Electric Vehicle Charging Impact Study

Overgeneration Mitigation Electric Vehicle Charging Report

DR20SDGE0001

Prepared for:

Emerging Technologies Program
San Diego Gas & Electric Company

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Acknowledgements

San Diego Gas & Electric's (SDG&E's) Emerging Technologies Program is responsible for this project. It was developed as part of SDG&E's Emerging Technologies Program under internal project number DR20SDG0001. Alternative Energy Systems Consulting, Inc. (AESC) conducted this technology evaluation with overall guidance and management from Jeff Barnes. For more information on this project, contact ETinfo@sdge.com.

EXECUTIVE SUMMARY

The successful implementation of solar photovoltaic in California has resulted in a monumental shift of our daily grid net demand profile. So much so, that net demand dips well below historic usage profiles and has shifted our peak demand period from the middle of the day to the evening hours (4:00 pm – 9:00 pm) and has led to the infamous duck curve. This discrepancy has become so pronounced that California has been forced in certain circumstances to curtail renewables or rely on neighboring states to offload excess generation or overgeneration.

One promising mitigating factor for the overgeneration is workplace electric vehicle (EV) charging in facilities that have solar generation. Shifting load from grid net metering to EV charging, during daylight hours, has the potential to help offset the impact on the grid.

Plug-in EVs integration in California transportation is ever increasing. There has been recent legislation that mandates 100% electric new vehicles sales by 2035. All vehicle manufacturers have been ramping up their EV offerings with some committing to completely electrify their entire model lineup this decade (Mercedes-Benz, 2023).

The EV revolution combined with workplace charging offers not only needed grid relief but also provides California's utilities an opportunity to participate in a very substantial decarbonization effort. Shifting from fossil fuels to electricity will not only reduce California's carbon footprint but will also increase the overall load on the grid. Workplace charging generally occurs at the right time to help counteract overgeneration. However, this growth must be understood, forecasted, and managed.

PROJECT GOAL – The objective of this study is to identify the mitigation potential, to understand how EV charging will interact with other distributed energy resources (DERs) within a workplace, and to assess financials. This study will help inform the next steps by identifying what information is needed to further promote and direct appropriate workplace charging.

TECHNOLOGY DESCRIPTION - The technology assessed in this study is the interaction of workplace EV charging with solar and battery operations and its time valued impact on the grid. It is partially a behavioral study to understand when charging and building load occurs and how that fits into a managed load flex building.

Because workplace charging generally occurs when workers and guests occupy the building, typically during daylight hours, the chargers can operate when solar charging is most likely to occur. This allows the facility to "charge on sunshine" at least to some extent. The battery energy storage system (BESS) allows the building to store excess solar generated energy for future consumption. The MelRok Touch controller allows a signal to be sent to the BESS for charge/discharge based on some predefined optimization.

Grid, energy costs, and emissions optimizations can be counter beneficial to one another. This study primarily looks at whether workplace charging can help support the grid by redirecting energy that would have been sold back to the grid into charging vehicles. Secondarily the study intends to show how customer energy costs will be affected by the additional EV consumption.

Benefits for this study will be demonstrated in the time dependent shifting of energy from grid net metering to EV charging.

PROJECT FINDINGS -- The study evaluated the following four hypotheses.

Grid Impacts - The study found that even with minimal utilization, EV charger usage was impactful on the building's export to the grid. As charger utilization increases to reasonable levels, the impact will be much greater. For example, if utilization was at 75% for this site, most of the grid export would be removed.

Timing - Workplace charging generally occurs when net demand on the California grid dips ("belly of the duck") and it generally subsides during the ramp up to the peak demand period ("neck of the duck"). The study clearly demonstrated that the increased demand occurred at the right time. Because a sizable majority of commercial businesses operate during the "daylight" it is expected that workplace charging will greatly offset solar net metering.

Utilization - It's widely known in the transportation electrification industry that charging utilization is the key to making a business case for financial return on investment However, utilization is also key to making a big enough impact so that the site can take advantage of excess solar and lower cost electricity. Individual site utilization is an important objective because as more sites are aggregated, the effect becomes incrementally more impactful on the grid.

Costs - In this specific case, the chargers and installation costs were fully covered and building management did not intend to make a profit. It is clear from the data that they are substantially able to recoup costs. Since the chargers are powered during the solar period an argument can be made that EVs are being fueled by solar generation. Management is charging approximately 21 cents per kWh to charge which translates roughly to $1.60 per equivalent gallon.

PROJECT RECOMMENDATIONS -- Workplace EV charging offers the state of California a means to tackle overgeneration and flatten daily grid demand. Electrification, especially transportation electrification, offers California utilities a unique opportunity to add growth. However, this growth must be understood, forecasted, and managed. The following next steps are recommended:

- Expand the study to include a variety of other workplaces and operating hours. Obtain a better understanding of utilization and how to increase individual workplace usage. Develop workplace charging potentials by building type.
- Perform a characterization study of market potential for workplace charging in CA. Include existing and projected solar workplace estimates.
- Project statewide impact using study findings and market potential. Incorporate findings into resource adequacy forecasts.
- Develop an incentive or rebate program promoting workplace charging that specifically encourages daytime charging. Develop individual measures based on total system benefits.

ABBREVIATIONS AND ACRONYMS

BESS	Battery Energy Storage System
BTM	Behind the Meter
CAISO	California Independent System Operator
DER	Distributed Energy Resources
EVSE	Electric Vehicle Service Equipment
EVSP	Electric Vehicle Service Provider
GHG	Greenhouse Gas
IPMVP	International Performance Measurement and Verification Protocol
MW	Megawatts
PV	Photovoltaic
VGI	Vehicle Grid Integration
ZEV	Zero Emission Vehicle

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INTRODUCTION

The successful advancement of solar photovoltaic (PV) generation in California has resulted in the infamous duck curve and the realized threat of overgeneration. The state has experienced overgeneration events over the past several years to curtail renewables or rely on neighboring states to off-load the excess generation (Figure 1). On the surface, electric vehicle (EV) workplace charging is a natural solution to this over-production while simultaneously reducing the largest single source of greenhouse gas (GHG) production in the state. Conversely, solar generation and charging demand are highly variable (time dependent and/or sporadic) and the actual impact to the grid is complex and not easily modeled.

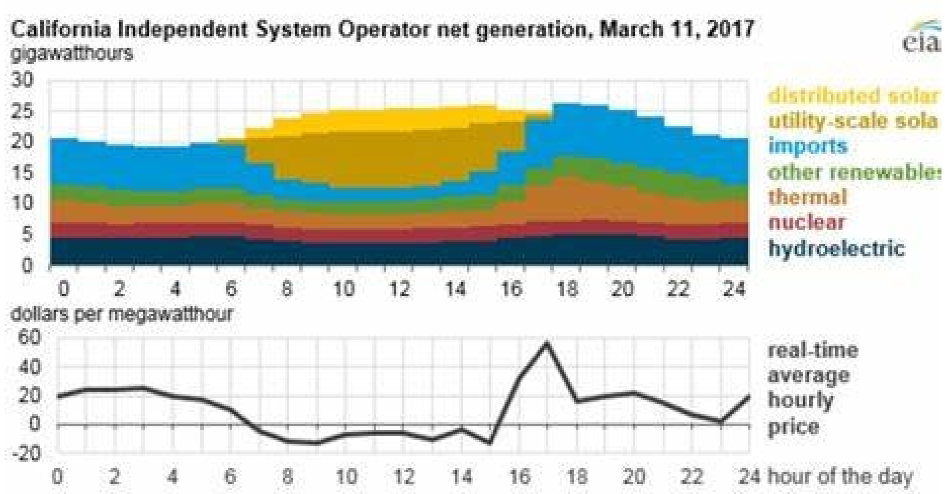

FIGURE 1. EXAMPLE OF NEGATIVE CAISO ENERGY REAL-TIME PRICING MARCH 2017 (SOURCE: EIA)

Intelligent control of stacked Distributed Energy Resources (DERs) provides the promise of optimizing energy cost for the energy consumer. However, the positive transmission and distribution (T&D) advantages, characterized as net grid impact, are a very important grid-level benefit that should be studied and understood. Customer energy savings and grid benefits need to be considered together so that they both can be maximized to their fullest extent.

This study analyzes typical EV charging behavior in a commercial building, within SDG&E's territory, outfitted with a rooftop solar PV system and battery energy storage. The building's BESS is managed by a MelRok Touch intelligent gateway device. The primary objective of this field study is to understand if workplace EV charging can help offset the amount of net metering the building produces, while continuing to optimize for solar/battery energy storage system (BESS) cost benefits.

Intelligent DER management has become crucial to California's needs as it transitions from traditional on-demand generation to renewable generation. Behind the meter (BTM) control strategies and devices will become critical to better manage the time dependent nature of DERs and the subsequent transition to transactive energy and real-time pricing tariffs.

Understanding the interactive nature of the specific generation assets, storage, and controllable loads is essential to this pursuit.

The vast majority of BTM DERs are currently optimized for their individual use based on specific objectives such as customer costs. This study will look at the interactive nature of the DERs and determine whether positive grid impacts can be achieved while maintaining customer value and services.

This study specifically examines workplace charging in a commercial building, but parallels can be drawn to any facility that has workers who park their vehicles on site for significant periods during daylight hours. This study does not explicitly assess the control gateway device; however, it is evident that a control scheme must be employed to shift and shed energy away from the utility’s peak demand periods. This is an important element to best utilize renewable and off-peak utility energy.

Considering ever-increasing customer solar generation and EV charging loads, the ability to shift/shed building energy is essential for the commercial and industrial market segment and for the grid in general.

BACKGROUND

California and SDG&E have been at the forefront of EV research since the 1980s. However, it wasn't until the advent of advanced commercially available battery technology within the last two decades that transportation electrification became a viable alternative to internal combustion engine vehicles. In 2020, Governor Newsom signed Executive Order N-79-20 that directs the state to require that, by 2035, all new cars and passenger trucks sold in California be zero-emission vehicles (Executive , 2020).

The advancement of EV technology and the interjection of the regulatory requirements have resulted in the need for substantial increases in charging infrastructure in California and the U.S. There has been a discernable undercurrent of excitement in the transportation electrification industry, as there is now tangible evidence that we have reached the tipping point in the EV transition. According to the SDG&E 2022 report Path to Net Zero, SDG&E service territory will have 900K EVs by 2030 and 3,230K EVs by 2045 along with a 96% increase in energy and a 60% increase in net peak demand between 2020 and 2045 (SDG&E, 2022). Substantive regulatory policies have been enacted and an initial wave of substantial charging infrastructure funding has been allocated through the federal Infrastructure Investment and Jobs Act (IIJA). Bipartisan political will seems to have finally become a reality as energy, transportation, and security concerns have merged to show transportation electrification is a national priority. It is now up to the individual states to act and wisely invest this seed money as it is estimated that $87B nationwide is needed to get up to speed (Allen, 2023).

Simultaneously, the penetration of home solar generation reached significant proportions. The Solar Energy Industries Association (SEIA) estimates that in the second quarter of 2023, there was 41,675 megawatts (MW) of solar capacity and a growth projection of an additional 21,002 MW over the next five years (SEIA, 2023). This unprecedented growth has led to a phenomenon in California of instances of overgeneration where the state produces more energy than it requires. The reduction in demand can be seen in daily net load profiles referred to as the duck curve. Figure 2 from the U.S. Energy Information Administration (EIA) shows the "belly of the duck" getting progressively deeper as more solar and other renewable generation is brought online.

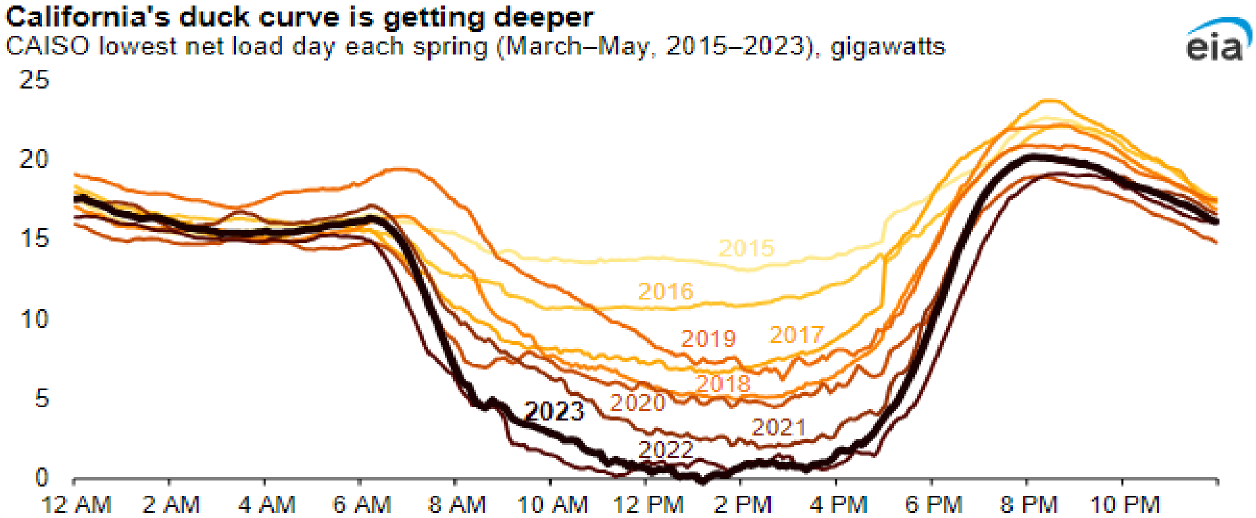

FIGURE 2. CALIFORNIA SPRING NET LOAD - DATA SOURCE: CALIFORNIA INDEPENDENT SYSTEM OPERATOR (CAISO)

According to the office of the governor, "The transportation sector is responsible for more than half of all of California's carbon pollution, 80 percent of smog-forming pollution and 95 percent of toxic diesel emissions – all while communities in the Los Angeles Basin and Central Valley see some of the dirtiest and most toxic air in the country". The transition to zero emission vehicles (ZEV) and hybrid vehicles (primarily Plugin EVs) will substantially reduce emissions throughout the ZEV transition.

EMERGING TECHNOLOGY/PRODUCT

This study investigated the interaction of workplace EV charging with solar PV and battery operations and its impact and timing on the grid. It is partially a behavioral study to understand when charging and building load occurs and how that fits into a managed load flex building.

The physics behind the underlying EV charging and BESS technologies are established and well understood. The load flex (shifting of load from one time-period to another) in the building is primarily based on BESS charge and discharge timing. Other, less common elements, such as hot water control, thermal energy storage, building thermal sink, and lighting control were not implemented at the building.

Workplace EV charging generally occurs when workers and guests occupy the building, typically during daylight hours. Thus, EV chargers can operate when solar generation occurs. This allows the vehicles to "charge on sunshine" at least to some extent. The BESS allows the building to store excess solar generated energy for future consumption. The Touch controller allows a signal to be sent to the BESS for charge/discharge based on a predefined optimization.

ASSESSMENT OBJECTIVES

This project is a field study of stacked DER technologies. A building's demand profile will be assessed by comparing an EV charging scenario to a non-EV charging scenario. SDG&E can use these results to better inform their promotion of EV charging, future rate structures, and resource adequacy as EV adoption increases.

The goal of this field study is to identify and quantify the benefit of interconnected workplace EV charging by means of mitigating solar overgeneration. The results should provide insight into the potential for mass transportation electrification adoption's ability to achieve this goal.

It is anticipated that workplace EV charging will have a net positive impact on solar overgeneration. In simplest terms, workplace charging and solar generation should occur concurrently so that generation can be effectively directed to the EV batteries instead of the grid.

The following questions were examined in this field study:

- Can EV charging help mitigate the impact of solar overgeneration on the grid?
- Can a BESS be utilized to help flatten the energy usage curves and is day-time EV charging counterproductive to shifting of demand?
- What charging utilization threshold must be achieved to attain reasonable impact and how long does it take from launch to achieve the threshold level of usage?
- Is workplace charging cost effective for site hosts?

Grid, cost, and emissions optimizations can be counter beneficial to one another. This study primarily looks at whether workplace charging can help support the grid by redirecting energy that would have been sold back to the grid into charging vehicles. Secondarily the study intends to show how customer energy costs will be affected by the additional EV consumption. The BESS in this study was programmed to provide demand cost optimization. The BESS was charged during solar generation and discharged during the On-Peak demand period of 4pm to 9pm

Another component of the study was to understand when and at what level building occupants charge their EVs in a typical office workplace environment.

TECHNOLOGY/PRODUCT EVALUATION

The field study was performed at a 57,000 sq. ft. commercial office building in SDG&E's territory. The testing occurred over the course of one full year (January 2021 – December 2021) examining the real-world impact of introducing EV level-2 charging to a building with existing solar PV and battery. The test building, located in Carlsbad, CA, was equipped with a 90 kW (AC) solar PV system, a 30 kW /40 kWh BESS. In 2020, four Level-2 EV charging stations (eight ports) were installed through an Electrify America grant.

A field study was deemed most appropriate for this assessment because the primary objective was to determine if workplace EV charging has potential to offset overgeneration in California. The study was also aimed to inform how utilities can use this information to promote transportation electrification and plan for future resource adequacy. COVID-19 quarantine certainly affected workplace attendance, but the impact was order of magnitude and not necessarily impactful to the shape of the load profile. Additionally, the study looked at how existing solar and battery overlaps and interacts with EV charging and it was important to have the field study to understand this real-world impact.

The assessment occurred in SDG&E territory of Carlsbad, CA. Carlsbad is a coastal community, and the weather is temperate year-round. This was an ideal site for the pilot because there are few hot days that significantly reduces the solar net metering. The site had been a subject of a previous SDG&E study and solar, battery and instrumentation were existing and in place. The site was deemed a good candidate to represent a typical mid-size office building in the state.

Test data were measured though several on-site and cloud-based data collection systems including building power (utility meter), electric vehicle services provider (EVSP) sessions (charging events), solar inverter, battery inverter, and EV energy. Additional data was obtained through the California Independent System Operator (CAISO) and the San Diego County Health and Human Services Agency for COVID-19 data.

The test site needed to fulfill the following criteria to act as a field pilot for this study:

- Located within utility service territory
- Existing and sufficiently sized solar, battery, and EV charging
- Mid-size office building
- EVSP backend data system
- Typical office operating hours (i.e., 8am – 5pm)
- On TOU tariff rate schedule
- Willing management company
- Master metered in common areas
- Open during COVID-19

TECHNICAL APPROACH/TEST METHODOLOGY

The project assessed the ability of workplace charging to offset or mitigate importing energy to the grid. Secondarily, it evaluated the interaction of solar PV generation and BESS with EV charging. A separate SDG&E project, previously commissioned and executed, tested the solar PV and BESS's ability to reduce peak demand and customer energy costs.

The system was monitored for one year, 2021, and the results were analyzed following the data collection. Twelve months of data were appropriate to understand the behavioral aspects of workplace charging and the resulting impact.

PROJECT KICKOFF

In June of 2020, AESC initiated the study with a project kickoff meeting followed shortly after by an on-site assessment of building equipment, electric panels, building control systems, and overall facility layout. During the meeting, AESC presented SDG&E with a list of potential study areas, and collectively agreed to tentatively proceed with the four objectives in this paper. In October 2020, AESC executed a planning meeting with SDG&E and considered:

- Review of initial data
- Study period length and timing
- Review and finalize study objectives

One of the main issues discussed was project timing. Because COVID-19 was in full swing, the impact of the work from home order and reduced workplace attendance was reviewed and assessed. Figure 3 shows the comparison of electric charging (kWh) between a pre-COVID and COVID period. The pre-COVID period showed 83% charge days value versus 45% for the COVID period. Additionally, the level of charging was reduced to approximately half the energy for the COVID period. Ultimately, it was decided to move forward and to extend the test period to the full calendar year 2021.

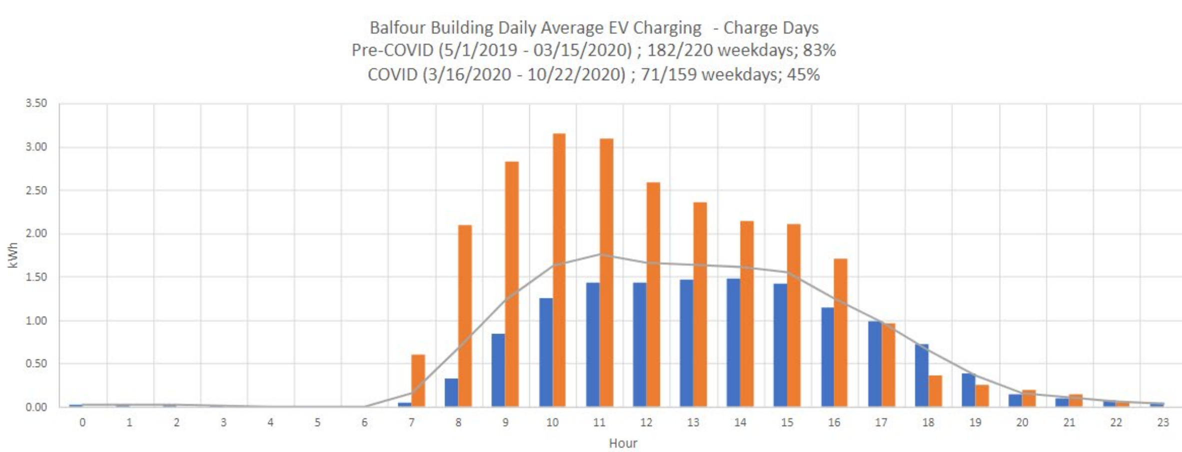

FIGURE 3. COMPARISON OF PRE-COVID AND COVID PERIOD DATA

FIELD TESTING OF TECHNOLOGY

This study looks at a system of technologies and their interactions internally within the building and externally to the grid. The building is at the top of the hierarchy covering the operation of individual systems of common loads (lighting, HVAC, elevators, etc.), solar PV generation, BESS, EV charging power, and EV charging sessions.

This site was selected because it contained all the necessary DERs, was in SDG&E territory, and represented a typical workplace. The site was not meant to be a statistically significant sample but rather a typical representation of a workplace.

Four level 2 EV chargers (dual port) were newly installed at the test building in 2021. The EV chargers are available to tenants and guests through a Greenlots backend system. EV drivers are charged approximately $0.21/kWh. The chargers are accessed through the front panel using a smart phone application or through an existing Greenlots RFID. Figure 4 exhibits the pedestal charger display panel and Greenlots network information.

FIGURE 4. BALFOUR EV CHARGER WITH GREENLOTS NETWORK

Data is captured by the Greenlots in two different ways: 1) the backend system captures the charge session data including vehicle ID, start/stop charge times, energy provided, and revenue; and 2) Energy meter at the subpanel records the time series energy data that the bank of chargers consumes. The session data was obtained from the Greenlots cloud-based interface, and the power data was logged and downloaded from the subpanel in the building's electrical room.

Baseline data was established by simply subtracting the measured EV load from the net demand. The differential between the two is the impact EV charging has on the building and grid. Testing adhered to IPMVP Option B: Retrofit Isolation (all Parameter Measurement).

TEST PLAN

The study compared net energy changes of an office building with and without EV charging. Because the EV chargers were recently installed, the equipment was assumed to be performing at original specifications. Degradation of all other measured equipment was accounted for as part of the exiting building performance and did not impact the energy analysis.

The building is on the Schedule TOU-M tariff rate. All time-series data will be associated with appropriate TOU Period for peak analysis and costing. Table 1 shows the time periods.

TABLE 1. TIME PERIODS FOR SCHEDULE TOU-M

SCHEDULE TOU-M Sheet 3

GENERAL SERVICE - SMALL - TIME METERED

Time Periods (Note: for Grandfathered TOU periods, see SC 13)

All time periods listed are applicable to local time. The definition of time will be based upon the date service is rendered.

TOU Period – Weekdays	Summer	Winter
On-Peak	4:00 p.m. – 9:00 p.m.	4:00 p.m. – 9:00 p.m.
Off-Peak	6:00 a.m. – 4:00 p.m.; 9:00 p.m. – midnight	6:00 a.m. – 4:00 p.m. Excluding 10:00 a.m.–2:00 p.m.in March and April; 9:00 p.m. - midnight
Super-Off-Peak	Midnight – 6:00 a.m.	Midnight – 6:00 a.m. 10:00 a.m. – 2:00 p.m. in March and April

TOU Period – Weekends and Holidays	Summer	Winter
On-Peak	4:00 p.m. – 9:00 p.m.	4:00 p.m. – 9:00 p.m.
Off-Peak	2:00 p.m. – 4:00 p.m.; 9:00 p.m. – midnight	2:00 p.m. – 4:00 p.m. 9:00 p.m. - midnight
Super-Off-Peak	Midnight – 2:00 p.m.	Midnight – 2:00 p.m.

Seasons:

Summer June 1 – October 31

Winter November 1 – May 31

SPECIAL CONDITIONS

1. Definitions: The Definitions of terms used in this schedule are found either herein or in Rule 1.
2. Voltage: Service under this schedule normally will be supplied at a standard available Voltage in accordance with Rule 2.
3. Voltage Regulators: Voltage Regulators, if required by the customer, shall be furnished, installed, owned, and maintained by the customer.

Instrumentation Plan

The study measured multiple subsystems to understand the interactive impact of the EV chargers:

- Solar Photovoltaic
- Battery Energy Storage System
- Building Power
- Electric Vehicle Power
- Electric Vehicle Sessions

The study also pulled public data to supplement the understanding of building and grid operation:

- COVID-19 Testing
- Grid Demand Data

Most of the data collection was in-place at the onset of the project. An Onset Hobo datalogger was installed, at the panel, to capture input energy for the aggregated four EV charging devices. The BESS controller and communication cards were replaced by the battery manufacturer.

The Solar, BESS, and Utility Meter were used in a previous SDG&E project and calibrated at that time. The EV session data was part of the newly installed charging equipment and commissioned by Electrify America contractors. The EV power datalogger was spot checked with a calibrated power meter.

Table 2 lists all variables used in the study and their source.

Table 2. Variables and Source Instrumentation

Variable	Units	Collection Device	Sensor	Comment
EV Charger Input Power	kW/kWh	Direct Download - Site Datalogger (Onset Hobo)	Current Transformers	Voltage measured once; 3-phase current converted into power
EV Charging Sessions Energy Output	kWh	Cloud – Greenlots Backend	Onboard monitoring	Event data
EV Charging Sessions Duration and Count	Hours, ID	Cloud – Greenlots Backend	Onboard monitoring	Event data
EV Sessions Revenue	$	Cloud – Greenlots Backend	Payment system	Event data
Building Power	kW/kWh	Cloud - MelRok Touch through Rainforest	Utility meter reading device	Net energy with consumption and generation

Battery Charge/Discharge	kW/kWh	Cloud - MelRok Touch through BESS controller	Onboard monitoring	Data collection only operational October – December 2021
Solar Output	kW/kWh	Cloud - Solar System Inverter	Onboard monitoring	
COVID-19 Testing Positivity	Number	Website	Survey	Used to judge "work at home" impact
Net Demand	kW	CAISO	Aggregate Power	Daily profile

Time series data was captured in one-minute or 15-minute intervals. Data was then rolled up to one-hour, daily, and monthly values and combined for analysis and reporting. Electric vehicle session data was captured per event and COVID-19 data was captured per day. All data other than the EV Vehicle Power data was downloaded from the secure cloud. The EV vehicle power data was downloaded from a datalogger on site.

All data, except the BESS, was monitored for the entire year. The BESS was only operational for the last six months of the year because of a faulty controller. The onboard data collection system was functional for October, November, and December. Operating strategy was extremely consistent during its functional period and was simulated for the rest of the study period.

Data periods and handling meets or exceeds requirements in IPMVP. Time series data was downloaded from the cloud and on site on roughly a monthly basis. Event based data was downloaded roughly every two months.

RESULTS

The field study found that while workplace charging helped reduce the amount of back feed to the grid, the results were less impactful than anticipated. This is partly due to the low EV charger usage resulting from the substantial reduction of the workforce in the office during the COVID-19 pandemic. Low charger usage is also related to the fact that the charging stations had been newly installed in 2020 and the site hadn't had proper "soak time" to attract new customers. Additionally, the building owners chose to maintain the chargers primarily as an amenity to their tenants. As such, they have not advertised charging on public sites such as PlugShare.

To fully assess the effectiveness of workplace EV charging to mitigate overgeneration, and to ascertain the appropriate impact on utility programs and tariffs rates, the following elements, based on the hypothesis, were individually evaluated:

- **Grid Impacts** – Is net energy and demand from solar generation converted to beneficial consumption?
- **Timing** – Does workplace EV charging occur during useful times of the day, and can energy be shifted by a BESS to additionally help flatten the usage curves?
- **Utilization** – What level of workplace charging is necessary to make a significant impact?
- **Costs** - Is workplace charging cost effective for site hosts?

GRID IMPACTS

Over the test period (calendar year 2021) there were 328 charge sessions that resulted in $1,659 ($5.06 average per session) in revenue for the building owners. According to session data, charging accounted for 7,949 kWh in total annual energy usage and 4.75 kW in average demand. According to charging energy data, the total energy used was 8,164 kWh, the differential accounting for the ancillary energy used to power the charger electronics such as control panels. Table 1 shows the average energy usage and demand associated with EV charging during charge days.

TABLE 1. EV CHARGING COINCIDENTAL ENERGY AND DEMAND

TOU PERIOD	DAILY AVERAGE EV ENERGY	DAILY AVERAGE EV DEMAND	DAILY AVERAGE PEAK EV DEMAND
Off-Peak	27.95	2.29	6.71
Peak	9.24	1.85	3.05
Super Off-Peak	3.57	0.38	1.18

Figure 2 shows the average weekday change in net energy with and without the EV charging. Solar PV generation, BESS load, building load, and EV charging load are also presented for context. The difference between the red and purple lines represent the impact.

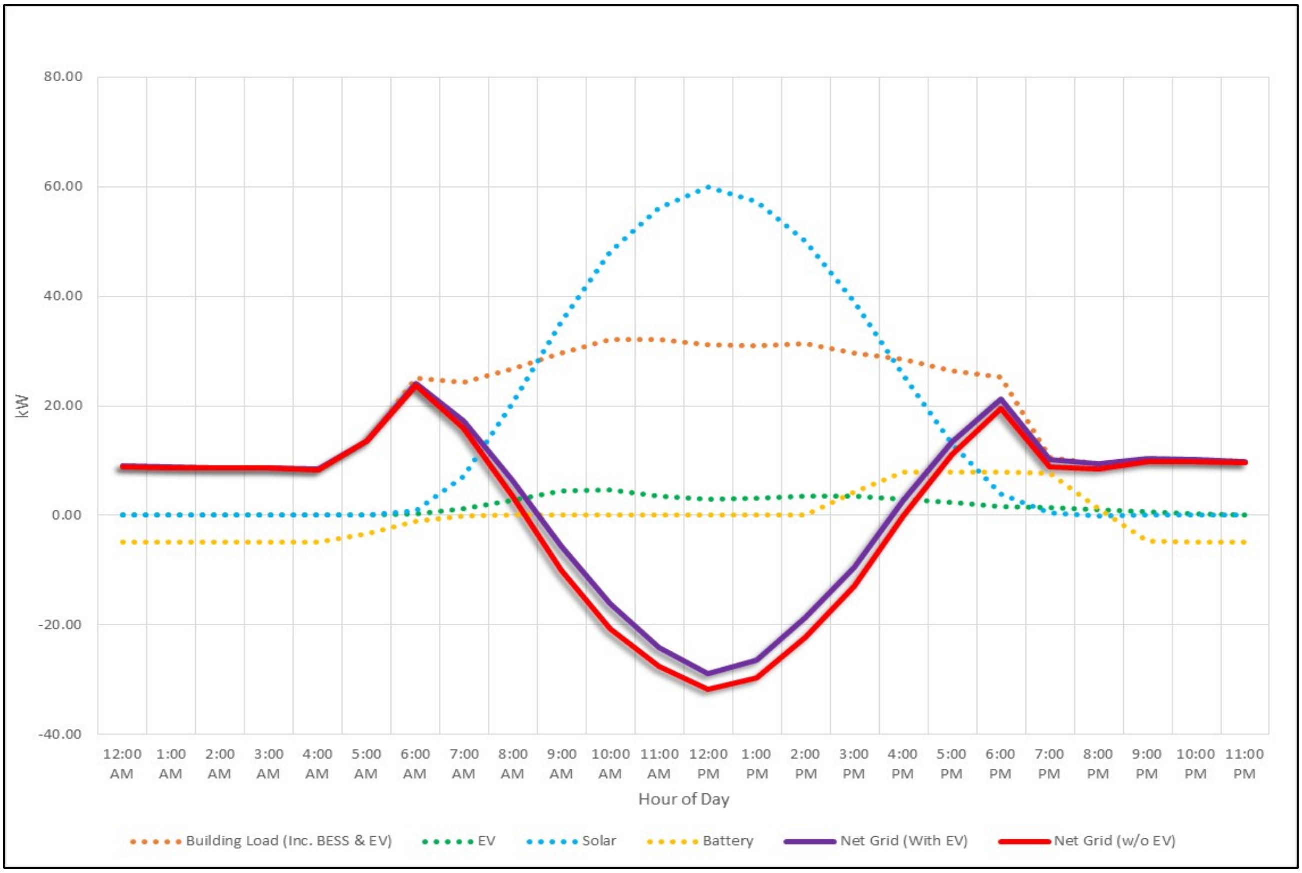

FIGURE 5. BALFOUR AVERAGE WEEKDAY OPERATIONS (DURING CHARGE DAYS)

TIMING

The field study found that the workplace charging occurred appreciably coincident to grid overgeneration. Figure 6 compares weekday average grid demand in CA and EV charging data for March 2021, which was selected because it recorded the most overgeneration. As shown, EV charging begins to ramp up in the morning around 7:00 am – 8:00 am as building occupant arrives. Charging peaks at 9:00-10:00 am as staff continue to arrive and plug in. The EV charging begins to drop around 11:00 am – 12:00 pm as EV batteries begin to fill and people leave for lunch. Active EV charging is at its lowest at 6:00 – 7:00 pm but there is a small increase at 7:00 – 10:00 pm when staff is presumably working late.

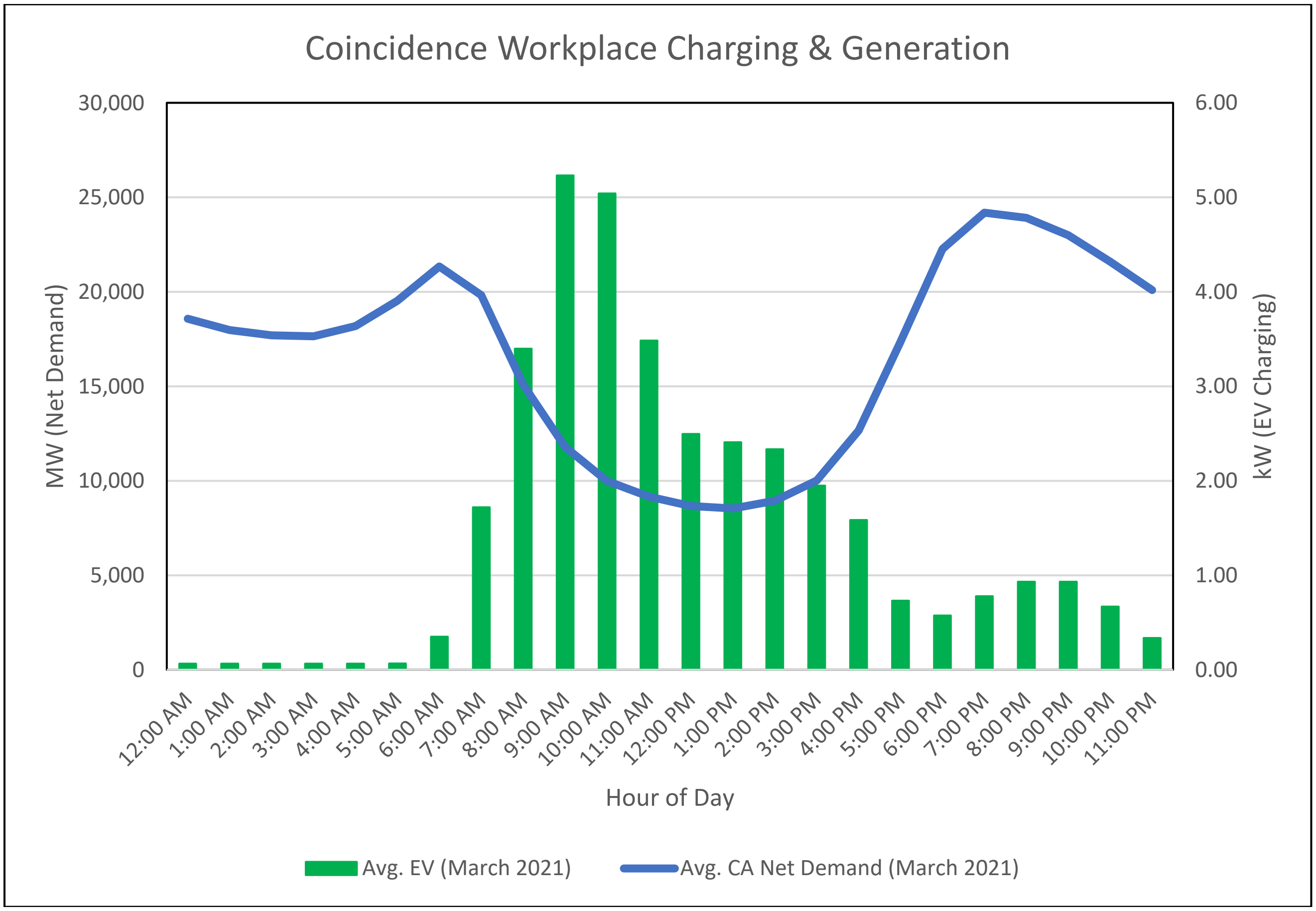

FIGURE 6. COINCIDENT CHARGING AND GENERATION (SOURCE: CALIFORNIA ISO WEBSITE WWW.CAISO.COM)

The test building was on the Schedule TOU-M General Service – Small – Time Metered (see above) tariff. Because the EV charging was installed at a workplace, most of the charging occurred during the working daylight hours when staff vehicles are parked and connected. Table 3 shows this phenomenon with most of charging occurring during Peak and Off-Peak hours and less than 9% of all charging occurring during the Super Off-Peak period. One item of note is that the tariff includes a provision that shifts the 10:00 am – 2:00 pm period from Off-Peak to Super-Off-Peak during March and April.

TABLE 3.MONTHLY PERCENTAGE CHARGING BY PERIOD

TOU PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOT
Off-Peak	83%	84%	48%	50%	80%	77%	88%	93%	70%	67%	52%	56%	69%
Peak	14%	15%	13%	10%	19%	22%	10%	4%	28%	32%	47%	43%	23%
Super Off-Peak	3%	2%	39%	39%	1%	1%	1%	2%	2%	1%	1%	1%	9%

Figure 7 shows the average EV charging daily profile, by peak periods, against the BESS charge and discharge cycles. A secondary finding of this study is that the BESS did not significantly affect the benefits to the grid from the EV charging. The BESS was programmed to charge during super Off-Peak hours and to discharge during the Peak hours primarily to reduce peak demand charges. When the EV charging began at 6:00 am, the battery was already in 100% state of charge. The BESS began to discharge at 4:00 pm but there was still sufficient load in the building and solar production to overshadow the diminishing load of the EV chargers. At 6:00 pm, the solar has almost stopped producing and the battery was discharging at full capacity. Thus, the BESS did not significantly affect the EV charging's benefit to the grid. Figure 4. shows the average EV charging daily profile, by peak periods, against the BESS charge and discharge cycles.

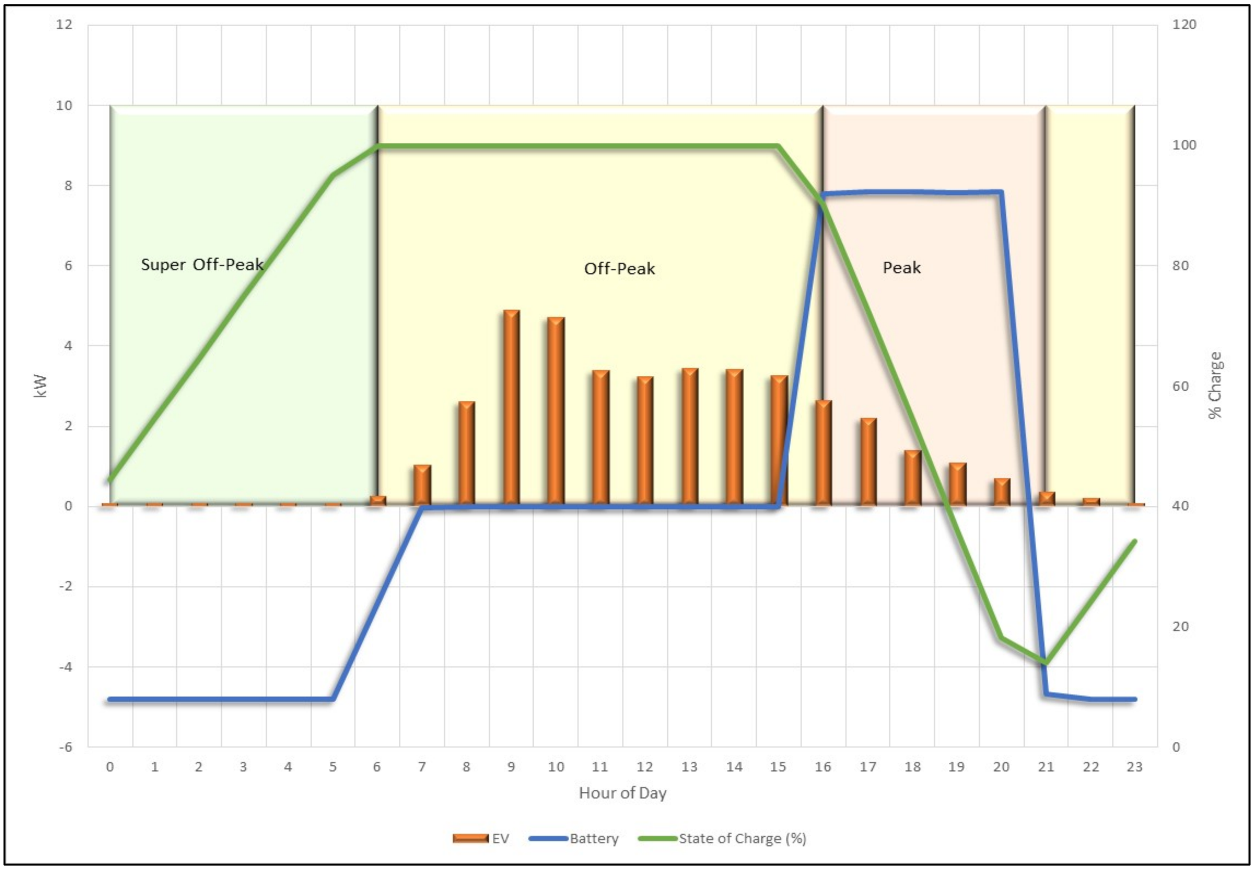

FIGURE 7. WEEKDAY BESS AND EV CHARGING CYCLES

UTILIZATION

There are two primary components to utilization: 1) How often EV charging occurs, and 2) how many EV charging stations are used as a percent of total system capacity. During 2021, there were 194 charge days out of a total of 365 calendar days (Table 4). Only two charge days occurred on the weekend so there was a total of 192 charge days out of a total of 261 weekdays or 74%.

TABLE 4. CHARGE DAYS

DAY TYPE	CHARGE DAY	NO CHARGE DAY	TOTAL
Weekday	69	192	261
Weekend	102	2	104
Total	**171**	**194**	**365**

For reasons previously discussed, EV charging was minimal during the reporting period. The average number of charge sessions per day, during charge days, was just under one (0.899). Table 5 illustrates the distribution of the number of vehicles charging at the workplace concurrently at any one time. Most charging sessions consisted of one vehicle with just under 12% of time with two vehicles.

TABLE 5. DISTRIBUTION OF CONCURRENT VEHICLE CHARGING

# VEHICLES	HOURS	% TOTAL CHARGE HOURS
1	1277	87.41%
2	172	11.77%
3	11	0.75%
4	1	0.07%

An interesting side note is that there appears to be an inverse correlation between monthly 7-day % COVID-19 testing positivity for the County of San Diego and EV vehicle charging. Figure 5shows as testing positivity lowered electric vehicle charging went up.

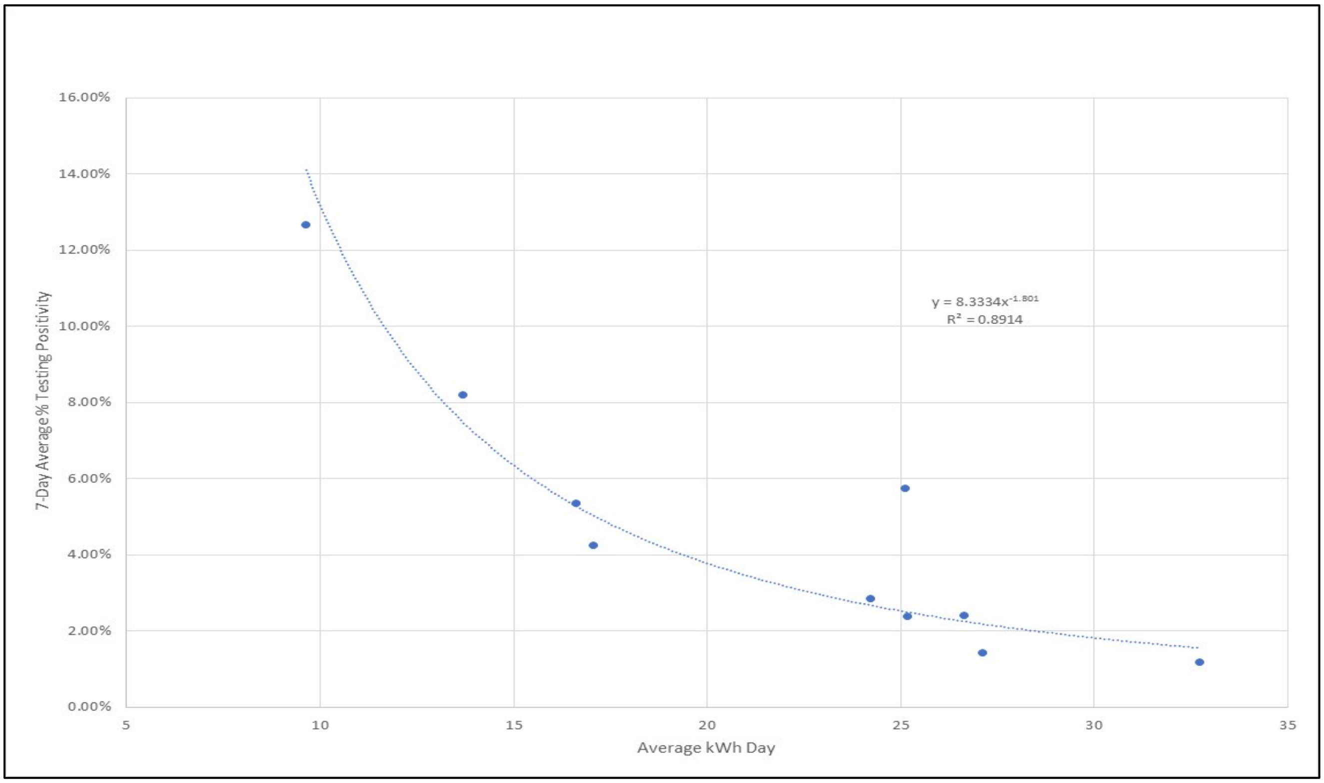

FIGURE 5. MONTHLY TESTING POSITIVITY VS. CHARGER ENERGY USAGE (C-19 DATA SOURCE: CA DEPARTMENT OF PUBLIC HEALTH)

The total energy used and EV charging sessions per day varied during the year as COVID-19 peaked and lulled. Figure 6 shows the EV charging energy and sessions per day by month.

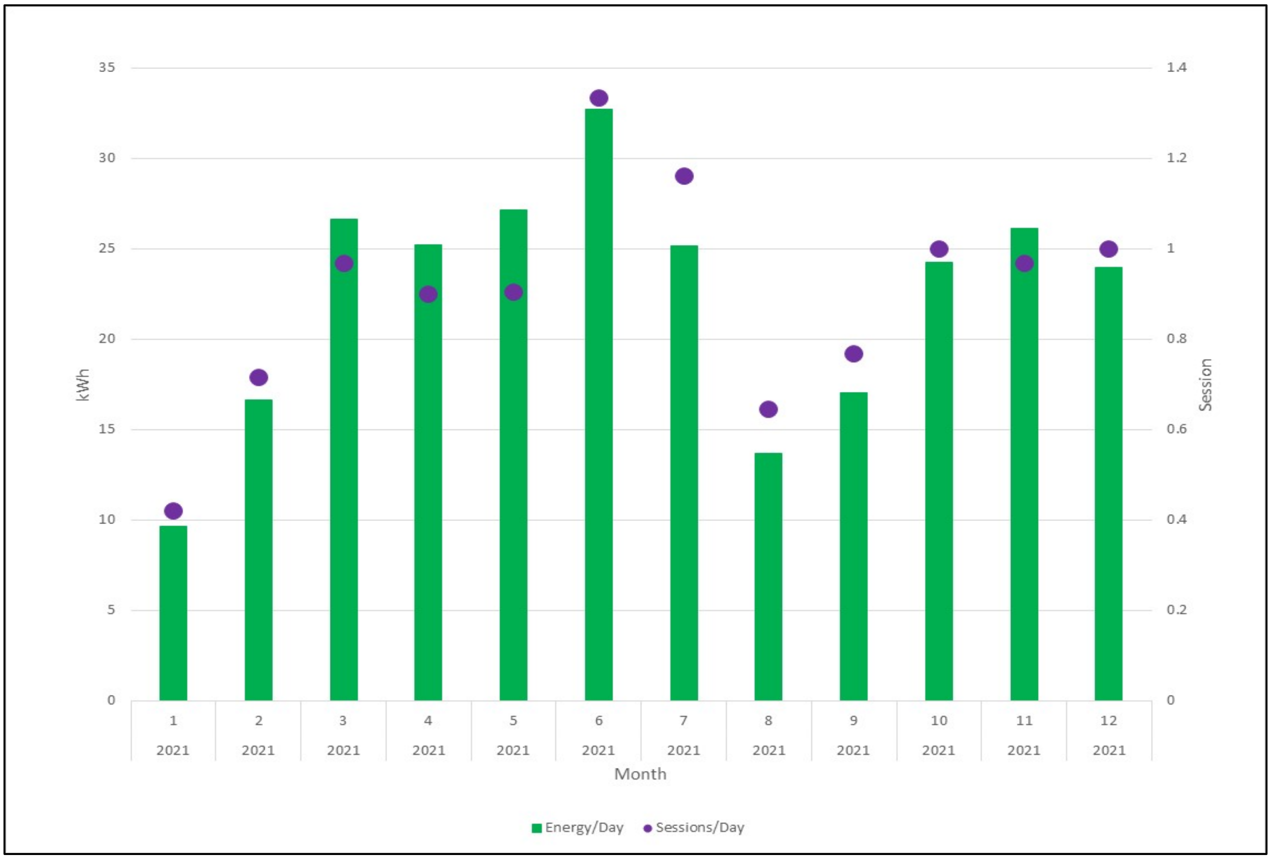

FIGURE 6. EV CHARGING ENERGY AND SESSIONS BY MONTH

Overall EV charger utilization during the study period was low. On average, utilization peaked at about 10% of total charge capacity. The peak day exhibited an all-time high peak of 40% at 10:00 am on Friday August 13th, 2021. Figure 7 shows the hourly load profiles for both the average and peak day. It is observable that this workplace has additional capacity to contribute to grid overgeneration.

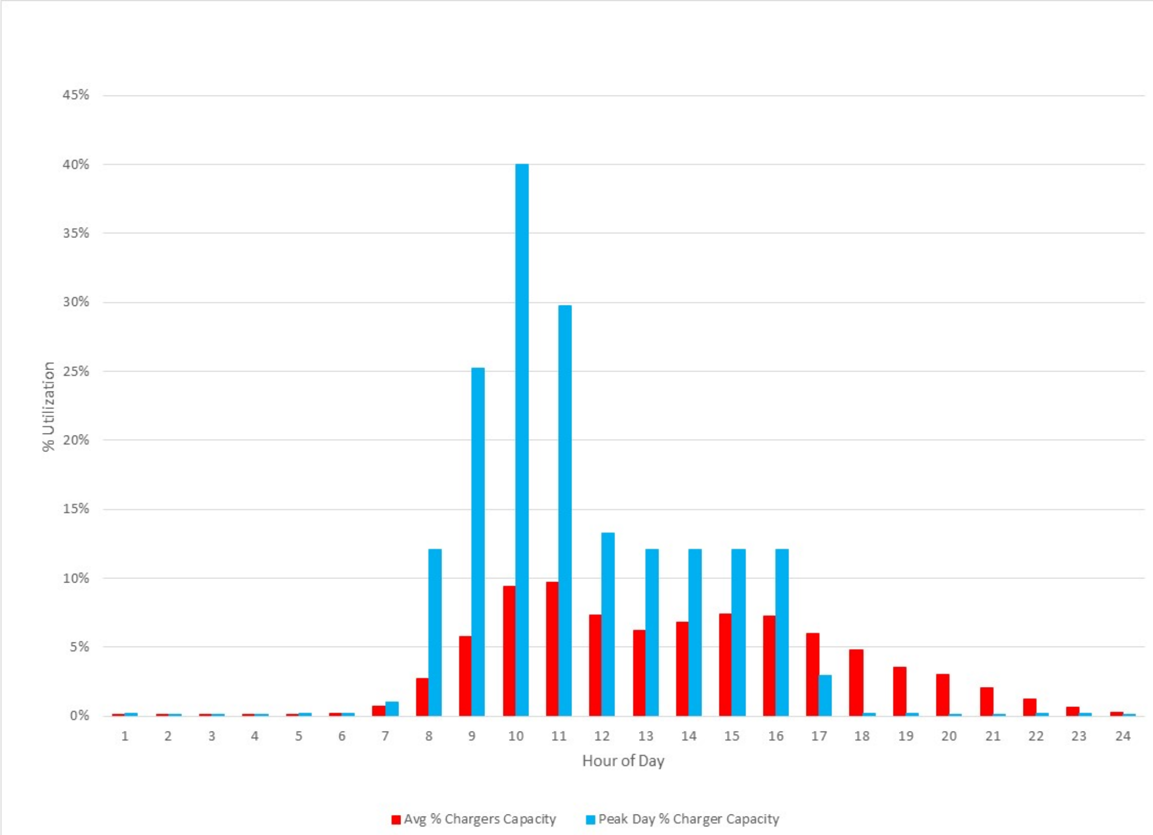

FIGURE 7. AVERAGE AND PEAK DAY UTILIZATION

The EV charging utilization at higher levels were simulated in Figure 8. It illustrates projected savings and simulates benefit at 25%, 50%, and 75% charging system utilization. There is still a mid-day dip because solar production is at its highest point and charging naturally drops off around lunchtime. However, much of this variation could potentially be evened out using effective BESS charging strategies.

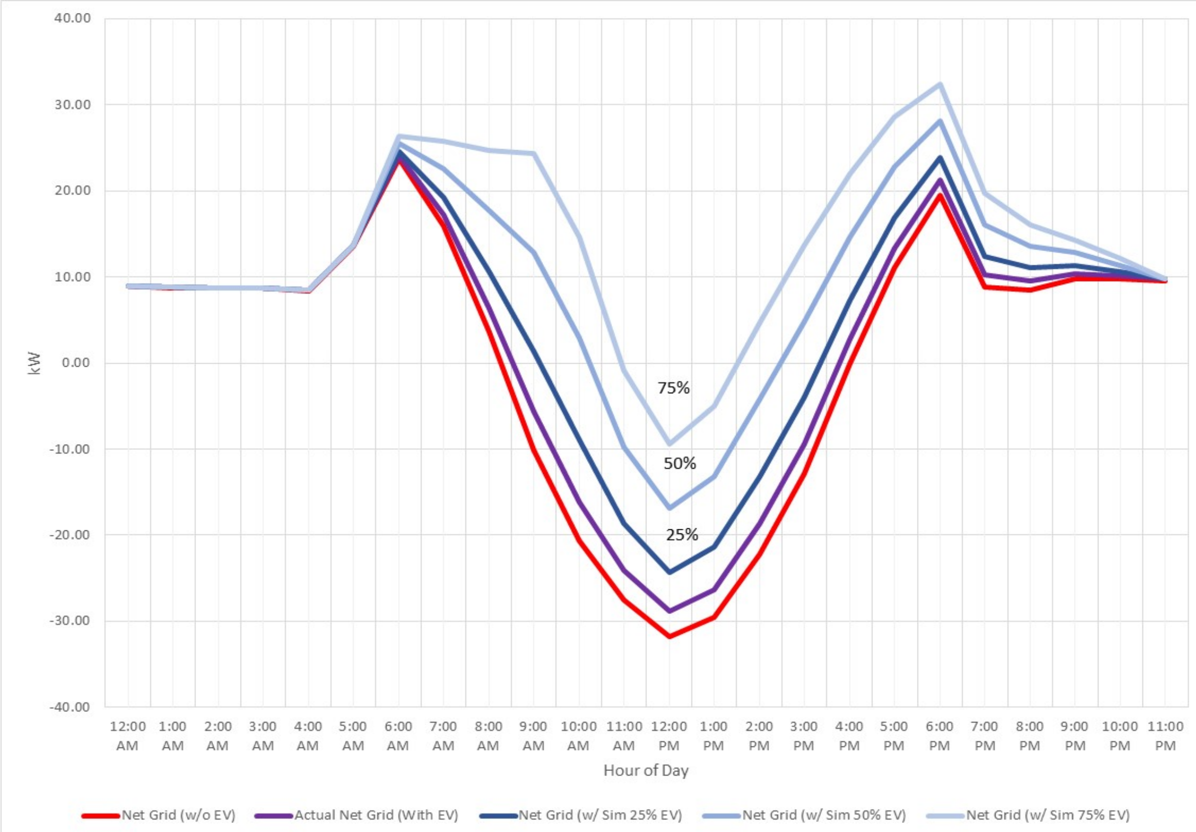

FIGURE 8. ACTUAL AND SIMULATED UTILIZATION GRID IMPACT

COSTS

As previously mentioned, the building management was not intent on making a profit from EV charging, viewing these capabilities/service as an amenity to building tenants and their staff. Their objective was to break even on additional electrical usage and demand.

In 2021, the test building received $1,659.00 (~$0.21/kWh) from the EV chargers. The approximate costs for energy and demand charges were $1,951.12 (including ancillary energy for charging and non-charging periods). This resulted in a loss of $292.12.

Most of the EV charging occurred during periods when the solar system was generating and providing net energy to the grid. Using SDG&E renewable energy credits from the true up monthly rate table, the energy value associated lost opportunity was $301.36 (i.e., value the building would have received if they sold back to the grid). If we approach the benefit analysis from the solar generation perspective, The test site received $1,357.64 in additional funding than what it would have received "selling" the energy to the grid.

Figure 9 shows the revenue and costs of the EV charging energy by session. It is evident from the data that the revenue covers most but not all the costs from a utility energy purchase perspective.

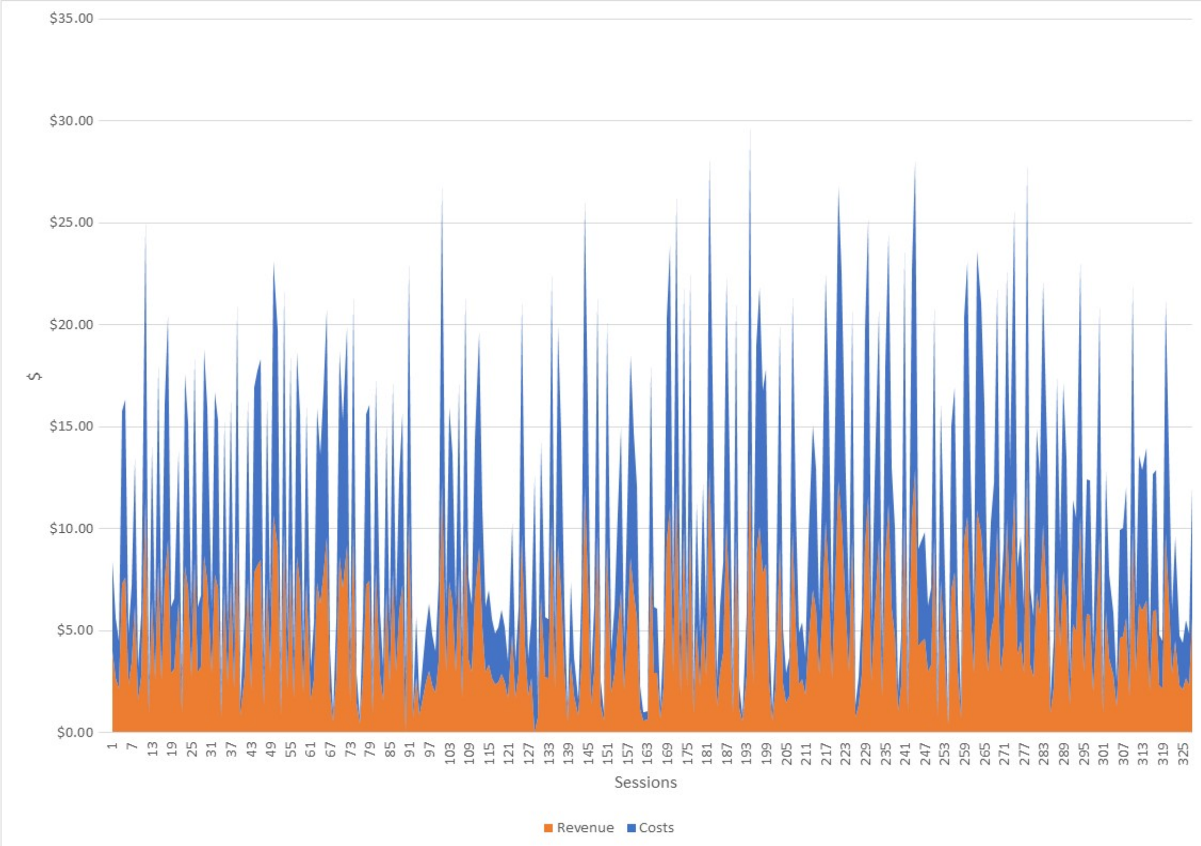

FIGURE 9. REVENUE AND COSTS BY SESSION

Using the same strategy for increased utilization as above, estimated annual revenue and costs can be projected for this site. Table 6 below demonstrates the potential at this site for increased EV charger utilization (25%, 50%, and 75%). While it is unlikely that this site will increase its utilization to 50% or 75% soon, 25% is certainly a reasonable estimate based on the ~10% utilization operation during the COVID-19 period.

TABLE 6. ANNUAL ENERGY AND FINANCIAL FOR VARIOUS UTILIZATION SCENARIOS

Utilization Schedule	Assumed Charging Days	Estimated Energy	Annual Costs	Annual Revenue	Profit/Loss
25%	196	20,252	$4,840	$4,227	-$613
50%	209	43,065	$10,292	$8,988	-$1,304
75%	222	68,549	$16,383	$14,307	-$2,076

DISCUSSION

The study demonstrated that workplace charging will substantially help mitigate the risk of overgeneration in California. Renewable curtailment or compensating neighboring states to offload excess generation is a risk and is not sustainable (NREL, 2015). Because workplace charging generally occurs during the daylight hours, the migration from carbon fueled to zero emission vehicles, particularly plug-in battery electric vehicles and battery hybrid electric vehicles, has tremendous potential to solve this problem. New regulation has mandated and accelerated the transition. Recently California has surpassed the electric vehicle 25% of new cars sold milestone (White, 2023). Monumental federal infrastructure bills have provided the funds necessary to begin to tackle the charging infrastructure dilemma.

There were many barriers to achieving the expected goals. Not the least of which was a global pandemic throughout the entire test period. The statewide work at home order caused many non-critical workplaces to effectively be shut down or operated with minimal in-office staff. Workplace presence and telecommuting has forever changed in California. However, as we transition out of the emergency, a significant proportion of the workforce has returned to the workplace. Telecommuting will reduce travel to and from the workplace to some extent, however EV owners may still need to charge their vehicle during the day to commute to other daily activities. Additionally, problems with the BESS, first the battery controller and then the battery communications circuitry caused the device to be inoperable for much of the study period. However, the project was able to employ workarounds for both the COVID-19 and BESS issues and reasonable data was logged to adequately assess the hypotheses.

While EV chargers cannot necessarily be identified as new technology, the implementation at scale of various types/use cases of charging (Fleet, Destination, Corridor, Workplace, etc.) and the stacking and interaction of DERs is certainly emerging technology. The technology is "load building" but ultimately it is one of the single biggest potentials for decarbonization and electrification. It also allows for load flexibility with various charging schemes, integrated renewable generation/storage, and vehicle grid integration (VGI). This study showed that energy could be shifted to loads during periods of grid over production.

Transportation electrification holds many promises. The ability to fuel transportation from an increasingly renewable grid as well as reduce the reliance on fossil fuels is monumental. In that respect, EVs are "better" than the incumbent technology.

There are many barriers to mass EV market adoption. Range anxiety, access to charging, charging dwell time, charging costs, infrastructure costs, vehicle availability, battery life and recycling are just to name a few. But all these issues are being actively tackled and progressively resolved. Understanding the grid benefits such as the hypotheses in this study are critical to transitioning.

CONCLUSIONS

The study began with several questions that were then transformed into four hypotheses. The study analysis and assessment were able to effectively evaluate each of the four hypotheses.

Grid Impacts - Workplace charging will help mitigate overgeneration in California.

The study found that even with minimal utilization, EV charger usage was impactful on the building's overgeneration and export to the grid. As EV charger utilization increases to reasonable levels, the impact is expected to be much greater. For example, if 75% utilization rate was achieved at this test site, most of the grid export would have been removed. As more and more workplaces add EV charging stations, this impact is expected to grow exponentially.

Timing - Workplace charging will occur at the most effective time of day to counteract solar PV production. Using a BESS will help flatten the usage curves and will not be counterproductive to the benefits of workplace EV charging.

Workplace charging generally occurs when net demand of the California grid dips ("belly of the duck"), and it generally subsides during the ramp up to the peak demand period ("neck of the duck"). The study demonstrated that the increased demand occurred at the right time. It is expected that workplace charging will greatly offset solar net metering because a sizable majority of commercial businesses operate during the "daylight".

The BESS for this site was set up to charge during the super off-peak period and discharge during the peak period. This primarily allowed the building management to avoid peak usage and demand charges. Because EV charging occurred mostly during the off-peak period and BESS charging and discharging occurred during the super off-peak and peak periods respectively, the two systems did not interact much. However, a BESS charging during the off-peak period could be used to help further mitigate overgeneration and help flatten the curve.

Utilization - Charger utilization is key to significant grid-level benefits and will take a few years to achieve.

It's widely known in the transportation electrification industry that charging utilization is the key to making a business case for financial return on investment (Luskin Center for Innovation, 2012). However, utilization is also key to making a big enough impact so that the site can take advantage of excess solar and lower-cost electricity. Individual site utilization is an important objective because as more sites are aggregated, the affect becomes incrementally more impactful on the grid.

As more and more workplaces incorporate charging for their staff and visitors, this is expected to grow exponentially, but it takes time for employees to shift their habits and to acquire new EVs. Because of SDG&E and other utility EV tariffs, it is most advantageous for EV owners to charge at home during the super off-peak period. However, the convenience to "top off" and supplement by charging at work becomes more evident as the technology matures.

Costs - Workplace Charging can be cost effective or neutral to site hosts.

In this specific case, the chargers and installation costs were fully covered by the Electrify America fund. Additionally, the building management did not intend to make a profit but rather to cover most of their operating costs. It is clear from the data that they are doing so. Since the chargers are powered during the solar period, an argument can be made that

EV drivers are “driving on the sun” and that only costs are the lost solar credits. The Management is charging approximately 21 cents per kWh to charge which translates roughly to $1.60 per equivalent gallon. There is opportunity to increase the charges, but EV charging is always compared to ICE vehicle costs and like any other industry is subject to supply and demand.

RECOMMENDATIONS

Workplace EV charging offers the state of California a means to tackle overgeneration and flatten daily grid demand. Electrification, especially transportation electrification, offers California utilities a unique opportunity to add growth. However, this growth must be understood, forecasted, and managed. AESC recommends the following next steps:

- Expand the study to include a variety of other workplaces/building stock, weather variations and operating hours. Obtain a better understanding of utilization and how to increase individual workplace usage. Develop workplace charging potentials by building type, geography, population, equity, and other variables.
- Investigate if there are controllers/technologies that can control the interaction of building, BESS, and EV Chargers together.
- Perform a characterization study of market potential for workplace charging in CA. Include existing and projected solar workplace estimates.
- Project statewide impact using study findings and market potential. Incorporate findings into resource adequacy forecasts. Tariffs should be adjusted accordingly.
- This study focused on the period of grid impact during daylight hours. California's expected 15-fold increase in forecasted EV charging need should be evaluated across the full daily grid profile, especially impact to the peak periods. Battery and Vehicle to Grid technologies and DR/DER initiatives can help mitigate but the full impact should be forecasted (CalMatters, 2023).
- Develop an incentive or rebate program promoting workplace charging that specifically encourages daytime charging. Develop individual measures based on total system benefits.

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