CALIFORNIA
ENERGY COMMISSION

California Energy Commission
Clean Transportation Program

Blueprint for Medium- and Heavy-Duty Zero-Emission Vehicle Infrastructure: Lowest Cost to Charge for Stockton Unified School District

Prepared for: California Energy Commission
Prepared by: Center for Transportation and the Environment

January 2023 |

California Energy Commission

Erik Bigelow
Leslie Eudy
Grace Leslie

Center for Transportation and the Environment
730 Peachtree Street, Suite 450
Atlanta, GA 30308
https://cte.tv/

Contract Number: ARV-21-005

David Wensil
Commission Agreement Manager

Elizabeth John
Branch Manager
MEDIUM- AND HEAVY-DUTY ZERO EMISSION TECHNOLOGIES BRANCH

Hanoon Rasool
Director
FUELS AND TRANSPORTATION DIVISION

Drew Bohan
Executive Director

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance, and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued GFO-20-601, to accelerate the deployment of MD/HD ZEVs and ZEV infrastructure with a holistic and futuristic view of transportation planning. In response to GFO-20-601, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards April 8, 2021, and the agreement was executed as ARV-21-005 on September 24, 2021.

ABSTRACT

This blueprint project used Stockton Unified School District's bus fleet operation as a case study to analyze the lowest possible cost for charging electric school buses (ESB). The Center for Transportation and the Environment partnered with The Mobility House (TMH) and Sage Energy Consulting (Sage), a NV5 company, to complete the analyses which included costs of alternating current and direct current charging with and without charge energy management, investigating potential value of photovoltaic (PV) energy with and without battery energy storage, optimizing for self-consumption of PV, and value of vehicle-to-grid technology.

The results showed that alternating current is sufficient for the district's charging needs, as there is a marginal difference in the value of the energy compared to direct current charging, which has increased costs associated with infrastructure upgrades and hardware. The use of a charge management system was found to provide significant savings by limiting charging spikes and avoiding high demand charges. Additionally, photovoltaic and battery energy storage systems under NEM3.0 may be difficult to justify if there is a time of use rate, sufficient capacity to use the off-peak charging time, and a charge management system in place. Lastly, vehicle-to-grid charging can produce revenue, but it is unclear at this time if it is enough to justify the additional costs.

The project team recommends school districts install alternating current unless there is a need for direct current charging and advise against photovoltaic and battery storage systems under the new net energy metering rules and utility rates. Also, the additional costs associated with vehicle-to-grid technology diminish returns and make it hard to justify the potential cost benefits. Vehicle-to-grid use should continue to be researched as policies and technology can change to make bi-directional charging more favorable. These results and recommendations will be valuable to other school districts when planning electric school bus fleet transitions.

Keywords: Electric School Bus, ESB, Charging Infrastructure, Vehicle-to-Grid, Lowest Costs to Charge, Stockton Unified School District

Please use the following citation for this report:

Bigelow, Erik, Leslie Eudy, Grace Leslie. 2023. *Blueprints for Medium- and Heavy-Duty Zero-Emission Vehicle Infrastructure: Lowest Cost to Charge for Stockton Unified School District*. California Energy Commission.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

List of Tables

This page intentionally left blank.

Executive Summary

School bus fleet electrification is proceeding rapidly with over 24,000 school buses in California. The transition to an all-electric fleet can be complex and challenging for many school districts who are unsure of which technology and equipment their districts need. This blueprint identifies the lowest cost to electrify a school bus fleet by evaluating various approaches for full electrification, determining lowest total cost of infrastructure, and evaluating energy cost options to accelerate electric school bus adoption throughout the State of California. The project includes a case study that analyzes Stockton Unified School Districts bus fleet, to provide school districts with the best practices for selecting charging infrastructure at the lowest possible cost. Center for Transportation and the Environment partnered with The Mobility House and Sage to complete the analysis. The Mobility House was responsible for defining charging profiles for lowest cost charging with alternating current and direct current charging, as well as vehicle-to-grid revenue analysis. Sage provided estimated future revenue and cost impact of photovoltaic and local battery energy storage under net energy metering 2.0 and projected net energy metering 3.0 scenarios.

The project team is comprised of:

- Center for Transportation and the Environment: As the project lead, Center for Transportation and the Environment was responsible for managing the work and compiling the analysis into the final report.
- The Mobility House: The Mobility House was responsible for defining charging profiles for lowest cost charging with alternating current and direct current charging, as well as vehicle-to-grid revenue analysis.
- Sage: Sage provided estimated future revenue and cost impact of photovoltaic and local battery energy storage under net energy metering 2.0 and projected net energy metering 3.0 scenarios, and vehicle-to-grid analysis.

Stockton Unified School District is an average sized district located in the Central Valley of California. The district has added eleven electric school buses to its fleet and operates 111 buses that serve 55 schools.

The primary goal of the project was to determine the lowest cost way for Stockton Unified School District to charge a 100 percent electric school bus fleet based on its current operations. The secondary goal was to evaluate the financial benefit and resiliency (grid support) profile for Stockton Unified School District with vehicle-to-grid.

The objectives of this project were to:

- Determine whether alternating current or direct current charging for an electric school bus fleet has a lower total lifetime cost when taking installation, charger, and electricity costs, with predicted vehicle-to-grid revenue and Low Carbon Fuel Standard credit into consideration. The project will determine the degree to which the final plan improves on a baseline infrastructure case using all alternating current charging.

- Determine the value created by using a vehicle-to-grid connection along with local solar generation. This will be measured against a scenario without utilizing vehicle-to-grid energy transfer.

The following conclusions have been made:

Alternating vs. Direct Current Charging: Alternating current charging is sufficient for charging scenarios evaluated, as higher power charging associated with direct current charging is not necessary and hardware, installation, on-going costs for alternating current charging is lower compared to direct current charging.

Charge Energy Management: Use of charge energy management results in significant savings by limiting charging spikes and avoiding high demand charges. Charge energy management is also critical in aligning charging needs with photovoltaic availability, and therefore, making solar a viable option under net energy metering 3.0.

Onsite Distributed Energy Resources (Photovoltaic and Photovoltaic with Battery Storage: Photovoltaic and paired photovoltaic and battery energy storage system under net energy metering 3.0 may be difficult to justify on a cost savings basis. Photovoltaic and photovoltaic with battery energy storage do not provide additional savings to Stockton Unified School District if a charge management system is able to optimize charging during off-peak periods and flatten demand. However, optimizing electric school bus charging to periods when solar generation is available improves the value of photovoltaics and benefits the district. Charging the electric school buses with a photovoltaic system sized to offset 90 percent annual consumption results in lower costs to the district compared to a baseline without photovoltaic, where electric school buses charge primarily overnight with an energy management system.

Vehicle-to-grid Charging Potential Revenue: Vehicle-to-grid charging can produce revenue, but it is unclear if this is enough to justify additional costs. Districts should continue to research vehicle-to-grid use to determine if changes to policy or electric rates change this in the future. To offset the added costs of vehicle-to-grid on Level 2 19.2 kilowatt alternating current charging, the district's vehicle-to-grid exported energy must, on average, be valued at $0.19 per kilowatt-hour if receiving Pacific Gas & Electric's vehicle-to-grid pilot incentives, and $0.29 per kilowatt-hour without incentives.

The following are recommendations for all interested parties moving forward based on the results obtained:

- With moderate range needs, Stockton can plan to install alternating current charging unless there's a demonstrated need for direct current charging. Some higher-powered direct current charging may be necessary to support field trips, especially for buses from visiting schools but this use case was not evaluated under this project.
- Photovoltaic is not recommended for districts under net energy metering 3.0 rules and Pacific Gas & Electric's Battery Electric Vehicle rate unless the district can use a charge energy management system to optimize electric school bus charging to self-consume the energy produced.
- Battery storage is not recommended for the district. Under net energy metering 3.0 and the current Pacific Gas & Electric Battery Electric Vehicle rate, the additional cost

savings from implementing battery storage with solar do not offset the added costs for the battery energy storage system. The charge energy management will contribute to the greatest peak demand savings, leaving only marginal opportunity for battery storage peak demand savings.

- The additional costs associated with vehicle-to-grid technology diminish returns and make it hard to justify the potential cost benefits. However, the landscape of policies and available rates for V2G are changing rapidly. Future development could reflect the true value of V2G and allow stacking of different rates and programs. Utilities and regulators should explore ways to combine this type of rate with demand response programs that allow exports to reflect the potential applications and value of V2G capability while appropriately addressing the nature of V2G as a storage resource.
- Vehicle-to-grid charging planning should include a full evaluation of all operating costs, including battery degradation, energy to replenish vehicle-to-grid use, additional hardware/software, and infrastructure upgrades if direct current charging is required. The optionality for future vehicle-to-grid capability should be left open as vehicle and infrastructure decisions are made today. The outlook may be much different in the next five to 10 years and vehicle-to-grid use should continue to be researched as policies and technology change.

Introduction:

Project Background

This project provides critical support of future market adoption for large fleets of electric school buses (ESB) by providing a comprehensively analyzed case study that can show best practices for charging infrastructure. ESB fleets have dramatically different requirements than transit fleets and best practices will not accurately transfer from transit or commercial fleet experience. Charging time available is typically sufficient with a 19-kilowatt (kW) Level 2 alternating current (AC) charger, which is significantly cheaper to install than direct current (DC) charging. Alternatively, with peak solar output mid-day, rapidly charging buses during the solar peak may provide lower cost charging. The savings may be significant when multiplied across an entire fleet. Higher power DC charging may also provide an avenue to realize higher future vehicle-to-grid (V2G) revenue.

Determining the right balance of chargers, local generation, V2G energy transfer with utility tariffs, and operating needs is a challenging problem. This analysis will provide a clear case study looking at how these trade-offs can be balanced to provide the lowest total cost solution for Stockton Unified School District (SUSD), and an example for the industry to build on.

Project Team

Center for Transportation and the Environment

The Center for Transportation and the Environment (CTE) works to improve the health of our climate and communities by bringing people together to develop and commercialize clean, efficient, and sustainable transportation technologies. CTE collaborates with federal, state, and local governments, fleets, and vehicle technology manufacturers to advance clean, sustainable, innovative transportation and energy technologies.

The Mobility House

The Mobility House (TMH) is a technology company focusing on electric vehicle (EV) charging services to help create a zero-emission energy and mobility future.

Sage Energy Consulting

Sage Energy Consulting (Sage), an NV5 Company, helps clients plan and implement their transition to zero-emission transportation across light-, medium-, and heavy-duty applications.

Project Approach

CTE partnered with TMH and Sage to complete the analysis. TMH was responsible for defining charging profiles for lowest cost charging with AC and DC charging, as well as V2G revenue analysis. Sage provided estimated future revenue and cost impact of PV and local battery energy storage under Net Energy Metering (NEM) 2.0 and projected NEM 3.0 scenarios. The analyses included several phases and were iterative, meaning that results from one analysis fed into and directed the follow-on analyses. The phases of analysis included the following:

Charging Scenario Analyses

1. Charge energy management (CEM) to optimize for the SUSD utility tariff
    a. AC chargers only
    b. DC chargers only
    c. Combination of AC and DC chargers
    d. AC and DC Optimized for PV self-consumption
2. PV or a PV + BESS combination (AC charging only)
    a. PV and PV + BESS without CEM to optimize for PV generation
    b. PV and PV + BESS using CEM to optimize for PV self-consumption

Vehicle to Grid (V2G) Revenue Analyses

1. Estimate V2G revenue, profit, and cost for SUSD using a day ahead real time pricing tariff for 19.2 kW and 50 kW chargers
    a. Stationary bus
    b. Current operations at a 1:1 bus to charger ratio
    c. Current operations at a 2:1 bus to charger ratio
2. Analyze the minimum average export rate to provide a net cost savings to SUSD under current operations

Scope of Work

CTE was responsible for completing the following tasks from the agreement: Task 1- Administration, Task 2- Determine Operating Scenario(s), Task 4- Outcome Review with Partners, Task 5- Project Fact Sheet, and Task 6- Blueprint. CTE worked with TMH and Sage to complete Task 3- Analyze Charging Scenarios. The goals and outcomes of each task are described below.

The goal of Task 1 was to establish the lines of communication and procedures for implementing this Agreement. For Task 1, CTE attended the kickoff meeting, identified and obtained matching funds and required permits, obtained and executed subcontracts, participated in critical project review (CPR) meetings, completed Monthly Progress Reports summarizing all agreement activities conducted during the reporting period, executed the Final Report, and presented findings and recommendations in the final meeting for the closeout of the agreement.

The goal of Task 2 was to determine the fully electric fleet vehicle operating scenario and constraints. CTE's operating scenarios document defined the operating requirements of the fleet, and ensured the analysis takes all vehicle operating needs into account.

The goal of Task 3 was to determine charging arrangements for three scenarios: AC charging, DC charging with shared outputs, and containerized DC charging. CTE coordinated with TMH and Sage to complete this analysis. TMH was responsible for defining charging profiles for lowest cost charging with AC and DC charging, ang V2G revenue analysis. Sage provided estimated future revenue and cost impact of PV and local battery energy storage under Net Energy Metering (NEM) 2.0 and projected NEM 3.0 scenarios. CTE used the analysis results from TMH and Sage to create the Lowest Cost to Charge Summary document.

The goal of Task 4 was to summarize overall findings from the case study and review results with project partners while developing a final blueprint (Task 6). CTE met with the following stakeholders and incorporated their feedback into the blueprint and report: Stockton Unified School District (SUSD), PG&E utility, San Joaquin Valley Clean Cities, World Resources Institute (WRI), and AlphaStruxure. As a result of these stakeholder reviews, CTE prepared a summary of overall findings for a non-technical audience.

The goal of Task 5 was to develop an initial and final project fact sheet that describes the CEC-funded project and the resulting benefits for the public and key decision makers. In the fact sheets, CTE provided photographs from the project site and described the project benefits and lessons learned.

This document serves as the Final Blueprint document for Task 6. The goal of Task 6 was to prepare the final Stockton case study report documenting findings, recommendations, and generalized conclusions to help accelerate electric school bus adoption throughout the State of California.

SUSD Operating Scenarios and Constraints

The Operating Scenarios and Constraints document served as the technical foundation for the project.[1] The document lays out the school district profile, vehicle operating requirements, available charging windows, and displays site diagrams. SUSD operates regular routes, special education routes, and extracurricular trips. Extracurricular trips vary depending on the purpose and location and include activities such as transporting sports teams to another school or field trips for educational purposes. **Table 1** provides the School District General information. **Table 2** provides the vehicle operating information and **Table 3** details the charging infrastructure.

Table 1. School District Profile

General Information	
Name:	Stockton Unified School District (SUSD)
State:	California
LEA ID:	638010
Locale:	Urban
Land Area Served (mi^2):	57
Number of Students Served:	36,190
Number & Type of Schools Served:	53-55 schools of all types
Median Household Income:	$44,393
Average Ozone (ppb):	49.06
Average of PM2.5 (ug/m3):	12.15

Source: CARB Clean Mobility in Schools Project: SUSD

Table 2. School District Vehicle Operating Information

Vehicle Operating Information	
Typical School Schedule:	August - May
Number of Full Operating Days:	180
Types of Service:	Regular Routes, Special Education Routes, Extracurricular
District Fully Self-Owned:	Yes
District Fully Self-Operated:	Yes
Number & Types of Vehicles:	111 total buses (11 full-size ESBs; 54 short fuel-fired buses; 46 full-size fuel-fired buses)
Active:	39 active short buses; 45 active full-size buses (11 ESBs)

---

[1] CARB Clean Mobility in Schools Pilot Project: SUSD, available at https://ww2.arb.ca.gov/lcti-getting-stockton-zero-emissions-clean-air-our-community

Number of Buses Owned by District:	111
Number of Buses Owned by Other:	0
Number of ESBs Purchased:	11
Number of ESBs Planned to Purchase:	SUSD currently has five active grants for 66 ESBs (40 full-size ESBS for general education; 26 short buses for special education)

Source: CARB Clean Mobility in Schools Project: SUSD

Table 3. Charging Infrastructure

Infrastructure Information	
Number of Parking Locations:	1 (fully outside)
Number of District-Owned Parking Locations:	1
Addresses of District-Owned Parking Locations:	2909 Sanguinetti Lane, Stockton CA, 95205
Number of Non-District-Owned Parking Locations:	0
Addresses of Non-District-Owned Parking Locations:	n/a
Number & Types of Charging Equipment Installed by Site:	20x16.8kW BTC AC chargers & 4x50kW BTC DC fast chargers (not compatible with full-size)
Number & Types of Charging Equipment Purchased by Site:	4x50kW ABB DC fast chargers (compatible with full-size)

Source: CARB Clean Mobility in Schools Project: SUSD

Vehicle Operating Requirements

Regular Weekly Routes

Table 4 depicts SUSD's regular weekly route schedule. A total of 18 buses, including 11 ESBs operate on morning and afternoon runs. The morning runs range from 15.8 to 34.4 miles with an average distance of 24 miles. The afternoon runs range from 12.4 to 45.6 miles with an average distance of 21.4 miles.

Table 4. Regular Weekly Routes

Bus #	AM/PM Route	Start Time	End Time	Total Mileage	Operating Days
7	AM	6:46	9:00	34.25	M,T,W,Th,F
7	PM	13:23	16:19	45.64	M,T,W,Th,F
39	AM	7:04	9:15	21.33	M,T,W,Th,F
39	PM	13:12	15:35	21.8	M,T,W,Th,F
40	AM	7:03	8:49	23.65	M,T,W,Th,F
40	PM	13:32	15:12	19.6	M,T,W,Th,F
43	AM	7:06	8:22	20.65	M,T,W,Th,F

Bus #	AM/PM Route	Start Time	End Time	Total Mileage	Operating Days
43	PM	13:31	15:22	22.3	M,T,W,Th,F
44	AM	6:43	8:39	34.42	M,T,W,Th,F
44	PM	13:25	14:24	15.37	M,T,W,Th,F
47	AM	7:01	8:34	16.25	M,T,W,Th,F
47	PM	13:29	15:25	16.99	M,T,W,Th,F
48	AM	6:31	8:44	27.65	M,T,W,Th,F
48	PM	13:29	15:18	12.4	M,T,W,Th,F
ZEB 1	AM	6:55	8:30	28.54	M,T,W,Th,F
ZEB 1	PM	13:31	15:13	23.59	M,T,W,Th,F
ZEB 2	AM	6:57	8:40	23.8	M,T,W,Th,F
ZEB 2	PM	13:33	15:33	20.16	M,T,W,Th,F
ZEB 3	AM	7:00	8:51	29.16	M,T,W,Th,F
ZEB 3	PM	13:32	15:52	21.07	M,T,W,Th,F
ZEB 4	AM	7:40	8:51	22.88	M,T,W,Th,F
ZEB 4	PM	13:44	15:26	26.99	M,T,W,Th,F
ZEB 5	AM	7:12	9:00	24.58	M,T,W,Th,F
ZEB 5	PM	13:34	15:22	21.36	M,T,W,Th,F
ZEB 6	AM	7:06	8:04	15.77	M,T,W,Th,F
ZEB 6	PM	12:06	14:36	22.68	M,T,W,Th,F
ZEB 7	AM	7:47	8:51	18.31	M,T,W,Th,F
ZEB 7	PM	13:27	15:20	18.9	M,T,W,Th,F
ZEB 8	AM	6:51	9:00	24.79	M,T,W,Th,F
ZEB 8	PM	13:02	14:39	19.46	M,T,W,Th,F
ZEB 9	AM	7:04	8:22	22.1	M,T,W,Th,F
ZEB 9	PM	13:32	14:32	12.78	M,T,W,Th,F
ZEB 10	AM	6:54	8:03	25.04	M,T,W,Th,F
ZEB 10	PM	13:23	14:48	20.49	M,T,W,Th,F
ZEB 11	AM	6:46	7:41	20.91	M,T,W,Th,F
ZEB 11	PM	13:29	15:39	24.02	M,T,W,Th,F

Source: CARB Clean Mobility in Schools Project: SUSD

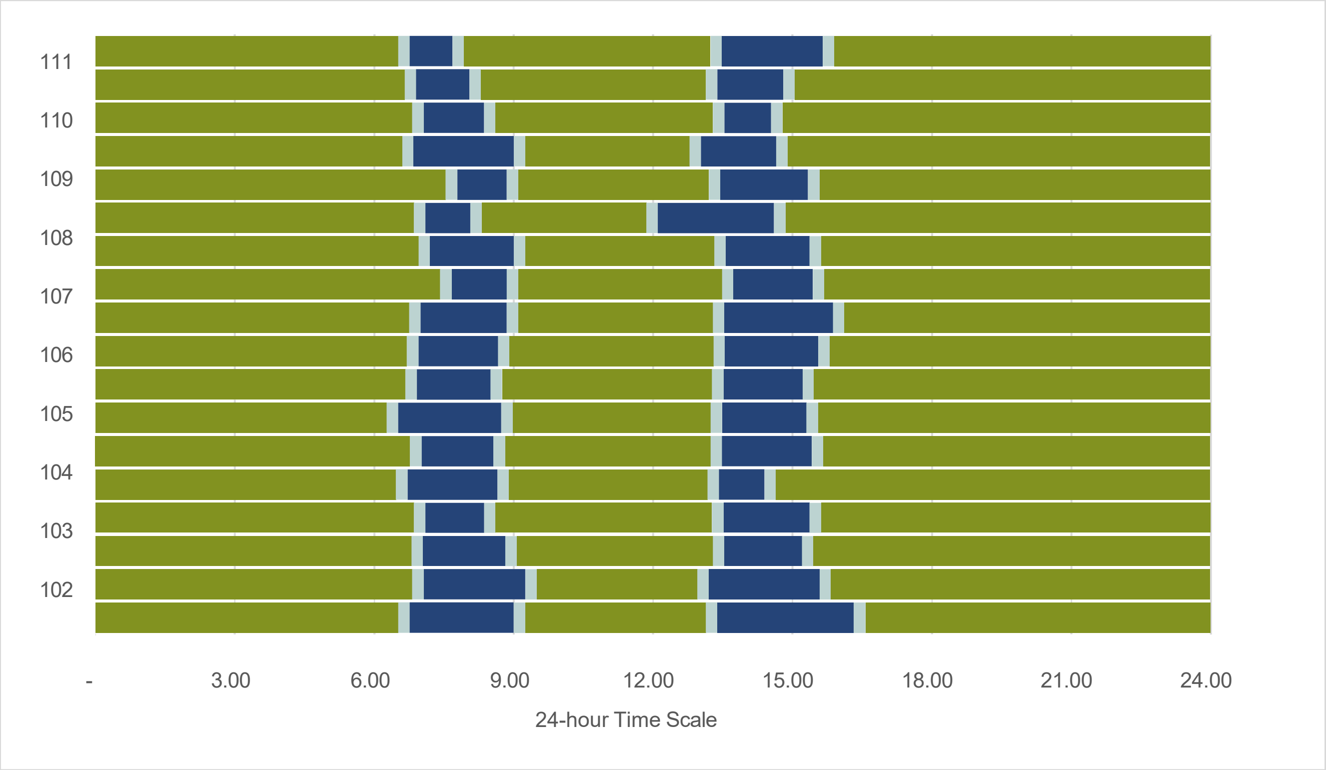
Special Education Routes

Table 24-Appendix depicts the weekly route schedule for SUSD's Special Education transportation service. A total of 45 buses operate on morning and afternoon runs. The morning runs range from 17.6 to 55.6 miles with an average distance of 30.5 miles. The afternoon runs range from 15.6 to 56.9 miles with an average distance of 31.2 miles. (Detailed Table of Special Educations Routes is located in Appendix A)

Available Charging Windows

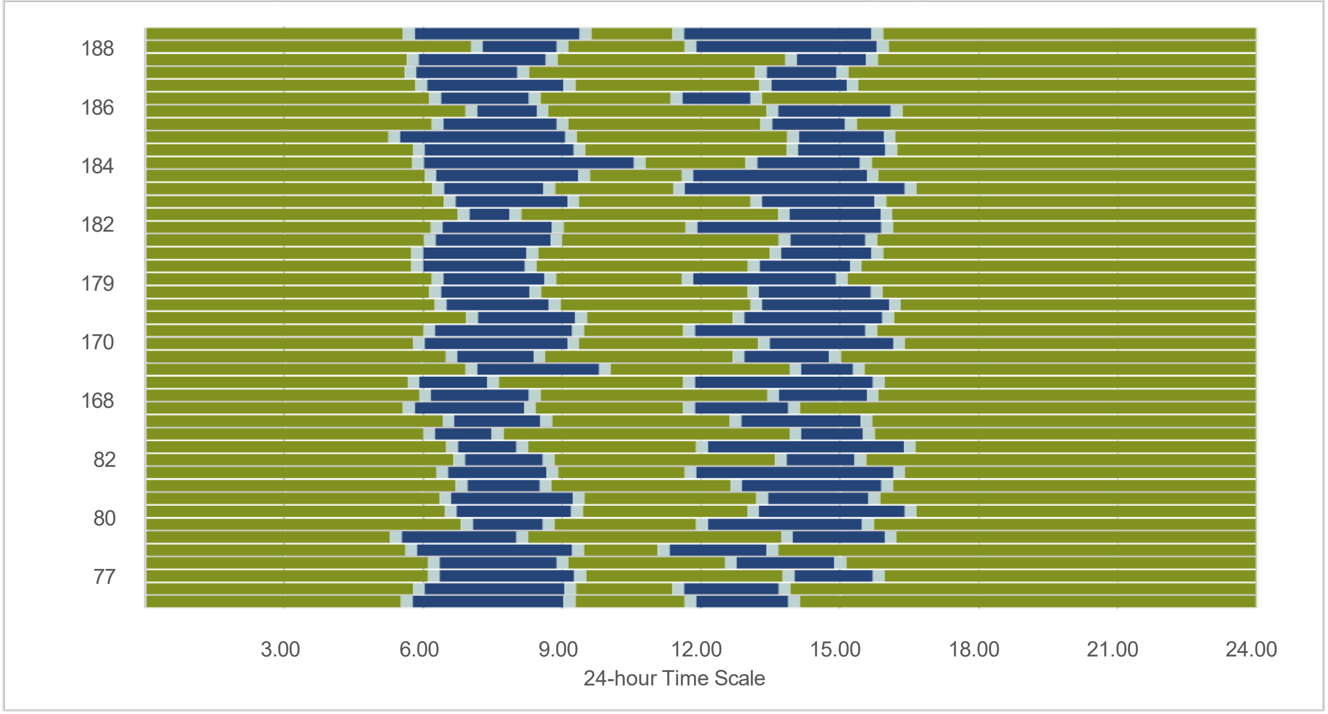
Figure 1 depicts SUSD's regular weekly route operational schedule and available charging windows. The dark blue areas indicate when the bus is in operation and unavailable to charge, the light blue areas indicate when the vehicle might be unavailable for charging due to service or operational constraints, and the green areas indicate when the vehicle is available for charging and/or to be plugged in for energy distribution. **Figure 2** depicts SUSD's Special Education operational schedule and available charging windows.

Figure 1. Regular Route Charging Windows



Source: CARB Clean Mobility in Schools Project: SUSD

Figure 2. Special Education Route Charging Windows



Source: CARB Clean Mobility in Schools Project: SUSD

Site Diagrams

Figure 3 shows SUSD’s school bus parking lot located at 2909 Sanguinetti Lane, Stockton CA, 95205. CTE is currently working with Schneider Electric to develop long-term site plans for SUSD’s transition to electric.

Figure 3 Stockton Unified School District’s Bus Parking Lot

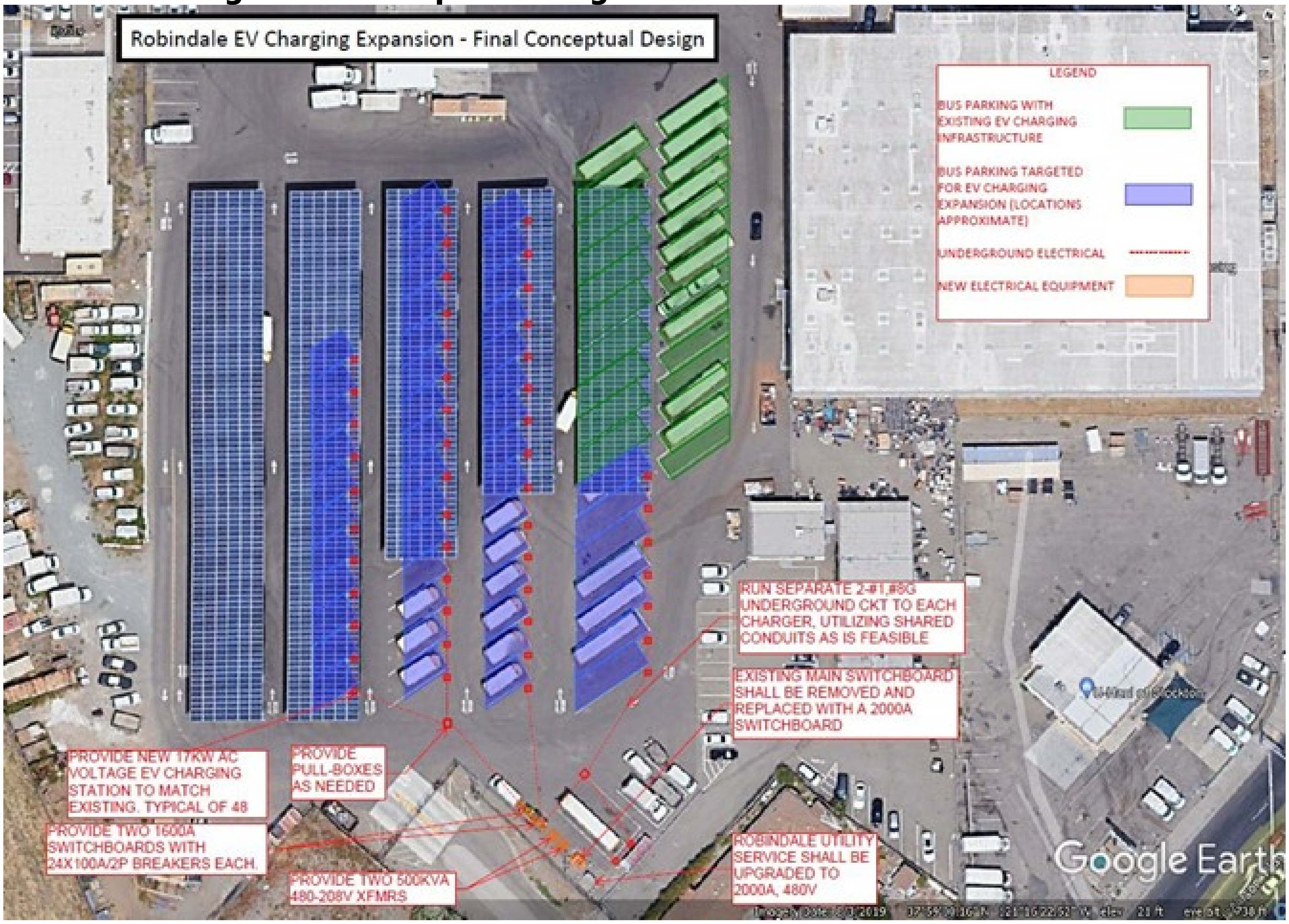
Source: CARB Clean Mobility in Schools Project: SUSD

Charging Infrastructure Capital Costs

Costs to install electric charging infrastructure varies greatly depending on several factors. Site layout and space constraints can add to the overall cost of construction. If the existing electric infrastructure cannot handle the needed power, the local utility provider will have to make upgrades. CTE estimates that the cost to install AC chargers for SUSD would range from $34,000 per charger up to $114,000 per charger. The higher average is based on a design/build estimate from an engineering firm and the lower is from CTE cost modeling templates using assumptions from various projects. CTE uses averaged data from a selection of past projects to develop assumptions such as cost per charger, design/engineering layouts, initial construction (trenching, conduits, electrical, charger stub outs), and final charger installation. Utility infrastructure installation varies widely with local conditions, responsibility for grid upgrades, work needed to meet current codes, site layout and charger protection, and other factors. With historic inflation and supply chain challenges affecting pricing, cost models based on prior builds may underestimate costs. Because every installation is different, the estimate may not align fully with actual costs for SUSD. The project team expects the broad trends to continue however, with AC charging being less expensive per bus and per kW than

DC charging. **Figure 4** shows the conceptual design for electric charging infrastructure at the SUSD site. The drawing shows the existing charging infrastructure in green and new charging stations in blue.

Figure 4. Conceptual Design for EV Infrastructure at SUSD

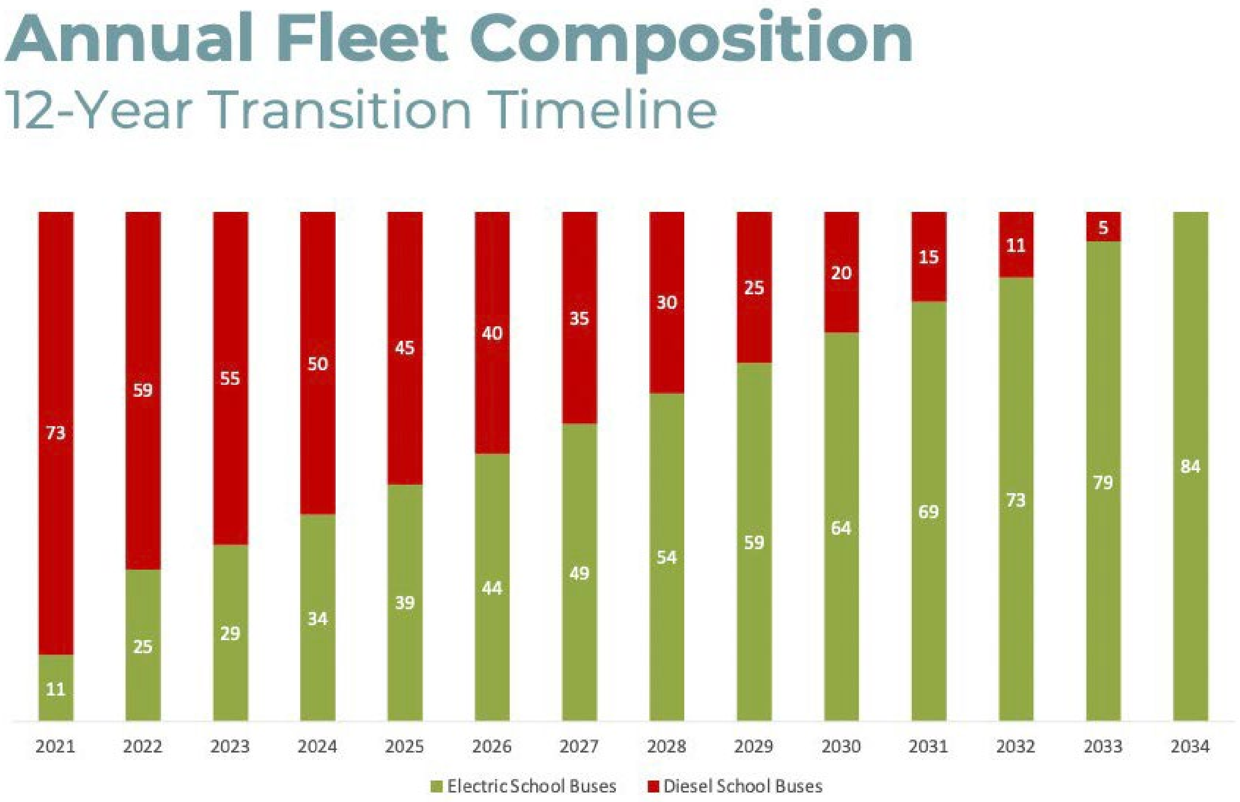


Source: CARB Clean Mobility in Schools Project: SUSD

SUSD's Transition Plans

SUSD currently operates a total of 111 buses. The district's 84 active buses are comprised of 39 short buses and 45 full-size buses. Beginning in late 2019, SUSD partnered with Schneider Electric, the CTE, Sage, and TMH to apply for the California Air Resources Board's (CARB) Clean Mobility in Schools Project. SUSD received a grant through this program as well as other sources including awards from the California Energy Commission, the San Joaquin Valley Air Pollution Control District, and utility rebates from Pacific Gas & Electric (PG&E). In all, SUSD secured $8.3 million for 11 electric school buses and 24 chargers with a mixture of four DC fast and 20 Level II chargers). The 11 ESBs were placed into service in August 2021. SUSD's goal is to transition all the school district's buses to ESBs. **Figure 5** shows the transition plan produced by CTE as a part of the Clean Mobility in Schools Project.

Figure 5. SUSD 12-Year Transition Timeline



Source: CARB Clean Mobility in Schools Project: SUSD

As shown in **Figure 5,** based on SUSD’s replacement schedule, it is feasible to reach a 100 percent ESB fleet by 2034. SUSD is currently procuring additional ESBs as they work through their transition plan. In October 2022, SUSD was awarded the EPA Clean School Bus Rebate award for an additional $7.9 million toward the purchase of an additional 20 ESBs.

Charging Scenario Analyses

Charge Energy Management to Optimize for SUSD Utility Tariff

The first analysis was conducted by TMH to review how charge energy management (CEM) could benefit SUSD. TMH used its proprietary python-based simulation tool to provide optimized charging simulations and savings calculations for the ESB fleet. Using CEM algorithms, TMH's simulation tool determines the optimal charging schedule for fleets based on vehicle requirements, local utility rates, and potential for Active Load Management (ALM) to work within onsite electrical restrictions. TMH gathered site-specific data needed for simulations from the project partners; any unknown or missing data were filled in based on market knowledge and TMH recommendations as described below. The project team reviewed and agreed upon all assumptions prior to the analysis. Using these data, TMH developed an expected vehicle schedule for the ESB fleet at SUSD, which served as input for the simulation CEM algorithm. The simulation algorithm then provided optimizations for various cost and emissions scenarios.

Charging Scenarios Included:

1. All AC chargers
2. All DC chargers
3. Combination of AC and DC chargers

Charging Scenario Analysis Assumptions:

1. 84 electric school buses (ESBs) running school year shifts and summer shifts
2. Schedule data for school year and summer (Source: SUSD, 2021 – 2022 Electric Bus School Year Routes and 2018 & 2019 Summer Bus Routes)
    a. School year schedule:
        i. Same weekly schedule with no weekend use
        ii. 180-day school year
    b. Summer schedule:
        i. June & July – based on SUSD annual schedules
3. Battery Availability: 80percent of 150 kWh nameplate capacity
4. State of Charge (SoC): 20percent SoC buffer to account for unknowns including driver patterns, terrain, weather, passenger loads, and lifetime battery degradation
5. Plug Time buffer: 15-minute buffer added between end shift time and possible start charging time, and 15-minute buffer for vehicle to be completely charged before start shift time
6. Site Load: Zero additional site loads to optimize charging
7. PG&E Business Electric Vehicle rates (BEV-1 & BEV-2-S)

    a. SUSD is in PG&E territory and is therefore eligible for the 2020 Business Electric Vehicle (BEV) utility tariff. These tariffs consist of BEV-1 and BEV-2 (Primary & Secondary); to qualify for BEV-1 the maximum demand of the load must remain at or below 100kW, the Stockton fleet charging load exceeds 100kW and therefore use BEV-2. Each tariff contains a single subscription-based demand charge per month and time- varying energy charges for three time-of-use (TOU) periods. This is a non-seasonal rate, which means the same TOU periods and costs apply for all 12 months of the year

8. Electric Vehicle Supply Equipment (EVSE) chargers according to three scenarios:
    a. all 19.2 kW AC chargers
    b. all 50kW DCFC chargers
    c. 8 50 kW DCFC chargers and 76 19.2 kW AC chargers

Charging Scenarios with CEM Results

Table 5 provides the annual costs for each scenario with and without CEM. In all charger scenarios, CEM results in significant savings for charging. Yearly savings range from 26.6 up to 40.6 percent over non-managed charging. The lowest cost with or without CEM was for all DC charging at 40 percent. This analysis does not account for the difference in capital cost of the chargers.

It's worth noting that some CEM systems also include ALM functionalities, which at appropriate sites can minimize grid infrastructure upgrade (capital) costs as well. ALM can manage EV load to allow charger nameplate capacity at a site to safely exceed the main panel capacity by ensuring aggregate charge load never rises to the site limit. With ALM, customers can mitigate the need for infrastructure upgrades – saving time, money, and materials for large EV installations.

Table 5. Annual Savings with CEM

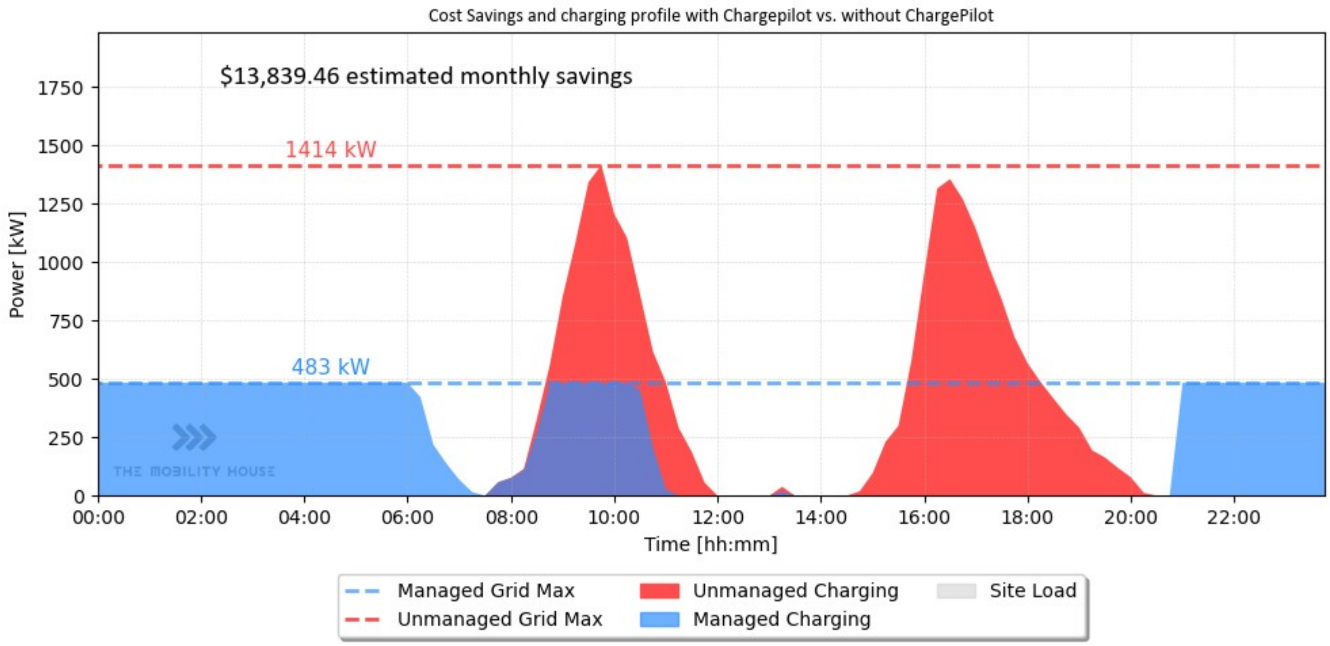
Scenario	Yearly Cost without CEM	Yearly Cost with CEM	Yearly Savings Percentage
AC Charging	$405,695.42	$244,520.06	39.7percent
DC Charging	$399,321.20	$237,228.80	40.6percent
DC+AC Charging Combination	$406,156.76	$297,917.92	26.6percent

Source: The Mobility House Analysis

Scenario 1: All AC Chargers

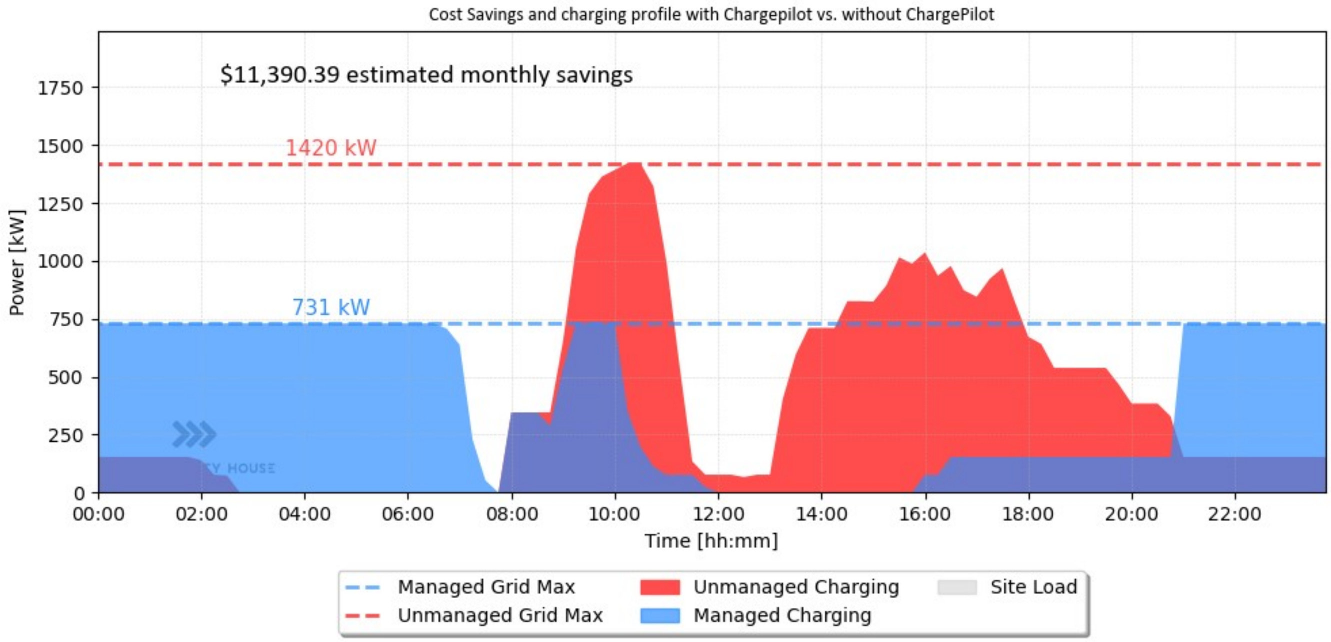
Figure 6 provides the charging profile for the AC only scenario during the school year, with and without CEM. Controlling the charge times reduces the peak power demand by 931 kW, resulting in a monthly savings of over $13,000. **Figure 7** provides the charging profile for the AC only scenario during the summer, with and without CEM. Controlling the charge times reduces the peak power demand by 689 kW, saving more than $11,000 each month.

Figure 6. AC Only Cost Savings and Charging Profile with and without CEM, School Year



Source: The Mobility House Analysis

Figure 7. AC Only Cost Savings and Charging Profile with and without CEM, Summer

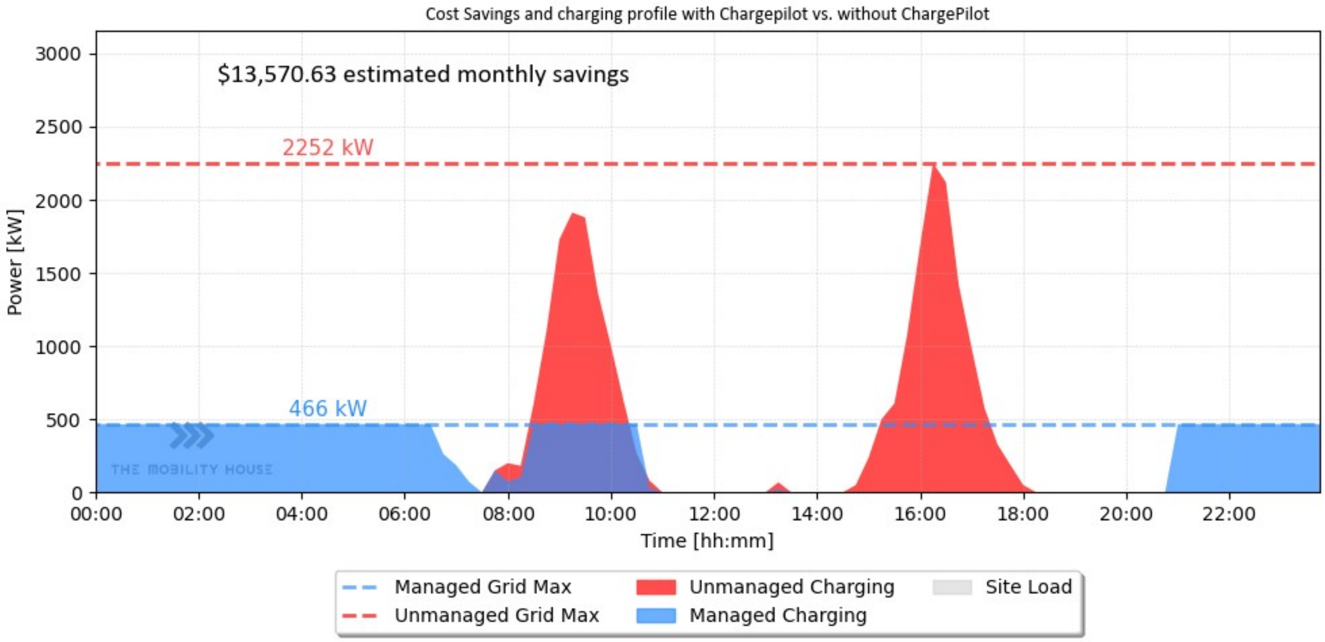


Source: The Mobility House Analysis

Scenario 2: All DC Chargers

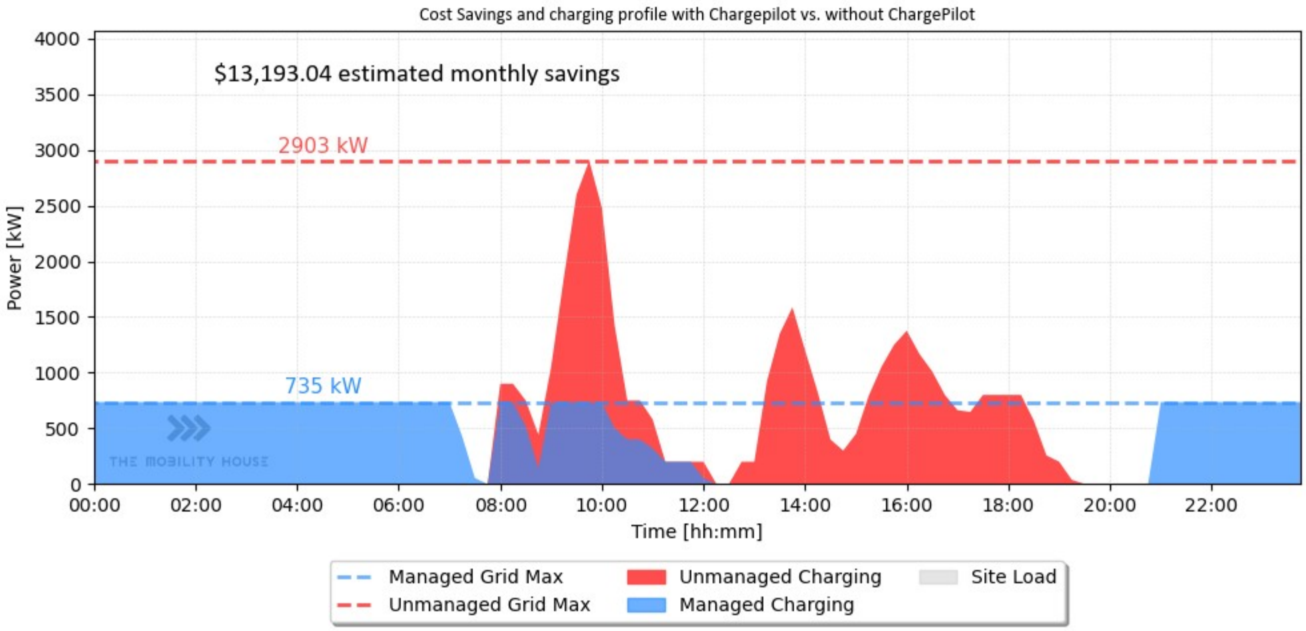
Figure 8 and **Figure 9** provide the charging profile with and without CEM for the DC only scenario during the school year and summer, respectively.

Figure 8. DC Only Cost Savings and Charging Profile with and without CEM, School Year



Source: The Mobility House Analysis

Figure 9. DC Only Cost Savings and Charging Profile with and without CEM, Summer

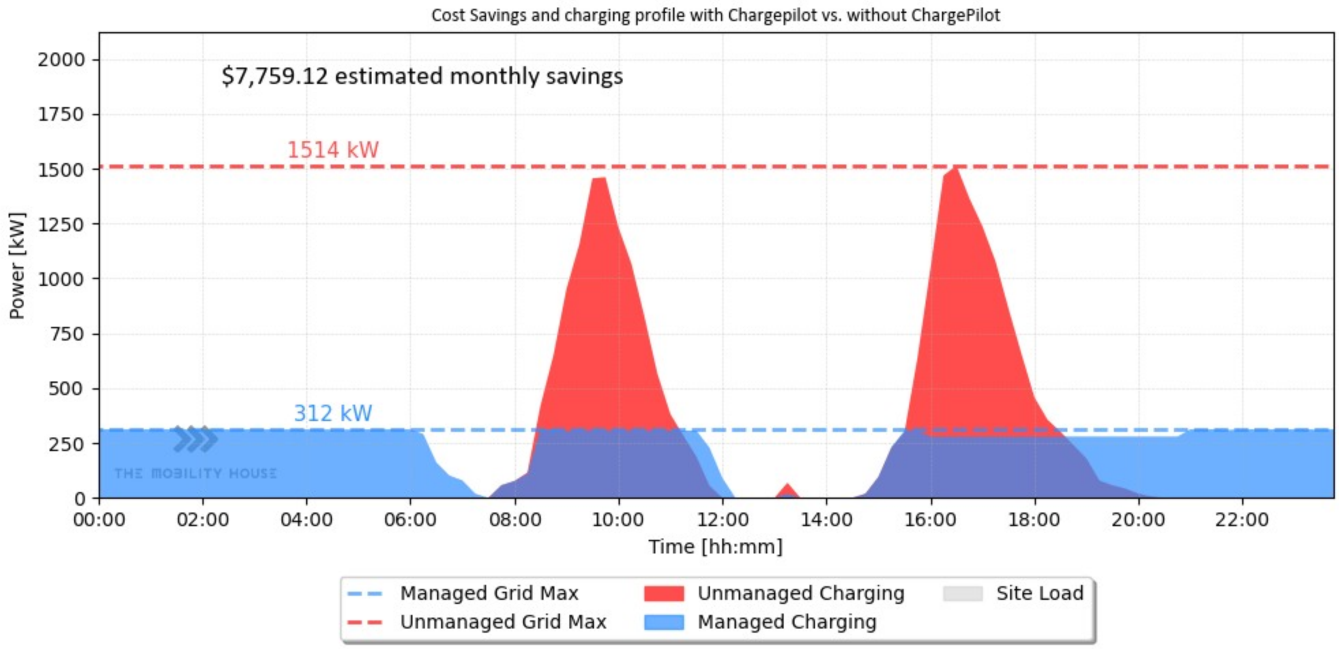


Source: The Mobility House Analysis

Scenario 3: Combination of AC and DC Chargers

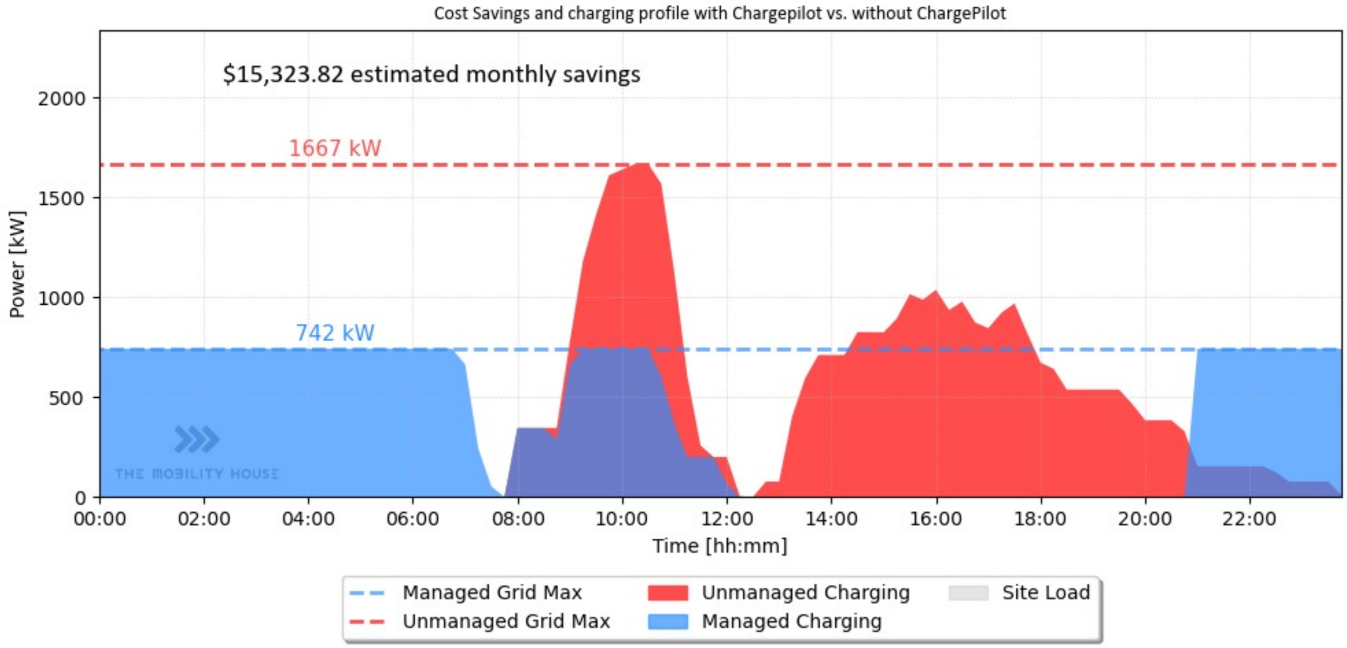
Figure 10 and **Figure 11** provide the charging profile for the AC and DC combined scenario with and without CEM for the school year and summer, respectively.

Figure 10. AC+ DC Cost Savings and Charging Profile with and without CEM, School Year



Source: The Mobility House Analysis

Figure 11. AC +DC Cost Savings and Charging Profile with and without CEM, Summer



Source: The Mobility House Analysis

Table 6 provides a summary of the monthly charging costs per scenario with and without CEM.

Table 6. Results Summary - Monthly fleet charging costs with & without CEM

	Cost without CEM ($/month)	Cost with CEM ($/month)
DC+AC School Year	$31,680.31	$23,921.19
DC+AC Summer	$44,676.83	$29,353.01
AC School Year	$31,676.06	$17,836.60
AC Summer	$44,467.41	$33,077.03
DC School Year	$31,402.56	$17,831.93
DC Summer	$42,647.80	$29,454.75

Source: The Mobility House Analysis

Through this modeling we see that all charging options successfully charge the buses, and that charge management results in significant savings, making a CEM system worthwhile. This also shows that the energy cost between different charger scenarios is not significantly different. From an energy cost standpoint, there is not a reason to choose one charger over another.

AC Charging with CEM to Optimize Self-Consumption of PV

The previous analysis showed an AC only charging scenario meets SUSD charging requirements at a marginally higher energy cost standpoint. However, considering the cost of charger procurement and installation fees, AC only charging scenario has the lowest total cost. Therefore, TMH ran an analysis of how self-consumption of PV energy would affect cost for AC charging only. The analysis used the original assumptions plus the following:

1. EVSE chargers: all 19.2 kW AC charger.
2. $0/kWh cost for energy charged with PV not including any value for PV exports.
3. PV load: hourly simulation of PV production on four typical days in four seasons from Sage.
4. Aligned ESB charging profiles with PV production profiles to increase self-consumption and reduce PV exports.

Table 7 summarizes the monthly cost for fleet charging with and without CEM by season. CEM optimizing for self-consumption with a PV system can save roughly 45percent in the summer and up to roughly 60percent during the fall.

Table 7. Monthly Fleet Charging Costs for PV Self-Consumption with and without CEM

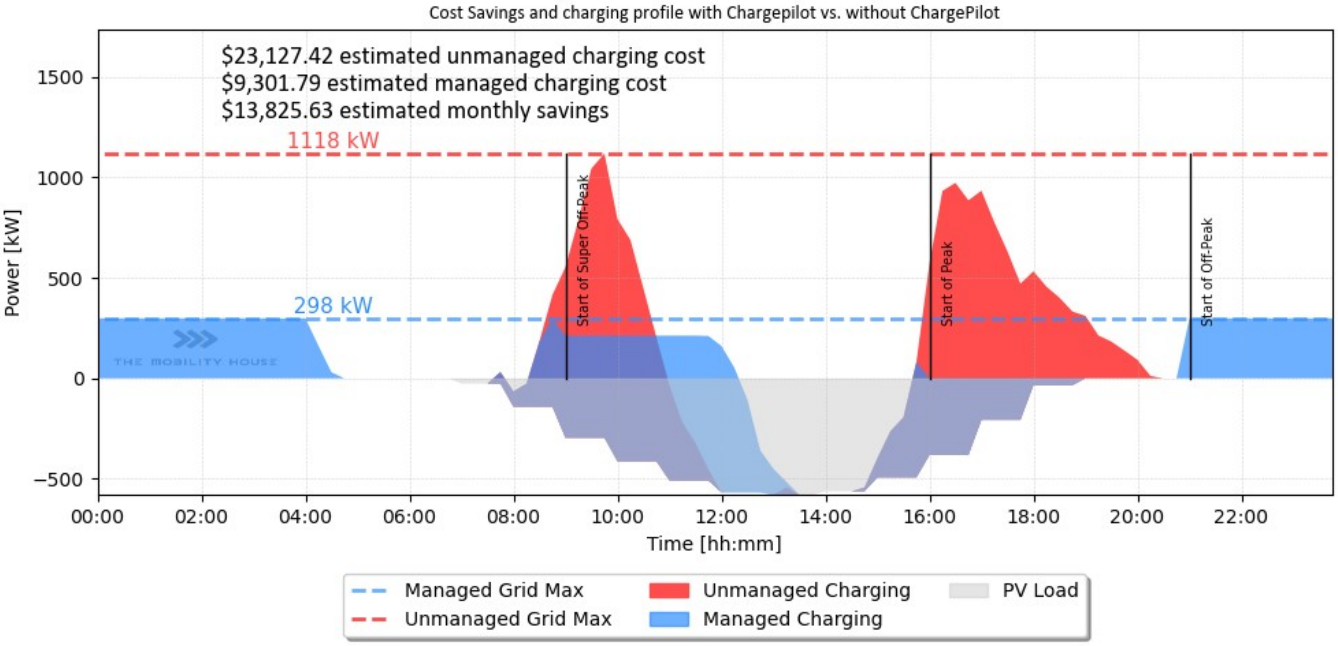
	Cost without CEM ($/month)	Cost with CEM ($/month)	Monthly Saving ($/month)	Savings Percentage
School Year Spring	$20,329.21	$9,403.92	$10,925.29	53.74percent
Summer	$25,743.93	$14,244.46	$11,499.47	44.67percent
School Year Fall	$23,127.42	$9,301.79	$13,825.63	59.78percent
School Year Winter	$29,335.29	$12,831.62	$16,503.67	56.26percent

Source: The Mobility House Analysis

Charging load

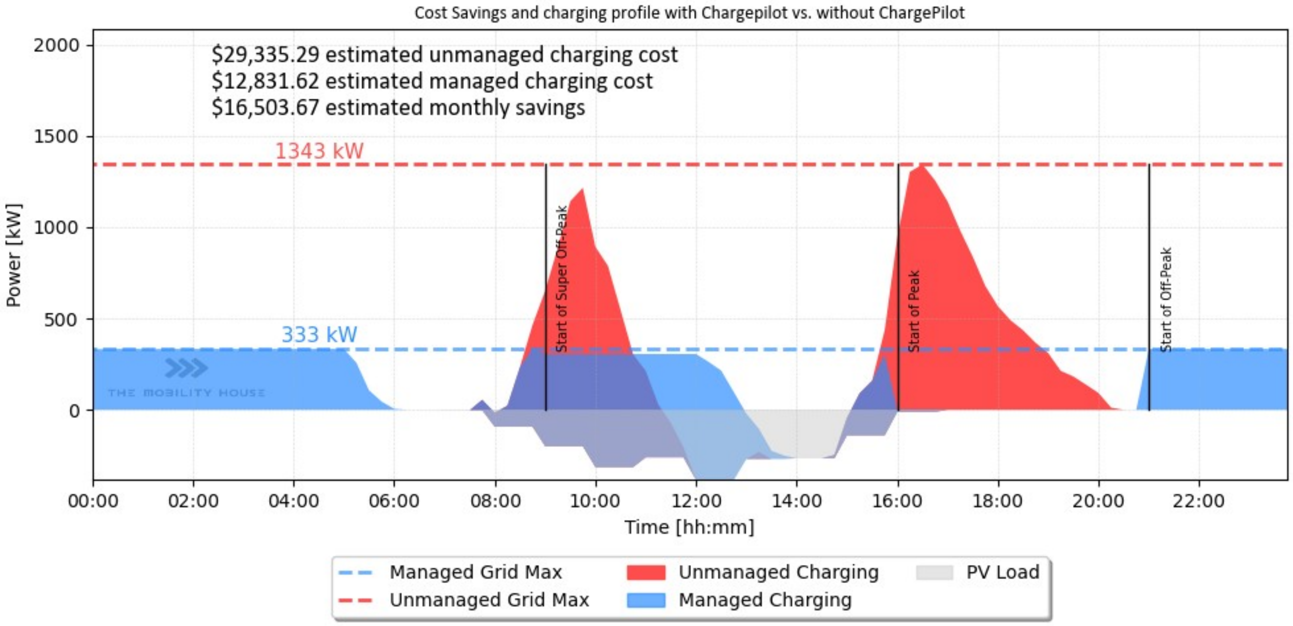
THM analyzed the cost savings for all AC charging during the four seasons. The resulting graphs show the charging load with an onsite PV system. In each graph, red shows charging without CEM, blue shows charging with CEM, and grey shows the PV load. **Figure 12, Figure 13**, and **Figure 14** show the charging load during the school year in fall, winter, and spring. **Figure 15** shows the charging load during the summer break. For all four conditions, CEM can maximize PV energy consumption and avoid charging at peak hours to reduce demand costs.

Figure 12. Site Charging Load in a Typical Day in Fall with PV System



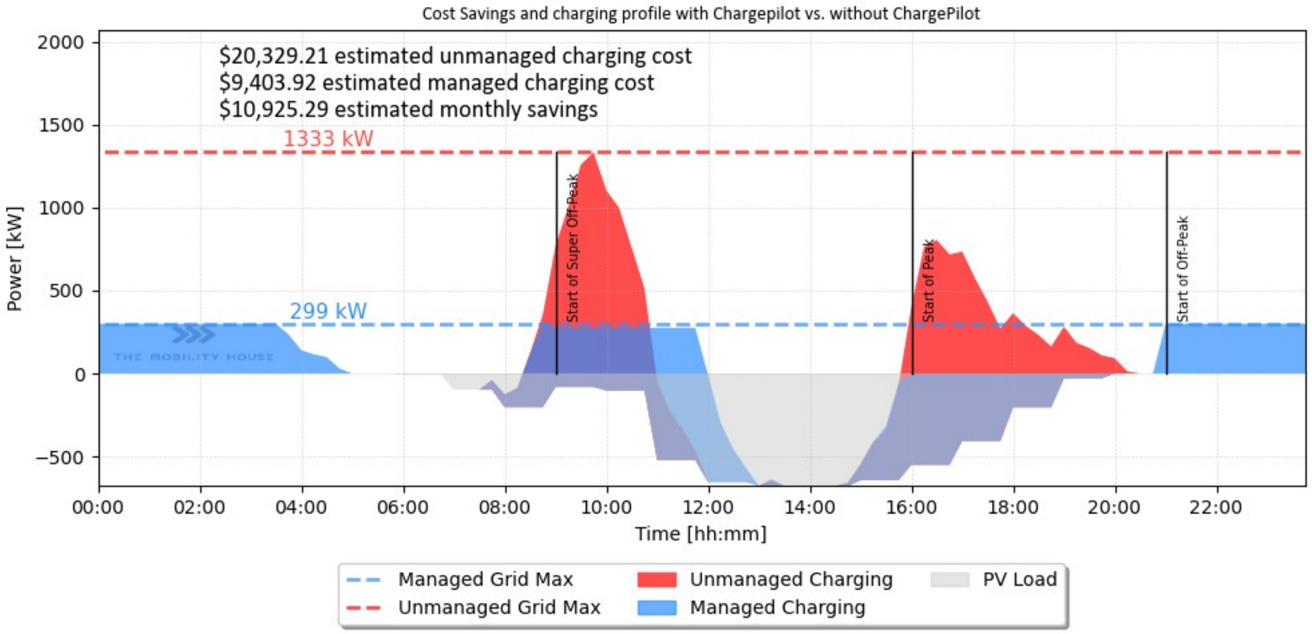
Source: The Mobility House Analysis

Figure 13. Site Charging Load in a Typical Day in Winter with PV System



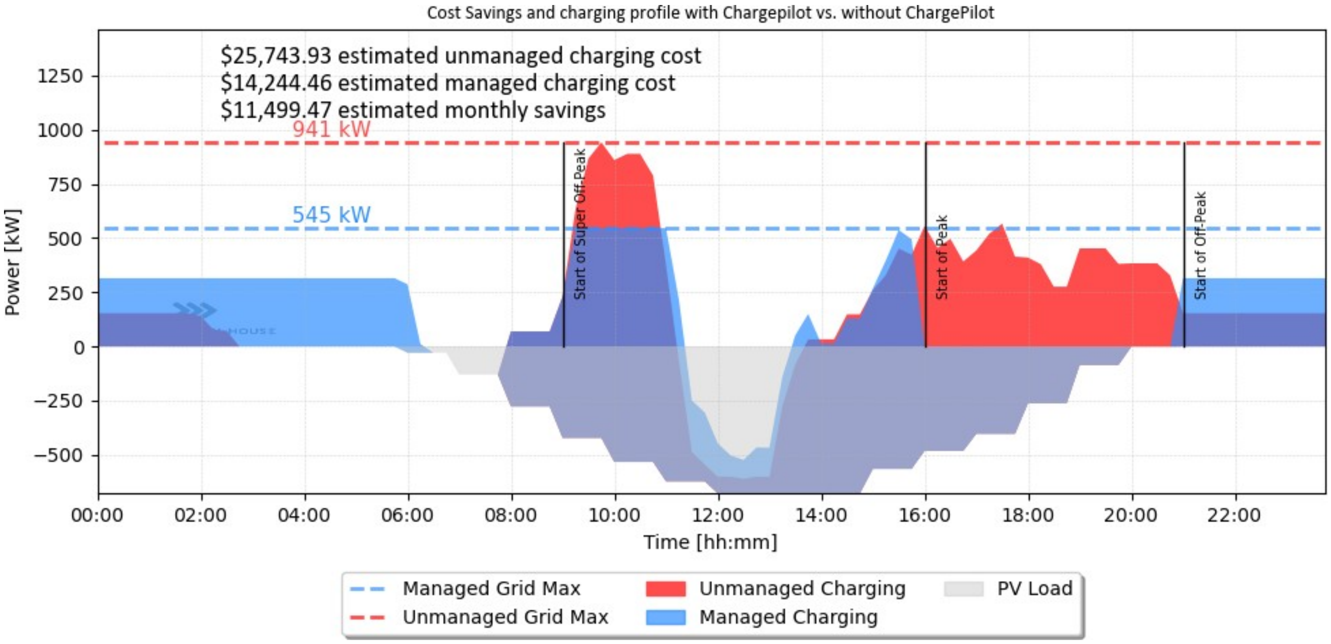
Source: The Mobility House Analysis

Figure 14. Site Charging Load on a Typical Day in Spring with PV System



Source: The Mobility House Analysis

Figure 15. Site Charging Load on a Typical Day During Summer Break with PV System system



Source: The Mobility House Analysis

PV or a PV + BESS combination Analysis

Sage conducted two analyses of how a photovoltaic system and battery energy storage system would affect the cost of charging for SUSD. In the first analysis, Sage explored PV and PV +

BESS without using a CEM to optimize for PV generation. The second analysis focused on a PV and PV + BESS using CEM to optimize for self-consumption of PV.

Net Energy Metering

Net energy metering (NEM) is the process by which a business or homeowner with installed PV is allowed to sell excess solar energy back to the utility. At the beginning of this project, California was under NEM2.0, which is the state policy on how utilities can buy and sell energy from customers with PV installations. A new policy—NEM3.0—was adopted by the California Public Utilities Commission (CPUC) on December 15, 2022. This new policy reduces the value of on-site PV compared to NEM2.0. This analysis used industry expectations for NEM3.0 while it was still under consideration. In particular, the CPUC proposed decision from December 2021 results in a dramatic reduction of the value of exported energy, compensating exports based on the Avoided Cost Calculator rather than a function of the retail rate of electricity.[1] Due to the energy charge profiles, the buses are expected to mostly charge overnight; therefore, PV alone will result in a substantial portion of the PV generation to be exported. For this reason, Sage modeled three PV system sizes representing 90 percent offset, 50 percent offset, and 30 percent offset to optimize cost savings and minimize exported solar generation.

Investment Tax Credit

In mid-August 2022, Congress passed the Inflation Reduction Act (IRA) which sets the base Investment Tax Credit (ITC) for this project at 30 percent. The IRA also allows for tax-exempt entities to receive a direct payment for the eligible credit amount. Additionally, SUSD could be eligible for 40 percent ITC if qualifying for either the domestic content adder, per the Treasury Department guidance, or securing the low- income community adder. If SUSD qualifies for both, the ITC could be up to 50 percent. For purposes of this analysis, Sage assumed the base 30 percent ITC.

PV and PV + BESS without CEM

Sage modeled six scenarios of PV and PV + BESS with the goal of minimizing net costs to SUSD as it transitions to 100 percent electric buses. The systems were modeled under NEM3.0, which was adopted December 15, 2022, and goes into effect April 15, 2023. Sage used the summer and school year charge profiles from TMH to determine the maximum PV system size necessary to offset annual energy consumption. The PV system was modeled in Helioscope[2] and the energy cost savings were modeled in Energy Toolbase.[3] Helioscope is a web-based software used by the industry to design PV systems for proposals. Energy Toolbase is a modeling software used to model, control, and monitor combined PV/energy storage projects.

---

[1] California Public Utilities Commission, available at https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M430/K903/430903088.PDF

[2] Helioscope, available at https://www.helioscope.com/

[3] Energy Toolbase, available at https://www.energytoolbase.com/

PV and BESS Sizing and Siting

The modeled PV system sizes represent 90 percent, 50 percent and 30 percent of the annual bus energy consumption. The PV arrays at SUSD are canopies over the existing bus parking. Solar canopies can be more expensive than rooftop systems and siting them over bus parking areas requires added clearance height which can increase costs. However, the project team considered the quality of the existing roof coatings and the unknown structural capacity of the nearby buildings in this siting selection.

Sage investigated whether pairing BESS with the PV could provide additional cost savings by storing daytime PV generation to charge the buses overnight and to export PV to the grid during high priced periods. Sage sized the BESS to maximize utility savings while keeping the aggregate system (PV + BESS) below one megawatt CEC-AC to avoid SUSD covering the burden of PG&E interconnection grid upgrades. The BESS sizes are not based on available market products, but rather the size determined to achieve the best net savings. **Table 8** provides the PV and BESS sizes for each modeled scenario.

Table 8. PV and BESS System Sizing

Scenario	PV System Size (kWp-DC)	BESS Size (kW / kWh)
90% Annual Energy Consumption Offset	905	300 / 600
50% Annual Energy Consumption Offset	525	576 / 1,152
30% Annual Energy Consumption Offset	328	746 / 1,492

Source: Sage Analysis

PV and PV + BESS Analysis Modeling Assumptions

The financial feasibility analysis assessed both cash purchase and third-party power purchase agreement (PPA) financing. The analysis considers the net impact to SUSD, considering upfront PV and BESS system costs, on-going operations and maintenance costs, added Low Carbon Fuel Standard (LCFS) credits for "Zero Carbon Intensity Pathway", and end-of-life decommissioning costs under the cash purchase. **Table 9** provides the primary assumptions for the analysis.

Table 9. PV and BESS Modeling Assumptions

Assumption	Value
ITC	30%
Interconnection	NEM3.0
Utility Tariff	PG&E BEV-2-S
Tariff Subscription Blocks (50 kW each)	15
PV System Lifetime (Yrs)	25
Net Present Value (NPV) Discount Rate (DR)	2%
Annual Utility Cost Escalator	3%
Annual Consumer Price Index (CPI)	2%
PV Installed Cost ($/Wp)	$3.53 - $4.32
PV PPA Rate, at 0% escalator ($/kWh)	$0.14 - $0.17
BESS Installed Cost ($/kWh) [a]	$610 - $1,222

BESS Capacity Pricing ($/kW-month)	$7.76 - $15.42
BESS Augmentation (Yr)	13
BESS Self Generation Incentive Program (SGIP) Funding	None, PG&E step 5 currently fully subscribed
Low Carbon Fuel Standard (LCFS) Price ($/credit, Yr-1)	$91
LCFS Annual Credit Value Change (percent)	-3%

Source: Sage Analysis

[a] Depending on selected BESS manufacturer, size, and supply chain constraints, BESS Installed Cost may be as high as $1,800/kWh.

PV and PV + BESS Analysis Results

Based on the financial feasibility analysis, neither PV nor PV + BESS would be beneficial to SUSD; SUSD's lowest cost option would be to charge the electric buses using the PG&E BEV-2-S tariff. The analysis findings show that this is the case over a 25-year lifetime due to the reduced value of exported PV generation. PV on its own cannot produce enough utility cost savings to be cost-effective. Using BESS to optimize the discharge of the PV at times when the buses are charging or to on-peak pricing periods provides some additional savings, but not enough to offset the high upfront and on-going cost of BESS. BESS typically provide the best savings opportunity for spikey loads with high peak demand, but in this case, the CEM will be managing demand and smoothing out the peaks. Therefore, the BESS is only able to provide savings through energy arbitrage. **Table 10, Table 11**, and **Table 12** provide the 25-year lifetime savings for each scenario under a Cash Purchase, using the Direct Payment provision of the IRA, and a PPA.

Table 10. 25-Year Lifetime Savings for PV and PV+BESS Cash Purchase Scenarios

Scenario	Net Lifetime Savings, Nominal ($)	Net Lifetime Savings, NPV at 2% DR ($)
PV-Only, 90% Offset, NEM3.0	($325,000)	($762,000)
PV-Only, 50% Offset, NEM3.0	($300,000)	($569,000)
PV-Only, 30% Offset, NEM3.0	($251,000)	($427,000)
PV+BESS, 90% Offset, NEM3.0	($995,000)	($1,394,000)
PV+BESS, 50% Offset, NEM3.0	($840,000)	($1,132,000)
PV+BESS, 30% Offset, NEM3.0	($974,000)	($1,132,000)
PV-Only, 90% Offset, NEM2.0 [a]	*$3,562,000*	*$2,264,000*
PV+BESS, 90% Offset, NEM2.0 [a]	*$2,372,000*	*$1,237,000*

Source: Sage Analysis

[a] NEM2.0 modeled for comparison.

Table 11. 25-Year Lifetime Savings for PV and PV+BESS PPA Scenarios

Scenario	Net Lifetime Savings, Nominal ($)	Net Lifetime Savings, NPV at 2% DR ($)
PV-Only, 90% Offset, NEM3.0	($1,057,000)	**($889,000)**
PV-Only, 50% Offset, NEM3.0	($881,000)	**($730,000)**
PV-Only, 30% Offset, NEM3.0	($698,000)	**($574,000)**

PV+BESS, 90% Offset, NEM3.0	($1,775,000)	**($1,475,000)**
PV+BESS, 50% Offset, NEM3.0	($1,373,000)	**($1,153,000)**
PV+BESS, 30% Offset, NEM3.0	($1,286,000)	**($1,071,000)**
PV-Only, 90% Offset, NEM2.0 [a]	*$2,830,000*	***$2,136,000***
PV+BESS, 90% Offset, NEM2.0 [a]	***$1,591,000***	***$1,156,000***

Source: Sage Analysis

[a] NEM2.0 modeled for comparison.

As shown in **Table 10**, **Table 11**, and **Table 12**, Sage modeled the 90 percent offset scenarios under the current NEM2.0 regime for comparison to the recently adopted NEM3.0 savings. The systems would provide significant lifetime savings in the NEM2.0 scenario. However, with the CPUC approval of NEM3.0 in 2022, most school districts that are seeking to transition to ESBs will not be able to capture those savings. **Table 12** shows the Value of PV in Year One for each modeling scenario.

Table 12. Year 1 Value of PV, by Scenario

Scenario	Value of Solar, Year 1 ($/kWh)
PV-Only, 90% Offset, NEM3.0	$0.075
PV-Only, 50% Offset, NEM3.0	$0.077
PV-Only, 30% Offset, NEM3.0	$0.080
PV+BESS, 90% Offset, NEM3.0	$0.089
PV+BESS, 50% Offset, NEM3.0	$0.119
PV+BESS, 30% Offset, NEM3.0	$0.143
PV-Only, 90% Offset, NEM2.0 [a]	$0.178
PV+BESS, 90% Offset, NEM2.0 [a]	$0.180

Source: Sage Analysis

[a] NEM2.0 modeled for comparison.

The analysis demonstrates four points:

1. Under NEM3.0, the expected value of PV is very low. Comparing the $0.075-0.080/kWh values for the PV-Only systems to the estimated $0.14-0.17/kWh PPA rates demonstrates the difficult economic proposition under NEM3.0.
2. Under NEM3.0, the expected value of PV increases with smaller PV systems. This is due to the higher portion of self-consumed energy relative to exported energy achieved with a smaller system.
3. BESS can significantly enhance the value of a PV system by storing PV and offsetting consumption or exporting at higher value periods. Unfortunately, this increased value does not justify current BESS costs.
4. Even the highest value NEM3.0 scenario (small PV, large BESS) cannot compete with a NEM2.0 system, whether a BESS is included.

Sage explored opportunities which could potentially make PV or PV + BESS installations financially feasible for SUSD and similar school districts.

1. **LCFS booster for on-site PV**: the current CARB LCFS program provides added credit for using renewable energy to charge vehicles through the "Zero Carbon Intensity

Pathway". The added credit can be accessed through either purchasing Renewable Energy Credits (RECs), using a utility 100 percent green tariff, or retiring RECs from an on-site PV system. If the credit were to have an added value for on-site PV, this could support the financials to promote a PV system which will power the on-site BEBs.

2. **BESS Incentives**: BESS has significant upfront and on-going costs which cannot be recuperated by utility bill savings by SUSD under the recently adopted NEM3.0. The Self Generation Incentive Program (SGIP) is currently fully subscribed in the PG&E territory and any new reservation requests are waitlisted. Incentive opportunities would greatly benefit this project, as it was shown that BESS increases the potential on-bill savings compared to a PV-only system.

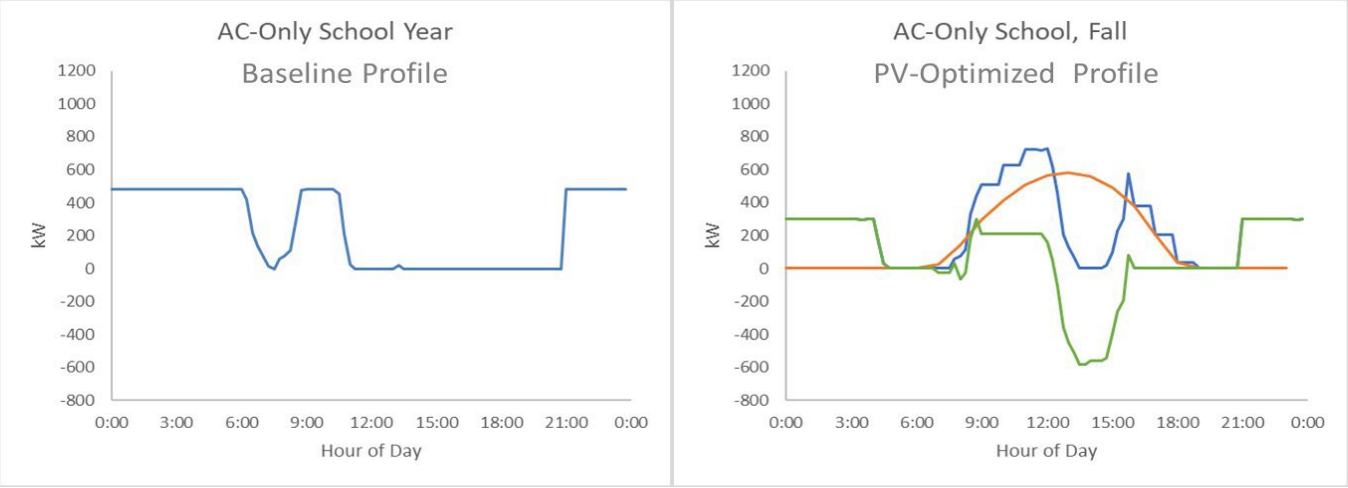
PV and PV + BESS using CEM to optimize for self-consumption of PV

Since the PV and PV + BESS modeling results showed that SUSD would not benefit from PV, Sage analyzed charging the buses on the PG&E BEV-2-S tariff using CEM to optimize for self-consumption of PV generation.

Bus Charging Profiles

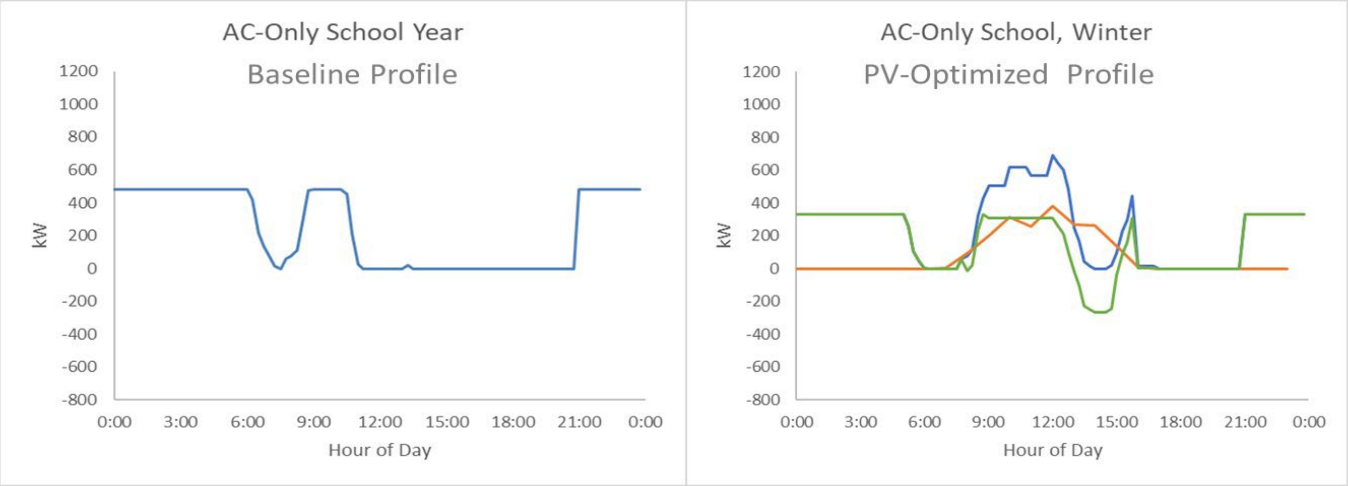
A major factor in the low value of PV-produced energy is the lack of coincidence with the bus charging, leading to a large volume of exported energy at a low value. To improve the expected value of PV under NEM3.0, Sage worked with TMH to better align the bus charging profiles at times when PV generated energy is available. Sage provided TMH with four daily PV profiles representative of each season based on the 90 percent offset PV system. With these PV profiles, TMH developed four seasonal charging profiles which Sage used to develop an annual charging profile. The results of this annual bus charging profile do not perfectly mimic what a real-time CEM would be able to achieve, meaning this analysis represents a conservative estimate of the value of solar production that could be expected from a real-time CEM that is able to dynamically adjust to daily PV generation. **Figure 16, Figure 17, Figure 18**, and **Figure 19** show the baseline and solar-optimized daily AC-only charging profiles for each season, with the PV profile shown in orange and the net load in green. As can be seen in the PV-optimized profiles, the bus charging coincides with the PV generation.

Figure 16. Baseline and PV Optimized Charging Profiles, School Year-Fall



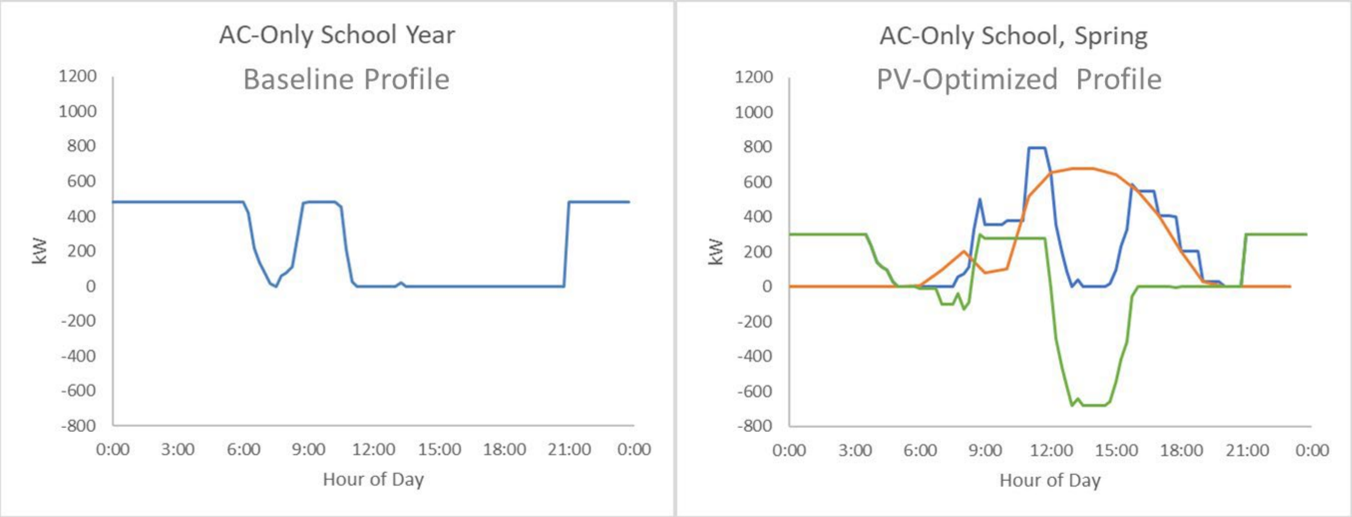
Source: Sage Analysis

Figure 17. Baseline and PV Optimized Charging Profiles, School Year-Winter



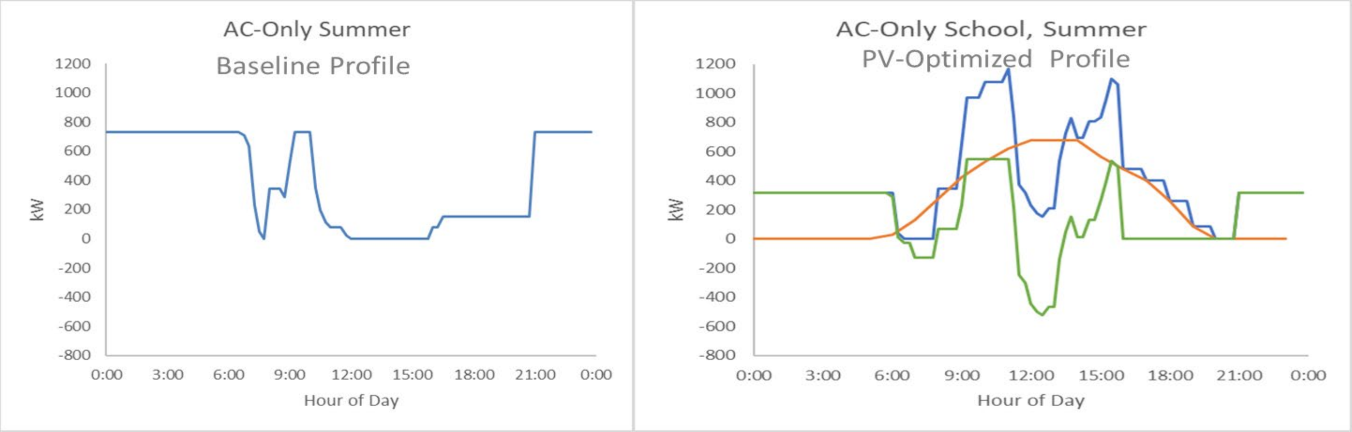
Source: Sage Analysis

Figure 18. **Baseline and PV Optimized Charging Profiles, School Year-Spring**



Source: Sage Analysis

Figure 19. **Baseline and PV Optimized** Charging Profiles, School Year-Summer



Source: Sage Analysis

Demand Subscription Blocks

When aligning the bus charging with PV generation, it could be feasible for the PV to reduce peak demand below the CEM threshold in the baseline profiles. While this may occur in real-time, the PG&E BEV-2-S tariff uses subscription blocks of 50 kW instead of rate-based (i.e., $/kW) charges. To financially benefit from the reduced peak demand due to coincident PV, SUSD would need to predict and adjust subscription blocks monthly or seasonally. Sage estimated this could save roughly $5,000 in Year-1, which is a 25 percent reduction in demand charge costs. There are several risks to this, including the PG&E overage fee if peak demand exceeds the subscribed amount and SUSD tracking and managing monthly on-going requests with PG&E. For this reason, Sage has maintained the same demand subscription fee between baseline and PV-optimized profiles, which the CEM would manage.

PV and PV + BESS with Self-Consumption Analysis Results

The analysis findings show that optimizing bus charging when PV is available improves the value of PV and benefits SUSD. Charging the buses with the 90 percent annual consumption offset PV system resulted in lower costs to SUSD compared to a baseline without PV where buses charge primarily overnight.

Results are only shown for the 90 percent consumption offset PV system which was used to develop the bus charging profiles. The 50 percent and 30 percent consumption offset PV scenarios are not representative of cost savings potential because the bus charging is based on the 90 percent offset system, and therefore, there would result in higher consumption during peak TOU periods. Based on the analysis of the 90 percent offset system, Sage expects that SUSD would similarly benefit from reduced costs to charge electric buses for the 50 percent and 30 percent consumption offset scenarios if the bus charging is aligned with the PV system.

If the CEM can optimize bus charging to coincide with times that PV generation is available, then the marginal savings from using BESS will not offset the high upfront and on-going cost of installing BESS. BESS typically provides the best savings opportunity for spikey loads with high peak demand, but in this case, the CEM will manage demand and smooth out the peaks. Therefore, the BESS is only able to provide savings through minimal energy arbitrage.

Table 13 and **Table 14** provide the 25-year lifetime savings for the 90 percent offset scenario under a Cash Purchase using the Direct Payment provision of the IRA and a Power Purchase Agreement (PPA). Aligning bus charging with PV generation in NEM3.0 results in an increase of roughly $1,000,000 in Lifetime Net Present Value (NPV) savings for PV-only and roughly $880,000 for the PV + BESS.[4] Due to the higher value of PV exports under NEM2.0, aligning bus charging and PV is not critical for savings.

---

[4] Calculated by taking the difference between the PV-Optimized scenario outcome and the Tariff-Optimized outcome under the NEM 3.0 scenario in Table 13.

Table 13. 25-Year Lifetime Savings for PV and PV+BESS Cash Purchase Scenarios

Scenario	Net Lifetime Savings, Nominal ($)		Net Lifetime Savings, NPV at 2% DR ($)	
	Tariff-Optimized	PV-Optimized	Tariff-Optimized	PV-Optimized
PV-Only, 90% Offset, NEM3.0	($325,000)	$980,000	($762,000)	$237,000
PV+BESS, 90% Offset, NEM3.0	($995,000)	$157,000	($1,394,000)	($511,000)
PV-Only, 90% Offset, NEM2.0 [a]	*$3,562,000*	*$3,569,000*	*$2,264,000*	*$2,269,000*
PV+BESS, 90% Offset, NEM2.0 [a]	*$2,372,000*	*$2,544,000*	*$1,237,000*	*$1,369,000*

Source: Sage Analysis

[a] NEM2.0 modeled for comparison.

Table 14. 25-Year Lifetime Savings for PV and PV+BESS PPA Scenarios

Scenario	Net Lifetime Savings, Nominal ($)		Net Lifetime Savings, NPV at 2percent DR ($)	
	Tariff-Optimized	PV-Optimized	Tariff-Optimized	PV-Optimized
PV-Only, 90% Offset, NEM3.0	($1,057,000)	$247,000	($889,000)	$110,000
PV+BESS, 90% Offset, NEM3.0	($1,775,000)	($624,000)	($1,475,000)	($592,000)
PV-Only, 90% Offset, NEM2.0 [a]	*$2,830,000*	*$2,836,000*	*$2,136,000*	*$2,141,000*
PV+BESS, 90% Offset, NEM2.0 [a]	*$1,591,000*	*$1,763,000*	*$1,156,000*	*$1,288,000*

Source: Sage Analysis

[a] NEM2.0 modeled for comparison.

Table 15 provides the gross value of PV looking at the Net Present Value approach. Each case is comparing a financial outcome for whether or not to proceed with the scenario described. This analysis is based on financial modeling using the current available knowledge for system costs and profits. The Tariff-Optimized scenarios prioritize bus charging during low-cost periods based on the PG&E BEV-2-S tariff, while the PV-Optimized scenarios prioritize bus charging when PV generation is available. Each scenario is compared to the no-PV lowest cost charging baseline on BEV-2-S.

Table 15. Year 1 Value of PV, by Scenario

Scenario	Non-Solar Optimized, Value of PV, Year 1 ($/kWh)	Solar Optimized, Value of PV, Year 1 ($/kWh)
PV-Only, 90% Offset, NEM3.0	$0.073	$0.102
PV+BESS, 90% Offset, NEM3.0	$0.085	$0.111
PV-Only, 90% Offset, NEM2.0 [a]	*$0.168*	*$0.168*
PV+BESS, 90% Offset, NEM2.0 [a]	*$0.170*	*$0.173*

Source: Sage Analysis

[a] NEM2.0 modeled for comparison.

As shown in **Table 13** and **Table 14** Sage modeled the 90 percent offset scenarios under the NEM2.0 regime for comparison to the NEM3.0 savings. While the PV systems would provide significant lifetime savings under NEM2.0, most future school districts will not be able to capture those savings under NEM3.0.

Table 15 shows the Value of PV in Year One for each modeling scenario. This demonstrates four points:

1. Under NEM3.0, aligning bus charging times to when PV generated energy is available reduces exported energy and increases the value of PV; however, the value of PV is still much higher under NEM2.0.
2. The expected value of PV remains relatively low after aligning bus charging with PV. Comparing the Year One $0.102/kWh value of solar for the PV-Only system to the estimated $0.14/kWh PPA rate demonstrates the difficult economic proposition under NEM3.0.
3. Under NEM3.0, the value of PV increases by 30-40 percent with the PV optimized charging profiles. This is due to the higher portion of self-consumed energy relative to exported energy achieved under this scenario.
4. BESS can enhance the value of a PV system by storing excess solar energy and offsetting consumption or exporting at higher value periods. However, even with this increased value, it does not justify current BESS costs.

The modeled results show that a 90 percent offset PV system interconnected under NEM3.0 where the CEM optimizes charging at times when solar energy is available could be marginally beneficial for SUSD compared to a scenario without PV in which buses charge primarily overnight. PV + BESS is not expected to benefit SUSD. The value of PV under NEM3.0 is relatively low, but PV could provide net savings to the district compared to purchasing all its energy from PG&E on the BEV-2-S tariff. The modeling is conservative and actual savings could be higher with a sophisticated CEM that can predict and adjust charging in real-time.

Vehicle to Grid (V2G) Analyses

TMH and Sage conducted V2G analyses with different approaches. TMH took a top-down approach to estimate V2G revenue, profit, and cost for SUSD using a day ahead real time pricing tariff for both AC and DC chargers under three scenarios. Sage took a bottom-up approach to analyze the minimum average export rate needed to provide a net cost savings to SUSD under current operations.

V2G Revenue, Profit, and Cost for SUSD using Day Ahead Real Time Pricing

As mentioned previously, SUSD is in Pacific Gas & Electric (PG&E) territory. In 2020, PG&E proposed the "Day-Ahead Hourly Real-time Pricing" (DAHRTP) rate, a real time rate for eligible Electric Vehicle (EV) customers which includes a component to compensate for V2G energy export; SUSD is eligible for this rate. The rate is finalized and will be available in October 2023. In this analysis, TMH included the DAHRTP rate structure in its proprietary simulation model to estimate the profit for school buses with V2G capability using SUSD as an example. The rate is modeled per what is known in its rate case and subsequent filings by November 9, 2022. For elements that had yet to be defined in the rate structure, TMH made assumptions based on industry knowledge.

Overview of PG&E's DAHRTP rate

Beginning with its application submittal to the California Public Utilities Commission (CPUC) on October 23, 2020,[5] PG&E initiated the process to introduce the DAHRTP rate structure that establishes hourly customer electricity rates one day prior to use. Though the initial duration for this rate is three years, this rate will continue indefinitely if no better revenue generating option for V2G is established.

Customers cannot participate in this rate and a demand response program like Emergency Load Reduction Program (ELRP) at the same time.

The DAHRTP rate includes an import rate that measures the customer's payment for energy consumption and an export rate that measures the customer's compensation for energy export. Export and import rates are both energy-based and do not include demand charges.

Methodology

Once implemented, the DAHRTP rate's import and export rates will use a real-time energy price. TMH modeled the rates using a year of public historical energy data from May 2021 to April 2022 to best estimate the rates. In addition to the rate information, TMH used the school

---

[5] APPLICATION OF PACIFIC GAS AND ELECTRIC COMPANY (U39M) FOR APPROVAL OF ITS PROPOSAL FOR A COMMERCIAL ELECTRIC VEHICLE DAY-AHEAD HOURLY REAL TIME PRICING PILOT, available at https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M349/K245/349245263.PDF

bus schedules, vehicle specifications, and charger specifications from SUSD as input to the company's simulation tool. The simulation tool models vehicles' charging and discharging behavior respecting all operation considerations of the fleet (listed under "Vehicle charging and discharging modeling with V2G") and aims to optimize profit. For simplicity, TMH modeled a single representative bus in the analysis for one year.

DAHRTP rate structure

To model DAHRTP rate, TMH first researched the relevant CPUC proceedings for the rate including the most recent "Proposed Decision on the Export Compensation settlement for PG&E's DAHRTP rate".

In DAHRTP, both import and export rates change hourly, and their compositions are as follows:

- For import rate, it is the sum of three components
    - Marginal Energy Charge, which is the Day Ahead hourly market energy prices from California Independent System Operator for a given hour
    - Marginal Generation Capacity Cost for a given hour
    - Revenue Neutral Adder, which is designed to ensure the utility does not make or lose money on this rate
- For export compensation, it is the sum of two components
    - Marginal Energy Charge, which is the Day Ahead hourly market energy prices from California Independent System Operator for a given hour
    - Marginal Generation Capacity Cost for a given hour

The export rate is the same as the import rate but without the Revenue Neutral Adder. PG&E successfully argued that this component represents utility fixed costs that would be unaffected by export. They acknowledge there is an infrastructure value there, but argue it is unknown. There are opportunities arising to discuss how best to determine this value in the regulatory space and TMH is tracking them. The export rate is separate from the import rate—customers do not have to enroll in both the import rate and the export rate at the same time. In this analysis, TMH modeled both rates to include benefits for using V2G export on-site.

DAHRTP rate modeling

To accurately estimate the price value for the three components that make up import and export rates, TMH used a year of historical energy price data and applied inflation at the end to adjust for 2021-dollar value to 2034-dollar value. SUSD is estimated to complete its transition to 100 percent ESBs by 2034 and have all V2G compliant chargers.

As mentioned in the previous section, DAHRTP rate has three key components, Marginal Energy Charge (MEC), Marginal Generation Capacity Cost (MGCC), and Revenue Neutral Adder (RNA), TMH calculated each of them in the following ways:

- MEC is the Day Ahead hourly market energy prices from the CAISO. TMH downloaded yearly Day Ahead energy prices data from May 1, 2021-April 31, 2022, from CAISO OASIS
- MGCC is the hourly marginal capacity cost to generate energy. According to PG&E, the value of MGCC at hour h ($MGCC_h$) is calculated from the MGCC value, and adjusted for Net Load, capacity loss, and planning capacity reserve margin (see equation below). Note that the exact numbers of MGCC and Thresh the rate will use are still in discussion, TMH used the best available data to estimate the values. For example, the annual MGCC should reflect the cost in the given year when the rate is used, in the analysis, TMH used the 2021 value of MGCC ($65.16/kW-year); Adjustment for Net Load include 10 different weather simulation scenarios, TMH used a single scenario of real historical data from May 2021 to April 2022.

$$MGCC_h = \frac{MGCC * (ANL_h - Thresh) * CapLoss * PRM}{Sum(\ ANL\ above\ Thresh)}$$

Where:

- $MGCC_h$= Marginal Generation Capacity Cost at hour h
- MGCC = Annual Marginal Generation Capacity Cost; TMH used 2021 value of $65.16/kW-year
- ANL_h= Adjusted Net Load at hour h. Adjusted Net Load is the hourly generation on the grid in CAISO minus any generation coming from GHG net-zero emission sources (e.g., Hydro, Wind, Solar, etc.)
- Thresh = 80 percent of average annual peak ANL over all 10 different 2021 weather scenarios; TMH modeled thresh from a single scenario of real 2021 historical data.
- CapLoss = Loss factor for capacity (1.091);
- PRM = Factor for planning reserve margin (1.15);
- Sum [Adjusted Net Load (ANL) above Threshold] = Average annual sum of ANL 5 above Thresh over all 10 different 2021 weather scenarios, for Thresh, TMH modeled thresh from a single scenario of real 2021 historical data.
- RNA: TMH used the assumed rates per CPUC's Decision 21-11-07[6] on November 18, 2021. Time of use hours and dates are not included in the file, so TMH assumed TOU

---

[6] CPUC decision 21-11-07, available at https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M424/K557/424557371.PDF

schedules from current PG&E Business Electric Vehicle rate plans (Table 16 provides the RNA values by TOU period).

- Inflation: In the result section, a 29.7 percent inflation[7] rate on price is added to account for conversion of 2021-dollar value to 2034-dollar value. Different inflation rates can be applied to the 2021-dollar value for a different year.

Table 16. Value for RNA applied

TOU Period	TOU Revenue-Neutral Adder
Peak (4-9 pm)	$0.14304
Off-Peak (9 pm-9 am, 2 pm-4 pm)	$0.00519
Super Off-Peak (9 am-2 pm)	$0.00519

Source: The Mobility House Analysis

Vehicle charging and discharging modeling with V2G

TMH modeled a single vehicle's charging and discharging behavior to maximize profit while fulfilling all driving requirements using two charger models for an entire year.

- Charging Equipment: This model assumes 19.2 kW and 50 kW bidirectional chargers for DAHRTP applications (noting that 19.2 kW is for illustrative purposes only, as commercial AC V2G is on-track to be commercially available in three to five years)
- Charging Efficiency: 93 percent charging and discharging efficiency
- Schedule: One typical vehicle schedule (ZEV01) is chosen for school year and summer break to represent the whole fleet for V2G modeling, ZEV01 travels 42.3 miles/day on weekdays during school year in morning and afternoon trips and travels 86.35 miles/day on weekdays during summer morning and afternoon trips. The school year is from August 2 to May 26 of the next year and May 27 to August 1 is the summer break.
- State Of Charge (SoC): Minimum SoC of 20 percent, 100 percent SoC before any trip
- School bus: 150 kWh nameplate capacity

Summary of Revenue, Profit, and Cost Under Current Operations

Table 17 and **Table 18** provide a summary of annual profit, revenue, and cost per charger at SUSD for 2021 and 2034 dollars respectively. **Figure 20** provides the data graphically. Both charger models can generate profit after accounting for charging costs to fulfill vehicles' travel duty. A 50 kW charger can generate up to $638.54 annual profit, a 19.2 kW charger can generate $49.74 in 2021-dollar value. Assuming a fleet of 84 vehicles and 84 chargers, this will

---

[7] U.S. Energy Information Administration: Annual Energy Outlook 2022, available at https://www.eia.gov/outlooks/aeo/data/browser/#/?id=1-AEO2022percentC2percentAEion=0-0&cases=ref2022&start=2020&end=2050&f=A&linechart=ref2022-d011222a.3-1-AEO2022~ref2022-d011222a.48-1-AEO2022&ctype=linechart&sourcekey=0

translate to an annual profit of $4,116 - $53,637 (number differs based on charger model mix). The profit will decrease if multiple vehicles share one charger dispenser due to less available charging and discharging time.

Table 17. Summary Profit, Revenue, and Cost before Inflation Adjustment, 2021-Dollar Value

Charger Power	Annual Profit $/charger	Annual Revenue $/charger	Annual Costs $/charger
50 kW	$638.54	$3,573.17	$2,934.63
19.2 kW	$49.74	$2,660.26	$2,610.52

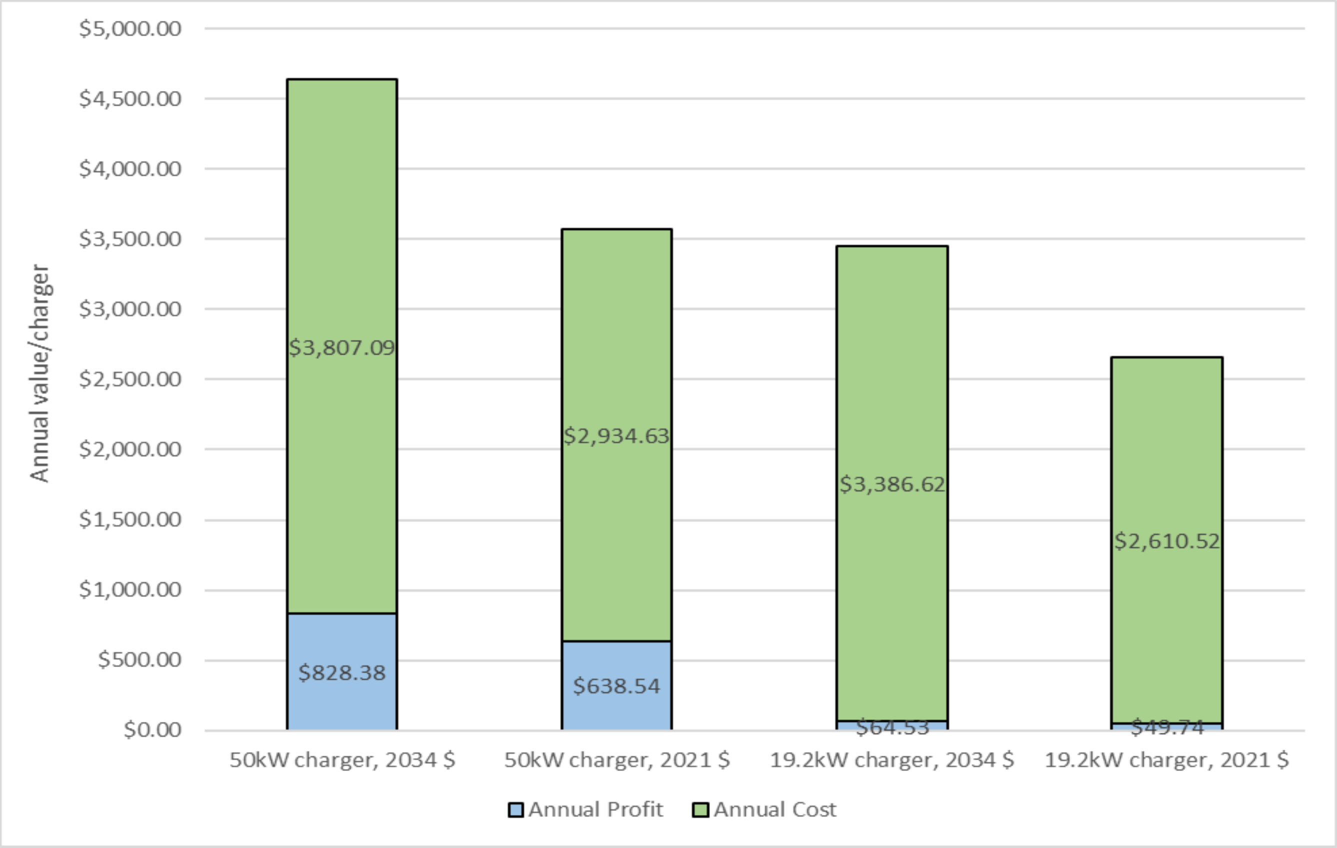
Source: The Mobility House Analysis

Table 18. Summary Profit, Revenue, and Cost After Inflation Adjustment, 2034-Dollar Value

Charger Power	Annual Profit $/charger	Annual Revenue $/charger	Annual Costs $/charger
50 kW	$828.38	$4,635.47	$3,807.09
19.2 kW	$64.53	$3,451.15	$3,386.62

Source: The Mobility House Analysis

Figure 20. Profit, Revenue, and Cost Summary



Source: The Mobility House Analysis

Summary of Charging and Discharging Strategies

Figure 21 and **Figure 22** show the daily change of import and export rates in one day during the school year and summer respectively. Import and export rates in both figures follow similar patterns across the day with a noticeable increase in the afternoon around 4-9pm. Though the afternoon spike for import rate is more significant compared to export rate, the difference between the two rates is small outside of afternoon spike hours.

Figure 21. Sample Import and Export Rate in a Day During School Year

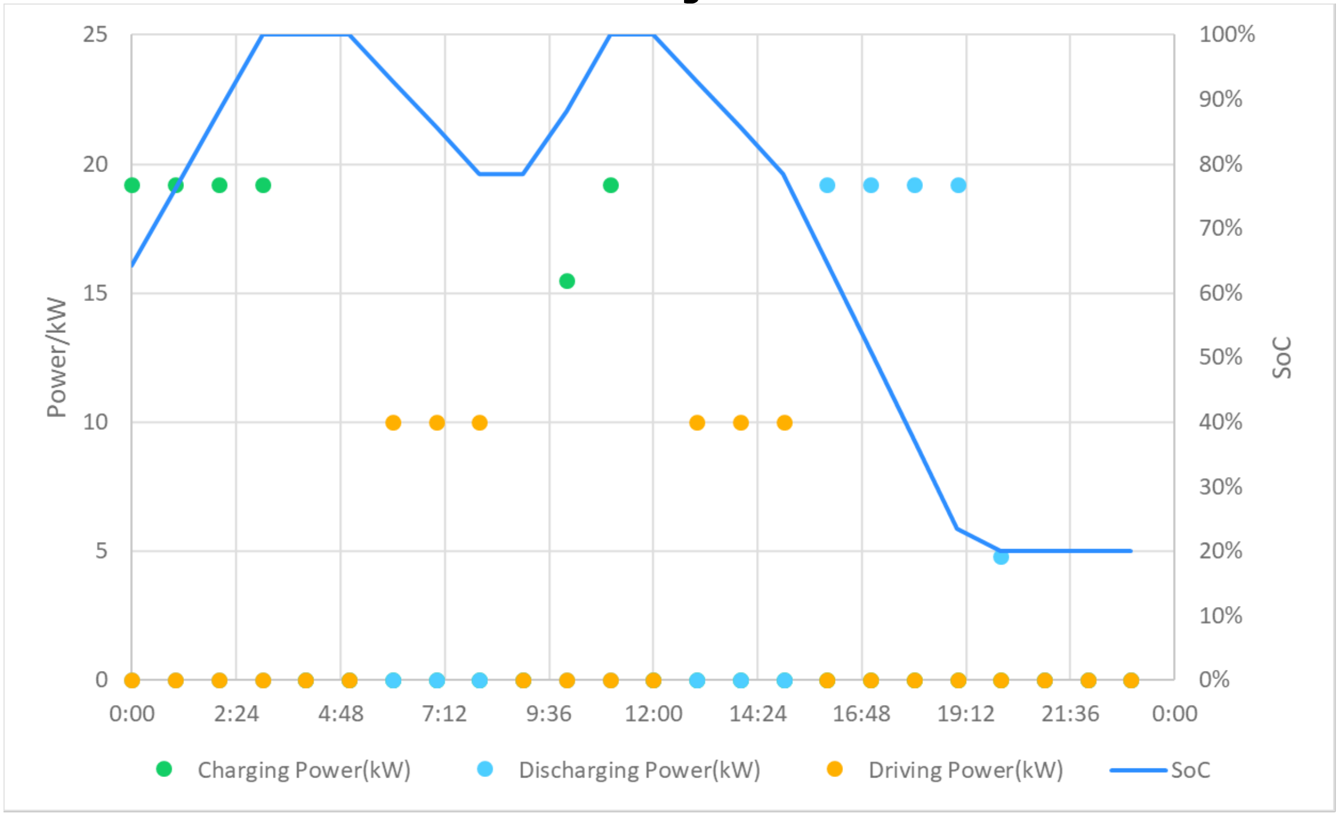
Source: The Mobility House Analysis

Figure 22. Sample Import and Export Rate in a Summer Day

Source: The Mobility House Analysis

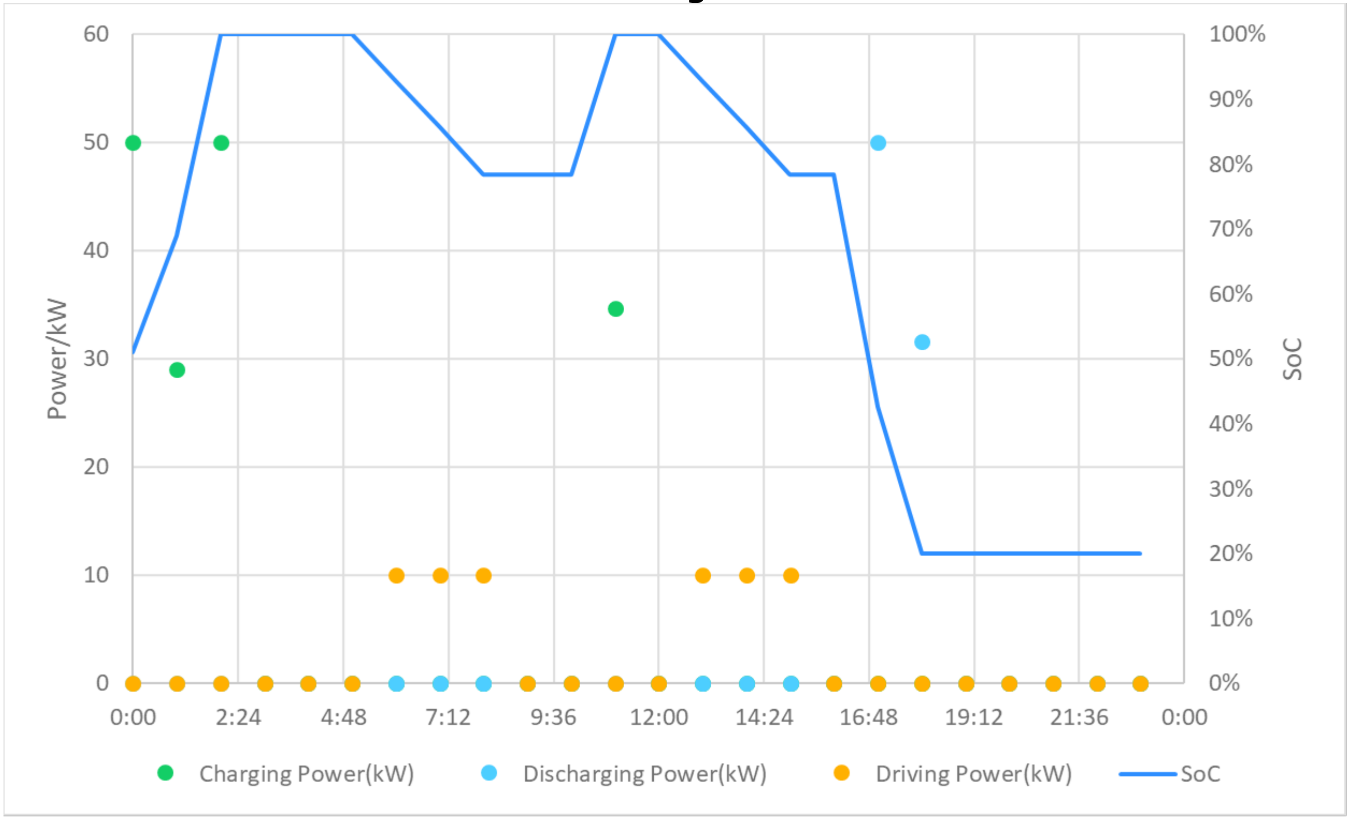
Figure 23 and **Figure 24** show the daily power use during the school year for 19.2 kW and 50 kW charger models respectively. **Figure 25** and **Figure 26** show the daily power use during the summer for both charger types. For all four figures, the left-hand y-axis shows the power, and the right-hand y-axis tracks the daily battery SoC change. SoC change follows the assumption that it will reach 100 percent before any trip, and the minimum SoC of any time is 20 percent.

Figure 23. Sample Daily Power Usage for One Day During School Year, 19.2 kW Charger



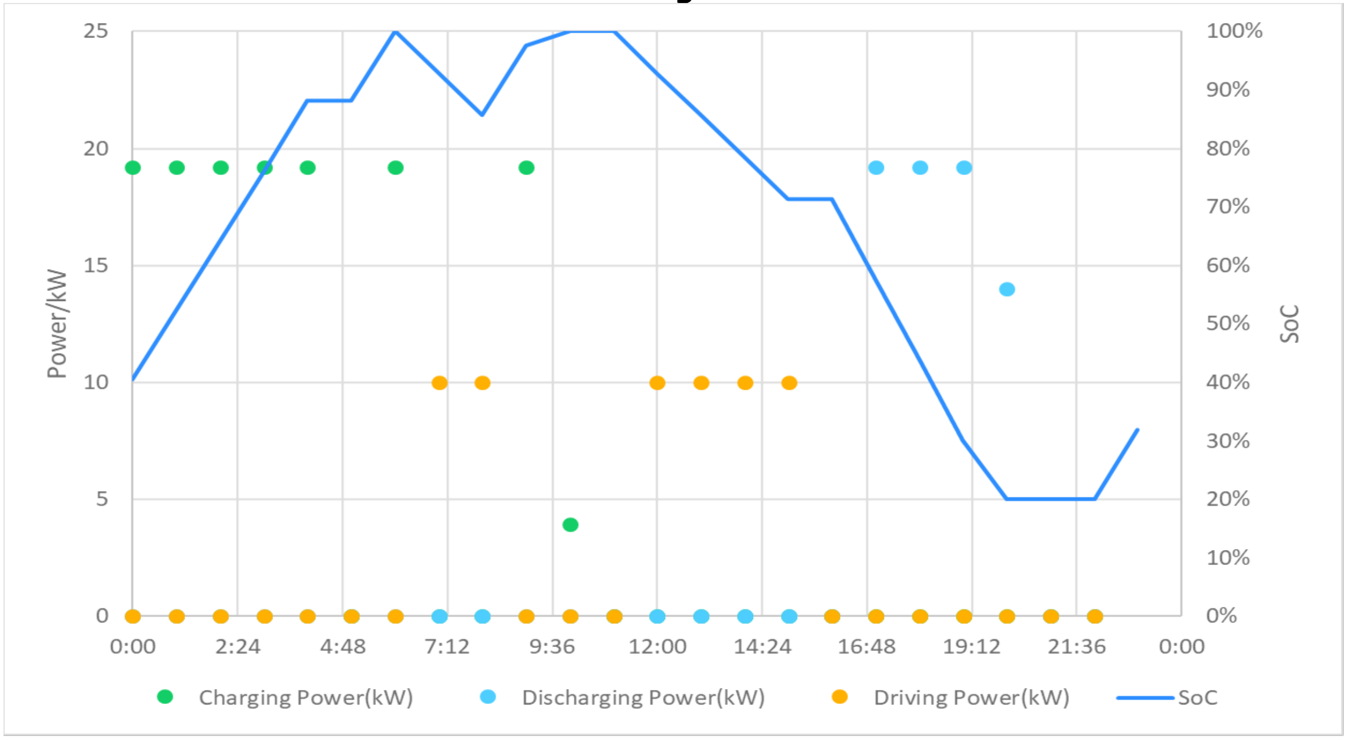
Source: The Mobility House Analysis

Figure 24. Sample Daily Power Usage for One Day During School Year, 50 kW Charger



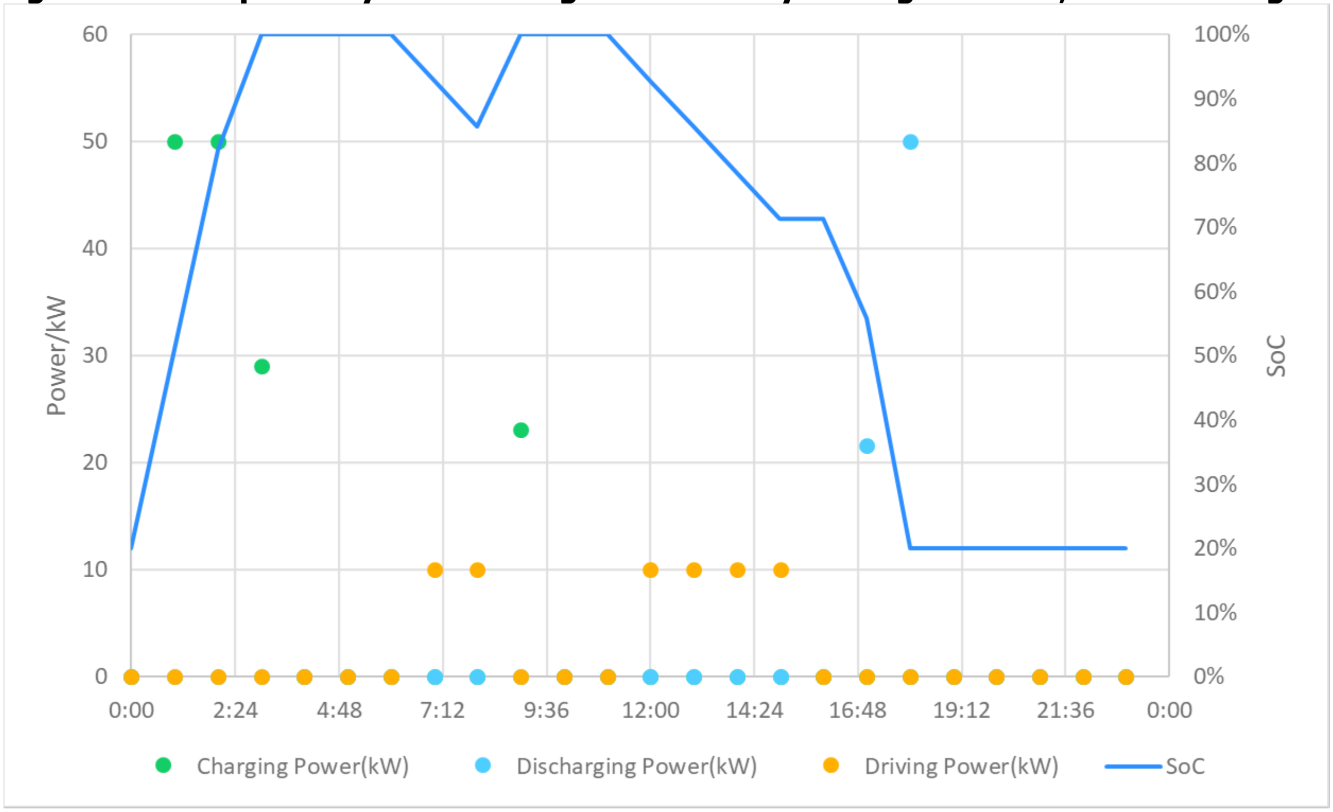
Source: The Mobility House Analysis

Figure 25. Sample Daily Power Usage for One Day During Summer, 19.2 kW Charger



Source: The Mobility House Analysis

Figure 26. Sample Daily Power Usage for One Day During Summer, 50 kW Charger



Source: The Mobility House Analysis

As indicated by driving power in the figures, a school bus at SUSD usually has two trips per day during school year and summer break, one in the morning (AM trip), and another one in early afternoon (PM trip). Analyzing the optimization results, the school bus always starts charging early in the morning when the import rate is lowest to reach 100 percent SoC before its first trip. The second charge event happens between the vehicle's AM and PM trips while the import rate is still relatively low. Each trip uses 15-29 percent of the battery capacity. After coming back from the PM trip between 3-4 pm, the battery has over 70 percent SoC. This time (3-4pm) is also when import and export rates start to spike, discharging the battery after the PM trip is therefore the strategy to maximize profit.

Looking at the school day figures (**Figure 23, Figure 24**), on a typical day during the school year, the school bus has a SoC of 78 percent at the end of the PM trip. With a 19.2 kW charger (19.2kW discharge power), it takes more than four hours to discharge the battery from 78 percent to 20 percent. The discharging strategy is to discharge at full power for the top four hours with highest export rates, and discharge with limited power at the hour with the fifth highest export rate until hitting 20 percent of battery SoC. For example, in **Figure 23**, school bus discharges with full 19.2 kW during 4–7 pm (the four hours with the highest export rate) and discharged with 4.78 kW during 8-9 pm until reaching 20 percent battery SoC. The same strategy applies to a 50 kW charger; however, with a 50 kW charger, it only takes about one hour to discharge the battery from 78 percent to 20 percent, which means the school bus can get more compensation from exporting more energy in the hour with the highest export rate when compared to a lower power charger. In **Figure 24,** the school bus begins discharge at 5 pm (the hour with the highest export rate) and is discharged to 20 percent SoC at 6 pm - the hour with the second highest export rate. Similar strategies are used on a summer day (**Figure 25, Figure 26**) Note that changing operation limitations around the minimum SoC and SoC before each trip will change the charging and discharging strategies to maximize profit.

Implementing these charging and discharging strategies requires no operational changes in bus schedule or manual intervention. Effective use of V2G needs integration with a system that can communicate with the real-time price signals and manage charging and discharging for the fleet.

In summary, compared to the retail rate that PG&E has for its EV customers, the DAHRTP rate can use V2G capability of ESBs to generate revenue. For school buses at SUSD, each bus can generate an estimated annual profit of $49.74 and $638.54 with a 19.2 kW and 50 kW charger respectively, using the charging and discharging strategies described. Although the analysis shows a profit, as a single value stream V2G does not make a viable business case considering the cost of required infrastructure upgrade and system integration. The landscape of policies and available rates for V2G are changing rapidly, and DAHRTP rate is a good starting point. Future development could reflect the true value of V2G and allow stacking of different rates and programs. Utilities and regulators should explore ways to combine this type of rate with demand response programs that allow exports to reflect the potential applications and value of V2G capability while appropriately addressing the nature of V2G as a storage resource.

V2G Revenue, Profit, and Cost for additional Scenarios

In the last round of analysis, TMH modeled three additional scenarios to account for different bus schedules and charger setup:

1) V2G revenue, profit, and cost for a stationary ESB. TMH modeled both 19.2 kW and 50 kW chargers by month. To model an ESB without travel, TMH assumed the bus would be always plugged in.
2) V2G revenue, profit, and costs at a 1:1 ESB to charger ratio. TMH modeled both 19.2 kW and 50 kW chargers by month.
3) V2G revenue, profit, and costs at a 2:1 ESB to charger ratio. TMH modeled both 19.2 kW and 50 kW chargers by month.

The monthly results for each scenario can be combined to account for ESBs with various schedule and various charger setups. All other assumptions remain the same as the previous analysis.

Table 19 provides a summary of annual profit, revenue, and cost per charger at SUSD in three different scenarios: stationary bus, 1:1 bus to charger ratio, and 2:1 bus to charger ratio. Findings include:

- A stationary bus has the most availability and will generate the most profit, and the profit will decrease when two vehicles share one charging dispenser due to lower available charging and discharging time.

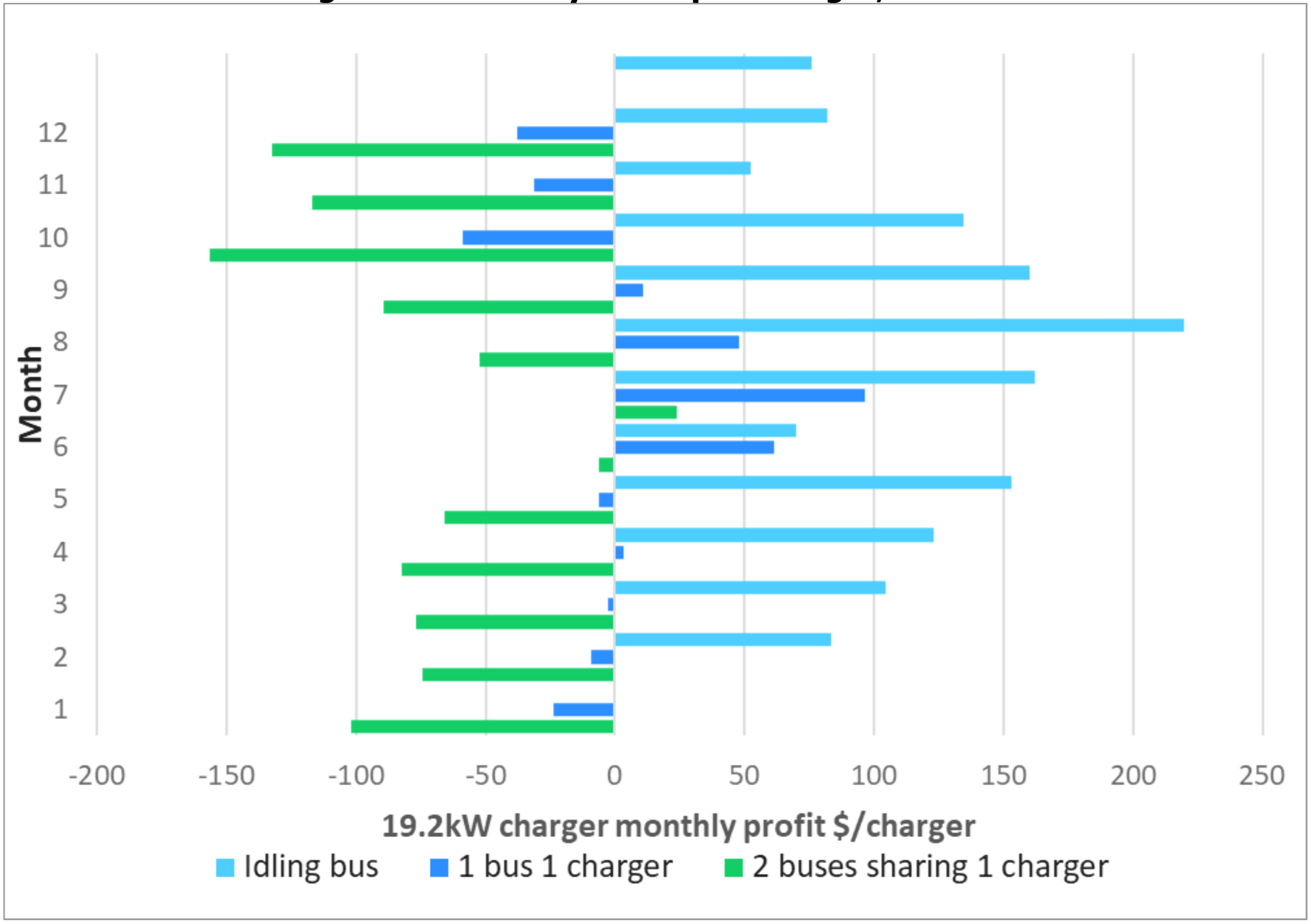
- 50 kW chargers can generate more net profit than 19.2 kW chargers.
- In all scenarios, the two summer months generate at least 25 percent of annual profits. If the bus is not used in summer months, each charger can generate up to twice as much profit compared to a scenario where each bus uses one charger. Summer months are June and July based on school schedule (summer break from May 27-August 1). Figure 27 and Figure 28 show more detailed information about monthly profit in each scenario for a 19.2 kW and 50 kW charger respectively.

Table 19. Summary Profit, Revenue, and Cost Before Inflation Adjustment, 2021-Dollar Value

Modeling Scenario	Charger Power	Annual Profit $/charger	Annual Revenue $/charger	Annual Costs $/charger	Profit in Summer $/charger
Stationary bus	50kW	$2,358.65	$5,574.67	$3,216.02	$640.32
	19.2kW	$1,420.97	$3,737.96	$2,316.99	$381.75
1 bus 1 charger	50kW	$638.54	$3,573.17	$2,934.63	$316.88
	19.2kW	$49.74	$2,660.26	$2,610.52	$157.92
2 buses sharing 1 charger	50kW	$514.21	$6,078.55	$5,564.34	$421.98
	19.2kW	-$931.02	$2,759.23	$3,690.25	$17.54

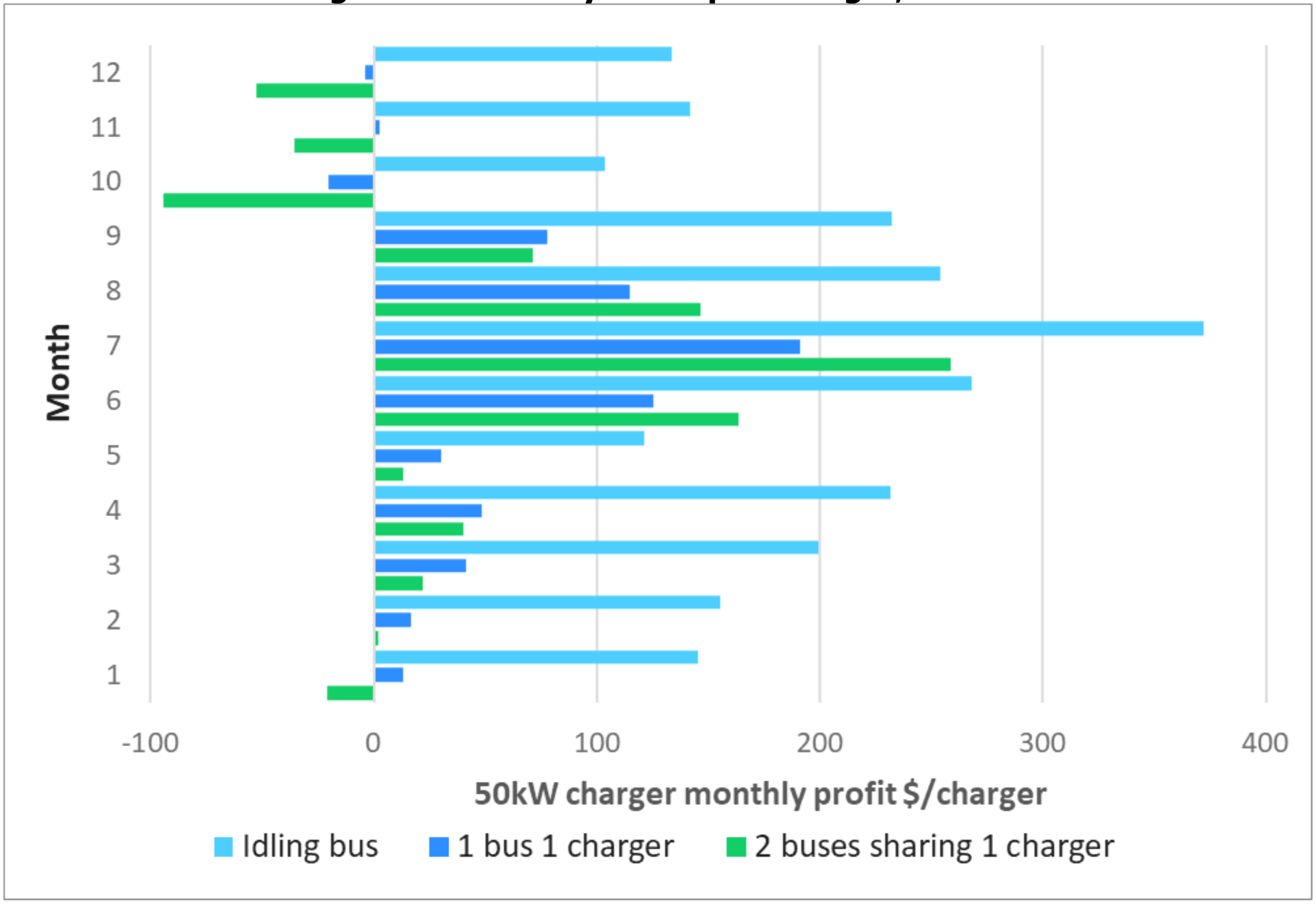
Source: The Mobility House Analysis

Figure 27. Monthly Profit per Charger, 19.2 kW



Source: The Mobility House Analysis

Figure 28. Monthly Profit per Charger, 50 kW



Source: The Mobility House Analysis

V2G Charging and Discharging Strategies

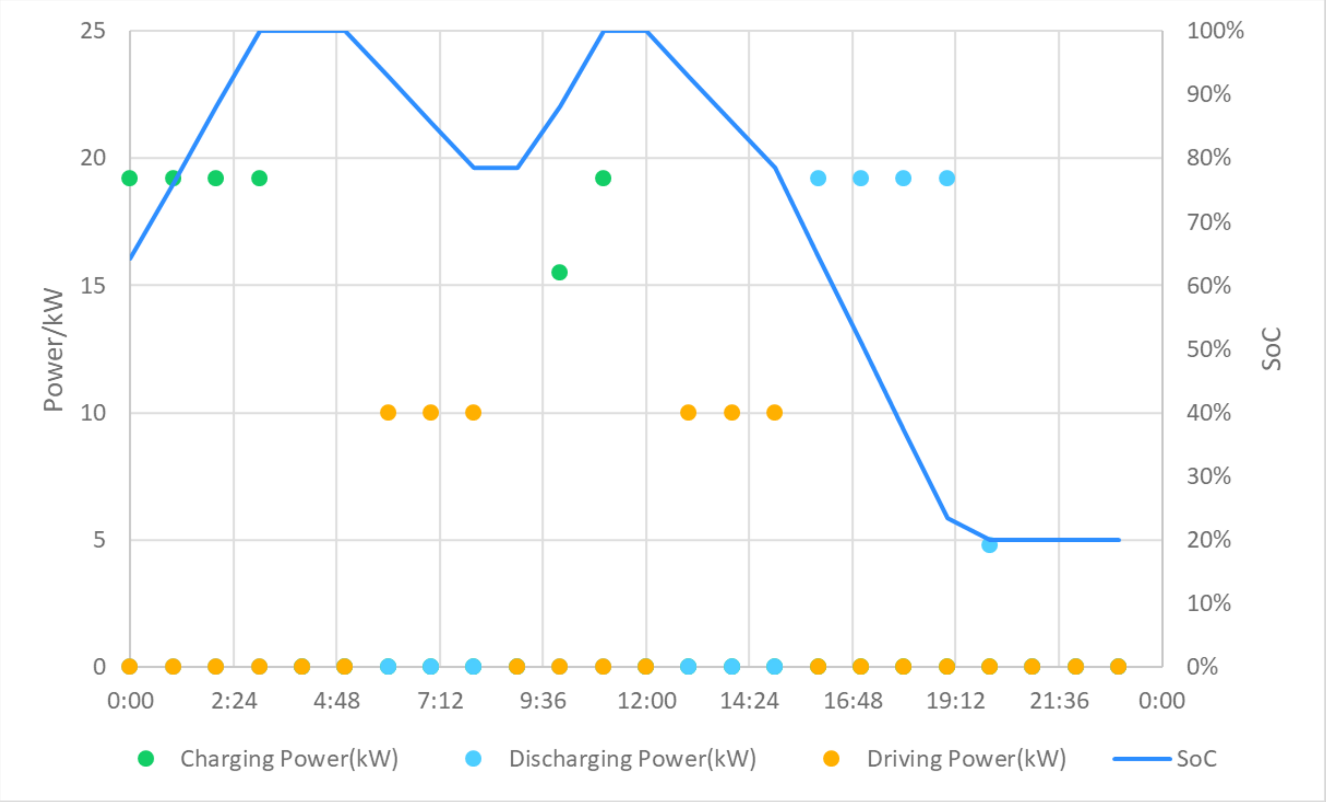
School Year

This analysis used the same example school year import and export rates as the earlier analysis (see **Figure 21**), where the period between 3:00 pm and 7:00 pm have the highest import price. **Figure 29, Figure 30,** and **Figure 31** show the results of the three scenarios for a 19.2 kW charger. **Figure 32, Figure 33**, and **Figure 34** provide the same charts for a 50 kW charger. Compared to a 1:1 bus to charger ratio, if a bus does not have a trip on that day, it will simply charge during hours with the lowest import price and discharge during hours with the highest export rate. Note that the bus would not discharge and charge all 24 hours because of the minimum SOC restriction in place. Minimum SOC restriction therefore serves to limit excessive battery degradation.

Figures for a 2:1 bus to charger ratio scenario show driving power as the sum of two buses, and the SOC as an average SOC of two buses. A 2:1 bus to charger ratio would result in higher use of the charger. Using the 19.2 kW charger as an example, outside of the six hours driving window, the chargers are actively charging for eight hours, and are discharging for nine hours – about twice the amount of time for charging and discharging for a 1:1 scenario.

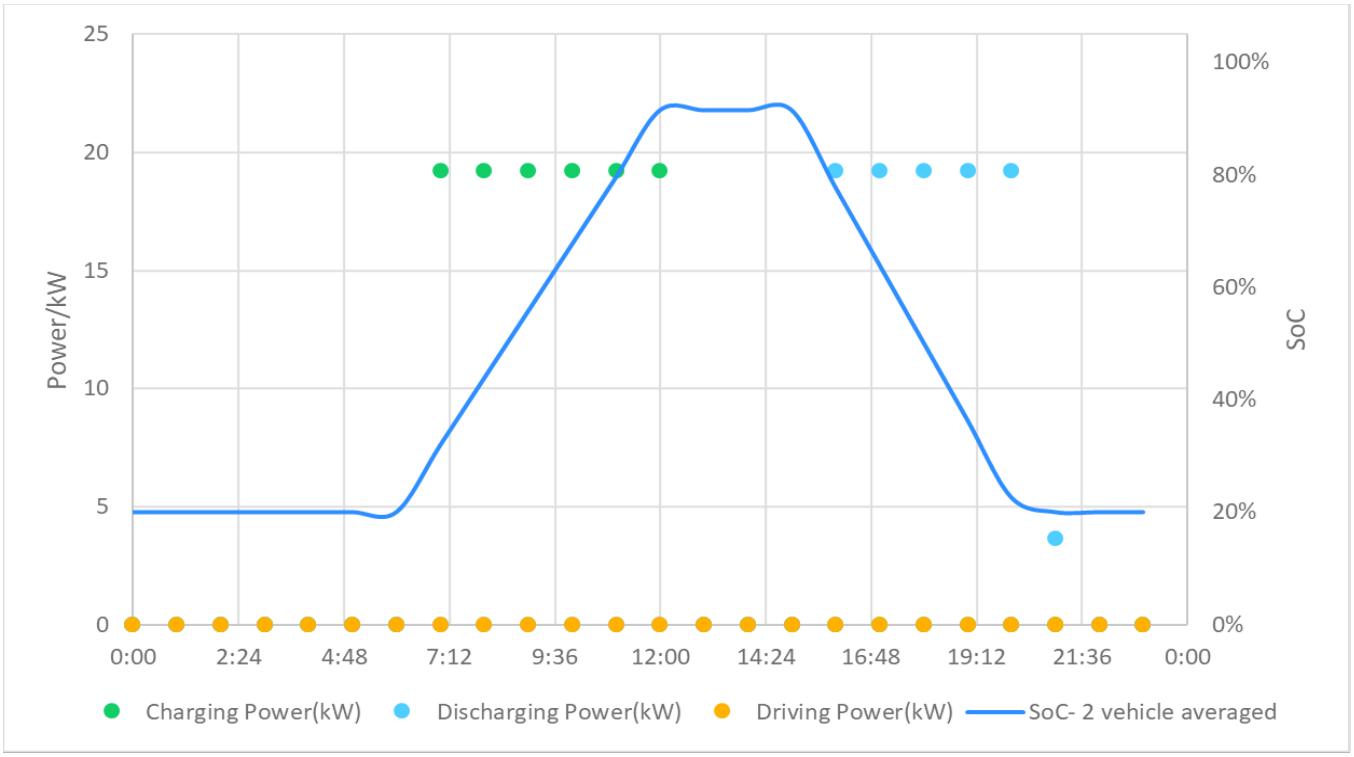
Charging and discharging follow the same strategy, but the discharging hours will expand into a wider window in the afternoon/night to take full advantage of the residual energy in two buses' battery. Note that this operation will require labor to switch charging and discharging of two buses.

Figure 29. Sample Daily Power Usage for One Day During School Year, 19.2 kW Charger, Vehicles with No Trip



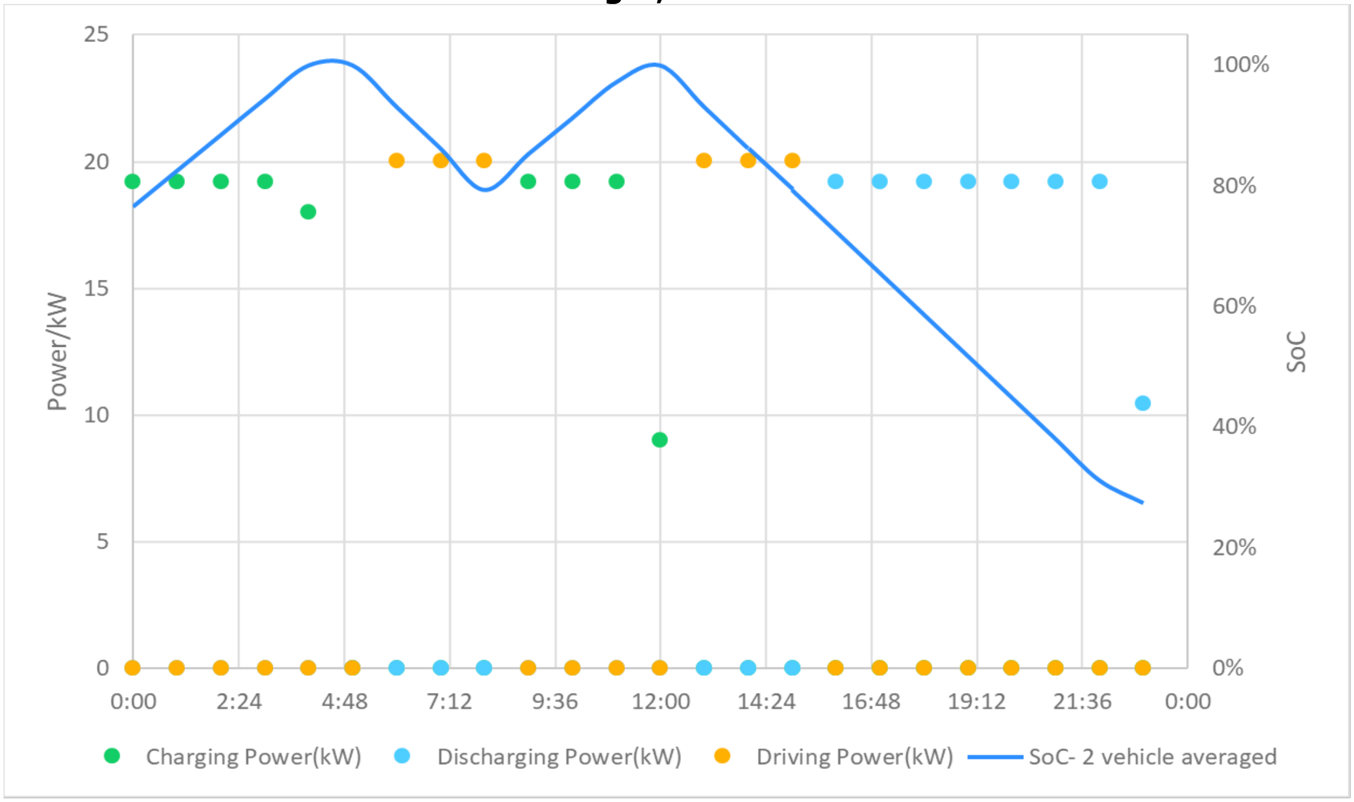
Source: The Mobility House Analysis

Figure 30. Sample Daily Power Usage for One Day During School Year, 19.2 kW



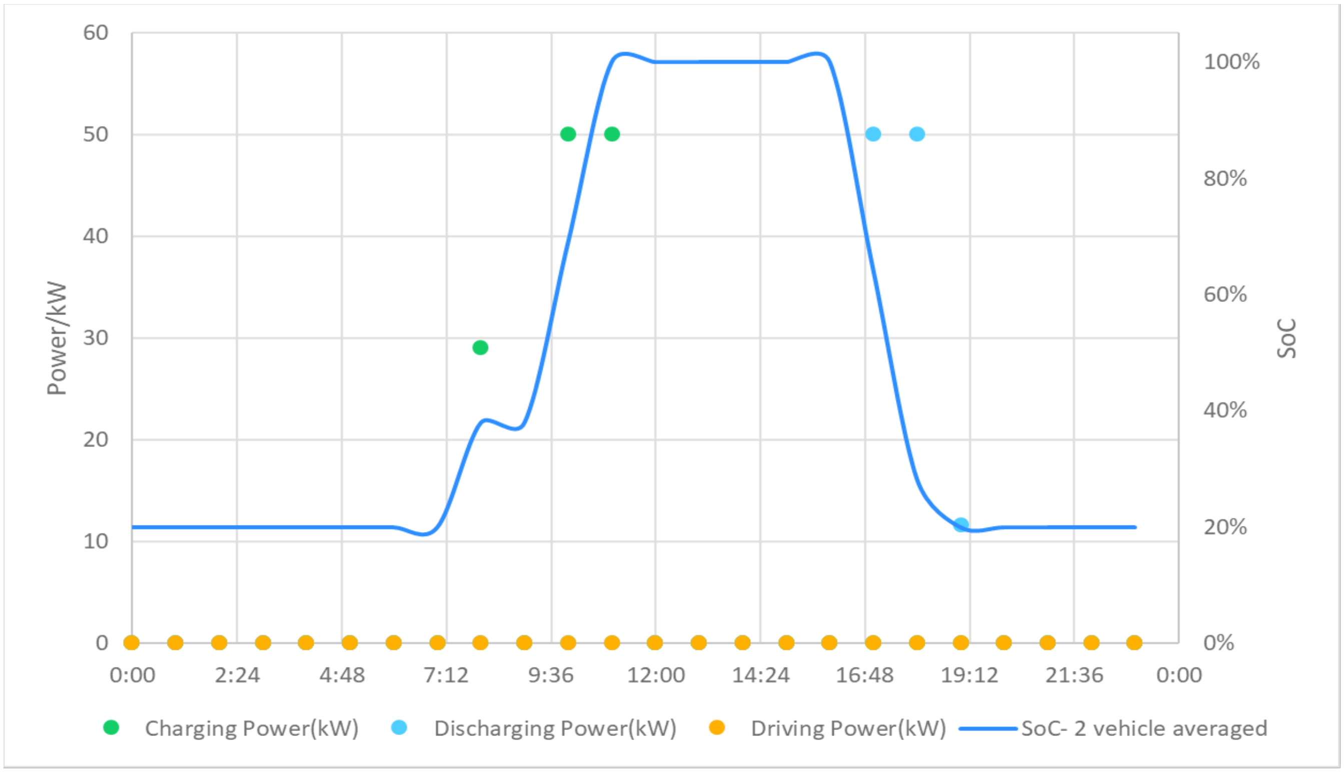
Source: The Mobility House Analysis

Figure 31. Sample Daily Power Usage for One Day During School Year, 19.2 kW Charger, 2:1 Ratio



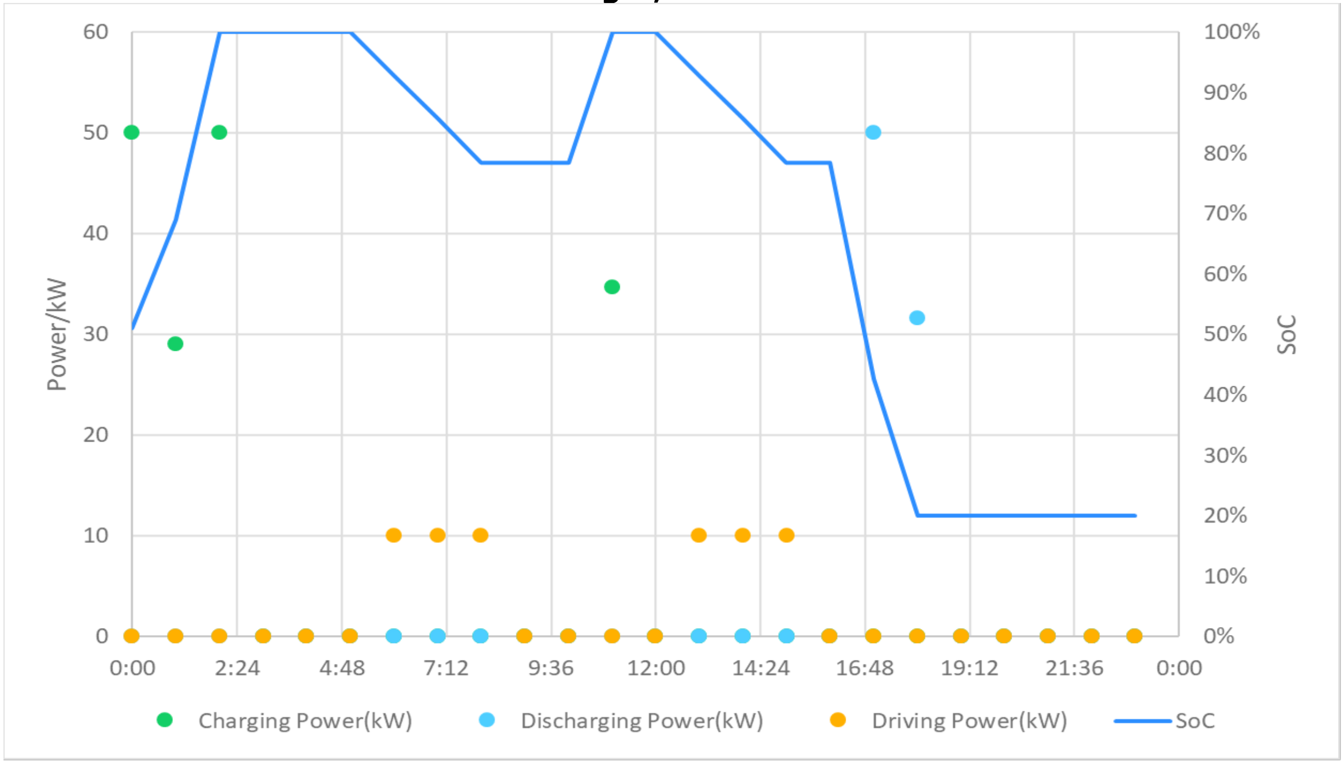
Source: The Mobility House Analysis

Figure 32. Sample Daily Power Usage for one day during school year, 50 kW charger, vehicles with no trip



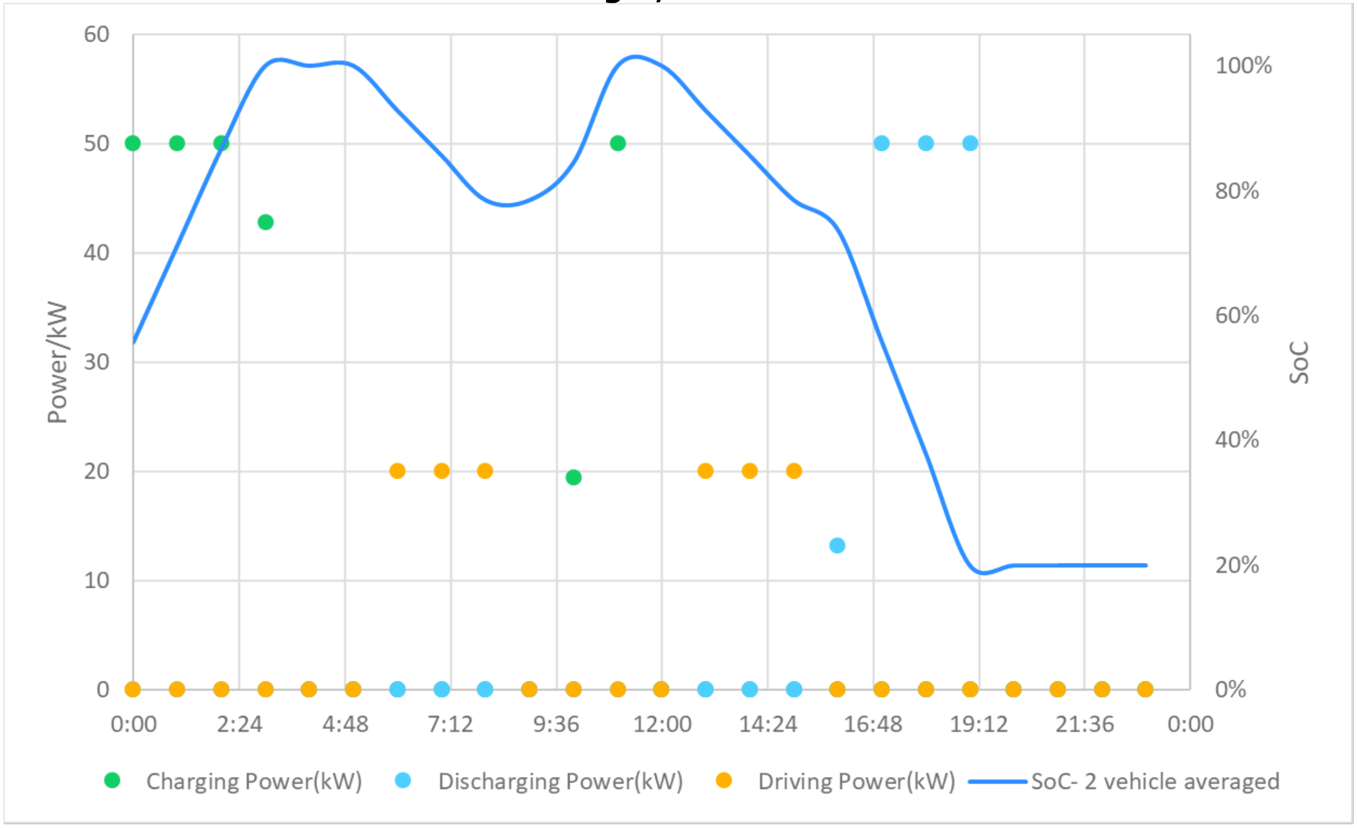
Source: The Mobility House Analysis

Figure 33. Sample Daily Power Usage for One Day During School Year, 50 kw Charger, 1:1 Ratio



Source: The Mobility House Analysis

Figure 34. Sample Daily Power Usage for One Day During School Year, 50 kw Charger, 2:1 Ratio

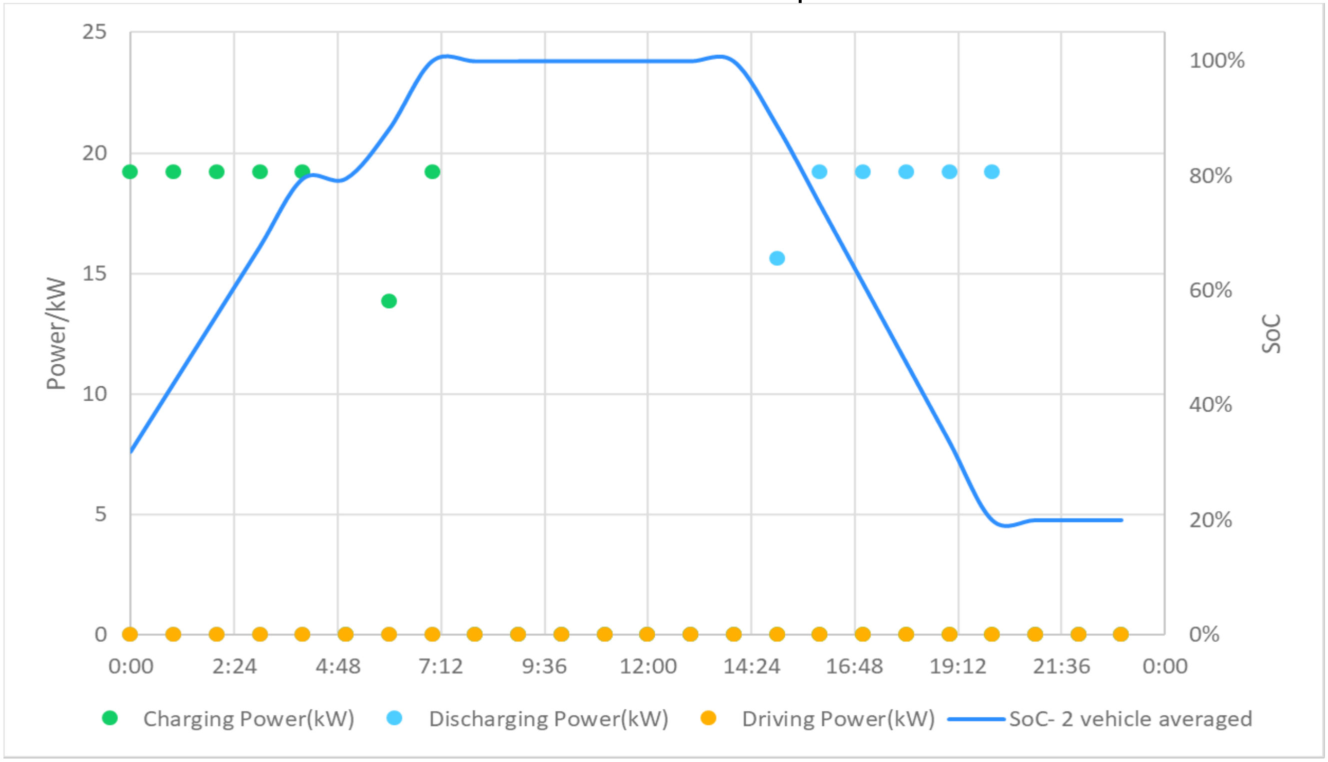


Source: The Mobility House Analysis

Summer

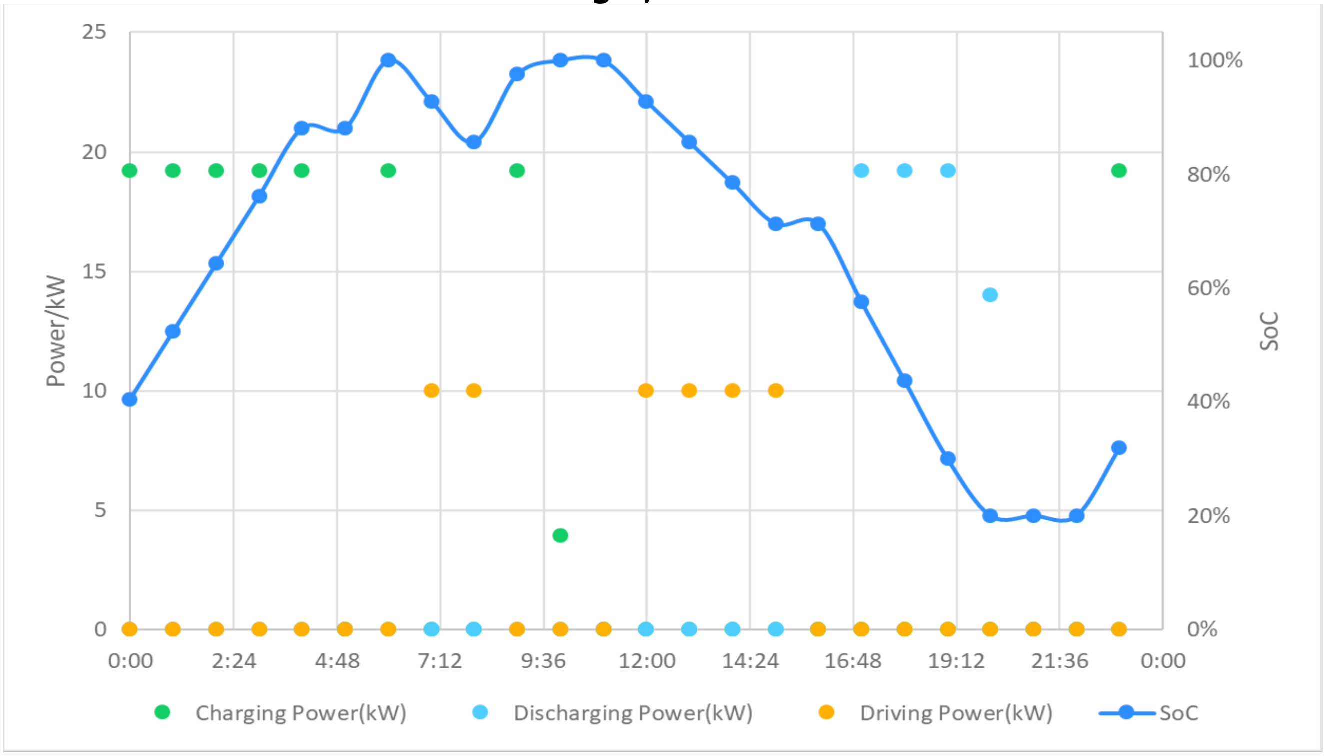
For SUSD, the summer schedule has more daily mileage and higher energy consumption than during the school year. The analysis used the same example of the daily import and export rates during the summer (**Figure 22**). **Figure 35, Figure 36**, and **Figure 37** show the results of the three scenarios for a 19.2 kW charger. **Figure 38, Figure 39**, and **Figure 40** provide the same charts for a 50 kW charger. A 2:1 charger ratio in the summer leads to higher charger use. For a 50 kW charger, a 2:1 charger ratio result in doubling of the charging and discharging hours in the summer day, the same as a school day. However, for a 19.2 kW charger, due to high energy consumption from traveling, chargers are mostly used for charging. Outside of the six hour driving window, the chargers are actively charging for 13 hours, and are discharging for five hours, for only one more hour of discharging than a 1:1 scenario.

Figure 35. Sample Daily Power Usage for One Day During Summer, 19.2 kw Charger, Vehicles with No Trip



Source: The Mobility House Analysis

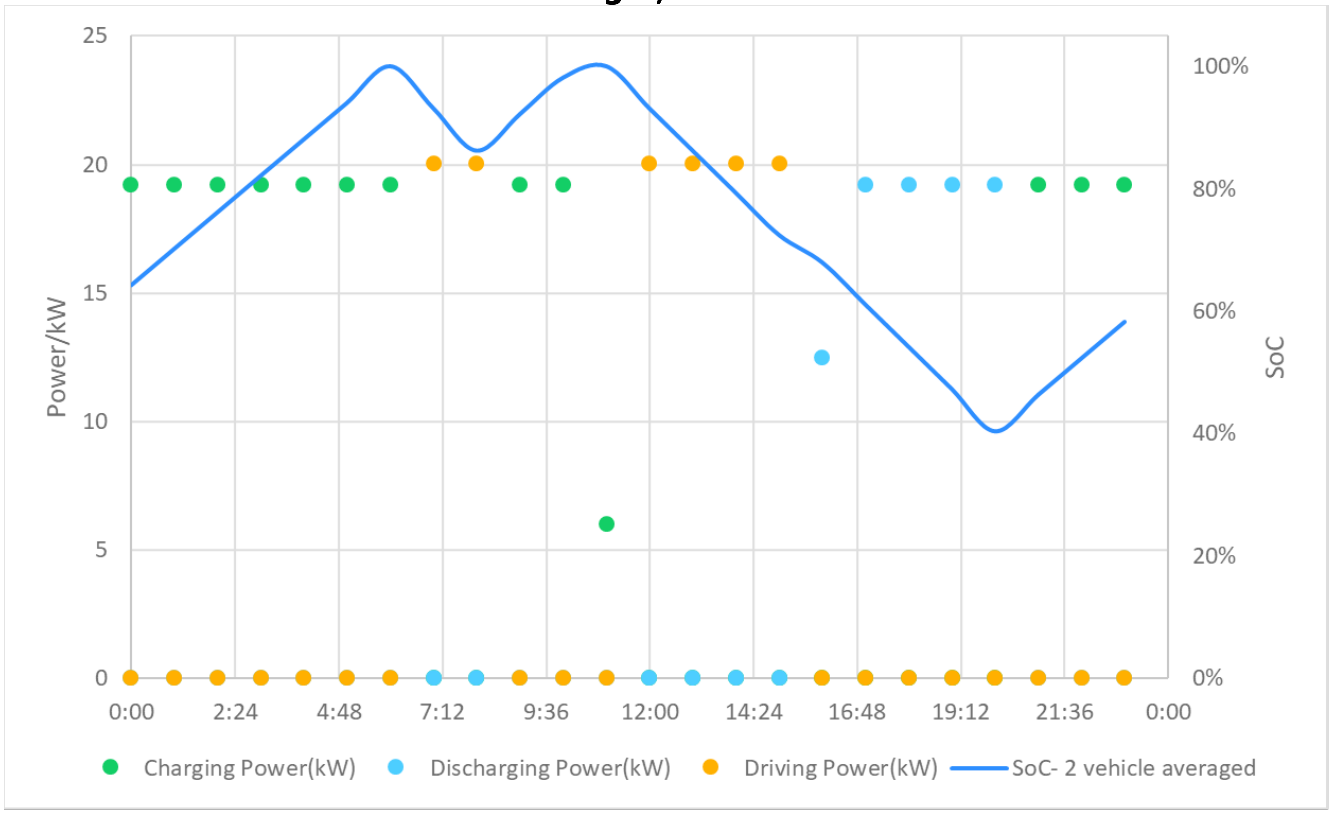
Figure 36. Sample Daily Power Usage for One Day During Summer, 19.2 kw Charger, 1:1 Ratio



Source: The Mobility House Analysis

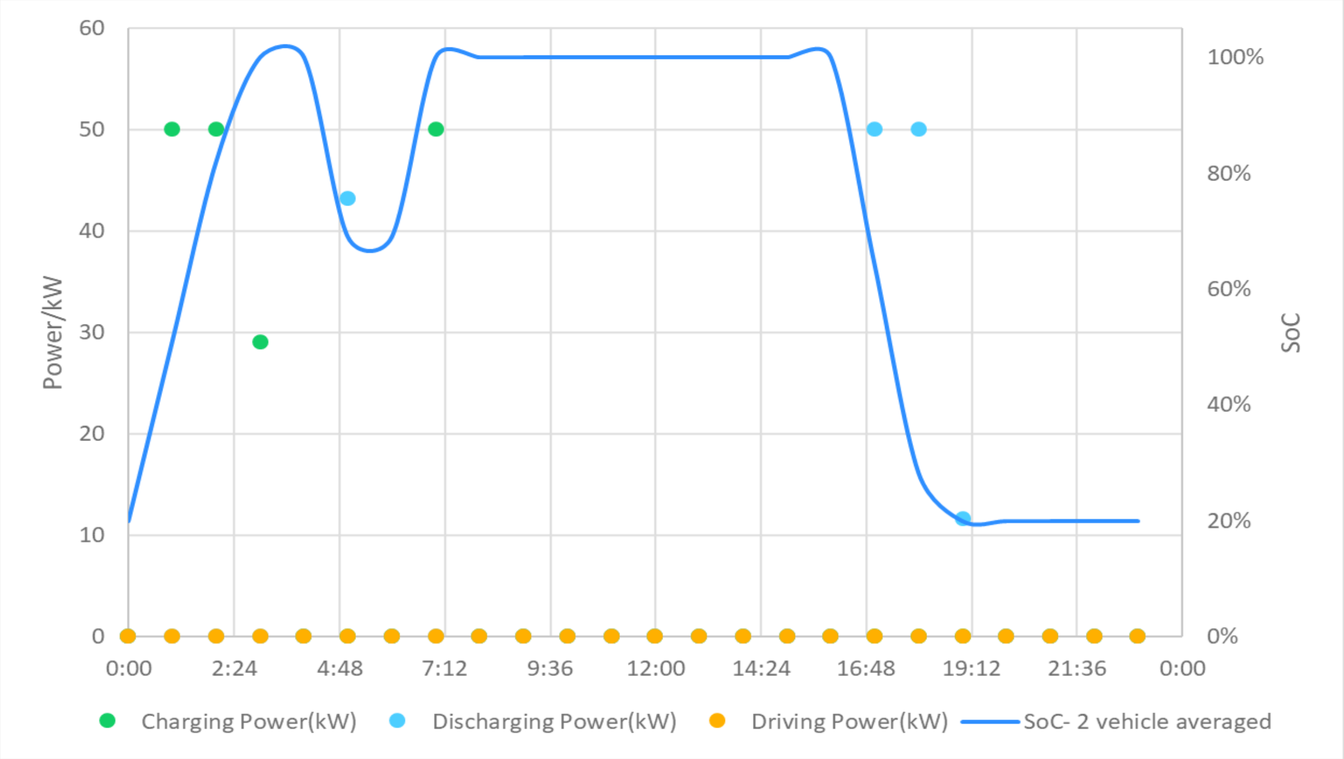
Figure 37. Sample Daily Power Usage for One Day During Summer, 19.2 kw

Charger, 2:1 Ratio



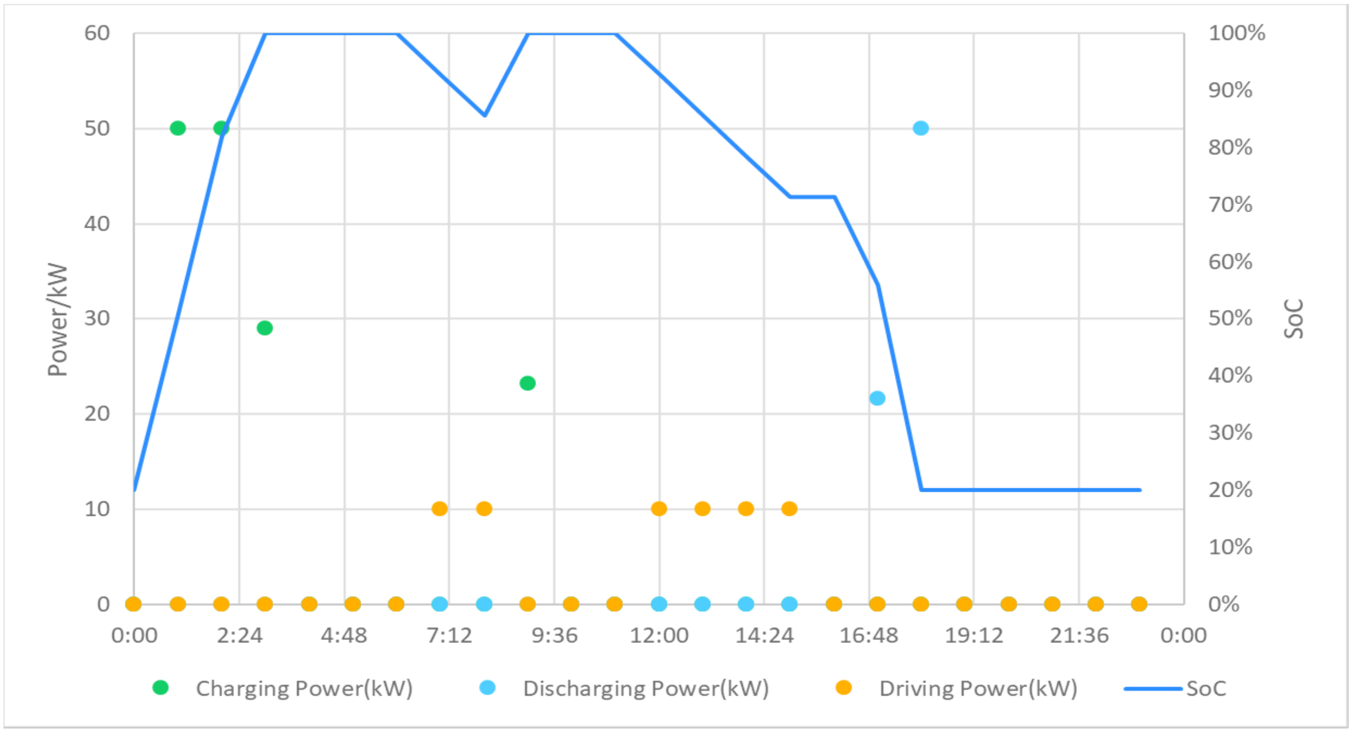
Source: The Mobility House Analysis

Figure 38. Sample Daily Power Usage for One Day During Summer, 50 kw Charger, Vehicles with No Trip



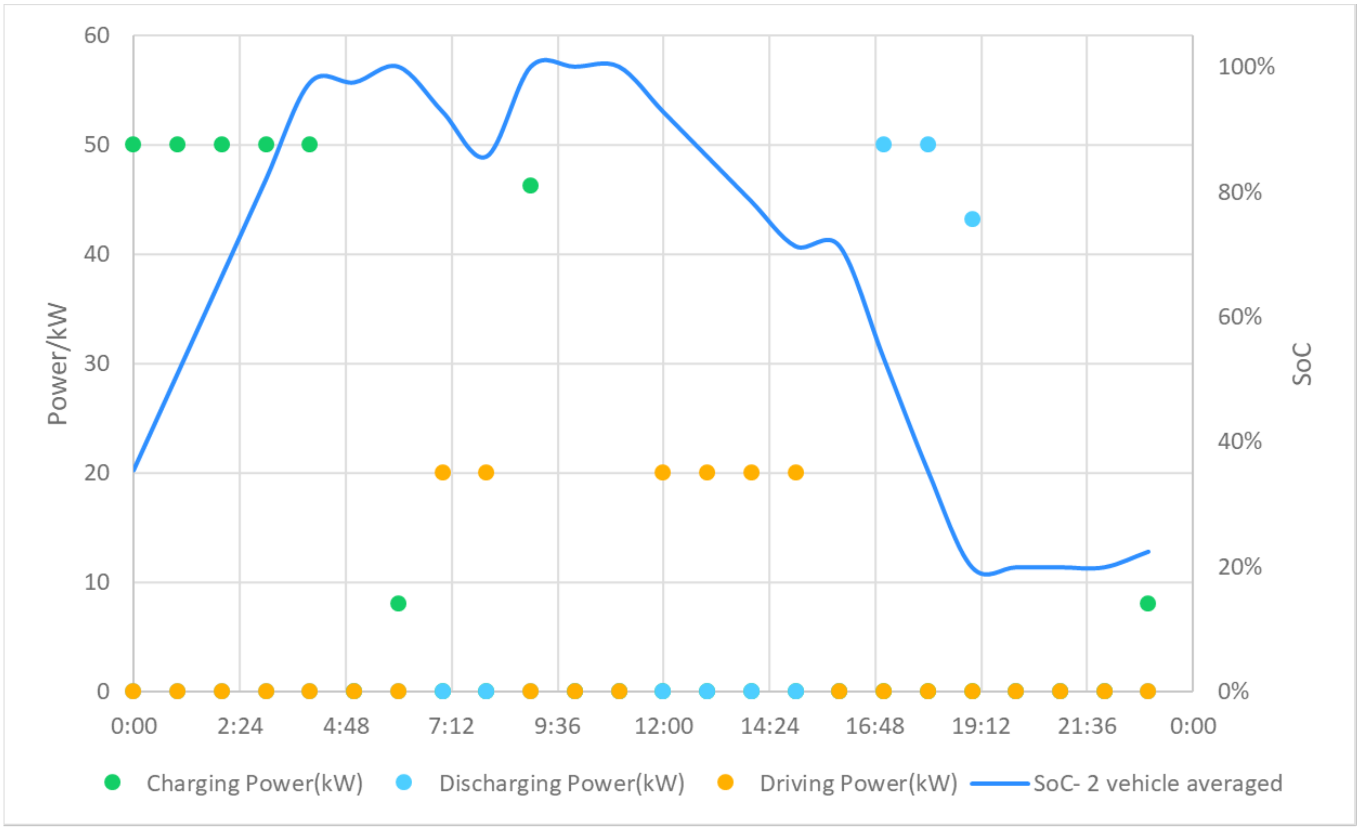
Source: The Mobility House Analysis

Figure 39. Sample Daily Power Usage for One Day During Summer, 50 kw Charger, 1:1 Ratio



Source: The Mobility House Analysis

Figure 40. Sample Daily Power Usage for One Day During Summer, 50 kw Charger, 2:1 Ratio



Source: The Mobility House Analysis

V2G Analysis: Minimum Export Rate Required for a Net Cost Savings

As part of this exploration, Sage performed a V2G analysis of SUSD's current fleet to determine what the minimum average export rate would have to be for V2G operation to provide net cost savings. Sage incorporated TMH's optimized charging profiles as well as the added charging costs and battery degradation associated with V2G. At this time, Sage has not modeled V2G in coordination with a PV system due to numerous unknowns regarding this type of system setup with PG&E. Sage used the charging profiles from TMH to determine the bus charging schedules and usage rates as a starting point for analyzing whether V2G strategies could potentially be beneficial and cause the least disruption to the school's operations. For simplicity, Sage modeled a single representative bus in the analysis. The financial feasibility analysis considers added costs and benefits such as upgrading to bidirectional chargers, added energy consumption, contribution to battery degradation and early battery replacement cost, potential revenue from discharging, and incentives available for V2G.

Modeling Assumptions

For consistency with previous SUSD modeling, we have assumed that a Level 2 V2G charger capable of 19.2 kW bi-directional charging would be available, and that the charger results in conversion losses for both charging and discharging.

Recent CARB regulations require that vehicle manufacturers provide a warranty on electric or hybrid electric passenger car and light-duty vehicle batteries to maintain 70 percent state of health for eight years or up to 100,000 miles, whichever comes first, starting in 2026. In the absence of a regulation specific to medium- and heavy-duty vehicles, we have used this as the basis of our battery lifetime assumption.

While electric vehicles will not cease to operate at this point, a threshold of degradation has become the industry-accepted definition for battery lifetime. To date, there is limited research to conclude how V2G operation will affect battery health, and how or if warranties will be adapted for V2G operation. For this analysis, we have assumed V2G will increase battery cycling and contribute to accelerated degradation; therefore, reducing lifetime. Sage converted V2G kWh to equivalent vehicle miles to determine the lifetime reduction of 3.7 years.

While Sage includes the estimated future cost of a battery replacement, we have not included costs associated with labor or taking the bus offline for battery replacement; it is assumed that these costs would be incurred regardless, just sooner due to accelerated degradation. **Table 20** provides the assumptions used for the V2G analysis.

Table 20. V2G Modeling Assumptions

Assumption	Value
Battery Electric Bus (BEB) Battery Capacity (kWh)	155
Battery Electric Bus Efficiency (kWh/mi)	1.61
Utility Tariff	PG&E BEV-2-S
Minimum State of Charge (SOC) Limit (%)	30%
Electric Vehicle Supply Equipment (EVSE) Charger Power (kW)	19.2
EVSE Charger Conversion Efficiency (%)	97%
Bus Operational Days per Year	227
Average Miles Driven per Year per BEB	16,700
Battery Replacement Cost ($/kWh of Capacity)	$100/kWh[8]
California Electric Vehicle Battery Warranty	8 years or 100,000 miles[9]
Reduced Battery Lifetime due to V2G (yrs)	3.7
Added Cost of Upgrading to a Bidirectional EV Charger	$700[10]

Source: Sage Analysis

---

[8] BloombergNEF: Average Battery Prices Fell To $156 Per kWh In 2019, available at https://insideevs.com/news/386024/bloombergnef-battery-prices-156-kwh-2019/

[9] CARB Regulation Order Section 1962.8, Title 13, California Code of Regulations, available at https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/acciifro1962.8.pdf#:~:text=Adopting%20new%20regulatory%20text%3A%20Adopt%20Section%201962.8%20of,Year%20Passenger%20Cars%20and%20Light-Duty%20Trucks%20%28a%29%20Applicability.

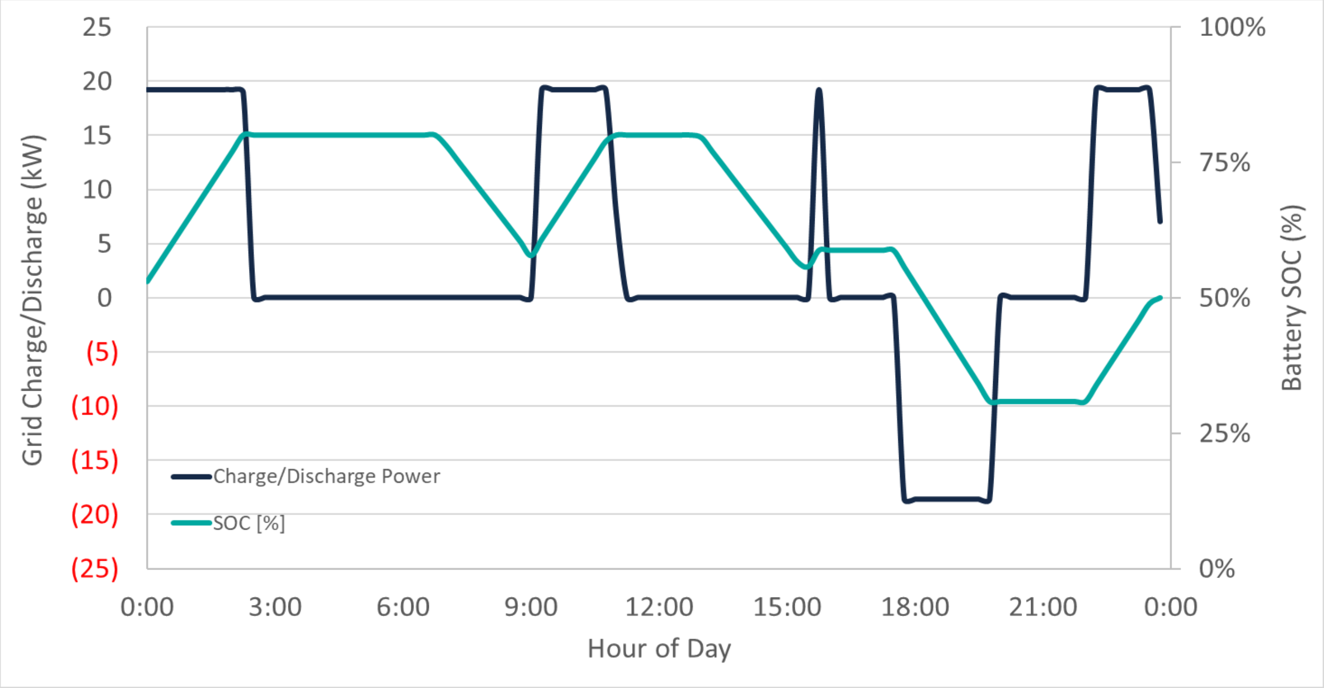
[10] Review of price difference between comparable uni-directional and bi-directional chargers.

Vehicle Charge and Discharge Profiles

Sage selected bus route 39 from the bus operation schedule as representative of SUSD's fleet. The analysis uses TMH's cost-optimized AC-only charging profile as the basis for creating a V2G profile. This profile reduces peak demand and optimizes for discharging during peak periods and charging during super off-peak and off-peak periods. For this analysis, Sage only considered the 227 days of bus operation; the analysis does not consider weekends, nor does it incorporate separate summer and school year V2G profiles.

Figure 41 shows the charge and discharge profile used for the analysis for a single bus on a typical weekday. Two important components of V2G operation are that the vehicles must recuperate the discharged energy and the added charging cycles increase overall conversion losses.

Figure 41. BEB V2G Daily Profile



Source: Sage Analysis

V2G Incentive Programs

V2G is a new technology and Sage expects research and pilot programs to be developed which will support adoption. This analysis includes two known incentive opportunities which are currently available to V2G customers: PG&E's V2G pilot program and CPUC's Emergency Load Reduction Program (ELRP).

PG&E is offering pilot V2G programs which could alleviate the added costs for this new technology. The commercial program is aimed at medium- and heavy-duty commercial fleets and provides $3,000 upfront incentives for the purchase and installation of V2G chargers and participation-based incentives of $151 per EV per month. Pilot program incentives are currently available through 2024.

CPUC's ELRP program provides $2/kWh to reduce load during events and runs through 2025.

The program can call up to six events per year from May to October during 4:00–9:00 PM, which can last up to five hours each. In 2020, CPUC called four ELRP events of varying duration, which is used as the basis of our assumption. While it is unknown how many and for what duration ELRP events will be called, Sage assumed four events per year, varying from one to three hours, which results in $188 per electric bus per year. In our analysis, the bus is not allowed to drop below 30 percent SOC. Sage has assumed that SUSD will be eligible for ELRP under the BEV-2-S tariff.

For this analysis, these incentives are spread out over the expected 10-year vehicle lifetime.

Calculating Added Costs for V2G

To calculate annual incremental costs due to V2G, we have assumed the following:

- The one-time cost of the bidirectional charger is spread out over the expected 10-year vehicle lifetime.
- The battery replacement cost is spread out over the period of the reduced battery lifetime.
- Charging costs are based on the current (June 2022) BEV-2-S tariff without annual utility escalation. With utility escalation, the export rate must increase relative to the escalation of charging costs.
- All costs are nominal and do not consider Net Present Value (NPV). This is relevant because current V2G incentives are available in the early years and battery replacement would occur further out. An NPV analysis would change the export rate value, though the magnitude of this change would depend on the discount rate of the customer.

Findings

Table 21 provides the minimum export rates needed for SUSD to have annual cost neutral V2G operations (e.g., any rate higher than that would result in positive returns). **Figure 42** provides a breakdown of the expected annual added costs, incentives, and export rate. The following is a description of each scenario:

1. **Added V2G charging costs without incentives**: the export rate needed to offset added costs for V2G operation, inclusive of marginal cost for a bidirectional charger, additional charging to recuperate discharged energy (including conversion losses), and contribution to battery degradation.
2. **Added V2G charging costs with incentives**: this scenario calculates the export rate of scenario 1 after PG&E V2G and ELRP incentives.

Table 21. SUSD V2G Breakeven Export Rates

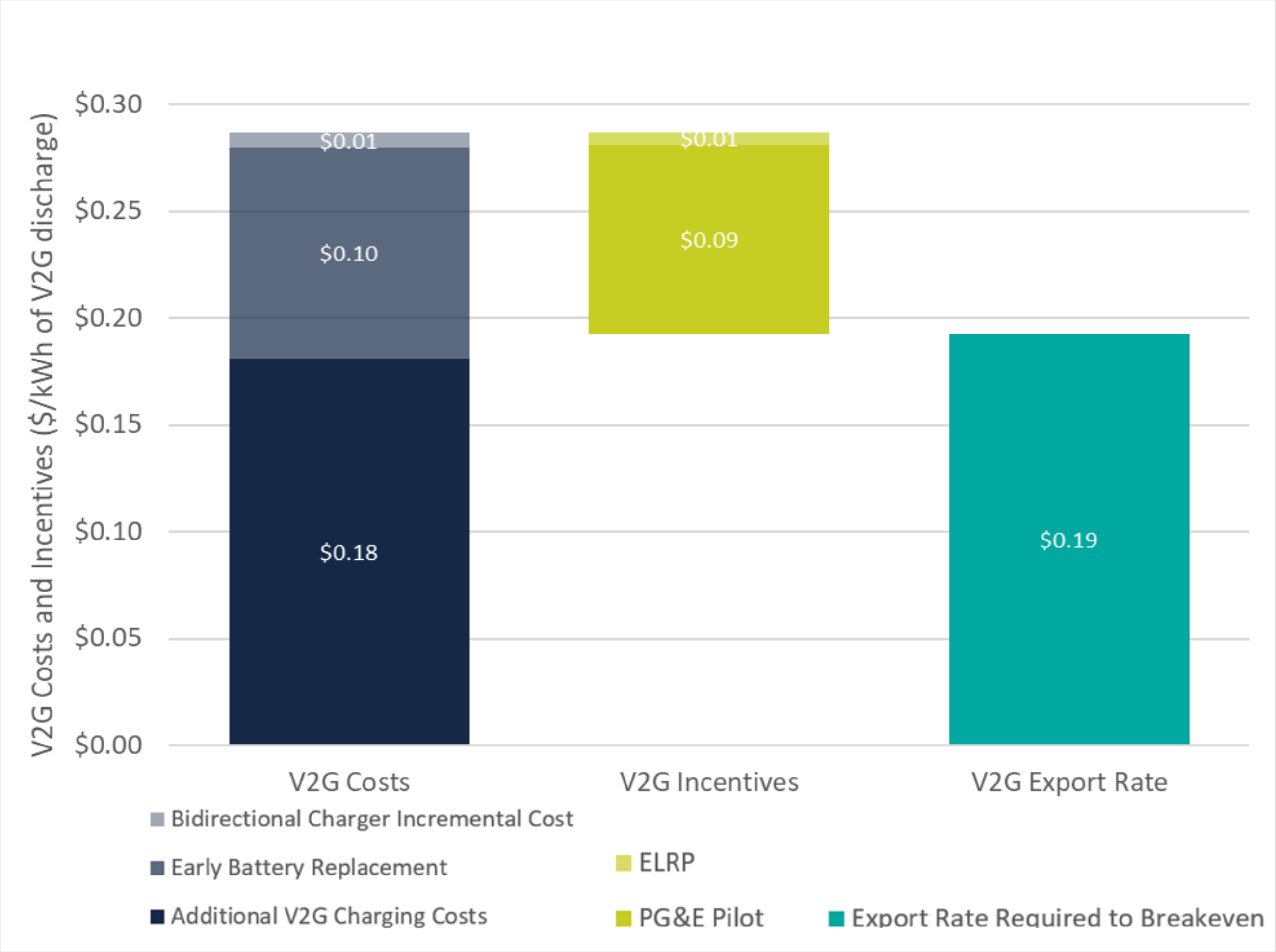
Assumption	Net Annual Added Costs per Vehicle	V2G Breakeven Rate ($/kWh)
Added V2G charging costs	($2,700)	$0.29
Added V2G charging costs + incentives	($1,800)	$0.19

Source: Sage Analysis

As shown in **Table 21**, to offset the added costs of V2G, SUSD's V2G exported energy must, on average, be valued at $0.19/kWh if receiving PG&E and ELRP incentives (or other incentives of similar value), and $0.29/kWh without incentives. For reference, the BEV-2-S tariff has an on-peak energy charge of $0.381/kWh and an off-peak energy charge of $0.168/kWh, which are within the range of the calculated V2G export rates.

As can be seen in **Figure 42**, the current V2G incentive programs cover less than the costs associated with increased battery degradation and incremental bidirectional charger costs. Additionally, there are increased energy losses from additional charging and discharging that need to be recuperated. Therefore, the V2G export rate must exceed the import rate on its own, even with incentives.

Figure 42. Breakdown of V2G Export Rate



Source: Sage Analysis

This analysis includes numerous unknown variables and assumptions which may need to be updated as V2G is further developed in the California market. Specifically, the study had the following limitations:

- The analysis only considered a single bus route. When scaled across a fleet, it is feasible that certain assumptions may change. For example, with a fleet, not every bus may need to discharge daily which would result in less effect on battery degradation for any single bus.

- A single V2G charge and discharge profile was used, and the analysis did not differentiate between school year and summer daily driving profiles. The greatest expected value for exporting energy is currently 4:00–9:00 PM in the summer. However, SUSD's buses operate more during a summer day, and therefore, there is less opportunity for V2G.
- This analysis calculated a single average export rate with the assumption that export rates will generally follow the time-of-use patterns of current import rates. Depending on the variability of export rates in the future, different V2G charge/discharge patterns may be incentivized, which could influence the volume of V2G activity per year.

Over the coming years, V2G will mature, and California will develop additional programs and tariffs to promote V2G. Sage explored opportunities which could potentially affect V2G benefits for SUSD and similar school districts. The following list includes considerations that could affect the financial feasibility of V2G:

- PV and V2G: PG&E and CPUC have not released a methodology for how to value V2G export when EVs are charged directly with PV. If the system would be treated consistent to PV + storage, which is valued at the effective NEM tariff, then V2G will not likely be beneficial to SUSD because the NEM3.0 export values may be too low to offset V2G costs.
- Added EV Charging Software Costs: If V2G export value is based on day-ahead real-time pricing, it is likely that SUSD will need to have EV charging software capable of managing a complex dynamic tariff to optimize charging and discharging. This software could come at an incremental cost. Due to unknowns on these costs, Sage did not include added software costs to the analysis.
- V2G Incentives: In addition to the PG&E pilot program and ELRP, additional V2G incentives could support wider adoption of V2G and would benefit this project. With export values currently unknown and difficult to predict with real-time pricing, SUSD and other early adopters may need incentives to support a decision to pursue V2G.
- Balancing Battery Degradation and Warranty with V2G Export Rate: There is limited research on the impacts of V2G on battery degradation. Our analysis assumes that V2G will contribute to accelerated battery degradation. Further analysis could optimize between V2G revenue and battery degradation.
- Power Outage Resiliency: Operating school buses in V2G can increase the risk that buses are not ready for routes in the event of a power outage. To mitigate this risk, SUSD will need to set specific operating requirements within the V2G operating software, and may consider limiting discharging to weekends, holidays, and breaks.

There are numerous unknowns for the viability of V2G for SUSD. Specifically, CPUC has not yet approved an export tariff to value V2G in PG&E territory at the time of this analysis. Also, there is limited research on the long-term effects of V2G on battery health, and there are added costs which need to be considered. This analysis required several assumptions to be made to quantify the added costs for V2G operation to SUSD. For early adopters, there are risks in new technologies, but they also provide learning opportunities that will be valuable for California public schools. The analysis results show that the average export rates needed to achieve cost neutrality if participating in V2G operations are $0.19/kWh and $0.29/kWh with and without incentives, respectively. These rates are within the range of the current BEV-2-S tariff and other PG&E applicable tariffs, and therefore, V2G could potentially be economically feasible for SUSD.

Conversely, if SUSD plans to install a NEM PV system and if the value of V2G exports is treated as NEM exports, it is unlikely that V2G would be feasible. The NEM3.0 export rates, are well below the needed values. Before adopting V2G, SUSD should confirm all added costs and risks are considered, including battery warranties, additional software fees, and potential incentives.

Lowest Cost to Charge Summary

The goal of this project is to evaluate the lowest total cost of ESB charging for SUSD, including options for PV, onsite BESS, AC and DC charging types, and potential V2G revenue. **Table 22** and **Table 23** provide a summary of the results by scenario.

Table 22. Summary of Charging Analysis Results by Scenario

Scenario	AC Only	DC Only	AC + DC	AC + PV
Annual Energy Cost without CEM	$405K	$399K	$406K	$287K
Annual Energy Cost with CEM	$244K	$237K	$298K	$134K
Energy cost savings with CEM	39.7percent	40.6percent	26.6percent	53percent
Benefit of PV (NEM3.0)	N/A	N/A	N/A	None
Benefit of PV+BESS (NEM3.cost 0)	N/A	N/A	N/A	None
Benefit of PV self-consumption	N/A	N/A	N/A	
Chargers per bus	1:1	1:2	1:1; 1:2	1:1
Charger Capital cost	Lowest	Highest	Medium	Lowest

Source: The Mobility House and Sage Analysis

Table 23. Summary of V2G Analysis Results

V2G Scenario	AC Only	DC Only
Current Operations, 1:1 bus to charger ratio	49.74	638.54
Bus at idle	1,420.97	2,358.65
2:1 bus to charger ratio	(931.02)	514.21
Minimum export rate for net annual profit, without incentives	0.29 $/kWh	
Minimum export rate for net annual profit, with incentives	0.19 $/kWh	

Source: The Mobility House and Sage Analysis

The following are key findings from the analysis:

AC vs. DC vs, AC & DC charging cost under current BEV rate

The team evaluated the feasibility and charging scheme under the current TOU rate designed for electric vehicle charging in PG&E territory. Under this rate, there is an off-peak and super off-peak rate. If a higher power DC charger was able to effectively use lower cost super off-peak electricity, the total purchased power cost may be lower for DC than AC. This DC charging scenario did result in a lower energy cost, with approximately $7,000 saved per year. This amount will not justify the additional cost of DC charging throughout the site. This demonstrates that AC charging can meet the site needs, and at a much lower cost than DC infrastructure. CTE estimates that DC charging infrastructure would cost 2.2 times more than AC charging infrastructure.

Onsite PV and PV+BESS under NEM3.0

PV installations were a reliable way to reduce energy costs under the NEM2.0 rules, and with the planned expansion of the electric fleet additional solar may be a pathway to reduce overall costs. With the adoption of NEM3.0 rules, Sage evaluated the net impact of a PV system, as well as a PV system with additional battery storage. The NEM3.0 rules provide much lower compensation for energy returned to the grid during peak solar production. The modeling results show that future PV installations under NEM3.0 will have a net negative value without being able to plan for self-consumption. As the fleet already has a charge management system, there was little to no additional utility provided by a BESS. In this case, marginal savings benefits of a BESS were not enough to outweigh the added capital cost based on this, under NEM3.0 rules and the PG&E BEV rate, there is no rationale to add additional PV production.

Onsite PV and PV+BESS with Self-Consumption

Optimizing bus charging when PV is available improves the value of PV and benefits SUSD. Under NEM3.0, the expected value of PV increases by 30-40 percent with the PV self-consumption optimized charging profiles. This is due to the higher portion of self-consumed energy relative to exported energy achieved under this scenario.

Potential V2G Revenue

The modeling results for future V2G revenue under the proposed DAHRTP system provide enough revenue to pay for the energy costs for normal operation, as well as the energy to service the V2G energy dispatch. This provides a small net profit of $50 per AC charger and $639 per DC charger annually. The DC charger likely had higher revenue as it was able to return more energy to the grid during the highest revenue hours. This net profit is close enough to zero, having the potential to offset the energy cost for the operation of the buses at around $244,000 per year. The costs required for SUSD to successfully implement large scale V2G are not readily available today but will consist of at least a sophisticated V2G management platform, along with the additional stress and use on the batteries and chargers. While $244,000 is a significant amount of revenue associated with V2G use, some recent quotes for sophisticated charge management without V2G capability can cost thousands per year per charger, which along with battery degradation may erase much of the benefit. The recommendation of this report is to leave the option open for future V2G use and make the decision to implement as the cost impacts become clearer.

V2G Minimum Export Rate for a Net Cost Savings

To offset the added costs of V2G, SUSD’s V2G exported energy must, on average, be valued at $0.19/kWh if receiving PG&E and ELRP incentives (or other incentives of similar value), and $0.29/kWh without incentives.

Recommendations and Conclusions

- School districts should plan to install AC charging unless there is a demonstrated need for DC charging.
- PV is not recommended for districts under NEM3.0 rules and PG&E BEV rate unless they plan to optimize ESB charging to self-consume the energy produced.
- BESS paired with PV is not expected to provide a net additional benefit to SUSD given the current NEM3.0 valuation, the PG&E BEV tariff, and the CEM managing peak demand.
- The additional costs associated with V2G technology diminish returns and make it hard to justify the potential cost benefits. V2G export rates under NEM3.0 are undervalued—the CPUC should revaluate this compensation rate to incentivize use of electric vehicles to increase grid reliability. V2G use should continue to be researched as policies and technology changes.
- V2G charging planning should include a full evaluation of all operating costs, including battery degradation, energy to replenish V2G use, additional hardware/software, and infrastructure upgrades if DC charging is required.

Best Practices to Support Market Adoption of Future Electric Fleets

CTE developed a Guidebook for Deploying Zero Emission Transit Buses,[11] which offers best practices as agencies electrify their fleet. This guidebook was written with a focus on transit buses, however many of the takeaways stay the same for ESBs and school districts planning their own electrification. Below is a list of best practices to support future electric fleets.

Assessing needs and requirements

- Initiate the planning process for your Zero Emission Bus (ZEB) deployment by engaging key staff members to define short- and long-term goals and constraints; designing a phased approach to deployments to meet those goals.
- Identify applicable regulations and utility funding programs, as well as grant opportunities that will support your deployments.
- Engage internal and external stakeholders to ensure your efforts are properly coordinated and incorporate the constraints and needs of each group.

Technology selection and specification

- Select suitable ZEB technology and deployment strategy based on bus performance evaluation using modeling and deployment data analysis.
- Ensure that buses and EVSE are compatible with each other.
- Develop clear technical specifications and performance requirements to ensure your buses and infrastructure meet your needs.
- Ensure ZEB procurement documents include thorough and effective considerations for inspections, acceptance testing, and warranties.

Capital costs and funding opportunities

- Estimate current costs of your selected vehicle and fueling technology through thorough research and modeling.
- Assess short- and long-term fueling infrastructure needs and available capital to make the smartest investments for your ZEB plans, while meeting current service needs.
- Assess potential for mitigation or avoidance of electrical upgrades using load management technologies and discuss plans with your permitting authority and utility.

---

[11] National Academies, Guidebook for Deploying Zero-Emission Transit Buses, available at https://nap.nationalacademies.org/catalog/25842/guidebook-for-deploying-zero-emission-transit-buses

- Identify available Local, State, and Federal funding opportunities to support the procurement of ZEB technology.

Fueling infrastructure strategy and cost

- Conduct an electricity rate model analysis to understand how bus operation will drive electricity costs.
- Determine total fueling costs and opportunities for demand management.
- Identify charge management strategies for BEB operation that will meet all service needs, while minimizing cost.
- Consider ALM to maximize use of existing infrastructure, especially at locations with utility-side electrical constraints.

Fueling infrastructure deployment

- Coordinate between your agency, permitting authorities, equipment providers, designers, contractors, and utility providers.
- Design for current and long-term plans.
- Clearly delineate contractor and Original Equipment Manufacturer (OEM) responsibilities for infrastructure installation.
- Ensure commissioning and acceptance of infrastructure coincides with bus delivery

Acceptance, validation, and deployment

- Create and execute a clear inspection plan supported by a well-defined technical specification.
- Conduct acceptance and validation testing to ensure delivered buses perform as planned.
- Refine your initial deployment strategy based on validation results.

Personnel training and development

- Coordinate operations and maintenance training prior to, or in conjunction with bus delivery.
- Ensure that OEM-provided training includes sufficient high-voltage hazards and safety training as well as hydrogen fuel safety training, if applicable.
- Require OEMs to conduct first responder training.

Operation and maintenance of ZEBs and fueling infrastructure

- Promote energy efficient driving behaviors.
- Monitor battery state of health.
- Understand and prepare for bus and fueling infrastructure maintenance activities, including spare part inventories and lead times.

Data monitoring and evaluation

- Define key performance indicators and metrics for reporting.
- Identify and coordinate internal and external sources for operations and maintenance data.
- Ensure bus performance data is developed for fair and accurate reporting of metrics, especially when compared to non-ZEB vehicles.

Workforce Training and Development

SUSD initially planned to explore options with the Weber Institute of Applied Science and Technology to create a certificate program where students could earn vehicle electrification or energy management certificates. Weber Tech is a career focused school in the SUSD system which prepares students for technical careers. SUSD engaged with Weber Tech to discuss this project in-depth, but the project has not yet been completed due to differing curriculum goals. More time is needed for SUSD and Weber Tech to standardize a curriculum to train and certify students in vehicle electrification.

Additional workforce training and development should be completed within the district. As previously mentioned, CTE's Guidebook for Deploying Zero Emission Transit Buses offers best practices as agencies electrify their fleet. SUSD is in the early stages of transition and should consider the following best practices for workforce training and development from the guidebook.

Components or operations may differ slightly across OEMs and models. ESBs will have many new components and operations that operators, maintenance staff, and facilities staff may be unfamiliar with. During this phase of deployment, SUSD should provide training for their operations, maintenance, and facilities staff on the safe and efficient operation and maintenance of ESBs. They should coordinate with first responders to schedule training on potential hazards and recommended response techniques. Request for Proposal or contract language for SUSD bus procurements should include requirements for the OEM to provide sufficient training to the SUSD staff.

As stated in the *Best Practices to Support Market Adoption of Future Electric Fleets* section of this report, best practices for personnel training and development include:

- Coordinate operations and maintenance training prior to or in conjunction with bus delivery.
- Ensure that OEM-provided training includes sufficient high-voltage hazards and safety training as well as hydrogen fuel safety training, when applicable.
- Require OEMs to conduct first responder training.

SUSD should set up plans for staff training, operations training, fueling process training, maintenance training, safety training, and first responder training to ensure all staff are familiar with processes, procedures, and hazards associated with the new buses and the associated infrastructure.

Stakeholder Review

CTE prepared a presentation summarizing the analysis results for review by various stakeholders. This section outlines the targeted stakeholders and feedback provided during the reviews.

San Joaquin Valley Clean Cities

In 1993, the Department of Energy created Clean Cities to provide informational, technical, and financial resources to fleets that were required to adopt alternative fuel vehicles because of the Energy Policy Act of 1992. Currently, there are more than 75 active coalitions around the country working with communities to implement energy efficient technologies. SUSD is located within the San Joaquin Valley Clean Cities Coalition's area. CTE held a conference call with the leaders of this coalition to present the results and gather feedback.

The team was very interested in this project and felt that the results were very informative. The Clean Cities team reported that they work with a lot of rural schools and have seen similar challenges with electrifying on longer routes. They agreed that districts will need to weigh all the different charging options to best understand which works best for the districts unique fleet needs. They also recommend rural districts consider incorporating solar technology and were curious to see if the results of this project would change if a rural district was used as the case study instead, as rural districts are often those that may need more than just AC chargers.

The Clean Cities team did not have any recommendations or additional things that they would like to see out of this project. They were excited about the results however, as they think that the final blueprint could help their team learn more about electric buses and guide them through the different charging options for districts in their region.

PG&E

As the utility responsible for providing power to the district, PG&E can provide valuable feedback on the analysis results. CTE spent some of the feedback time clarifying the methods used. For example, CTE confirmed that SUSD route and ESB range constrictions were considered in the analysis and that in terms of real time energy prices, the cost model was put together with DAHRTP. PG&E expressed that both factors were important. CTE and PG&E also clarified AC/DC/Level 2/Level 3 terms, as they are often incorrectly used interchangeably. Regarding the V2G analysis, PG&E reported that they have not seen charging scenario analysis of this type before and were excited that it was being researched. They were also grateful to be looped into the stakeholder calls, as it directly relates to their own research plans and customer relationships.

PG&E reported that they believe V2G is coming although it will be a slower ramp-up than they would prefer. Overall, they are excited about the idea of it and have a few pilots lined up to test different use cases for V2G. They plan to test the technology and user experience by focusing on customer behavior and potential savings.

From a utility standpoint, PG&E is concerned about the grid’s capacity to handle future scaling of electricity storage and are hopeful that ESBs will have the capacity to shift electricity across time to increase grid stability long-term. PG&E also reported there is a push to shift toward real time rates. They also have learned more about how to best support electric vehicle charging around off-peak times. PG&E had initially recommended charging at night, but they now realize that there are benefits to charging during peak solar time instead. Overall, they are expecting a lot of shifting around consumer use and how people will choose to charge their electric vehicles as they become more widely available. They are concerned about the current uncertainty of how consumer use will impact the grid throughout the day, so they are especially excited about research that is being done on charging recommendations.

In reviewing the methods of the blueprint, one PG&E team member expressed curiosity about the incremental cost of the bi-directional charger. For example, they asked if a bi-directional charger has more expensive management systems and wondered how significant the cost of battery degradation would be. This was not included in the analysis, and CTE and PG&E discussed the complications of measuring battery degradation between having V2G and not; the value that a customer associates with battery degradation is variable. However, both parties agreed that it would be interesting to add a degradation cost to the analysis. CTE pointed out that most of the revenue from V2G came during the summer which could allow districts to use V2G above a threshold of return to sustain long-term battery health. There was also discussion of a current CARB project that plans to model the impact of charger degradation.

CTE concludes that V2G technology should be left open for future discussions but cautions toward investing into the V2G technology currently. PG&E is very hopeful that the technology will be a helpful investment in grid resilience even if there are not any significant cost benefits.

World Resources Institute

CTE has an existing project funded through the World Resources Institute (WRI) to develop ESB transition plans for three school districts. WRI has a vested interest in electrification of school bus fleets and agreed to be a stakeholder reviewer for this project.

WRI met with CTE on December 12, 2022, to review the CEC Blueprint projects methods and results. WRI reported that the analysis was helpful in providing some insight into a new industry that is difficult to predict. WRI agrees that V2G technology may not have significant cost savings and are concerned that the current lack of data around V2G technology could harm school districts that expect a greater monetary benefit than currently exists. However, WRI is generally optimistic about non-monetary V2G benefits like grid resiliency. WRI follows the benefits closely so that they can best support districts that are interested in V2G technology installation. WRI reported that this analysis was a helpful step in understanding the outcomes and risks associated with different charging scenarios.

For future analysis, WRI would like to have battery degradation and fleet turnover costs included in the V2G analysis to best understand the costs and risks associated with V2G charging. WRI also recommended including transaction costs in the final report to help contextualize the savings numbers. They were interested in the comparison of the savings to the costs associated with the CEM or V2G analysis. WRI also questioned whether charge management costs differ between AC and DC charging. This was not explored in CTE's analysis but is worth further research.

WRI is also strongly recommending level 2 charging due to the lower cost and were pleased to see that the results of this project echoed this recommendation. WRI and CTE discussed that this project is looking at a single case study of SUSD, and while results can be helpful for districts that are planning charging, the results may differ across districts. For example, DC charging may be beneficial or even crucial for some districts to charge their buses between service windows.

Both WRI and CTE discussed how field trip routes are an added complication for school districts planning their bus range capacities and may require DC fast charging on site to reach full route feasibility. This may be especially true for rural districts that need to travel farther for their regular service and field trip service routes.

WRI has been surprised by the amount of school districts asking about V2G and wondering how it plays into the role of ESB adoption. WRI and CTE discussed how this analysis as well as future charging analysis will shape the policies and technology adoption in the ESB market. The results of this study may encourage OEMs to reconfigure the charging options available to districts that are using the lowest cost to charge framework similar to this blueprint.

Outreach and Economic Benefits:

Stockton Unified School District

As the primary focus of the analysis and resulting Blueprint, the feedback of SUSD is important to ensure the results are reasonable. CTE met with SUSD's Director of Transportation, Nate Knodt, on December 19, 2022, to review the blueprint and understand what a full transition to ESBs would mean for the district. This discussion showed how the results will apply to SUSD based on their current operations.

SUSD is currently only using AC chargers but have purchased some DC chargers for their special education routes. Our results recommend that the district only purchase AC chargers because most bus/route combinations can be met with lower power charging. SUSD should use the DC chargers that they have for routes with lower feasibility.

The results for the analyses for PV reflect what the district has seen in solar energy prices. SUSD has been grandfathered into existing solar energy export pricing under NEM 2.0; they can pay for the cheaper rate of energy and sell it back to PG&E at the NEM 2.0. Nate found the NEM 2.0 and NEM 3.0 analysis extremely valuable. Nate also pointed out that the district's service runs year-round because two thirds of their service runs are special-ed summer school routes. This is important because in the case of SUSD, solar may be even less advantageous because the buses are not sitting idle in the summer months. Nate reported that the district has solar panels in their bus yard, but he believes the solar panels operate the work yard building which uses a more constant stream of energy than the buses would.

In reviewing the V2G results, SUSD is concerned that the state policies will not incentivize the technology enough to benefit the district. However, Nate believes that the buses should be adapted as emergency portable generators in a crisis. ESBs could add value to communities by adding grid resiliency and providing backup to the city's emergency services.

Nate enjoyed learning about this research and is excited to implement the results into their operations. He also recommended that we share these results with other types of transportation groups. For example, he pointed to a non-profit that the district works with that runs a vanpool service. He believes vanpool services and rental companies could benefit from knowing about the project results. He is hopeful that the transition to electric will benefit the local community, as the central California region of Stockton has some of the worst air quality in the country.

Nate reported that a full transition to ESBs is a current priority for their district, especially given the aggressive transition timeline in California. The district has been extremely proactive in their procurement and deployment of ESBs, but they still feel the stress of being able to transition to 100 percent. Currently, SUSD has five active grants for 66 new buses. Of these, 40 would be large general-ed buses and the other 26 would be smaller capacity special ed buses with wheelchair lifts. SUSD will need to retire 45 special ed buses soon, so they are trying to get more replacement buses. The temporary plan is to procure 56 more electric buses in the next 18 months. Nate reported that he is really interested to see how it all works out, and believes it is critical that all districts start transitioning to meet California's requirements. The priority at SUSD is getting kids to school and on ESBs.

Financial Institution Engagement:

AlphaStruxure

AlphaStruxure is a joint venture between the Carlyle Group and Schneider Electric. The business provides an Electrification-as-a-Service (EAAS), broadly looking at combining charging infrastructure, electric vehicles, and electricity management. The organization's input is critical to understand if there are considerations from a financing partner who is looking at large ESB fleet deployments. CTE met with AlphaStruxure on December 20th, 2022, to review the CEC Blueprint projects methods and results. The AlphaStruxure team reported that they have worked with roughly five other school bus projects and are excited to comment on this market because they believe there could be an opportunity to work together in the ESB market in the future.

From the transit side, they suspect that people are vastly underestimating the costs of charging infrastructure and think it is important to consider the upfront costs and added maintenance and operations costs. AlphaStruxure was concerned that the methodology for this project does not calculate all of the hidden infrastructure costs. CTE responded that this project is solely looking at the value of energy, and it does not include any additional installation, procurement, or management costs. However, this project was an iterative process; if the results had shown a large potential savings, then more costs would have been investigated. CTE and AlphaStruxure agreed that this analysis is a good starting point to understand the simplified charging costs and risks.

AlphaStruxure is not surprised that utility companies are pushing for V2G use and understands how there is a benefit to them from a grid perspective. However, utility companies can control different incentives and AlphaStruxure reported that it has witnessed some clients become more restricted throughout the transition process as rebates and incentives change. AlphaStruxure urges clients to research how long the utility is willing to allow access to an EV rate because that is uncertain. This is important for EV planning, as EV rates may become less attractive overtime. Often the EV incentives and rates have changed and are less advantageous as soon as districts and fleets have completed the transition.

The team reported that they liked the overall approach that CTE took and gave some ideas of potential future research to build on this project. For example, AlphaStruxure is interested in learning more about the potential for vehicle-to-building and how it could align with the self-consumption analysis. They are curious if there is any opportunity in changing the focus from saving the grid to making facilities more resilient. CTE and AlphaStruxure discussed how this could be an interesting path to explore especially for school districts that may want to use its schools for community emergency response housing or sanctuaries. If this were the focus, Federal Emergency Management Agency resilience money along with other federal or state grants for resilience may be able to help plan and finance the technology.

Along with some of the other stakeholders, AlphaStruxure inquired about the cost of battery degradation, as V2G technology could lower the lifetime of the battery. There is not enough data on what this looks like over time, although it may add an additional capital cost. AlphaStruxure expressed concerns about this and is skeptical about the V2G financial benefits.

Overall, AlphaStruxure said the results are validating to the company's concerns about V2G and would like to see future analysis done with more consideration put into the total cost to manage and implement these technologies, with special regard given to California.

Glossary

ALTERNATING CURRENT (AC)—Flow of electricity that constantly changes direction between positive and negative sides. Almost all power produced by electric utilities in the United States moves in current that shifts direction at a rate of 60 times per second.

BATTERY ELECTRIC VEHICLE (BEV)—Also known as an “All-electric” vehicle (AEV), BEVs utilize energy that is stored in rechargeable battery packs. BEVs sustain their power through the batteries and therefore must be plugged into an external electricity source in order to recharge.

CALIFORNIA ENERGY COMMISSION (CEC)—The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The Energy Commission's five major areas of responsibilities are:

1. Forecasting future statewide energy needs
2. Licensing power plants sufficient to meet those needs
3. Promoting energy conservation and efficiency measures
4. Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
5. Planning for and directing state response to energy emergencies.

DIRECT CURRENT (DC)—A charge of electricity that flows in one direction and is the type of power that comes from a battery.

KILOWATT (kW) — One thousand watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon, a typical home — with central air conditioning and other equipment in use — might have a demand of 4 kW each hour.

KILOWATT-HOUR (kWh) — The most commonly used unit of measure telling the amount of electricity consumed over time, means 1 kilowatt of electricity supplied for 1 hour. In 1989, a typical California household consumed 534 kWh in an average month.

APPENDIX A: Detailed List of SUSD Special Education Routes

Table 24. Special Education Routes

Bus #	AM/PM Route	Start Time	End Time	Total Mileage	Operating Days
29	AM	5:46	9:02	35.88	M,T,W,Th,F
29	PM	11:54	13:53	27.49	M,T,W,Th,F
50	AM	6:02	9:03	29.3	M,T,W,Th,F
50	PM	11:38	13:41	30.51	M,T,W,Th,F
51	AM	6:21	9:16	41.98	M,T,W,Th,F
51	PM	14:01	15:43	22.19	M,T,W,Th,F
52	AM	6:21	8:53	31.5	M,T,W,Th,F
52	PM	12:46	14:53	24.63	M,T,W,Th,F
54	AM	5:52	9:13	55.62	M,T,W,Th,F
54	PM	11:19	13:25	26.85	M,T,W,Th,F
55	AM	5:32	8:01	43.53	M,T,W,Th,F
55	PM	13:59	15:58	28.92	M,T,W,Th,F
56	AM	7:04	8:35	19.46	M,T,W,Th,F
56	PM	12:09	15:29	29.11	M,T,W,Th,F
57	AM	6:43	9:12	38.36	M,T,W,Th,F
57	PM	13:15	16:24	44.64	M,T,W,Th,F
58	AM	6:36	9:14	31.13	M,T,W,Th,F
58	PM	13:27	15:37	31.41	M,T,W,Th,F
59	AM	6:57	8:31	17.71	M,T,W,Th,F
59	PM	12:53	15:54	26.57	M,T,W,Th,F
60	AM	6:32	8:40	28.25	M,T,W,Th,F
60	PM	11:54	16:09	51.64	M,T,W,Th,F
61	AM	6:54	8:35	17.63	M,T,W,Th,F
61	PM	13:51	15:19	15.55	M,T,W,Th,F
62	AM	6:45	8:01	21.08	M,T,W,Th,F
62	PM	12:09	16:23	29.85	M,T,W,Th,F
63	AM	6:15	7:29	23.17	M,T,W,Th,F
63	PM	14:10	15:30	31.12	M,T,W,Th,F
64	AM	6:40	8:32	25.29	M,T,W,Th,F
64	PM	12:52	15:27	22.19	M,T,W,Th,F
65	AM	5:49	8:11	27.26	M,T,W,Th,F
65	PM	11:52	13:53	30.26	M,T,W,Th,F
66	AM	6:10	8:17	30.3	M,T,W,Th,F
66	PM	13:41	15:35	29.13	M,T,W,Th,F
67	AM	5:55	7:23	22.01	M,T,W,Th,F
67	PM	11:52	15:43	56.89	M,T,W,Th,F
68	AM	7:10	9:48	29.2	M,T,W,Th,F
68	PM	14:10	15:17	19.68	M,T,W,Th,F
69	AM	6:44	8:23	29.24	M,T,W,Th,F
69	PM	12:56	14:46	43.23	M,T,W,Th,F
70	AM	6:02	9:07	38.67	M,T,W,Th,F

70	PM	13:29	16:09	34.33	M,T,W,Th,F
71	AM	6:15	9:13	34.33	M,T,W,Th,F
71	PM	11:52	15:33	43.27	M,T,W,Th,F
72	AM	7:11	9:17	26.2	M,T,W,Th,F
72	PM	12:56	15:55	40.58	M,T,W,Th,F
73	AM	6:30	8:43	25.71	M,T,W,Th,F
73	PM	13:19	16:04	35.06	M,T,W,Th,F
74	AM	6:23	8:18	21.62	M,T,W,Th,F
74	PM	13:15	15:40	35.75	M,T,W,Th,F
76	AM	6:26	8:37	28.14	M,T,W,Th,F
76	PM	11:50	14:55	34.47	M,T,W,Th,F
77	AM	6:00	8:12	25.82	M,T,W,Th,F
77	PM	13:16	15:13	24.3	M,T,W,Th,F
79	AM	6:00	8:14	27.72	M,T,W,Th,F
79	PM	13:44	15:41	29.25	M,T,W,Th,F
80	AM	6:16	8:45	29.3	M,T,W,Th,F
80	PM	13:56	15:33	23.67	M,T,W,Th,F
81	AM	6:25	8:47	25.34	M,T,W,Th,F
81	PM	11:55	15:54	43.91	M,T,W,Th,F
82	AM	7:00	7:52	18.71	M,T,W,Th,F
82	PM	13:55	15:53	26.45	M,T,W,Th,F
85	AM	6:42	9:07	35.66	M,T,W,Th,F
85	PM	13:19	15:45	32.51	M,T,W,Th,F
168	AM	6:27	8:36	29.38	M,T,W,Th,F
168	PM	11:39	16:24	54.03	M,T,W,Th,F
169	AM	6:17	9:21	35.11	M,T,W,Th,F
169	PM	11:50	15:35	35.43	M,T,W,Th,F
170	AM	6:01	10:33	44.28	M,T,W,Th,F
170	PM	13:13	15:26	18.09	M,T,W,Th,F
175	AM	6:02	9:15	38.27	M,T,W,Th,F
175	PM	14:06	15:59	25.23	M,T,W,Th,F
179	AM	5:30	9:04	44.69	M,T,W,Th,F
179	PM	14:07	15:57	20.6	M,T,W,Th,F
181	AM	6:26	8:53	26.77	M,T,W,Th,F
181	PM	13:32	15:07	19.98	M,T,W,Th,F
182	AM	7:10	8:27	21.99	M,T,W,Th,F
182	PM	13:40	16:06	32.91	M,T,W,Th,F
183	AM	6:23	8:17	26.4	M,T,W,Th,F
183	PM	11:36	13:04	18.99	M,T,W,Th,F
184	AM	6:05	9:02	30.57	M,T,W,Th,F
184	PM	13:31	15:09	31.38	M,T,W,Th,F
185	AM	5:51	8:02	31.57	M,T,W,Th,F
185	PM	13:25	14:56	16.39	M,T,W,Th,F
186	AM	5:54	8:39	32.62	M,T,W,Th,F
186	PM	14:04	15:34	26.01	M,T,W,Th,F
187	AM	7:17	8:53	25.7	M,T,W,Th,F
187	PM	11:54	15:48	42.2	M,T,W,Th,F
188	AM	5:49	9:23	48.89	M,T,W,Th,F
188	PM	11:38	15:41	39.01	M,T,W,Th,F

Source: CARB Clean Mobility in Schools Project: SUSD