Energy Metering (VNEM) rate structure meant that the benefits of solar PV accrue mainly to the tenants. The Solar on Multifamily Housing (SOMAH) program, which also influenced the project design, effectively prevents the landlord from charging the tenants for the benefits of solar, which means that the property owners have to justify solar just based on the common area usage. In many cases, common area usage is very limited (in this case just over 10,000 kWh a year), and that means that property owners, if they are leasing solar cannot cover the lease payments.

Because of the difficulties in monetizing grid services from energy storage, the cost-benefit analysis suggests that all scenarios without outside funding support would bear a negative net present value (NPV). Used to estimate the value of a future stream of payments, a positive number suggests an attractive investment with future cash flows. The NPV for the best performing scenario was -312,619. This cost-benefit analysis only monetizes the utility bill savings to the property and excludes any financial benefit from greenhouse gas emissions, net peak load reduction or other distribution services that could defer distribution upgrades nor added customer resiliency from the DC distribution and appliance project scope, which can benefit the property, utility and rate base at-large.

This demonstration proved that the scope was not as easy as it appeared on paper due to a number of factors such as limited product availability, lack of familiarity by permitting authorities and stakeholders, code limitations and compatibility issues. Still, this project, especially the DC minigrid has garnered a lot of attention lately not just energy efficiency and DR but as promising model for resiliency as it could provide backup power and create a resiliency center during local outages to support critical loads like medical devices, AC, etc. The host site experienced a relatively high number of outages during the project that disrupted the property's electrical supply and HVAC operations. The team therefore expanded its model to include an automatic transfer switch so that common critical loads at this affordable housing complex could operate exclusively off of DC power from the solar.

TECHNOLOGY TRANSFER

According to the California Department of Housing and Community Development, there are approximately 4.3 million multifamily units in the State of California with approximately 480,000 that are deed-restricted affordable housing. EPRI focused on disseminating research and results from this project to affordable multifamily housing developers and owners as well as the program administrators and policy makers that address them and their low income resident constituents with building and energy services and environmental equity solutions. EPRI presented at conferences and disseminated publications to a combination of industry, government and utility audiences using Willowbrook as a test case for implementing low income multifamily solar + storage.

Examples of other additional technology transfer activities include the following:

- Southern California Edison, a project partner and co-funder, used the Willowbrook project as a case study for in-house engineering training in summer 2021. SCE representative Mark Martinez stated that the utility will be using the lessons from this and other EPRI projects in the utility's future DER forecasting and modeling work as well: "These projects help identify opportunities for future models of DER programs…This and other projects will continue to help us understand how future customer solar and storage systems can provide local grid reliability, and what we can do to help our customers maximize their benefits."
- EPRI and project partner OhmConnect, a DR aggregator, are actively discussing expansion of its Willowbrook specific platform in order to support other California low income multifamily properties as the larger residential market shifts to TOU rates.
- Site host and project partner Linc Housing has collaborated with EPRI on one virtual site visit with plans for offering one more before the end of the agreement term covering the DC demonstration. The virtual site visit is designed to provide utilities, fellow affordable housing owners and operators, engineers and facility managers the ability to talk directly to the project team and staff and ask them direct and pointed questions about the installed system.

Importantly, the lessons learned as part of this project reveal the gaps and barriers needed to commercialize the deployed technologies. Examples that are given in the report and in presentations conducted as part of the project's technology transfer activities include the need to update the National Electric Code standards and building codes for general utilization of higher DC voltages, to provide more incentives to expand availability of DC equipment, including but not limited to 380VDC or higher voltage DC lighting for optimal efficiency as well as the need to establish availability of UL-listed DC lighting controls and finally to developing better monetization strategies to improve the ROI of behind-the-meter storage where it is aligned with State policy and rate base needs, such as through grid services or strategic dispatch during hours of high marginal carbon emissions.

BENEFITS TO CALIFORNIA

As an integrated solution for low-income multifamily housing in California, the estimated project benefits are promising.

a. Lowered Costs: Extending the results of this project to California's deed-restricted affordable multifamily households shows potential for a bill reduction of $253 million for California's low-income households.
b. Increased Reliability: Reduced evening demand by 8.6 percent during TOU peak periods, which will contribute to increased grid reliability, ultimately benefiting all California ratepayers.
c. Economic Development: Job creation equivalent to 8 person-years. This can also be scaled to major job growth if similar retrofit work is conducted statewide for the target sector. The reduction in energy bills and DR participation payments also leave tenants with greater disposable income, which is particularly impactful for low-income populations, which constitute nearly 20 percent of all California ratepayers
d. Environmental Safety: Extending the results of this project to California low-income multifamily households show a potential for statewide CO2 reduction of ~ 83,331 metric tons per year.
e. Public Health: This project improves public health by reducing pollution and greenhouse gas (GHG) emissions. This project also tests a resilience strategy in disadvantaged communities through the DC distribution and appliance demonstration, which theoretically can help vulnerable populations in need of continuous power for medical devices during an outage.
f. Consumer Appeal: This project is enhancing a sustainable, Leadership in Energy and Environmental Design- (LEED) certified urban in-fill, mixed use and transit-oriented property that allows people to live close to employment. This project will enhance the comfort and affordability of this housing to further consumers' interest in renting and owning it.
g. Energy Security: The reduction of energy usage via energy efficiency and renewable measures provides energy security by avoiding resources needed to build more power plants and being more self-sustained for energy requirements. This project has the engagement of major California investor-owned utility (IOU) SCE and affordable housing developer Linc, which are using the results of this work to inform their future planning and development.

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BACKGROUND

OVERVIEW

The project EPC 16-068 (DR18.06) Solar+: Enabling Clean Energy in Disadvantaged Communities w/ Integrated PV + Storage is a demonstration of community-level resource integration and controls at an affordable housing property in a low-income, disadvantaged neighborhood in Compton. The primary objective of the project was to identify scalable community models to maximize the economic and environmental benefits of solar photovoltaic energy systems for low-income populations and affordable housing facility operators. With Southern California Edison as a key partner and local utility, this resource integration project also evaluated how to further scale and to enable grid flexibility, reliability and greenhouse gas emission reduction that is beneficial to the entire rate base.

The technology innovations were selected based on their potential to align with the policy direction of California targeting the low income multifamily sector. Emphasis was placed on business models that supported the economic and environmental advancement of low income residents as California Investor Owned Utilities transition all residential customers, including those on affordable discount rates, to time of use (TOU) rates with time differentiation and peak pricing and that benefitted utilities and the larger rate base including balancing solar to avoid distribution upgrades and shave peaks, reducing GHG from the California electric system and managing bulk system capacity through DR.

The Electric Power Research Institute (EPRI) is the prime researcher and lead on this research and demonstration project. The California Energy Commission (CEC) and Southern California Edison (SCE) are funders, for whom EPRI had specific deliverables and expected outcomes. Other team members include Linc, a California-based affordable housing developer, project site host and manager of Gridscape, the solar + storage technology integrator. Staten is the licensed contractor and installer of the solar + storage as well as the designer and installer of the direct current (DC) distribution and appliance demonstration. Primus is the construction manager, representing Linc's interests and managing on-site activities and construction. OhmConnect manages the behavioral DR program that is being deployed among the host site's residents. Finally, Kliewer & Associates is a consultant to SCE, providing technical support and representing SCE's research interests in the project. The project partners are denoted in Figure 1.

Source: EPRI

FIGURE 1. PROJECT TEAM

THE CUSTOMER STORY

By May 2022, SCE is expected to transition all residential customers to Time-of-Use (TOU) rates. Currently, all residents at Willowbrook, and the majority of the low income residents at properties owned by Linc, a California non-profit affordable housing owner and developer, are on California Alternate Rates for Energy (CARE) discounted electrical rates and do not have time differentiated rates, but rather tiered rates. When TOU starts in 2022, CARE customers will, for the first time, face different energy rates by the season and by the time of day. While they will still have their rates discounted under the CARE program, the variable rates can lead to greater overall bills, especially during peak summer times.

In a 2017 pilot program to understand TOU impacts, the California Public Utilities Commission (CPUC) found that all Pacific Gas and Electric Company (PG&E) and SCE CARE customers in hot climates experienced higher total annual electricity costs under TOU pricing, ranging from $20 - $40 in average monthly bill increases. SCE CARE customers were also generally found to be unable to offset a significant portion of the bill increases by load shifting.[2] Table 1 highlights current and predicted rates for Willowbrook residents.

[2] Hawiger, Marcel. Hayley Goodson. Opening Brief of the Utility Reform Network Concerning Compliance with Section 745 Requirements for the Implementation of Default Residential Time of Use Rates. 2017. https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M191/K054/191054131.PDF. The Utility Reform Network.

Table 1 - SCE CARE: Current and Predicted CARE TOU Rates*, $/kWh

Current Rates ($/kWh)	Time of Day	TOU Rates – Summer*	TOU Rates – Winter*
	Peak	$0.3134	N/A
	Mid-Peak	$0.1849	$0.1317
	Off-Peak	$0.1218	$0.1152
	Super Off-Peak	N/A	$0.0934

*Applies a 30 percent discount to rates to estimate impact of CARE discounts for residents only

EPRI approached Linc with a project to pay for the ~$1.1 million in development costs for the installation of a solar PV and battery storage demonstration project at Willowbrook with funding and in-kind labor and equipment support. The project would feature advanced solar technologies, batteries, DC distribution and appliances and controls and behavioral DR strategy to effectively reduce the community's energy costs and carbon footprint. Linc's Board of Directors consented to EPRI's proposal to use Willowbrook as a showcase of early stage technologies based on their potential to effectively counter bill increases from the TOU rate transition. Staff highlighted the boost in yield from the bifacial solar PV and the battery storage as being particularly helpful during peak and mid-peak periods. When utility-generated electricity is at its most expensive, the battery would transmit stored electricity to the property instead.

The following project benefits were presented to the Linc governance/board by staff to seek approval to proceed:

- Costs savings for the common area and tenants: The solar system is designed to supply 100 percent of common area electricity usage and 66 percent of tenant electricity usage. It would discount the electricity rate by 10 percent for tenants, as compared to current SCE rates, in Year 1. With TOU rates, the battery storage would draw and store electricity during off-peak times (daytime). This would make cheaper electricity available for the property during peak times (evening).
- Provide greater cost stability for the common area and for tenants: the solar would provide electricity on a low 2.5 percent escalation rate for the common area and tenants for the next 20 years.

Policy Context

Not only did this project take place at a unique moment in the transition to TOU rates for all California IOU residential customers, there has been a confluence of program and policy

initiatives since the proposal submission advancing decarbonization, zero net energy, solar and storage in the multifamily segment and equitable access to energy innovations to all sections of society to enable everyone to derive the economic and quality of life benefits from meeting these goals. This project was designed to demonstrate an implementation pathway where possible for some of these important policy initiatives:

- Gas reduction landmark bill Assembly Bill (AB) 32 and State Bill 32, 100 and 350. To achieve carbon neutrality by 2045 will require replacement of fossil fuel use in buildings with renewable generation and techniques.

- The Long-Term Energy Efficiency Strategic Plan, which set the "Big Bold Goal" that all new homes in California be Zero Net Energy (ZNE) by 2020.[3] Extending these goals, the State committed to making all new public buildings ZNE by 2020, and all new commercial buildings ZNE by 2030, and to reduce energy use in existing buildings by 50 percent by 2030 (SB 350).
- Title 24 code: One of the big needs was models around community solar as it is very difficult to establish enough properly oriented roof space in new home communities. There was very active engagement with the Title 24 development team and this work was informed by and in turn directly inform development of the 2019 Title 24 code, which was aimed at achieving ZNE in residential communities.
- AB 693: This project provided technologies and implementation strategies in low income multifamily housing to address two major constraints for implementing solar in affordable housing are technology – site fit and the business models. This project sought to address both of these constraints as California scales solar in multifamily affordable housing to 300 Megawatt (MW).
- 2022 State Energy Code: This project provides critical learnings in anticipation of the CEC's proposed requirement that new multifamily buildings be equipped with solar PV AND storage.
- Enabling Self Generation Incentive Program (SGIP): This project sought to bridge the gap through load shaping with loads and storage that will make storage implementation more effective and enable SGIP installations to be better tuned to enabling distribution systems.
- AB 2514: With SCE as a highly engaged partner and co-funder of this effort, the team addressed business models to enable utilities to implement their targets for storage

[3] http://www.cpuc.ca.gov/NR/rdonlyres/D4321448-208C-48F9-9F62-1BBB14A8D717/0/EEStrategicPlan.pdf; Section 1, p6

PROJECT PURPOSE

The project team established the overarching goal of this solar + storage demonstration project as identifying scalable community models to maximize the economic benefits of solar photovoltaic energy systems for low-income multifamily populations and to evaluate how these technologies could enable grid flexibility and benefits that are beneficial to the entire rate base. The project team sought to use the demonstration project at Willowbrook to address several larger research questions within the context of a working California low-income multifamily example that include:

What are the economics of community-scale solar + storage?

How does it fit within the State's policy goals?

What are the early stage technologies that overcome barriers of solar + storage in the field?

What are some business models for IOUs to engage in for customer and grid benefit?

With these questions in mind, the team established the following project objectives for this demonstration:

- Evaluate new solar technologies that can address space constraints through higher efficiencies. Demonstrate bifacial solar with target efficiency around 23 percent that can substantially assist commercial and multifamily buildings with roof area constraints to meet Zero Net Energy goals.

- Demonstrate integration of solar and storage with smart inverters with segmentation of storage for meeting various needs – peak demand management, utility-controlled distribution grid flexibility and so on... Address problems of late evening peaks as buildings get tighter, plug load soars, using storage and loads to better match usage with solar production. Implement and test technical innovative integration of solar, storage and loads

- Demonstrate platform that can manage both loads (connected devices) and storage to manage both diurnal solar production, evening peaks and increase overall efficiency of solar utilization – achieved using customer-responsive as well as automated demand-side resources. Test how innovative controls can be used to balance the customer needs for rate and tariff management with utility need for flexible load balancing

- Integration of DC mini grids that will eliminate conversion losses for solar PV to HVAC and lighting feed loads and further enhance Integration of DC mini grids that will eliminate conversion losses overall system efficiency. Evaluate integrated building technologies such as DC lighting and minigrids that are enabled by integration of solar + storage and can offer efficiencies to the customer

- Improve near-term grid flexibility and reliability using connected DER with DR capability. Demonstrate load management using integrated control for two objectives:

- Managing energy cost through rate optimization

- Provide flexible DR any time of year for the CAISO and utility markets
- Evaluate various business models around community-scale solar and storage and how it can enable benefits such as economics and reliability while also providing grid benefits. Develop models to establish social equity using renewable generation working with a low-income community serving formerly homeless populations.

PROJECT APPROACH

PROJECT AND SITE DESCRIPTION

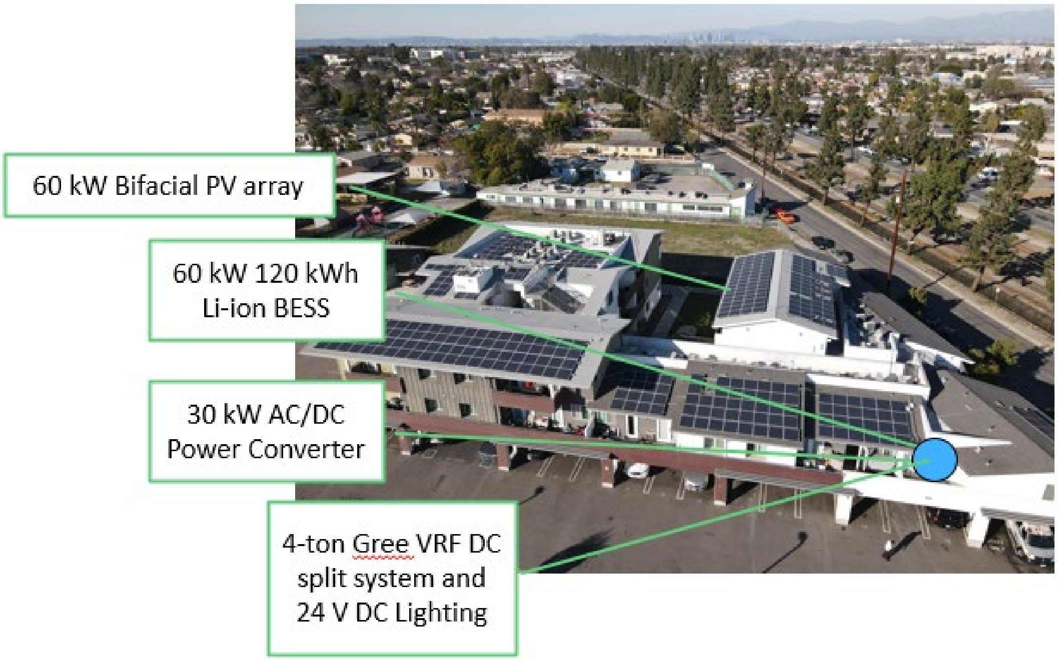
Mosaic Gardens at Willowbrook (Willowbrook) is an affordable multifamily housing property in Compton, California, a highly disadvantaged community (DAC) in Southern California. It was constructed in 2017 by Linc Housing achieving LEED Silver certification and incorporates transit-oriented development concepts. Today, Willowbrook provides 61 housing units to low-income families with 31 units reserved for individuals or families transitioning from homelessness. The site was selected because it represented the target market of affordable multifamily housing and the owner was motivated to investigate the benefits of solar + storage for its larger portfolio. While EPRI, Linc and its partners started development of the project shortly after Willowbrook's construction completion in 2017, construction of the solar + storage project scope only officially began in Fall 2020 once all necessary approvals were secured. The site layout is depicted in Figure 2.

Source: EPRI

FIGURE 2 - WILLOWBROOK SITE LAYOUT

TECHNOLOGY DESCRIPTION

As depicted in the Figure 3 below, two near-identical solar PV + storage systems were set up at each housing building (Building 1 and 2) at Willowbrook. A direct current (DC) distribution and appliance technology demonstration was also installed at Building 2.



Source: EPRI

FIGURE 3 - PROJECT SYSTEM CONFIGURATION

The technology demonstration is comprised of the following:

- 2 battery cells 60 kW / 2-hour, provided by EnergPort
- 2 60-kW bifacial solar PV arrays, provided by Canadian Solar
- Direct Current- (DC) coupled PV and storage system, with inverter provided CE+T
- Inverter meeting CA Rule 21 Phase mandates for grid supportive functions
- A local controller coordinating PV, battery, and inverter, provided by GridScape
- A level up is the Open Demand Side Resources Integration Platform (OpenDSRIP), developed by EPRI and funded through another CEC grant (EPC 15-075), coordinating overall system controls
- This project utilizes VNEM. The production and operation of the PV and battery will be distributed (allocated) across each of the residential unit meters and the Common Building meter
- The project will include certain DC loads at Building 2, directly coupled with the battery system, including common area lighting and air conditioning

PROJECT INNOVATIONS

The team incorporated several key innovations into the scope, which are described in more detail below.

HIGH-EFFICIENCY BIFACIAL SOLAR PV

Bifacial PV models are designed to optimize use of limited roof space, such as in commercial and multifamily applications where roof space can be relatively sparse, by collecting energy from not only the top but from the back of the modules to improve yield. This project deployed 170 Canadian Solar CS3U 355-watt bifacial panels. Figure 4 shows a portion of the bifacial solar PV installation at the project site. Target efficiency for the panels was 23 percent. The project team paired the bifacial solar PV with two 60 kW - 2-hour batteries, manufactured by EnergPort (Model L3060) as pictured in Figure 5.

Source: EPRI

FIGURE 4 - BIFACIAL SOLAR INSTALLATION AT PROJECT SITE

Source: EPRI

FIGURE 5 - L3060 ENERGPORT BATTERY INSTALLATION AT PROJECT SITE

DC-COUPLED BI-DIRECTIONAL SMART INVERTER

A DC-coupled PV and storage system with Stabiliti 30C3 bi-directional inverter manufactured by CE+T (formerly Ideal Power) was selected partially because it fulfills CA Rule 21 Phase 1 mandates for grid supportive functions, which govern required "autonomous" functions that DER with inverter-based interfaces must possess in order for utility interconnection, including:

- Anti-Islanding: Trip off under extended anomalous conditions
- Low/High Voltage Ride-Through: Ride through voltage excursions beyond normal limits
- Low/High Frequency Ride-Through: Ride through frequency excursions beyond normal limits
- Volt-VAr: Dynamic reactive power injection through autonomous responses to local voltage measurements
- Ramp Rate: Define default and emergency ramp rates as well as high and low limits
- Fixed Power Factor: Provide reactive power by a fixed power factor
- Soft Reconnect: Provide "soft-start" methods

The Stabiliti 30C3 is a multi-port and DC-coupled inverter with three bi-directional ports (2 AC and 1 DC), including:

A. AC port for utility grid connection,

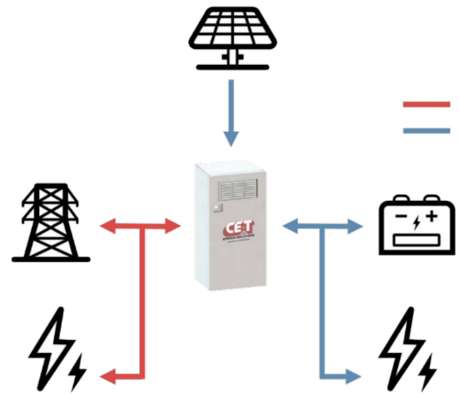
B. DC port for PV modules

C. DC port for battery energy storage.

An inverter, such as this one, allows individual control of storage and PV modules. It also saves conversion losses between solar PV and battery system charging without converting to AC. The roundtrip efficiency is 97 percent. Figure 6 shows one of the bi-directional inverters installed in the field. Figure 7 shows a schematic bi-direction inverter diagram setup.

Source: EPRI

FIGURE 6 - INSTALLED CE+T STABILITI 30C3 INVERTER UNITS (LEFT) AND ENCLOSED ENERGPORT L3060 BATTERIES (RIGHT



Source: CE+T (right)

FIGURE 7 - BI-DIRECTIONAL INVERTER DIAGRAM (RED LINE IS AC, BLUE LINE IS DC)

ENERGY EFFICIENT DC DISTRIBUTION AND APPLIANCES (MINIGRID)

Use of AC power, which is the standard mode of distributing electricity to customers today is primarily a legacy of the 20th century, when the only to step voltage up and down was via transformers, which require AC. Direct utilization of DC power, on the other hand, may have the potential to reduce distribution losses, by reducing the number of conversions between generation and utilization.

As solar PV, storage and DC loads are naturally compatible, the team demonstrated a DC distribution and appliance system to compare the energy use to a traditional AC distribution systems with compounding energy losses estimated to be as high as 33 percent. This is noteworthy considering residential applications have particularly high potential as one-third of US residential loads are native DC (and could be higher with electric vehicles).[4]

The appliances deployed as part of this project include a DC-enabled Gree GMV-Y36WL/A-T(U) Variable Refrigerant Flow (VRF), a variable speed mini split heat pump that can work in 100-380 voltage direct current (VDC) as well as alternating current (AC) mode as shown in Figure 8. The VRF features a permanent magnetic brushless DC compressor and fan motors, two stage high efficiency motors and DC electronics that can accept a broad voltage range. Figure 9 also shows the 24VDC Lamar lighting that were installed along exterior hallways common area. There were eighteen 24VDC lighting that were installed. The DC mini-grid also included 24VDC Lamar lighting, Amatis bridge, sensors and switches, and 2 Nextek power hubs.

This project proved more complex than it appeared on paper. Some of the components proved incompatible, specifically the Stabiliti 20C3 bi-directional inverter and VRF. While the

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[4] Pantano, Stephen. Peter May-Ostendorp, Katherine Dayem, Demand DC: Adoption Paths for DC Power Distribution in Homes. 2016. https://www.aceee.org/files/proceedings/2016/data/papers/1_156.pdf. American Council on Energy Efficiency.

manufacturer's engagement and interest in such systems may prove to resolve these issues with future product revisions, the team addressed this issue at the project level by connecting the solar directly to the VRF, rather than via the DC port of multiport inverter. Some of the components were also hard to find – for example, high-voltage DC breakers and DC lighting controls. The local permitting authority required as a condition of approval hiring an NRTL to conduct a UL2108 Low Voltage Lighting Systems field evaluation of the Amatis sensors and switches. Deployment and testing results are described in further detail in Chapter 4: Project Results.

Source: EPRI

FIGURE 8 - GREE VRF GMV-Y36WL/A-T(U)

Source: EPRI

FIGURE 9 - LAMAR 24V DC LIGHTING

Controls Description

EPRI designated four primary control objectives for the project, which include:

1. Futureproofing against rate changes for vulnerable populations without tools to manage TOU and demand rates
2. Local load balancing with solar PV, to get ready for electrification of buildings, while avoiding upgrade of distribution transformers and secondaries
3. Managing storage to reduce GHG emissions from the California Electric system
4. Methods to manage bulk-system capacity using demand-response based on participation in DR Auction Market (DRAM).

As depicted in Table 2, the controls strategies employ the levers of the battery system controller (Gridscape Energyscope API) as well as customer notifications through an online behavioral DR platform (OhmConnect's #OhmHour messaging platform).

Table 2. Controls Strategies

Control Objective	Use Case	Strategies	Levers
TOU Management & EV Peak Shaving	Increase customer awareness of TOU	Inform customers periodically about high-rate periods.	#OhmHour messaging based notification
	Customer sided load management	Call to action for customers to reduce energy use	#OhmHour messaging with call to action
	Use battery during high TOU periods	Discharge batteries to defray high TOU energy costs and system-wide EV peak charging	Gridscape Energyscope API based battery control.
Solar Balancing	Use batteries to soak up solar	Charge batteries during periods of high solar output	Gridscape Energyscope API based battery control.
GHG emissions reduction	Use batteries to reduce source carbon footprint	Discharge batteries during high marginal carbon emissions time (based on CAISO emissions data)	Gridscape Energyscope API based battery control.
Demand Response	Customer participation in DRAM	Enroll customers for DRAM participation	OhmConnect #OhmHour platform

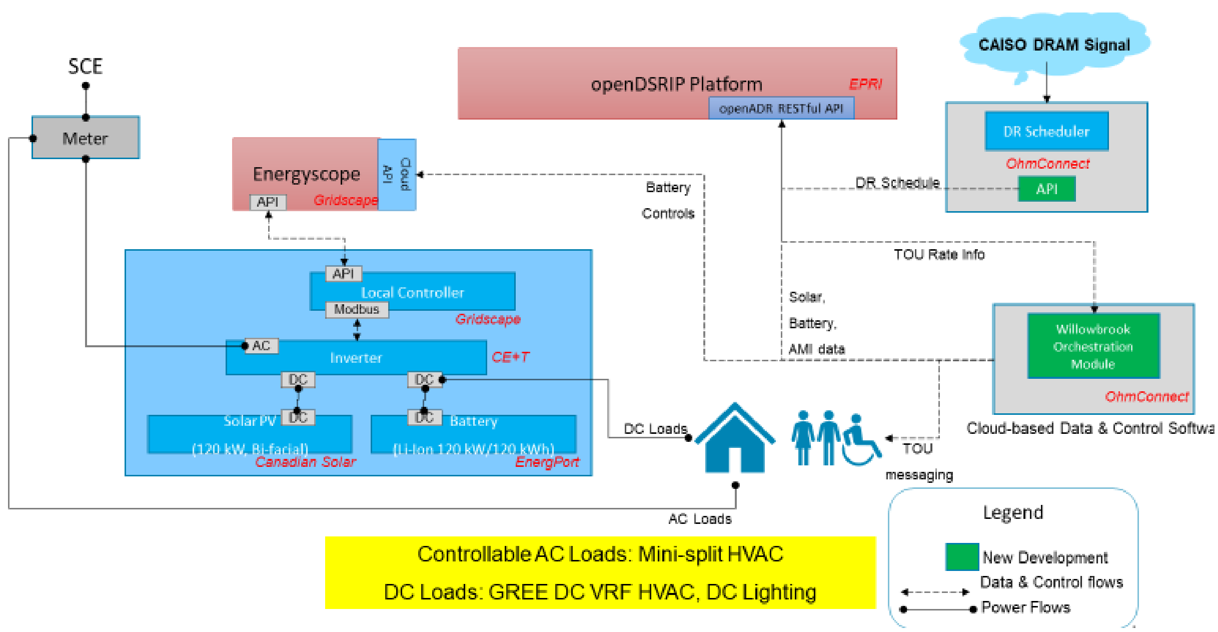
Hardware and Software Architecture

Figure 10 depicts the distributed energy resource technologies within the project scope and the communication interfaces in the hardware architecture. To further map these hardware interfaces and components to a set of controllable entities, the project team developed a hardware and software architecture, depicted in Figure 11, which involves various software or virtual components that are housed either in the cloud or locally (depending upon the specific hardware, connectivity, and performance requirements).

Hardware Control Architecture Summary

- The primary hardware for providing controls for customer and grid services in Willowbrook are mini-split HVAC systems installed in living units, and two lithium-ion energy storage systems installed in common-area locations in the community.
- Controls for living-unit level controllable loads are enabled via OhmConnect-developed messaging platform which provides a "gamified" mechanism to influence customer behavior towards energy efficient behaviors especially during high TOU periods.
- Controls for energy storage systems is enabled through a combination of cloud-based high level controls (through a battery-profile setting interface) and an in-premises local controller (for low-level charge/discharge control and Self Generation Incentive Program (SGIP) compliance).

Figure 10 depicts the DER technologies within the project scope and the communication interfaces in the hardware control architecture.



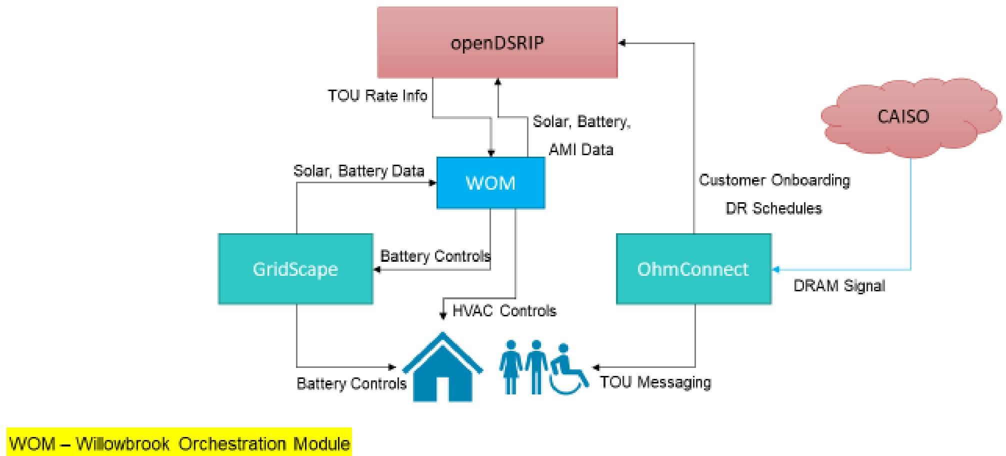
Source: EPRI

Figure 10 - Hardware Control Architecture

Software Control Architecture Summary

The OhmConnect-developed Willowbrook Orchestration Module (WOM) acts as a data aggregation and control platform. All data is backhauled to openDSRIP for measurement and verification (M&V) and evaluation of project performance. The main controls are implemented via battery profiles enabled through the Energyscope Cloud-based interface. The controls are implemented in a distributed manner between the openDSRIP control module that provides control actions for the Solar+Storage at the community level and the Willowbrook Orchestration Module (WOM) which provides control actions for the flexible load.

The software control architecture, depicted in Figure 11, involves various software or virtual components that are housed either in the cloud or locally (depending upon the specific hardware, connectivity, and performance requirements).



Source: EPRI

FIGURE 11 - SOFTWARE CONTROL ARCHITECTURE

MEASUREMENT AND VERIFICATION

The Measurement and Verification (M&V) plan was informed by the project objectives and the need and requirements to verify that the systems being demonstrated were operating as expected.

PV ARRAY CONVERSION EFFICIENCY

Solar PV efficiency determination required precision measurement of inputs (sunlight and local environmental conditions) and outputs (electrical power and energy), including:

- Irradiance measured using secondary standard calibrated thermopile pyranometers, enclosed in an active ventilation housing to minimize effects of self-heating and moisture build-up on the lens. Irradiance sampled at least once every 10 seconds (1-second preferred) to capture varying conditions due to cloud movement. Typical daily insolation uncertainty was less than 2 percent (≤1.5 percent preferred).

- PV module back-surface temperature measured using surface-mount thermocouples or thermistors with appropriate adhesion and thermal conductivity. Measurement uncertainty should be less than 2 °C (≤1 °C preferred).

INTEGRATION OF SOLAR AND STORAGE WITH SMART INVERTERS AND MINI DC GRIDS

Measurement of DC power flow across key buses: from the solar array, to/from the batteries, and to the DC loads. This was accomplished by measuring DC current and DC voltage and then calculating DC power and integrating over time to determine DC energy:

- DC Voltage measured with uncertainty less than 0.5 percent and sampled at least once per second.
- DC Current measured with uncertainty less than 0.5 percent and sampled at least once per second.
- Temperature measurements for obtaining surface or air temperatures surrounding the batteries or inside battery cabinets.

INTEGRATION AND SEGMENTATION OF STORAGE FOR MEETING VARIOUS NEEDS

Isolating and capturing the electrical parameters for the PV/energy storage inverter, in the context of overall power flow within the site, required measurement of power flow to/from the utility grid, to tenant loads, and to/from the PV-battery inverter.

- Power Quality (PQ) Metering supported additional data capture of harmonics, flicker levels, and triggered waveform events as the PV-battery inverter to provide verification of successful grid-support functions.

BUILDING/UNIT LEVEL MEASUREMENT REQUIREMENTS

Detailed measurement of Building/Unit level parameters allows accurate dis-aggregation of overall energy consumption and allows comparison of pre-treatment to post-treatment performance at an individual energy efficiency measure level. Building/Unit level measurements are split into the following components:

- Advanced Metering Infrastructure (AMI) 15-minute interval data resident data and owner common area accounts used instead of circuit-level monitoring
- PV plus Storage control parameters: Parameters used by Gridscape for control of PV + Storage at the community level.

MONITORING EQUIPMENT AND INSTRUMENTATION

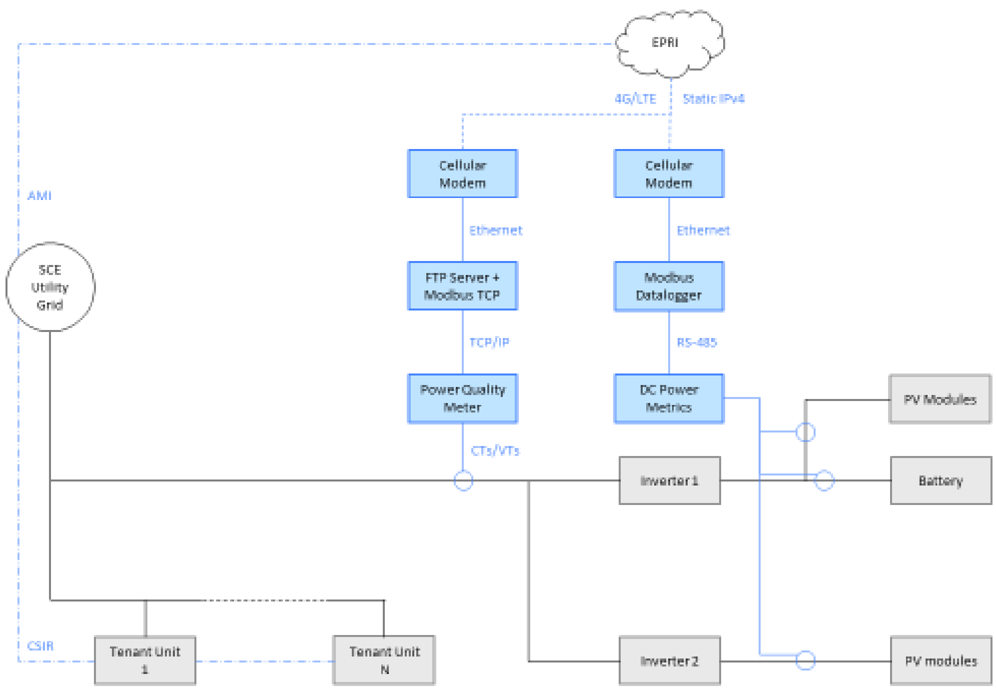
EPRI procured, assembled, and configured data acquisition equipment prior to delivering the equipment to the field site. Hardware procured included instruments listed in Table 3 and additional components including but not limited to: enclosures, cellular data plan, wired and wireless networking devices, data loggers, input modules, and power supplies. Configuration included data point definitions, calibration checks, and network routing and security. Quantities shown in Table 3 are based on a site layout that contains 2 separate buildings: each building having 1 energy storage system and 1 PV array. One building (Building 2) having DC loads.

TABLE 3 - M&V INSTRUMENTATION LIST

ITEM	MANUFACTURER/MODEL	QUANTITY
Irradiance sensor	Kipp & Zonen / SMP10	6
PV module temperature sensor	Kipp & Zonen / RT1	3
DC voltage sensor	Flex-core / VT7-014D-24	10
DC current transformer	Flex-core / DT1-010-24D-BD-SP	10
DC Current Transformer	Flex-core / DT0-010-24U-U-FL	2
AC power quality meter (bidirectional)	Schweitzer Engineering Labs / SEL-735	2
AC current transformers	SEL	4
Thermocouples	Vaisalia / HMP3 Humidity and Temperature Probe	2
AC power meter	Resident AMI data, Gridscape EnergyScope API	62
Battery temperature sensor	Gridscape EnergyScope API	0
Cell modem	Cradlepoint / COR IBR600C	5
Data logger	Obvius A8810-0	5
Din Rail mounted 8 port industrial switch	Advantech EKI-2525 5FE Unmanaged Ethernet Switch	5
A/D converters	Advantech Adam 6024e - confirmed by vendor	5
Power Supply	MEAN WELL RD-35B AC-DC Power Supply Dual Output 5V 24V 4 Amp 1.3 Amp 35W	5
Enclosure	Altelix 14x12x6 Fiberglass Weatherproof NEMA Enclosure with 120 VAC Power Outlets and Aluminum Equipment Mounting Plate	5
Wiring	GS Power 18 Gauge 200' Red /200' Black (400 feet Total) Bonded Zip Cord	1
Screw Terminal Strips Blocks	MILAPEAK 8 Positions Dual Row 600V 15A Screw Terminal Strip Blocks with Cover + 400V 15A 8 Positions Pre-Insulated Terminals Barrier Strip (Black & Red) by MILAPEAK	5
Wire Cable Glands	TUPARKA 32 Pcs Cable Gland Waterproof Adjustable Joints with Gaskets 3-16mm PG7 PG9 PG11 PG13.5 PG16 PG19	2
DIN Rail Block Kit and Rail Terminal	Dinkle DIN Rail Block Kit #2 DIN Rail Terminal Block Kit Dinkle 20 DK4N	5
Item	**Manufacturer/Model**	**Quantity**
Irradiance sensor	Kipp & Zonen / SMP10	6
PV module temperature sensor	Kipp & Zonen / RT1	3
DC voltage sensor	Flex-core / VT7-014D-24	10
DC current transformer	Flex-core / DT1-010-24D-BD-SP	10
DC Current Transformer	Flex-core / DT0-010-24U-U-FL	2
AC power quality meter (bidirectional)	Schweitzer Engineering Labs / SEL-735	2
AC current transformers	SEL	4
Thermocouples	Vaisalia / HMP3 Humidity and Temperature Probe	2

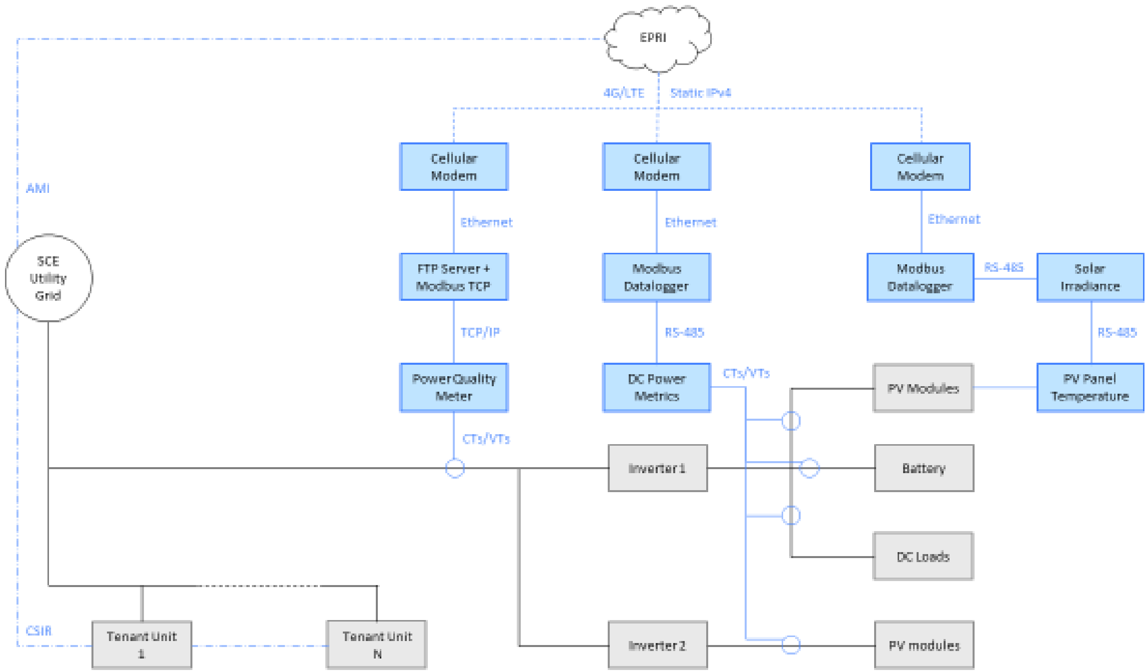
AC power meter	Resident AMI data, Gridscape EnergyScope API	62
Battery temperature sensor	Gridscape EnergyScope API	0

EPRI provided installation schematics of the monitoring system, measurements points, specification sheets, and installation procedures to its contractor. Monitoring equipment was installed in various locations on the site including near the utility service entrance, rooftop, near DC loads, and at the energy storage systems. The M&V layout that was ultimately installed is depicted by building in Figures 12 and 13. As a high level summary, power quality (PQ) meters monitor and record the output and performance of the inverters and controller as they manage the solar PV, batteries, and DC loads. Rooftop instruments monitor and record the amount of solar irradiance experienced by the solar PV and its effect on panel temperatures.



Source: EPRI

FIGURE 12 - M&V SCHEMATIC FOR BUILDING 1



Source: EPRI

FIGURE 13 - M&V SCHEMATIC FOR BUILDING 2

Data collection parameters are denoted below:

MAIN SERVICE ENTRANCE (BUILDING 1 & 2)

- Voltage (V), per phase: 1-second resolution
- Current (A), per phase: 1-second resolution
- Active power (kW): 1-second resolution
- Reactive power (kVAR): 1-second resolution
- Active energy (kWh), delivered and received: 1-minute resolution
- Reactive energy (kWh), delivered and received: 1-minute resolution

INVERTER AC GRID INTERFACE (BUILDING 1 & 2)

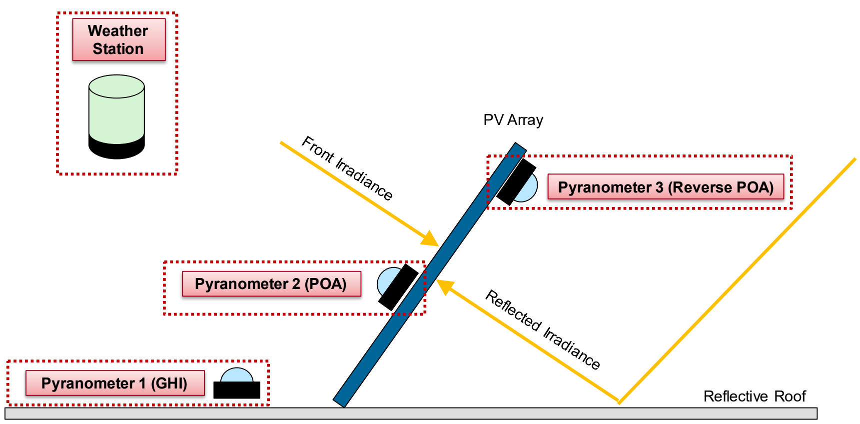
- Voltage (V), per phase: 1-second resolution
- Current (A), per phase: 1-second resolution
- Active power (kW): 1-second resolution
- Reactive power (kVAR): 1-second resolution

- Frequency (Hz): 1-second resolution
- Power factor, displacement and true: 1-second resolution
- Active energy (kWh), delivered and received: 1-minute resolution
- Reactive energy (kWh), delivered and received: 1-minute resolution
- Flicker, short-term (PST) and long-term (PLT): 10-minute and 2-hour resolutions
- Total harmonic distortion, voltage and current per phase (percent): 10-minute resolution
- Selected fundamental magnitudes, phase angles, and harmonic quantities: (as needed)
- Voltage and current waveforms, event triggered: 128 samples per cycle, 2-second window

PV Array (Building 1 and 2)

- Plane-of-array (POA) irradiance (W/m^2): 1-second resolution, quantity 2
- Reverse plane-of-array (R-POA) irradiance (W/m^2): 1-second resolution, quantity 2
- Global horizontal irradiance (GHI) (W/m^2): 1-second resolution
- PV module back-surface temperature (°C): 1-minute resolution, up to quantity 8
- DC voltage (V) and current (A) at inverter solar input terminal: 1-second resolution

Figure 14 depicts a diagram of the bifacial solar PV irradiance sensor placement.



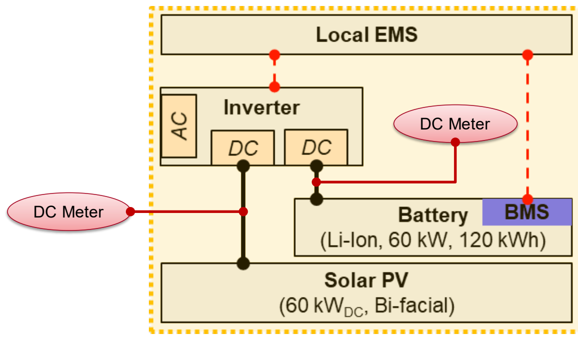
Source: EPRI

Figure 14 - Bifacial Solar PV Irradiance Sensor Placement

Battery (Building 1 and 2)

- DC voltage (V) and current (A) at inverter's battery bus: 1-second resolution
- Battery module and/or cabinet temperature (°C): 1-minute resolution, up to quantity 8
- State of charge (percent), operating mode, and other parameters if available via inverter's communication interface: 1-minute resolution.

The DC monitoring points for energy storage and PV systems for both buildings in shown in Figure 15.



Source: EPRI

Figure 15 - DC Monitoring Points for Energy Storage and PV systems

DC Loads (Building 2)

- Common area lighting: voltage (V), current (A): 1-second resolution
- HVAC: voltage (V), current (A): 1-second resolution
- HVAC: thermocouples, air flow sensors

Data Collection and Analysis

EPRI verified data collection (for example, acquisition, system, logging) at 1-second, 1-minute, or 15-minute intervals (depending on metric and sensor device) and reported back to EPRI's server to be imported to a SQL database and properly warehoused and secured.

EPRI collected data from the M&V systems described above to provide technical support for deployed systems and to conduct the analysis required using a measurements-based, statistical approach:

- Functionality: validate successful operations of battery and PV systems. This included confirming inverters were operating properly; determining if inverters actually change operating mode when commanded; and quantifying how accurately inverters implement advanced functions based on inputted parameters, such as volt-var curves or fixed power factor settings.

- Solar Energy Performance: determine how much solar energy is generated from use of bifacial PV array. This includes computing performance-based metrics to compare solar generation relative to localized environmental conditions, which compensates for incident solar radiation and PV module temperature throughout the day. Measured performance was correlated with modeled performance of a non-bifacial PV array to determine the efficiency gain in using bifacial technology.

- PQ Implications: study of common power quality factors – harmonics, flicker, and momentary voltage events – in relation to the inverters' operations. This is intended to identify how much advanced inverters are contributing to overall power quality within the site and interaction with the utility grid.

- Comparison of energy utilization pre- versus post- treatment: using data collected before energy efficiency measures were put in place to establish a baseline of energy utilization, a detailed comparison of the energy utilization post treatment will be conducted. This analysis provided quantitative indicators of the efficacy of the energy-efficiency retrofits in improving energy utilization.

- Load Shed DR performance: using a set of control strategies that are applied at the PV plus Storage, the efficacy of the controls and behavioral DR in providing short-term grid performance and reliability enhancements will be analyzed.

More specific M&V methodology details are denoted in Project Results.

PROJECT RESULTS

This section highlights the demonstration results organized by objective.

1. Bifacial PV Conversion Efficiency
2. Integration and Segmentation of Storage for Meeting Various Needs
3. Building/Unit Level Measurement Requirements
4. Project Performance
    a. Solar, Storage, and Load
    b. Energy Efficiency
5. Distribution System Analysis
6. Cost Benefit Analysis
7. Customer Value Proposition
8. Integration of Solar and Storage with Smart Inverters and Mini DC Grids

BIFACIAL PV CONVERSION EFFICIENCY

BACKGROUND

Bifacial solar modules have received substantial interest from stakeholders interested in boosting available energy yield from solar installations. Land costs, development costs, and roof space all drive interest in more solar yield from less space. Bifacial modules are increasing in popularity for larger ground mount tracking solar systems for this reason. In multi-family housing especially, rooftop space for solar is often insufficient to produce enough solar energy with conventional solar modules to cover the electrical loads of the building occupants.

Figure 16 shows a bifacial module while Figure 17 shows a mono-facial module of the same nameplate wattage from the same manufacturer.

Source: EPRI

FIGURE 16 - BIFACIAL MODULE BACK SHEET

Source: EPRI

FIGURE 17 - MONO-FACIAL MODULE BACK SHEET

Conventional mono-facial solar modules collect solar energy only from the front side of the module. The back of mono-facial modules is covered with an opaque plastic back sheet material and the cells are only made to collect energy through one side. Mono facial modules can collect direct normal or diffuse irradiance but cannot collect reflected irradiance. While these modules have the same nameplate rating, the bifacial module can potentially harvest reflected irradiance reflected from the surface below and therefore has a potentially higher efficiency.

Ground reflected irradiance (GRI)[5] or albedo is light that has been reflected from the ground, roof, or other material. Bifacial modules are configured with cells that can collect irradiance from

[5] Sun, Xingshu, Khan, Mohammad Ryyan, Deline, Chris, and Alam, Muhammad Ashraful. Optimization and performance of bifacial solar modules: A global perspective. United States: N. p., 2018. Web. https://doi.org/10.1016/j.apenergy.2017.12.041. National Renewable Energy Lab (NREL).

both sides as the name implies. Bifacial modules typically use a glass back sheet instead of the opaque plastic used on mono facial modules. The additional glass adds weight and cost to bifacial modules, as does the additional cell processing. However, the additional solar collector area on the back of bifacial modules can improve the output and solar conversion efficiency without making the modules or solar array any larger.

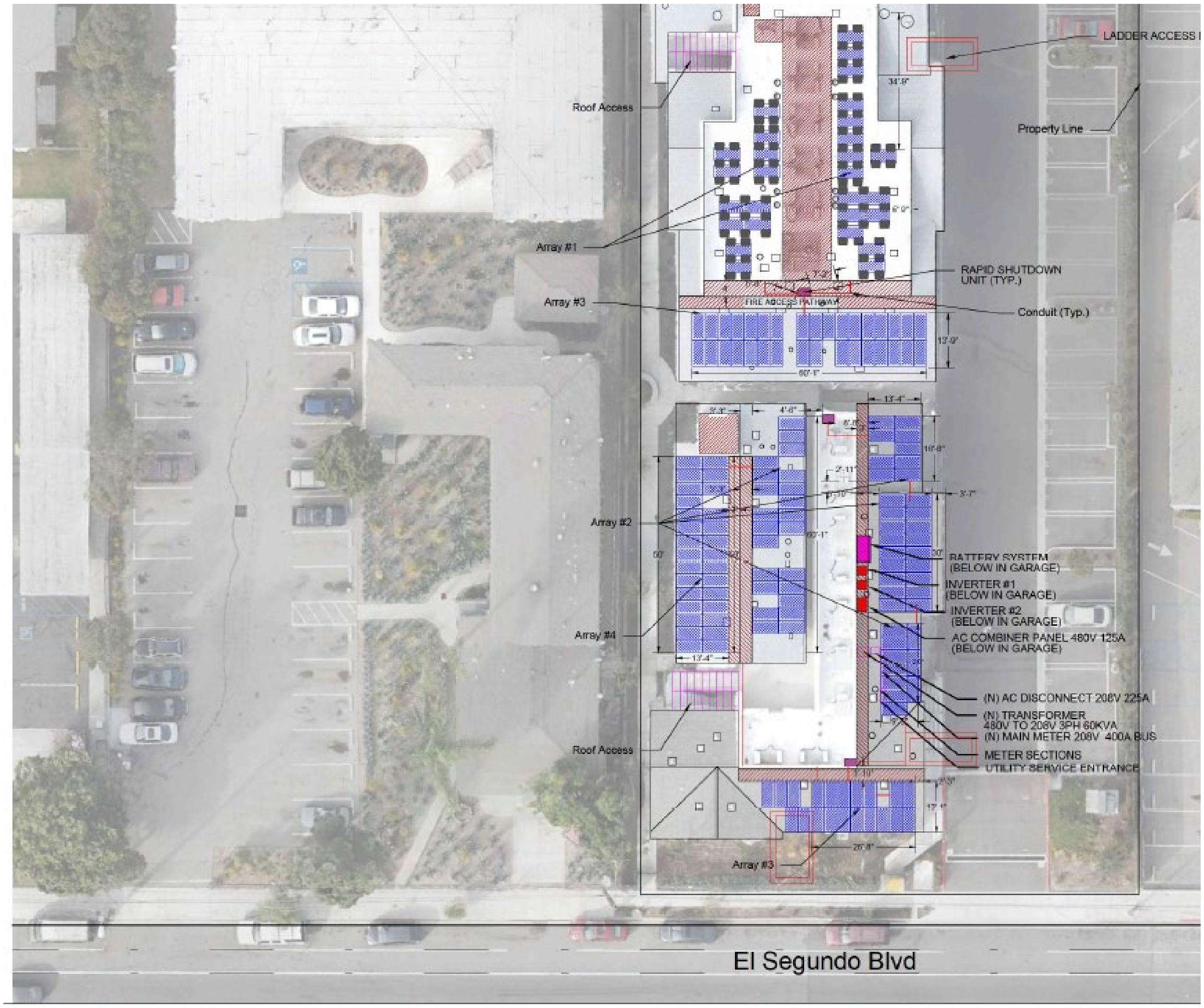
As with mono-facial modules, the energy output from the back of a bifacial module is directly related to the irradiance received. Reflected irradiance at any given point on an array or even across a single module is very sensitive to shading, color and reflectivity of the roof or ground and numerous other factors. Because of this, developers using bifacial modules often design arrays, racking, and background materials to maximize uniform reflected irradiance received by the modules. These design choices can involve use of solar trackers, racking with increased height and spacing between modules, light colored background materials, module level power electronics, among others.

Where the site is not designed specifically to maximize uniform reflected irradiance, a reduction in energy boost from bifacial modules can occur. In fact, the bifacial boost can be negative under certain circumstances. This reduction occurs where mismatch between modules or substrings within modules exists, and mismatch is most often created by non-uniform irradiance. Sandia National Lab conducted a study on module level power electronics and found that gains are available by mitigating mismatch with power electronics[6]

WILLOWBROOK TEST SITE

The California Energy Commission expressed an interest in implementing innovative solar technologies that can increase the solar energy yield from constrained rooftop spaces, such as those found on multifamily housing. EPRI worked with Linc housing to implement a test installation of bifacial solar at Willowbrook. This installation was done in conjunction with multi-port DC coupled bi-directional inverters and energy storage. Staten Solar installed 60kW or (170) 355W Canadian Solar Bifacial modules per building. These modules were coupled to two 30kW CE+T three-port bi-directional inverters on each building. Each inverter has a single maximum power point tracker, and module strings were connected to a rapid shutdown devices and string combiners. Each inverter has five solar strings connected. The solar designs with various tilts and azimuths are depicted in Figures 18 and 19.

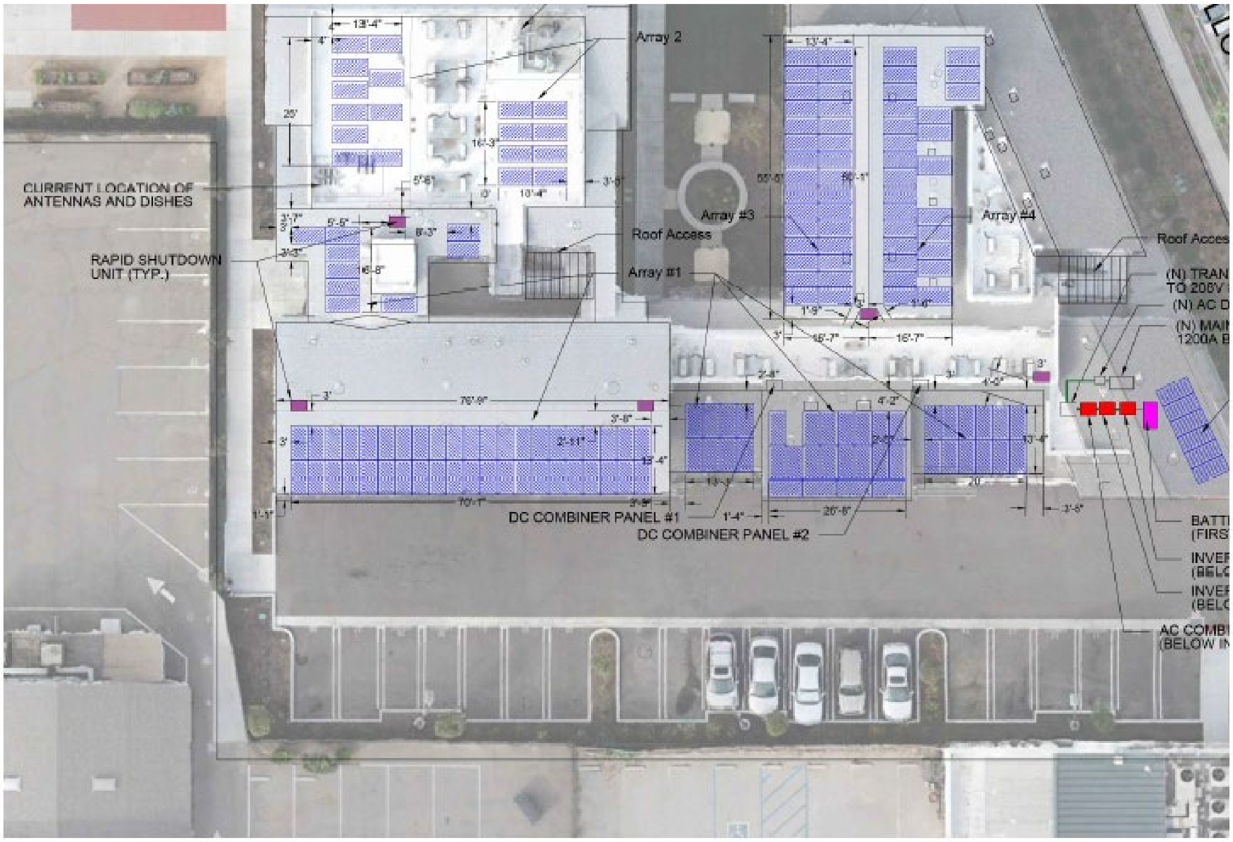
[6]Riley, Daniel. Joshua Stein, Craig Carmignani. SAND2018-8627C Performance of Bifacial PV Modules with MLPE vs. String Inverters. https://www.osti.gov/servlets/purl/1581914. Sandia National Laboratories.



MODULE COUNT AND RATING PER ARRAY						
ARRAY	TYPE	MODULE TYPE	MODULE DIMENTIONS	MODULE RATING	AZIMUTH	TILT
ARRAY 1	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18"	355W	180	5
ARRAY 2	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18"	355W	90	12
ARRAY 3	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18"	355W	180	12
ARRAY 4	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18"	355W	270	12

Source: As Builts by Staten Solar

FIGURE 18 - BUILDING 1 SOLAR PV ARRAY AS-BUILTS WITH TILT AND AZIMUTH



MODULE COUNT AND RATING PER ARRAY						
ARRAY	TYPE	MODULE TYPE	MODULE DIMENTIONS	MODULE RATING	AZIMUTH	TILT
ARRAY 1	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18 "	355W	180	12
ARRAY 2	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18 "	355W	180	5
ARRAY 3	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18 "	355W	270	12
ARRAY 4	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18 "	355W	90	12
ARRAY 5	ROOF TOP	LR6-72BP-355M	77.83" X 39.21" X 1.18 "	355W	75	12

Source: As Builts by Staten Solar

FIGURE 19 - BUILDING 2 SOLAR PV ARRAY AS-BUILTS WITH TILT AND AZIMUTH

The buildings at Willowbrook were not optimized for rooftop solar exposure and have several different roof exposures, angles and azimuths. The roofs are however coated in light colored materials which can increase available GRI. This project was required to implement a DC-coupled architecture for solar and storage. Unfortunately, module level power electronics (MLPE) options for commercial scale DC coupled solar and storage systems are very limited and were not available at the time of procurement for this project. Because of this, four sets of five strings, twenty strings in total, of solar modules were connected to four inverters with only one maximum power point tracking channel per inverter.

Boost from bifacial modules requires GRI received by the modules to be maximized and uniform. Tilt, azimuth and elevation should be optimized to take advantage of benefits available from bifacial modules.[7] Where numerous solar strings are connected in parallel, any underperforming string(s) create mismatch losses by pulling the operating parameters away from the maximum power point. This effectively reduces the output of all collective strings. The magnitude of this reduction can be challenging to model, but a reduction to other string outputs is likely when just one of several parallel strings is underperforming.

The solar contractor provided modelling for the solar installations conducted in PVSyst, a solar PV modeling tool. The basic results are shown in Figures 20, 21 and 22. Column "EArray", provides the DC energy forecast before the inverters while "E_Grid" forecasts the production exported through the generation meters month-by-month. The modelling assumed the mono-facial nameplate module conversion efficiency of 17.7 percent and so does not presume gain from bifacial. The PVSyst modelling also assumed only a 0.1 percent production loss due to mixed module orientations though the various orientations are noted in the document.

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Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	84.3	36.43	13.73	89.4	82.5	2.441	2.277	0.797
February	95.5	41.70	14.23	99.7	92.7	2.739	2.442	0.766
March	147.5	57.69	14.56	150.7	141.1	4.133	3.710	0.771
April	177.1	68.02	15.77	176.6	166.2	4.816	4.511	0.799
May	197.4	87.05	16.97	195.4	183.8	5.317	4.983	0.798
June	213.9	86.58	18.19	209.1	197.2	5.657	5.305	0.794
July	226.5	77.08	19.86	224.2	211.9	6.024	5.327	0.744
August	208.3	75.64	20.05	207.9	196.0	5.605	5.257	0.791
September	163.0	57.29	19.81	163.1	153.1	4.385	4.108	0.788
October	129.4	47.80	18.14	133.2	124.2	3.606	3.375	0.793
November	97.5	35.06	16.24	103.6	95.6	2.808	2.622	0.792
December	84.2	33.29	14.32	90.2	82.8	2.451	2.286	0.793
Year	1824.6	703.64	16.84	1843.2	1727.0	49.982	46.202	0.785

Legends:
- GlobHor: Horizontal global irradiation
- DiffHor: Horizontal diffuse irradiation
- T_Amb: Ambient Temperature
- GlobInc: Global incident in coll. plane
- GlobEff: Effective Global, corr. for IAM and shadings
- EArray: Effective energy at the output of the array
- E_Grid: Energy injected into grid
- PR: Performance Ratio

Source: PVSyst Model Results, EPRI

FIGURE 20 - BUILDING 1 INVERTER 1 PV SYSTEM MODEL

[7] https://www.osti.gov/pages/servlets/purl/1423188 Optimization and Performance of Bifacial Solar Modules: A Global Perspective Xingshu Sun,1 Mohammad Ryyan Khan, 1 Chris Deline, 2 and Muhammad Ashraful Alam1,

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Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	84.3	36.43	13.73	90.5	83.5	2.194	2.042	0.794
February	95.5	41.70	14.23	99.9	93.0	2.431	2.161	0.762
March	147.5	57.69	14.56	152.6	143.0	3.708	3.332	0.769
April	177.1	68.02	15.77	181.4	170.9	4.391	4.114	0.799
May	197.4	87.05	16.97	199.2	187.5	4.818	4.516	0.798
June	213.9	86.58	18.19	216.5	204.6	5.214	4.893	0.796
July	226.5	77.08	19.86	228.3	216.1	5.458	4.834	0.745
August	208.3	75.64	20.05	211.6	199.6	5.069	4.758	0.792
September	163.0	57.29	19.81	169.9	159.9	4.067	3.812	0.790
October	129.4	47.80	18.14	136.6	127.6	3.291	3.079	0.793
November	97.5	35.06	16.24	105.1	97.1	2.533	2.362	0.791
December	84.2	33.29	14.32	92.1	84.6	2.227	2.073	0.793
Year	1824.6	703.64	16.84	1883.6	1767.4	45.402	41.976	0.785

Legends:
GlobHor Horizontal global irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Source: PVSyst Model Results, EPRI

FIGURE 21 - BUILDING 1 INVERTER 2 PV SYSTEM MODEL

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	84.3	36.43	13.73	91.7	84.7	4.73	4.43	0.801
February	95.5	41.70	14.23	101.3	94.2	5.24	4.52	0.740
March	147.5	57.69	14.56	153.0	143.3	7.91	7.43	0.805
April	177.1	68.02	15.77	179.7	169.1	9.24	7.95	0.733
May	197.4	87.05	16.97	197.4	185.7	10.13	9.51	0.798
June	213.9	86.58	18.19	212.5	200.6	10.85	10.20	0.795
July	226.5	77.08	19.86	226.4	214.1	11.47	10.79	0.789
August	208.3	75.64	20.05	210.5	198.3	10.69	10.05	0.791
September	163.0	57.29	19.81	167.5	157.3	8.49	7.98	0.789
October	129.4	47.80	18.14	136.5	127.5	6.97	5.95	0.722
November	97.5	35.06	16.24	106.3	98.3	5.43	5.10	0.794
December	84.2	33.29	14.32	93.1	85.6	4.77	4.47	0.796
Year	1824.6	703.64	16.84	1876.0	1758.8	95.92	88.38	0.781

Legends:
GlobHor Horizontal global irradiation
DiffHor Horizontal diffuse irradiation
T Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Source: PVSyst Model Results, EPRI

FIGURE 22 - BUILDING 2 PV SYSTEM MODEL (BOTH INVERTERS)

MEASUREMENT AND VERIFICATION

The site was instrumented with two SEL 735 V4 PQ meters. These meters are each positioned to measure the cumulative power flows of two inverters to and from the facility and grid. No loads are connected to the meters, only inverters. Therefore, the SEL 735 meters are positioned similarly to and measure only the inverter output like a generation meter. The storage and controls vendor, Gridscape, is also monitoring solar input to the inverters, which can be compared to "EArray" from Figures 20, 21 and 22. Several Kipp and Zonen CMP 11 pyranometers are positioned across the array in addition to several corresponding module temperature sensors. One CMP 11 is positioned to capture GHI (global horizontal irradiance); another faced vertically down at the roof to capture GRI. Other units are placed to capture POA irradiance at the various array angles as well as GRI 180° to plane of array.

A sample month of data was collected from these meters and sensors was captured and compared to the models for a period beginning in late July 2021. During this period, the inverters on Building 1 were off due to ground faults for the majority of the test period. Therefore, data comparisons here are based solely on the operable system on Building 2. Compared to the forecast for August 2021, August 2021 production was less than the PVSyst model, which did not incorporate bifacial gains. Table 4 depicts the forecast and actual output at both buildings. DC Production was 84 percent of modeled production, and AC generation was 78 percent of modeled production. Performance ratio (PR) was calculated separately based on actual irradiance, temperature, and measured power values. When corrected for measured GRI, production was 68 percent of forecast. No contribution from the bifacial component of the modules is evident in the output data.

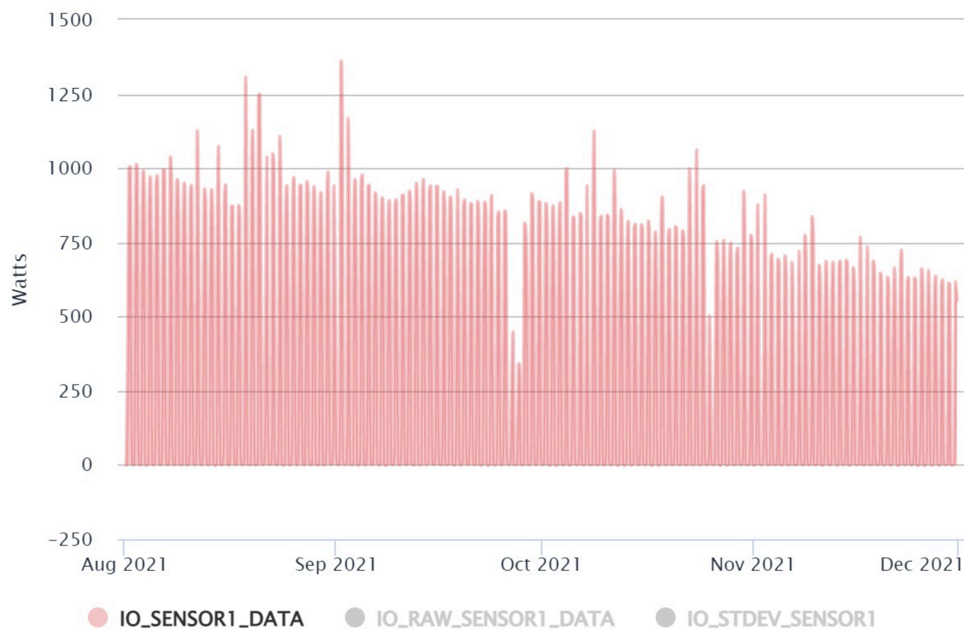
Probable causes for losses include:

1. Mixed string orientations connected to single maximum power point tracking
2. Modules not located to maximize received GRI
3. String mismatch due to mixed orientations and variable GRI
4. Soiling

TABLE 4 - FORECAST AND ACTUAL OUTPUT

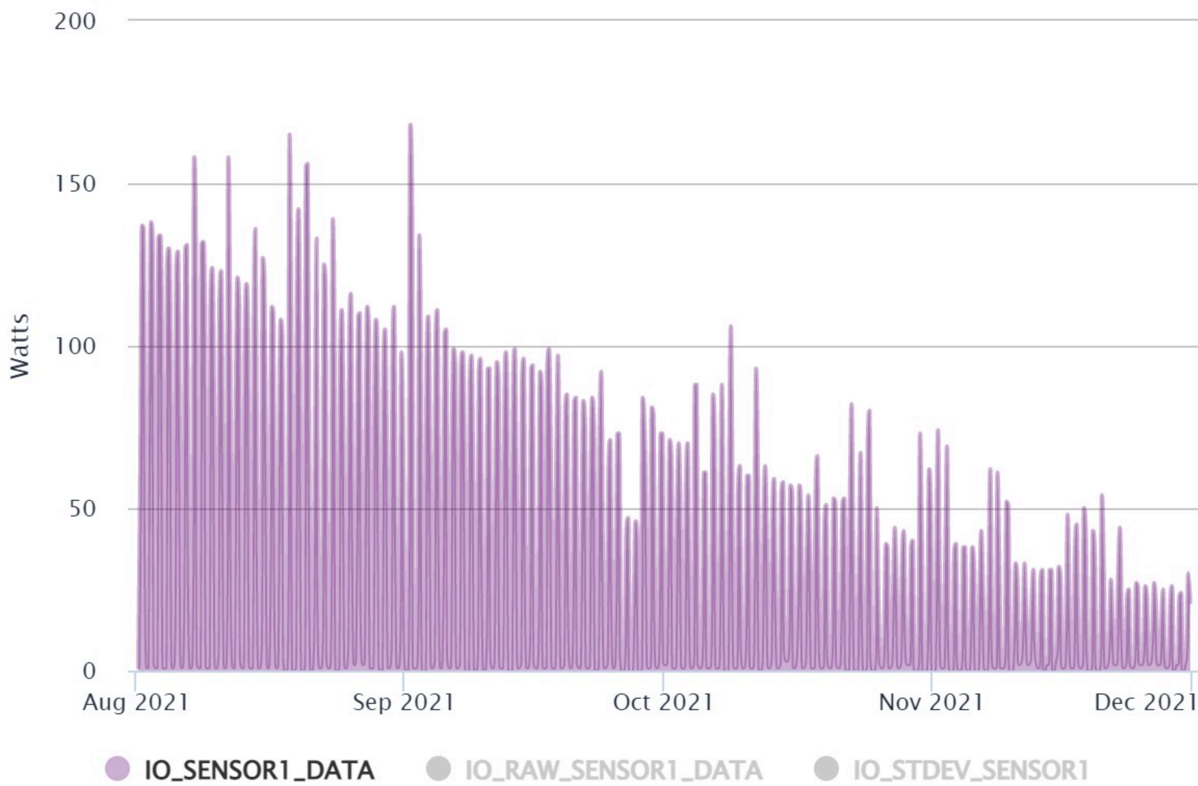
	WILLOWBROOK DC	BUILDING 1 DC	WILLOWBROOK AC
PV Syst Model August	10,690 kWh	9,700 kWh	10,005 kWh
Actual Output	8,973 kWh	1,368 kWh	7,745 kWh
Performance Ratio W/O GRI	83.94 percent	14.10 percent	78.36 percent
Performance Ratio W/GRI	67.96 percent	10.36 percent	

Since the measurements used in Table 4 were taken, PV output has continuously remained significantly lower than PVSyst forecasts would suggest. The shortfall is not likely due to any unusual prevalence of cloudy conditions or otherwise low irradiance. Figure 23 and Figure 24 depict the POA and albedo captured by CMP-11 sensors, recording irradiance as would expected for a 15° tilt during this time.



Source: EPRI

FIGURE 23 - PLANE OF ARRAY IRRADIANCE



Source: EPRI

FIGURE 24 - PLANE OF ARRAY ALBEDO

While much of the PV output shortfall is due to limited actual DC yield from the arrays, part is due to conversion and battery efficiency. Table 5 compares predicted solar array DC kWh versus actual, as well as energy to the grid (yield) predicted by PVSyst to actual yield from SEL 735 meters.

TABLE 5 - FORECAST AND ACTUAL OUTPUT

	Willowbrook PV Syst DC	Willowbrook DC	% of Expected DC	Willowbrook PV Syst Yeild	Willowbrook AC	% of Expected AC	El Segundo PV Syst DC	El Segundo DC	% of Expected DC	El Segundo PV Syst DC	El Segundo AC	% of Expected AC
September	8490	7331	86%	7980	6680	84%	8452	6269	74%	7920	5110	65%
October	6970	6037	87%	5950	4360	73%	6897	5588	81%	6454	4540	70%
November	5430	2686	49%	5100	1940	38%	5341	3334	62%	5254	2300	44%
		Average	**74%**		Average	**65%**		Average	**73%**		Average	**60%**

The PVSyst DC predictions assumed standard efficiency for the modules and did not consider any bifacial boost. Yet, the DC production is always substantially lower than predicted. Curve tracing was conducted; however, results were uniform and did not suggest failed modules or wiring. Therefore, the reduced output observed is presumed to be due to mismatch losses. These mismatch losses have two general causes; one is that the modules are installed at many different angles and azimuths with only four total MPPT channels and GRI mismatch due to variable mounting arrangements. As noted by Sandia, bifacial modules may actually produce lower power than equivalent mono facial modules where mismatch is present and granular MPPT is not available.[8]

Conversion efficiency was also lower than predicted, with a 9 and 13 percent loss beyond the predicted difference between DC and AC. This is in part because the PVSyst models did not anticipate power being diverted through a DC-coupled battery. DC HVAC was not operating due to a failed board during this data collection period, and both buildings exhibited similar losses, so these losses are not attributable to the DC minigrid. Based on DC measurements in October 2021, the Willowbrook battery round trip efficiency was 68 percent on a total input of 586 kWh, or about 10 percent of the total system throughput. Inverter losses are also higher than anticipated in part because the model assumed that the inverter would operate at peak efficiency. In reality, this peak efficiency is possible at only one power level with any other power level being lower. At times when no power is flowing, the inverter still consumes idle power to maintain operation and at those times the efficiency is 0 percent. Solar-only projects often shut off the inverters to avoid these idle losses, but this is not feasible in a minigrid arrangement.

CONCLUSIONS

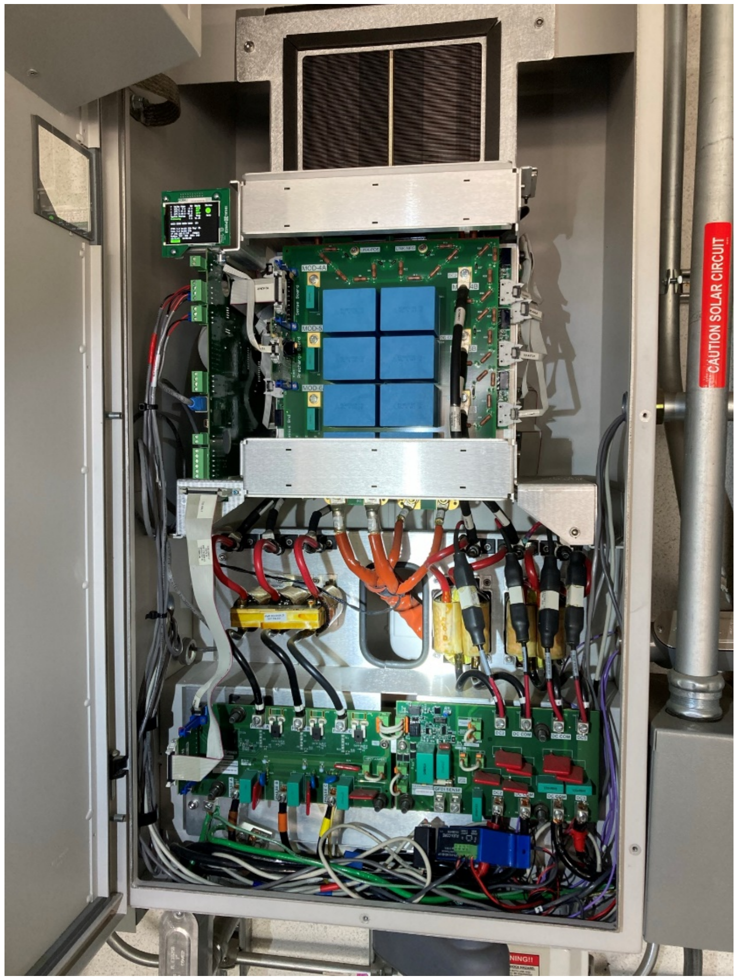
Rooftop systems are typically designed around an existing roof design rather than designing the roof specifically to optimize solar exposure. Bifacial solar modules may not provide improved performance where GRI cannot be maximized, and mismatch cannot be managed though careful and uniform array design. Module level power electronics (MLPE) may be able to mitigate mismatch between modules and strings. Bifacial modules have been demonstrated to provide improved yield where these design issues can be addressed, however, may not provide performance to justify the costs if the site design is not optimal. The incorporation of DC-coupled storage necessarily costs energy due to round trip efficiency losses inherent to charging and discharging a battery, and while other benefits might be realized through energy time shifting, the efficiency losses negatively impact total solar yield.

INTEGRATION AND SEGMENTATION OF STORAGE FOR MEETING VARIOUS NEEDS

INVERTER DC PORTS: SOLAR PV, BATTERY, LOADS

A total of four DC-coupled inverters were installed at the sites, two per housing building. See photo depicting the interior of one inverter in Figure 25. Each inverter receives and distributes solar power from the bifacial PV panels that are on the roof. One inverter at each building is connected to the batteries, which charges and discharges based on a schedule set by the inverter and controller. At one of the buildings, a DC minigrid was installed and is used to power DC loads, specifically lighting and HVAC.

[8] Riley, Daniel. Joshua Stein, Craig Carmignani. SAND2018-8627C Performance of Bifacial PV Modules with MLPE vs. String Inverters. https://www.osti.gov/servlets/purl/1581914. Sandia National Laboratories.

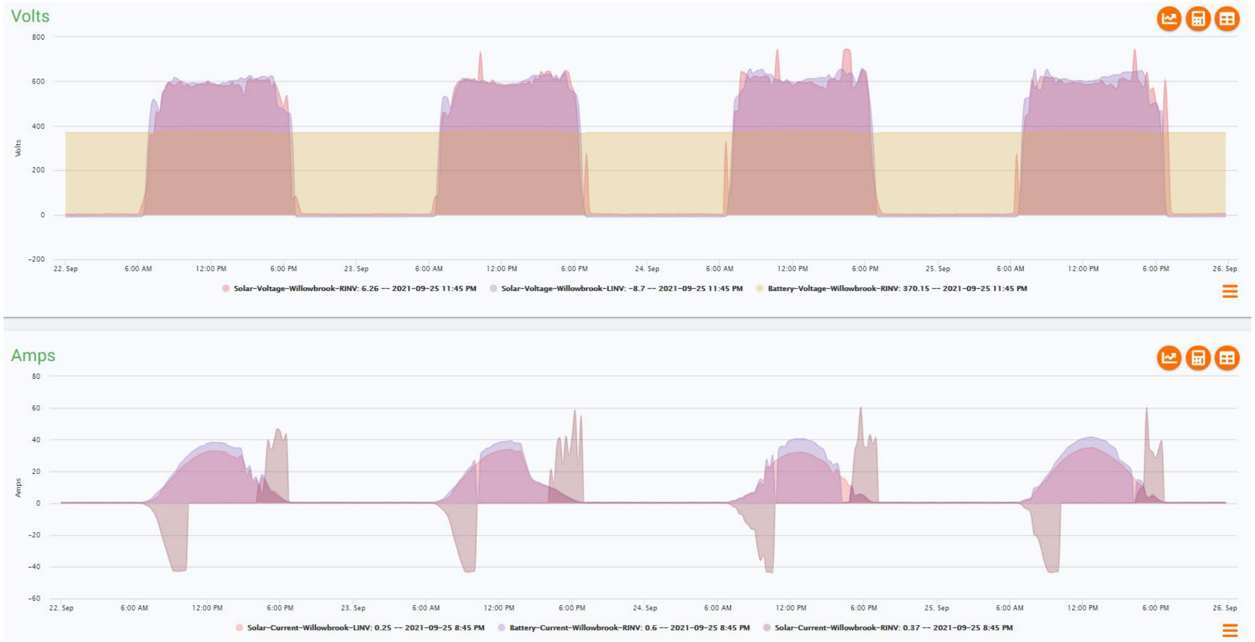


Source: EPRI

FIGURE 25 - CE+T 30KW 3-PORT INVERTER

Monitoring equipment was installed to record the DC power flows in and around the system. Specifically, DC current transformers and DC voltage transducers were installed at each of the DC terminal ports of all four inverters. Altogether, this included four pairs of solar PV DC voltage and current measurements, two pairs of battery energy storage DC voltages and currents, and one pair of DC loads voltage and current.

As illustrated in Figure 26, the data from these instruments quantify and verify the DC power flows of the system and allowed the research team to understand how solar and battery power were being generated, routed, and used. The data shows how the multiple converter stages of the DC-coupled inverter allow independent management of battery charging as well as solar maximum power point tracking depending on the amount of sunlight reaching the panels.



Source: EPRI

FIGURE 26 - POWER FLOW DATA

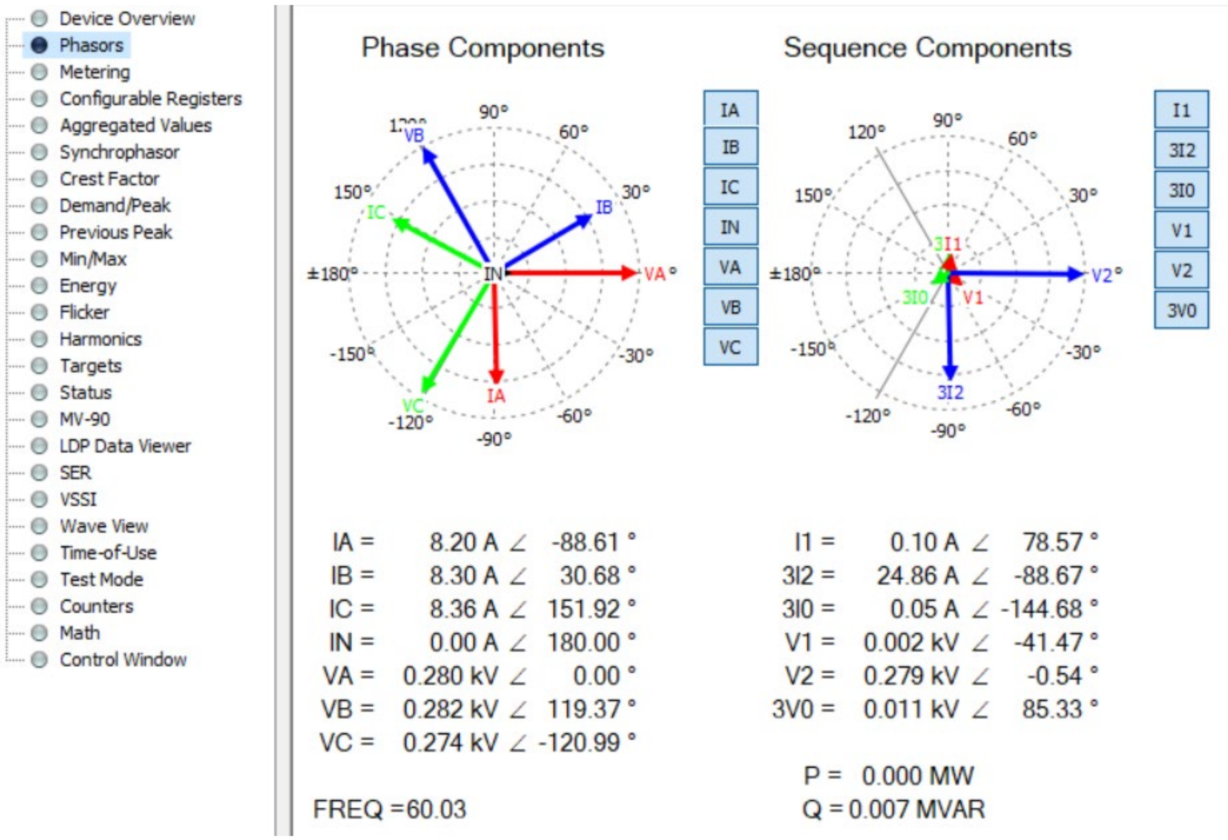
POWER QUALITY METER DATA: INVERTER OUTPUT AT THE TRANSFORMER

Two PQ meters were installed, one at each building, to measure and record the combined output of the inverters to the grid. See depiction of one PQ meter in Figure 26. The location of these meters allowed for accounting of the cumulative generation of the bifacial solar PV panels and battery energy storage systems, as well as providing detailed PQ data.

Source: EPRI

FIGURE 27 - SEL 735 V4 POWER QUALITY METERS

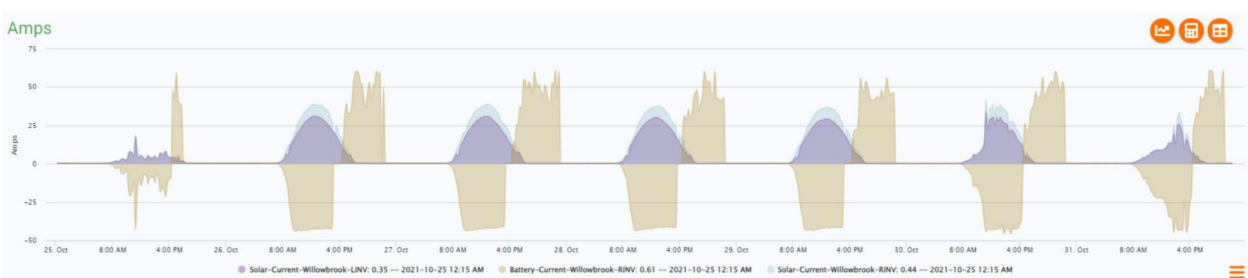
The meters record the PQ of the inverter output, including voltage and current magnitudes, harmonics, power factor, phase angle, real, reactive, and apparent power. As depicted in Figure 27, the voltage and current of each of the three phases of the immediate combined inverter output are monitored at the high side of the transformer.



Source: EPRI

FIGURE 28 - REPRESENTATIVE 735 SEL HUMAN MACHINE INTERFACE (HMI) SCREEN

INVERTER OPERATION AND CONTROL ON SOLAR PV GENERATION AND BATTERY DISPATCH



Source: EPRI

FIGURE 29 - SEL 735 V4 POWER QUALITY METERS

As demonstrated in Figure 28, current data measured and recorded from the inverters' DC terminal ports for solar PV generation and battery dispatch show that the system charges the battery with solar power starting in the morning and throughout the day. On cloud-covered, low production days, all solar PV generation is used to charge the energy storage system, since the power generated is below the maximum charge current for the batteries. While it may seem good to have all solar power being used to charge the energy storage system, what this usually indicates is that the batteries are not being fully charged during the day. This is the case here, made evident by observations that 1) the charge waveform matches the solar waveform and 2) the immediately following discharge event is of considerably less duration than the other days depicted.

On sunny, normal production days, not all of the solar PV generation can be used to charge the energy storage system, since the maximum charge current limit is being reached. This means that 1) some solar power is redirected to the grid and, more importantly, 2) that the energy storage system is likely to be fully charged from solar power generated during the day alone. In most cases, the system seems well and properly sized, as the energy storage stops charging just before the afternoon, when it will begin discharging to offset energy charges during the mid- and on-peak time-of-use periods. Such an operational schedule and strategy aligns well with the dispatch modelled in the Distribution System Analysis section later in this Chapter.

BUILDING/UNIT LEVEL MEASUREMENT REQUIREMENTS

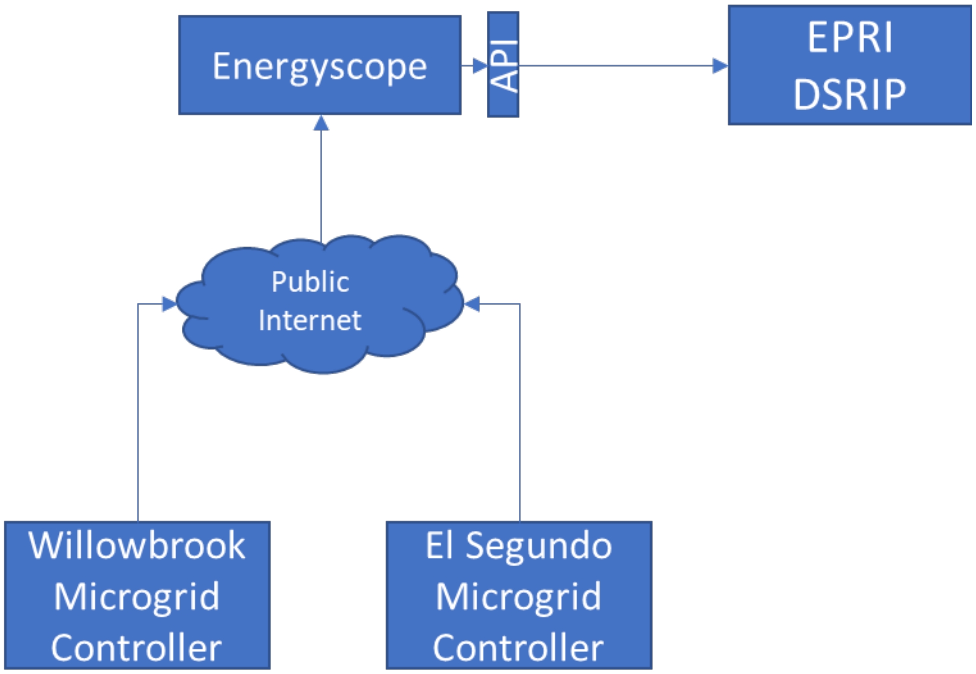
BUILDING-LEVEL ANALYSIS REQUIREMENTS

To evaluate the performance of the Willowbrook community as a whole, three types of energy performance analyses were conducted:

- Solar PV Profile Analysis
- Battery Profile Analysis
- Building-Level Load characterization.

DATA PIPELINE REQUIREMENTS

The source of these analyses is the data collected from Gridscape's Energyscope Application Programming Interface (API). Using Gridscape's Energyscope API, interval data on solar production measured on the DC side of the inverter is made available in real time. The data flow including Gridscape's EnergyScope API is shown in Figure 29. Data from solar production, battery, load monitors, and grid monitors at the installed system controller are backhauled to the Energyscope cloud instance via a dedicated broadband connection. Energyscope cloud instance provides a private API that is accessible to select 3rd parties (including EPRI) for exposing Solar, Storage, Load, and Grid data. In addition, Energyscope also provides a customer portal that may be used to visualize the Solar, Storage, Load, and Grid Energy data and to help troubleshoot any data anomalies, for example data loss.

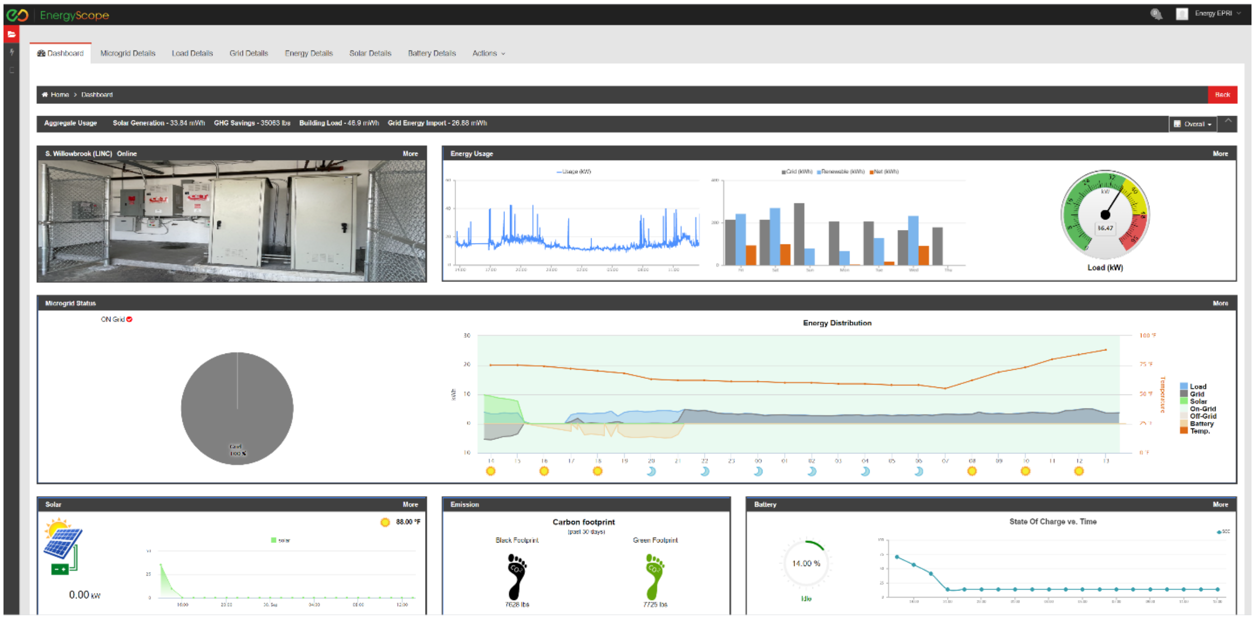


Source: EPRI

FIGURE 30 - PIPELINE FOR DATA FLOW FROM WILLOWBROOK AND BUILDING 1 SITE MICROGRID CONTROLLERS TO EPRI DSRIP

DATA AVAILABILITY AND QUALITY

Data for this analysis are not directly measured from the source using a utility grade meter. The results of the analysis need to be caveated with an understanding of the data availability and sufficiency. One of the challenges with the data pipeline from Energyscope API is the need to understand if a zero is a true-zero or if it represents data unavailability. Some data reporting systems use notations such as "N/A" for representing data that is missing or unavailable as opposed to reporting them as zero value. However, the data collected from Energyscope API are numerical quantities, a heatmap is used to characterize the data availability. The heatmap is based on Solar production values with clear distinction between areas where a solar production value of zero is expected (e.g., after sunset) as opposed to lower than expected solar production (which could indicate data loss if it is zero). Figure 30 shows a screenshot of the EnergyScope customer portal screen.



Source: EPRI

Figure 31 - EnergyScope Customer Portal Dashboard to Visualize Data from Solar, Storage, and Load

Solar PV Profile Analysis

The Solar PV Profile Analysis is scoped differently compared to the PV Performance Analysis detailed in the sections above. In this analysis, we are attempting to understand how the Solar PV production contributes to the field control objectives by establishing the hourly pattern of production, peak production, and compare how the bifacial production here compares to standard panels from a different PV installation in a different multifamily community in Southern California. The analysis requires an estimation of the hourly solar output from each building in the Willowbrook community.

Battery Profile Analysis

The Battery Profile Analysis is similar to the Solar PV Profile Analysis except that the quantity that is being profiled is the battery's SOC. The purpose of this analysis is to understand how the battery's SOC varies during the day and if it would be conducive to being used for energy management during periods of peak TOU rates. The profile would also help understand if the battery is charging from renewable sources consistent with California Rule 21. The field control trials surrounding the use case of GHG has the battery discharging to the grid between the hours of 3AM and 8AM and the profile helps identify if the battery performs according to these profile expectations.

Building Load Performance

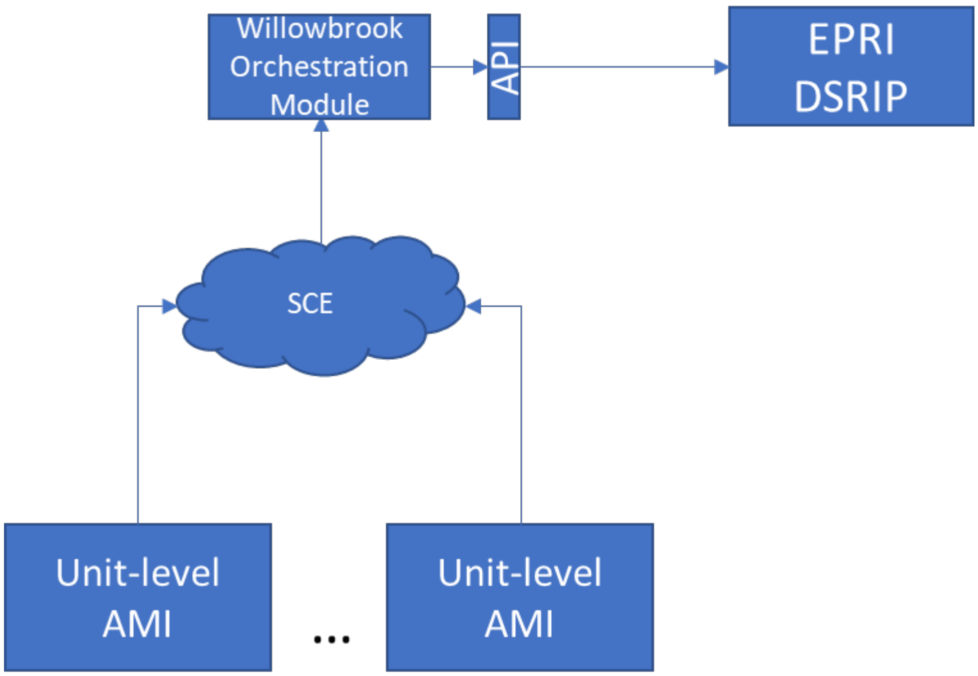
The third performance analysis is at the building level (living area plus common areas) to understand when energy is being used in the building. The load profile helps to identify the average load levels at different times of the day including when peaks occur. This analysis can also help identify how much energy is being used by the building over several days (for example, seasonal energy performance identifies when and how much energy is used each season).

Ultimately, the goal is to be able to compare the performance of the building post-installation of Solar+Storage package and when TOU messaging is used to nudge building occupants towards energy conservation behaviors especially during TOU peak hours. The data from summer 2020 may be used to compare it to summer 2021 with the caveat that the data has be weather-normalized. Additionally, with potential data availability issues impacting 2021, it may be necessary to normalize for data loss as well.

Unit-level Analysis Requirements

Data Pipeline Requirements

The source data for all unit-level analyses is the AMI data collected from OhmConnect's Willowbrook Orchestration Module (WOM). The WOM implements an API that delivers data to EPRI's Demand Side Resource Integration Platform (DSRIP) on a daily basis. The data flow including WOM is shown in Figure 31. Data from customers' smart meters are backhauled to SCE through their normal AMI data collection process. This data is then shared with OhmConnect via the Green Button link. OhmConnect uses the AMI data for DR settlement and sends the data to EPRI's DSRIP on a daily batch data drop.



Source: EPRI

Figure 32 - Pipeline for Data Flow from Willowbrook and Building 1 Site System Controllers to EPRI DSRIP

Unit-level Load Performance

This analysis is performed to understand when and how much energy is being used at the unit-level. The load profile helps to identify the average load levels at different times of the day including when peaks occur. Ultimately, the goal is to be able to compare the performance at the unit-level post-installation of Solar+Storage package and when TOU messaging is used to nudge occupants towards energy conservation behaviors especially during TOU peak hours. The data from summer 2020 summer may be used to compare it summer 2021 with the caveat that the data has be weather normalized. Unlike the building level analysis, given that 2020 and 2021 data are based on AMI data collected via the Green Button process, there is no major data loss issues to contend with at the unit level.

PROJECT PERFORMANCE

- Solar, Storage, and Load
- Energy Efficiency

DATA AVAILABILITY AND QUALITY

Before discussing the results of Solar PV, Battery and Load profiles, it is necessary to understand the availability and quality of data that is the source for the analysis. The analyses and the accompanying data are defined in Table 6.

TABLE 6 - ANALYSES AND DATA SOURCES

ANALYSIS	DATA NEEDS
Building Level Solar PV Profile	Solar PV production data from Energyscope
Building Level Battery Profile	Battery State data from EnergyScope
Building Level Load Profile	Building level Load data from EnergyScope Baseline Data (2020) - AMI data from individual units - Common Area AMI data Weather data (Cooling Degree Days)
Unit-level Load Profile	AMI data from OhmConnect developed WOM

A set of heatmaps are used to visualize the availability and quality of data from Energyscope API. Figure 32 through **Error! Reference source not found.**43 show the data availability. The color coding is done to show in black all instances of 0 Solar PV production as indicated in **Error! Reference source not found.** (July 14), when this happens in the middle of the day, it is attributed to data loss as opposed to other factors such as shade and cloud cover. The Red color indicates a median point in the range of daily production and green indicates better than the 75th percentile. Grey cells indicate a complete lack of data.

From **Error! Reference source not found.**32 thru **Error! Reference source not found.**43, one could make the following observations:

1. Building 1 and Building 2 have very different failure modes, that is there were independent causes for data failures that impact the two sites.
2. In general, the Building 2 site has better data availability compared to Building 1 site even though the relative sizing of Solar PV capacity on the respective inverters were about the same.

3. After a few days of data loss in early June, Building 2 gets back to having a high data availability.
4. The Building 1 site had a major data outage in Aug 2021 lasting 23 days.
5. The data flow in Building 1 recovered in the fall months (Sep thru Nov 2021).

Hourly Prod Date	Hour 12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Jun						0.16	1.54	3.71	8.96	16.01	20.44	22.43	21.79	20.16	16.11	9.27	4.86	3.16	0.92					
2-Jun						0.19	1.31	2.6	4.62	11.51	20.06	22.87	22.02	20.13	16.83	10.75	6.73	3.11	0.81					
3-Jun						0.17	1.59	4.47	13.33	18.83	21.17	21.67	22.19	20	16.43	10.18	6.42	3.08	0.65					
4-Jun						0.78	4.53	7.78	14.72	18.54	32.7	40.05	39.29	37.3	31.65	18.59	14.45	6.01	1.69	[illegible]				
5-Jun						0.29	2.6	7.24	17.5	24.33	37.97	38.85	38.69	38.15	31.85	15.47	9.39	6.52	1.7	[illegible]				
6-Jun						0.43	3.09	7.51	18.55	30.97	38.46	41.53	39.17	37.41	32.8	17.95	9.81	7.46	1.98	[illegible]				
7-Jun						0.18	1.5	2.68	4.48	5.82	7.16	9.83	20.72	11.82	19.3	22.19	0.63	0.33	[illegible]					
8-Jun						1.26	6.17	16.33	13.38	24.02	29.84	41.9	40.39	35.83	32.29	16.28	10.13	6.16	1.89	[illegible]				
9-Jun						1.7	4.66	8.23	12.56	27.9	35.29	38.64	38.96	35.17	33.15	18.91	10.17	6.84	1.81	[illegible]				
10-Jun						1.31	6.09	14.89	24.48	31.97	37.69	41.58	39.3	38.72	33.01	16.93	8.6	5.97	1.76	[illegible]				
11-Jun						1.29	6.59	12.3	24.27	31.99	37.02	39.91	36.55	38.22	32.66	17.84	8.66	6.68	1.78	[illegible]				
12-Jun						1.29	6.67	14.44	24.19	31.78	36.84	36.16	40.13	37.81	32.4	16.79	8.81	6.89	1.92	[illegible]				
13-Jun						0.6	4.11	14.23	23.96	29.98	29.44	38.03	40.45	38	32.71	17.18	10.17	6.73	1.76	[illegible]				
14-Jun						1.24	6.36	13.87	23.46	29.84	36.19	36.68	38.05	37.15	31.69	18.63	11.55	6.48	1.82	[illegible]				
15-Jun						1.39	6.41	11.51	17.21	18.73	33.68	38.64	30.43	28.21	24.1	15.05	14.07	4.4	1.86	[illegible]				
16-Jun						1.06	6.26	12.61	21.96	30.61	33.98	37.78	37.11	29.71	25.47	18.85	13.38	6.71	2.45	[illegible]				
17-Jun						0.97	5.87	12.57	11.18	13.41	31.46	38.88	24.9	35.39	31.07	17.77	11.25	7.62	2.52	0.17				
18-Jun						0.2	3.21	3.59	5.85	21.82	25.35	33.11	32.93	26.73	16.36	23.97	16.35	7.58	2.41	0.16				
19-Jun						0.69	4.63	9.74	22.85	32.27	38	41.4	41.85	37.06	33.75	18.53	10.53	7.87	2.3	[illegible]				
20-Jun						0.31	2.25	6.04	15.44	25.4	36.03	38.89	39.16	35.12	31.82	18.11	12.55	7.85	2.43	[illegible]				
21-Jun						0.3	2.96	16.17	25.37	32.88	38.13	41.72	40.12	39.54	34.16	18.47	10.61	7.91	2.25	0.2				
22-Jun						1.04	6.15	13.21	25.46	33.71	39.45	42.69	40.66	40.08	36.51	17.02	8.24	5.11	2.15	[illegible]				
23-Jun						1.33	5.36	11.88	23.57	32.11	37.38	41.08	38.58	34.93	34.78	15.15	9.77	7.67	2.22	[illegible]				
24-Jun						1.03	3.51	9.39	25.29	2.59								18.05	2.21	0.21				
25-Jun						1.2	6.76	15.4	25.74	33.64	39.26	41.94	43.4	40.76	31.07	21.67	9.96	7.72	2.25	0.22				
26-Jun						1.26	6.62	14.84	24.71	32.24	38.18	37.26	41.75	39.25	33.84	21.99	14	7.6	2.3	[illegible]				
27-Jun						1.06	3.43	10.48	21.61	30.71	37.6	40.95	41.08	34.72	32.91	17.38	16.15	7.65	2.29	[illegible]				
28-Jun						1.02	5.09	14.23	24.05	31.83	37.69	40.76	39.55	35.89	32.61	18.47	12.32	5.62	2.98	0.22				
29-Jun						0.32	3.25	9.77	18.34	20.42	26.03	35.63	29.53	33.21	36.04	16.88	11.12	5.48	2.1	[illegible]				
30-Jun						0.21	1.42	4.17	9.48	28.35	38.11	40.44	40.3	36	32.8	19.65	15.81	7.43	2.25	[illegible]				

Source: EPRI

FIGURE 33 - SOLAR DATA AVAILABILITY FOR BUILDING 1 IN JUNE 2021

Hourly Prod Date	Hour 12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Jul						0.29	2.12	6.66	21.17	31.86	37.1	37.69	40.82	37.15	34.01	23.4	16.45	7.66	2.32	0.2				
2-Jul						0.4	2.22	6.01	19.82	30.1	36.49	41.24	42.23	30.36	20.74	18.98	16.77	6.98	1.64	0.07				
3-Jul						1.17	6.91	13.33	20.82	33.19	38.33	40.12	41.44	34.74	33.76	22.33	11.42	7.55	2.14	0.16				
4-Jul						0.17	2.51	9.15	16.96	30.47	35.06	40.96	41.71	32.82	33.68	18.16	12.51	7.65	2.31	0.13				
5-Jul						0.4	1.91	4.03	9.95	28.15	35.19	38.07	38.93	32.84	31.85	22.46	9.07	6.67	2.24	0.18				
6-Jul						0.38	2.2	8.42	21.37	31.79	37.69	40.69	40.04	36.8	33.45	19.05	12.01	7.63	2.19	0.15				
7-Jul						0.54	3.79	12.61	22.54	30.91	36.33	39.46	37.71	37.2	31.93	22.31	15.47	7.1	2.09	0.14				
8-Jul						1.31	6.27	13.74	22.89	26.16	21.89	30.9	21.91	25.61	28.81	19.09	15.26	7.27	3.42	0.13				
9-Jul						0.12	0.46	0.96	1.61	2.02	2.42	2.59	2.28	1.26	1.03	1.48	0.91	0.34	0.09					
10-Jul						0.11	0.43	0.78	1.02	1.63	1.82	2.53	2.83	1.88	1.84	1.48	0.76	0.37	0.11					
11-Jul						0.93	5.15	12.44	21.71	29.64	34.67	38.08	31.53	35.4	30.42	22.28	14.84	6.79	2.09	0.11				
12-Jul						0.83	4.82	10.91	21.22	29.13	34.62	37.82	36.34	35.5	30.46	19.94	14.85	6.76	2.19	0.12				
13-Jul						0.79	4.47	8.84	18.44	24.86	29.54	34.61	33.33	32.7	28.23	21.92	14.96	6.92	2.1	0.11				
14-Jul						0.32	3.86	11.34	19.59	28.28	34.45	37.27	34.44	35.84	30.38	21.17	14.77	6.43	1.88	0.08				
15-Jul						0.88	5.04	12.13	20.85	28.5	34.1	37.42	33.6	35.04	30.1	22.24	14.72	6.29	1.99	0.13				
16-Jul						0.65	4.91	11.59	21.06	28.88	34.51	37.53	34.7	35.9	30.78	18	14.42	6.75	2.19	0.13				
17-Jul						0.93	5.42	12.45	21.17	26.93	34.43	37.37	34.85	36.17	30.74	17.12	9.8	6.71	2.36	0.2				
18-Jul						0.39	4	6.64	13.48	28.21	33.37	35.18	25.03	34.99	31.29	17.68	14.66	6.55	2.09	0.12				
19-Jul						0.75	4.37	11.09	21.36	28.56	34.7	34.08	38.25	36.66	30.44	4.05	0.25	0.24	0.24	0.13				
20-Jul						0.27	0.32	0.31	0.29	0.28	0.28	0.27	0.28	0.27	0.27	0.28	0.28	0.28	0.25	0.13				
21-Jul						0.25	0.3	0.29	0.28	0.25	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.13				
22-Jul						0.26	0.3	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.28	0.26	0.27	0.24	0.13				
23-Jul						0.25	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.13				
24-Jul						0.26	0.32	0.32	0.32	0.3	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.11				
25-Jul						0.27	0.32	0.32	0.32	0.31	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.12				
26-Jul						0.19	0.31	0.32	0.32	0.32	0.3	0.32	0.32	0.32	0.32	0.3	0.32	0.31	0.29	0.12				
27-Jul						0.24	0.29	0.32	0.32	0.32	0.32	0.31	0.29	0.29	0.28	0.29	0.29	0.28	0.27	0.12				
28-Jul						0.27	0.32	0.32	0.32	0.3	0.29	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.12				
29-Jul						0.28	0.32	0.32	0.32	0.29	0.28	0.28	0.28	0.28	0.27	0.23	0.29	0.29	0.28	0.13				
30-Jul						0.28	0.32	0.32	0.32	0.32	0.32	0.3	0.28	0.3	0.31	0.32	0.31	0.3	0.29	0.13				
31-Jul						0.27	0.32	0.32	0.32	0.32	0.32	0.32	0.31	0.3	0.31	0.32	0.32	0.31	0.29	0.13				

Source: EPRI

FIGURE 34 - SOLAR DATA AVAILABILITY FOR BUILDING 1 IN JULY 2021

Hourly Prod Date	Hour 12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Aug						0.01	0.28	0.32	0.32	0.32	0.32	0.29	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.11			
2-Aug						0.01	0.28	0.34	0.32	0.32	0.3	0.06		9.16	40.81	34.64	19	17.06	7.29	1.89	0.06			
3-Aug							0.43	4.92	13.73	24.37	32.93	38.33	41.23	41.94	39.53	32.95	20.29	12.55	6.62	1.81	0.03			
4-Aug							0.37	4.68	13.22	23.44	31.96	37.81	40.7	41.92	38.87	31.22	17.82	12.75	6.66	1.68	0.04			
5-Aug							0.07	0.36	0.95	1.72	2.24	2.59	2.79	2.79	2.54	2.1	1.36	0.9	0.35	0.07				
6-Aug							0.15	2.62	9.14	22.7	29.68	36.76	42.94	39.16	39.79	30.14	24.73	16.16	0.28					
7-Aug							0.1	1.69	5.82	10.38	27.34	38.53	41.75	41.79	38.49	32.85	17.65	16.11	6.55	1.64	0.01			
8-Aug																								
9-Aug																								
10-Aug																								
11-Aug																								
12-Aug																								
13-Aug																								
14-Aug																								
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27-Aug																								
28-Aug																								
29-Aug																								
30-Aug																								
31-Aug																4.21	17.05	13.46	4.85	2.45	0.28			

Source: EPRI

FIGURE 35 - SOLAR DATA AVAILABILITY FOR BUILDING 1 FOR AUGUST 2021

Date/Hour	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Sep							0.05	1.78	5.31	3.54	5.78		8.48	10.08	18.84	17.28	18.44	11.21	5.19	0.49				
2-Sep							0.02	0.54	2.24	5.17	7.52	10.58	18.41	28.47	36.66	30.98	22.28	11.86	4.02	0.41				
3-Sep							0.03	1.09	4.71	12.44	27.31	36.54	40.60	33.39	37.44	31.66	17.61	11.18	3.72	0.39				
4-Sep							0.07	3.00	11.48	21.84	29.19	31.23	40.25	40.81	37.71	31.63	21.63	12.04	3.92	0.41				
5-Sep							0.08	3.02	10.95	21.69	28.38	29.62	35.84	36.21	34.63	30.00	20.23	10.58	3.22	0.29				
6-Sep							0.06	1.95	8.55	20.73	28.13	31.62	38.06	38.29	35.21	29.00	19.02	9.32	3.21	0.27				
7-Sep							0.06	2.66	7.58	15.34	29.06	30.32	37.35	37.23	33.70	27.75	17.26	10.07	3.41	0.28				
8-Sep							0.04	2.32	8.72	8.57	19.41	33.45	33.01	36.91	33.66	28.36	16.59	10.05	3.03	0.23				
9-Sep							0.06	2.58	9.97	20.00	28.75	32.26	36.59	36.13	32.95	26.19	17.17	9.59	3.52	0.44				
10-Sep							0.03	1.65	5.85	8.33	28.05	31.07	36.13	36.68	34.79	28.94	19.05	9.93	3.17	0.17				
11-Sep							0.05	2.57	10.34	19.43	29.96	35.36	38.76	38.82	35.67	29.37	19.22	9.84	3.15	0.23				
12-Sep							0.05	2.75	11.10	19.76	29.42	34.17	37.27	37.11	34.13	28.13	16.37	9.54	2.92	0.18				
13-Sep							0.02	1.11	6.68	20.84	29.55	37.08	40.26	40.29	36.80	30.46	25.96	13.45	3.40	0.16				
14-Sep						0.02	1.49	11.89	20.61	30.19	36.82	39.39	39.11	35.79	29.52	18.99	9.92	2.82	0.16					
15-Sep						[illegible]	0.80	4.32	13.71	29.76	35.81	24.07	18.77	30.65	29.72	15.35	6.32	2.43	0.08					
16-Sep						[illegible]	0.57	3.51	11.98	30.50	35.86	33.71	17.98	28.43	26.43	13.41	6.31	2.35	0.11					
17-Sep						[illegible]	1.06	5.78	11.00	15.20	34.65	37.25	26.76	18.27	13.90	12.85	5.99	2.06	0.11					
18-Sep						0.03	0.68	3.17	6.95	10.86	27.97	38.67	36.75	29.73	22.45	10.56	6.42	2.18	0.10					
19-Sep						0.05	1.49	4.05	10.94	25.90	32.55	31.40	19.83	16.46	13.76	13.25	5.64	1.94	0.08					
20-Sep						0.06	1.53	7.91	7.19	23.24	33.93	36.71	25.68	15.89	13.60	12.18	5.20	1.67	0.08					
21-Sep						0.03	1.47	9.07	19.49	25.98	30.74	32.40	32.81	30.20	24.48	13.63	6.24	1.73	0.02					
22-Sep						0.02	2.09	9.11	10.64	11.39	14.12	16.35	16.78	15.66	12.25	14.51	7.56	2.00	0.02					
23-Sep						[illegible]	2.11	9.13	19.52	26.89	33.97	36.81	36.83	25.69	14.25	10.14	5.96	1.48	[illegible]					
24-Sep						[illegible]	1.01	4.76	11.99	26.45	30.54	35.25	34.97	30.97	24.87	9.44	5.73	2.66	0.02					
25-Sep						[illegible]	1.19	8.42	17.87	25.43	32.73	35.70	35.18	31.46	25.38	13.73	5.31	1.57	0.03					
26-Sep							0.21	1.21	2.80	4.59	8.28	8.81	10.99	12.00	12.37	8.49	4.64	0.90	[illegible]					
27-Sep							0.20	1.56	3.19	7.26	7.80	7.93	7.65	8.79	10.31	5.21	2.82	0.61	[illegible]					
28-Sep						[illegible]	1.21	6.02	11.05	17.26	10.48	9.35	11.41	14.37	17.37	11.46	6.34	1.68	0.02					
29-Sep						[illegible]	1.56	8.00	16.58	23.80	28.40	30.68	32.57	29.76	22.49	12.91	6.39	1.36	0.02					
30-Sep						[illegible]	2.02	8.75	18.80	26.02	32.30	20.47	19.07	10.45	5.79	13.74	5.90	1.28						

Source: EPRI

FIGURE 36 - SOLAR DATA AVAILABILITY FOR BUILDING 1 FOR SEP 2021

Date/Hour	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Oct						0.01	1.94	4.39	1.12	27.37	6.91	5.50	32.66	30.39	24.02	14.99	6.24	1.45	0.01					
2-Oct						0.01	1.94	8.47	18.66	25.66	32.00	34.58	34.15	30.37	23.89	14.79	6.10	1.26	0.01					
3-Oct						0.01	1.77	7.79	17.61	24.88	31.69	31.97	32.19	28.91	22.89	14.02	5.79	1.15						
4-Oct						0.01	1.78	4.33	8.66	16.20	23.59	25.70	32.31	20.81	17.63	1.74	0.04	0.26						
5-Oct						0.01	1.65	8.27	18.53	27.92	33.17	35.58	35.71	31.46	23.12	14.78	5.95	1.16						
6-Oct							0.31	2.22	5.92	4.97	6.53	16.83	22.14	21.06	23.17	13.69	6.14	0.96						
7-Oct							0.48	5.28	9.16	14.06	9.51	11.74	13.94	7.20	6.93	7.13	2.07	0.54						
8-Oct							0.45	5.20	14.18	14.80	12.22	16.21	31.16	23.63	23.84	12.26	5.87	0.94						
9-Oct						0.01	1.27	8.34	18.78	27.33	33.67	35.02	35.93	31.74	24.39	14.58	5.47	0.92						
10-Oct							1.24	8.25	19.10	28.24	33.61	34.12	35.05	30.97	24.08	14.31	5.29	0.83						
11-Oct							0.87	5.86	12.01	22.01	20.67	9.77	13.48	26.84	21.39	13.94	4.92	0.68						
12-Oct							1.10	7.20	19.36	29.41	35.48	36.27	35.68	31.70	24.25	13.95	5.11	0.74						
13-Oct							1.37	7.76	18.21	25.55	31.35	35.24	32.86	30.52	23.26	13.43	4.78	0.67						
14-Oct							1.34	7.68	17.79	26.87	32.16	34.56	30.26	29.02	22.07	12.83	4.68	0.63						
15-Oct							1.16	7.34	17.65	26.56	31.79	32.23	32.32	28.32	21.37	12.15	1.67							
16-Oct							1.17	7.42	17.73	26.67	32.01	34.08	31.23	28.78	21.89	12.38	4.40	0.56						
17-Oct							1.05	7.13	16.97	24.61	29.32	29.64	30.75	27.22	20.13	11.57	4.20	0.47						
18-Oct							0.50	4.27	14.24	19.23	29.79	36.29	35.02	28.66	22.17	12.41	4.30	0.48						
19-Oct							1.08	7.27	17.49	25.23	30.23	32.25	31.54	28.54	21.34	12.02	4.18	0.45						
20-Oct							0.90	6.95	17.00	25.74	31.60	33.64	31.67	29.21	21.63	9.24	5.48	0.54						
21-Oct							1.01	7.20	16.10	24.94	31.15	31.63	32.20	28.73	21.61	12.17	4.07	0.39						
22-Oct							0.23	1.38	6.55	20.09	32.04	27.24	29.98	26.34	19.28	10.60	3.46	0.26						
23-Oct							0.47	2.15	0.72															
24-Oct							0.69	5.54	14.10	16.54	21.98	13.77	22.09	26.84	18.11	10.68	3.49	0.29						
25-Oct							0.19	1.03	2.16	6.31	9.46	4.13	4.03	4.93	6.55	3.58	2.17	0.29						
26-Oct							0.63	6.12	16.72	25.93	31.51	33.49	32.63	28.37	19.78	10.85	3.46	0.25						
27-Oct							0.58	5.82	14.03	24.14	30.56	32.53	29.55	26.39	19.60	10.42	3.44	0.22						
28-Oct							0.72	5.66	13.38	22.44	29.45	31.60	28.64	26.46	19.36	10.14	3.34	0.18						
29-Oct							0.60	5.91	15.31	24.02	29.26	31.20	28.63	25.86	18.76	9.77	3.24	0.17						
30-Oct							0.09	1.38	4.80	9.77	26.49	31.75	30.66	23.92	19.36	9.16	3.26	0.14						
31-Oct							0.09	1.22	3.93	7.10	9.20	11.03	15.12	23.71	15.52	6.15								

Source: EPRI

FIGURE 37 - SOLAR DATA AVAILABILITY FOR BUILDING 1 FOR OCTOBER 2021

Hour/Date	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Nov							0.21	5.50	10.54	13.58	11.38	13.70	12.91	9.56	8.97	7.26	3.39	0.29						
2-Nov							0.11	1.51	3.87	7.39	12.03	21.84	29.18	25.02	18.24	8.84	2.76	0.11						
3-Nov							0.12	1.65	8.70	22.14	28.03	30.36	29.54	23.76	18.07	9.24	2.35	0.07						
4-Nov							0.07	1.52	5.65	20.05	27.51	29.55	28.74	23.18	17.39	8.77	2.54	0.10						
5-Nov							0.10	1.60	7.03	21.11	28.27	30.31	28.23	22.16	17.54	8.80	2.52	0.08						
6-Nov							0.04	1.25	3.74	9.21	18.39	28.85	28.09	22.76	17.03	8.86	2.55	0.08						
7-Nov							0.04	1.06	3.24	6.40	6.32	17.93	25.44	23.23	15.71	8.38	2.48	0.07						
8-Nov							0.04	1.57	5.27	10.09	28.15	29.93	28.70	22.44	16.47	8.40	2.26	0.06						
9-Nov							0.22	3.45	7.87	21.31	22.64	24.90	25.76	21.15	15.94	8.33	2.14	0.06						
10-Nov							0.18	2.04	8.47	16.18	16.54	16.22	27.26	22.77	16.22	8.03	2.19	0.05						
11-Nov							0.25	3.88	7.61	13.44	16.12	16.18	3.16	1.68	12.81	2.42	2.07	0.04						
12-Nov							0.21	1.69	8.47	17.46	26.13	28.30	27.14	22.84	15.89	7.82	1.92	0.03						
13-Nov							0.16	2.69	8.60	13.13	15.62	12.16	24.09	21.67	5.23									
14-Nov							0.14	3.87	8.94	20.50	26.32	28.39	18.06	5.57	15.86	7.92	2.03	0.03						
15-Nov							0.16	1.40	7.46	12.39	17.08	24.80	16.73	21.30	4.64	2.15	1.95	0.01						
16-Nov							0.06	0.89	3.41	5.57	17.68	21.29	21.44	20.92	14.10	4.84	2.44	0.01						
17-Nov							0.07	1.52	3.52	6.05	8.41	12.52	18.46	14.21	9.98	7.38	1.69	0.01						
18-Nov							0.07	0.86	3.53	6.28	19.67	10.43	19.89	17.41	11.61	3.32	1.58	0.01						
19-Nov							0.02	0.68	2.53	6.20	7.87	13.83	12.03	10.07	5.39	5.19	1.77	0.01						
20-Nov							0.03	0.66	3.11	6.65	14.57	14.09	13.22	9.10	5.75	4.20	1.26	0.01						
21-Nov							0.06	2.89	7.67	12.42	13.66	15.07	15.03	14.95	7.74	4.24	1.37	0.01						
22-Nov							0.08	2.51	7.50	13.07	14.36	15.26	14.14	13.32	12.50	6.94	1.42	0.01						
23-Nov										11.31	23.55	25.77	24.53	20.53	14.26	6.40	1.57	0.01						
24-Nov							0.09	1.11	7.02	11.12	6.79	0.56	0.41	6.70	10.58	2.63	1.61	0.01						
25-Nov							0.05	1.55	7.07	12.85	19.70	20.15	16.59	13.57	10.28	6.29	1.59	0.01						
26-Nov							0.04	2.28	8.70	11.76	14.40	14.93	19.22	20.12	3.77	3.47	1.37	0.01						
27-Nov							0.04	2.68	7.96	11.42	14.25	14.64	12.80	10.35	2.68	2.77	1.46	0.01						
28-Nov							0.03	2.86	7.90	10.99	13.65	14.28	13.08	10.37	4.96	2.62	1.40	0.01						
29-Nov							0.05	1.36	7.00	10.85	12.89	13.12	11.88	16.10	5.83	6.12	1.24	0.01						
30-Nov							0.05	0.63	2.63	5.18	10.57	28.30	11.80											

Source: EPRI

FIGURE 38 - SOLAR DATA AVAILABILITY FOR BUILDING 1 FOR NOVEMBER 2021

Hourly Prod Date	Hour 12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Jun																								
2-Jun																								
3-Jun																								
4-Jun																								
5-Jun						0.03	0.58	3.18	7.02	19.6	35.53	42.98	41.58	46.5	43.3	35	16.9	12	7.93	2.17	0.09			
6-Jun						0.03	0.67	3.48	8.24	21.6	35.08	42.22	44.38	46.8	41.9	36	20.6	9.38	9.47	2.52	0.1			
7-Jun						0.02	0.4	2.23	3.5	5.26	6.61	8.22	11.07	22.1	12.5	21.5	17.5	12.1	7.45	1.83	0.05			
8-Jun						0.03	1.4	5.68	18.5	23.3	26.87	35.19	47.46	43.9	42.8	35.5	19.6	10.9	7.45	2.3	0.11			
9-Jun						0.03	1.75	4.97	8.91	20.1	35.19	40.84	47.01	45.2	43.2	36.5	18.7	10.7	8.4	2.38	0.11			
10-Jun						0.03	1.16	5.43	15.3	25.9	35.48	42.12	44.53	47.4	43.9	36.1	18.3	9.65	7.64	2.28	0.11			
11-Jun						0.03	1.22	5.67	15.4	25.2	35.77	42.02	45.21	44.2	43.4	36	20.1	9.67	8.28	2.36	0.11			
12-Jun						0.03	1.17	5.53	15.7	25.4	32.59	39.09	42.36	40.9	40.7	35.7	17.8	10.5	8.64	2.51	0.12			
13-Jun						0.03	0.94	5.17	14	26.4	35.88	42.53	43.02	46.3	43.4	36.1	22.2	10.6	8.32	2.17	0.09			
14-Jun						0.03	1.07	5.28	15.4	25.2	34.53	41.15	44.16	43.9	42.3	34.9	17.6	10.8	8.12	2.47	0.12			
15-Jun						0.03	1.39	5.97	14	22.2	29.81	36.13	41.13	34.3	30.3	25.1	15.7	14.8	4.78	3.7	0.12			
16-Jun						0.03	1.3	6.46	13.5	12.4	3.49	5.49	11.06	43.8	38.2	28	25.3	15.6	7.94	2.87	0.15			
17-Jun						0.02	1.28	5.59	13.2	12.3	20.36	42.69	43.17	47.6	34.8	18.2	11.9	8.96	4.33	0.88				
18-Jun						0.05	0.91	3.76	4.23	6.59	23.11	38.9	45.18	39.1	36.3	33.2	21.4	11.4	8.57	2.94	0.19			
19-Jun						0.03	0.9	5.1	14.3	26.8	36.55	43.37	47.16	45.7	44.7	37.7	20.5	13.1	9.24	2.98	0.17			
20-Jun						0.04	0.52	2.81	6.9	17.7	29.98	43.3	47.54	46.2	45.4	38	23.5	10.6	9.06	3.08	0.2			
21-Jun						0.04	0.52	3.51	17.1	26.7	32.68	43.14	45.07	48.3	45.3	38.1	25.2	11.9	9.54	2.9	0.2			
22-Jun						0.04	1.07	5.84	16.9	27.1	37.68	44.86	46.21	49.4	45.9	40.5	23.4	10.3	6.38	2.53	0.15			
23-Jun						0.04	1.26	5.03	10.4	25.5	36.11	43.41	47.47	46.1	45.7	39.3	17.4	10.3	8.69	2.98	0.19			
24-Jun						0.03	1.41	4.15	10.5	20.9	38.44	45.54	49.36	47.5	46.9	39.3	27.2	12.5	9.68	2.92	0.17			
25-Jun						0.03	1.08	5.46	16.8	27.6	37.79	44.55	48.89	47.6	46.8	38.9	23.1	10.7	8.55	2.83	0.19			
26-Jun						0.05	1.21	5.64	16.2	26.4	35.24	43.61	45.39	47.9	45.1	37.7	21.2	10.8	8.6	2.89	0.19			
27-Jun						0.03	1.32	3.98	12.1	25.7	36.27	43.01	44.36	47.2	44.4	36.8	18.8	12.3	8.99	2.74	0.17			
28-Jun						0.04	1.24	5.42	15.2	26	35.85	43.01	45.68	44.8	43.8	36.4	19.1	12.3	6.61	3.51	0.23			
29-Jun						0.02	0.47	3.72	10.9	20.1	19.25	29.83	42.04	35.7	38.4	40.7	21.1	10.3	6.28	2.52	0.21			
30-Jun						0.02	0.33	1.73	4.82	10.5	30.51	43.05	46.2	46.4	41.9	36.6	19.3	10.1	8.77	2.86	0.17			

Source: EPRI

FIGURE 39 - SOLAR DATA AVAILABILITY FOR BUILDING 2 SITE IN JUNE 2021

Hourly Prod	Hour																							
Date	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Jul								2.58	7.48	22.6	35.29	42.56	46.14	44.8	44.9	37.9	27.1	11.4	9.08	2.9				
2-Jul								2.75	7.19	22.4	36.2	43.05	47.26	45.6	43.3	35.4	20	12.1	8.02	2.04				
3-Jul							1.17	7.02	12.2	23.3	37.14	43.77	46.78	47.7	42.7	37.8	26.2	12.9	9.04	2.67				
4-Jul								3.02	10.6	20.6	35.86	43.16	47.2	45.7	44.9	37.6	19.3	13.3	9.24	2.94				
5-Jul								2.26	4.57	11.6	32.76	43.22	46.64	47.7	43.3	37.9	20.5	10.8	8.8	2.89				
6-Jul								2.67	9.51	20.9	35.56	43.15	46.63	45.4	44.6	37.3	21.8	14	7.02	2.61				
7-Jul								4.61	15.3	24.9	34.83	41.12	45.29	43.8	42.5	35.6	18.9	11.5	8.53	2.62				
8-Jul							1.39	6.25	12.5	24.7	27.16	22.94	33.11	25.3	27.7	32	20.1	17.8	8.94	4.1				
9-Jul							[illegible]	4.81	13.6	21.7	31.46	40.16	44.13	44.9	40.7	35.3	25.7	16.8	7.76	2.3				
10-Jul								4.49	13.5	15.8	19.58	28.7	37.69	43.2	38	28.1	18.6	14.3	8.42	2.95				
11-Jul								4.69	13.5	23.6	31.59	39.99	43.86	37.7	38.5	34.2	21.3	16.5	7.92	2.63				
12-Jul							[illegible]	5.41	12.3	23.4	32.8	39.9	43.61	44.3	39.4	34.5	20.8	15.3	7.73	2.46				
13-Jul								5.08	9.67	17.6	16.93	35.99	42.64	43.9	40.4	32.6	24.8	16.3	8.03	2.31				
14-Jul								4.43	12.3	22.6	31.86	39.56	43.59	44.4	39.4	34.3	18.6	15.6	7.59	2.38				
15-Jul								5.41	11	11.5	31.86	39.1	42.9	39.2	40.6	14.9								
16-Jul								5.51	12.2	21.8	32.35	36.73	40.36	38.9	36.4	32.2	17.7	11.2	8.05	2.6				
17-Jul							[illegible]	5.16	13.1	23	32.56	39.42	42.9	41.9	41.7	34.4	20.6	16.7	7.96	2.84				
18-Jul								4.58	7.55	15	33.1	35.95	40.4	32.7	37.3	35	20.9	2.52	7.92	2.52				
19-Jul								3.87	12.8	20.3	19.33	20.22	28.42	44.8	42.2	18.5	26.2	16.7	8.03	2.36				
20-Jul								4.2	12.9	22.8	33.12	37.97	41.51	38.3	37.6	32.9	18.7	13.1	7.72	2.2				
21-Jul								5.3	12.4	22.6	32.35	39.28	42.63	41.8	41.4	34.5	22.5	16.6	7.87	2.34				
22-Jul								4.53	12.1	23.2	32.66	37.15	43.12	40.9	40.2	32.9	20.9	16.4	8.94	2.87				
23-Jul								5.52	8.92	22.2	32.22	39.19	42.86	42.8	37.9	33	24.2	16.2	7.89	2.29				
24-Jul								4.11	8.86	18.8	29.68	40.24	36.25	38.9	28.1	21.3	23.1	10.6	7.16	1.6				
25-Jul								4.66	8	16.1	28.47	36.98	41.43	42.2	33.4	32.6	17.8	10.7	7.51	3.36				
26-Jul								3.41	10.3	10	14.19	10.83	21.02	21.5	28.4	29.4	15.6	10.7	8.64	2.51				
27-Jul								2.13	5.71	10.5	22.63	37.53	47.93	48.7	46.2	36.9	23.9	12.6	8.88	2.49				
28-Jul								4.13	13.9	24.4	33.31	40.83	45.08	45.8	41.3	36.1	21.2	11.3	9.05	2.46				
29-Jul								4.01	14.1	25	36.11	43.74	48.36	50	33.9	5.51	20.9	17.4	9.55	2.69				
30-Jul								4.1	13.1	20.9	36.33	44.59	48.27	49.7	44.9	39.8	23.3	14.6	8.85	3.38				
31-Jul								5.11	13.5	26	37.49	45.13	49.34	47.9	46.4	39.6	19.9	11.4	8.81	2.21				

Source: EPRI

FIGURE 40 - SOLAR DATA AVAILABILITY FOR BUILDING 2 IN JULY 2021

Hourly Prod	Hour																							
Date	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Aug							0.55	3.91	13.8	25.8	36.46	43.76	48.3	49.4	44.5	39.2	21.2	14.2	8.47	2.16	0.08			
2-Aug							0.52	3.86	13	25.8	36.44	43.62	47.37	49.3	46.9	37.3	24.3	12.7	8.66	2.19	0.07			
3-Aug							0.51	3.86	13.8	26	34.28	40.83	43.87	45.3	40.3	36.3	18.8	9.5	8.13	2.15	[illegible]			
4-Aug							0.51	3.75	13.3	24.6	35.59	43	47.28	48.1	43.2	37.7	20	15.9	7.37	1.77	[illegible]			
5-Aug							0.49	3.71	12.9	24.9	35.45	43.21	47.26	48.3	45.1	35	20.5	15.6	7.97	1.81	[illegible]			
6-Aug							0.31	3.12	10.2	24.6	36.2	44.84	49.08	49.1	43.9	38	20.6	13.3	7.78	1.7	[illegible]			
7-Aug							0.18	2.1	6.58	11.6	29.74	43.9	47.75	48.2	45.6	36	24.6	15.6	8.13	1.99	[illegible]			
8-Aug							0.41	2.94	7.14	14.2	34.72	43.29	46.98	46.8	43.9	34.8	20.3	12.9	7.85	1.83				
9-Aug							0.49	3.84	12.3	24	22.61	18.22	45.39	46.3	43.7	34.8	19	10.4	6.58	1.78				
10-Aug							0.35	3.43	9.22	24	33.98	41.01	45.48	46.5	41.8	36.1	18	13.7	7.14	1.51				
11-Aug							0.34	3.05	10.9	23.6	26.4	28.35	40.95	22.5	22	21.3	13	12.3	4.46	1.47				
12-Aug							0.48	3.47	11.4	23	33.35	40.85	44.36	44.8	39.8	34.6	24.7	15.5	6.83	1.67				
13-Aug							0.37	3.51	11.1	23.1	31.6	41.34	44.78	45.3	40	34.1	19.6	15.1	6.72	1.47				
14-Aug							0.6	3.6	11	22.8	33.15	40.33	41.61	44.5	37.5	32.1	12.9	8.88	5	1.15				
15-Aug							0.32	3.31	10.8	22.2	28.94	39.61	43.23	44.5	39.9	35.6	18.4	15.4	6.34	1.18				
16-Aug							0.33	3.73	9.7	20.6	32.04	28.76	42.63	42.6	39.9	31	22.6	13.2	5.66	1.19				
17-Aug							0.28	3.2	9.51	20.3	31.27	38.55	42.32	43	37.8	33.1	22.2	14.6	6.29	1.33				
18-Aug							0.09	0.73	3.76	11.4	13.54	19.97	16.61	26	33.1	16.6	18.8	9.39	3.84	0.47				
19-Aug							0.34	3.47	11.4	20.9	32.15	30.54	26.75	41.3	38.2	34.7	17.6	11.4	6.06	1.15				
20-Aug							0.11	1.35	4.42	8.07	13.32	24.03	32.71	29.2	36.4	33.1	18.5	13	6.55	1.25				
21-Aug							0.07	0.85	4.11	6.74	9.74	12.45	19.03	19	16.9	24	24.1	17.9	5.87	0.85				
22-Aug							0.1	1.2	2.63	5.17	8.85	10.01	19.42	24.8	40	35.9	26.5	15.7	5.84	1.03				
23-Aug							0.17	1.94	5.06	10.5	17.56	23.97	36.21	45.2	41	32.4	17	10.3	5.75	0.97				
24-Aug							0.23	2.97	11.1	21.1	34.44	41.87	46.18	46.6	41.9	32.5	19.1	13.8	5.27	0.91				
25-Aug							0.22	3.08	10.7	22.8	33.2	40.81	44.81	44.9	40.5	29.4	23.3	12.7	5.88	0.65				
26-Aug							0.2	2.53	10.9	23.6	33.9	40.9	45.09	46.2	37.1	33.9	17.3	13.9	6.11	0.66				
27-Aug							0.2	2.5	11.2	24.4	34.84	42.1	46.2	46.4	41.6	35.2	24.7	14.5	5.96	0.77				
28-Aug							0.1	2.35	3.63	10.4	22.88	35.85	42.44	45.7	42.3	33.7	25.2	14.5	5.59	0.72				
29-Aug							0.08	1.8	7.86	22.9	34.76	42.1	45.83	46.4	42.1	33.4	16.7	12.1	5.91	0.9				
30-Aug							0.21	3.41	10.8	22.1	30.1	40.23	44.54	42.1	40.2	30.4	13.7	9.4	5.23	0.51				
31-Aug							[illegible]	2.42	2.95	5.09	8.13							12.6	1.66	0.38				

Source: EPRI

FIGURE 41 - SOLAR DATA AVAILABILITY FOR BUILDING 2 FOR AUGUST 2021

Date/Hour	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Sep							0.13	1.32	3.46	6.30	8.59	9.87	9.24	12.46	13.95	15.76	26.46	14.01	5.88	0.53				
2-Sep							0.03	0.67	2.29	5.77	8.33	13.06	23.22	35.41	42.16	34.32	24.81	13.66	4.94	0.43				
3-Sep							0.05	1.33	5.59	11.05	31.68	33.99	46.33	47.46	41.13	34.21	21.65	11.08	5.03	0.45				
4-Sep							0.11	1.97	11.51	20.77	32.12	39.38	44.60	44.64	43.37	34.82	18.96	8.93	4.75	0.32				
5-Sep							0.10	2.01	11.12	23.76	33.97	40.86	41.96	44.78	41.46	33.11	22.70	12.72	4.53	0.29				
6-Sep							0.09	2.34	9.32	22.10	33.42	40.58	41.76	44.52	40.92	32.31	21.13	12.00	4.13	0.34				
7-Sep							0.09	2.38	8.12	15.54	31.46	36.98	37.97	40.42	36.56	28.96	20.92	10.83	4.32	0.32				
8-Sep							0.07	2.62	9.60	10.64	25.57	39.11	40.25	42.76	39.03	31.43	15.13	11.23	3.95	0.27				
9-Sep							0.08	2.16	10.12	22.07	32.38	39.30	39.65	42.19	37.78	29.19	19.07	11.37	3.97	0.51				
10-Sep							0.08	1.85	9.97	21.42	29.25	37.75	41.39	43.62	40.12	31.85	16.64	11.96	3.66	0.24				
11-Sep							0.08	1.80	10.69	23.07	32.02	40.54	44.25	44.61	41.14	32.18	21.66	12.06	3.95	0.18				
12-Sep							0.08	1.87	10.94	23.91	33.16	41.78	45.57	45.86	42.01	33.00	17.72	12.32	3.91	0.19				
13-Sep							0.04	0.92	7.52	21.22	33.23	42.30	46.06	45.59	42.29	33.36	23.77	13.17	3.89	0.13				
14-Sep						0.03	1.79	12.46	23.91	33.87	42.20	45.26	45.22	41.13	32.27	15.06	10.80	3.46	0.15					
15-Sep						0.04	0.98	4.96	15.26	33.01	40.95	42.65	45.35	41.66	32.51	16.89	11.65	3.55	0.10					
16-Sep						0.03	0.73	4.13	12.40	30.92	38.12	39.56	41.99	38.05	31.84	17.11	11.27	3.32	0.11					
17-Sep						0.03	1.36	6.84	16.33	27.66	38.79	43.87	43.48	39.38	30.84	18.15	10.45	3.09	0.10					
18-Sep						0.02	0.87	3.59	5.02	15.41	35.88	41.30	40.04	39.99	30.63	15.76	10.11	2.81	0.08					
19-Sep						0.04	1.34	4.71	7.54	17.34	19.53	34.52	40.18	36.42	30.08	13.99	8.71	2.69	0.06					
20-Sep						0.04	2.10	9.15	20.89	27.94	36.25	39.37	39.38	35.14	26.87	17.28	8.75	2.41	0.06					
21-Sep						0.05	1.87	9.82	21.74	20.43	36.22	41.17	40.33	36.66	28.85	18.52	8.26	2.47	0.03					
22-Sep						0.03	1.64	9.51	21.31	29.48	38.14	41.78	41.06	37.69	24.13	5.27								
23-Sep						[illegible]	1.71	9.77	21.88	30.23	39.12	42.17	42.57	29.06	15.88	10.96	6.55	1.63	[illegible]					
24-Sep						[illegible]	1.26	5.37	13.68	28.94	37.74	42.49	43.02	37.92	29.67	11.62	8.45	3.48	[illegible]					
25-Sep						[illegible]	1.59	10.38	22.28	32.08	41.16	44.77	44.59	39.76	31.09	15.99	6.98	2.24	[illegible]					
26-Sep							0.28	1.56	3.60	5.58	10.08	10.88	12.82	15.45	15.16	13.19	5.75	1.06	[illegible]					
27-Sep						[illegible]	0.28	1.99	4.15	8.77	9.52	9.58	9.02	11.37	12.85	7.20	3.47	0.71						
28-Sep						[illegible]	1.52	7.45	13.79	20.72	13.49	11.60	13.99	17.62	21.22	14.85	9.11	2.14	[illegible]					
29-Sep						[illegible]	1.65	9.34	20.75	28.48	33.43	36.35	38.90	35.01	8.16		[illegible]							
30-Sep																								

Source: EPRI

FIGURE 42 - SOLAR DATA AVAILABILITY FOR BUILDING 2 FOR SEP 2021

Date/Hour	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Oct																								
2-Oct																								
3-Oct																								
4-Oct																								
5-Oct																								
6-Oct																								
7-Oct																								
8-Oct														111.67	332.11	175.79	94.55	14.08	0.08					
9-Oct						0.01	1.13	8.89	21.39	32.08	41.04	44.88	44.18	37.00	28.80	17.98	8.01	1.21	0.01					
10-Oct						0.01	0.92	8.24	23.11	33.90	40.79	44.06	43.36	35.90	28.46	15.49	7.73	1.05						
11-Oct						0.01	1.12	6.96	14.37	25.96	29.53	13.37	16.27	37.70	26.20	14.37	6.31	0.84						
12-Oct						0.01	0.95	8.67	23.62	35.57	43.43	46.04	44.51	37.03	28.96	13.07	7.64	0.85						
13-Oct						0.01	0.89	8.16	22.24	33.00	40.18	43.14	42.83	35.52	27.74	12.64	6.95	0.77						
14-Oct						0.01	0.83	7.52	21.57	32.56	39.73	42.42	41.27	34.24	26.45	15.23	7.15	0.59						
15-Oct						0.01	0.80	7.70	21.68	32.21	38.70	41.22	40.19	32.93	25.70	15.24	6.73	0.61						
16-Oct						0.01	0.84	7.65	21.73	30.21	36.36	38.83	37.88	31.15	24.50	14.56	6.25	0.67						
17-Oct						0.01	0.76	7.13	20.81	31.45	38.50	41.14	41.01	34.21	26.39	15.16	6.40	0.62						
18-Oct							0.65	5.04	16.80	23.65	35.00	44.66	43.13	37.16	25.59	11.84	5.57	0.51						
19-Oct						0.01	0.77	7.21	21.40	32.41	39.67	42.35	41.44	35.42	25.31	13.63	6.41	0.44						
20-Oct						0.01	0.83	6.70	20.83	31.54	38.82	41.31	41.88	36.23	25.74	10.28	6.99	0.61						
21-Oct						0.01	0.65	7.12	20.56	31.32	38.32	41.00	40.26	35.65	25.55	14.13	5.78	0.45						
22-Oct							0.36	1.68	7.79	23.77	39.35	33.08	37.19	34.28	23.74	15.08	5.33	0.31						
23-Oct							0.68	2.71	4.28	6.80	17.80	32.75	5.27	13.37	20.08	11.21	5.61	0.31						
24-Oct							0.88	6.29	17.07	22.16	26.48	16.62	27.22	33.43	23.02	10.70	4.79	0.38						
25-Oct							0.26	1.38	2.83	7.10	11.06	5.00	4.69	5.75	7.64	4.37	2.51	0.36						
26-Oct							0.63	6.16	20.27	31.38	38.53	41.00	40.64	35.45	24.86	14.12	5.48	0.27						
27-Oct							0.53	5.91	19.73	30.73	37.57	39.86	38.03	33.10	23.74	12.85	5.39	0.22						
28-Oct							0.49	5.83	19.20	29.64	36.27	38.96	38.04	33.19	23.68	13.04	5.05	0.19						
29-Oct							0.49	5.42	18.71	29.18	36.09	38.53	38.01	32.63	22.80	12.57	4.90	0.23						
30-Oct							0.12	1.68	5.71	11.38	33.56	39.35	38.35	32.93	24.80	12.04	4.15	0.17						
31-Oct							0.11	1.48	4.69	8.28	10.68	12.83	17.83	28.89	20.30	8.07								

Source: EPRI

FIGURE 43 - SOLAR DATA AVAILABILITY FOR BUILDING 2 FOR OCTOBER 2021

Date/Hour	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
1-Nov							0.37	6.07	12.31	16.19	13.49	16.50	15.25	10.58	10.50	9.23	4.01	0.30						
2-Nov							0.10	1.86	4.58	9.15	15.21	28.58	37.75	31.84	23.45	12.97	4.16	0.16						
3-Nov							0.15	2.03	13.03	27.20	34.43	37.61	37.17	31.59	22.00	11.32	3.15	0.12						
4-Nov							0.12	1.90	6.67	22.93	31.55	34.08	33.76	28.64	22.04	12.29	3.81	0.13						
5-Nov							0.11	1.94	8.72	25.87	34.90	37.63	10.58											
6-Nov							0.19	0.97	2.54	5.72	12.60	19.87	19.64	16.75	12.36	6.82	1.80	0.17						
7-Nov							0.16	0.82	2.21	3.72	3.66	11.57	17.43	16.39	11.81	6.43	1.95	0.15						
8-Nov							0.18	1.26	3.69	6.30	19.28	20.57	20.32	17.09	12.67	6.81	1.83	0.14						
9-Nov							0.30	2.02	10.89	12.32	13.32	17.07	18.13	16.64	11.63	6.46	1.30	0.05						
10-Nov							0.09	2.61	8.35	14.03	9.77	8.24	17.85	15.11	11.17	5.82	1.55	0.04						
11-Nov							0.09	2.62	8.93	14.39	4.83	1.79	2.69	13.36	12.00	6.37	1.75	0.01						
12-Nov							0.08	2.49	8.73	14.26	16.85	17.30	19.26	15.00	12.02	6.68	1.50	0.04						
13-Nov							0.09	2.54	8.63	14.24	6.04	1.28	6.60	16.07	11.84	6.22	1.80	0.06						
14-Nov							0.08	2.48	8.55	14.30	16.55	15.94	5.36	14.68	11.98	6.35	1.86	0.04						
15-Nov							0.08	2.45	8.37	13.78	13.74	17.83	17.89	15.41	11.03	0.88	0.47	0.06						
16-Nov							0.03	0.75	2.25	4.85	9.49	8.05	18.14	14.59	8.49	0.92	0.46	0.05						
17-Nov							0.04	0.86	2.14	4.91	9.86	4.41	12.01	15.24	10.81	5.74	1.39	0.02						
18-Nov							0.03	0.73	2.42	4.94	13.23	9.73	14.48	11.78	8.28	3.56	0.91	0.01						
19-Nov							0.02	0.35	1.71	3.96	8.50	11.49	12.70	13.56	6.13	3.26	0.66	0.04						
20-Nov							0.02	0.40	1.86	5.65	13.11	12.74	13.61	11.82	7.32	4.84	0.50	0.04						
21-Nov							0.03	1.88	6.71	12.44	9.19	1.70	3.12	13.34	10.05	5.52	1.36	0.06						
22-Nov							0.04	1.72	7.93	7.96	14.32	14.34	18.30	9.63	9.29	5.56	0.63	0.02						
23-Nov							0.02	1.41	7.18	12.76	16.72	16.45	17.97	13.84	11.40	3.61	1.09	0.02						
24-Nov							0.03	1.51	7.07	11.27	8.17	1.99	0.44				5.76	0.01						
25-Nov							0.02	1.67	7.34	12.94	10.77	1.08	2.53	15.56	11.61	5.86	1.52	0.03						
26-Nov							0.02	1.44	6.74	12.55	15.02	0.86	9.14	15.31	10.65	6.00	0.66	0.06						
27-Nov							0.02	1.34	6.93	6.35	2.59	0.22	0.26	0.23	0.23	0.40	0.91	0.06						
28-Nov							0.01	1.37	5.37	0.21	0.26	0.22	0.21	0.27	0.27	0.44	0.87	0.06						
29-Nov							0.01	1.27	5.73	0.24	0.23	0.25	0.22	13.68	5.00	5.55	1.11	0.02						
30-Nov							0.01	0.34	1.45	2.53	10.62	14.19	12.53	13.59	7.33	5.32								

Source: EPRI

FIGURE 44 - SOLAR DATA AVAILABILITY FOR BUILDING 2 FOR NOVEMBER 2021

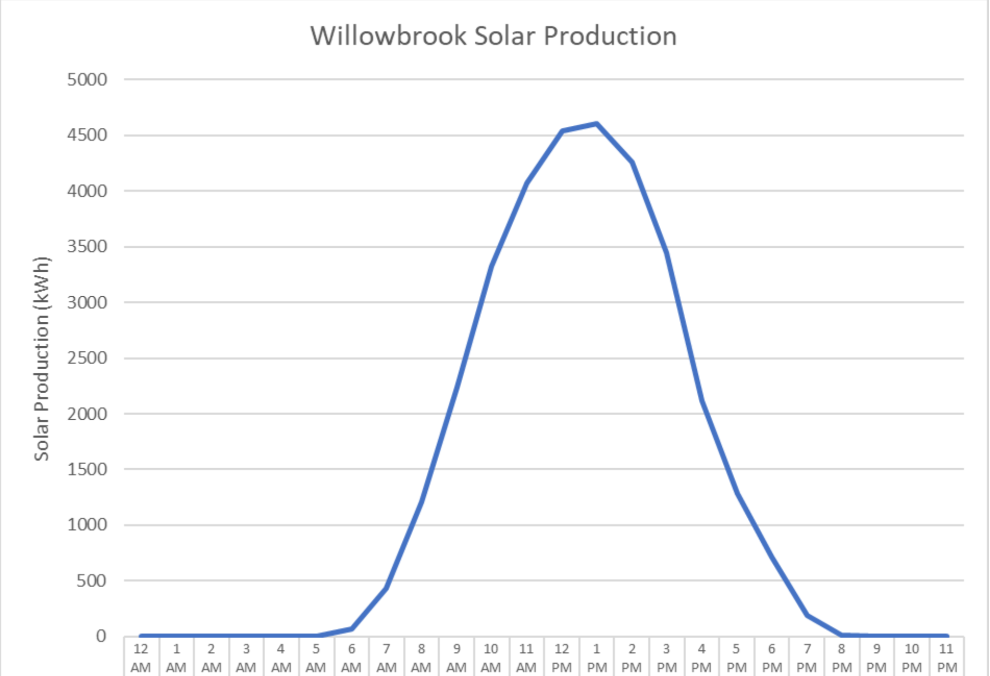
The observations on the data availability are vitally important to understanding what the solar PV profile means. Table 6 shows the average sunrise and sunset times for Southern California for the months of June thru September 2021. Given the length of day, the tails of the profiles are an interesting indicator of non-trivial solar production that may be attributed to reflection off the horizontal plane onto the real face of the bifacial solar panel.

TABLE 7 - SUNRISE AND SUNSET TIMES IN SOUTHERN CALIFORNIA

MONTH	SUNRISE TIME	SUNSET TIME
June	5:34 AM	7:57 PM
July	5.39 AM	8:03 PM
August	5:59 AM	7:46 PM
September	6:22 AM	7:08 PM
October	7:01 AM	6:33 PM
November	6:27 AM	4:49 PM

SOLAR PV PROFILE ANALYSIS

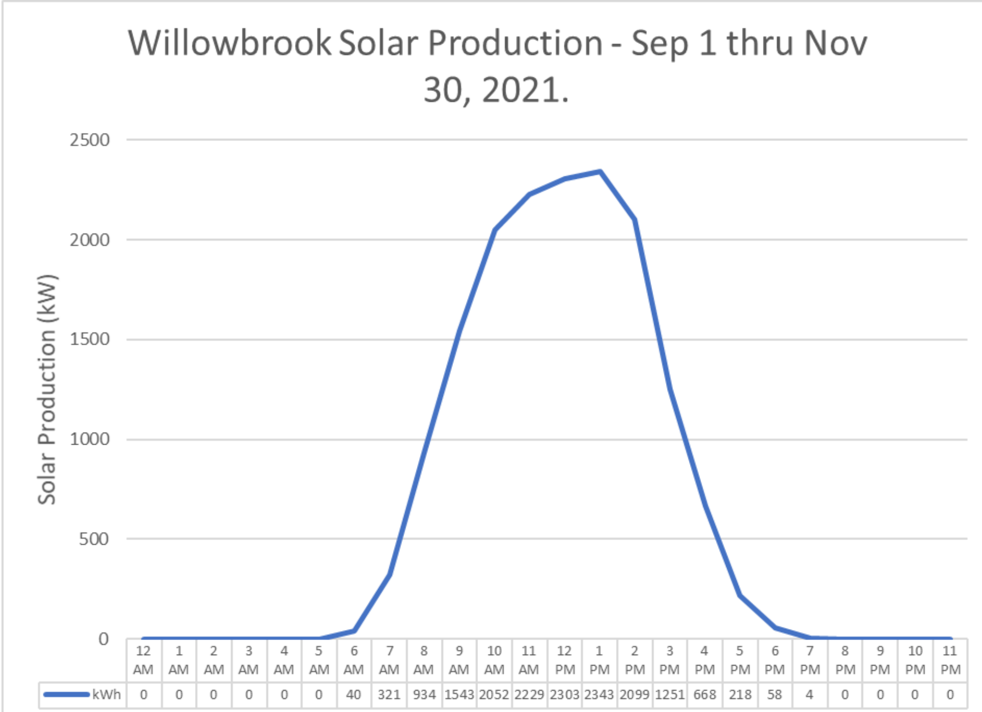
Figure 44 through Figure 49 show the Solar PV profile for both buildings for a summer season (June 1 through September 15, 2021, fall season (September 1 through November 30, 2021), and winter (December 1, 2021 through February 28, 2022). Given the approximately 117 days in the time period with 4 days of data loss, the Building 2 peak production of 4,604 kWh at 1pm, is estimated to be about 40.74 kW during the summer period. Comparing this to the Building 1 site, the PV profile shows much less production. Taking into account the data loss of 23 days, the peak production is 26.87 kW during the same period. In the fall, Building 2 shows a peak production of about 31.49 kW which is consistent with the decreasing irradiance in the Fall compared to Summer. At the same time, we see that the peak production for Building 1 (which has much better data availability) still lags Building 2 at 28.33 kW. We also observe that the Building 1 peak occurs at a different time compared to the Building 2 which is to be expected given the orientation difference between the two buildings. We also observe that compared to the sunrise and sunset times, there is non-zero solar production outside of these times. As expected, the winter peak production is much less compared to Summer and Fall with peak production in Building 1 at 1,647 kWh representing at 12pm, estimated to be about 19.61kW and lower 1,302 kWh representing a peak production of 15.5kW.



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
kWh	0	0	0	0	0	1.59	72.7	434	1205	2241	3324	4076	4538	4604	4256	3442	2118	1288	709	190	8.42	0	0	0

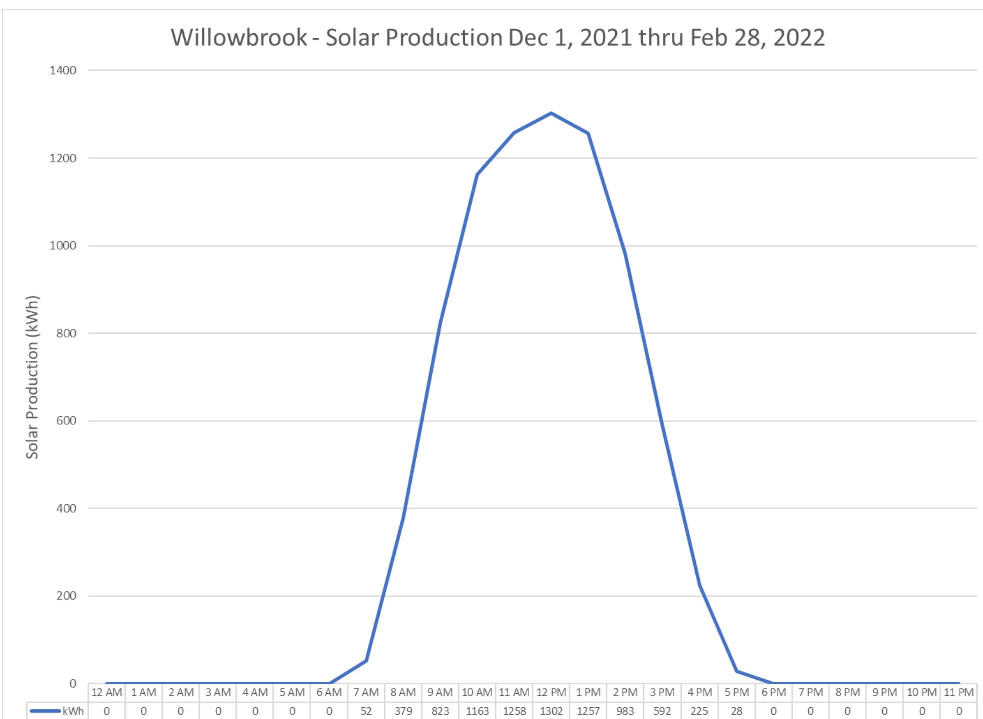
Source: EPRI

FIGURE 45 - SOLAR PV PROFILE FOR BUILDING 2 FOR JUNE 1 TO AUGUST 31, 2021



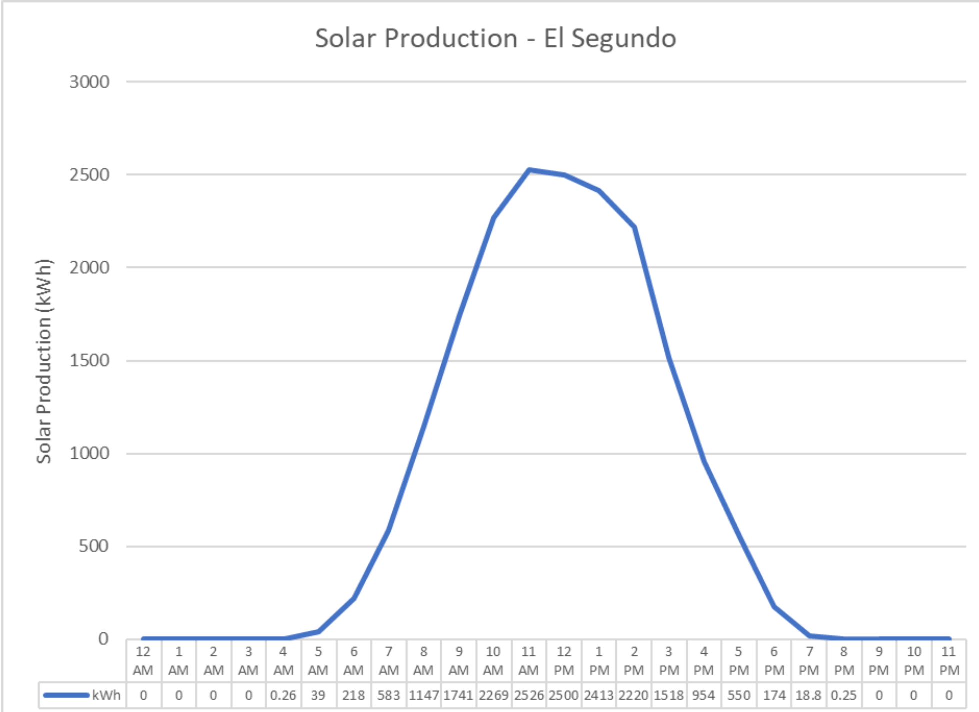
Source: EPRI

FIGURE 46 - SOLAR PV PROFILE FOR BUILDING 2 FOR SEPTEMBER 1 TO NOV 30, 2021



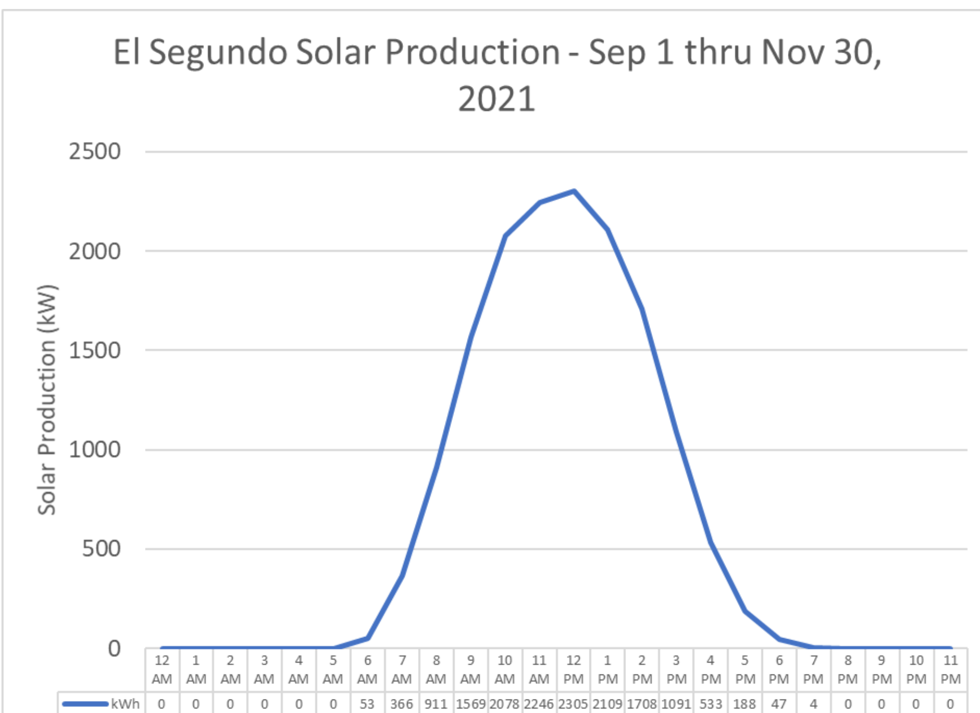
Source: EPRI

FIGURE 47 - SOLAR PV PROFILE FOR BUILDING 2 FOR DEC 1, 2021 TO FEB 28, 2022



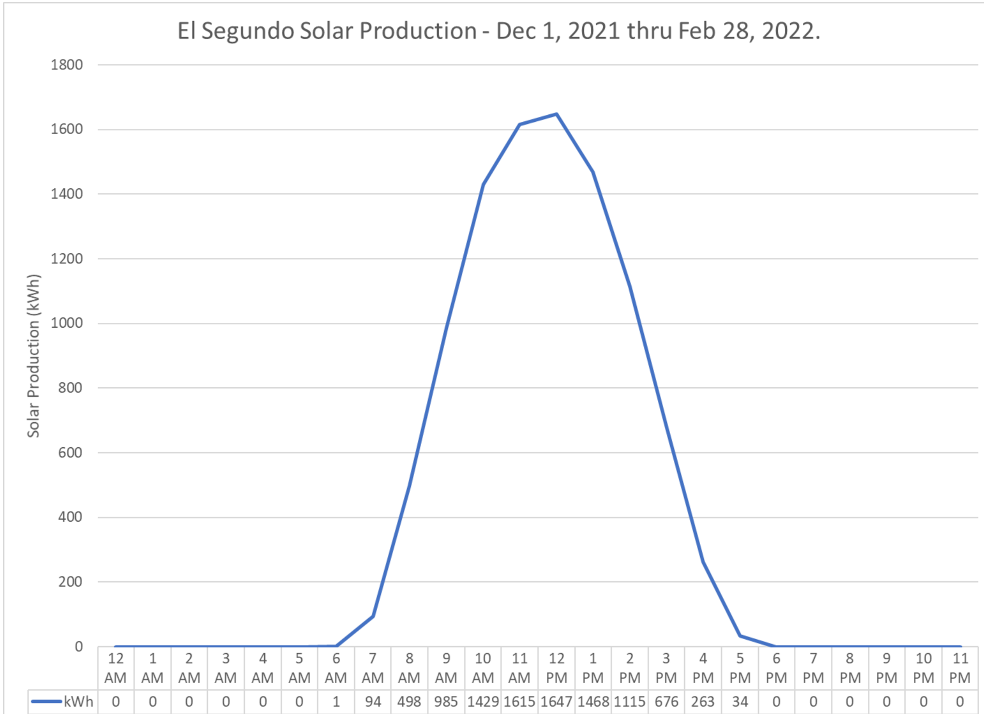
Source: EPRI

FIGURE 48 - SOLAR PV PROFILE FOR BUILDING 1 FOR JUNE 1 TO AUGUST 31, 2021



Source: EPRI

FIGURE 49 - SOLAR PV PROFILE FOR BUILDING 1 FOR SEPTEMBER 1 TO NOV 30, 2021



Source: EPRI

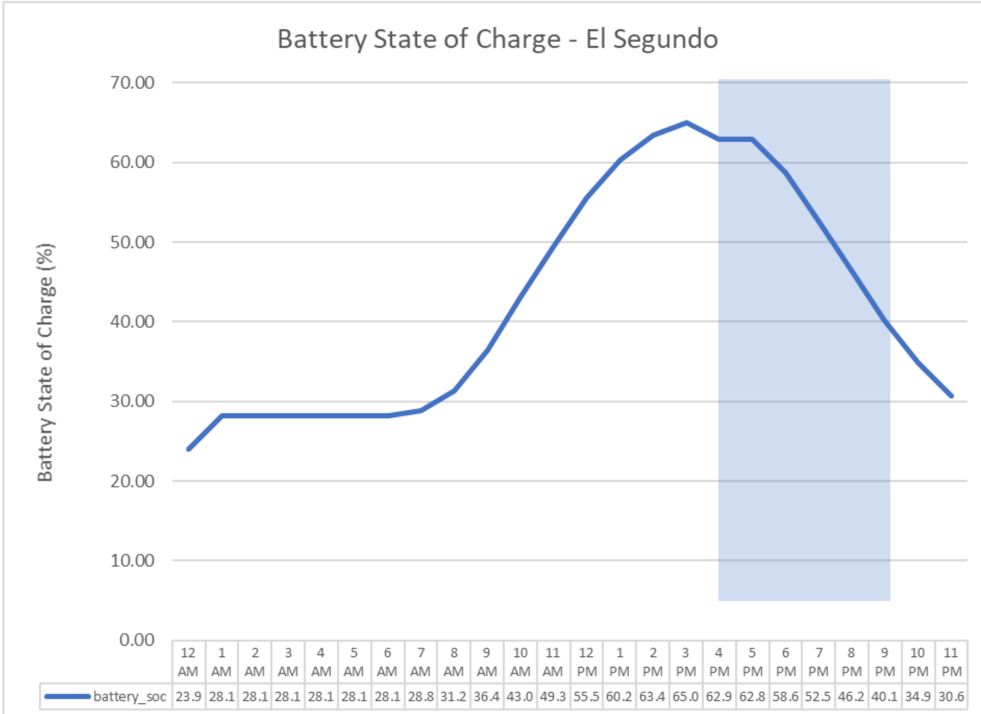
FIGURE 50 - SOLAR PV PROFILE FOR BUILDING 1 FOR DEC 1, 2021 TO FEB 28, 2022

BATTERY PROFILE

The battery profile analysis was done by observing the charge and discharge patterns of the two batteries as indicated by the change in their SOC. Given that SOC is a non-cumulative quantity, it is represented as an average over the days pertaining to the hour. Figures 48 to 51 show the average battery SOC profile for the Building 1 and 2.

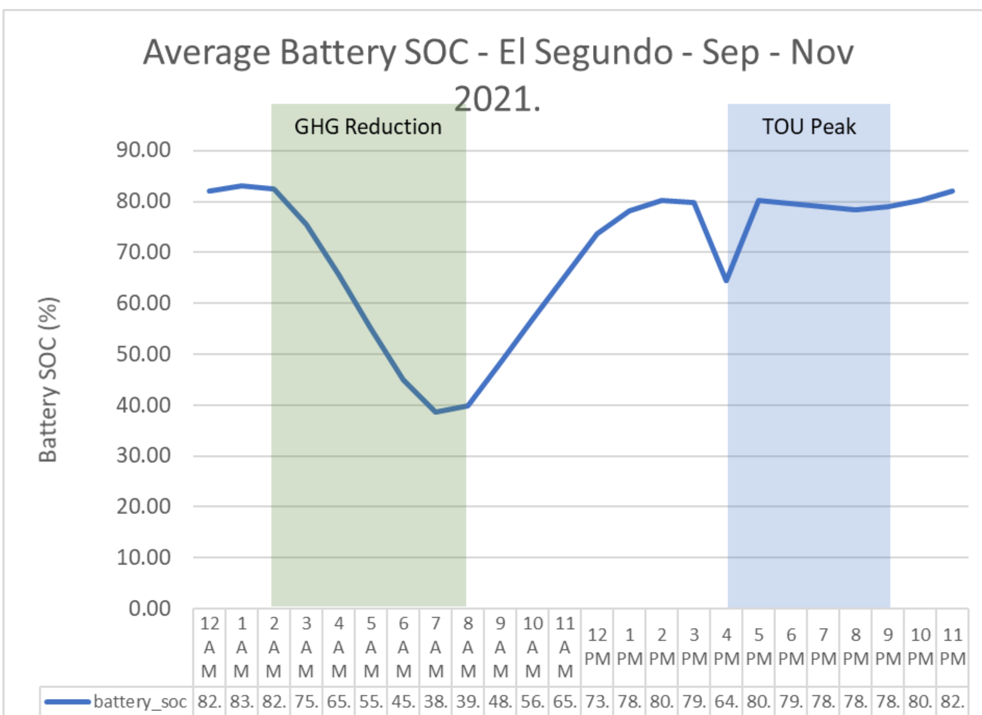
Observing the patterns of charge increase and decrease through the day, it is clear that the battery charges during the times of high solar production (8AM to 3PM) and discharges during the period of peak TOU (4PM to 9PM) and beyond. Throughout the night the charge is held constant around 20 percent. Another point to observe is that the battery Building 2 charges to a higher SOC (~ 80 percent) through the day and discharges about 38 percent (from 77 percent to 39 percent) whereas Building 1 charges to only about 63 percent SOC through the day and discharges about 23 percent (63 percent to 40 percent) during TOU peak hours. Given the significant data loss in Building 1, adjusting for the data loss, the peak of the SOC in Building 1 is consistent with that of Willowbrook (~ 78 percent) and TOU discharge change in SOC is about 30 percent.

During the fall (Sep-Nov), the Building 2 battery continues to charge, and discharge based on the TOU pattern whereas the Building 1 battery is programmed on to a profile which discharges between 2am and 7am to coincide with the period of highest marginal carbon emissions in the state's electricity grid. The goal is to be able to contribute to understanding the effect of the reduction in GHG emissions as a result of discharging the battery to the grid and reducing the net energy drawn from the grid. In Winter (Dec through Feb) both batteries were profiled to discharge in the early morning hours (GHG reduction profile).



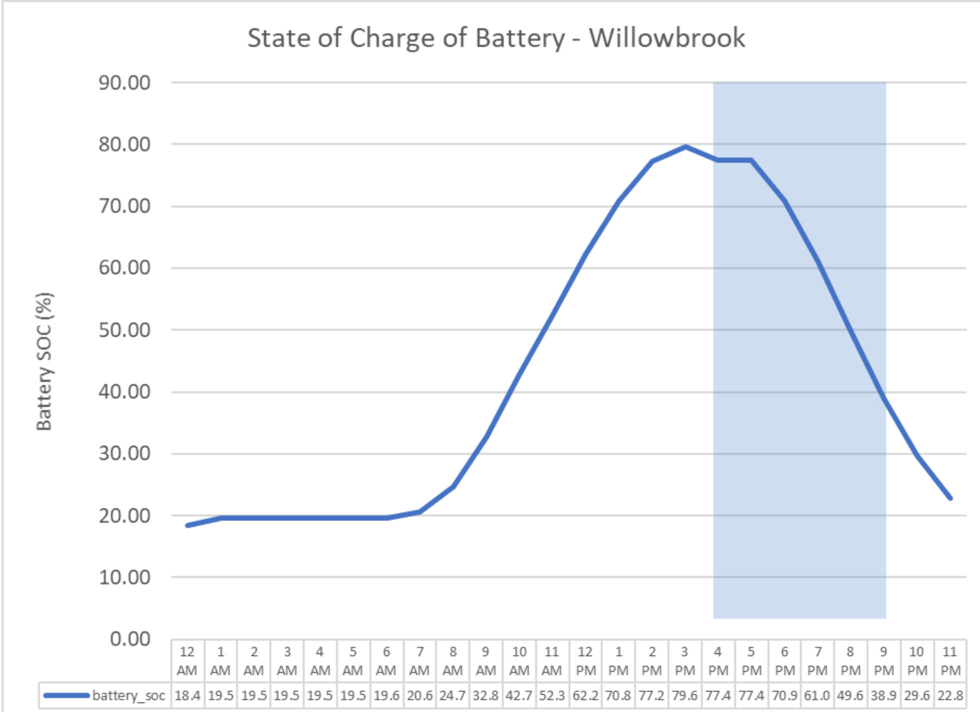
Source: EPRI

FIGURE 51 - BATTERY SOC PROFILE FOR BUILDING 1 JUNE 1 TO AUGUST 31, 2021



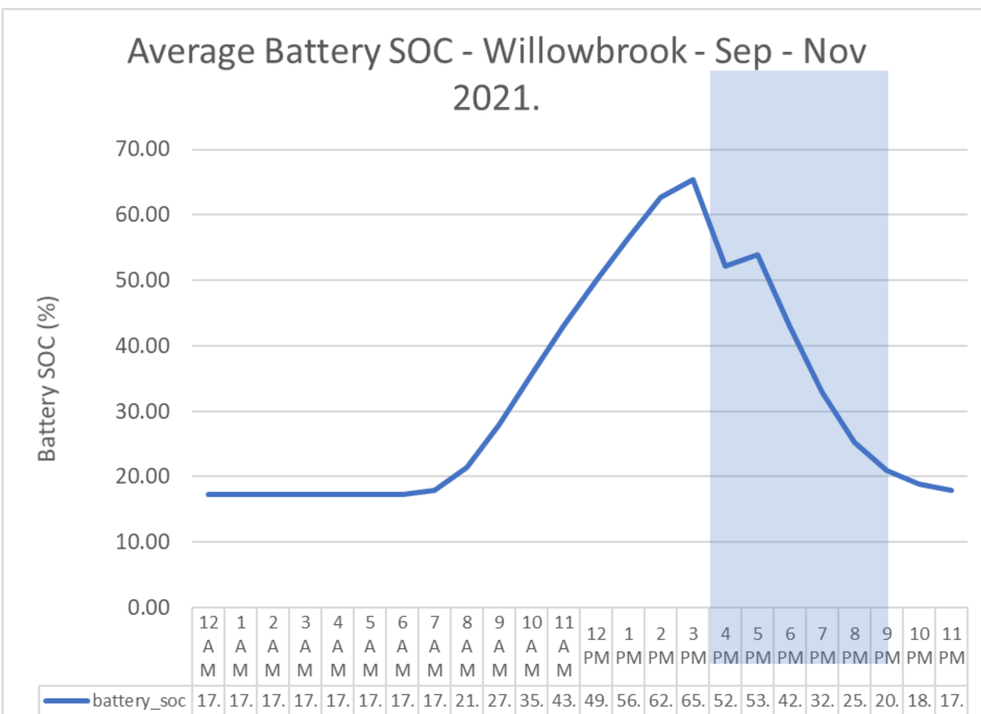
Source: EPRI

FIGURE 52 - BATTERY SOC PROFILE FOR BUILDING 1 SEPTEMBER 1 TO NOV 30, 2021



Source: EPRI

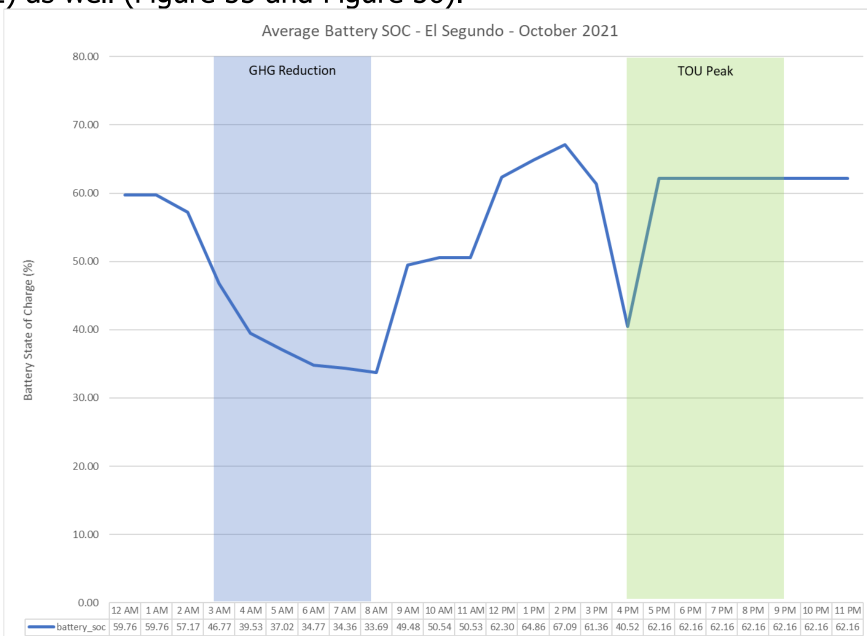
FIGURE 53 - BATTERY SOC PROFILE FOR BUILDING 2 JUNE 1 TO AUGUST 31, 2021



Source: EPRI

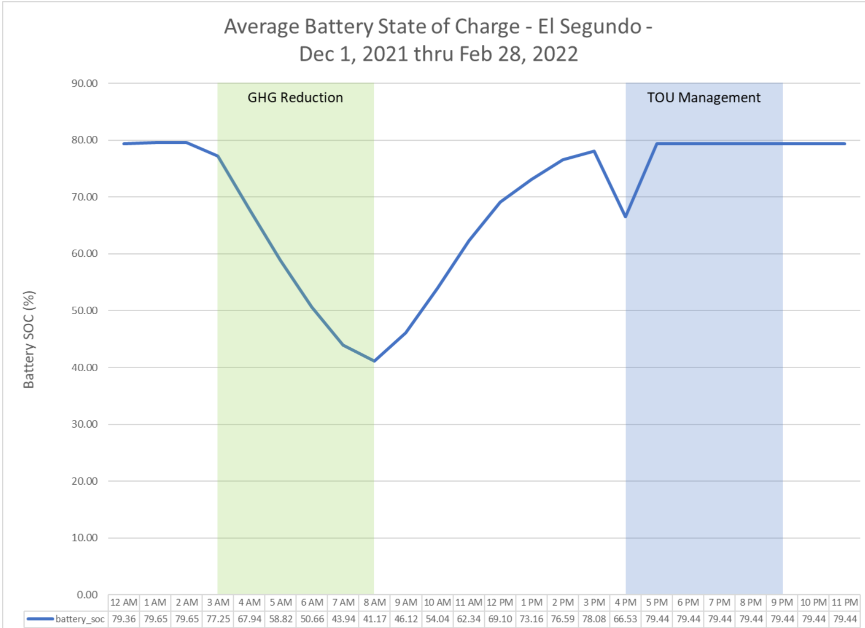
FIGURE 54 - BATTERY SOC PROFILE FOR BUILDING 2 FOR SEPTEMBER 1 TO NOV 30, 2021

During the TOU Winter months (Oct 1 thru May 31), the battery profile was set to a "GHG Emissions Reduction" profile where the battery discharges from 3AM to 8AM, which is the time period with the highest average grid GHG emissions based on CAISO 2019 emissions data. By charging the battery with renewable power and discharging it during the periods of highest GHG emissions, the GHG Emissions profile attempts to zero out the building's source GHG emissions (Scope 2 emissions) during the periods of highest GHG intensity in the Grid. As an example, the battery profile after the battery was set to the GHG Emissions Reduction profile is shown for Building 1 in Figure 52 . As expected, the battery discharges between 3AM and 8AM. After 8AM the battery starts to charge from the Solar PV and holds the charge steady during the TOU peak hours. The same profile continued in operation in winter (December 2021 through February 2022) as well (Figure 55 and Figure 56).



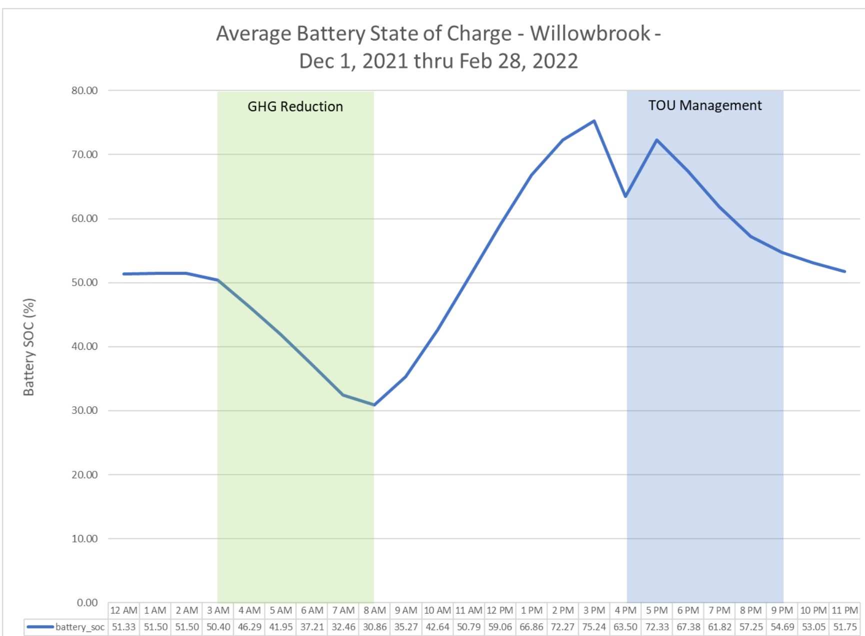
Source: EPRI

FIGURE 55 - BATTERY PROFILE FOR BUILDING 1 FOR OCTOBER 1 TO 5, 2021



Source: EPRI

FIGURE 56 - BATTERY PROFILE FOR BUILDING 1 FROM DEC 1, 2021 TO FEB 28, 2022

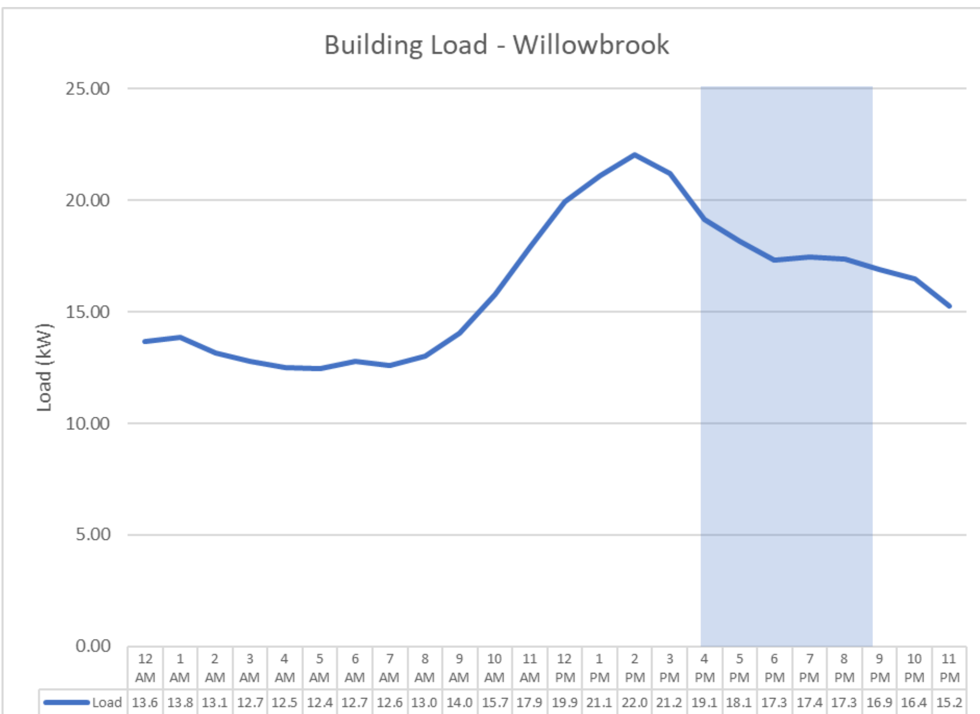


Source: EPRI

FIGURE 57 - BATTERY PROFILE FOR BUILDING 2 FROM DEC 1, 2021 TO FEB 28, 2022

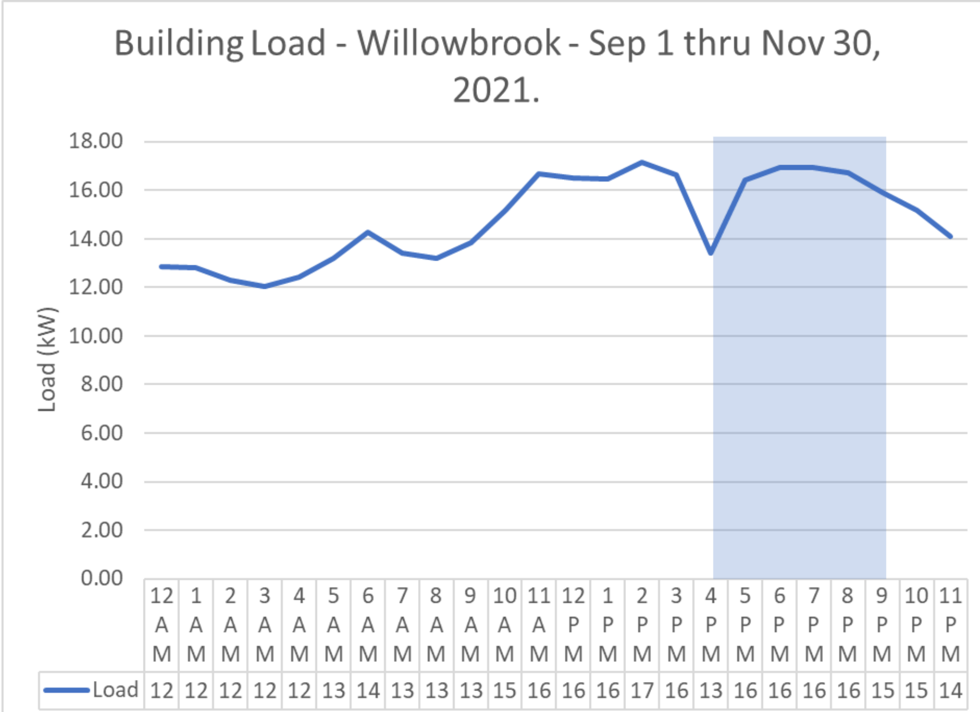
BUILDING LEVEL LOAD ANALYSIS

The building level load analysis is performed for both buildings separately followed by a full-scale campus-level Mosaic Gardens at Willowbrook load analysis. Figure 53 through Figure 56 show the raw load profile at the building level. We use the term "raw" load because we want to distinguish it from the net load which is effectively the load after renewable exports (solar and storage). This raw load represents the amount of demand on the distribution system pertaining to the whole building, which includes living areas (apartments) and common areas. The load peaks to about 22 kW around 2PM during the summer and about 18kW during the fall. The fact that the load peak occurs around 2PM forebodes an interesting result considering that typically buildings with Solar PV systems tend to peak in load around the time the solar production reduces significantly. Comparing this load profile to Building 1 in Figure 26, we observe a very similar profile albeit a slightly smaller overall load peak. Building 2's peak is about 22 kW compared to Building 1 which is at 17.5 kW in summer and 20.1 kW in the fall. The winter performance of Building 2 and Building 1 are shown in Figure 59 and Figure 62 respectively with both peaking during the TOU peak hours albeit the TOU rates are lower in the winter compared to summer. The relative peaks are also similar between the two buildings around 22kW.



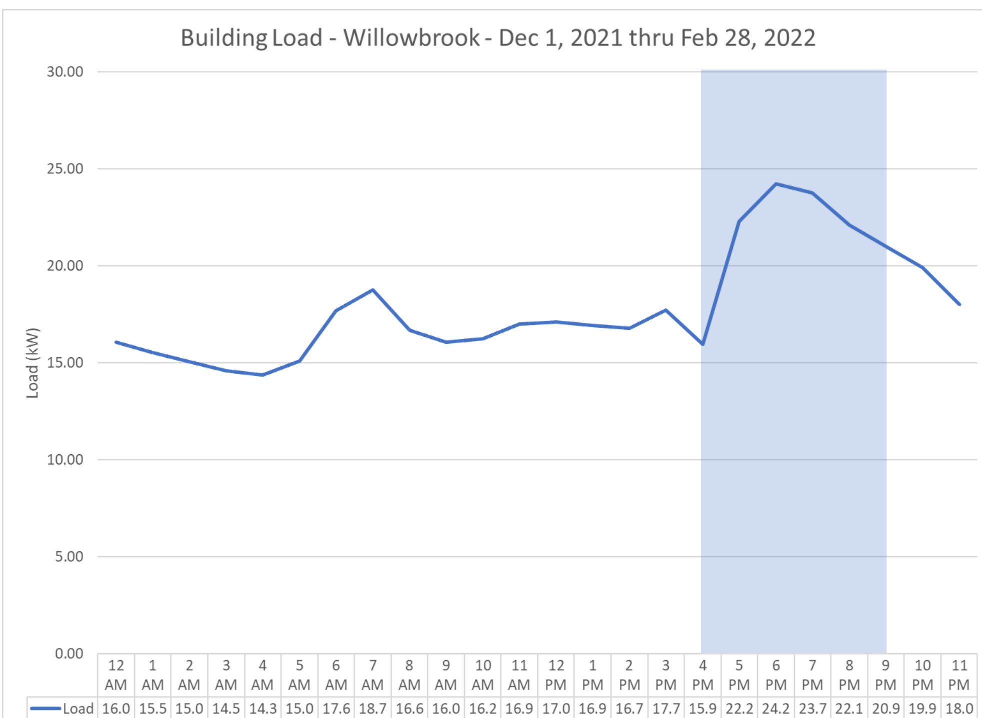
Source: EPRI

FIGURE 58 - LOAD PROFILE FOR BUILDING 2 FOR JUNE 1 THRU AUGUST 31, 2021



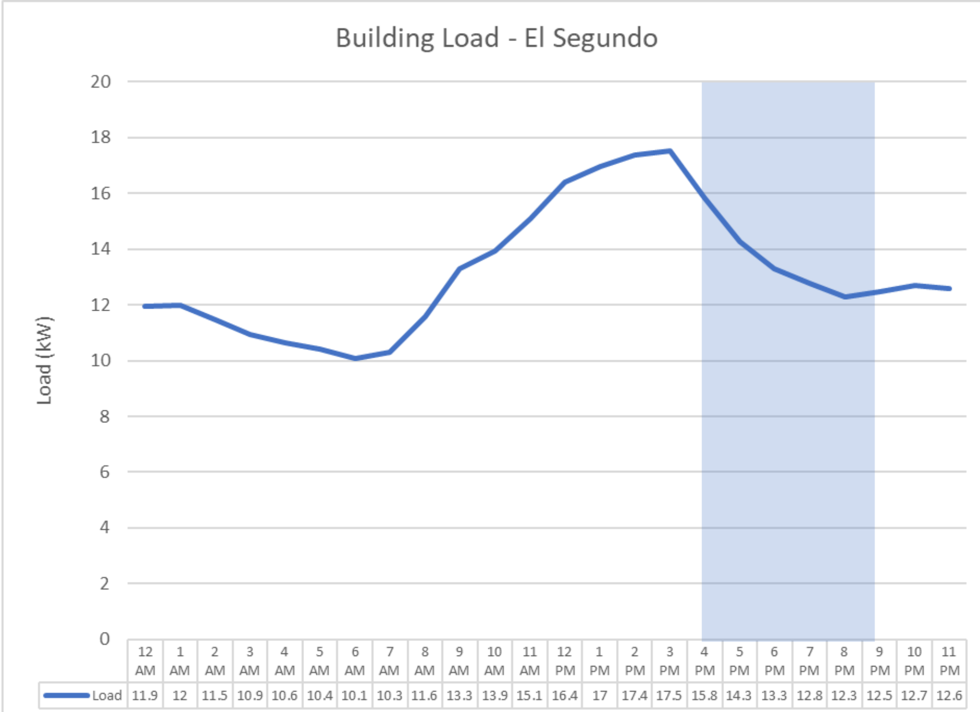
Source: EPRI

FIGURE 59 - LOAD PROFILE FOR BUILDING 2 FOR SEP 1 TO NOV 30, 2021



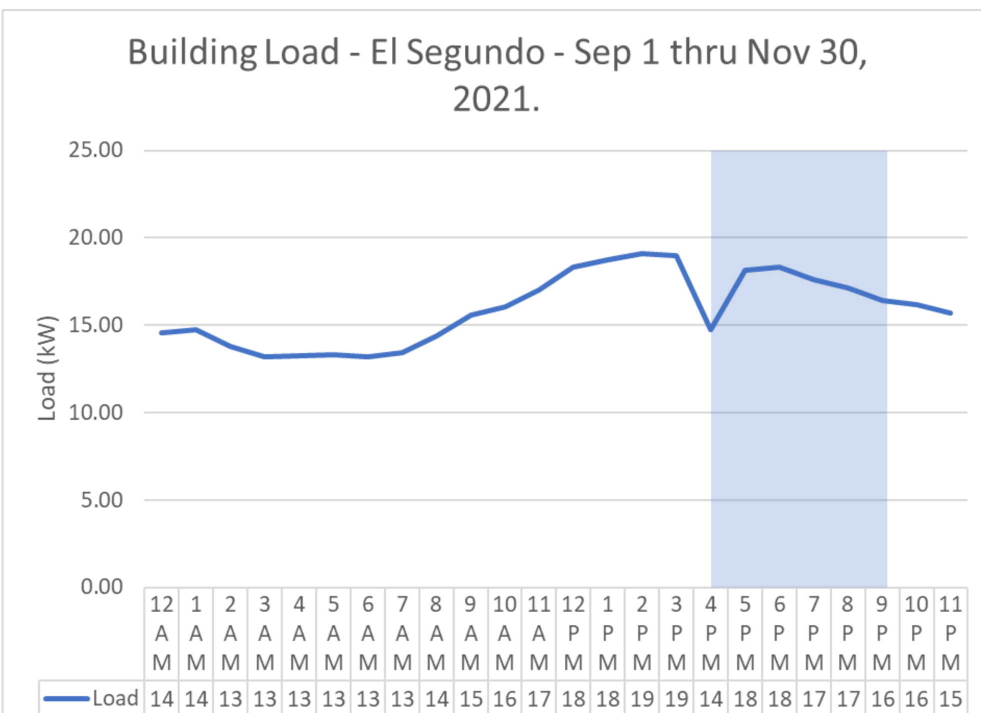
Source: EPRI

FIGURE 59: LOAD PROFILE FOR BUILDING 2 FOR DEC 1, 2021 TO FEB 28, 2022



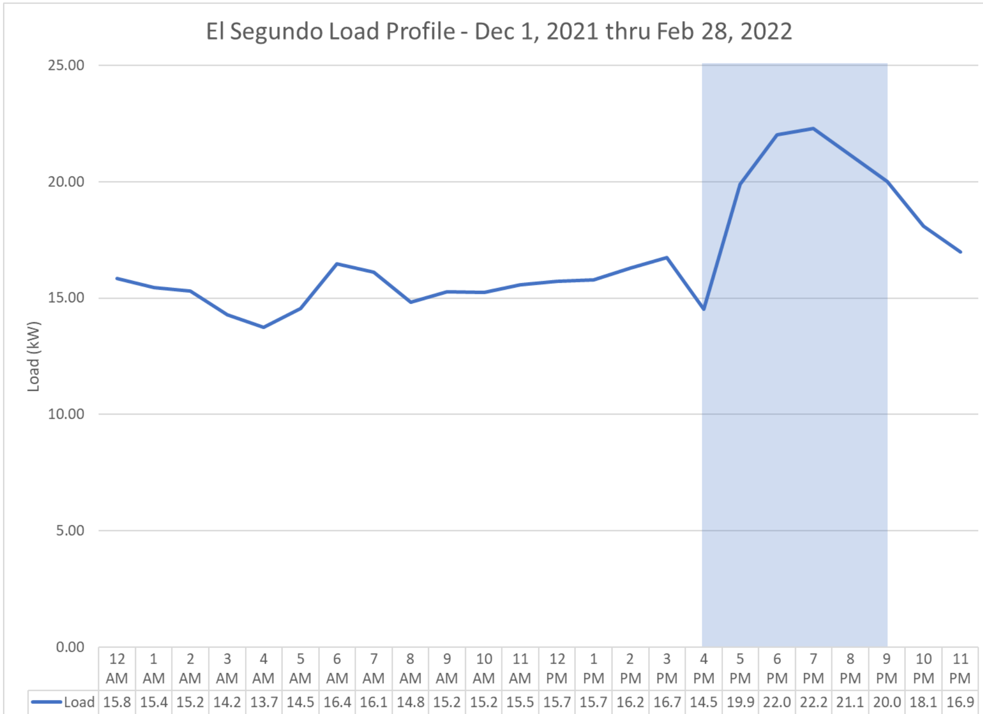
Source: EPRI

FIGURE 60 - LOAD PROFILE FOR BUILDING 1 FOR JUNE 1 TO AUGUST 31, 2021



Source: EPRI

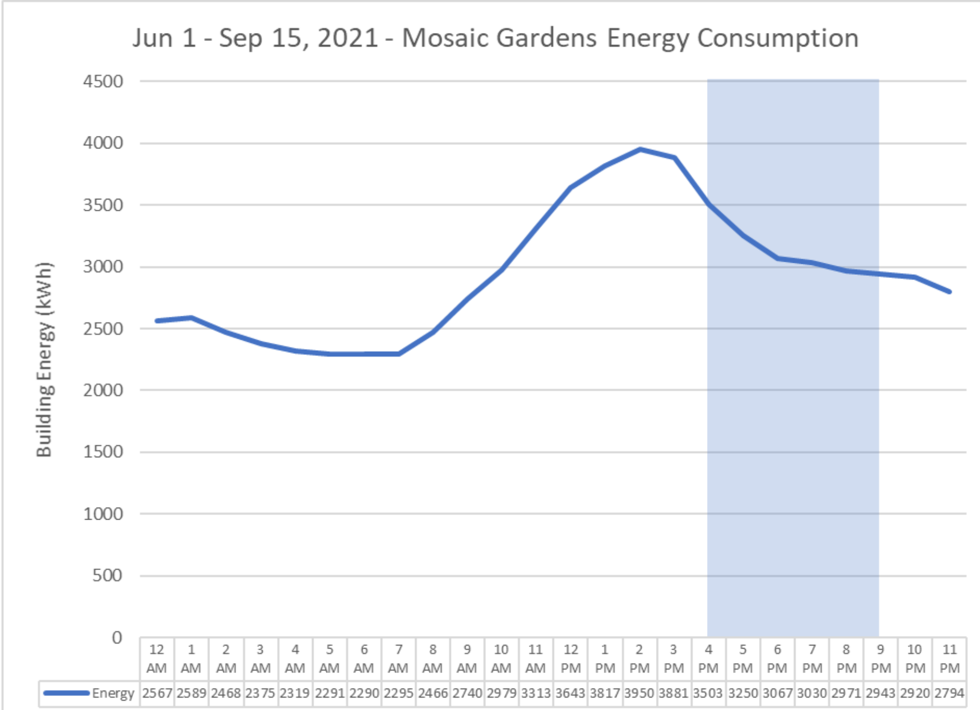
FIGURE 61 - LOAD PROFILE FOR BUILDING 1 FOR SEPTEMBER 1 THRU NOV 30, 2021



Source: EPRI

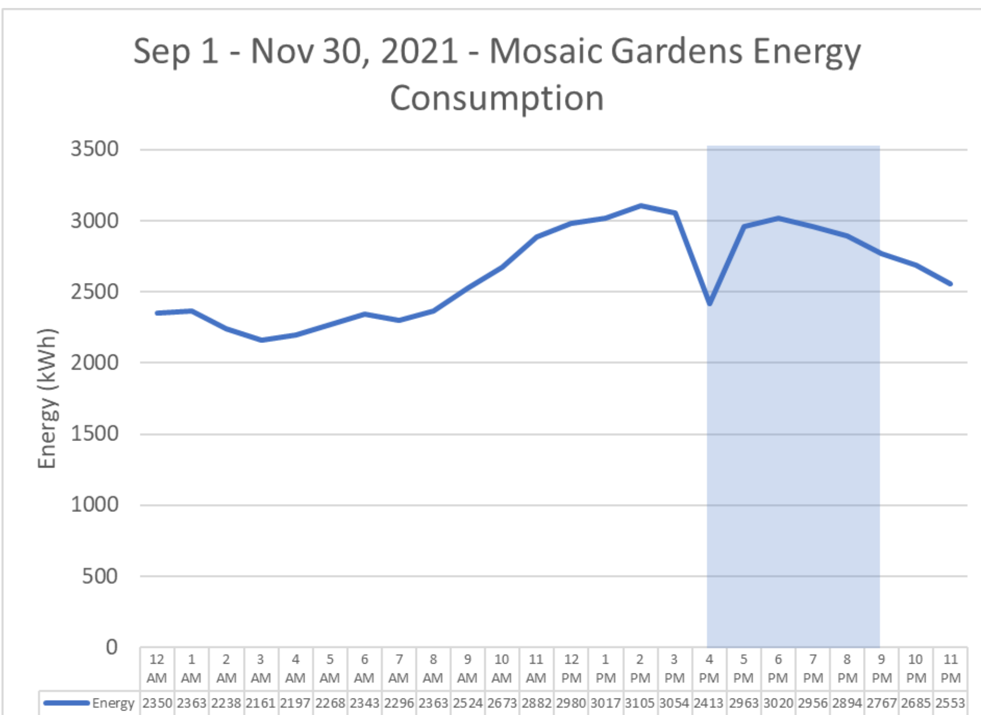
FIGURE 62 - LOAD PROFILE FOR BUILDING 1 FOR DEC 1, 2021 TO FEB 28, 2022

The Mosaic Gardens at Willowbrook campus level energy profile for the summer of 2021 is shown in Figure 57 and 58. All load profiles indicate peaks outside the 4 to 9PM timeframe and also shows a reduction in load as the evening progresses. Given that this is the raw load, and the community is being subject to active TOU energy management via messaging done through the OhmConnect messaging platform, an immediate question that comes up is "How does this performance compare to the time before these renewables, storage, and active load management methods were employed?"



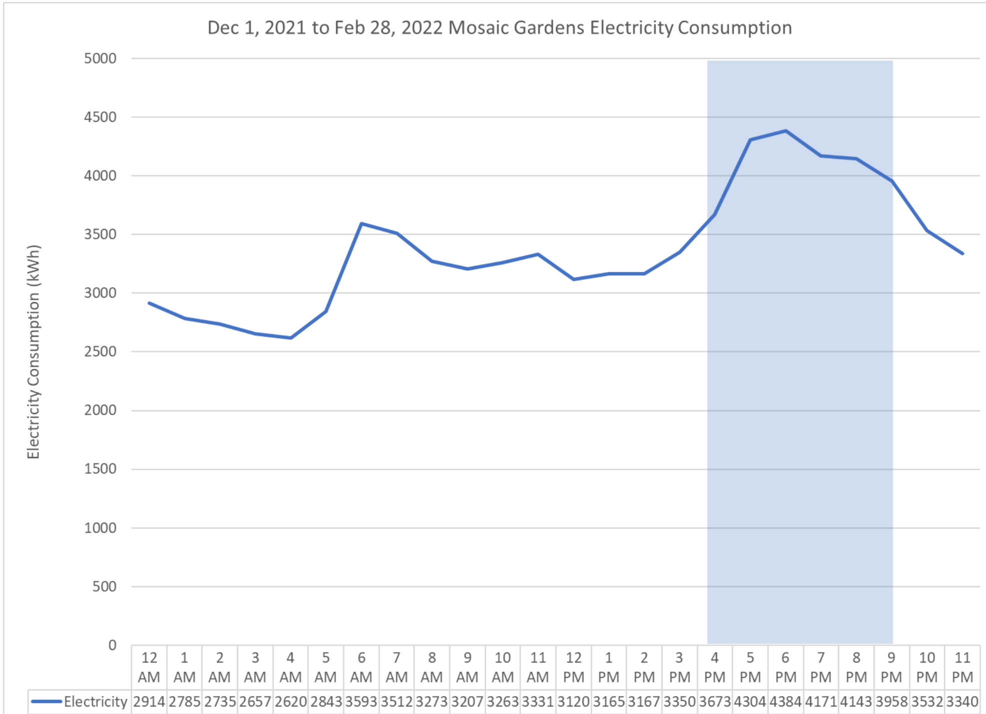
Source: EPRI

FIGURE 63 - CAMPUS ENERGY PROFILE FOR JUNE 1 TO AUGUST 31, 2021



Source: EPRI

FIGURE 64 - CAMPUS ENERGY PROFILE FOR SEP 1 THRU NOV 30, 2021

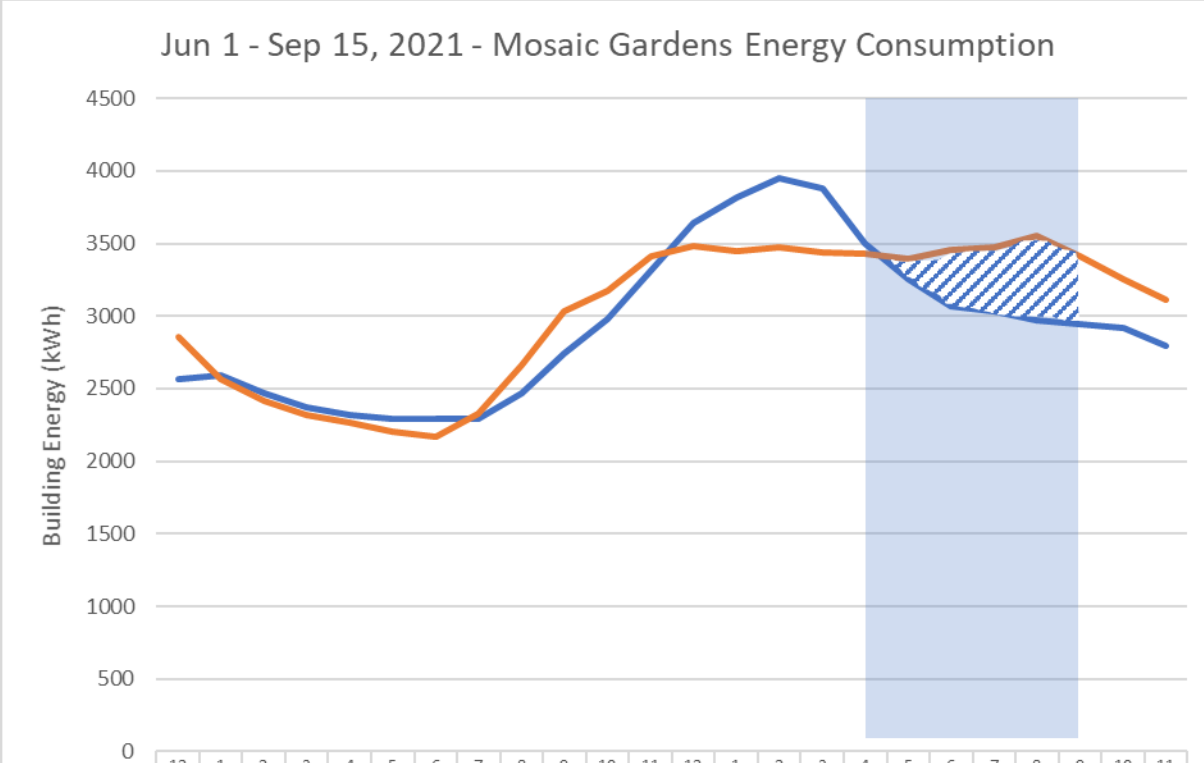


Source: EPRI

Figure 65 - Campus Energy Profile for Dec 1, 2021 to Feb 28, 2022

Comparison of Pre-Retrofit to Post-Retrofit Energy Performance

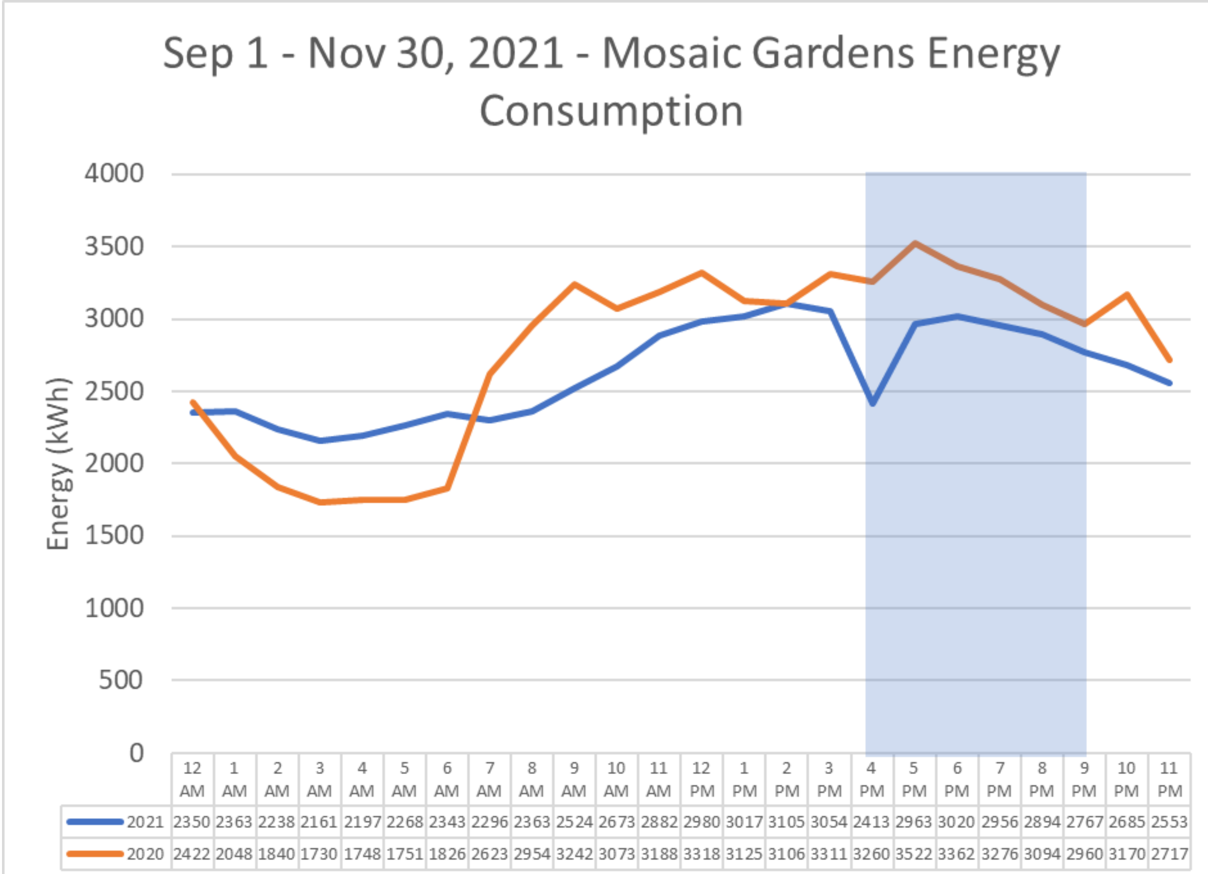
To compare the current post-retrofit energy performance (shown in Error! Reference source not found.59) to the pre-retrofit performance, the data from 2020 at the unit level and the common area level were compiled together. Of the energy consumption data set of 21 residents that the project team had access to, only six of the homes had data going back to summer of 2020. A method of scaling the data from these six homes was employed alongside detailed hourly common area meter data available via SCE's customer portal. The result was used to develop an energy performance pre-retrofit. This pre-retrofit performance (2020) was compared to the post-retrofit performance (2021). The result of the comparison is shown in Figure 59, 60, and 61.



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
2021	2567	2589	2468	2375	2319	2291	2290	2295	2466	2740	2979	3313	3643	3817	3950	3881	3503	3250	3067	3030	2971	2943	2920	2794
2020	2854	2567	2420	2319	2269	2201	2169	2326	2662	3033	3178	3411	3484	3447	3472	3443	3432	3391	3457	3472	3551	3410	3254	3109

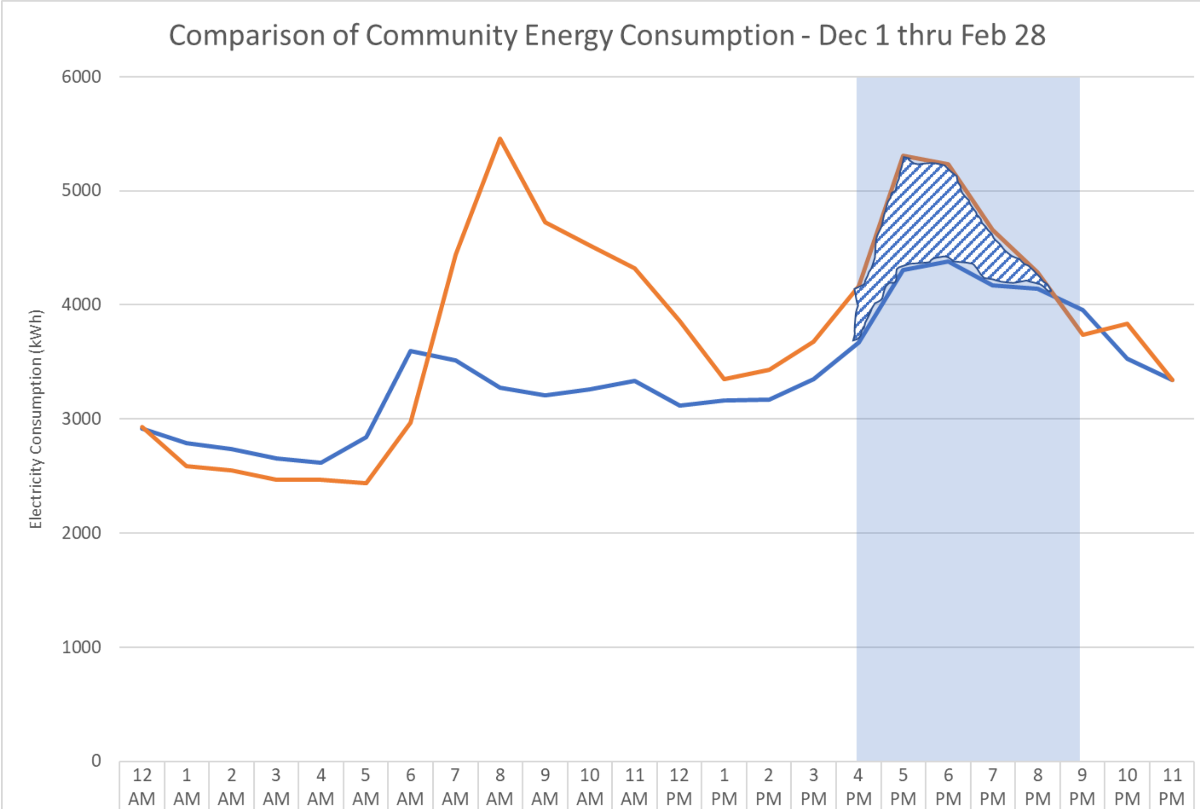
Source: EPRI

FIGURE 66 - COMPARISON OF PRE-RETROFIT (2020) TO POST-RETROFIT (2021) ENERGY PERFORMANCE FOR JUNE 1 TO SEPTEMBER 15



Source: EPRI

Figure 67 - Comparison of Pre-Retrofit (2020) to Post-Retrofit (2021) Energy Performance for September 1 to Nov 30, 2021



	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM
2021	2914	2785	2735	2657	2620	2843	3593	3512	3273	3207	3263	3331	3120	3165	3167	3350	3673	4304	4384	4171	4143	3958	3532	3340
2020	2932	2586	2550	2470	2465	2437	2967	4438	5455	4722	4520	4324	3861	3346	3430	3675	4165	5310	5232	4656	4286	3737	3834	3345

Source: EPRI

FIGURE 68 - COMPARISON OF PRE-RETROFIT (2020-2021) TO POST-RETROFIT (2021-2022) ENERGY PERFORMANCE FOR DECEMBER 1 TO FEBRUARY 28

The comparison leads to a few observations:

- The energy performance of 2020 had fewer peaks 2021 but also the energy used during the 4-9PM timeframe is higher in summer whereas the energy in 2020 Fall (on a weather normalized basis) is higher almost throughout the day. This downward shift in the entire load profile is more attributable to energy efficiency as opposed to signaling or TOU management. This trend continues and is more heavily pronounced in Winter where there is downward shift in peak as well as overall energy performance.
- The energy performance of 2021 peaks well before the 4-9PM timeframe but is quite similar in trend compared to 2020 in summer and in the Fall the energy performance trends similar to 2020 with the exception of early morning hours. In winter, there is an elimination of a morning peak as the peak shifts to the evening hours but is also lower in 2021 compared to 2020 by about 13% (900kWh reduction on the basis of 5200 kWh for 2020).
- There is load-shifting that is evident from the 4-9PM timeframe to the 12-3pm timeframe which leads to the peak around 2PM in summer. Such a pattern is not observed in the fall. This is to be expected (especially after Oct 1) when the peak TOU rates are lower. There is no perceptible load-shifting behavior observable in winter.

- Given that this is the "raw" load and not the net load, it is quite possible that the inclusion of exports during the 12-3PM (solar exports minus what is used to charge the battery) and 4-9PM timeframe (battery discharge exports), and 2-7AM (battery discharge exports) the load performance for 2021 is expected to be even better.
- The estimated reduction in energy use (shaded in blue hatch) compared to 2020 is about 1.48MWh over the period (June 1 thru September 15) and the overall reduction in load (over 24 hours) in the Fall is 3.07 Megawatt-hour (MWh).
- The estimated reduction in energy use over 24 hour period in winter (December 1 thru February 28) is 9.7MWh and 2.9MWh in the 4-9pm timeframe. This corresponds to a 11% reduction in energy use over 24 hours and 13% during 4-9pm timeframe.

TOU MESSAGING AND DR

OHMCONNECT AND CAISO

Project partner OhmConnect is registered as a "Demand Response Provider" (DRP) with CAISO. DRP build demand-side resources, or virtual power plants, that aggregate users' electricity reductions as the source of generation. While most electricity resources create new electricity (like coal or solar power plants), DRP value reductions of electricity as a replacement for new electricity.

OhmConnect bids aggregated residential customers' load reductions as DR into CAISO markets on a daily basis. OhmConnect is fully integrated into the CAISO market and participates by bidding its virtual power plants' reductions into the Day-Ahead Market and Real-time Market. If dispatched in the CAISO energy markets, OhmConnect is paid for the reductions that it provides. In turn, OhmConnect pays its users for their energy reductions.

OhmConnect seeks to align its bids with when users are able to contribute their reductions to periods of grid stress, as reflected by prices in the day-ahead and spot markets for electricity. Specifically, OhmHours tend to be called during periods of high locational marginal prices (LMPs), which reflect periods of higher grid stress. However, because OhmConnect values customer engagement, OhmHours that keep customers engaged are called year-round. OhmConnect called at least 1 event over 164 days in 2020 and 175 days in 2021.

WILLOWBROOK RESULTS

The OhmConnect, Linc, and EPRI teams worked together to enroll as many Willowbrook residents as possible into the OhmConnect program. There were challenges in a few cases when certain residents did not have credentials to their SCE online accounts. In the end, 29 Willowbrook residents signed up with OhmConnect, and of those 29 residents, 21 connected their utility accounts and have been participating in OhmConnect's OhmHour events. You can see a summary of the participation of the Willowbrook residents in Table 8 below.

TABLE 8 - SUMMARY OF WILLOWBROOK RESIDENT PERFORMANCE

USER ID	NUMBER OF OHMHOUR EVENTS	PERCENT OF SUCCESSFUL EVENTS	MAX KWH REDUCTION
1	1	100 percent	0.44
2	56	80 percent	0.95
3	59	80 percent	1.20
4	50	76 percent	1.04
5	56	71 percent	1.22
6	58	69 percent	0.86
7	51	69 percent	1.74
8	59	68 percent	0.67
9	46	65 percent	0.52
10	54	65 percent	1.33
11	53	64 percent	0.61
12	48	63 percent	0.62
13	45	62 percent	1.72
14	51	61 percent	1.28
15	50	56 percent	0.77
16	56	55 percent	2.01
17	49	55 percent	0.16
18	44	55 percent	2.24
19	52	54 percent	1.21
20	55	49 percent	0.59
21	55	47 percent	1.38
Average	*49*	*65 percent*	*1.07*

The Willowbrook residents have an OhmHour event between 4PM to 9PM, on average, one hour per week throughout the year. Prior to each OhmHour, the Willowbrook residents receive a notification from OhmConnect via email and text message. The notifications come about 24 hours and five minutes before the start of each OhmHour. The Willowbrook residents also receive summaries of their OhmHour performance within about two days of each event. Table 9 below provides a summary of every OhmHour event that included at least one Willowbrook resident between June and December 2021. There were 56 unique events, with 765 resident opt-ins or an average of 16 opt-ins per event.

TABLE 9 - SUMMARY OF OHMHOUR DISPATCHES

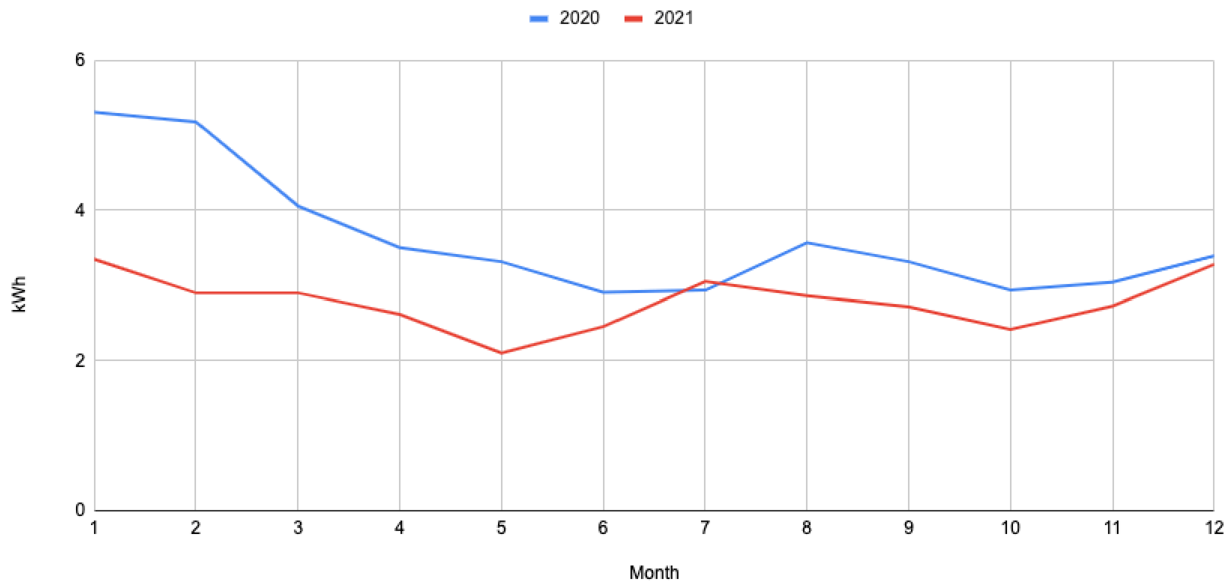
	OHMHOUR EVENTS	RESIDENT OPT-INS	AVERAGE OPT-INS PER EVENT
June	10	160	16
July	9	180	20
August	16	160	10
September	7	119	17
October	4	72	18
November	2	32	16
December	5	42	8
Total	53	765	(Average) 15

Through January 2022, the Willowbrook residents have collectively saved nearly 200 kWh through their behavioral participation in OhmHour events. On average, the Willowbrook residents saved ~0.30 kWh during each 1-hour event. During one event, one resident was able to achieve a 2.24 kWh reduction. Nearly 45 percent of the Willowbrook residents have attained Gold or Platinum status on the OhmConnect platform, indicating that they are consistently reducing their energy consumption between 15 percent (Gold) to 80 percent (Platinum) relative to their baseline forecast when called on to do so. Compared to the population of OhmConnect users in the SCE territory, the Willowbrook residents generally perform similarly or better.

TIME-OF-USE RATE MESSAGING

The residents of the Willowbrook community will shift over to a TOU rate plan offered by SCE in May 2022. For this project, OhmConnect has built out custom messaging for Willowbrook residents around the TOU rate plan. OhmConnect incorporated TOU-related messaging into its day ahead and day of notifications for OhmHour events, and OhmConnect has been sending a monthly newsletter to Willowbrook residents with information about TOU rates, as well as energy saving tips.

Using all of the data available to compare monthly averages of daily energy consumption per resident during the 4-9PM window, it appears that energy consumption generally fell in 2021 versus 2020 as indicated in Figure 61. There are several factors that could explain the difference, including: turnover in residents, differences in weather, the shelter-in-place-related increases in 2020, improvement in “energy literacy” from participation in OhmConnect.



Source: OhmConnect

FIGURE 69 - MONTHLY AVERAGE OF DAILY ENERGY CONSUMPTION PER RESIDENT BETWEEN 4 TO 9PM

The team wanted to perform a simple analysis to determine whether the custom TOU-related messaging was having any measurable effect on the residents' average energy consumption during the 4-9PM time period during the summer months. The team was able to access historical meter data dating back to the beginning of the summer of 2020 for a very limited sample size of seven Willowbrook residents due to the occupancy turnover rate among the 21 enrolled participants. See the data in Figure 62 for a summary of the behavior of those seven residents on the OhmConnect platform.

All 7 residents successfully participated in more than 50 percent of their OhmHour events and saved up to 50 percent compared to their historic baseline. Looking at their reductions in energy consumption cumulatively across all of their OhmHour events, 4 of the residents have been successful at saving energy, and three of the users have not.

Using meter data from June to August 2020 and June to August 2021, the average energy consumption (in kWh) was calculated during 4-9PM for each of the seven residents. There is not a clear trend, as four out of seven users have consumed more energy during TOU rate times in summer 2021 vs. 2020, and the other three residents consumed less energy during TOU rate times in summer 2021 vs. 2020. This result is not unexpected given the very limited sample.

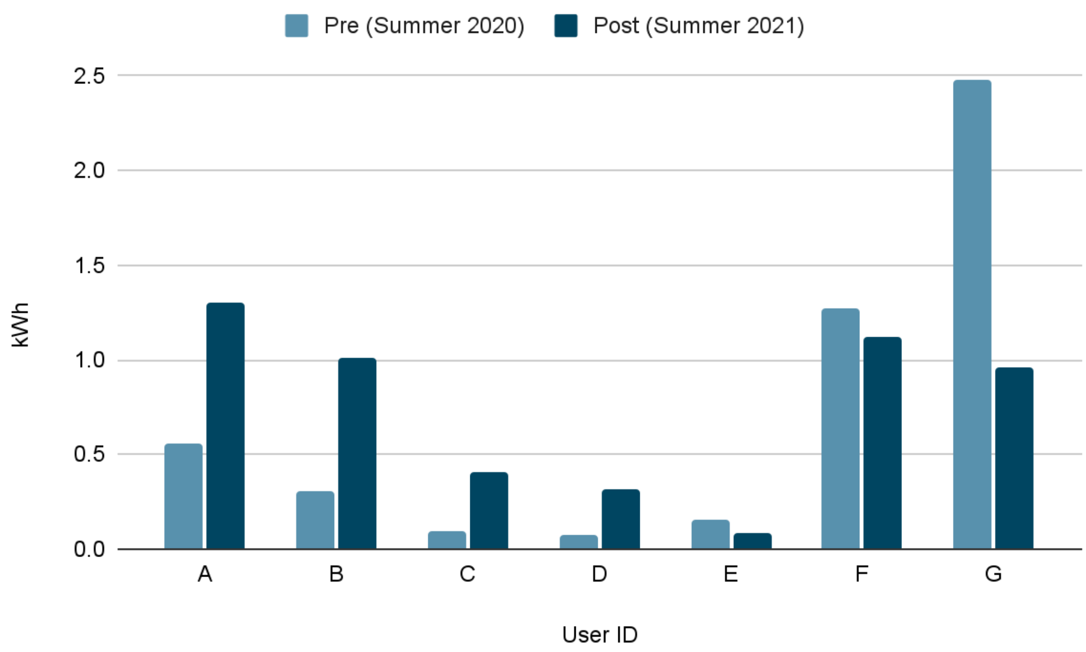


FIGURE 70 - COMPARISON OF WILLOWBROOK RESIDENT ENERGY CONSUMPTION IN SUMMER 2021 VS. SUMMER 2020 FOR RESIDENTS WITH DATA AVAILABLE PRIOR TO SUMMER 2020

Source: OhmConnect

The team plans to rerun the analysis in summer of 2022 with a larger sample size and after the Willowbrook residents have been transitioned over the TOU rate plans by SCE.

DISTRIBUTION SYSTEM ANALYSIS

OVERVIEW

This section is designed to answer one of the project's key research questions: What are some alternate business models or arrangements to engage IOUs more effectively in community-scale, customer-sited DER for both end-customer and grid-support benefits? The goal of this distribution system analysis is to evaluate the cost effectiveness of community-scale BTM PV + Storage resources for the rate payers as well as utility grid especially when these solutions are distributed across other multiple locations within a utility's distribution feeder. As part of the technical and economic analysis different control scenarios were studied to determine how the benefits to the end-user and grid can be maximized.

A comprehensive technical and economic analysis was conducted in this project that involved the operation of the integrated PV + Storage system for control objectives among three different scenarios that are presented in Table 10.

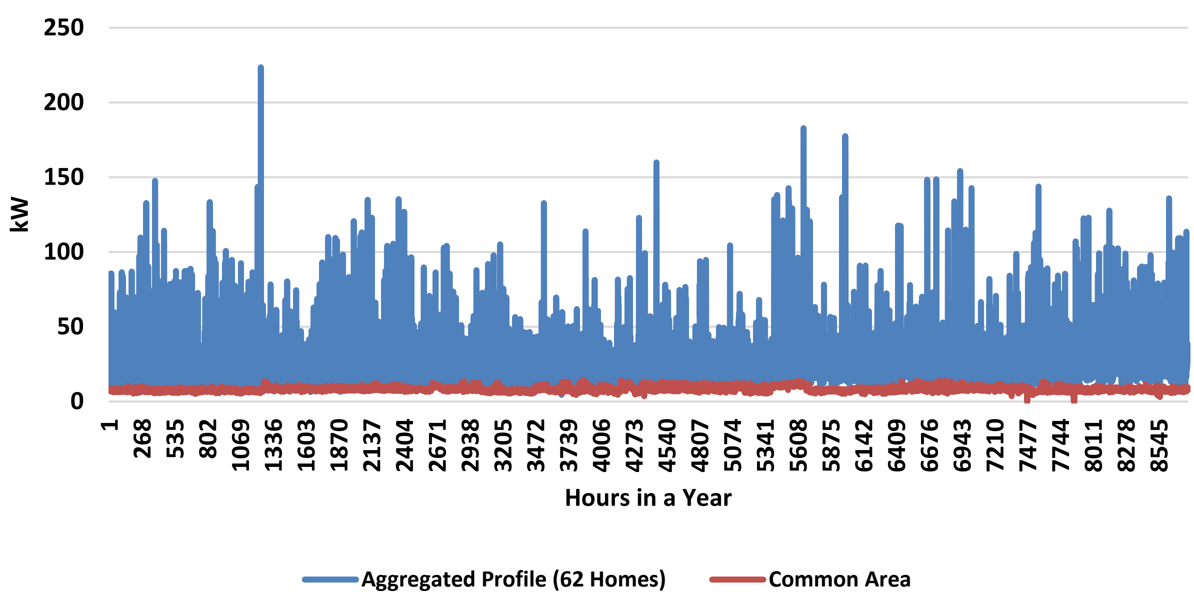
TABLE 10 - SUMMARY OF OHMHOUR DISPATCHES

OBJECTIVE	SCENARIO 1	SCENARIO 2	SCENARIO 3
TOU + EV Peak Shaving (Discharge)	All Months (4 – 10 PM)	Summer Months Only (4 – 10 PM)	All Months (4 – 10 PM)
Solar Balancing (Charge)	All Months (10 AM – 2 PM)	All Months (10 AM – 2 PM)	All Months (10 AM – 2 PM)
GHG Reduction (Discharge)	All Months (3– 8 AM)	Winter Months Only (3– 8 AM)	All Months (3– 8 AM)

DATA AND BACKGROUND

INDIVIDUAL CUSTOMER LOAD PROFILES

The community consists of 61 individual homes spread across two housing buildings and a common area which is aggregated to estimate the total community load. These homes are a combination of 1 Bedroom (BR), 2 BR and 3 BR units. Due to the load data unavailability of each of the 61 individual customers, representative load profiles of certain customers (residing in 1 BR, 2 BR & 3BR units) for whom load data was readily available was scaled up based on the total number of individual units of each unit type. Figure 63 depicts the aggregated load profile of the residents (blue) and the common area (red) for a year.

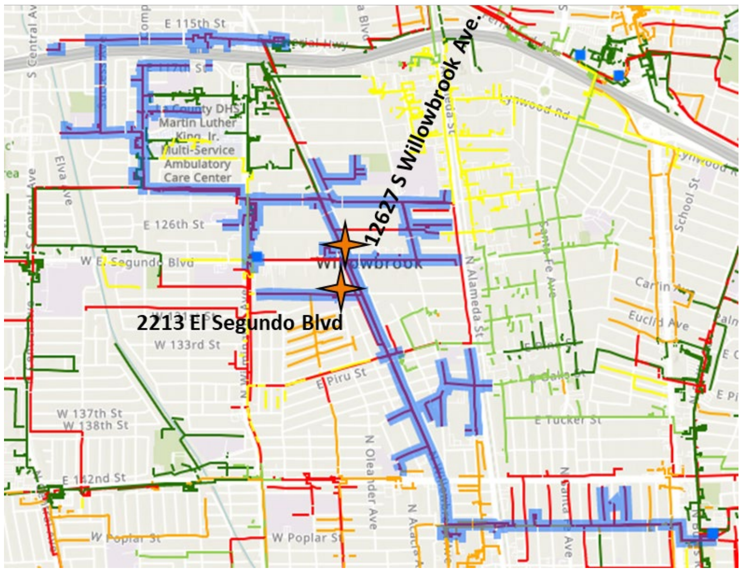


Source: EPRI

FIGURE 71 - ANNUAL LOAD PROFILE OF THE COMMUNITY

Distribution Circuit Load Profile

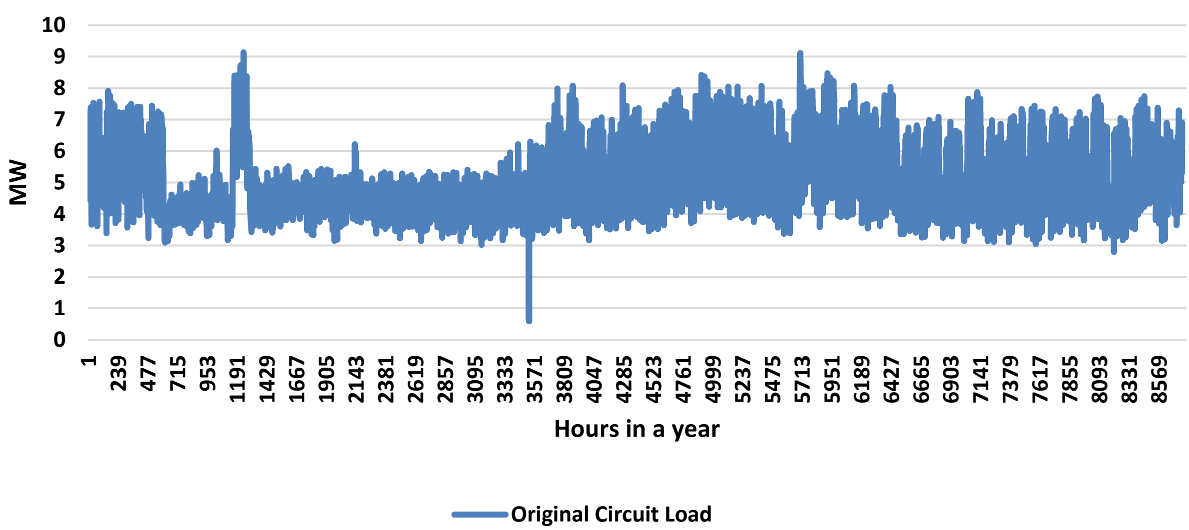
The Willowbrook community is connected to the Trochu Distribution Circuit, highlighted in blue in Figure 64 below, which primarily comprises of a combination of residential and industrial customers in the SCE territory.



Source: SCE Distribution Resource Plan External Portal

Figure 72 - Trochu Distribution Circuit Layout

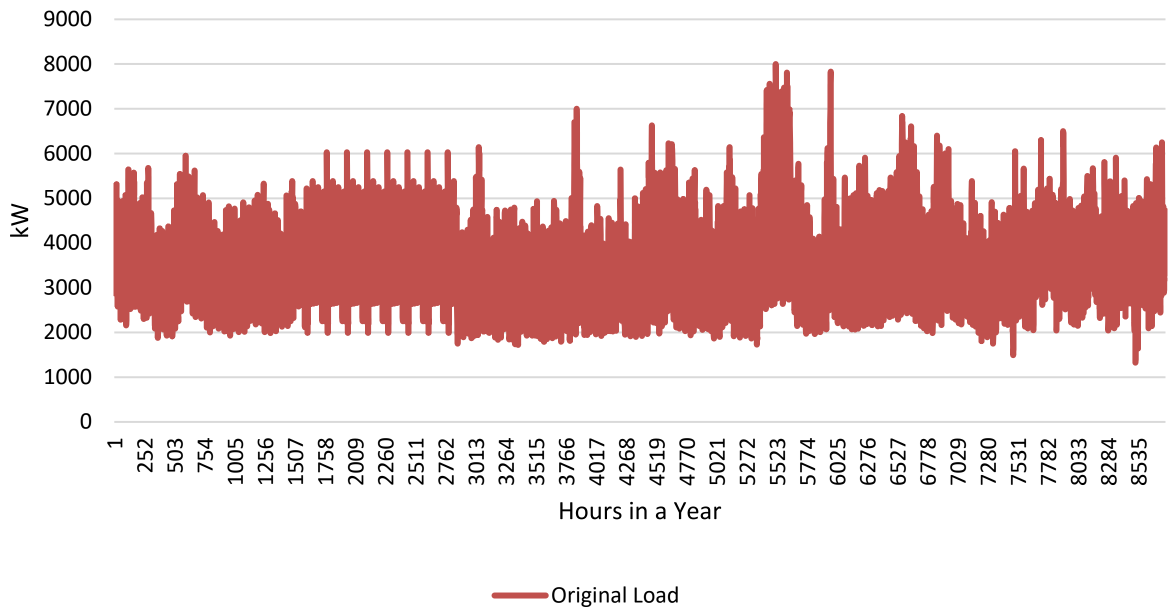
The annual load profile of this distribution circuit is shown in Figure 65 below. The circuit has an annual peak load of 9.14 MW. This load profile was used for the Scenarios 1 and 2 of the analysis.



Source: EPRI

Figure 73 - Annual Load Profile of the Trochu Circuit

For Scenario 3, the scaled-up load profile of the service transformers serving the Willowbrook Community was utilized to illustrate the load shape of a typical residential distribution feeder. The annual peak load of this feeder is 8 MW, as demonstrated in Figure 66.

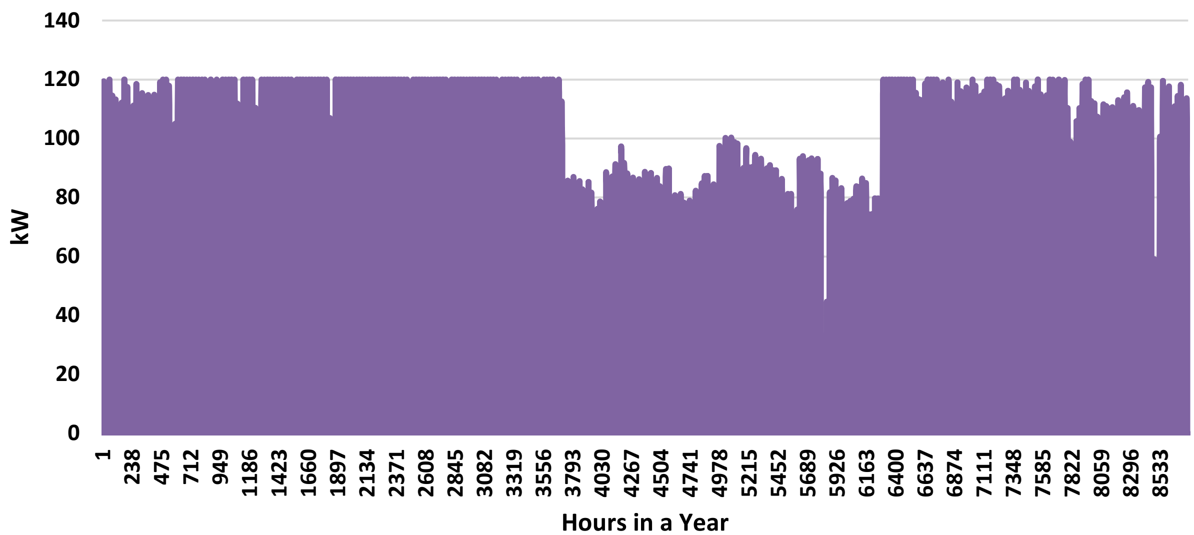


Source: EPRI

FIGURE 74 - ANNUAL LOAD PROFILE OF THE SCALED UP RESIDENTIAL DISTRIBUTION CIRCUIT

SOLAR PRODUCTION PROFILE

The Willowbrook community now includes a 120 kW PV system installed onsite. The AC solar production profile is represented in Figure 67 below.



Source: EPRI

FIGURE 75 - MOSAIC GARDENS AT WILLOWBROOK ANNUAL PV PRODUCTION PROFILE

DER TECHNOLOGIES

TABLE 11 - DER TECHNOLOGY PARAMETERS

TECHNOLOGY	PARAMETER	VALUE
Li Ion Energy Storage	Power	60 kW
System	Energy	120 kWh
	Round Trip Efficiency	85 percent
	Lifetime	10 years
	Usable SOC Range	5 percent - 95 percent
Photovoltaic System	DC Nameplate Rating	120 KW
	Lifetime	20 years

The roundtrip loss of the battery is incorporated into the modeling as the additional energy required for charging the battery while calculating its state of charge (SOC). For instance, a battery is fully charged (100 percent SOC) would be able to provide 120 kWh with its stored energy while a battery which is completely empty (0 percent SOC) would require 141.17 kWh (120 kWh/0.85) to get its SOC to 100 percent.

UTILITY TARIFF

The Willowbrook community is subjected to the SCE GS-1 (Option E) TOU tariff. The tariff primarily comprises of TOU energy components. This is summarized in Table 12 and **Error! Reference source not found.**13.

TABLE 12 - UTILITY BILL COMPONENTS

SUMMAR			WINTER		
On Peak	**Mid Peak**	**Off Peak**	**Mid Peak**	**Off Peak**	**Super Off Peak**
$0.4701/kWh	$0.2774/kWh	$0.1828/kWh	0.2975/kWh	$0.1728/kWh	$0.1401/kWh

TABLE 13 - TIME OF USE DEFINITION

SEASON	PERIOD	HOURS
	On Peak	4-10 PM (Weekdays)
	Mid Peak	4-10 PM (Weekends)
Summer	Off Peak	Midnight to 4 PM & 10 to Midnight (Weekdays & Weekends)
	Mid Peak	4-10 PM (Weekdays & Weekends)
	Off Peak	Midnight to 8 AM & 10 PM to Midnight (Weekdays & Weekends)
Winter	Super Off Peak	8 AM to 4 PM (Weekdays & Weekends)

SCENARIO DEVELOPMENT

This project involves performing both technical and economic analyses involving an integrated PV and storage system to achieve numerous objectives described in the previous section. The first step in this process involves the development of the base and change cases.

- Base Case: The "business as usual" operation of the community is defined as the base case. The base case doesn't comprise of any DER and the total load in the community is served solely by the utility.

- Change Case: The change case involves the inclusion of the BTM community-scale PV + Energy Storage system. This system is operated in such a way that it achieves all the objectives defined in the previous section.

The "stackable" aspect of the integrated system to achieve all the objectives identified previously was analyzed through the development of three different scenarios as summarized in Table 14 and Table 15. The timeframe from June to September is termed as "Summer" and the remaining 8 months is referred to as "Winter".

Scenarios 1 and 2 employ a "bottom-up" approach whereas Scenario 3 employs a "top-down" approach.

For Scenarios 1 and 2, the operation of individual communities was primarily driven by the four control objectives defined in the previous section. Subsequently, operations of similar communities along the same feeder were aggregated to compute the net load reduction at the distribution level.

For Scenario 3, the goal was to attain a 10 percent net peak load reduction for one distribution circuit. Once, this primary objective is met, the feasibility of meeting the secondary benefits is evaluated with the residual capacity of the PV and the BESS. The DER will not offer secondary benefits during those days that have a primary service requirement to avoid conflicts between the two objectives.

TABLE 14 - OBJECTIVES FOR DER OPERATION (SCENARIOS 1 & 2)

OBJECTIVE	TYPE	SCENARIO 1	SCENARIO 2
TOU Energy Time Shift + EV Peak Shaving	Primary	All Months (4-10 PM)	Summer Months Only (4-10 PM)
Solar Balancing	Primary	All Months (10 AM to 2 PM)	All Months (10 AM to 2 PM)
GHG Reduction	Primary	All Months (3-8 AM)	Winter Months Only (3-8 AM)
Distribution Peak Reduction	Secondary	Aggregated across multiple similar communities based on the operation for meeting primary objective	Aggregated across multiple similar communities based on the operation for meeting primary objective

TABLE 15 - OBJECTIVES FOR DER OPERATION (SCENARIO 3)

OBJECTIVE	TYPE	SCENARIO 3
Distribution Peak Reduction	Primary	Aggregated across multiple similar communities based on the operation for meeting the 10 percent annual peak load reduction target
TOU Energy Time Shift + EV Peak Shaving	Secondary	All Months (4-10 PM)
Solar Balancing	Secondary	All Months (10 AM to 2 PM)
GHG Reduction	Secondary	All Months (3-8 AM)

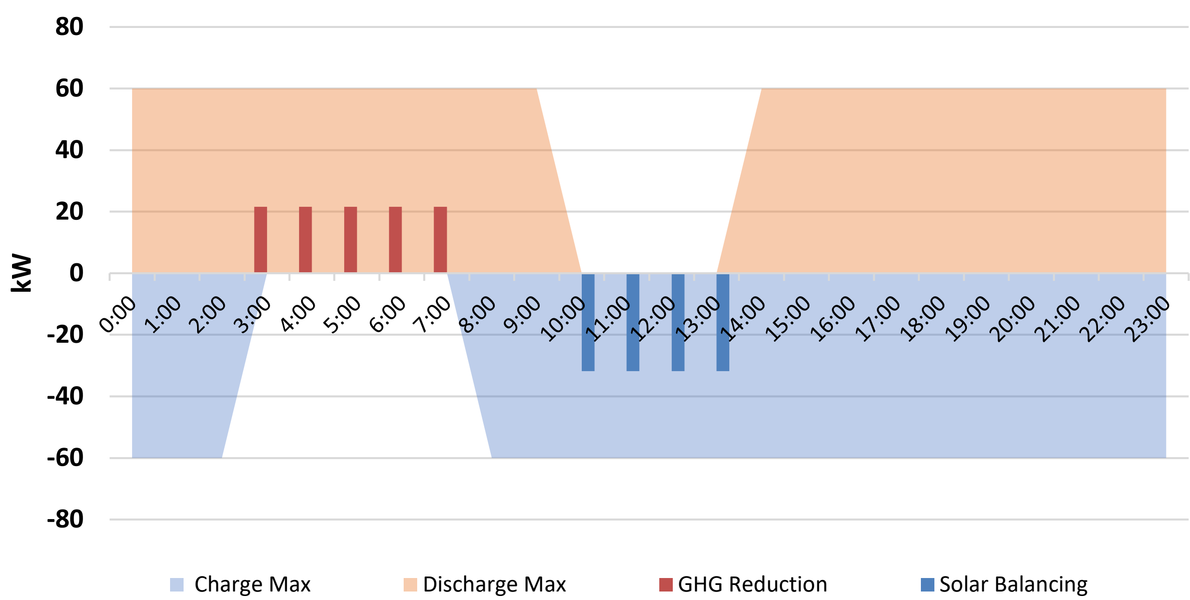
MODELING APPROACH

The first step involved in the modeling of the integrated PV + Storage system is the classification of different objectives into constrained and optimization services. Secondly, for the different objectives described previously, the power capacity at which the energy storage system is to be dispatched is identified. The maximum power capacity for dispatching the battery is estimated in such a way that it does not cause any adverse violations to the distribution circuit. The boundary conditions of the battery are illustrated in Table 16. The timeseries constraint profile applied for Scenarios 1 and 3 and Scenario 2 (only during winter) are illustrated in **Error! Reference**

source not found.68. It must also be noted that the charging is represented by a negative value and discharging is represented by a positive value.

TABLE 16 - OBJECTIVES FOR DER OPERATION (SCENARIOS 1 & 2)

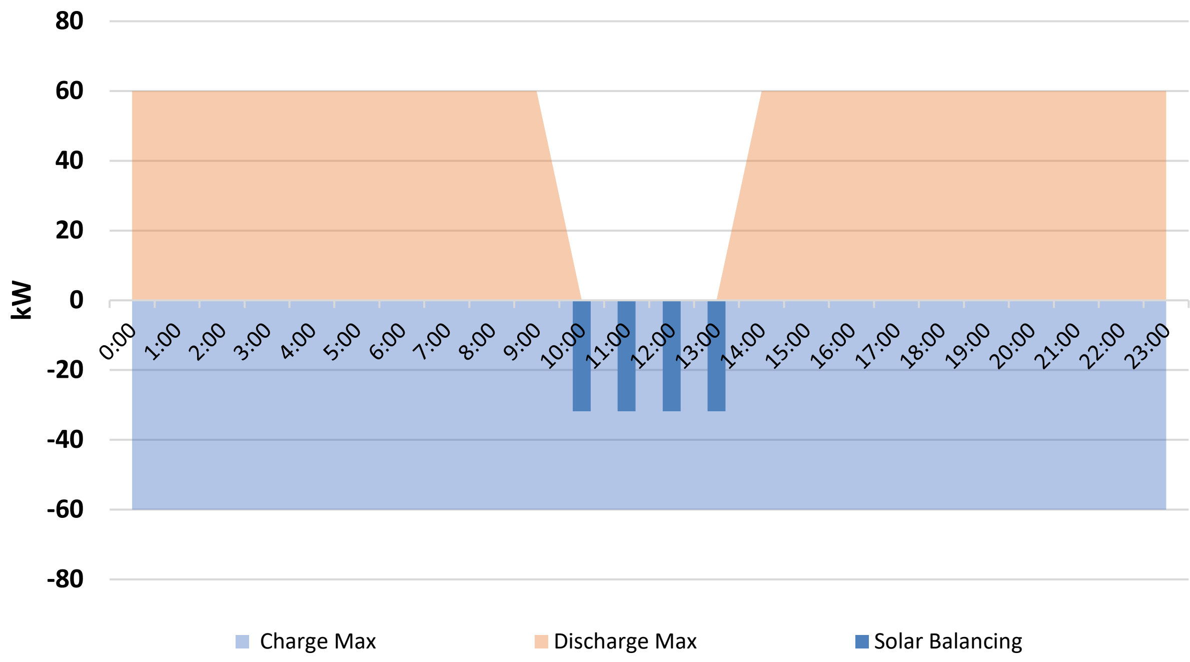
OBJECTIVE	SERVICE TYPE	BATTERY DISPATCH	DURATION	POWER CAPACITY
Solar Balancing	Constrained	Charge	4 Hours	31.76 kW
GHG Reduction	Constrained	Discharge	5 Hours	21.6 kW



Source: EPRI

FIGURE 76 - DAILY CONSTRAINT PROFILE - SCENARIO 1, SCENARIO 3 & SCENARIO 2 (WINTER)

The timeseries constraint profile illustrated in Figure 69 applies only to the summer months in Scenario 2.



Source: EPRI

FIGURE 77 - DAILY CONSTRAINT PROFILE - SCENARIO 2 (SUMMER)

Due to Rule-21 implications, the battery can only be charged by PV, and hence its SOC must be managed carefully to ensure that all the services identified previously are served.

DER-VET OVERVIEW

The analysis was performed through EPRI's Distribution Energy Resource Value Estimation Tool (DER-VET) by utilizing several different types of data like customer load profiles, distribution circuit load profile, solar production profile and utility tariff.

DER-VET is an open-source, optimization-based planning tool to aid in the design of distributed energy resource and microgrid deployments to maximize benefit to individual customers, ratepayers, and to society. DER-VET provides a platform to model the operation and subsequent value of a set of DERs, potentially configured in a microgrid, collectively providing a set of stacked services. DER-VET uses load and other site-specific data to optionally optimize the size of the DER concurrently with its dispatch optimization. The technologies modeled in DER-VET include various types of energy storage, intermittent renewable generation, fueled generation, controllable loads/EV, and hybrid resources like combined heat and power (CHP). These energy resources can be used in any combination to improve grid reliability, improve customer resilience by providing backup to local critical loads, decrease the electricity bill incurred by the site, participate in wholesale energy or ancillary services markets, provide DR or resource adequacy, or some allowable combination of these.

Services in DER-VET are activities the DER mix can do to generate value. Services are broken into two categories – "pre-dispatch (constrained) services" and "optimization services".

a) Pre-dispatch Services: A constrained service is a service relating to reliability, which defines bounds on the state of the system. Pre-dispatch services require fixed contributions of power and energy from the DERs to achieve. These services are treated as constraints in the optimization problem, so are effectively modeled before the operation of the DERs are known.

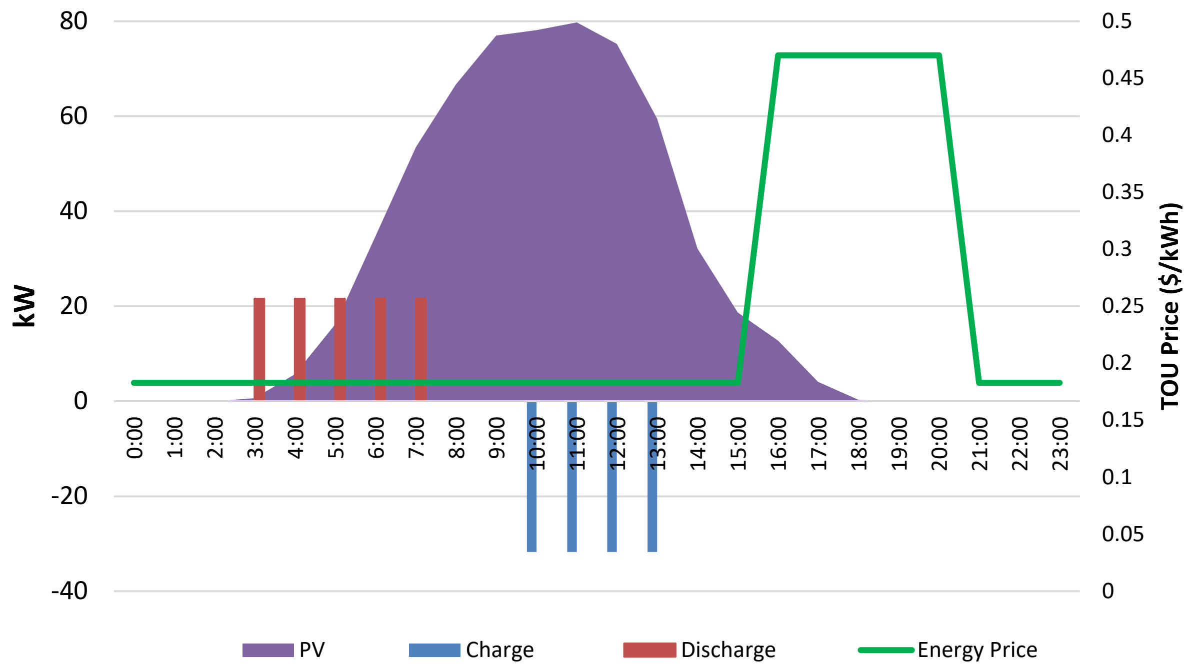
b) Optimization Services: An optimization service does not have hard requirements and the DER mix is free to operate in a way that generates the maximum economic benefit with no constraints apart from those that ensure the result is feasible. These services are usually economic in nature, like customer bill reduction services or wholesale market participation. The operational profile that maximizes the combined service value.

TECHNICAL RESULTS

For Scenarios 1 and 2, the net load shift is estimated for the Willowbrook community as a first step. Subsequently, the net load shift at the distribution circuit level is determined by aggregating the operation of several other similar communities connected to the same TROCHU distribution circuit as the Willowbrook community.

SCENARIO 1

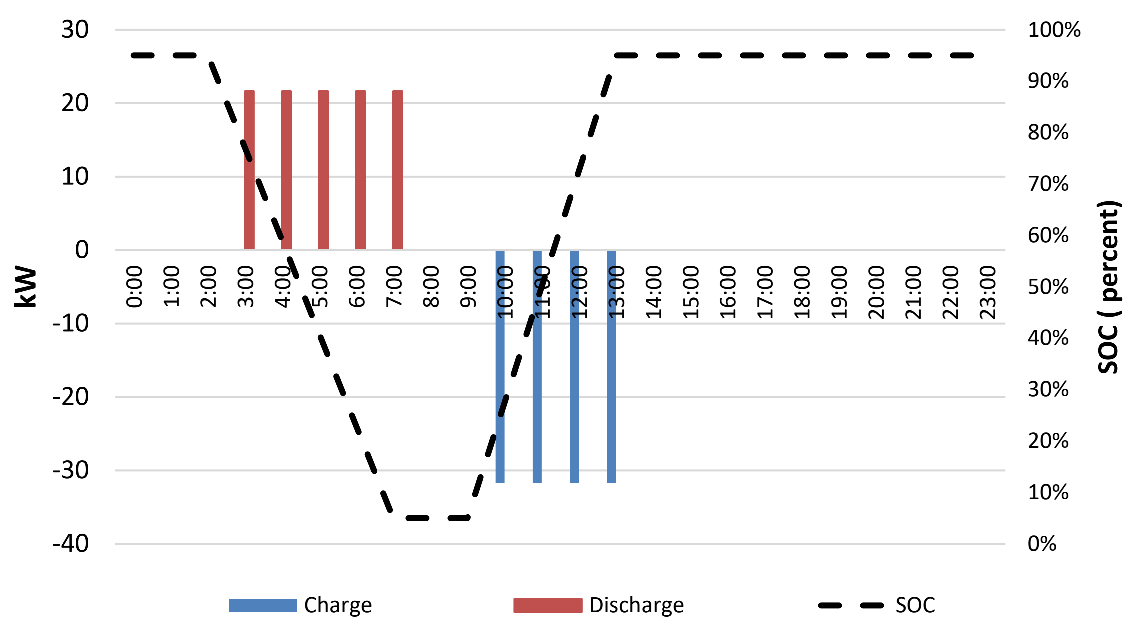
In the first scenario, the operation of the energy storage system is identical for all the days since the objectives are applicable right throughout the year. Figure 70 illustrates the daily operation of the battery during the winter month. Over the course of the day, the battery discharges in the early morning hours for satisfying the GHG reduction. It charges mid-day to achieve the solar balancing objective. The excess PV generated is exported to the grid to earn net metering credits.



Source: EPRI

FIGURE 78 - DAILY BATTERY OPERATION - SCENARIO 1

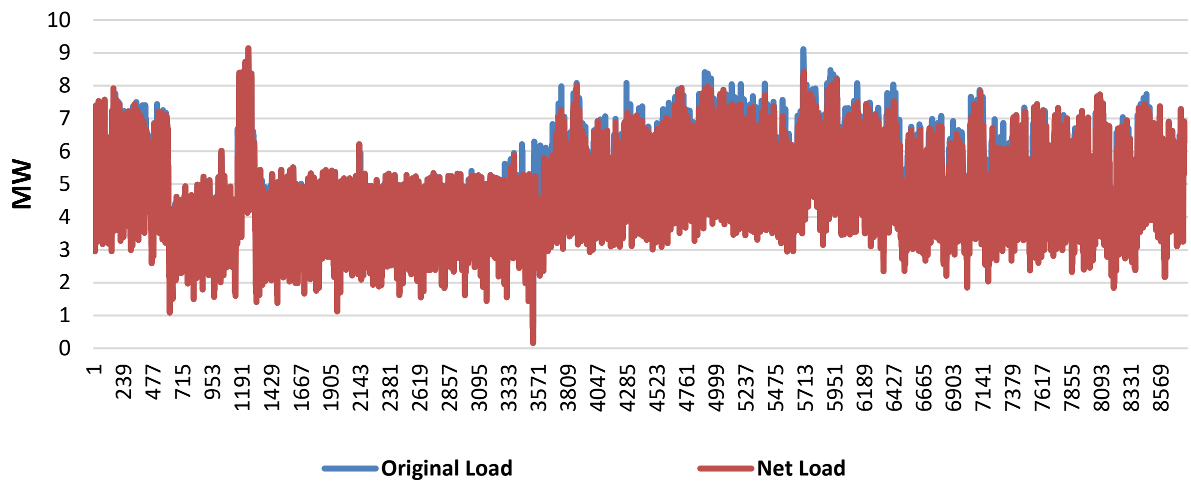
Figure 71 illustrates the SOC evolution of the battery due to the operation of the battery. Since the battery is required to discharge early morning for GHG reduction, it must be ensured that its SOC is maintained at the maximum level (95 percent) overnight to satisfy this requirement.



Source: EPRI

FIGURE 79 - BATTERY OPERATION VS SOC EVOLUTION (SCENARIO 1)

By assuming that there are a total of 20 low-income communities similar to the Willowbrook community that are connected to the Trochu distribution circuit and all of them are operated based on the same objective, the net load on the circuit feeder is estimated as shown in Figure 72 below by aggregating their operation. An average of 2.1 percent net peak load reduction was achieved over the course of the year due to the operation of the 20 communities at the circuit level.



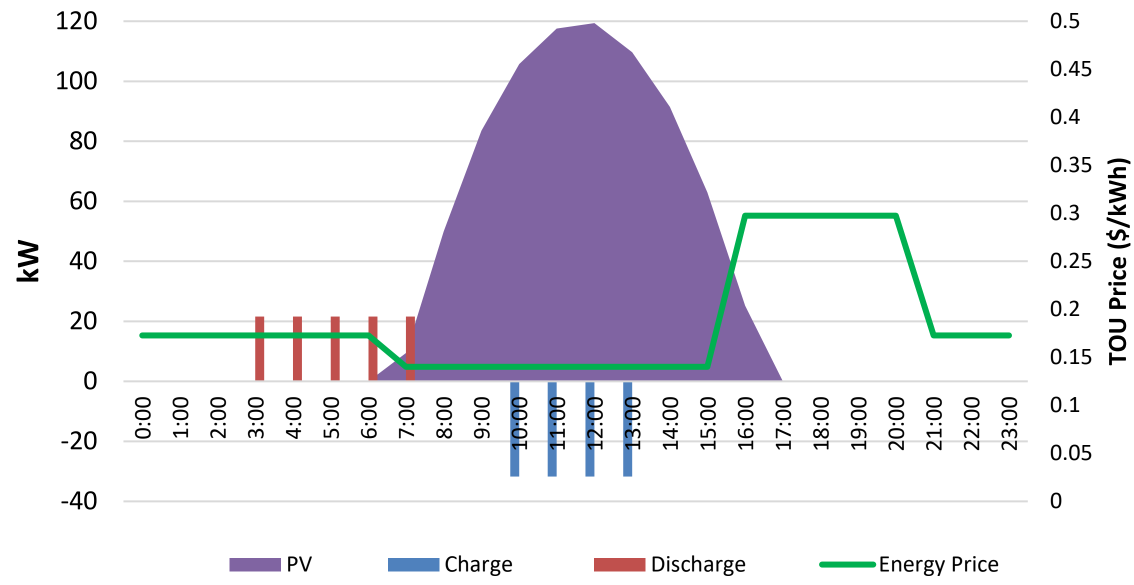
Source: EPRI

FIGURE 80 - DISTRIBUTION CIRCUIT LOAD COMPARISON (SCENARIO 1)

SCENARIO 2

In Scenario 2, the operation of the energy storage system varies slightly based on the season considered.

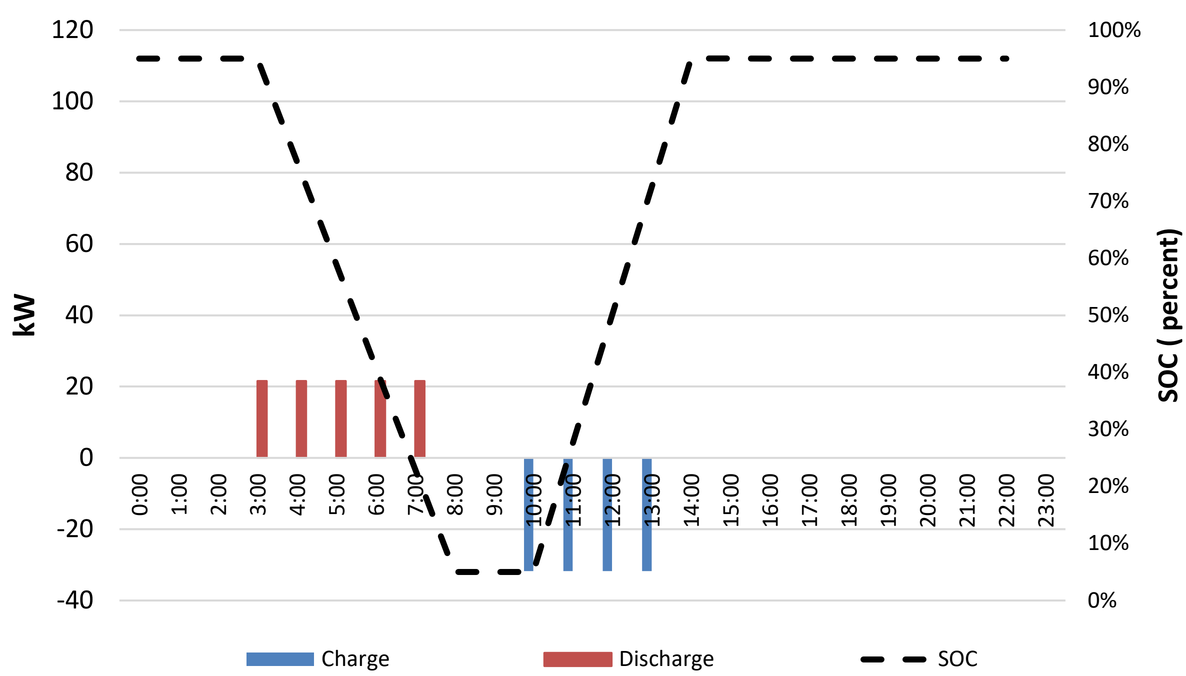
Winter Season: During the winter months, the battery is only operated for the GHG emission and solar balancing objectives. This is achieved by discharging the battery early morning (between 3 and 8 AM) and charging the battery during hours of high PV availability (between 10 and 2 PM) respectively. This is illustrated in Figure 73.



Source: EPRI

FIGURE 81 - DAILY BATTERY OPERATION - SCENARIO 2 (WINTER)

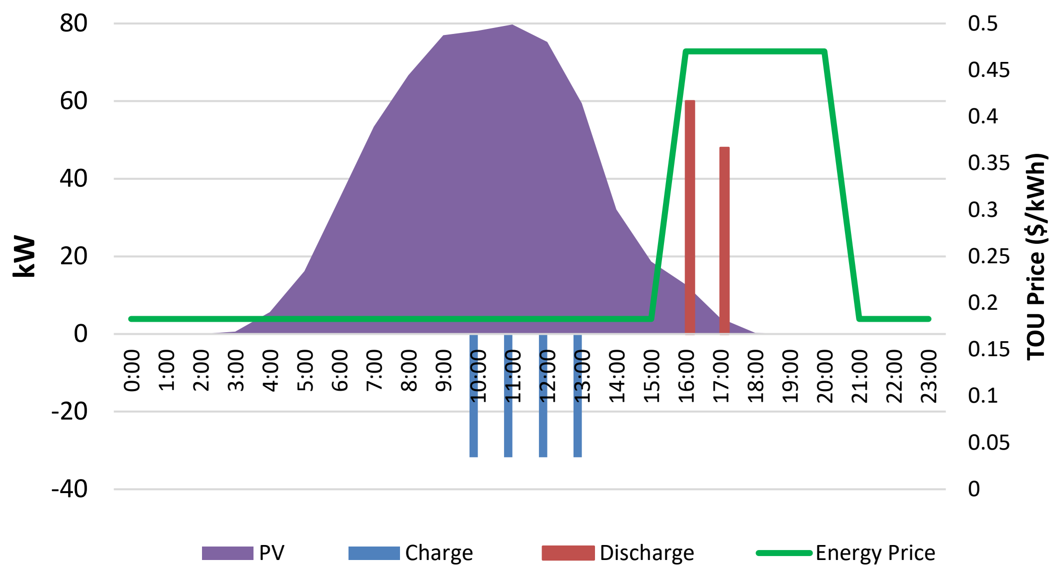
The SOC evolution of the battery over the course of the day is illustrated in Figure 74.



Source: EPRI

FIGURE 82 - BATTERY OPERATION VS SOC EVOLUTION (SCENARIO 2 - WINTER)

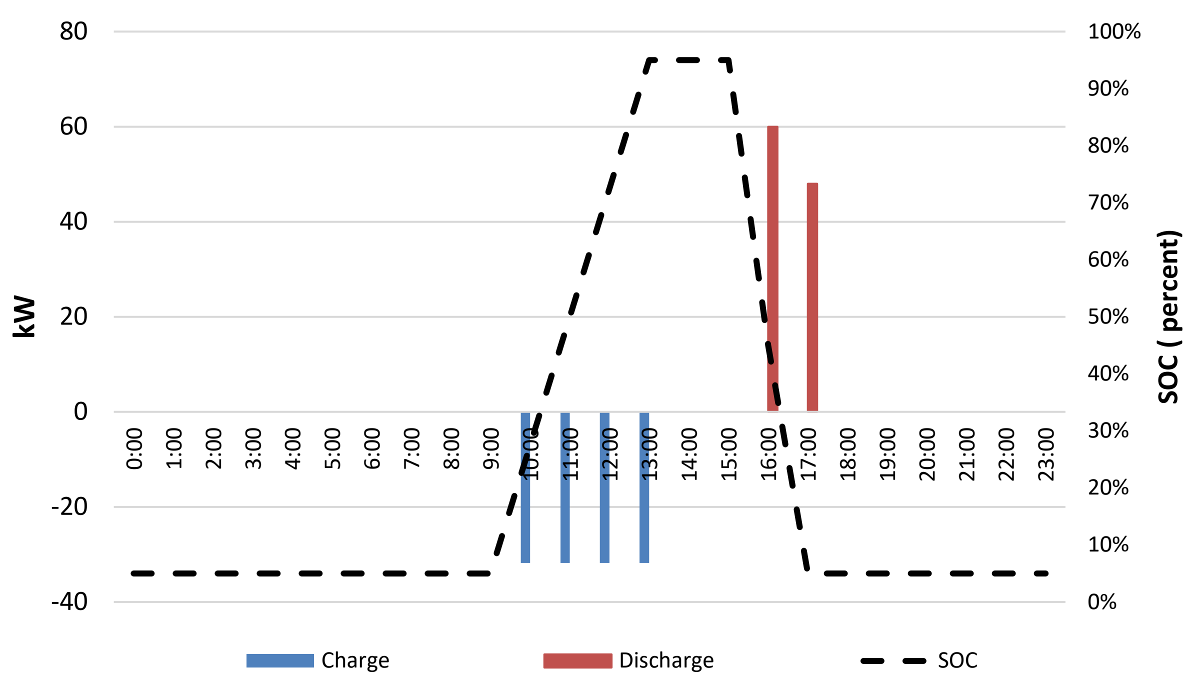
Summer Season: During the summer months, the battery is only operated for the TOU+EV peak shaving and solar balancing objectives. This is achieved by discharging the battery in the evening (between 4 and 10 PM) and charging the battery during hours of high PV availability (between 10 AM and 2 PM) respectively. This is illustrated in Figure 75.



Source: EPRI

FIGURE 83 - DAILY BATTERY OPERATION - SCENARIO 2 (SUMMER)

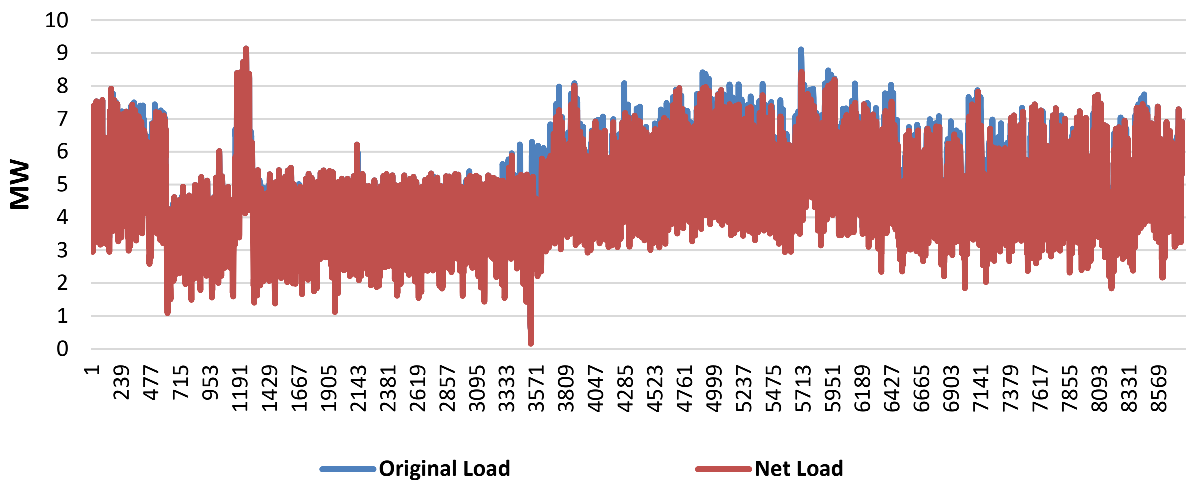
The SOC evolution of the battery over the course of the day is illustrated in Error! Reference source not found. 76.



Source: EPRI

FIGURE 84 - BATTERY OPERATION VS SOC EVOLUTION (SCENARIO 2 - SUMMER)

Similar to Scenario 1, by assuming that are a total of 20 low-income communities like the Willowbrook community that are connected to the Trochu distribution circuit. And that all of them are operated based on the same objective, the net load on the circuit feeder is estimated as shown in the Figure 77 above by aggregating their operation. An average of 3.1 percent net peak load reduction was achieved over the course of the year due to the operation of the 20 communities at the circuit level.

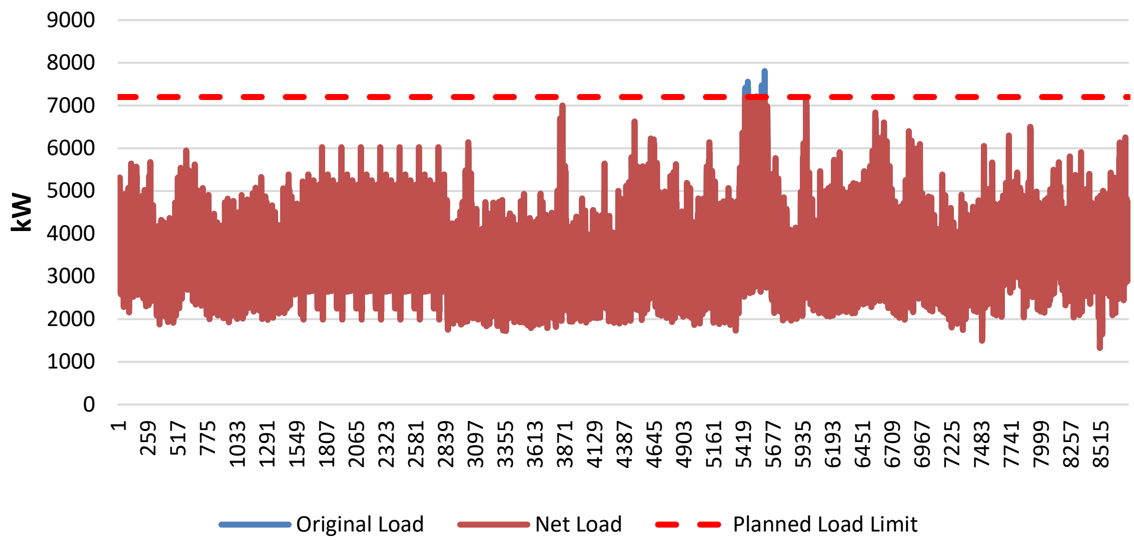


Source: EPRI

FIGURE 85 - DISTRIBUTION CIRCUIT LOAD COMPARISON (SCENARIO 2)

SCENARIO 3

In the Scenario 3, the integrated PV+BESS systems of the individual communities are operated to achieve 10 percent net peak load reduction of the residential distribution circuit considered through the aggregated operation of 16 other similar communities. For the residential distribution feeder considered, which has an annual peak load of 8 MW, this 10 percent net peak load reduction corresponds to a planned load limit of 7.2 MW. This operation is illustrated in Figure 78 below.



Source: EPRI

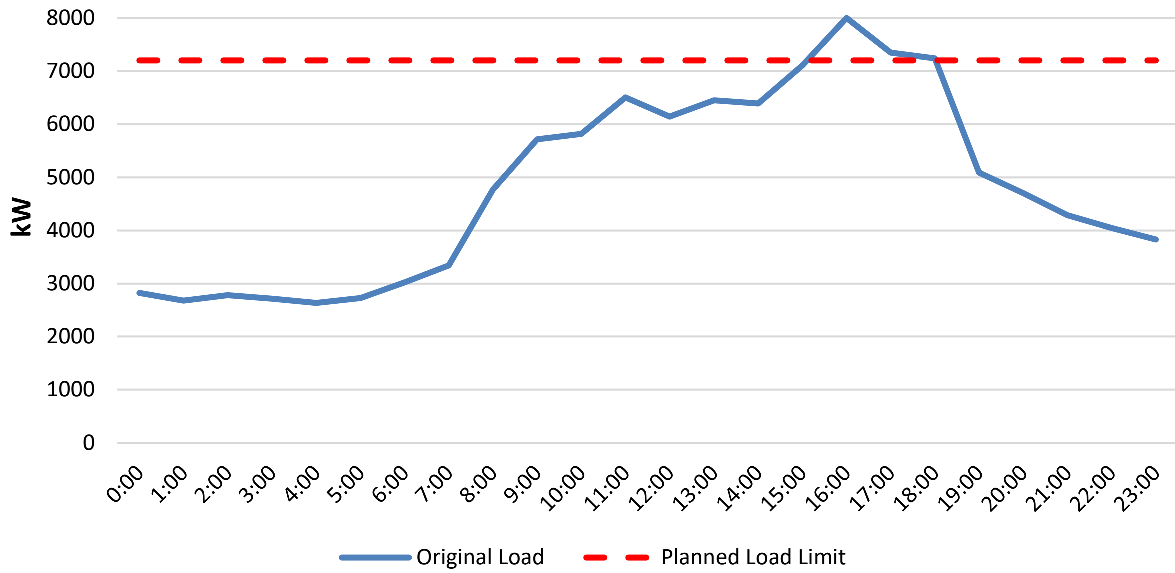
FIGURE 86 - DISTRIBUTION CIRCUIT LOAD COMPARISON (SCENARIO 3)

Error! Reference source not found.17 represents a comparison of monthly peak load of the original load and the net load because of the aggregated operation of the 16 communities considered.

TABLE 17 - MONTHLY PEAK LOAD COMPARISON

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Original Load (kW)	5946	5326	6025	6025	6141	7000	6627	8000	7830	6836	6502	6253
Net Load (kW)	5946	5326	6025	6025	6141	7000	6627	7200	7200	6836	6502	6253

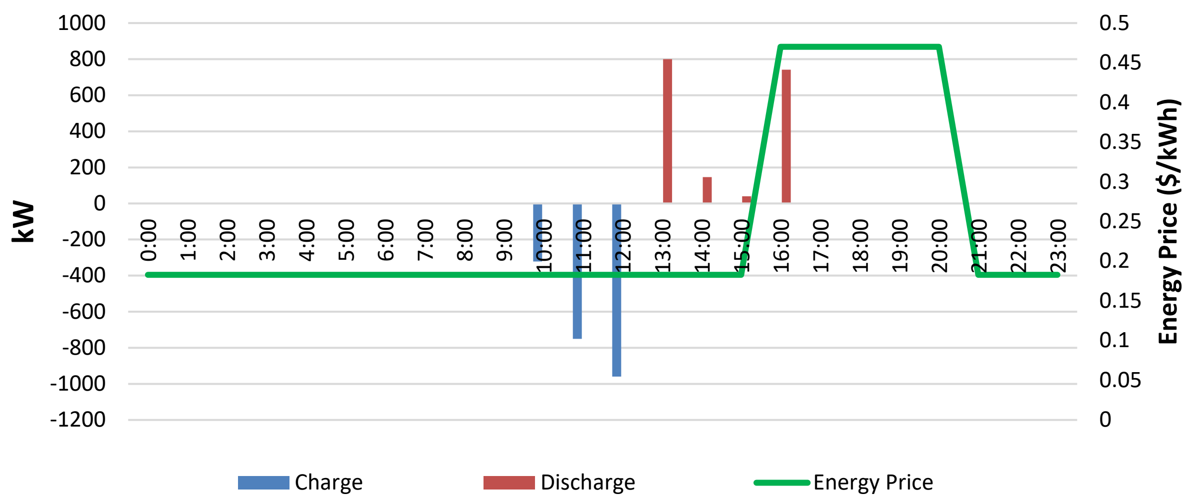
Figure 79 represents a 24-hour profile of the summer day where the annual load peak of the distribution feeder occurs. It could be observed that the feeder load exceeds the planned load limit of 7.2 MW between hours 4 and 6 PM.



Source: EPRI

FIGURE 87 - RESIDENTIAL DISTRIBUTION CIRCUIT LOAD PROFILE (ANNUAL PEAK LOAD DAY)

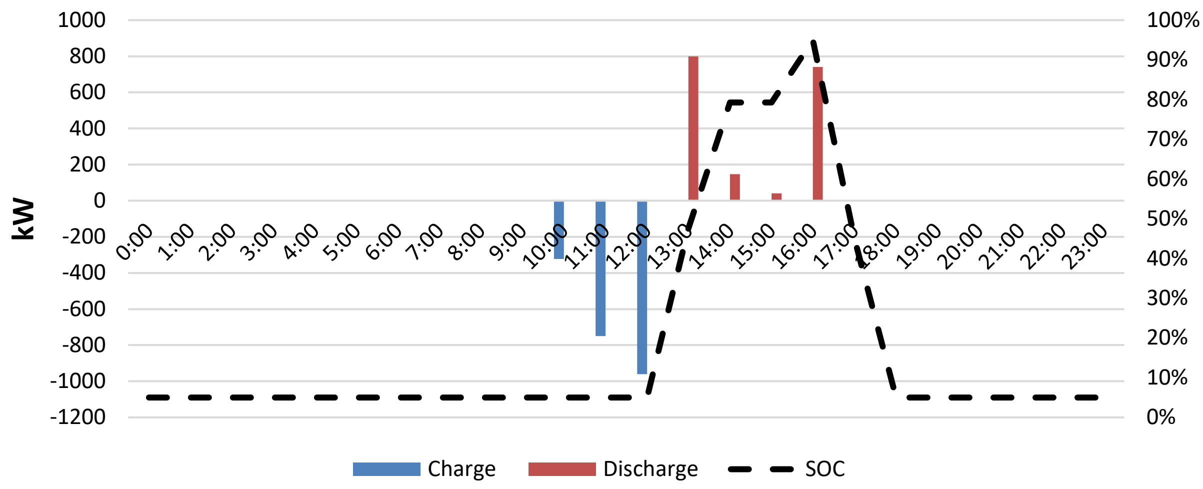
The daily operation of a single BESS during this summer day is illustrated in **Error! Reference source not found.**. The battery charges mid-day from PV to reach maximum SOC to discharge for the distribution peak shaving event during the evening hours.



Source: EPRI

FIGURE 88 - DAILY BATTERY OPERATION - SCENARIO 3 (ANNUAL PEAK LOAD DAY)

The SOC evolution of the battery over the course of the day is illustrated in Error! Reference source not found. 81.



Source: EPRI

FIGURE 89 - BATTERY OPERATION VS SOC EVOLUTION (ANNUAL PEAK LOAD DAY)

FINANCIAL RESULTS

There are two differences between the three scenarios analyzed:

- The primary difference is the seasonal operational variation of the battery for accomplishing the different objectives (GHG reduction, TOU + EV Peak Shaving and Solar Balancing) described previously. In Scenarios 1 and 3, all the 3 objectives are achieved all through the year while in Scenario 2, only 2 out of the 3 objectives are accomplished at any point of time.

- The secondary difference is that in Scenarios 1 and 2, the three different objectives (GHG reduction, TOU + EV Peak Shaving and Solar Balancing) are always achieved. However, in Scenario 3, since these benefits are secondary, they have lower priority as compared to the distribution peak shaving benefit, they are offered as much as possible. To prevent conflicts, the DER will not offer any of the secondary services like GHG reduction, solar balancing and TOU energy time shift during days in which it dispatches for distribution peak shaving events.

The financial benefit of TOU energy time shift and EV peak shaving can be captured by calculating the utility bill of the community in the base and change cases. The financial benefit of GHG reduction and solar balancing is not monetized. An annual comparison of the financial results of the two scenarios for the Willowbrook Community is listed in the Table 18 below.

TABLE 18 - FINANCIAL RESULT SUMMARY FOR A SINGLE MULTI-FAMILY PROPERTY

OBJECTIVE	SCENARIO 1	SCENARIO 2	SCENARIO 3
TOU Energy Time Shift + EV Peak Shaving	$43,967	$17,364	$44,181

Solar Balancing	N/A	N/A	N/A
GHG Reduction	N/A	N/A	N/A
Total	**$43,967**	**$17,364**	**$44,181**

RESULTS SUMMARY

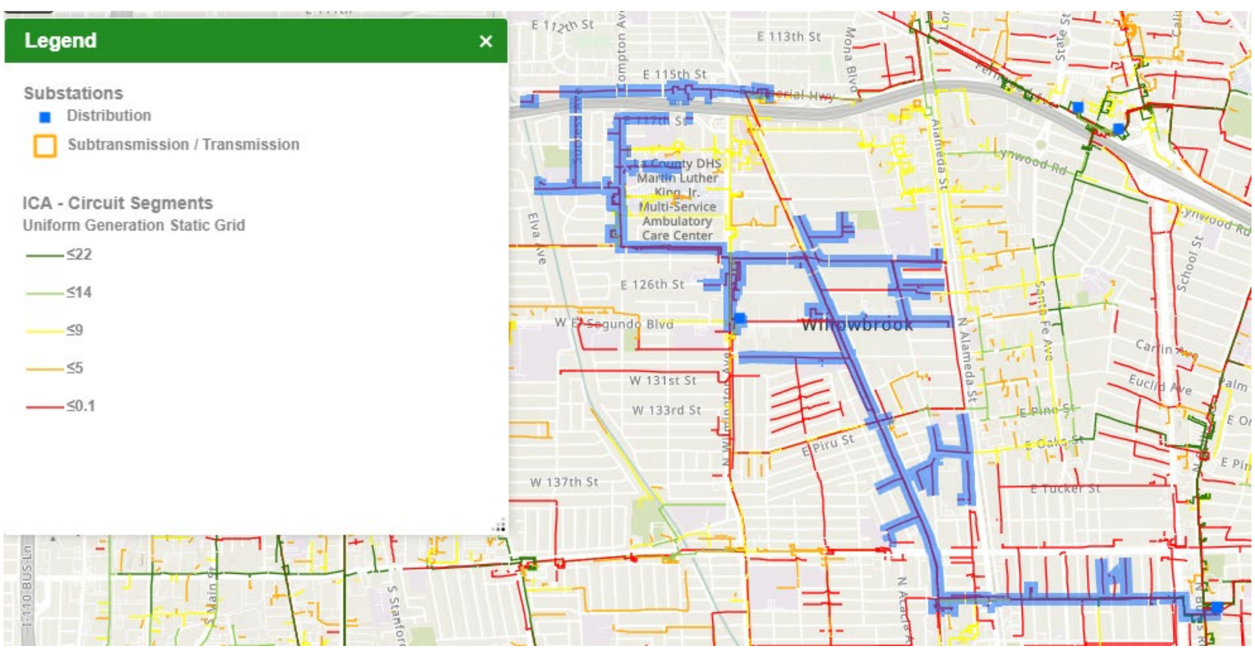
A summary of the technical and financial results of the three scenarios by aggregating the impact of different communities like Willowbrook is shown in the Table 19 below.

TABLE 19 - RESULT SUMMARY OF SIMILAR AGGREGATED COMMUNITIES

ITEM	SCENARIO 1	SCENARIO 2	SCENARIO 3
Circuit Level Peak Load Reduction	2.1 percent	3.1 percent	10 percent
No. of Communities Aggregated	20	20	16
Annual Financial Benefit	$879,340	$347,280	$706,896

HOSTING CAPACITY

The DER Integration Capacity Analysis (ICA) of the Trochu distribution circuit is available through SCE and the results were extracted from SCE's Distribution Resource Plan External Portal (DRPEP) as illustrated in Figure 82. It could be observed that the circuit has very limited hosting capacity available to integrate (< 0.1 MW) DER.



Source: SCE's Distribution Resource Plan External Portal

FIGURE 90 - INTEGRATION CAPACITY ANALYSIS (ICA) OF TROCHU DISTRIBUTION CIRCUIT

COST BENEFIT ANALYSIS

The financial assumptions for performing the Cost Benefit Analysis are shown in Table 20.

TABLE 20 - COST BENEFIT ANALYSIS FINANCIAL PARAMETERS

PARAMETER	VALUE
Inflation	1.5 percent
Discount Rate	7 percent
Analysis Horizon	10 years
BESS & PV Lifetime	10 years

The total cost breakdown for the project is provided in Table 21.

TABLE 21 - COST BENEFIT ANALYSIS FINANCIAL PARAMETERS

ITEM	COST
PV System Cost	$132,775
Battery Cost	$109,500
Controller & Software Cost	$31,350
Labor Cost	$198,345
Equipment Cost	$64,000
Design & Construction Cost	$70,030
Miscellaneous Cost	$36,000
Total Cost	**$642,000**

The 10-year Net Present Value for the different scenarios considered is summarized in Table 21. It could be observed that none of the scenarios breakeven economically.

TABLE 22 - 10-YEAR NET PRESENT VALUE

	SCENARIO 1	SCENARIO 2	SCENARIO 3
NPV (Year 0 Dollars)	($314,214)	($512,547)	($312,619)

CUSTOMER VALUE PROPOSITION

The operation of the integrated PV + BESS for the different control objectives offers the following benefits to the customer.

- Customer Bill Reduction: The integrated DER system is operated in such a way that a major share of the community's load is served by local generation during the On-Peak hours. Subsequently, the residual energy generated is exported to the grid for earning net metering credits. This substantially reduces the customer's monthly utility bill.

- Solar Energy - Maximizing Utilization: The charging of the battery during the afternoon hours ensures that the excess solar energy produced is stored to be used during the evening hours when TOU peak pricing will go into effect and there is an absence of solar availability.

- GHG Emission Reduction: The discharging of the battery during the early morning hours greatly reduces GHG emissions thus benefitting California ratepayers.

- Distribution Feeder Upgrade Deferral: The aggregated operation of multiple similar communities leads to a net peak load reduction at the feeder level which in turn aids in deferring the upgrade of the feeder thus benefitting the utility economically.

LESSONS LEARNED

- This analysis involved the installation and operation of an integrated PV + BESS for accomplishing stacked benefits both at the individual community level and the distribution circuit level (upon aggregating multiple similar communities)

- The development of multiple scenarios demonstrated how the following can impact the technical and financial analysis:

  - ❖ Prioritization of services based on season of operation can help achieve multiple objectives without causing adverse impacts on the distribution circuit

  - ❖ The difference between adopting a "Top down" versus a "Bottom up" approach for achieving multiple objectives

- The analysis also revealed the importance of selecting the right distribution feeder for performing the stacked benefit analysis. For Scenarios 1 and 2, a non-residential feeder was chosen and hence the battery's operation for providing three services (GHG reduction, Solar Balancing & EV Peak Shaving) did not coincide with the distribution peak shaving objective since only 2 percent reduction in net load reduction was possible. However, in Scenario 3, there was significant coincidence among all of the services offered. On top of the 10 percent net distribution peak load reduction offered, the three other additional secondary services were offered for over 97 percent of the days

- Scenario 1 led to higher financial returns in terms of utility bill reduction since battery operation for TOU energy time shift operation was performed year-round with a 2.1 percent reduction in net load reduction on the distribution circuit

- Scenario 2 yielded a lower annual bill reduction number since battery operation for TOU energy time shift was limited to just the summer months. On the other hand, it resulted in a slightly higher net peak load reduction on the distribution circuit as compared to Scenario 1

- Scenario 3 led to a 10 percent reduction in net annual peak load and provided bill savings in the same range as Scenario 1 thus proving that the "stacked benefit analysis" is more effective for a residential distribution circuit than a circuit serving different types of customers (residential, commercial, and industrial).

INTEGRATION OF SOLAR AND STORAGE WITH SMART INVERTERS AND MINI DC GRIDS

The standard mode of distributing electricity to customers today is via AC power. This is primarily a legacy of 20th century technology. Before the advent of modern solid-state power electronics, the only way to step voltage up and down was via transformers, which require AC.

Recent advances in technology are stimulating a re-think of this for several reasons:

1. Distributed power generation is primarily via PV, which is inherently DC
2. Energy storage using batteries is inherently DC
3. Re-connecting DC loads to a distribution system would at first appear simpler in DC than it is in AC, since there is no need for re-synchronization and phase matching
4. DC power may have the potential to reduce distribution losses, by reducing the number of conversions between generation and utilization

Until recently, the use of DC power was limited to remote off-grid installations, boats, or campers. As a result of the potential advantages offered by modern solid-state power conversion, there is a growing interest in using DC to power entire buildings or even entire distribution grids, sometimes in the form of residential microgrids. Recent examples of this trend include the recently approved "Block Energy System" (BES) by Emera Technologies, which will provide up to 37 homes with power in the Hillsborough County housing development, Medley at Southshore Bay, within TECO's service area.

The deployment of DC systems such as the BES is hindered, to some extent, by the limited availability of native-DC appliances of all sizes, from Watts to kilowatts. In a modern home, most small loads are inherently low-voltage DC. This DC power is provided by converting single-phase AC to DC via a step-down transformer, a rectifier, and often a buck converter. Increasingly, even appliances that require high power, are becoming native DC appliances, for example:

1. Heat pumps: single-speed AC induction motors that drive the compressor and fans are being replaced by variable speed electronically commutated DC motors;
2. Dryers and water heaters: Resistance elements are being replaced by heat pumps, which can be powered by high-efficiency electronically commutated DC motors.

In the context of a DC distribution system or microgrid, with on-site PV generation and BESS, it therefore makes sense to consider DC appliances for two reasons:

1. To improve the conversion efficiency, by eliminating some of the AC-DC conversion steps;

2. To decrease costs, by reducing the size of the inverter that is needed to power individual end loads.

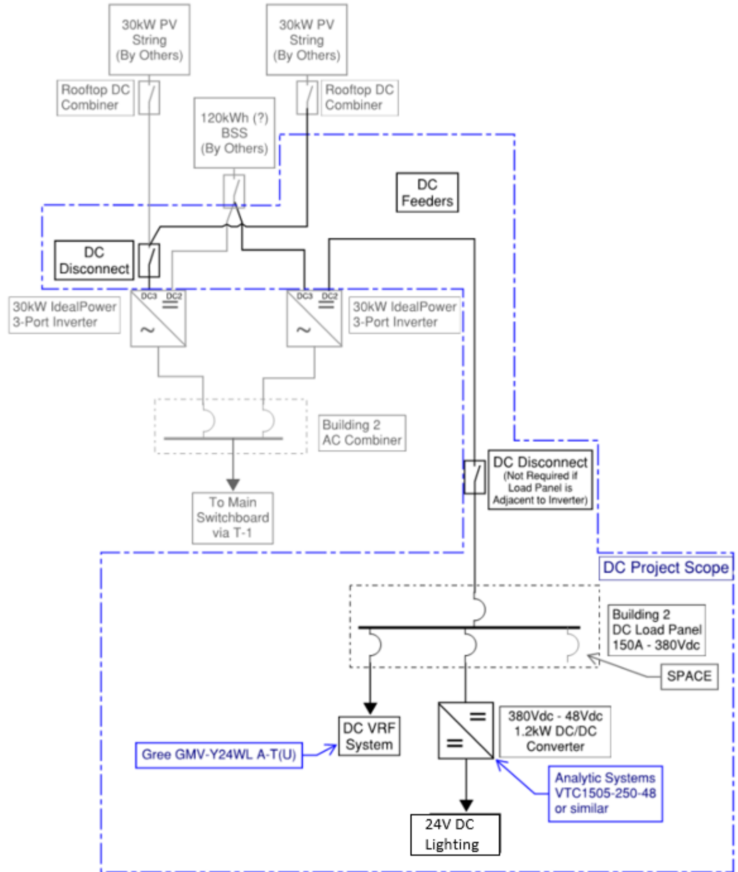
Consider, for example, the case of a heat pump, one of the largest, if not the largest load on a residential system, in the context of a grid-tied building with PV generation and battery storage, which is capable of islanding. To drive a modern variable capacity heat pump, power from the PV array must go through these steps:

1. DC-DC conversion from maximum power point tracking voltage to battery charge control voltage;
2. DC-AC conversion via the inverter to match grid power
3. AC-DC conversion from grid voltage and frequency to DC bus of the heat pump inverter
4. DC to commutated AC as needed to drive the compressor and fan motor

In contrast, if a DC-native heat pump were to be connected to the same DC bus as the battery, conversion steps 2 and 3 could be eliminated. In the case an islanding building (for example, a resilient building microgrid), the required rating of the building inverter could be reduced by an amount equal to the rated power of the heat pump. This could be substantial, as the heat pump is usually the largest single load on the building.

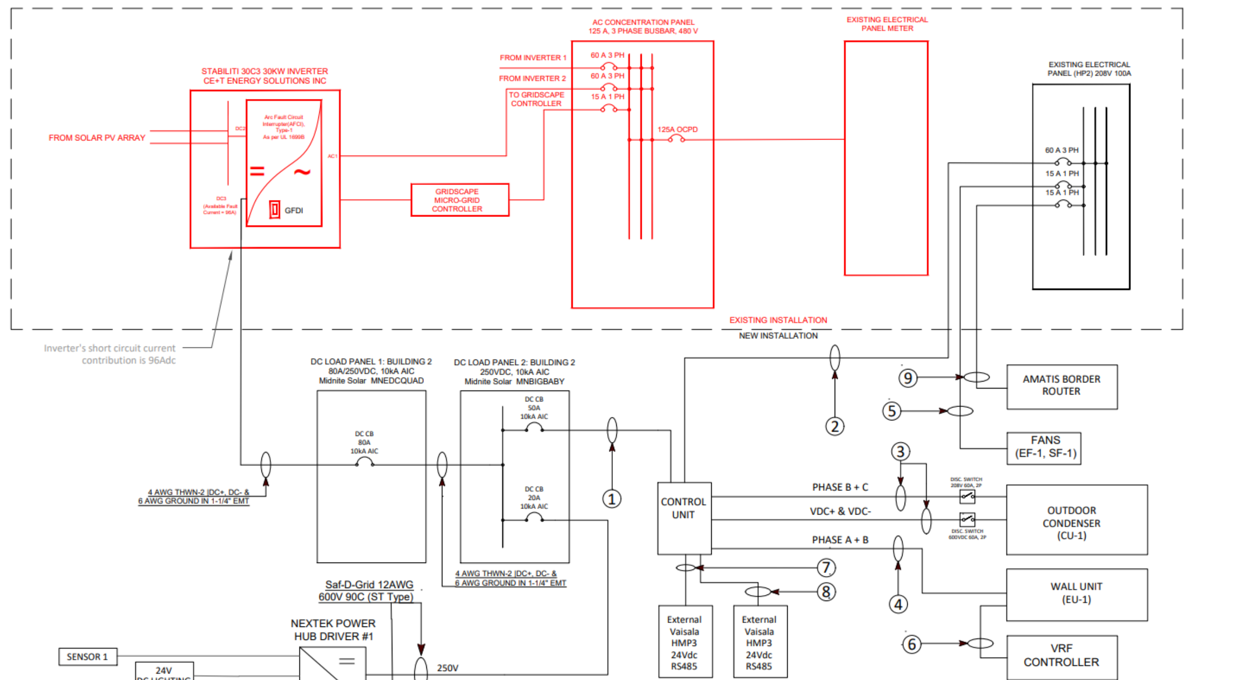
Project Scope

The goal with the DC distribution and appliance demonstration at Willowbrook is to test the avoided conversion losses and the associated reduction in inverter capacity and cost by using DC power direct from the solar + BESS to feed common area 24V DC lighting and a DC-enabled 4-ton VRF. The DC demonstration single line diagram and detailed design drawing is depicted in Figure 83 and 84 respectively.



Source: EPRI

FIGURE 91 - DC DISTRIBUTION AND APPLIANCE DEMO SCHEMATIC



CONDUCTOR SCHEDULE

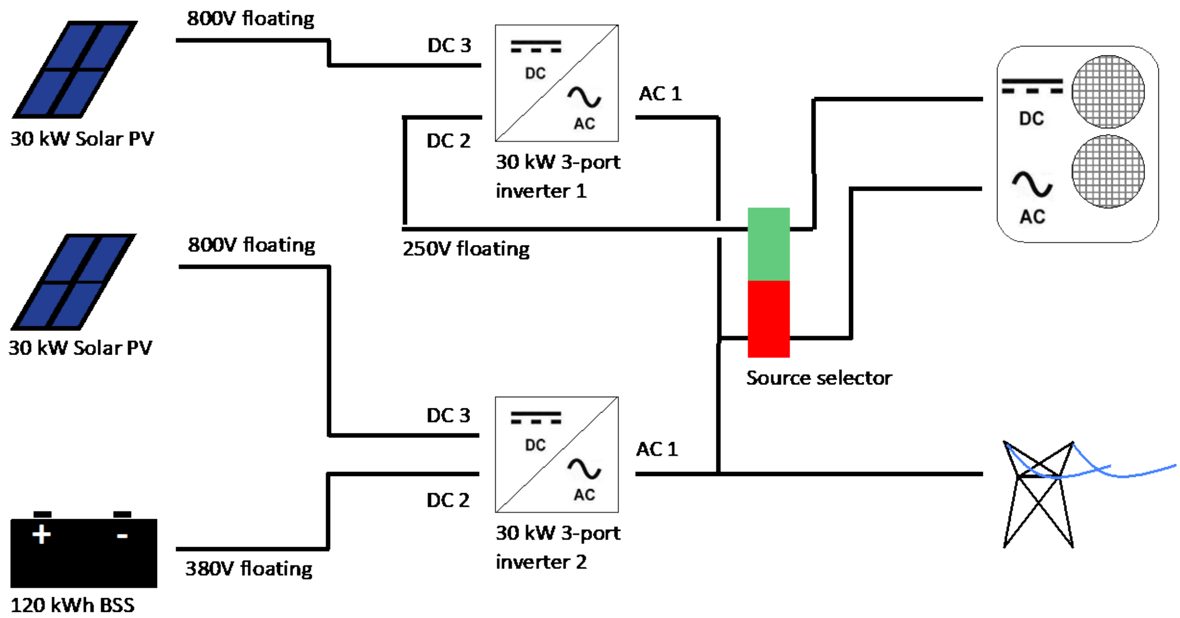
TAG	INITIAL CONDUCTOR LOCATION	FINAL CONDUCTOR LOCATION	CONDUCTOR	CONDUIT	# OF CURRENT CARYING CONDUCTORS	CONDUIT FILL %	OCPD	EGC	TEMP. CORR. FACTOR		CONDUIT FILL FACTOR	CONT. CURRENT	MAX. CURRENT	BASE AMP	DERATED AMP	TERM. TEM RATING
1	DC LOAD PANEL	CONTROL UNIT	4 AWG THWN-2 COPPER	1" DIA. PVC/EMT	2	26.52	60	10 AWG THWN-2 COPPER	1	30°C	1	60	60.00	95	95	90°C
2	(E) ELECTRICAL PANEL	CONTROL UNIT	4 AWG THWN-2 COPPER	1.25" DIA. PVC/EMT	3	23.44	60	10 AWG THWN-2 COPPER	1	30°C	1	60	60.00	95	95	90°C
3	CONTROL UNIT	OUTDOOR CONDENSER	8 AWG THWN-2 COPPER	0.75" DIA. PVC/EMT	2	24.56	50	10 AWG THWN-2 COPPER	1	30°C	1	35	43.75	55	55	90°C
4	CONTROL UNIT	WALL UNIT	14 AWG THWN-2 COPPER	0.5" DIA. PVC/EMT	2	16.51	15	10 AWG THWN-2 COPPER	1	30°C	1	1	1.25	25	25	90°C
5	(E) ELECTRICAL PANEL	FAN	14 AWG THWN-2 COPPER	0.5" DIA. PVC/EMT	2	16.51	15	10 AWG THWN-2 COPPER	1	30°C	1	1.2	1.5	25	25	90°C
6	WALL UNIT	VRF CONTROLLER	14 AWG THWN-2 COPPER	0.5" DIA. PVC/EMT	2	16.51	15	10 AWG THWN-2 COPPER	1	30°C	1	1.2	1.5	25	25	90°C
7,8	CONTROL UNIT	VAISALA	14 AWG THWN-2 COPPER	0.5" DIA. PVC/EMT	2	16.51	15	10 AWG THWN-2 COPPER	1	30°C	1	1.2	1.5	25	25	90°C
9	(E) ELECTRICAL PANEL	AMATIS BORDER ROUTER	14 AWG THWN-2 COPPER	0.5" DIA. PVC/EMT	2	16.51	15	10 AWG THWN-2 COPPER	1	30°C	1	1.2	1.5	25	25	90°C

Source: Staten Solar

FIGURE 92 - DC DISTRIBUTION AND APPLIANCE DEMO DETAILED DESIGN DRAWING

VARIABLE REFRIGERANT FLOW UNIT

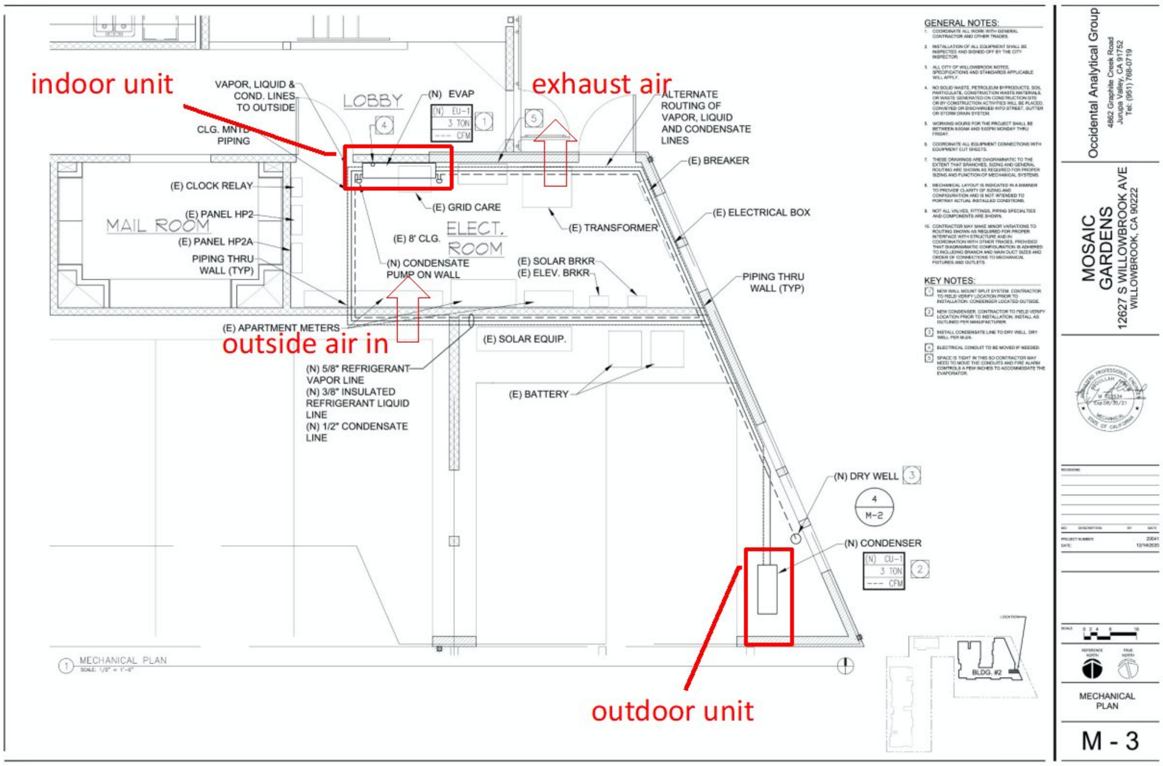
The experimental setup is based on a 4-ton Gree GMV-Y48WL/A-T(U) VRF outdoor unit, with associated indoor unit. The GMV-Y48WL/A-T(U) unit is capable of working with either AC power supply (208/240 V, 1 phase, 60 Hz), or with DC power supply (100 to 400 V DC). An automatic transfer switch was designed to transfer power supply to the outdoor unit either via the DC bus of the CET-30 inverter, or via the AC bus, as illustrated in Figure 85.



Source: EPRI

FIGURE 93 - TEST SETUP FOR DC-POWERED VRF UNIT

The rationale for using this experimental setup was to understand to what extent the native DC power supply is able to improve efficiency compared to the AC power supply. Specifically, the monitoring instrumentation provides measurement of the power upstream of the inverter (coming from PV or battery), and power downstream of the inverted, either in DC or AC mode. This would allow the determination of conversion losses in either mode. The instrumentation also would allow the measurement of efficiency inside the VRF unit itself, which in DC mode bypasses the AC-DC rectifier stage. In addition to power measurements, the tests plan also includes thermal performance monitoring of the VRF unit, by measuring indoor unit flow rate, return temperature and relative humidity and supply temperature and relative humidity. The thermal load is provided by introducing outside air, via two fans, at a controlled rate into the test space, which is the electrical room that serves Building 2. For example, cooling load will be simulated, in the warm season, by introducing warm outside air at a rate comparable to the volumetric capacity of the indoor unit fan. By varying the amount of outside air changes, it is possible to simulate an arbitrary load profile to match the rated cooling capacity of the system. Similarly, heating loads can be simulated in the winter by introducing cold outside air. The layout of the experimental apparatus is shown in Figure 86. Note that exhaust air vanes were installed at a location diametrically opposite to the ventilation fans.



Source: EPRI

Figure 94 - Layout of Components to Measure Performance of the DC VRF HVAC unit

The original test plan included the following experiments:

- Determining the volumetric capacity of the ventilation fans
- Determining the volumetric capacity of the indoor unit fan as a function of fan current
- Measuring power to the outdoor unit as a function of load at various stages (upstream & downstream of inverter) in DC and AC mode
- Measuring the thermal performance of the unit (COP) as a function of load and, if possible, temperature lift

These experiments, and their outcome, are described below.

Ventilation Fan Capacity

Ventilation to the Building 2 (Willowbrook site) electrical room is provided by two centrifugal fans, operating in parallel. Both fans can be controlled remotely. One of the fans can be turned on and off, while the other can be operated in variable speed mode. By using the variable speed fan only, a ventilation rate between 0 percent and approximately 50 percent can be obtained. By operating both fans, ventilation between approximately 50 percent and 100 percent of full capacity can be obtained. To calibrate the ventilation rate as a function of fan setting, a temporary hood was installed around the fans that could channel all the air flow to a TSI flow capture hood for measurement. The temporary flow hood, and the measurement flow hood during measurement are shown in Figure 87.

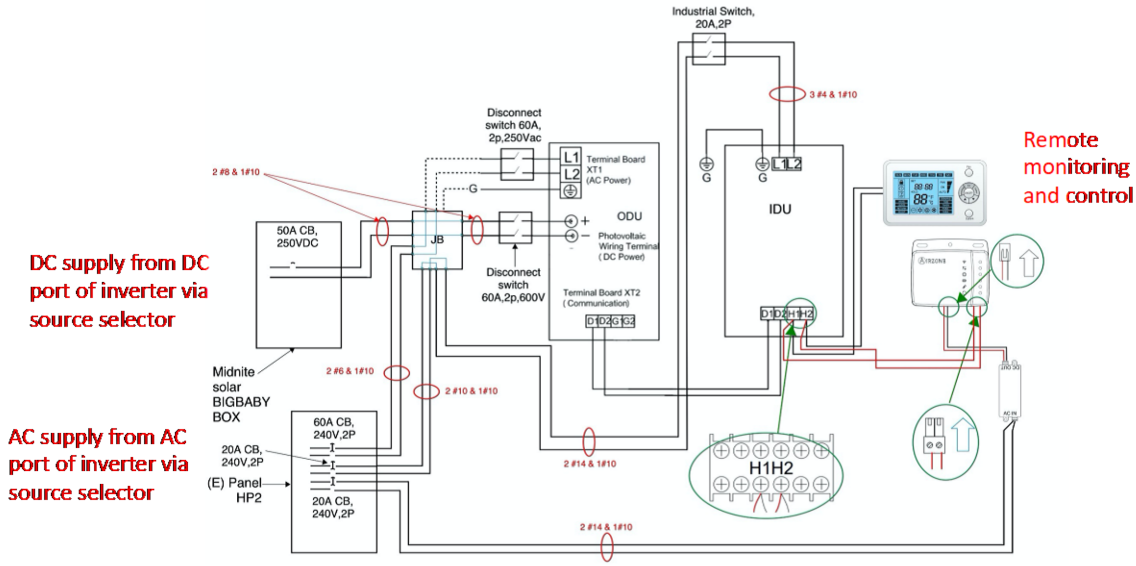
Source: EPRI

FIGURE 95 - HOOD TO CONVEY AIR FLOW TO FLOW MEASUREMENT DEVICE (LEFT), AND TSI VOLUMETRIC FLOW MEASUREMENT DEVICE IN USE (RIGHT)

The results of the calibration experiments, obtained on November 8, 2021, are shown in Figure 88. Based on these, air flow can be estimated accurately as a function of fan setting, using the equation: $\dot{\boldsymbol{V}} = \mathbf{8.64}\boldsymbol{S}$ where $\boldsymbol{S}$ is the combined speed setting and $\dot{\boldsymbol{V}}$ is the volumetric flow rate in cfm. The thermal load is the combined sensible load and latent load, which is a function of the temperature and relative humidity of the outdoor and indoor air, both of which can be measured. As an example, for outdoor temperature of 90 degrees F and relative humidity of 65 percent, and indoor air setpoint of 68 degrees F with relative humidity 55 percent, the combined load of 3 tons of refrigeration is achieved with a ventilation flow rate of 430 cfm, well within the range of the ventilation fans.

Power Measurement to Indoor and Outdoor units

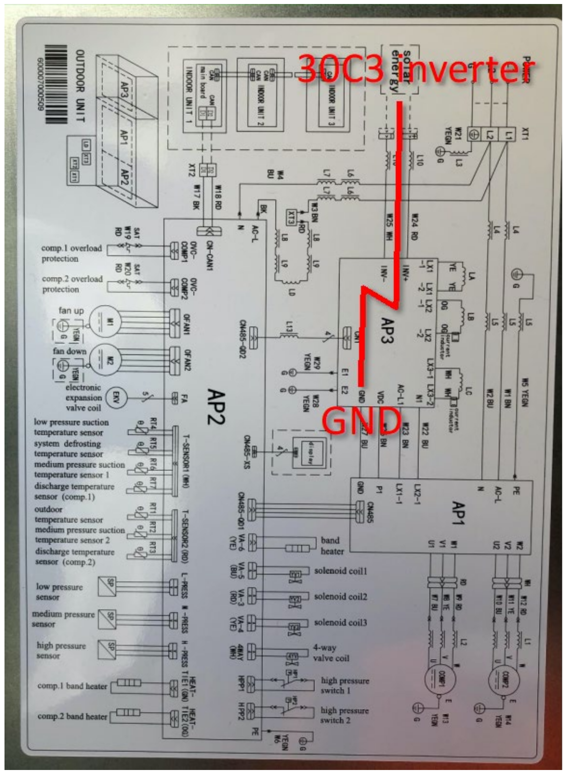
This measurement is obtained by utilizing the AC and DC current transducers located in the 30C3 power converter, in the source selector, and in the AC panel, as shown in Figure 89.



Source: EPRI

FIGURE 96 - CONFIGURATION OF ELECTRICAL MEASUREMENT DEVICES

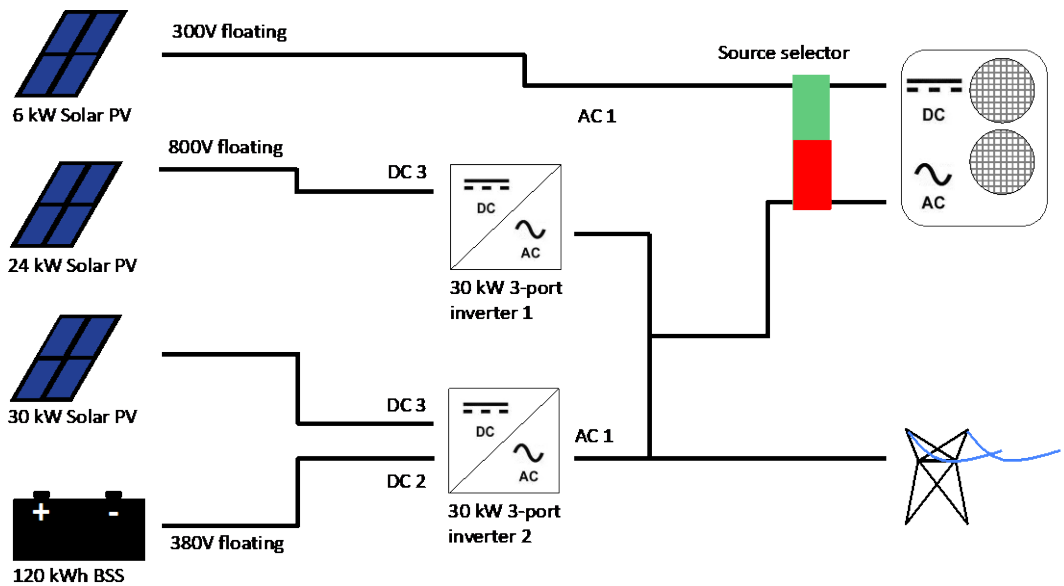
Events during Testing on November 9, 2021



Source: EPRI

FIGURE 97 - GROUND SHORT CURRENT PATH THAT LED TO THE FAILURE OF BOARD AP3

While calibrating the ventilation fans, before the planned measurement of the indoor unit fan volumetric capacity, a fault message appeared on the HVAC status display, indicating a "C2 – communication error between master control and inverter compressor drive". After several attempts at restarting the system failed to resolve the issue, and after ruling out refrigerant leak, it was determined that one of the control boards in the outdoor unit had suffered a catastrophic failure. Specifically, it was determined that the DC board AP3 had failed. The likely cause of damage was the floating DC voltage from the inverter shorting to ground, as indicated in Figure 90. Unfortunately, the initial understanding that the outdoor unit could operate in DC floating mode was incorrect, and detailed inspection of the circuit diagrams indicated that there is always a path from the DC supply to the grid. So, the initial design of the system had to be reconsidered. The major implication was that it is not possible to operate the existing hardware in the configuration originally intended, namely using the DC bus of the 30C3 power converter as a source of DC power to the HVAC unit.



Source: EPRI

FIGURE 98 - SYSTEM RECONFIGURATION WITH HVAC DC SUPPLY SOURCED DIRECTLY FROM A SUBSECTION OF THE PV ARRAY

Alternative system configuration

While the intended configuration of the system is not currently feasible, it is still possible to obtain performance measurements of the HVAC unit in native DC vs. AC, with a small system reconfiguration, as shown in figure 91. In this reconfiguration, a subsection of the PV array is isolated and connected directly to the HVAC unit. This configuration is known to work, since it is the default configuration specified by the manufacturer (Gree) for this system. After substitution of the AP3 board, the system was reconfigured and its correct operation was verified on 11/30/2021. Volumetric flow and thermal testing of the system will be carried out in early December. Compared to the original testing plan, the downside is that it will not be possible to determine the DC/DC conversion efficiency of the 30C3 power converter. However, DC-only, AC-only and combined DC-AC operation and testing of the HVAC unit will still be possible, allowing the determination of the AC conversion losses internal to the unit.

Measurement of thermal performance on December 7, 2021

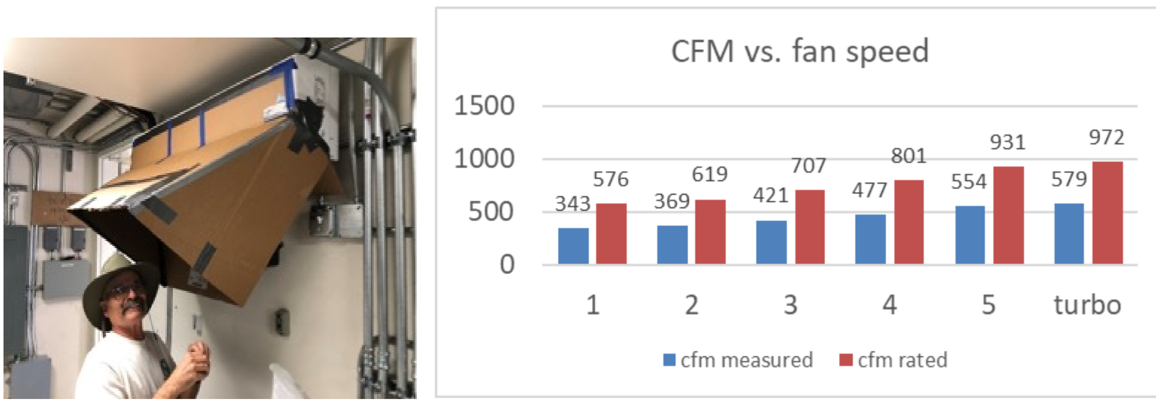
The coefficient of performance is the ratio of thermal capacity $\dot{Q}$ of the system to electrical input. Measurement is from

$$\dot{Q} = \dot{V}\rho(h_{supply} - h_{return})$$

where ρ is the air density and the specific enthalpy h is a function of the measured temperature and relative humidity. These, in turn, are measured using Vaisala temperature and relative humidity sensors located at the return and supply sides of the indoor unit, as shown in Figure 92.

Source: EPRI

FIGURE 99 - LOCATION OF VAISALA T/RH SENSORS



Source: EPRI

FIGURE 100 - ADAPTOR TO CONVEY AIR FLOW FROM INDOOR UNIT SUPPLY TO TSI VOLUMETRIC FLOW MEASUREMENT DEVICE (LEFT) AND FLOW RATE AS A FUNCTION OF FAN SPEED SETTING (RIGHT)

Volumetric Capacity of the Indoor Unit Fan

The procedure for determination of the indoor unit fan ventilation capacity was similar to that

used for the ventilation fan capacity. A temporary cardboard hood was installed on the indoor unit to convey supply air to the TSI flow measurement hood, as illustrated in Figure 93.

Following the reconfiguration of the system, a series of measurements to determine volumetric flow rate through the indoor unit as a function of fan speed setting were conducted using the flow hood. The results of the testing are also shown in Figure 93. The measured flow rates were substantially smaller than the rated flow, likely owing to the know sensitivity of ductless unit fans to pressure drop. As a result, "rated" flow rates are also shown. The maximum flow rate for the "turbo" setting according to the manufacturer is 972 cfm. Values for other fan speed settings are obtained by scaling the rated maximum value with the ratio of measured volumetric flow rate for the speed setting to maximum measured flow rate.

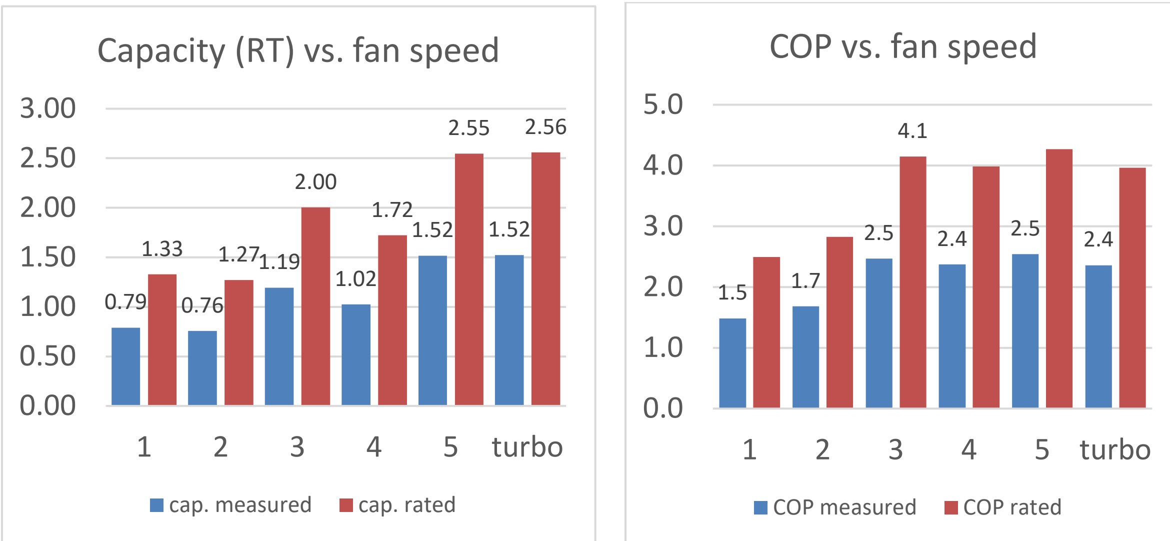
Thermodynamic Performance

In a typical situation, controlling the temperature of the zone while matching the heating or cooling load for the zone is done by varying the fan speed setting. Thus, to understand how the system performs under typical conditions, a series of tests were carried out to determine performance at various fan speed settings. For each fan speed setting, a 15-minute-long test was performed, recording AC power, supply temperature and relative humidity, and return temperature / relative humidity. The performance of the system at each speed setting was then calculated using the equation for thermal capacity $\dot{Q}$ above, and the measured power. The outcome of the tests is shown in Figure 94. Some general observations can be made from these results:

1. “Measured” performance is lower than “rated” performance. Which one is the true one? Probably somewhere in the middle. While the rated performance in obtained under ideal lab conditions, the measured performance is likely sub-optimal: the wall unit is mounted too close to the ceiling, owing to space constraints, restricting air flow to the return side of the unit, while the flow hood adds a static pressure drop on the supply side.

2. Performance is non-monotonic, contrary to the expectation that capacity should increase monotonically with air flow. This is likely a consequence of minute-scale “noise” the internal controls of the variable capacity unit, that probably seeks to maintain a given supply air temperature, in the face of changing room temperature, and step changes in fan speed.

3. Overall, the performance of the system is consistent with that of a modern, high performance variable capacity unit. Ultimately, the goal of this subsection of the project was to evaluate performance in AC mode vs. performance in DC mode. Owing to supply-chain issues, namely the unavailability of the source selector and associated metering, we were not able to obtain this comparison, yet. However, based on these preliminary results, we have learned that it is not realistic to expect such performance comparisons from a series of short tests. Rather, testing should be a long-term proposition, on the order of several days or even weeks. A likely scenario that would lead a robust comparison of DC vs. AC performance would be to run tests on alternate days, with AC power supply alternated with DC power supply, for a period of at least a month in the summer and a month in the winter.



Source: EPRI

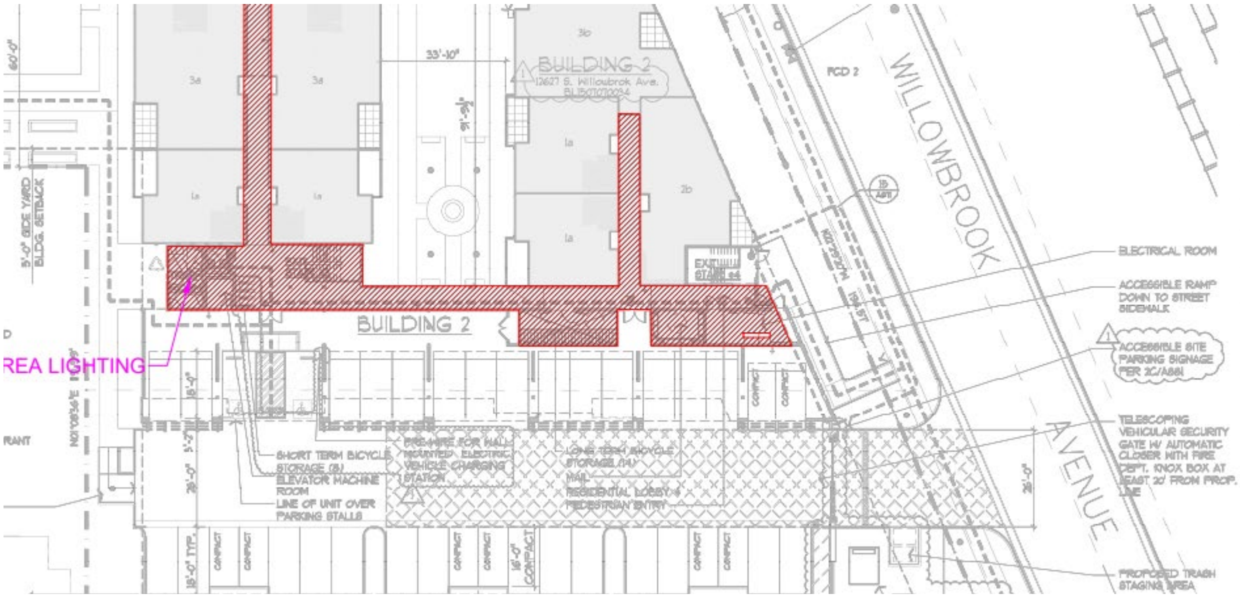
FIGURE 101 - SYSTEM THERMAL CAPACITY VS. FAN SPEED SETTING (LEFT) AND SYSTEM COP VS. FAN SPEED SETTING (RIGHT)

Lessons Learned Towards a Practical System Implementation

This exercise provided valuable insight into the design process of hybrid AC/DC resilient systems. The primary lesson is that design of these systems is more complex than it appears. Some of the components are incompatible, although manufacturer interest in such systems may resolve some issues in the near future. Some of the components are hard to find – for example, high-voltage DC breakers. While it was not possible to measure DC/DC conversion efficiency of the 30C3 power converter, keeping the system "all-DC" may not result in the expected efficiency gains. Finally, full integration may require some design changes that allow for integration, for example enabling the PV MPPT controller to work in parallel with the battery charge controller, however this would require cooperation between manufacturers and standardization.

LIGHTING

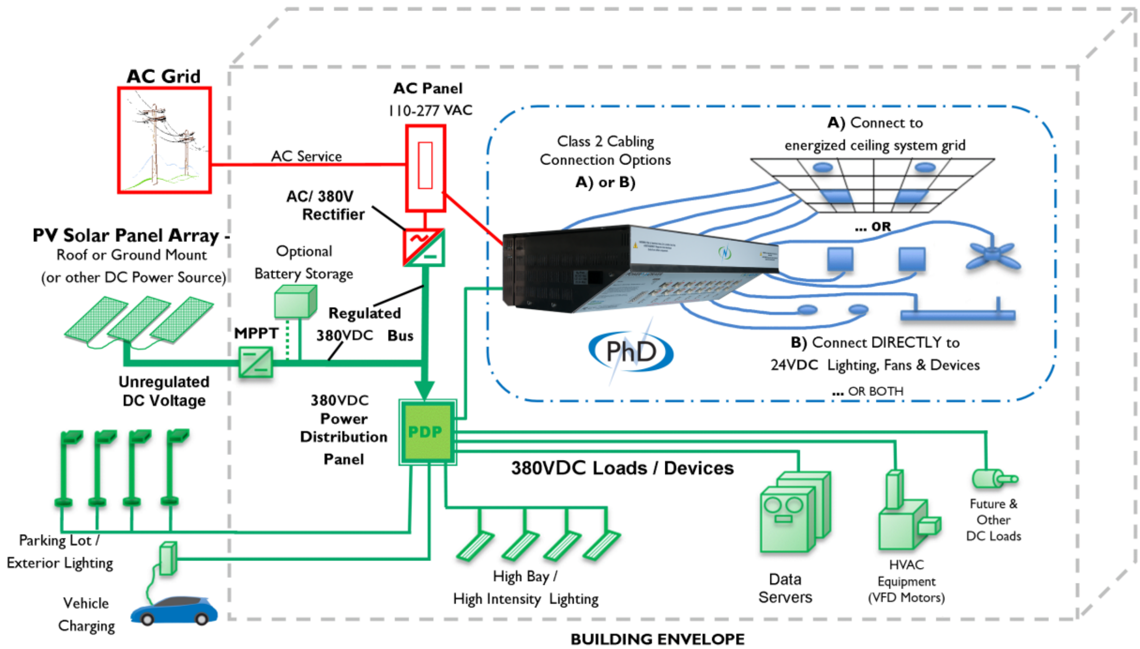
As part of the lighting scope, the project team installed supplemental DC lighting in the common area corridors of Building 2 as depicted in red in Figure 95 below.



Source: Staten Solar

FIGURE 102 - DC LIGHTING DEPLOYMENT AREA

The lighting system components consisted primarily of two 16-channel Nextek power hub drivers, 24VDC Lamar lighting fixtures and Sky (also known as Amatis) bridge sensors and switches. As depicted in the manufacturer Nextek's diagram in Figure 96, the Power Hub Driver converts 380VDC power to 24VDC through 16 individual Class 2 outputs. The Power Hub Driver has a wireless remote control and monitoring system and features a low-voltage DC distribution system for plugging in DC lighting.



Source: Nextek

FIGURE 103 - POWER HUB SCHEMATIC DIAGRAM

The Power Hub Driver (referred to as Power Source Hub in Figure 97 below, a Nextek-supplied graphic depicting the configuration in use at the Willowbrook project) is interconnected with the Sky (Amatis) bridge, sensors and switches, and so on through a wireless mesh network. The Sky border router is connected to the ethernet so that the network is also available online and can be monitored through a phone application and web-based monitoring platform (the monitoring platform keeps the network's programming stored in a cloud). Since all the devices are interconnected wirelessly, when a sensor detects anything, it is communicated to all the devices. The Sky border router works as the master device. Informed by the switches and sensors and its programming, the Power Hub driver dims the light fixtures and/or turns them on/off.

Source: Nextek

FIGURE 104 - LIGHTING SYSTEM COMPONENTS

Test Plan:

- DC distribution and appliance energy use baseline is measured against a traditional AC distribution and appliance baseline.
- In addition, because the Sky (Amatis) sensors and switches did not carry UL listings, a UL 2108 Low Voltage Lighting System field evaluation will be carried out on site by National Research Lab TUV Rheinland

As compared to the pre-existing LED AC lighting fixtures, which were already quite efficient at 49/42W 5500 lumens, the replacement 24W 2600 lumens DC light fixtures resulted in a 3.6 percent efficiency gain in terms of lumens per watt. Additional consumption reduction would be possible by reducing lumens per watt through dimming controls and occupancy sensors. However, building codes in general and title 24 California code require a minimum level of lumens per square foot and occupancy sensors. DC light fixtures are sometimes available in smaller individual fixture wattage and smaller fixtures enable a designer to right size the lighting to achieve the required level of lumens without overshooting.

Controls such as dimmers and occupancy sensors compatible with DC lighting are not readily available. EPRI and the project partners worked to establish a functional and code-compliant lighting control system by commissioning TUV to provide a field evaluation under applicable UL criteria. Using these controls, EPRI worked with the site host and vendors to establish a dusk to dawn schedule with occupancy sensors according to the following schedule:

- 5 PM -7 AM (Dusk until Dawn)
- Control Strategies: Occupancy Sensors and Wall Switches
- 8 PM to 6 PM –lighting is on as long as occupancy is sensed, turns off 5 minutes after last occupancy is sensed
- 6 to 8 PM and 6 to 8 AM lighting is on as long as occupancy is sensed, turns off 10 minutes after last occupancy is sensed

Lighting circuits often involve long cable lengths to provide adequate coverage over rooms, hallways, and outdoor spaces. Because of this, cable losses can be considerable. DC lighting often uses low voltage for safety and ease of installation. However, losses are relatively higher when low voltages are used. Losses in a circuit can be considered to be equivalent to I^2R, which means that for the same wattage, a circuit using lower voltage necessarily carries a higher current and is subject to additional loss.

For example, 24Vdc lighting of the same wattage and using the same length and size of cable as a 120Vac would be subject to 5X the ampacity and therefore 5X the cable losses. Cabling losses can be mitigated by using larger cable, which adds cost, or by using higher voltages. A few lighting vendors such as GVA lighting offer specialty architectural lighting products that operate on 380Vdc which can instead reduce cabling losses as compared to 120Vac lighting circuits. Currently 380Vdc lighting products are primarily for specialty architectural and display applications and are not readily available for indoor residential applications such as Willowbrook. Cable losses in the Willowbrook project are mitigated by using a 250Vdc lighting driver that is located as close as possible to the light fixes themselves, which are 24Vdc.

The primary opportunities identified during this lighting implementation are the need to explore expanding availability of 380Vdc or higher voltage DC lighting for optimal efficiency as well as the need to establish availability of UL-listed DC lighting controls.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

Technical and Market Barriers

DC Coupling

The major technical and market barriers concerned the DC-coupled systems, which are discussed in greater detail in this section. Other barriers and lessons learned will be covered below in the Lessons Learned section.

Summary

Conversion losses are typically encountered in any system where DC sources and alternating current (AC) loads are present. Where solar PV and energy storage are present, use of AC coupled systems can require energy to be converted three or more times before use or export. Many types of appliances or equipment convert AC back to DC internally before use of local solar generation as well. As any conversion causes losses, reducing or eliminating excess conversion steps would improve efficiency.

DC utilization has long been considered as a path to increase efficiency of electrical systems where native DC sources such as solar PV are present. Solar modules produce DC power and batteries operate on DC, so the premise is that optimal efficiency could be achieved if DC energy from solar or other renewable sources could be used and stored without conversion to AC. Conceptually, the reduction of power conversion steps and the associated equipment could substantially improve efficiency. While utilization of DC is technically feasible, several technical barriers exist to reducing conversion steps and increasing efficiency.

These barriers are listed below and described in more detail below.

1. Bridging varying voltage requirements from multiple appliances necessitate conversion, reducing system efficiency
2. Lack of DC compatible devices and experienced designers and installers
3. Use of proprietary low volume hardware creating future servicing/replacement risk
4. Codes and standards placing limits on DC voltages and hence DC utilization opportunity
5. Potential for unintended consequences from DC coupling of converters with different voltages (e.g., noise, ripple, negative impedance instability)

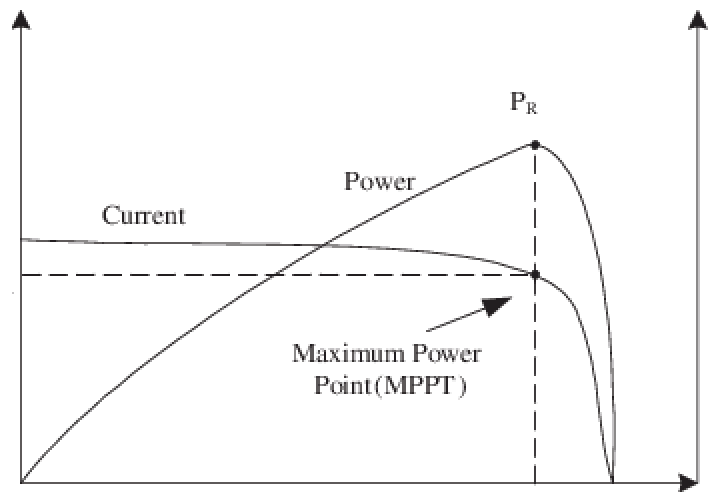
6. Beneficial DC coupling approaches for interconnection as it limits total connected kW

VOLTAGE MISMATCH

Voltage mismatch is the root cause for the proliferation of power conversion equipment. Internal voltage requirements for various equipment - from cord-and-plug appliances to luminaires to EV chargers - vary widely. For example, LED lighting internally converts AC input to single digit voltages while electric vehicle supply equipment and circuitry internal to vehicles convert AC input to several hundred volts DC. Computers have several separate internal DC bus voltages. Commercially available solar PV systems typically operate from 300 to 1500VDC and convert that to AC. Many appliances are dependent on induction motors, which require AC power to operate though inverters. VFDs are also becoming more popular, which can conceptually operate on DC input. Several valid engineering reasons exist for the various voltages employed by equipment. Irrespective of the question of AC vs DC, there is limited technical feasibility for all end devices to operate on one single voltage.

One driving reason for higher power equipment to operate at higher voltages is efficiency. Loss in a circuit could be described by current squared times resistance. Where current is doubled, loss is quadrupled. All wire has a constant resistance per length, which varies depending on the cross-sectional area of the wire. Any specific gauge of wire can conduct a specific amperage and power is equal to Volts times Amps. Meaning that higher voltages enable more energy to pass through the same size cable or semiconductor, or that a higher voltage leads to greater efficiency.

A key function of PV inverters is maximum power point tracking (MPPT), depicted in Figure 98. MPPT manipulates voltage and current find the maximum output of a PV array at any given time. If the maximum power voltage is not maintained, the output from the PV array can be far less than optimal. Stand-alone charge controllers are available to provide MPPT functionality when DC coupling PV modules with batteries. Batteries also have specific voltage requirements, and manipulation of voltage is typically used to control charge and discharge rates as well as to prevent excursions beyond allowable states of charge. Both batteries and PV arrays will each need a conversion device that may be a DC converter or an inverter to allow safe and optimal interface with each other, utilization equipment, or the grid.



Source: Chen Shaixun, Research Gate

FIGURE 105 - CHARACTERISTIC CURVE AND MAXIMUM POWER POINT OF PV

Because of the need for various voltages and because transformers do not work with DC power, DC:DC conversion becomes necessary in order to enable DC utilization. Like *transformers* or inverters, DC:DC converters are also not 100 percent efficient but, in some cases, may be higher efficiency than transformers and inverters. Hence, the need for a wide range of voltages for various devices.

CONVERTER VERSUS INVERTER EFFICIENCY

Transformers, DC:DC converters, and inverters are all available with efficiency ratings in the high nineties. All devices will have varying efficiency at varying power levels, and all types have some element of no-load loss if energized. DC converters may still have some advantage over transformer or inverter efficiency. DC converters still involve conversion, which necessarily entails losses. DC converter efficiency is generally higher for lower voltage buck or boost ratios, meaning that efficiency is lower for less similar input and output voltages. Compared to AC utilization efficiency, DC utilization efficiency would largely depend on what load is being driven and at what voltage. Voltage and cable size are likely larger drivers of efficiency loss than conversion methodology or AC versus DC.

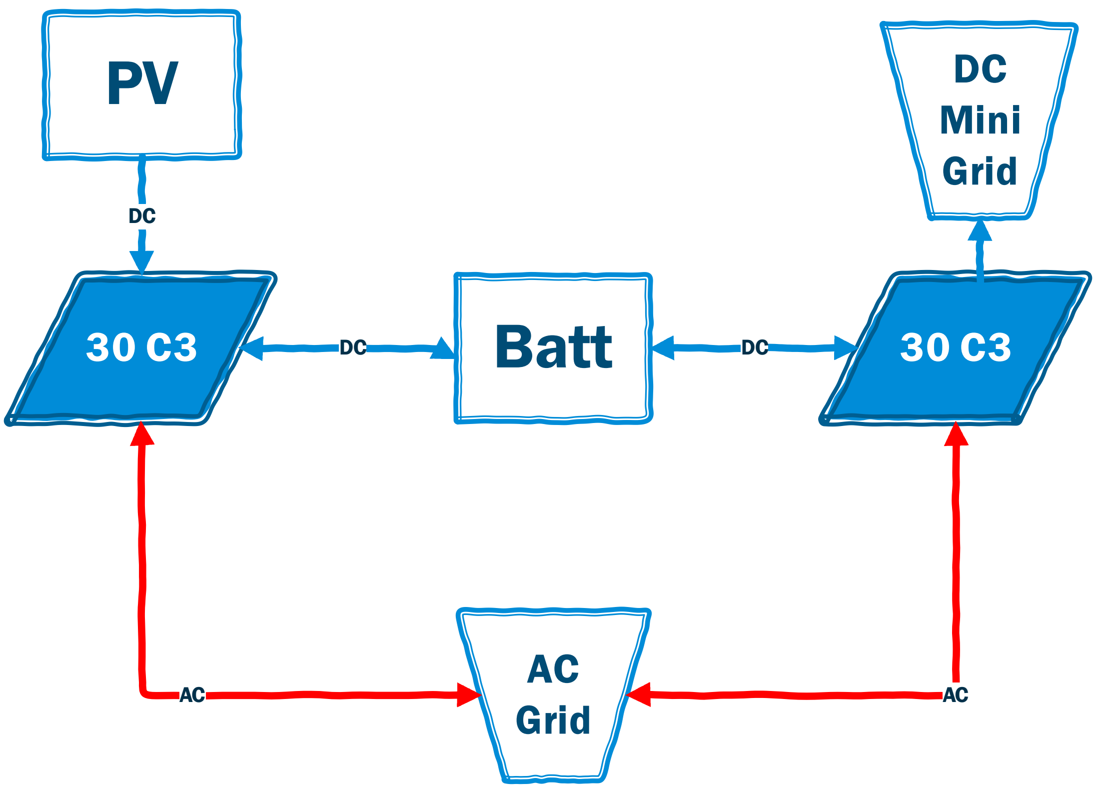
HARDWARE AVAILABILITY

For systems employing PV, battery storage and DC loads such as Willowbrook, it may be desirable to have DC coupling between these systems in order to prevent excess conversion steps. To have PV, BESS and DC loads interfaced with an AC system, either several discrete converters or a multi-port product would be required. Princeton Power and CE+T converters, for example, have offered four-port inverters in the past, but they are no longer producing them.

Some manufacturers are producing integrated DC-coupled PV and storage systems for residential use. Work is taking place to integrate load control with such productized residential systems, but it is not yet commonplace. For example, Lumin, which generally provides load control hardware, recently announced partnerships with storage providers. There are also large

DC:DC converters available for utility-scale projects seeking to DC-couple PV and storage. In the space between utility-scale and single family residential however, there are very few DC- coupled product offerings. Converters designed to serve multiple general-purpose DC loads are generally laboratory hardware designed and priced accordingly. Converters designed to provide DC distribution are not readily available.

CE+T is currently producing a 30kW three-port bidirectional inverter which is being used to DC couple PV and a battery for the Willowbrook project. This inverter is unique in the market in that it is also capable of operating as a regulated power supply for DC loads on one port while being connected to a battery on the other port. Therefore, the Willowbrook project will utilize two CE+T 30 C3 3-port inverters to integrate PV, batteries, loads, and the grid as depicted in Figure 99. The operation of the two devices will be coordinated by Gridscape's EnergyScope software and metering.



Source: EPRI

FIGURE 106 - WILLOWBROOK CONFIGURATION

AVAILABLE APPLIANCES AND FIXTURES

Appliances and fixtures for operation on DC power are of low availability or specialty items, such as those made for recreational vehicle use. DC large appliances such as washers, dryers, refrigerators, and oven ranges are not readily available. DC small appliances such as toasters, microwaves and televisions are similarly lacking. Low voltage DC lighting is readily available at several voltages up to 48VDC through a few suppliers. DC powered HVAC is becoming available that can use 380VDC, but availability and selection are lacking. Many types of appliance that use motors, such as refrigerators, are internally starting to use inverters to provide variable motor speeds for efficiency. The first step in such inverters is typically a rectifier that converts the incoming AC to DC for use by the inverter. Such appliances are not suitable or rated for DC input power as-is, though internally they are using DC and very little would have to be done to make them suitable for DC input.

Several types of appliances and fixtures operate using shaded pole motors. For example, bathroom ventilation fans use these cheap yet reliable devices. Shaded pole motors cannot operate on DC. Many millions of shaded pole motors are in use in the US. Brushless DC substitutes are available, however cost several times as much. Those labelled brushless DC typically rectify AC power to DC, so the technical leap to DC input is minimal though products configured for DC input do not appear to be readily available for residential use.

As described earlier in the Results section, Willowbrook is using a DC-enabled Gree VRF variable speed mini split heat pump that can work in 100-380VDC as well as AC mode. Willowbrook is also deploying 48V DC lighting manufactured by Lamar.

Codes and Standards

Codes are one reason higher voltage DC lighting availability is poor. The National Electric Code (NEC) treats systems below 50V separately from systems above 50V, so there has historically been a bias towards DC lighting voltages below this point. NEC 210.6 permits lighting voltages over 120V but only up to 277V. 210.6 is referenced in NEC 690 where DC utilization circuits from PV systems are contemplated. Other sections of the NEC and other building codes restrict the convenient use of higher DC voltages for general utilization. These restrictions do not line up with the most efficient operational voltages for PV and battery systems. Residential PV and battery systems may operate at up to 600V, and commonly operate around 380VDC for efficient conversion to 240VAC. DC PV circuits inside the home have been required to be encased in metallic conduit and conspicuously labelled, which is not conducive to cost effective general distribution circuits. Restricting DC operational voltages for PV and batteries to 50, 120, or 277 would have a corresponding negative impact on efficiency and/or would require larger conductor sizing which substantially increases installed pricing.

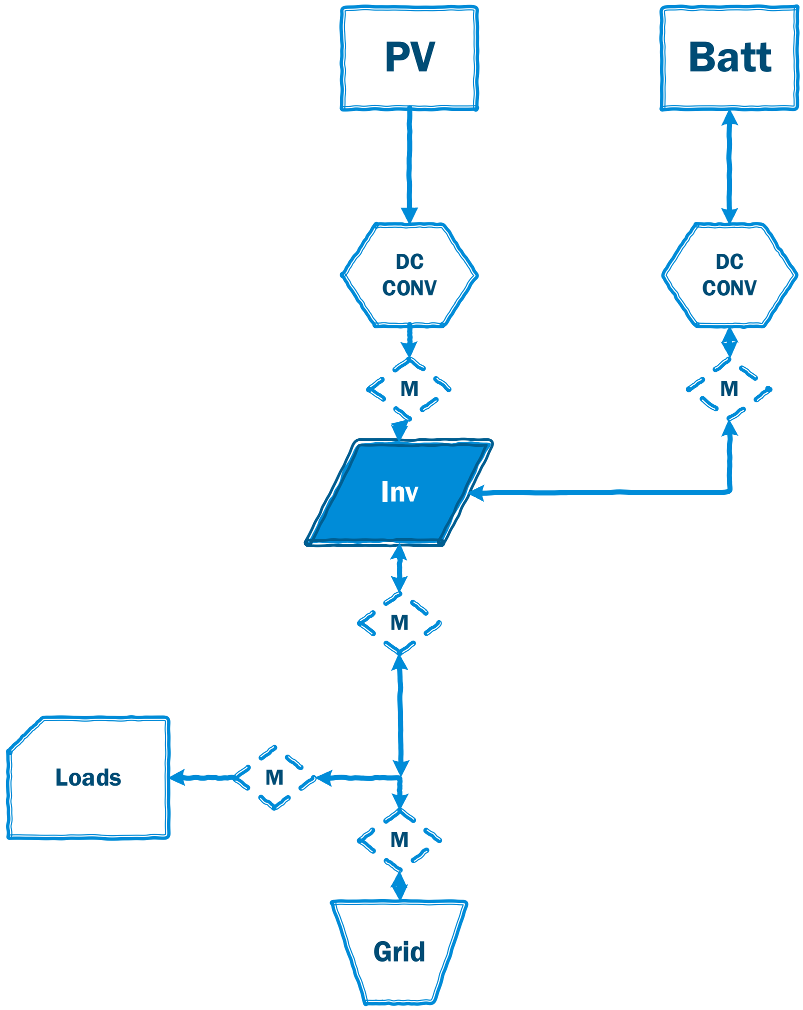
Since 1880 when Tesla and Edison were competing, there have been discussions about AC vs DC distribution. AC distribution has dominated primarily due to the ability to use transformers. Relatively recently, it has become possible to convert DC voltages. High VDC transmission lines are in operation today. DC distribution is conceptually technically feasible, however any effort to do so would have to overcome substantial industrial inertia and would require demonstration of a positive cost-benefit ratio.

AC arcing behavior has been the subject of much study and is better understood from a safety perspective than DC arcing. Because DC lacks a zero crossing, DC arcing tends to exhibit less self-extinguishing properties as compared to AC arcing. Incident energy and fault current calculations can be more complex for DC systems, especially where multiple sources and converters are in use as with PV plus storage systems. DC arc fault protection is available and required for some PV systems but may not be readily available for DC utilization. DC arc behavior, calculation methodologies, and protection best practices all could benefit from additional study ad well as code and standard development.

METERING AND TARIFF COMPLIANCE

DC metering is another technical and market issue. DC socket meters for utility metering are not available and a NEMA C12 standard is in progress but did not exist previously. Current transformers used for AC metering, do not yet work with DC, so shunts or transducers must be used. The lack of revenue-grade DC socket meters presently creates difficulty where DC coupled PV and storage systems exist in areas with net energy metering (NEM). In order to ensure NEM integrity, some utilities, including SCE in the case of Willowbrook, specify net generation output meters (NGOM) for qualifying resources such as PV. This is to ensure that customers do not charge the battery with grid power to provide rate arbitrage. In an AC-coupled system with separate inverters for batteries and PV, it is possible to use a standard form 2S socket meter.

In order to meter the PV output in a DC-coupled system, it would be necessary to install a DC meter. And such revenue grade DC socket meters do not exist. Further, if such a meter were available, it still would not fairly capture the actual qualified output of the PV due to conversion losses in converters and inverters. One potential resolution, which the SGIP considers for small systems is to utilize integrated inverter metering and controls to assure NEM integrity. The recent Underwriters Laboratory Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources (CDR) also makes recommendations for necessary controls and metering points as related to storage and solar plus storage systems that can clarify issues around qualified resources and NEM integrity. Some potentially desirable metering points for DC coupled systems are shown in Figure 99.



Source: EPRI

FIGURE 107 - POTENTIAL METERING POINTS

In summary, DC sources and loads are and will continue to be an increasing part of the electrical system. While there are some factors that point to DC-coupling for systems, each application presently must be evaluated for technical feasibility within available hardware and codes as well as economic feasibility comparing the costs and risks to the potential benefits. The Willowbrook project is proving the technical feasibility through demonstrations of DC-coupled solar, storage, and controlled loads. Demonstration of technical feasibility is often one of the first steps in achieving financial viability for new technologies.

SUMMARY OF APPROACH, ACTIVITIES AND PRODUCTS

The project partners navigated a number of delays and setbacks. First were delays in approvals to conduct extensive due diligence as Willowbrook is a tax credit financed property with multiple lenders, one of which had a poor experience with previous solar projects (leaking from roof penetrations). The due diligence involved demonstrating sufficient contractor insurance and performance bonds to protect the Willowbrook property and its investor against construction-related damages. Second was the prolonged sourcing, testing, permitting, and interconnection processes associated with implementing the emerging technologies of the project scope, especially the DC breakers and controls. Third was the emergence of the Covid-19 virus in early 2020 and ensuing global pandemic resulted in elevated precautionary measures to avoid transmission and exposure among crews and property occupants and staff, supply chain issues for some of the components and related setbacks to on-site work. To address these challenges, the project team took time, hired a dedicated construction manager, addressed issues in recurring weekly meetings and engaged external stakeholders. Furthermore, a technical advisory committee was formed and met 3 times throughout the duration of the project, during which some of these issues were addressed.

Program Design

There are a number of utility tariff and funding programs that influenced the project design that are summarized below.

1. The Federal Incentive Tax Credit for Solar (ITC) is a tax credit that can be claimed on federal corporate income taxes for 30 percent of the cost of a solar photovoltaic (PV) system that is placed in service during the tax year. The ITC can be used by businesses, but not by a tax-exempt entity. At the project onset, LINC, a non-profit, tax-exempt entity, established LINC Renewables LLC as a for-profit entity, that would own the equipment purchased as part of the project. This was in an attempt to capture the estimated $275K estimated in ITC benefits that it would otherwise not be eligible for as a tax-exempt entity. LINC, however, had trouble engaging investors for this deal, as it was a relatively small project, and most investors were looking for a portfolio with greater returns. Ultimately, this was not captured due to the lack of Willowbrook investor interest.

2. The Self-Generation Incentive Program (SGIP) is offered by the California Public Utilities Commission (CPUC) and California IOUs to provide incentives for customer-side distributed energy systems, including wind turbines, waste heat to power technologies, pressure reduction turbines, internal combustion engines, microturbines, gas turbines, fuel cells, and advanced energy storage systems. LINC evaluated this option to offset the costs for its energy storage components assuming minimum utilization rates could be met. The property was eligible for the SGIP – Equity incentives that are secured via a lottery. In this example, $100,000 incentives required a $5,000 deposit and roughly $7,000 paid to the system developer, Gridscape. Gridscape, the general contractor, stated it would need an O&M contract to guarantee the SGIP performance standard (minimum utilization rate) and submit the annual report needed to submit a report to the State. LINC had concerns that the net operating income from the battery would be insufficient to cover the application costs and the O&M charge, so this was rejected as an option until a financially-viable solution was developed. Gridscape and Linc are negotiating a reduced O&M fee at this time at which point SGIP incentives will be revisited.

3. The Solar on Multifamily Affordable Housing (SOMAH) program is another program administered by the CPUC that provides financial incentives to offset the cost of a solar PV system for affordable housing. SOMAH is the successor to the Multifamily Affordable Solar Housing (MASH) program that LINC previously used as part of its solar initiative. Designed to maximize community benefits, the program requires that most of the system directly powers tenant meters, but also provides incentives for

common area loads. At least 51 percent of the energy produced by the system must be allocated to tenants via virtual net energy metering. Property owners are not permitted to adjust rents or utility allowances based on the credits. Eligibility requirements include the following:

- Have at least five units
- Be deed-restricted low-income residential housing
- Satisfy one of the following
- 80 percent of property residents have incomes at or below 60 percent of the area median income
- Property is located in a defined DAC that scores in the top 25 percent of census tracts statewide in the CalEnviroScreen
- Be an existing building or retrofit (with Certificate of Occupancy)
- Have separately metered units
- Be a utility or community choice aggregator customer (with VNEM) in the PG&E, SCE, SDG&E, PacifiCorp or Liberty Utilities territories

LINC determined that the project was eligible to apply for the SOMAH rebate program. Based on the size of solar system, LINC determined it was also potentially eligible to receive up to $308k. While SOMAH was not pursued, Virtual Net Energy Metering was.

4. This project ultimately did apply for and utilize a **Virtual Net Energy Metering (VNEM)** tariff. The production and operation of the PV are therefore distributed (allocated) across each of the residential unit meters and the Common Building meter. Under the virtual net metering tariff for low-incoming housing properties, the property owner can choose how to allocate production from behind the meter systems freely to different utility customer accounts. The actual connection of the system is to the common area metering, with submeters for each tenant with a financial reallocation through VNEM.

LESSONS LEARNED

The project team encountered a number of barriers that included, but are not limited to:

- Making the business case for solar + storage pencil out for the affordable housing property owner to cover O&M fees
- Major delays in approvals process for owner and project team to conduct due diligence for its tax credit financed property lenders as required for solar and storage projects
- Permitting and interconnection of an emerging solution with a fairly unique DC side connection of solar and storage with a single inverter

- Finding sufficient roof space on reflective flat roofs for dual sided PV
- Securing compatible DC equipment and expertise for DC distribution and appliance demonstration.
- Finding open interface products for controls schema
- Tenant engagement for energy data release and behavioral DR program onboarding due to pandemic-related "Shelter in Place" restrictions, inconsistent computer and mobile device access and bill subsidies by 3rd party.

Some of the lessons learned are depicted according to the project phase:

PROJECT ENGAGEMENT

Lesson Learned: A general learning is the difficulty today for a multifamily property owner to implement a solar and storage project.

- Most low-income housing is funded through tax credit financing with multiple investors. This type of negotiation took a great amount of time given one of the lender's poor experience with solar PV to get sign-offs from all of its investors. During this time, the system was non-operational and the coordination effort was a drain on the operations staff resources of the property owner.
- The VNEM and SOMAH structure means that the benefits of solar accrue mainly to the tenants. The programs effectively prevent the landlord from charging the tenants for the benefits of solar, which means that the property owners have to justify solar just based on the common area usage. In many cases, common area usage is very limited (in this case only 20,000 kWh a year), and that means that property owners, if they are leasing solar, may not be able to cover the lease payments.

IMPLEMENTATION/DEPLOYMENT

Lesson Learned: DC coupled projects have to budget a substantial amount of time for testing and interconnection to happen, including how the property owner gets compensated for the time that the solar is not operational while waiting for interconnects.

- This project was unique in its DC side connection of solar and storage with a single inverter. Getting through the permitting process required a substantial amount of work with the permitting authority, as they were unfamiliar with a DC side connection. It was also difficult to obtain approval by the local utility, but it was enabled by prior work the vendor had completed with another utility in the State based on a software-based monitoring solution for non-export Rule 21 interconnect.

Lesson Learned: Unless there is sufficient space on reflective flat roofs, installing bifacial PV cannot deliver the full benefit of higher rated efficiencies.

- Canadian Solar 355-watt bifacial panels were installed on available roof space, which included both flat white reflective roofs as well as sloped asphalt shingle roofs. The PV installer then connected multiple strings at different planes of array and with different surface characteristics to an inverter with only one MPPT channel. The effect was the degradation of the overall performance of the modules on the same inverter, even those optimally-mounted, since they share the same MPPT channel and perform only as well as their least-producing module.

BATTERIES

Lesson Learned: Lab testing proved an important checkpoint for simulating and validating the integrated system components, namely the battery and inverter. Also, if possible, equipment purchases should only be made after all stakeholder approvals have been secured, including funder, AHJ, utility, property owner and investors in affordable housing applications.

- Batteries in the 60 kW – 120 kWh size had limited supplier options at the time of the project design. The manufacturer of the selected battery EnergPort was early in its product development and the feedback resulting from the EPRI lab testing of the integrated system helped to further the commercial-readiness of this product for the assembly and application, for which it was being tested. Resolutions related largely to safety, operability and transport including provision of loading/unloading equipment and additional strapping on trays, grounding plan, tray with front facing/external DC disconnect, verification of material selections for durability, verification of thermal sensors, connector ratings, etc.

- Furthermore, the lab testing led to the provision of a NEMA-rated enclosure to protect the indoor rated unit for a carport-enclosed setting. The vendor had purchased the battery prior to the AHJ approval ruling out the electrical room based on inadequate clearances being provisioned, leaving only a carport as a viable alternative.

INVERTERS

Lesson Learned: Manufacturer defects of inverter components caused thermal events in lab and field testing. Power quality issues are common with multiport inverter system integrations. EPRI used M&V equipment to troubleshoot inverter failures as part of the commissioning process.

- Thermal events occurred at both lab testing and in field testing with the inverters. In the former, manufacturer Ideal Power (now owned by CE+T) reviewed the damaged unit and found a manufacturer defect, specifically a burned link transformer relating to a likely breakdown of the Litz magnet wire insulation. The unit was repaired under the warranty. The failed inverter in the field appeared to have melted some solder in the power core, which is a separate part of the inverter that sits above the transformer. EPRI monitored the power quality readings and conducted testing to validate the DC input parameters and to confirm whether it was an installer or manufacturer related issue. CE+T diagnosed the thermal overload as stemming from an atypical issue with the gate drive board. A refurbished unit was shipped back to the site.

CONTROLS

Lesson Learned: A general learning is that the integration of solar, storage and loads (DR) is not as easy as it seems on paper.

- Most demonstrations of load aggregation work with "preferred" products, i.e., products that have been tested in a lab setting to work together. However, reality is different in that the customer end uses are primarily designed for meeting customer needs and chosen by the HVAC contractor, or plumber, etc., such as programmable thermostats. It means that the systems in the field would not necessarily work with aggregation platforms, especially if the product providers do not have open interfaces to equipment. A perfect example of this were the relatively new Carrier wired thermostats which were installed by the HVAC contractor which are not open interface were not compatible with the openDSRIP controls platform and limited the scope of the controllable loads as part of this project scope.

CONSTRUCTION

Lesson Learned: Have a local construction team and dedicated construction manager.

Generally, the construction management consisted of the following regime:

- Proactive Project Management
- Weekly Construction Calls
- Proactive follow-up on approvals with Authorities Having Jurisdiction (AHJ) and SCE for interconnections and permission to operate
- Dedicated Construction Manager
- Covid Protocol

Having a dedicated local construction manager to hold all parties accountable to budget, schedule and funder/stakeholder interests was critical to the success of this project. In addition, it also ensured smooth interaction with property management and residents. On the other hand, having a prime and subcontractor (Gridscape and Staten respectively) based in Northern California created repeated delays in permitting and installation. Having a local design-builder would have been preferable.

OPERATIONS

RESIDENT COORDINATION

Lesson Learned: Having a special resident engagement coordinator with social service/welfare background is highly recommended for transactions involving financial compensation, forms, legalese and account information with a community of affordable housing residents. Simplicity in asks and forms and financial incentives, in the form of cash cards, help a lot.

- Obtaining tenant sign-offs on standard utility energy data releases with the residents was a challenge, which was amplified by Covid social distancing protocol. Forms require a specific account number and format that took multiple iterations and engagement efforts to obtain accurately. Furthermore, many of the residents had their utility bills subsidized, which made approvals a multiple step process since they were not technically the account holder. Also, a number of the residents lacked computer or mobile devices or familiarity with using them. They struggled with the signup for the online DR platform, which required a 2-step verification and required online SCE account access via a phone number established upon sign-up.

- Fortunately, a special resident services coordinator with background in social service was assigned to assist in the effort and issued cash cards as an incentive. After training with EPRI, she interfaced with the residents and walked them through the processes individually, step by step with appropriate levels of sensitivity and training. In this case, incentives helped to rally engagement. Simplicity in the sign-up and release forms process and earlier engagement, especially for these types of efforts, would have accelerated and expanded uptake.

BATTERY

Lessons Learned: The provision of batteries did not pencil out for the affordable housing property owner, affecting the applicability of SGIP and the scalability of a solar + storage solution without a redesigned funding source.

- The cost of the O&M was not justified by the projected cost savings for the battery. The O&M would have been required to guarantee the SGIP utilization requirements would be met to secure the incentive. Without an O&M agreement beyond the 18-month term ending Q3 2022 that has been prepaid by EPRI, the value of the battery is uncertain as the system controller is proprietary and requires maintenance by Gridscape. This is under negotiation with expected resolution in January 2022 by Linc and Gridscape with the support project team as part of the project close-out and hand-off. Gridscape has suggested they will lower the O&M to a more competitive fee.

MARKET IMPACT

BUILDING PRODUCT AWARENESS AND WELL-DOCUMENTED PERFORMANCE HISTORY

The ability to demonstrate the deployed technologies at an affordable multifamily property in Southern California brings a unique opportunity to build their awareness and test their performance, economics and value proposition for low-income residents, affordable housing owners and operators and their stakeholders. This includes utilities like SCE which operates the local distribution infrastructure and implements programs that could incentivize these technologies and make them cost-effective in order to better serve this customer segment with robust energy efficiency and DR offerings.

Informing Industry Stakeholders

Pilot and early adopter customer success stories will be critical to spreading the word on this new technology, which may be shared through a variety of trade publications, webinars, and key industry thought leaders. A key target audience for the project's technology transfer activities included decision makers among affordable housing organizations. This project sought to share this project and the lessons learned to cement the value proposition first-hand, making decision makers increasingly willing to install and incentivize the technology in new buildings and retrofits in the future. As it became available, more supporting performance data strengthens the impact of the messaging and increases the potential to accelerate market adoption of these new solutions.

Government Channels

State government organizations such as California Energy Commission and the CPUC as well as local government organizations were a particularly important target market for technology transfer activities as they represent an additional conduit for sharing information as they produce a variety of forum and publications that have a wide-spread audience throughout the energy and building sectors. Furthermore, they set out relevant standards and (e.g., Title 24 JA12 and Rule 21 Phase 1) and can be informed by the demonstration on low income and affordable housing program implementation requirements.

Utility Channels

Presenting at the EPRI Utility Advisory Council and other utility consortium meetings not only across the State of California but the United States and the world, can assist in disseminating information on the topic that could accelerate technology adoption in energy efficiency and DR funding offerings. The project team focused on technology transfer with utilities that offer low-income energy efficiency and demand management programs.

Summary of Activities

Technical Advisory Committee Meetings

The project included two TAC meetings that were attended by a cross section of relevant market players, representing utilities, government, research, and industry across the US. As part of their committee charge, the attendees provided feedback and steering to the project team based on their technical or market expertise. The attendees are denoted in Table 23 and Table 24.

TABLE 23 - TECHNICAL ADVISORY COMMITTEE #1, APRIL 25, 2019

ORGANIZATION	ORGANIZATION TYPE	NAME
California Energy Commission	Government/Funder	Liet Le, Eric Ritter
Electric Power Research Institute	Research/Prime	Ram Narayanamurthy, Dean Weng
SCE	Utility	Mark Martinez
Linc Housing	Non Profit Housing Developer	Michelle Tirto
PG&E	Utility	Lydia Krefta
PG&E	Utility	Mark Esguerra
Sacramento Municipal Utility District	Utility	Jeanne Duvall
Sacramento Municipal Utility District	Utility	Gabriell Leggett
SDG&E	Utility	Chris Roman
SDG&E	Utility	Kate Zeng
Snohomish County Public Utility District	Utility	Suzanne Frew
Southern Company	Utility	Justin Hill
National Renewable Energy Laboratory	Research Lab	Roderick Jackson
Boy Scouts of America	Non Profit/Property Owner	Jason Lewis
GridScape	Technology Provider	Mark Aiello
Humboldt University	University	James Zoellick
Intech Energy	Technology Provider	Rich Fox
University of Colorado Boulder	University	Gregor Henze
Pennsylvania State University	University	Gregory Pavlak

TABLE 24 - TECHNICAL ADVISORY COMMITTEE #2, JUNE 29, 2021

ORGANIZATION	ORGANIZATION TYPE	NAME
California Energy Commission	Government/Funder	Liet Le
City of Culver City	Municipality	Ashley Hefner Hoang
Electric Power Research Institute	Research/Prime	Agatha Kazdan, Ram Narayanamurthy, Morgan Smith, Siva Sankaranarayanan, Evan Giarta, Ram Ravikumar, Arindam Maitra, Andrea Mammoli, Zack Allen
Gridscape	Technology Provider	Vipul Gore
Kliewer & Associates	Building Scientist	Christie Kjellman
Kliewer & Associates	Building Scientist	Ron Kliewer
Linc Housing	Housing Developer/Site Host	Teri Hoerntlein, Tania Boysen
National Renewable Energy Lab	Research Lab	Roderick Jackson
OhmConnect	Technology Provider	Elliot Marks
OhmConnect	Technology Provider	Srinivas Chaganti
PG&E	Utility	Kelly Cunningham
PG&E	Utility	Rachna Handa
SMUD	Utility	Josh Rasin
SDG&E	Utility	Kate Zeng
Snohomish Municipal	Utility	Suzanne Frew
SCE	Utility	Mark Martinez
UC Riverside	University	Alfredo Martinez-Morales

INDUSTRY CONFERENCES

On October 11, 2019, EPRI presented alongside PG&E and NREL at the **Getting to Zero Forum**. The Getting to Zero Forum is a public forum dedicated to zero energy and zero carbon buildings. EPRI participated in a session, entitled What We Need and What We Have, highlighting Willowbrook as an exemplar resource integration project example. The description of the session was detailed. The audience included international policymakers, design professionals, building owners, systems manufacturers, and commercial real estate experts.

In 2019, EPRI presented the Willowbrook project at **New Energy and Industrial Technology Development Organization (NEDO) Smart Communities Workshop** in Japan. NEDO is a non-governmental organization (NGO) focused on public research and development to implement economic and industrial policies to address global energy and environmental problems and enhancing industrial technology by integrating the efforts of industry, academia and government.

EPRI EVENTS

EPRI also held multiple **workshops** targeting affordable housing owners/developers with low-income program managers at utilities for dialogue on the topic of scalable decarbonization strategies for the low-income multifamily segment were discussed, using the project at Willowbrook as a case study. Table 24 details the speakers at the February 23, 2021 event.

TABLE 25 - LEARNING BY DOING: ENERGY BURDEN, FEBRUARY 23, 2021

ORGANIZATION	ORGANIZATION TYPE	NAME
EPRI	Research/Prime	Agatha Kazdan, Senior Technical Leader
New York City Housing Association (NYCHA)	Affordable Housing Agency	Vlada Kenniff, VP of Energy and Sustainability
Community Housing Partners	Affordable Housing Developer	Cathy Stripling, Green Team Chair
Tennessee Valley Authority (TVA)	Utility	Frank Rapley, Senior Low Income Program Manager
Mercy Housing	Affordable Housing Developer/Owner	Caitlin Rood, National Environmental Sustainability Director

The session was well attended by representatives from, including but not limited to, SDG&E, Southern Company, NYCHA, Seattle City Light, Los Angeles Department of Water and Power, SCE, Salt River Project and others.

EPRI Advisory Meetings address influential utility members that are used to shape EPRI research, develop demonstration and marketing opportunities for technologies and provide a conduit for the advisors to impart information to colleagues at their "home" utilities. Advisory meetings are held twice a year (spring and fall), usually in February and September.

- In 2019, EPRI presented at the EPRI EU Utility Advisory conference citing the Willowbrook project. The audience included EPRI a broad base of international utility members.
- Additionally, on February 2021, EPRI presented the Willowbrook project as one of the highlighted demonstration projects part of a joint presentation between Battery Storage and Advanced Buildings programs. SCE co-presented with EPRI on the Willowbrook project, while Puget Sound Energy, Madison Gas and Electric Company.

EPRI's Electrification Conferences explore the critical issues, benefits, and opportunities of electrification. Session tracks usually include Residential and Commercial Electric Technologies and as such afford an excellent opportunity to transfer project technology information to the target audience. Conference attendees typically include utilities, industry, government, and academic leaders.

In June 2021, EPRI organized an Electrification conference session convening affordable housing owners, program implementers and utilities (see Table 25 for session speakers) to discuss best practices for reaching rural and urban audiences with decarbonization related programming, citing Willowbrook as a multifamily case study.

Table 26 - Urban and Rural Energy Affordability, June 2021

Organization	**Organization Type**	**Name**
National Core Renaissance	Affordable Housing Developer/Owner	Tim Kohut, Director of Sustainability Design
Association for Energy Affordability	Low Income Program Implementer (Focused on Multifamily)	Sarah Hill
Tennessee Valley Authority (TVA)	Utility	Frank Rapley, Senior Low Income Program Manager

EPRI Publications

In September 2021, EPRI drafted an article on the Willowbrook project for the organization's monthly *Electrification* newsletter. In this article, EPRI interviewed project team members and project co-sponsor Southern California Edison. The newsletter goes to a broad audience of relevant utility, government, and industry professionals.

Utility Trainings

Southern California Edison, a project co-sponsor, has used the Willowbrook project as a case study for engineer training that it is offering to its staff starting in July 2021. SCE representative Mark Martinez stated that the utility will be using the lessons from this and other EPRI projects in the utility's future DER forecasting and modeling work as well. "This is a way to see how smart building systems with DERs can be responsive to future dynamic rate designs," said Martinez. "These projects help identify opportunities for future models of DER programs. This and other projects will continue to help us understand how future customer solar and storage systems can provide local grid reliability, and what we can do to help our customers maximize their benefits."

DR Aggregators

The EPRI and OhmConnect teams are actively discussing whether we could use the OhmConnect platform to support another project with SCE and EPRI at a multi-family building community in Irvine, CA.

Virtual Site Visits

EPRI, with Linc Housing LLC, has facilitated one virtual site visit with plans for offering one more upon completion of the DC minigrid installation before the end of the agreement term. The virtual site visit is designed to provide utilities, affordable housing owners and operators, engineers and facility managers the ability to talk directly to the project team and staff and ask them direct and pointed questions about the installed system.

CONCLUSIONS

The purpose of this project is to identify scalable community models to maximize the economic benefits of solar PV energy systems for low-income multifamily populations and to evaluate how these technologies could enable grid flexibility, environmental and other benefits that are beneficial to the entire rate base. The project team set out to test technology innovations that addressed that purpose by installing and testing bifacial PV conversion efficiency, the integration of solar and storage with smart inverters and segmentation of storage for various needs, a platform to manage customer loads, strategies to enable greater grid flexibility and reliability at the distribution system level and the use of DC distribution and appliances to eliminate conversion losses. The results at Willowbrook illustrate benefits that that include lowered costs for the property residents as well as greater load flexibility and environmental benefits for the utility and larger rate base. The demonstration also offers technology implementation pathways and lessons learned for more effective project, program and policy targeting the low-income multifamily sector in California with integrated resource deployments.

ADVANCED SOLAR TECHNOLOGIES

The bifacial PV panels were chosen as a promising technology to address space constraints that are typical in commercial and multifamily applications through higher efficiencies. Bifacial solar PV modules may not provide improved performance, however, where ground reflected irradiance (GRI) cannot be maximized, and array design is not uniform. Module level power electronics may be able to mitigate mismatch between modules and strings. However, MLPE compatible with multiport inverters were of limited availability at the time of procurement. While bifacial PV modules have demonstrated improved yield where these design issues can be addressed, bifacial PV performance gains were not observed because the site design was not optimized for solar exposure. There is a trades education opportunity for solar techs to be trained on how to design for bifacial PV technology. The project also reminds us of a general lesson from the project that certain ZNE and grid flexibility strategies are best adopted much earlier in the site planning and building design phase, such as through the use of passive design principles to minimize load, maximizing solar exposure of roof design and specifying open interface products that can connect with aggregation and control platforms.

SEGMENTATION OF STORAGE

The team modeled 3 scenarios that deployed the storage to address project control objectives to determine which offered the greatest benefits to the property and the rate base. Scenario 1 discharged stored solar energy from the battery to offset TOU prices and provide peak shaving during periods of anticipated high EV charging across the rate base, to maximize solar utilization and to discharge during periods of high carbon-emission from utility-produced power. Scenario 2 which was ultimately implemented at the Willowbrook site was the same as Scenario 2, albeit deploying TOU and GHG reduction objectives only seasonally. Finally, Scenario 3 tested a top-down scenario that prioritized a 10 percent annual peak load reduction at the feeder level while only secondarily addressing other control objectives. Ultimately Scenario 3 proved that the stacked benefit approach was most effective at providing the most notable annual bill savings and net annual peak load reduction for a residential distribution circuit, while addressing the other control objectives 97 percent of the days in the year.

The energy performance of 2021 (post-installation) peaked well before the 4-9pm timeframe but was otherwise quite similar in trend compared to 2020. There was load-shifting from the 4-9pm timeframe to the 12-3pm timeframe which led to the peak around 2pm. Given that this is the "raw" load and not the net load, it appears that the inclusion of exports during the 12-3pm (solar exports minus what is used to charge the battery) and 4-9pm timeframe (battery discharge exports), the load performance for 2021 is expected to be even better. The estimated reduction in energy use compared to 2020 is about 1.48 MWh over the period (June 1 thru September 15, 2021). Note full Project Benefits discussion in Chapter 7.

Platform to Manage Customer Loads

Twenty-one, or roughly one-third, of Willowbrook residents successfully enrolled in OhmConnect, a customized DR aggregation program that bids behavioral demand reduction into the DR Auction market. OhmConnect built out custom messaging and behavioral energy and demand reduction recommendations to prime residents for TOU rates that will take effect in January 2022. During the June to September 2021 timeframe, there were 42 unique events, with 619 resident opt-ins or an average of 16 opt-ins per event. Performance suggests that residents actively engaged and that monetary incentives and gamification mechanisms were motivating factors for participation. Sampled residents participated in at least 50 percent of DR events and saved up to 50 percent compared to their historic baseline.

Distribution System Analysis

Because of difficulties in monetizing grid services from BTM storage, the cost-benefit analysis suggests that all scenarios without outside funding support would bear a negative net present value (NPV). Used to estimate the value of a future stream of payments, a positive number suggests an attractive investment with future cash flows. The NPV for the best performing Scenario 3 was -312,619, which was a negligible improvement over Scenario 1 (1 percent), in which all controls objectives are implemented year-round, and a 64 percent gain over Scenario 2 in which TOU and GHG controls objectives are implemented seasonally. It is extremely important to note, however, that this cost-benefit analysis only monetizes the utility bill savings to the property and excludes any financial benefit from greenhouse gas emissions, net peak load reduction or other distribution services that could defer distribution upgrades nor added customer resiliency from the DC distribution and appliance project scope, which can benefit the property, utility and rate base at-large.

DC Distribution and Appliances

This project shows us that DC sources and loads show great promise as part of a future electrical system for added resiliency and efficiency. Today, each DC-coupling application must be evaluated for technical feasibility within available hardware and codes limits as well as economic feasibility comparing the costs and risks to the potential benefits. The Willowbrook project is proving the technical feasibility through demonstrations of DC-coupled solar, storage, and controlled loads. Demonstration of technical feasibility is often one of the first steps in achieving financial viability for new technologies. Furthermore, it can inform future electrical code updates and represents another workforce training opportunity.

This exercise provided valuable insight into the design process of hybrid AC/DC resilient systems. The primary lesson is that the design of these systems is more complex than it appears. Some of the components were incompatible, although the manufacturer's engagement and interest in such systems may prove to resolve these issues with future product revisions. Some of the components are also hard to find – for example, high-voltage DC breakers. While it was not possible to accurately measure DC/DC conversion efficiency of the 30C3 power converter, keeping the system "all-DC" may not result in the expected efficiency gains. Finally, full integration may require some design changes that allow for integration, for example enabling the PV MPPT controller to work in parallel with the battery charge controller, however this would require cooperation between manufacturers and standardization.

The primary opportunities identified during this lighting implementation are the need to explore expanding availability of 380Vdc or higher voltage DC lighting for optimal efficiency as well as the need to establish availability of UL-listed DC lighting controls.

LESSONS LEARNED

The project revealed the general difficulty in initiating a solar + storage project in a California tax credit-financed multifamily property from making the business case for a property owner to meeting due diligence requirements of its property lenders. There were a number of emerging technologies in scope that required additional time and resources compared to industry standard technologies to source, integrate, design, permit, interconnect install and operate. Funding programs and policy must consider interventions for making low income multifamily solar + storage financially feasible.

RECOMMENDATIONS

Recommendations for scaling solar + storage + DC + controls at low-income multifamily properties taken from the lessons learned at Willowbrook are summarized below:

- Encourage adoption of ZNE and grid flexibility strategies in the multifamily site planning and building design phases, such as through the use of passive design principles to minimize load, maximizing solar exposure of roof design and specifying open interface products that can connect with aggregation and control platforms.
- Create workforce training opportunities for design and application of advanced solar technologies for commercial and multifamily applications addressing solutions for roof constrained applications for solar techs covering bifacial technology and module level power electronics for optimization. Outlets could include the International Brotherhood of Electrical Workers or North American Board of Certified Energy Practitioners or community colleges.
- Promote updates to standards and building codes for general utilization of higher DC voltages. For metering and tariff compliance, inverter metering and controls can be used to ensure NEM integrity. See Chapter 5 on DC-Coupling Technical and Market Barriers for more specific recommendations.

- Convene a manufacturing consortium for establishing common standards for DC utilization design and equipment standards based on California's top use cases. EPRI is happy to facilitate.

- Make incentives available to DC equipment manufacturers to expand availability of DC equipment, such as 380Vdc or higher voltage DC lighting for optimal efficiency as well as the UL-listed DC lighting controls.

- The return on investment of the affordable housing property owner/manager, in particular, needs to be improved to make solar + storage financially viable. While offering clear benefits to the property, utility and rate base, GHG reduction, net peak load reduction and added resiliency cannot be easily monetized into cash flows, just utility bill savings. Incentive structures and/or modifications to SGIP, ITC and VNEM should be explored to help property owners or project financiers with the business case of doing solar + storage, including an assortment of ways to readily monetize benefits to improve the NPV and customer value proposition of solar + storage + DC especially where there are clear, overlapping stakeholder benefits and alignment with State policy.

- Having a specialized resident engagement coordinator with social service/welfare background is highly recommended for engaging and transacting with a community of affordable housing residents, like Willowbrook. Simplicity and straightforward asks, financial incentives and gamification mechanisms, in the form of cash cards and rewards, helped a lot with uptake.

- Power quality issues are common with multiport inverter systems. Lab testing to simulate integrated systems and close monitoring in the field of DC-coupled systems upon commissioning are highly recommended. Also, have a local construction team and dedicated construction manager.

- A list of stakeholders for low income multifamily properties (especially lenders for tax credit financed properties) should be established at the project onset to ensure all are consulted on the project terms. Equipment purchases should only be made after ALL stakeholder approvals have been secured including permitting authorities, utility, property owner and investors in affordable housing applications.

BENEFITS TO CALIFORNIA

This project delivers benefits to California in the form of lowered costs, greater reliability, increased safety, economic development and environmental safety, public health, consumer appeal and energy security.

LOWERED COSTS

The project is projected to demonstrate energy savings of 137 MWh to the grid on an annual basis just from the solar generation. If we add in another 10 percent savings through reduction in losses, we will save 151 MWh per year just from this one project. The energy and demand savings translate to lower utility costs to serve ratepayers, and ultimately results in lower costs allocated to ratepayers. Extending the results of this project to California's deed-restricted affordable multifamily households shows potential for a bill reduction of $253 million for California's low-income households. (~10 percent of California multifamily households are deed-restricted affordable multifamily)

GREATER RELIABILITY

This project will demonstrate an integrated solar, storage and end-use load platform to test control scenarios that can support greater grid reliability while supporting intermittent renewable energy resources. This project can reduce evening demand by 8.6 percent during TOU peak periods, which will contribute to increased grid reliability, ultimately benefiting all California ratepayers. The project team worked closely with the local utility, SCE, to study the distribution grid impacts (i.e., voltage, thermal, protection) that these DERs can potentially mitigate.

ECONOMIC DEVELOPMENT

This project created new jobs equivalent to eight person-years (five funded by the grant, three funded by match share). This can be scaled to significant job growth if similar retrofit work is conducted statewide for the target sector. The reduction in energy bills and DR participation payments also leaves tenants with greater disposable income, which is particularly impactful for low-income populations, which constitute nearly 20 percent of all California ratepayers.

ENVIRONMENTAL SAFETY

This project has the potential to reduce greenhouse gas (GHG) emissions due to the installation of renewable energy and energy efficient technologies. Extending the results of this project to California low income multifamily households shows a potential for energy use reduction of 1,182 GWh per year, which translates to statewide CO2 reduction of~ 83,331 metric tons per year, for California's low-income populations. (20 percent of California's ratepayers are low-income; 75 percent of low income are multifamily.)

PUBLIC HEALTH

This project improves public health by reducing pollution and GHG emissions. This project also tests a resilience strategy in DAC through the DC distribution and appliance demonstration, which theoretically can help with populations in need of continuous power for medical devices during an outage.

CONSUMER APPEAL

This project is enhancing a sustainable, LEED-certified urban in-fill, mixed use and transit-oriented property that allows people to live close to employment. This project will provide key insights and enhance the comfort and affordability of this housing to further consumers interest in renting and owning it.

ENERGY SECURITY

The reduction of energy usage via energy efficiency and renewable measures provides energy security by avoiding resources needed to build more power plants and being more self-sustained for energy requirements. This project has the engagement of major California IOU SCE and affordable housing developer Linc, which are using the results of this work to inform their future planning and development.

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GLOSSARY

TERM	DEFINITION
CAISO	California Independent System Operator
CARE	California Alternate Rates for Energy
CO2	Carbon Dioxide
DC	Direct Current
DR	Demand Response
GHG	Greenhouse Gas Emissions
HVAC	Heating Ventilation and Air Conditioning
IOU	Investor-Owned Utility
kW	Kilo Watts (Electricity)
kWh	Kilo Watt Hours (Electricity)
LEED	United States Green Building Council Leadership in Energy and Environmental Design (Green Building Standard and Certification)
MW	Mega Watts (Electricity)
MWh	Mega Watt Hours (Electricity)
PV	Photovoltaic
SOC	State of Charge
TOU	Time of Use
VRF	Variable Refrigerant Flow